DYNAMIS DH2

the Self-recharging fuel cells fast track to hydrogen adoption for reliable telecoms

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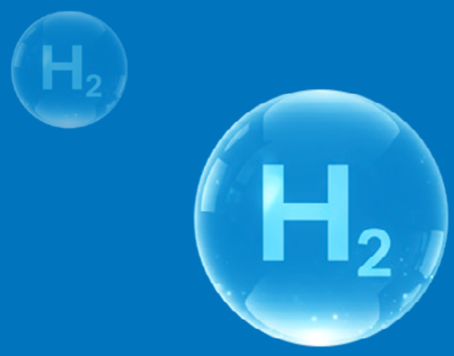
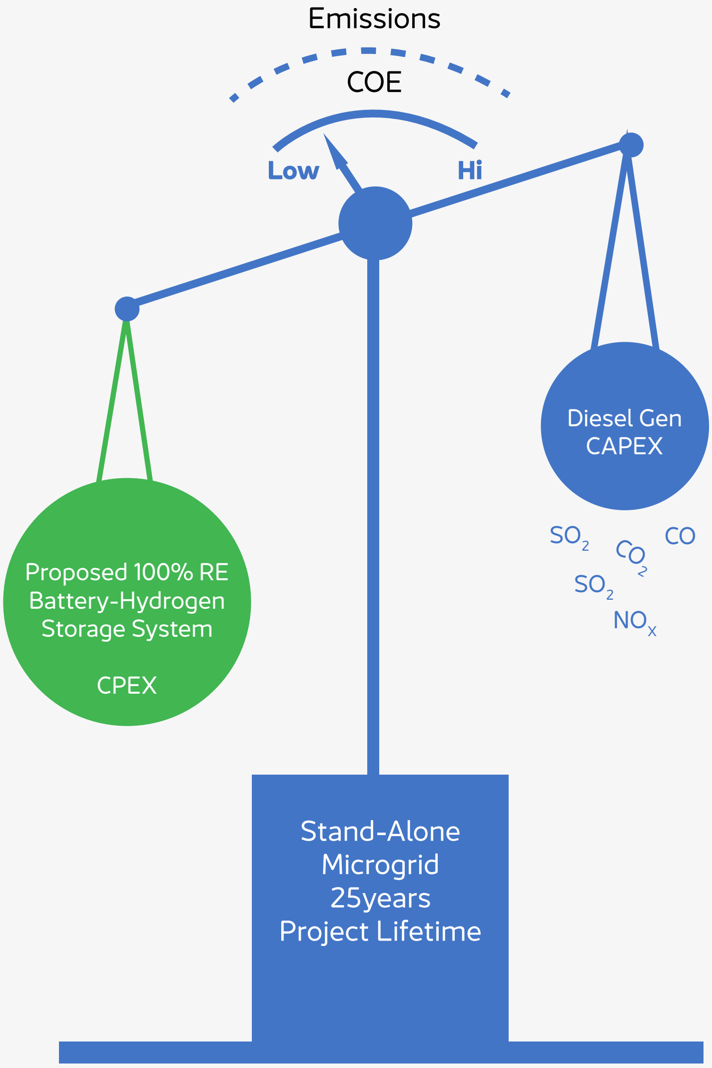


Summary

INTRODUCTION

The opportunity for fuel cell deployment is well understood in the telecom sector, offering significant operational and environmental benefits over traditional technologies such as diesel generators and batteries. H2Core Systems Gmbh in collaboration with NETIS has developed the PowerCore – DH2 self-recharging fuel cell system (SRFC), which regenerates the hydrogen fuel onsite, using electricity from the grid or renewable sources plus water. This eliminates the need to swap hydrogen cylinders, removing a major barrier to the deployment of hydrogen fuel cells in the telecom sector.

Fuel cell systems have long been considered suitable for remote stationary power applications which suffer from a high cost of downtime, such as mobile base stations. The adoption of hydrogen fuel cell



technologies for such applications is majorly hindered by the high capital cost. The tremendous advancement achieved in the fuel cell design and manufacturing methodologies combined with increased production volume have resulted in significant cost decline while technical performance, reliability and longevity have substantially improved. This technology transition over the last five years from field trials at base stations to commercial deployments has accelerated the implementation of hydrogen fuel cells in the telecom industry. This growth is apparent in the developed countries with existing good infrastructure to support hydrogen distribution and delivery, a prerequisite for the successful adoption of hydrogen fuel cell technologies. However, the markets and countries experiencing the largest growth in base station deployments are in emerging markets where hydrogen availability and poor road infrastructure make hydrogen delivery difficult or costly. This, combined with an overloaded existing electrical grid and unpredictable outages, makes a compelling case for hydrogen production onsite, or 'self-recharging' fuel cells.

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 (PEMFC). This type has been in operation since NASA started the Gemini space program – the precursor to the Apollo moon shot and PEMFCs have been used in telecommunications applications for more than 10 years now, although other types may come into use in the future.

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 grid, or in a growing number of installations, as the sole power source when used in conjunction with renewables. In the past when fuel cells have been deployed, they were displacing diesel generators rather than 'battery only' sites. However, fuel cells are extending into the 'battery only' space as well due to existing battery limitations such as life span, particularly in hot climates, and their attraction for theft. Fuel cells are also being considered in off-grid or renewable installations, where higher power and longer autonomy are needed and where excess renewable power can be used, once the batteries have been charged, to generate hydrogen rather than let it be wasted, as has traditionally been the case.

