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UK projects accelerate 'green' hydrogen energy

In the UK, five new government-backed projects will speed up the adoption of energy systems using hydrogen and fuel cell technologies.

Funded by the Technology Strategy Board innovation agency and the Department of Energy and Climate Change (DECC), the projects will demonstrate the use of fuel cell systems and hydrogen technologies in low-carbon energy systems and transportation. They will show how these technologies can be integrated with other energy and transport components, such as renewable energy generation, refuelling infrastructure and vehicles, to develop whole systems.

'These projects will complement the joint government/industry project UKH_2Mobility [*FCB*, January 2012, p1], which is currently evaluating potential rollout scenarios for hydrogen for transport in the UK,' says business minister Mark Prisk.

The five projects, selected through a competitive process, will be led by Air Products, BOC, ITM Power, Rutland Management Ltd, and SSE (formerly Scottish and Southern Energy). They will involve:

- The creation of the UK's first end-to-end, integrated, 'green' hydrogen production, distribution and retailing system, centred around a fully publically accessible, state-of-the-art 700 bar (10 000 psi) renewable hydrogen refuelling station network across London (led by Air Products Plc).
- The delivery of solar energy generated hydrogen for Swindon's existing public-access hydrogen refuelling station via an electrolyser, and its use in materials handling vehicles and light vans at Honda's manufacturing plant (led by BOC).
- The integration, in the Isle of Wight, of an electrolyser-based refueller with renewable energy, enabling zero-carbon hydrogen to be produced for use as a transport fuel for a range of vehicles as part of the Ecoisland project (led by ITM Power).
- The demonstration of a viable solar-hydrogen energy system, with benefits shared by multiple end-users of a business park in Surrey, through the 24/7 provision of green electricity and heat (led by Rutland Management Ltd, which operates Dunsfold Park and Aerodrome, home of AFC Energy).
- The demonstration of a whole renewable hydrogen system, connecting a 1 MW electrolyser to the grid, in conjunction with an Aberdeenshire wind farm, to explore the grid impacts and energy storage potential of hydrogen generation, and provide green hydrogen to power a fleet of fuel cell buses (led by SSE).

The Technology Strategy Board and DECC will provide total grant funding of £9 million (US$14 million), with the total value of the projects – including contributions from the industrial partners – in excess of £19 million ($29.5 million). These projects build on previous government support for fuel cells and hydrogen systems, accelerating the process towards commercialisation.

The £4.66 million ($7.2 million) Isle of Wight project [*FCB*, November 2011, p1] will see ITM Power collaborating with SSE, Toshiba, IBM, Cable & Wireless Worldwide, National Physical Laboratory, Cheetah Marine, Arcola Energy, Ecoisland Community Interest Company (CIC), and Glamorgan and Nottingham universities. The Ecoisland project will design, build, install, and operate two grid-connected hydrogen refuelling platforms in the Isle of Wight, with 100 kg/day and 15 kg/day capacities, for the operation of a fleet of hydrogen vehicles, including ones from Hyundai, Microcab [*FCB*, October 2011, p3], and Riversimple [*FCB*, November 2011, p2]. The vehicles showcased will include fuel cell electric vehicle (FCEV) cars, hydrogen internal combustion engine (HICE) vans, and a HICE boat [*FCB*, January 2012, p8].

[*See the feature on ITM Power's hydrogen refuelling technology in FCB, January 2012 – and the feature in this issue on ITM Power's fuel cell membrane technology, on pages 12–15.*]

Technology Strategy Board: www.innovateuk.org
Air Products Plc: www.airproducts.co.uk
BOC Ltd: www.BOConline.co.uk
ITM Power: www.itm-power.com
Ecoisland: www.eco-island.org

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ITM's membrane technology unlocks the power of hydrogen

By Dr Simon Bourne – Chief Technology Officer, ITM Power Plc, UK

ITM Power is best known for its hydrogen fuelling technology, but the technology behind its electrolyser systems can also be utilised in fuel cells. This article looks at how the company's hydrocarbon membranes can offer distinct advantages in applications such as fuel cell electric vehicles.

