Green Power for Mobile

Fuel Cell Systems for Base Stations: Deep Dive Study

An exploration of the current and future potential of fuel cell systems to provide green power for the telecoms industry

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Executive Summary

Introduction and motivation for the study

Fuel cell systems have long been considered suitable for remote stationary power applications with a high cost of downtime, such as mobile base stations. Fuel cell design and manufacturing improvements, combined with increased volumes being produced, have seen costs decline whilst technical performance, reliability and longevity has improved. This has seen the technology transition from field trials at base stations to commercial deployments over the last 2-3 years.

Misconceptions around fuel cells are common in the mobile industry for a variety of reasons, including the rate of technology development. Additionally, the term ‘fuel cell’ covers a broad family of technologies suitable for different applications which can also run on a variety of fuels, each with its own advantages and disadvantages. Base station energy requirements vary from site to site and region to region, meaning that finding the right solution is not always obvious.

The goal of this study is to condense the current technology status and outlook into a digestible form—considering technical, economic and environmental performance—for GSMA members.

Methodology

The research for this study included:

- Extensive review of published literature
- Interviews with a range of industry experts. These included fuel cell manufacturers, vendors, academic researchers, fuel providers, network operators with user experience and system integrators
- A dedicated fuel cell session at Green Power for Mobile’s South East Asian Working Group in July 2011
- A detailed case study carried out on fuel cell systems deployed in Indonesia since 2009
- Technical and economic simulations comparing fuel cell systems to traditional alternatives

White Paper Structure

The white paper is divided into four chapters: Chapter 1 investigates fuel cell technologies to assess those suitable for telecoms applications and the advantages and disadvantages of such systems; Chapter 2 provides an overview of telecoms deployments, the main players in the market, and the developments being pursued; Chapter 3 is a detailed case study examining the motivations and success of deployments in the Indonesian market; and finally, Chapter 4 looks at the economic and technical drivers in more detail for individual sites.

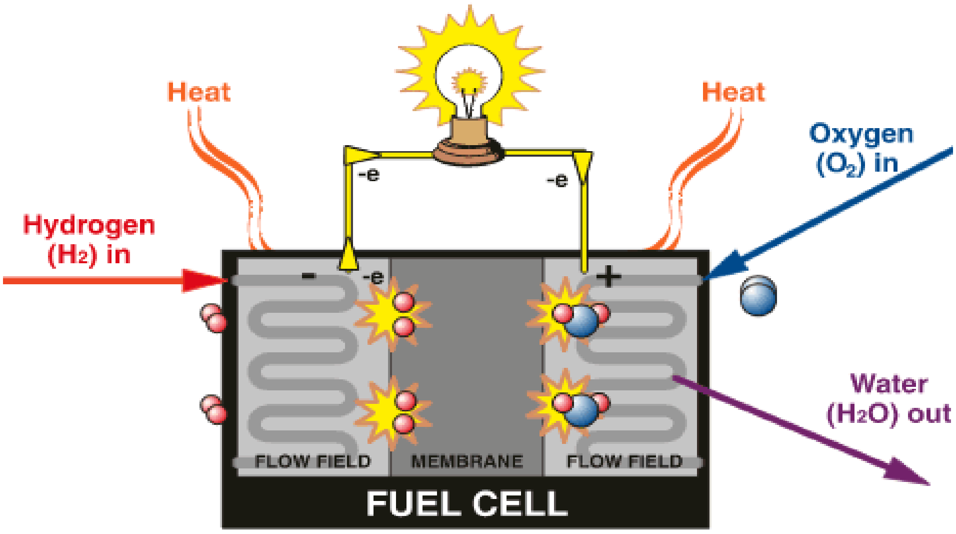
Chapter 1: Fuel Cell Technologies For Use In The Telecom Space

Introduction to fuel cells

- Fuel cells are energy conversion devices producing DC electrical current and commonly run on hydrogen
- They operate electrochemically, like batteries, but have an external source of fuel like an engine
- Individual cells are combined to form a fuel cell stack to provide the required voltage
- Fuel cell stacks are then integrated into a system with other components

There are various types of fuel cells which are suited to different applications, including powering portable devices, vehicles, domestic energy requirements and small power stations. The suitability of a fuel cell type to a particular application depends on cost and technical performance. The most common and versatile type of fuel cell is the Proton Exchange Membrane Fuel Cell (PEM-FC).[1] This type is currently used in telecoms applications, although other types may come into use in the future.

Figure 1: Simplified Hydrogen Fuel Cell System



How are fuel cells used in telecoms?

Fuel cells are used in the role often played by diesel generators or batteries: to provide backup for an unreliable power source, or in a limited number of cases, as the sole power source. Market research has shown that where fuel cells are deployed, in most cases they are displacing diesel generators rather than batteries. Fuel cell systems may rely upon refuelling or may be rechargeable depending upon the system type.

Fuel cells are most cost competitive at sites with low electrical loads, as these are the sites where diesel generators are least efficient. The greatest benefit will be achieved if efficiency measures to minimise power needs are also undertaken.

Advantages of fuel cells

Although fuel cell systems vary, in general they have the following advantages over traditional solutions:

[1] Stationary Fuel Cells, Kerry-Ann Adamson, 2007

Table 1: Advantages of fuel cell systems

Compared to diesel generators:	Compared to batteries:
- Virtually silent - Emission free at the point of use - Reduced life-cycle emissions possible - High efficiency - No moving parts results in reduced O&M costs - Fuel theft problems reduced - Fuel prices less variable - Fuel spills less hazardous - Improved reliability	- Provide longer run-times (power and energy needs separately addressed) - Operate over much greater temperature range - Improved reliability - Reduced environmental issues associated with disposal

Barriers to fuel cell deployment

As a relatively new technology, the perception of risk and lack of user experience are obstacles. The capital expense of fuel cell systems may have been the most significant barrier in the past, but as technology improves, this may no longer be the case. At sites with an electrical load in the order of a few kilowatts, fuel cells are very cost competitive with diesel generators.

The main obstacle limiting further adoption is the means of fuel supply. Transporting hydrogen can be expensive, especially where fuel supply chains are not set up. To decrease this obstacle, the fuel cell industry is now focussing its efforts in three areas:

- Improving hydrogen supply logistics. Companies such as Air Liquide, or Diverse Energy in partnership with Linde Gas, are working to provide an integrated solution to enhance efficiencies in the supply chain
- Designing systems to use fuels other than hydrogen that may have more efficient supply chains
- Using rechargeable fuel cell systems, such as those combining fuel cells with electrolysers

Improvements in alternatives technologies, such as battery advancements or intelligent use of battery-diesel hybrids, require fuel cells and fuel supply logistics to improve at a faster rate if they are to gain a competitive advantage – a benefit to energy service companies. Fuel cell intelligent hybridisation with batteries and renewable energies also benefit from these improvements in alternative technologies.