Fuel cell systems may rely on refueling or may be rechargeable, depending on the system type. Fuel cells are most cost-competitive at telecom sites with electrical loads between 2 kW and 10 kW, as these are the sites where diesel generators are least efficient.

Fuel cell advantages

Although fuel cell systems vary, in general they have several advantages over traditional solutions such as batteries and generator sets. With fewer moving parts and higher efficiency, fuel cells offer silent and reliable operation as compared to genset. Fuel cells can also operate in wide temperature range, -40°C to +50°C, than a battery and are suitable for longer duration operation. In terms of maintenance cost, a fuel cell system has a lower lifetime cost than both battery and generator with a requirement of only one maintenance visit per year. Moreover, compared to batteries and gensets, the fuel cell is the cleanest technology solution with near-zero emissions and minimal environmental impact.

The desirable system characteristics for powering base stations are outlined in Table 1. The benefit factor is a cogent metric for selection of power technology. With the highest benefit factor as compared to traditional power technologies, SRFC is an apt and incumbent power technology for the telecom sector.

	SRFC	Batterery	Genset
Low Energy Cost	✓	✓	✗
Low System cost per kW/h	✓	✗	✓
Low System cost per kWp	✗	✓	✗
Flat Power output	✓	✗	✓
No Fuel Logistics	✓	✓	✗
Long System Live on Standby	✓	✗	✓
No system life in Service	✓	✓	✗
Fast-Start up	✓	✓	✗
Low Maintenance Cost	✓	✓	✗
Fuel Price Stability	✓	✓	✗
Low Theft Risk	✓	✗	✗
Wide Temperature Limits	✓	✗	✓
Non-polluting	✓	✓	✗
Low Noise	✓	✓	✗
Easy Disposal	✓	✗	✓
Total Benifits (Score)	**14**	**9**	**5**

Table 1. Fuel cell systems (such as the PowerCore) have several advantages over traditional solutions such as batteries and diesel generators (gensets).

Barriers to fuel cell deployment

As a relatively new and evolving technology, the perception of risk and lack of user experience were obstacles to adoption in the past. However, their adoption is now more driven by cost-saving issues such as rising diesel fuel prices. This is seen especially in developing countries which are contemplating reducing or removing fuel subsidies. Associated with fuel costs, current operational expenditure (OPEX) for base stations in many regions represents almost 60% of total costs, which is motivating operators to adopt hydrogen-based power systems. This is most prevalent in parts of Asia and the Middle East.

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

- Improving hydrogen supply logistics. Companies such as Air Liquide or Linde Gas are working to provide an integrated solution to enhance efficiencies in the supply chain. However, they are limited to specific geographical areas.
- Designing systems to use fuels other than hydrogen that may have more efficient supply chains (for example, methanol).
- Using on-site, self rechargeable fuel cell systems, such as those that combine fuel cells with electrolysers.

Hydrogen supply logistics

Hydrogen bottles are typically transported full, and then returned to a distribution center for refilling. One approach is the bulk supply model adopted by Plug Power in the US, where bottles are refilled at the site rather than transported full and returned empty. Another is the delivery of large bundles of hydrogen bottles, adopted by Air Liquide in France. 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.

In locations where hydrogen is a by-product of industrial process or fossil fuel industries, it may be inexpensively sourced. However, hydrogen is expensive to transport and handle due to its low energy density by volume. As a result, costs have a strong geographical dependency. An emerging technology being implemented in parts of Asia and Africa is to use a methanol reformer, which produces hydrogen onsite directly by using a methanol- water mix and reforming this fuel to make hydrogen. However, reformers cannot produce completely 'green' energy owing to release of polluting CO2 and NOx emissions during the reforming process. Furthermore, reformers need continuous electrical power to be kept hot to reach a 300°C working temperature, and the complex start/stop processes do not tend to work well in grid conditions that experience repeated outages lasting several minutes.

The disadvantages of reforming, summarized by potential users considering a reformer solution, are as follows:

- Methanol is toxic for humans. It is not classified as a fuel, but as a chemical product following specific norms and regulations, which are country specific.
- Methanol in some cases is expensive, at an average cost of US$1.50 per liter, and difficult to find (potential provider lock-in).
- In terms of efficiency a reformer-based product is equally or less efficient than a diesel generator: a reformer consumes 1.1 litre/kWh, while a diesel genset driven at 10% efficiency gobbles 1.0 liter/kWh.
- But above all reformer-based products do not solve the logistic issue of having to transport a fuel to the site. Methanol is still another fuel in a tank that has to be refilled; in other words, fuel has to still be transported to the site bringing in logistic complications.

In conclusion, reforming potentially still presents similar logistical issues also associated with refilling the tank of the diesel genset. They have similar efficiencies, and similar costs associated with the logistical burden of transporting a fuel to remote sites.

Figure 1. The SRFC has been tested in pilot Telecom environments in Australia, SEA and Africa in addition to other application uses such as off-grid communities and refueling applications.

Hydrogen generation by electrolysis: 'self-rechargeable' fuel cells

The ability to produce hydrogen onsite – thus taking advantage of the higher efficiencies, autonomy, and reliability offered by fuel cells, while at the same time removing fuel distribution costs completely – is the 'holy grail' for fuel cell adoption by telecom operators. This is particularly relevant for countries experiencing growth in remote areas, which are serviced by unreliable grid conditions or poor infrastructure in general. To address this need, H2Core Systems and NETIS have designed and developed DH2 PowerCore a revolutionary product called a 'self-recharging' fuel cell power system SRFC as displayed in Fig. 1. The heart of the system the electrolyser technology, based on Enapter's AEM, an alkaline solid polymeric membrane that makes hydrogen production possible at a lower cost and more efficient energy levels, which was not possible before. The constitution of SRFC is shown in Fig. 2. The H2Core / NETIS DH2 PowerCore system integrates a PEM fuel cell with an advanced hydrogen generator, which regenerates the hydrogen reserve onsite, using only electricity from the grid (or from renewable sources) and water. In this way the need to replace empty cylinders with full ones is totally eliminated.

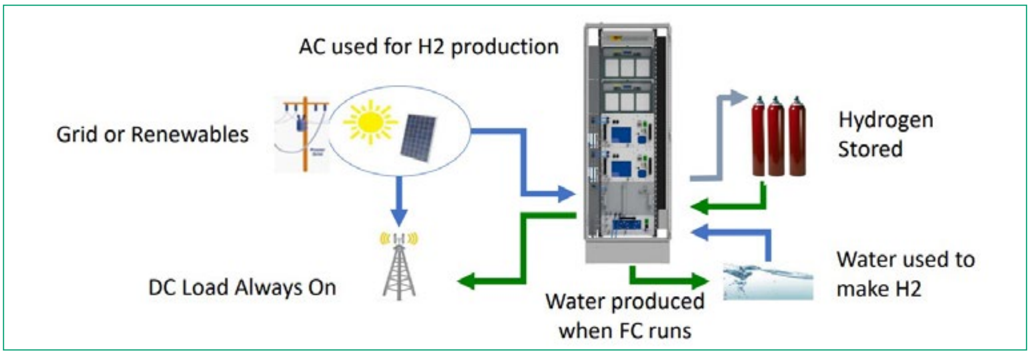


Figure 2. DH2 SRFC Cycle of life – Produce, Store, Use and Replace

The principle behind an electrolyser-based fuel cell system is the use of 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. There are basically three working modes:

- Power production: When there is a power outage, the DH2 PowerCore generates electricity by converting the stored hydrogen into power needed to meet the load, and as a by-product also producing water.
- Hydrogen production: When the grid or renewable energy is available, the DH2 PowerCore generates and stores hydrogen via electrolysis of water (this can be rain or tap water) utilizing the electricity from the grid or renewable energy source.
- Standby: When the grid is available and the hydrogen storage is full, the equipment automatically switches to standby mode.

The Enapter AEM electrolyser is key

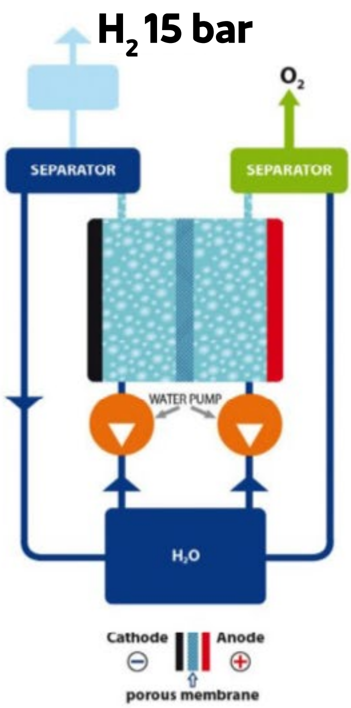
Hydrogen production from water electrolysis has been available since 1800, but it has historically been considered to be expensive and energy-inefficient, and typically involved using an alkaline or PEM electrolyser approach. These systems provide a challenge for adoption for telecom use, as they require a large amount of power to start the hydrogen process and need complex balance-of-plant to clean or dry the hydrogen. In addition, the hydrogen output from these technologies is generally at a low pressure, which requires some form of mechanical compression to store useful quantities – which is an additional energy requirement, and potential liability in terms of failure.

In addition, both alkaline and PEM electrolysers are not normally suited for remote deployments, where reliability under generally extreme weather conditions is the norm, and remote site visits must be reduced to a minimum.