Types of systems for use in telecoms

The fuel cell systems used in telecoms all convert hydrogen into electricity at their final stage. However, they are often differentiated by the use of integrated “processors” to enable the systems to run on different fuels. Figure 1 indicates how these systems may be categorised according to the application they are required for. (Note that these are not rigid boundaries; the suitability of a type of fuel cell system for a particular application is often a function of capital and running costs, which vary by region and supply chain maturity for different fuels.)

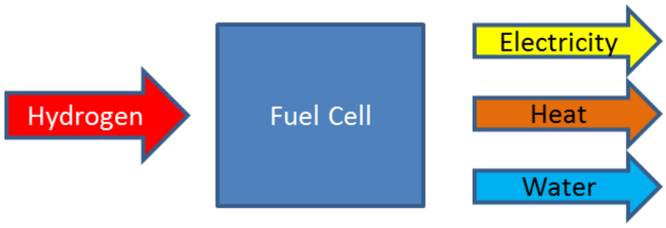
Figure 2: Fuel cell applications and system suitability

Type	Application	Processor	Fuel
1	Short Run Backup (4-6 Hrs)	Direct Hydrogen or Electrolyser	Bottled hydrogen or grid electricity for electrolysis
2	Poor Grid Sites (Total daily blackout hrs 7-18 hrs) with frequent short blackouts in a day	Direct Hydrogen	Bottled hydrogen
3	Poor Grid Sites (Total daily blackout hrs 7-18 hrs) with long non-frequent blackouts in a day	Reformer based or Direct Hydrogen	Hydrocarbon fuel – such as methanol/LPG/ammonia or bottled hydrogen
4	Off-Grid Sites (Continuous Power)	Direct Hydrogen Reformer based	Bottled hydrogen or hydrocarbon fuel such as methanol/LPG/ammonia

Direct Hydrogen as a fuel

In locations where hydrogen is a by-product of industrial process or fossil fuel industries it can be inexpensively sourced. However, hydrogen is expensive to transport and handle due to low energy density by volume. As a result, costs have a strong geographical dependency.

Figure 3: Simplified conceptual diagram of a hydrogen fuel cell system

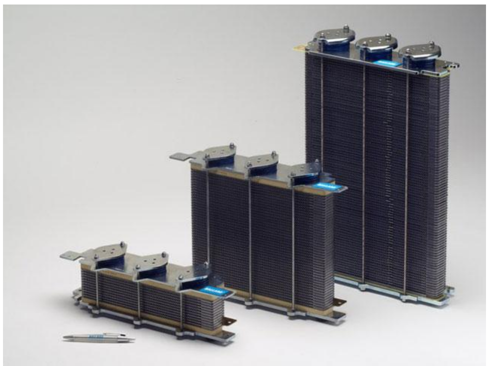


Hydrogen bottles are typically transported full and then returned to a distribution centre for refilling. There are hydrogen distribution models and technology in place to enable a longer duration backup or for use as the main power source. One is the bulk supply model adopted by ReliOn in the USA, where bottles are refilled at the site rather than transported full and returned.[2] Another is the delivery of large bundles of hydrogen bottles adopted by Air Liquide in France.[3] In 2011, Air Liquide's fuel cell systems powered more than 40 off-grid telecom sites in France with hydrogen bottles supplied via the existing Air Liquide supply chain. Another solution in the future will be based on the use of High Pressure bottles at 525 bars or higher, which will significantly reduce the refill frequency of hydrogen and the space requirement for the same power output.[4] Air Liquide is introducing these High Pressure bottles into their supply chain in 2013.

[2] Interview with Sandra Saathof of ReliOn, 2011
[3] Interview with Anne Hayum of Air Liquide, 2011
[4] Interview with Anne Hayum of Air Liquide, 2011

Figure 4.1: Hydrogen storage cabinet at telecoms site in Indonesia. Each bottle contains enough hydrogen to generate 7kWhr electricity.

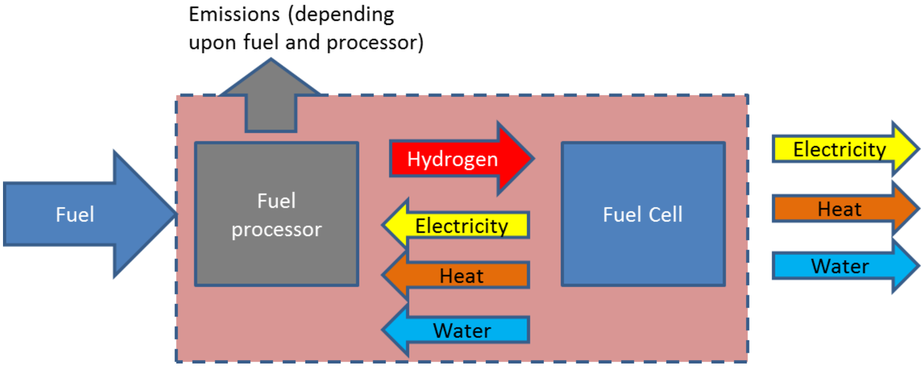
Fig 4.2 Ballard's FCgen ACS 1020 Fuel Cell Stack, mainly used in Hydrogen Fuel Cell



Hydrogen generation by reformation of hydrogen-carrying fuels

To resolve some of the issues with sourcing and transporting bottled hydrogen, other hydrogen-carrying fuels can be used including methanol, LPG, natural gas and ammonia. The fuel cell system will need an integrated fuel processor to reform the hydrogen-carrying fuel to hydrogen. Advantages include the ability to use fuels with a greater energy density, enabling longer run-times to be achieved between refuelling visits. Additionally, some alternative fuels are commonly used for other purposes, such as heating, cooking or as a fertiliser, and therefore have pre-existing supply chains. A disadvantage compared to direct hydrogen could be more complex systems and increased start-up time associated with hydrogen-carrying fuels. Consequences of this may include greater capital costs, increased warm-up times and potentially reduced reliability. Currently, these systems are less well developed than bottled hydrogen systems. IdaTech began commercial deployments of methanol-fuelled systems in 2011 and have scheduled field trials for LPG-fuelled systems.[5] Diverse Energy is also trialling ammonia-based systems.[6]

Figure 5: Simplified conceptual diagram of a reformer or fuel processor based fuel cell system



Hydrogen generation by electrolysis ("rechargeable" fuel cells)

Electrolyser-based fuel cells can use excess energy from another power source—such as an unreliable grid or renewable source—to electrolyse water to produce hydrogen, which is then stored until it is required. Round trip efficiencies of around 30% are much lower than for batteries, however hydrogen has the advantage of being able to decouple energy (and therefore backup time) and power needs unlike batteries. Most of the electrolyser-based fuel cell systems are unsuitable for off-grid or rural sites with poor grid (average daily blackout of more than 8 hrs), as they are unable to replenish hydrogen supplies at a sufficient rate for the required blackouts. Electrolyser-based systems have been commercially deployed to provide backup to grid-connected sites across Europe and in other regions such as Indonesia. There is also interest in using electrolyser-based systems with renewable energy sources, and although the Green Power for Mobile programme are aware of a small number of field trials, there are no commercial deployments due to the

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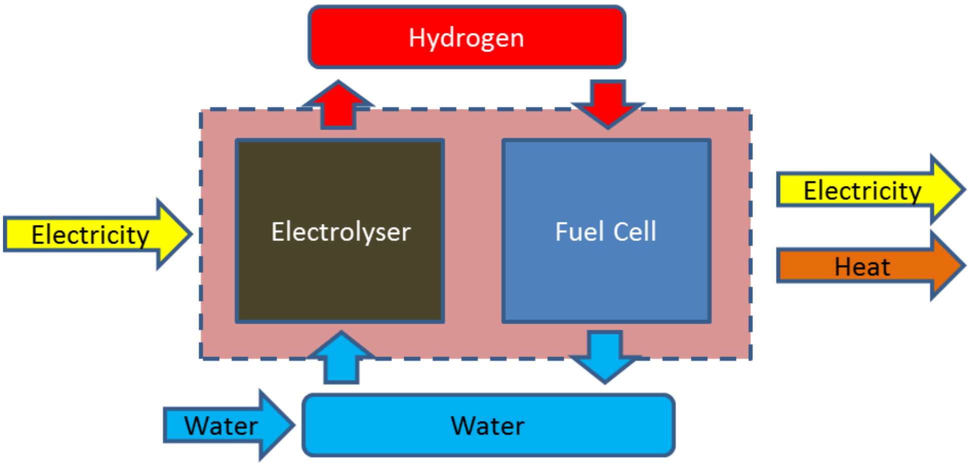
[5] Interview with Nicolas Pocard, IdaTech, 2011

[6] Interview with Mike Rendall, Diverse Energy, 2011

round trip efficiency and hydrogen generation rate being obstacles to successful use.

Figure 6: Simplified conceptual diagram of a rechargeable fuel cell system

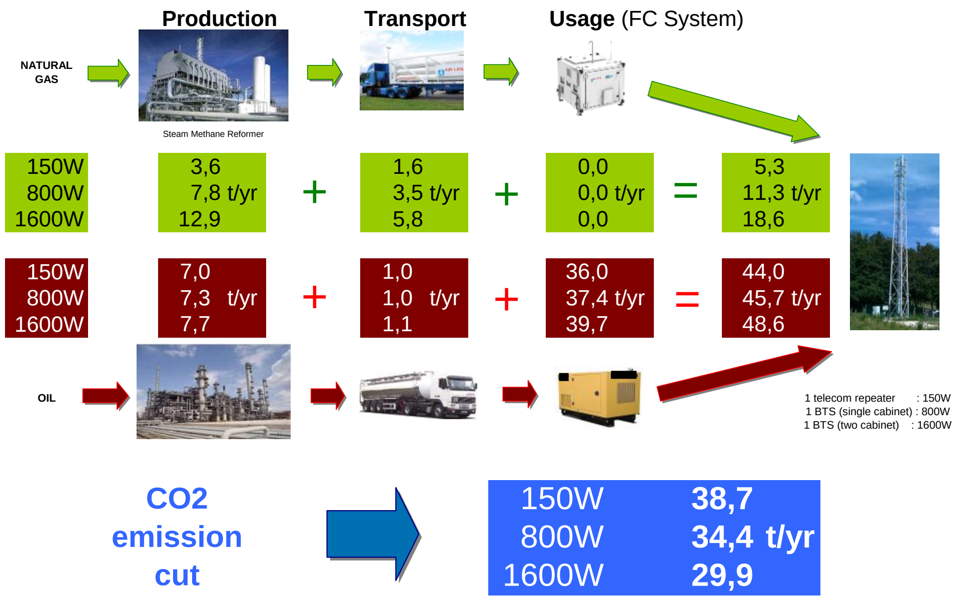


Are fuel cell systems "green"?

At the point of use, fuel cells emit no or low quantities of carbon dioxide, depending on the system type. There are other local environmental benefits compared to diesel generators, such as reduction in noise and other pollution such as particulate matter, nitrogen and sulphur oxides. Compared to batteries, fuel cell systems eliminate the potentially frequent disposal of batteries, which are a particular problem in developing countries.

Whether fuel cells are considered greener than alternatives on a life-cycle basis is not a simple question to answer. This depends on how the fuels are produced and transported, and what the alternatives are. Producing hydrogen can be energy- and carbon-intensive and transportation is more challenging than for liquid fuels; this stage may also involve significant additional emissions.

Figure 6: An example production cycle of hydrogen with associated CO_2 emission reductions



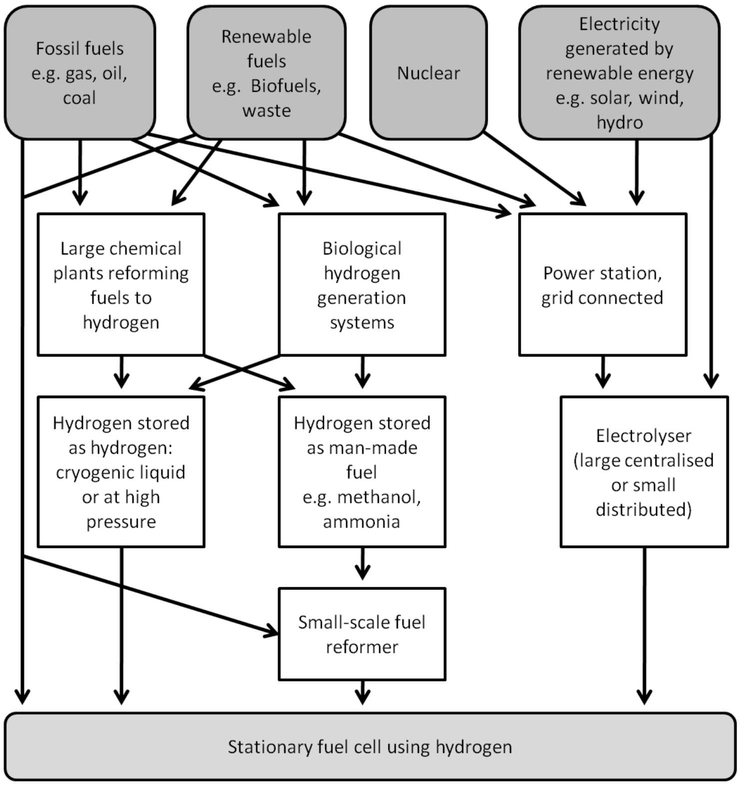
(Source: Air Liquide)

This graph compares the CO_2 emissions using fuel cells with hydrogen produced from reformed gas and a diesel genset. For a typical site equipped with one BTS consuming around 800W, the CO_2 emission is reduced by 34.4 tonnes per year using a hydrogen fuel cell.

Hydrogen is often produced as a by-product of industrial processes, which is normally taken into consideration for carbon accounting purposes. Air Products, Air Liquide and Linde Group are some of the main gas suppliers operating globally that are involved in development projects to produce hydrogen via more sustainable means, such as using waste gas from landfill sites.[7] The main routes from primary energy source to delivering hydrogen at a stationary fuel cell are shown in Figure 7. At each stage of conversion, there is normally energy consumption and related carbon dioxide emissions among other environmental impacts. Therefore even for the same fuels there can be huge variation in the embodied carbon depending upon the method of production and transportation of the fuel.