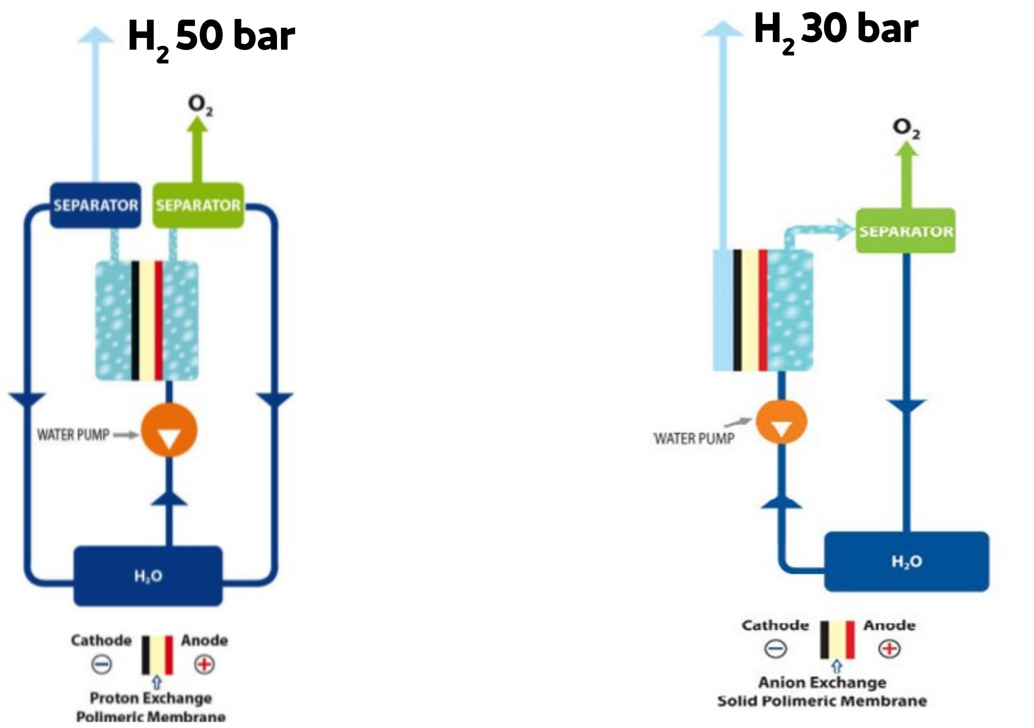
To further reduce the need for site visits, H2Core and NETIS also implemente a comprehensive remote management and control system that reduces the need for maintenance visits to potentially once a year, in addition to providing a window on the real power conditions onsite. The DH2 PowerCore's Enapter AEM electrolyser stack technology solves both cost and energy efficiency issues typically seen with existing electrolyser systems. The use of an AEM (alkaline solid polymeric membrane) eliminates the need to use expensive and rare noble metals on the electrodes and enables the safe production of directly compressed hydrogen without recourse to post-compression or sophisticated pressure- balancing systems, which add to the cost. The system is intrinsically simple, also saving the power required for the ancillary devices and for the compressor typically required for Alkaline or PEM-based systems.

Enapter AEM stack technology

DH2 PowerCore's AEM stack technology from Enapter combines the benefits of a liquid alkaline electrolyser with those of a polymer electrolyte membrane (PEM) electrolyser as shown in Fig. 3. Similar to the alkaline system, there is no need to use noble and rare metals at the electrodes of our AEM stacks, reducing costs and making the technology feasible on a gigawatt scale for global commercialization.



Alkaline Electrolyser KOH Electrolite
- Constant Power Needed
- KOH H20 Contamination



PFM Electrolyser / PEM Membrane
- Platinum Electrodes
- Ultra Pure Water
- H20 Contamination

Enapter AEM Electrolyser
- Non Noble Metals
- Demineralized/ Rain water
- Intermittent Power Available
- No water on H2 Electrode

Figure 3. DH2 PowerCore's Enapter AEM technology combines the benefits of a liquid alkaline electrolyser with those of a polymer electrolyte membrane (PEM) electrolyser.

At the same time, our AEM stack offers the advantage of safe hydrogen production and compression beyond 30 bar (435 psi) as with the PEM electrolysers without any need of a caustic electrolyte. Also, just like PEM systems can be directly powered by intermittent renewable energy.

The Core's alkaline solid polymeric membrane creates a physical barrier between the hydrogen and oxygen such that they can never mix in an explosive ratio as illustrated in Fig. 4. This is unlike traditional Alkaline electrolysers, where gases can blend across the porous separator when the current fluctuates, making them unsuitable for powering directly from intermittent renewable energy.

While existing electrolyser technology is generally limited to 15 bar (218 psi) hydrogen pressure, the DH2 PowerCore Enapter electrolyser stack can support hydrogen production at rates of 35 bar, and can adjust production rates (in real time) to match the variable and constantly changing power output typically supplied by renewables.