[7] Interview with Anne Hayum of Air Liquide, 2011 - Air Liquide Blue Hydrogen Initiative is a commitment to produce at least 50% of its hydrogen for fuel cells through carbon-free processes by 2020.

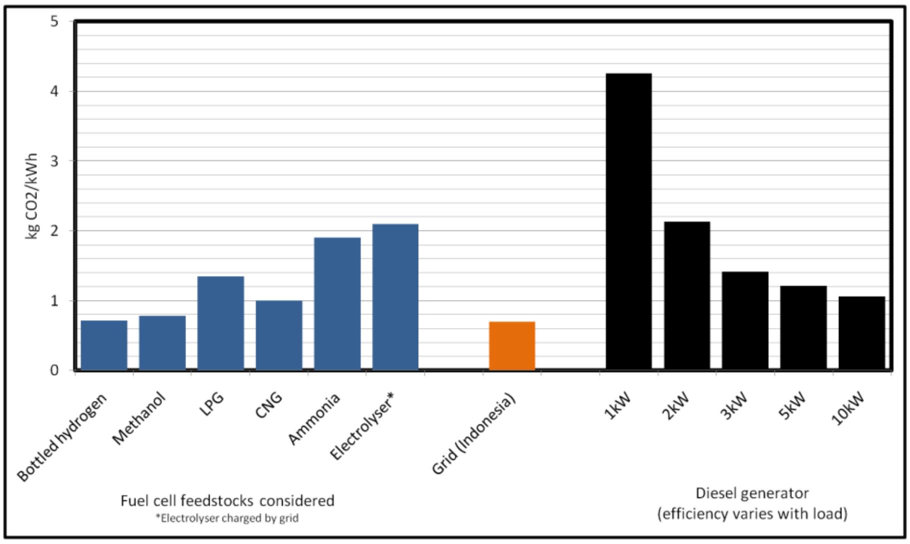
Figure 7: Routes to hydrogen for a stationary PEM fuel cell[8]



Estimates made by GPM in this study show that while fuel cells are not emission free, significant carbon savings can be achieved by using them while operating on a variety of different fuels in comparison to a diesel generator; particularly at low power load sites. Figure 8 shows some GPM estimates of carbon emissions for a variety of fuel cell fuels compared to diesel and grid electricity. These indicative estimates were calculated for this study using embodied carbon content of various fuels published by the IPCC and approximate fuel consumption rates advised by fuel cell manufacturers. There are many variables that impact carbon emissions from the system, including the type of fuel cell system and the source of the fuel.

[8] Adapted from Fuel Cell Systems Explained by J Larminie and A Dicks.

Figure 8: Estimated CO_2 emissions (including embodied) for a variety of electricity sources[9]



Despite some of the outlined issues, hydrogen is considered by many to be an important energy vector of a low carbon future. It can be produced using renewables or nuclear power and there are plentiful sources of hydrogen-carrying compounds, reducing the reliance on fossil fuels. As a result, with greener hydrogen supply chains in place, fuel cells will have an even greater emission reduction impact in the future.

Future fuel cell developments

It is commonly accepted that the cost of PEM fuel cell systems will continue to drop, particularly as the market grows, volumes increase and production becomes more competitive. Fuel cell costs have reduced by around 20% in the last 2 years, a trend that may be expected to continue. Aside from incremental cost reductions, a step change may be caused if large scale uptake of fuel cells by the automobile industry occurs.[10]

The other technical advance that may be expected is increased cell and membrane lifetimes which will improve life cycle costs. The lifetime of a fuel cell system is 15 to 20 years but stack life is around 10,000 operating hours for many vendors, having progressed from 3-4,000 hours over the last few years. The fuel cell stack is a replaceable component yet one which currently represents a substantial proportion of the overall cost of the system; roughly 15-20% of the total cost. Future development may see different schools of thought developing on stack life; as stacks designed for more frequent replacement may have overall lower lifecycle costs provided the replacement cost is sufficiently low.

Intelligent hybridisation of PEM fuel cells with renewable energies and batteries is also improving and will reduce the frequency of hydrogen refills and consequently the total cost of ownership.

Aside from PEM fuel cells, other fuel cell electrolytes such as molten carbonate and solid oxide fuel cells may enter the telecoms market in the future. Potential “disruptive technologies”, those that cause significant reduction in cost rather than gradual evolution are also possible. For example, developers of platinum-free fuel cells claim they will have products that are commercially ready in the next few years that will reduce stack prices by 70%[11] due to the high cost of platinum, a current component in traditional fuel cell stacks.

Aside from the costs of stacks, the majority of the cost is in the system integration. Individual components are not inherently expensive or reliant upon precious materials, but

[9] Calculations based upon embodied CO_2 figures for various fuels published by the IPCC and DEFRA and estimated fuel consumption. Diesel figures for a typical 10kVA system with a minimum load ratio of 30%. Figures to be considered as indicative only as actual emissions are based upon a large variety of factors.

[10] Uptake of fuel cell technology across various industries will undoubtedly act as a catalyst to further price reductions and optimisation of supply chains. This is being investigated further by a recent coalition of European technology developers and end users in the distributed generation space, who have agreed to undertake a fact based study into a range of distributed generation power and heat technologies in conjunction with McKinsey Consulting. The study will gather data and information on the costs and operational characteristics of a range of distributed generation technologies, including fuel cells. For more information please contact Jonathan Lewis: jonathan.c.lewis@btinternet.com.

[11] Interview with Ziv Gottesfield of CellEra, 2011

relatively low order volumes for telecoms (and other stationary power applications that can use the same products) have prevented further manufacturing efficiencies. However, signs indicate that this may now be changing. The cost and performance of small scale fuel reformers would also be expected to improve, subject to further uptake

Chapter 2: The Telecoms Fuel Cell Market Landscape

Deployments to date

Currently fuel cells deployments are still in the very early stages with around 900 units deployed worldwide (recorded in the GPM Green Deployment Tracker[12]). Some countries, such as Indonesia have most of the active fuel cell units: to date around 450 fuel cell units have been deployed in Indonesia, thanks to a partnership between Hutchison and IdaTech. In Africa, South African operator Vodacom is one of the only operators that has deployed fuel cells, with 107 units. Other fuel cell trials are taking place in African countries but no feedback has been received to date.

Table 2: Green Power for Mobile fuel cell deployment tracking (greater than 900 in total)

Region	Country	Operator	Fuel Cell Deployments
Africa	Kenya	Safaricom	2
Africa	South Africa	Vodacom	107
Americas	Mexico	Telcel (América Móvil)	43
Americas	Mexico	Other	60
Americas	Trinidad and Tobago	Other	59
Americas	Venezuela	Movistar (Telefónica)	9
Asia Pacific	China	China Mobile	30
Asia Pacific	Indonesia	3 (Hutchison)	472
Asia Pacific	India	Several Tower Companies	25
Europe Western	Spain	Vodafone	1
Europe: Western	Germany	O2 (Telefónica)	1
Europe: Western	Germany	Tetra	60
Europe: Western	UK	Everything Everywhere	1
Europe: Western	France	Several Operators	43
Europe: Western	Norway	Telenor	1
USA/Canada	USA	Other	43

GSMA Green Deployment Tracker: http://apps.wirelessintelligence.com/green-power/tracker

If you have installed fuel cell systems at your telecom sites, please contact the GSMA GPM team greenpower@gsm.org with details to help track deployment.

12 The number of fuel cell deployments is based on current feedback from main providers – Current list might not be exhaustive.

Fuel cell system vendors

The leading fuel cell stack manufacturer is the Canada-based Ballard, who supplies stacks to many of the fuel cell system vendors operating in the telecom space. Therefore one of the main differentiating features arises in the system integration and the auxiliary components included. Some example products targeted at telecoms are shown in Table 3:

Table 3: Example fuel cell systems targeted at telecoms

Application	Manufacturer(s)	Product(s)	Fuel	Reason feedstock is suitable for application
Emergency backup power	Dantherm Electro PS ReliOn	Various	Direct Hydrogen, Electrolyser	Infrequent use and short run times do not preclude delivering hydrogen to site or sufficient production of hydrogen on-site.
Poor Grid backup power	Dantherm IdaTech Air Liquide	DBX2000 DBX5000 ElectraGen ME System HYES	Direct Hydrogen, Methanol-Water	Backup the site for extended run times by storing hydrogen at high pressure to reduce logistics cycles or naturally hydrogen carrying fuels like Methanol.
Primary power source	Air Liquide IdaTech Diverse Energy	Energy Container HYES iGen LP System PowerCube	Direct Hydrogen LPG Anhydrous Ammonia	Fuel can be practically stored to enable run times comparable with diesel generators and is readily available.

(Source: GSMA, based on feedback)

There are various approaches adopted by fuel cell companies in the telecom space to offer attractive business propositions, as shown in Table 4, for some of the product and service providers interviewed for this study.

Table 4: Companies active fuel cells for telecoms

Company	Viewpoint
Air Liquide	■ Hydrogen based systems commercially deployed in France and beginning in other regions. ■ Goal is making hydrogen distribution significantly cheaper, with business plan to increase hydrogen bottle pressure from 200bar to 700bar by 2016. ■ Leasing or sale business model with fuel management and operation services. Provides short or long term baseload power.
Diverse Energy	■ Ammonia based systems under field trial in Africa to provide long-term base-load. ■ Current 1.2kW systems currently being field trialled in South Africa.
Electro Power Systems	■ Integrated electrolyser and fuel cell systems, to date all deployed are providing backup to an unreliable grid. ■ Claim over 1000 units deployed. ■ Systems up to 10kW available, with option to have 10,000 hour warranted stacks.
IdaTech	■ Expertise in reformer systems. ■ Deployed bottled hydrogen systems and beginning deployment of methanol based systems. ■ Trialling systems reforming LPG and CNG. Partner with Cascadiant in Indonesia.
ReliOn	■ Deployed hydrogen systems. ■ In the USA adopt a bulk supply model where it’s possible to significantly reduce hydrogen distribution costs.
CellEra	■ Platinum free fuel cell developer, expect to reduce stack cost by around 70%. ■ Under development at the moment.
Cascadiant	■ Fuel supply and maintenance for fuel cell deployments in Indonesia. ■ Deliver bottled hydrogen and methanol.
Plug Energia	■ History of deployments of fuel cell systems, particularly in Indian markets.

Chapter 3: Indonesia Case Study

Introduction

As seen in Chapter 2, Indonesia is one of the leading nations in fuel cell deployments in telecoms. The case study presented here is based on findings gathered as part of a visit in July 2011. The aim was to gain an understanding of the factors that led to fuel cells being adopted and to gauge their success while in use. Those responsible for deploying and maintaining these fuel cell systems—the supplier (IdaTech), their local partner responsible for keeping the sites maintained and refuelled (Cascadiant), the mobile operator 3 Hutchison—were interviewed and a visit to a site with a hydrogen fuel cell system was made.

Indonesia background information

Indonesia has areas with very high population densities and ability to pay for mobile telecommunication services, leading to a competitive business environment for service providers. The relatively low price of diesel by international standards suggests that this would be a difficult market for technologies competing with diesel; however there are political drivers to move away from oil dependency. Logistical challenges with network maintenance vary greatly depending on which part of the country you are in. The more densely populated islands such as Java have good road infrastructure yet serious traffic problems, while remote parts of islands such as Sumatra, Kalimantan and Sulawesi may take days to reach. The archipelago nature of the country also means that boat access is commonly required between islands. Finally the country is prone to natural disasters, with high profile volcanic eruptions, earthquakes and tsunamis in recent years. Although infrequent, the ability to maintain mobile network coverage during these events and rescue efforts is important to operators and is a consideration when planning backup power for telecoms sites.

Indonesia key facts:

- Made up of approximately 18,000 islands, with a population of 238 million, it is the 4th most populous nation in the world. Jakarta, the capital city, is located on Java, the most populated of the nation's islands with a population density of 940 people per sq. km.[13]
- The largest economy in Southeast Asia and a member of the G20. GDP of $707 billion (18th largest globally), which is $3,015 per capita. National electrification rate of 65% of total households.[14]
- It is the 3rd largest CO_2 emitter, behind China and the USA, primarily due to deforestation. Copenhagen Accord pledge to a target of either 26% CO_2 emission reduction by 2020 relative to business-as-usual, or 41% if international funding of US$18.2 billion is made available.[15]

Commodities and policy background

Indonesia is Southeast Asia's largest crude oil producer, however due to declining production and rising demand, the country became a net importer of oil in 2004 and pulled out of OPEC in 2008. Successive Indonesian governments have subsidised hydrocarbon fuels for many years, with sale prices fixed by the state. However the combination of a greater reliance on fuel imports and rising prices have led to this becoming an increasingly significant proportion of state expenditure, with the government attempting to lift these subsidies at several points over the last decade. In 2008 it was estimated that combined fuel and electricity subsidies amounted to US$20.5 billion or 20% of total government spending for the year.[16] The disparity between the subsidised price and the market price has made lifting subsidies politically challenging, resulting in significant public pressure and protests, which have forced some planned price rises to be abandoned. The policy currently in place for diesel sets a subsidised price for private users (although there are plans to phase this out) while commercial users pay the market rate. It is against this backdrop that commercial users, heavily reliant upon diesel use, have been considering alternatives. Also of significance for fuel cells is the gas production industry, as this is a source of fuels including hydrogen, methanol, and LPG. Indonesia is the eighth largest gas producing country in the world, and the largest gas producing country in Asia. The government is attempting to shift some of the oil demand to gas, and as part of this policy there is a programme to shift household cooking and lighting needs from kerosene to LPG.