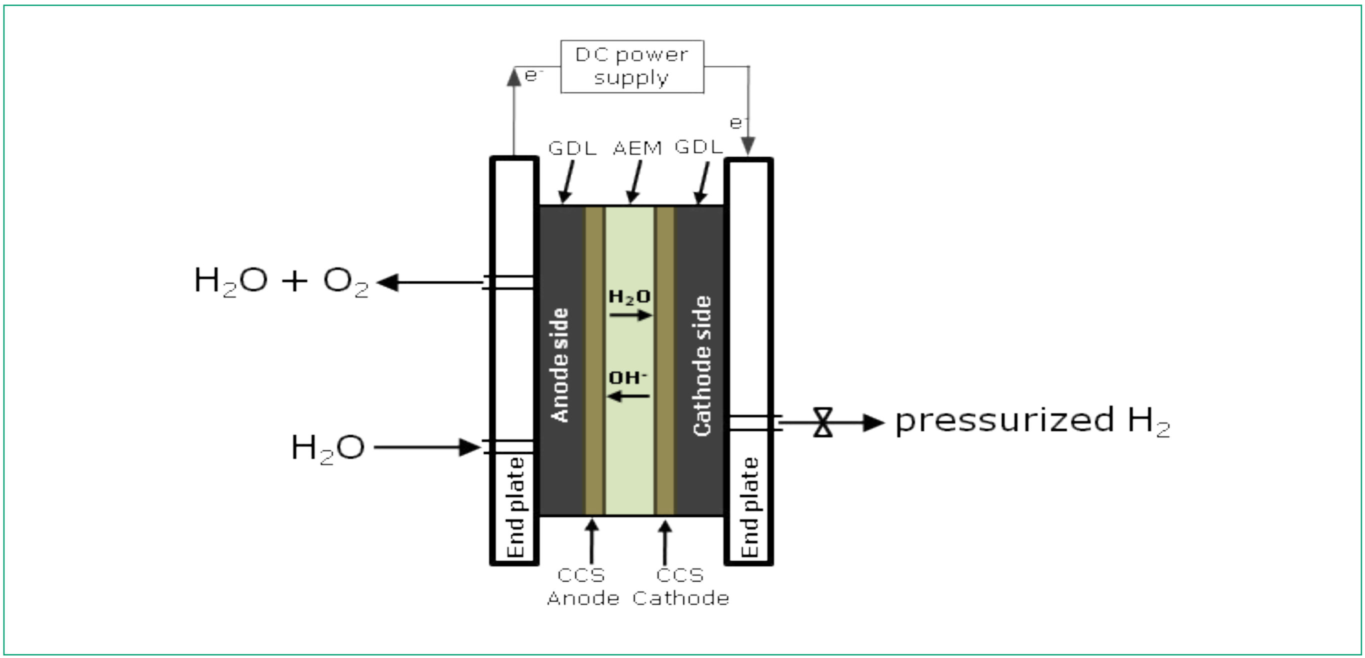


Figure 4. The Enapter alkaline solid polymeric membrane creates a physical barrier between the hydrogen and oxygen such that they can never mix in an explosive ratio.

The AEM Electrolyser as shown in Fig. 5 can be directly connected to an off-grid variable power source, such as solar panels or a wind generator, to produce a truly clean hydrogen fuel. The DH2 PowerCore alkaline membrane, unlike the PEM membrane, repels most metal ions and can be supplied with filtered rainwater for completely service- free, off-grid autonomous operation.

Figure 5. The AES stack can be directly connected to an off-grid variable power source, such as solar panels or a wind generator, to produce clean hydrogen.

The DH2 PowerCore SRFC range as displayed in Fig. 6 combines modular choice of 2.5 kW, 4 kW, 6.6 or 8kW fuel cell with scalable hydrogen generator (AEM electrolyser) depending on the duration of power autonomy. H2Core and NETIS offer SRFC modular systems with 1000 l/h hydrogen production rate with hydrogen stored at 35 bar in various sized to cater for 73 hours autonomy. Such system can be easily scaled for longer power autonomy by simply adding more empty vessels.

Sizing the System (73 kWh Autonomy)

1. What is the load
2. What is the required autonomy (in kWh) ?
3. How long do outages last for ?
4. What is the typical interval between outages ?

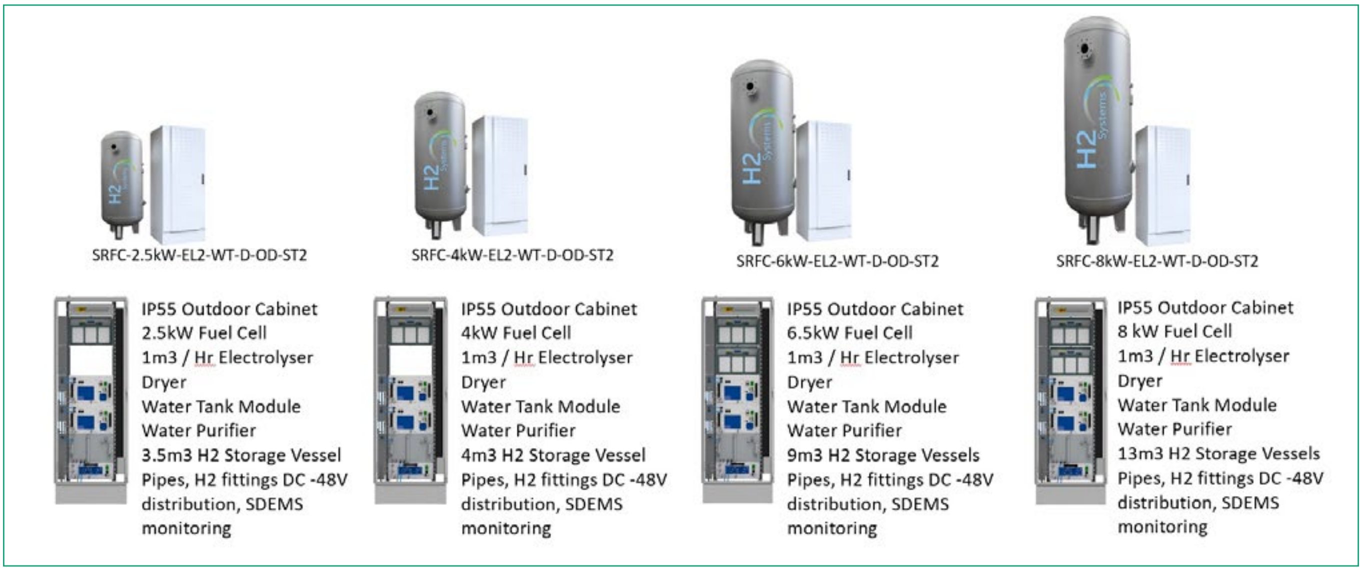


Figure 6. Cabinet design and modular approach enables single and multi cabinet systems to cater for different loads and site conditions from bad grid to off-grid.