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13 Indonesia National Statistics Data, Trading Economics
14 Asia Sustainable and Alternative Energy Programme
15 Deploying Renewables in Southeast Asian Countries, International Energy Agency 2010
16 Deploying Renewables in Southeast Asian Countries, International Energy Agency 2010

Indonesia is also a significant methanol producer, producing around 1 million tonnes a year, around 2.5% of world methanol consumption.[17]

Unlike some of the other countries that have significant fuel cell deployments, such as the USA, there has been no real policy support or subsidy in Indonesia. In fact, at the time of interviewing, fuel cell importers were required to pay 10% duty to the government. Another challenge is the price of hydrogen in Indonesia, where it is felt by Cascadiant that prices are currently artificially high, due to a limited number of suppliers and not much consumer power due to small purchase volumes. Lowering of hydrogen supply prices could improve the business case further.

Fuel cell deployments

Cascadiant began their involvement with fuel cells in 2008. They partnered with fuel cell manufacturers and began a dialogue with local telecoms operators to educate the companies to the features and possible benefits of using fuel cells as backup power systems, against the backdrop of rising diesel prices and the reduction in government fuel subsidies occurring at the time. Over the past three years the company has succeeded in deploying around 600 hydrogen fuel cell systems, with a further contract in place to install 20 methanol-based fuel cell systems and trials of LPG and Compressed Natural Gas (CNG) systems scheduled. A timeline of the company's progress is indicated in Table 5.

Table 5: Cascadiant's Fuel Cell (FC) Timeline in Indonesia

Year	Milestones
2008	Started FC market education in Indonesia
2009	Set-up a customer experience centre in Jakarta with FC demonstrations 10 trial and purchase sites deployed Conducted FC seminar for network operators Received contract for Hydrogen FC deployment
2010	Deployed Hydrogen FC sites in Sumatra Completed a Methanol FC trial
2011	Deployed Hydrogen FC sites in Java Received contract for Methanol FC implementation Trials for LPG and CNG based FC

The hydrogen systems have been deployed in unreliable grid situations replacing diesel generators, where typically power outages average between one and four hours per day. The majority of deployments are 2.5kW systems at sites with an average electrical load of around 1kW. The conditions upon which the mobile network operator agreed to adopt the fuel cells included:

- The capital cost of the fuel cell systems must match the cost of the typical diesel genset system that would otherwise be used.
- The responsibility of hydrogen supply logistics would not be taken on by the network operator.

For the first of these conditions, it is highlighted that diesel generators are oversized compared to the load and therefore the price-matching was typically comparing a 2.5kW fuel cell system with an 11-13kVA diesel genset. Even with current fuel cell stack prices, the fuel cell system suppliers were able to meet this condition. To meet the second condition, as there was no suitable existing service provider for hydrogen refuelling, Cascadiant took on this responsibility.

Setting up a hydrogen distribution network

All of the hydrogen is sourced from one supplier, an industrial gas supplier in Jakarta, who supplies in individual bottles each containing 0.5kg of hydrogen produced via steam reforming of natural gas. Each small distribution truck transports one hundred of these bottles, purchased by Cascadiant, to stock the warehouses. Three warehouses have been set up on Java, the furthest east of these is around 800km, or a 15-hour drive from Jakarta. Two warehouses have been set up at either end of Sumatra; to reach these, the Sunda straits that separate Java and Sumatra must be crossed by boat. The hydrogen bottles remain loaded on the truck for this crossing which normally takes around two hours although bad weather occasionally means services are cancelled. Once on Sumatra it takes a further 2 days by road to reach the warehouse in the north of the island. These sites are indicated in Figure 9, which also shows the areas that the telecoms base stations are located. Cascadiant did not wish to publish the exact locations of the base stations, but note that the sites on Java are fairly evenly distributed over the whole island, unlike on

[17] Energy Policy Review of Indonesia, International Energy Agency 2008

Sumatra there are two distinct regions clustered around the two warehouses. This is partially due to where population sites lie, but also by design, as the telecoms sites were chosen to be within reasonable delivery range of warehouses. In addition to the warehouses indicated on Figure 9, additional warehouses are planned.

Figure 9: Cascadiant Hydrogen supply areas

At each of the base stations there are six hydrogen bottles; three of these are running, with the other three on standby with an automated changeover system. A lithium battery provides short-term power to bridge the time between a grid outage and the fuel cells starting up. Normally a site will be refuelled when it switches over to the standby bottles, meaning that three bottles are exchanged during each refuelling visit. Each bottle contains the equivalent of 7kWh of hydrogen taking into account the conversion efficiency of the fuel cell. This means that running with a 1kW load, three bottles can provide 21 hours of backup and six can provide 42 hours.

Base station network

The portfolio of sites run by the operator interviewed are virtually all grid connected, with only a few sites completely off-grid across the whole of Indonesia. They have one solar-battery hybrid off-grid site, with the battery buried underground for temperature stabilisation and to lower the risk of theft.

Most sites are outdoors and greenfield rather than rooftop. In the vast majority of cases, the transmission towers are owned by a third party company who charges the network operator for the use of the site, although the network operator retains responsibility for powering the site. This has implications for the type of generation technology used, as the network operator will not invest in deploying renewable solar panels unless they own the site. There are many sites where multiple network operators have use of the same transmission tower, although transmission equipment and power needs are handled independently. Therefore there may be two or more sets of generation equipment on site, each powering a relatively low load BTS. This is unlike other business models, where if sites are shared it is the combined load that generation equipment needs to be sized for.

The cost of a grid connection and associated equipment is based on the maximum electrical supply rate, and therefore any equipment that requires additional power above that of the BTS may incur significant financial penalty. This has prevented the adoption of electrolysers at some sites, where the additional load of the electrolyser would require an upgrade of the grid supply. Despite this, electrolysers have been deployed at around 100 sites.

The fuel cell deployments have clearly been viewed as a success by the operator, who however does recognise that being an early adopter of the technology has involved some challenges. Areas where they hope to see improvements are in the reduction of hydrogen prices (noting that in India hydrogen costs around 50% less), improvements in available purity and ability to claim subsidies or credits for CO_2 emissions avoided.

In the Indonesian market, if competing on price alone, hydrogen fuel cells are currently seen as competing against diesel rather than batteries. Unless the site is of particular importance, the standard backup provided is 4 hours autonomy. Grid outages in the Jakarta area are estimated to average around 50 hours per month, and the operator believes than under these conditions batteries are currently more cost effective than fuel cells, where two battery banks will provide the required 4 hours autonomy. Contracts with battery suppliers don't specify a particular type of battery but require a warranty for two years.

The prices for diesel supply contracts are based on a portfolio rather than individual sites, and therefore difficult-to-access sites do not represent any additional fuel supply costs to the operator (although in principle they contribute to the overall rate paid). If a site was especially difficult to access, then special arrangements may be made if it was an important site in terms of revenue, but if it only supports end users, then downtime would be accepted rather than further outlay on extended backup.