The business case

The selection of technology for powering base stations by telecom operators is expectedly based on the total cost of ownership (TCO) of the new technology compared to the existing technology in use such genset or batteries. The element of "green "power policy for adoption of fuel cell power systems are seldomly considered for, the introduction of any new technology. Furthermore, the other important metric for the business case of fuel cell technologies is the criterion of providing better service level at a lower TCO value. The more savings that can be achieved without compromising, or better still, while improving the service level is an attractive proposition for quick adoption and wide scale commercialization.

The considerations for the deployment of an H2Core - NETIS DH2 PowerCore system include:

- Onsite hydrogen production and storage for later usage during power outages.
- Modular power autonomy duration- Autonomy can be increased by adding additional low-pressure vessels.

- Similar capital expenditure (CapExp) to existing technology, but reduced additional equipment and less complex operation.
- Reduced logistics costs- minimal maintenance as no refueling is required.
- Can be used in conjunction with grid or renewables, which may make some remote locations commercially viable.

Typical TCO analysis includes comparing a DH2 PowerCore system to the existing capital and operating costs of all relevant site equipment, including generators, batteries and cooling equipment. It also includes an evaluation of the total site energy requirement, including the base transceiver station (BTS), air-conditioning, and lighting. In this way, the costs and benefits of a fuel cell solution can be compared to traditional approaches (large batteries, diesel generators, cycle charging etc.) for various operational scenarios. The output from a typical TCO for the Southeast Asia region is shown in Fig. 7. It is to be noted that this TCO does not factor in fuel theft, which can run as high as 50% in some cases, or battery theft, which is typically recorded as 10–18%, particularly in remote locations.

The site in question has a power requirement of 4 kW, and currently experiences grid outages of 120 hours a month – ranging from many interruptions lasting a few minutes, to outages of up to 8 h in some cases. During certain times of the year the local utility also imposes enforced outages of up to 4–6 h during periods when regional consumption of electricity stresses the grid. In the TCO analysis, implementing an DH2 PowerCore system compared to using existing technology had a similar CAPEX cost.

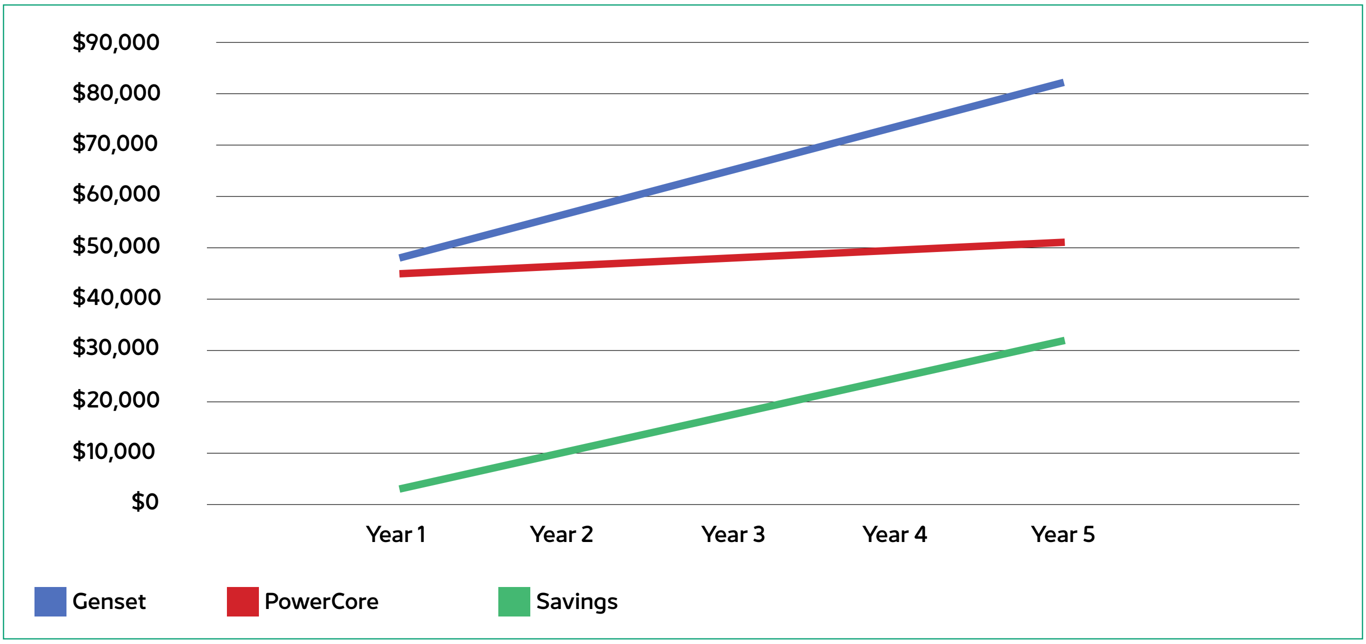


Figure 7. A typical total cost of ownership (TCO) analysis for Southeast Asia, comparing DH2 PowerCore with a traditional genset (excluding fuel or battery theft). This 4 kW site currently experiences 120 h of grid outages every month, ranging from a few minutes to 8 h.

However, the ability to produce hydrogen fuel onsite versus consuming diesel resulted in the new approach providing a much lower operational cost, with a total cost saving of more than US$ 31000 over five years. The opportunity for fuel cell deployment is well understood in the telecom sector, with benefits such as lower weight and space occupancy, lower maintenance needs, reduced fuel logistics – together with the environmental cleanness of fuel cells – exemplifies their advantage over legacy technologies such as batteries and diesel generators. In countries or situations where blackouts are frequent, distances to sites are long and infrastructure is poor, the use of fuel cell power systems in the past would have implied the need for frequent replacement of the empty hydrogen cylinders, and hence a very inconvenient logistic burden, both economically and operationally.

H2Core Systems GmbH and NETIS have integrated several fuel cell options around the Enapter AEM module which is the DH2 PowerCore, a self-recharging fuel cell power system that regenerates the hydrogen used onsite, using only electricity from the grid (or from renewable sources) and water. In this way the need to replace empty cylinders with full ones is completely eliminated, thus removing a major barrier to the deployment of hydrogen fuel cells in the telecom sector and offering a potential reduction of the billions of dollars spent globally on fuel logistics.

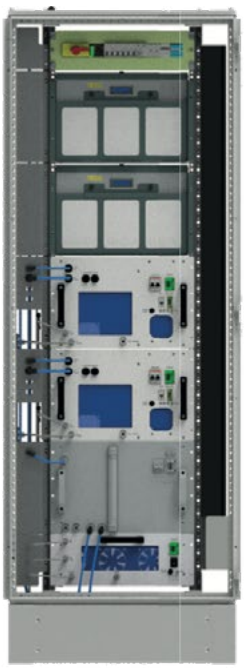
HydroCab PowerCore
Powerd by nature Self Recharging Fuel Cell

- Combines water electrolysis and fuel cells in one self-sufficient energy system for short- and long-term energy storage
- Can be integrated into all existing PV, wind or hydropower plants
- Logistics-free, sustainable energy solution
- Easy operation, independent of external Electricity price fluctuations
- Up to 2 Nm^3/h H2 production and up to 8 kW electric output power configurable
- Integrated dryer ensures H2 purity of 99.999% (5.0)
- H2 outlet pressure already 35 bar
- Fuel cells can be integrated modularly up to 8 kW power
- Suitable hydrogen storage solutions for effectively available energy from 40 kWh to > > 1,000 kWh
- Modularly scalable and expandable at any time
- Plug and play, easy installation and low maintenance operation

System configuration

- 25 kW FC
  0,5 Nm2 / h EL

- 4 kW FC
  0,5 Nm2 / h EL



- 8 kW FC
  1 Nm2 / h EL

- 2,5 kW FC
  1 Nm2 / h EL

- 4 kW FC
  1 Nm2 / h EL

	0,5m³ H2 per hour H2 Production		1m³ H2 per hour H2 Production		
Configuration	2.5 kW-0.5 Nm³/h	4 kW-0.5 Nm³/h	8 kW-1 Nm³/h	2.5 kW-1 Nm³/h	4 kW-1 Nm³/h
Power Output (Charging)	2.5 kW @ 48 V or 1.92 kW @ 24 V	4 kW @ 48 V o r 2.88 kW @ 24 V	8 kW@ 48 V or 5.76 kW @ 24 V	2.5 kW @ 48 V or 1.92 kW @ 24 V	4 kW @ 48 V or 2.88 kW @ 24 V
Rated Current	52 A @ 48 V or 80 A @ 24 V	83 A @ 48 V or 120 A @ 24 V	166 A @ 48 V or 240 A @ 24 V	52 A @ 48 V or 80 A @ 24 V	83 A @ 48 V or 120 A @ 24 V
H2 Consumption	Less than 70g per kWh				
Emission	Water Vapor				
Operation	Altitude 0-4000m | Ambient Temp +5°C - +40°C | Humidity 10-90%				
H2 Production (Storage)	500 NL/h 1 kg/24h	500 NL/h 1 kg/24h	1000 NL/h 2 kg/24h	1000 NL/h 2 kg/24h	1000 NL/h 2 kg/24h
Power Consumption	2.4 kW	2.4 kW	4.8 kW	4.8 kW	4.8 kW
Standby Consumption	15 W	15 W	30 W	30 W	30 W
Water Consumption	0.4 L/h	0.4 L/h	0.8 L/h	0.8 L/h	0.8 L/h
Output Pressure	35 bar				
H2 Purity	~99.9% (Impurities ~1000 ppm H_2O, < 1 ppm of any N2/O_2/Ar/CO/CO_2)				
With Dryer	~99.999% (Impurities: < 1 ppm of any H_2O/N2/O_2/Ar/CO/CO_2)				
Water purity	< 20 µS/cm (@25°C)				

Hydrogen Storage

850 L Steel Vessel @ 35bar	5 m³ Steel Vessel @ 35 bar	30 m³ Steel Vessel @ 35bar	Super Capacitors
30 Nm³/40 kWh (electrically usable)**	175 Nm³/230 kWh (electrically usable)	1050 Nm³/1400 kWh (electrically usable)	5 kWh @48 V
			7,5 kWh @48 V

* other sizes on request.
**Heat energy additionally usable.