Operational experience

Most of the fuel cell sites have been performing successfully for over a year. One of the more difficult periods was when the state-owned electricity supplier announced with minimal notice that there would be scheduled blackouts covering a large part of Sumatra over several days, due to nationwide insufficient electrical generation capacity. This sudden increase in hydrogen consumption for the majority of the fuel cell deployments stretched the distribution network, particularly the boat crossing of the Sunda straits, potentially a weak link in the supply chain especially as the electrical outages were during a period of inclement weather when the ability to make the crossing was in doubt. Despite the anxiety, it was possible to increase the rate of supply to maintain refuelling and with the exception of a few low priority sites, the network coverage was maintained with minimal impact on the operator.

In one case a fuel cell system was relocated due to difficulties restocking hydrogen bottles; where the base station is only accessible on foot via 500 steps. Although each bottle only contains 0.5kg of hydrogen, the bottle itself weighs 55kg and therefore refuelling the site presented some manual handling issues - highlighting one of the main challenges with using hydrogen as an energy vector.

In discussions about base station power options there are many references made to the issue of theft, particularly with regards to diesel fuel and lead-acid batteries, where it is assumed that because there is not an immediate application for fuel cells or hydrogen, that they will be less at risk from theft. This has broadly been shown to be true, with cases where cabinets containing fuel cell equipment have been breached, however the perpetrator has decided there is nothing of value and has left without damaging the equipment. There has been a case recorded where two hydrogen bottles were stolen, believed to be motivated by the resale value of the metal itself. Across all the sites nationwide, these thefts represent an acceptable level of loss compared to that expected for diesel or batteries, but this does demonstrate that fuel cell systems are not completely immune from theft issues. The network operator has decided not to install hydrogen systems on any rooftop sites yet, due to safety concerns for carrying bottled hydrogen through buildings.

The level of reliability that Cascadiant have signed up to with the network operator is 99%, which they have been exceeding. They are yet to experience a fuel cell system breaking down; any outages that have occurred have been due to lack of fuel supply. This reliability compares with 95% for diesel gensets. The financial benefit of increased reliability is difficult to quantify, however the operator noted that in the Indonesian market switching to an alternative network provider is very easy, as most customers are on "pay as you go" tariffs where there is no charge for a new SIM card. Therefore when customers experience network downtime while coverage is available on competing networks they have been known to switch, however this has not been quantified.

Recent natural disasters in Indonesia include the eruptions of Mount Merapi in central Java during October and November 2010, when there were hundreds of fatalities and an estimated 350,000 people evacuated, with an extensive area covered in volcanic ash[18]. Incidentally, this coincided with an earthquake and tsunami that hit Western Sumatra. Although only anecdotal rather than quantified, the network operator was satisfied with the performance of the fuel cell systems, which provided over 24 hours of backup during the

[18] The Guardian, 2010

grid outages. In contrast, sites backed up with batteries failed after 4 hours and those reliant on diesel gensets had lower reliability.

As described above, although the hydrogen fuel cell deployments have generally been deemed a success, the logistics of fuel supply, particularly in a relatively small scale system that may need to respond to significant fluctuations in usage has been the greatest challenge. This is highlighted by the interest in other feedstocks and also that the network operator has deployed around 100 electrolysers to sites where it was felt it would be more economical than delivering hydrogen. The one methanol system that has been trialled in Sumatera had so far been operational for 3 months, providing power for 45 hours over this period.

Site Visit

A telecoms site was visited on the outskirts of Bogor, a city around 2 hours' drive from Jakarta. The tower is owned by a third party company and shared by two network operators, each with their own BTS equipment and associated power needs. The company that owns the tower doesn't own the land, which is leased in five-year periods from the front yard of a domestic household.

The fuel cell system in place uses the same casing regardless of whether it is a 2.5kW or 5kW system. In this case it is a 2.5kW system and hence there is only one stack. Should the power needs of the site increase, the system can be upgraded by fitting another stack in the adjacent vacant space. In the hydrogen storage cabinet there are three "low" pressure bottles currently in use, and three "high" pressure bottles on standby, with automatic changeover when the pressure drops below the minimum operating pressure. The pressure gauges and fuel cell usage are remotely monitored.

Figure 10: Fuel cell system deployed by Idatech on Java

Over a six-month period the average usage at this particular site is only 10 minutes per day, however the recorded number of starts indicates an average grid outage of 30 minutes occurring every three days. The energy usage equates to seven hydrogen bottles, or a refuelling trip every two months. At this low level of usage it would take over 60 years to reach the 4000 operating hours that the fuel cell stack in the system is warranted for, exceeding the design life of the system. At this usage level the most significant OPEX advantage of a fuel cell system compared to a generator set would derive from a reduced maintenance regime rather than fuel savings. Comparing with batteries; if batteries did indeed need replacing every 2-3 years even at such low usage (despite having theoretical lifetimes much greater than this), then the fuel cell may also offer OPEX savings by avoiding replacement costs.

Chapter 4: Site Optimisation: Technical And Economic Modelling

System lifecycle costs

Life cycle cost effectiveness for a fuel cell system compared to an alternative technology clearly depends on a range of factors, including:

- Cost of Fuel Cell System and lifetime of the system
- The electrical load, hours per day usage and accessibility of the site
- The capital, fuel and maintenance cost of the alternatives, which may vary from site to site, region to region and over time, particularly with regards to diesel prices
- Production cost of hydrogen at site either by reformation of Natural Gas/Bio-mass/Methanol/LPG or water electrolysis or Supplied Cost of hydrogen at site from a nearby source e.g. large scale reformer or electrolyser or Chlor-Alkali Plant
- Fuel Cell Stack lifetime & replacement cost based on system runtime and on-off cycles

Fuel cell power output

Typical fuel cell systems targeted at telecoms are in the 1.5 to 10 kW range. There is nothing fundamental preventing higher power systems, multiple fuel cell modules of lower capacity can be cascaded to match the power and size specification of a telecoms site.

Fuel cell capital and fuel costs

Estimating the price of fuel cell systems for telecoms is challenging, as regional variations, marketing strategy of suppliers and order volumes can substantially impact price, and costs are constantly evolving.

Fuel cell stack costs can be considered proportional to the power output at around US$600-$800/kW. Complete system costs proportionally reduce for higher power systems, but an indicative current estimate is around US$3,000-US$4,000/kW, so a 5KW system may cost around US$15,000- US$20,000 installed.[19] Larger systems will be relatively cheaper by 20% on a per kW basis as the systems integration and auxiliaries' fixed cost doesn't increase in a linear fashion. The type of system and the fuel it is running on impacts the cost, with more complex reformer based systems costing more. Some example capital and fuel costs are included in Table 6, which are based upon discussions with a range of system suppliers.