Use Cases

Hydrogen's versatility as energy storage is possible with our plug-and-play building blocks

Grid Storage France

Hydrogen keeps this refuge in the Alps operational all year-round. Since 2015, it runs autonomously for up to 16 days without sunshine using a 2 kW fuel cell.

Electrolyser 500 NL/h Storage 5 kg

Mobile Refueling China

Electrolysers are integrated into a mobile drone refueling station. The electrolyser produces hydrogen right onsite to refuel drones that need to be in the air for durations of over 12 hours.

SOUTHERN GREEN GAS

Power-to-Gas Australia

Solar made hydrogen is combined with CO2which is extracted directly from the air to create renewable methane. Such "power fuel" can be used for heating and cooling, transport or industrial

Renewable Storage La Reunion Island

Only accessible by foot or helicopter, the community is energy independent with solar and hydrogen since 2017. The storage system provides 10 days of autonomy.

Electrolyser 500 Nl/h Storage 3 kg

Residential MicroGrid Chang Mai, Thailand

Off Grid community of 6 building with 86 kWPV solar is energy positive since operation. Power produced also operates water pumps for irrigation

Electrolyser 1000 NL/h

Power to Heat Netherlands

In June 2019, the first hydrogen project for residential heating was officially opened in Rozenburg near Rotterdam. Green hydrogen is directly used to generate heat.

Electrolyser 4,000 NL/h

Residential MicroGrid In Münster, Germany

1x EL 2.0 in combination with a fuel cell to provide seasonal storage.

Electrolyser 500 NL/h 600 L Storage

Telecom BTS Hoddies Greek Australia

2x EL 2.0 in combination with a fuel cell to provide fully autonomous energy 24/7.

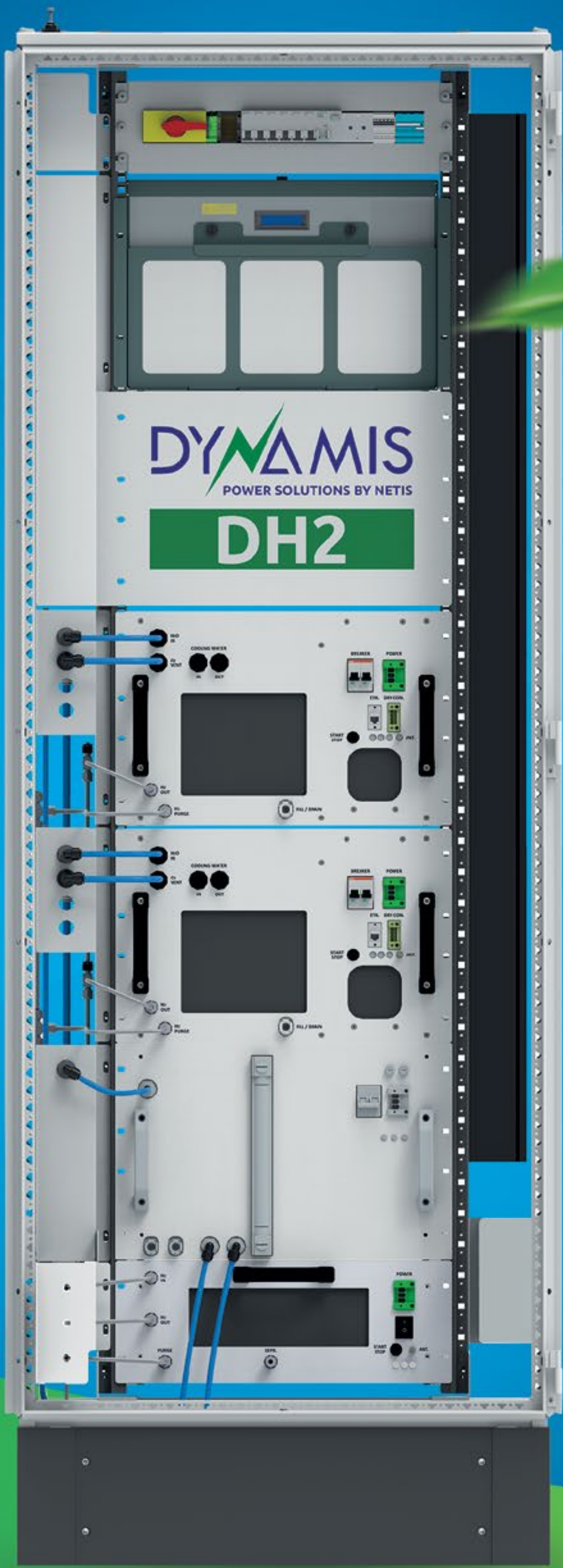
Electrolyser 1000 NL/h

Telecom BTS Lompia, Malaysia

2x EL 2.0 in combination with a fuel cell to provide fully autonomous energy 24/7.

Electrolyser 1000 NL/h

NETIS



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