Table 6: Approximate Costs of Fuel cell Systems

System Type	Indicative CAPEX for system ($/kW)	Cost of fuel	
		$/kg H2 Produced @150 bar	$/kWh electricity
Direct hydrogen	2,500-3,000	4.5-6.5 a	0.30 – 0.43
Reformer Based (Methanol/LPG/CNG/Ammonia	3,500-4,000	4.5-6.5 b	0.30 – 0.43
Electrolyser based	3,500-4,000	6.0-8.0c	0.43 – 0.53

[a]Cost of supply of hydrogen at site vary based on site location and density of sites.
[b]Cost of Hydrocarbon fuel for reformation vary based on site location and density of FC sites.
[c]Depends upon commercial electricity price in a region, year on year change in grid electricity price

Maintenance costs

Aside from the cost of fuel, maintenance and replacement costs can be significantly lower than for diesel or battery systems. Hourly preventive maintenance cost is in the order of US$0.01 per hour of use. Maintenance typically includes filter replacements every 500 hours of use, and replacement of the fuel cell stacks (US$3k-US$3.5k) when they reach the end of their warranted life, after 10,000 hours of use for example. These can compare favourably to some typical maintenance costs for running a 15kVA diesel generator (US$300/month general maintenance, yearly overhaul US$4K/year and replacement US$8.5K every four overhauls or 20,000 hr max life).[20]

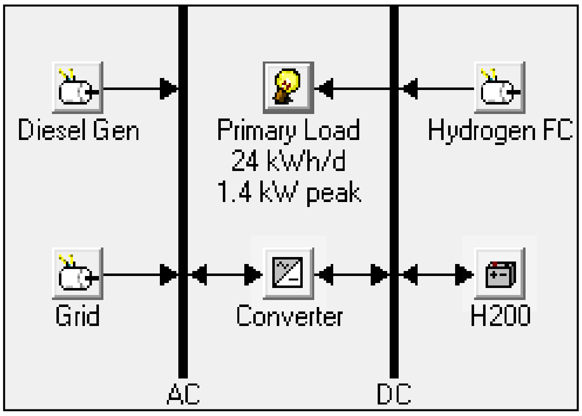
Site optimisation

To assess a range of different site conditions, simulations were run using HOMER (Hybrid

[19] Interview with Alok Goel, Plug Energia
[20] Interview with Rob Rallo, Ameresco

Optimisation Model for Electric Renewables), developed in the USA by National Renewable Energy Laboratory and available for free download.[21] The purpose of this was to assess how the economic viability of fuel cell systems over a ten-year project life depended on other factors, such as the grid availability or the price of diesel. The simulations were designed to draw general conclusions about the type of sites most suitable for fuel cell systems rather than be optimised for a particular site. Fuel cell vendors and energy system integrators will be able to provide business cases bespoke to particular regions and site specifications.

Figure 11: Example HOMER schematic showing components considered



Some of the general conclusions of the simulations were:

- Fuel cell systems are more likely to displace diesel generators rather than batteries on cost grounds alone
- Cost of refuelling a greater obstacle that the capital cost of the systems
- Reformer and electrolyser based fuel cells systems are more cost effective than delivering bottled hydrogen, until more widespread hydrogen supply chains are in place
- Fuel cell systems are most well suited to lower power need sites
- Calculations indicate reductions in carbon dioxide emissions by 50-80% compared to diesel may be achievable for a 1kW site

Results for off-grid sites (24hr/day use)

- Provided hydrogen can be cheaply sourced and delivered, direct hydrogen systems offer the greatest potential cost savings
- Reformer systems currently under development can be cheaper than diesel, offering carbon reductions and reduced maintenance
- Electrolyser with hydrogen store was not shown to be a cost effective means of storing energy for renewable hybrid systems in the simulation completed for this study. The low round-trip efficiency requires over-specifying solar panels, negating the benefit of hydrogen over batteries
- Current fuel cell solutions are shown to be less competitive compared to diesel and battery hybrid systems

Table 7 shows the conditions that are required for fuel cells to be the optimum economic choice for powering an off-grid site. These ranges are achievable for systems currently being field trialled. Competing with diesel battery-hybrids is more challenging, due to hybrid systems making the best use of the optimum efficiency range of diesel gensets.

[21] http://homerenergy.com/software.html

Table 7: Conditions required for economic viability of fuel cells systems vs diesel at off grid sites

External conditions		Fuel cell conditions required to be lowest NPC option		
Site Load (kW)	Diesel price ($/L)	System CAPEX ($/kW)	H2 price ($/kg)	Stack life (hrs)
To compete with diesel				
1kW	1.5	<24,000	<50	>4,000
1kW	1	<24,000	<40	>10,000
1kW	1	<18,000	<15	>4,000
2kW	1.5	<24,000	<20	>10,000
3kW	1.5	<12,000	<10	>10,000
To compete with diesel-battery hybrids				
1kW	<2	<12,000	<10	>10,000
All results are from simulations completed for this study and are therefore dependent upon the assumptions used. Fuel cell vendors will be able to prepare business cases which incorporate accurate and up to date cost assumptions.				

Results for unreliable grid sites (4hrs outage per day average)

- At the time of the study (mid 2011), electrolyser with hydrogen store was the most cost effective fuel cell solution simulated as there are no fuel supply costs, however the Capex assumption for electrolyser and storage system has a strong impact on conclusion
- Significant further reduction in refuelling costs needed for other systems to compete with batteries.
- Batteries shown to be more cost effective in the model, but theft, space and other issues (such as air conditioning to preserve the batteries performance) were not quantified.

Table 8: Conditions required for economic viability of fuel cells systems vs diesel at unreliable grid sites

External conditions		Fuel cell conditions required to be lowest NPC option		
Site Load (kW)	Diesel price ($/L)	System CAPEX ($/kW)	H2 price ($/kg)	Stack life (hrs)
1kW	>2	<6,000	<50	>10,000
1kW	1.5	<7,500	<40	>10,000
1kW	1	<10,000	<10	>10,000
2kW	1.5	<10,000	<20	>10,000
3kW	1.5	<2,500	<10	>10,000
1kW	1.5	<2,500	<50	>4,000
All results are from simulations completed for this study and are therefore dependent upon the assumptions used. Fuel cell vendors will be able to prepare business cases which incorporate accurate and up to date cost assumptions				

Chapter 5: Summary and Conclusions

The study has found that fuel cell systems have progressed from being a potentially promising technology to being a commercially-viable power solution to power mobile base stations. They are currently being successfully used in a variety of ways by telecom operators globally to reduce costs, increase reliability and reduce the environmental impact.

The versatility and range of applications for fuel cells, combined with the regional differences in fuel supply chains results in a large range of lifecycle costs for different systems in different regions. Developments over the last few years in both the system technologies and fuel supply options have improved, and will continue to improve, the economic viability of fuel cell systems. As these developments occur, the market share is expected to increase, particularly as larger volumes are systems are manufactured, reducing costs further.

White Paper feedback and continuing fuel cell research

The GSMA welcomes feedback and further questions on the issues discussed in this white paper and are always happy to receive new perspectives and updates relating to what is a changing technology landscape. We are particularly keen to receive direct operator experience and track deployments of green deployments. Please contact Michael Nique at mnique@gsm.org

About the author:

Mark Crouch has recently completed a Masters in Sustainable Energy Futures at Imperial College London specialising in the commercial applications of Fuel cell systems. He has been working with the GSMA for the past 6 months to establish the role of Fuel cells in the telecoms industry and can be contacted at mark.crouch10@imperial.ac.uk

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Cascadiant	Danny Tejo	Fuel supply logistics
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