When most commentators write about ITM Power they focus on energy storage, clean fuel production, and the company's packaged CE marked refuelling technology. Very little has been written about the ITM Power fuel cell MEA – mainly because the technology has been developed in 'stealth' mode. Patented worldwide, the technology is now being tested by many major players in the hydrogen energy industry.

ITM Power is a UK company making business out of hydrogen [*see the feature on its hydrogen fuelling technology in FCB, January 2012*]. Having designed, operated and sold fully integrated hydrogen refuelling systems, the company has made a name for itself as a provider of clean fuel. ITM has a few things to say about fuel cells too, having spent several years developing a unique membrane technology that offers stark differentiation from the competition.

While the company has no plans to commercialise a packaged fuel cell product itself, ITM does intend to make its fuel cell membrane available for integration within key partnerships – and there are a few good reasons why some big companies may be considering just that...

The heart of the system

Buried deep inside ITM's hydrogen generation systems is a series of electrolyser stacks. Each of these contains a number of membranes – solid polymer electrolyte in the form of a thin film. The membranes have catalyst on both sides, and play a crucial role in the electrochemical process of hydrogen creation from water by (among other things) allowing conduction of protons. The same function also enables the membrane to be used in a fuel cell, this time consuming hydrogen to generate power.

The fuel cell

Fuel cells convert fuel in the form of hydrogen and oxygen into electricity and water. They have no moving parts, release no harmful emissions, and can operate at high efficiency. Taken together, the positive attributes of fuel cells offer several advantages over batteries and conventional engines. Individual cells have a low voltage with the capacity to generate a high current. Therefore, it is common for multiple cells to be arranged in electrical series into stacks.

Figure 1. A Hyundai ix35 FCEV fuel cell electric vehicle is refuelled by an ITM Power HFuel hydrogen station that generates 'green' hydrogen onsite, at the All-Energy 2012 show in Aberdeen, UK.

Application

While fuel cells are gaining traction in several application areas, deployment in the next generation of vehicles is probably the most well known.

Hyundai is leading the charge among the automotive OEMs with deployment of fuel cell electric vehicles planned for 2013, followed by Daimler in 2014, and then just about every other manufacturer in 2015 (**Figure 1**). There are indeed several coordinated national schemes addressing the rollout of both FCEVs and the associated hydrogen infrastructure. The British scheme, called UKH_2Mobility, sees a joining of forces between three government departments (Energy & Climate Change, Business Innovation & Skills, and Transport) with industrial participants from the utility, gas, infrastructure, and global car manufacturing sectors.

So fuel cell components have now been selected and qualified for this first tranche of FCEVs. However, the fuel cell stack is acknowledged as being the single most expensive component on board the vehicles, and the search is on for the next generation of components that will achieve the aggressive cost reduction profile demanded by the automotive sector.

The ideal fuel cell membrane

There is no question that fuel cells have a lot going for them. It would be unfair not to admit that they have a few challenges too – the chief among them being cost.

It is widely accepted that power density is the single most important parameter in reducing fuel cell cost. The more power that can be squeezed out of a fuel cell, the less fuel cell you need, offering a prime route to reduce cost through miniaturisation. The catalysts used to promote the forward reaction tend to be precious metals such as platinum. There is a fair amount of platinum in a conventional car exhaust system, so this is not a financial disaster, but clearly there is a need to use as little as possible.

In addition to the stack, fuel cell systems carry around other kit, collectively referred to as the balance-of-plant. This is a collection of valves, blowers, pumps etc. with the job of ensuring that the fuel cell stack is provided with the right flow of reactants, maintained at the correct temperature, and generally kept happy. While a fairly crude measure, it stands to reason that a delicate stack (and the membrane in particular) demands more looking after, and hence more balance-of-plant. Some might argue that we have got used to carrying a lot of balance-of-plant, and therefore have cost saving opportunities here too, through the development of less sensitive stacks and membranes.

On top of all of this, the stack needs to be durable in the face of the demanding duty cycles associated with automotive applications – rapid changes in power output, varying ambient conditions, cold starts, and all the other things we have grown to expect from our cars.

Bridging the gap

In order to describe how ITM is bridging the gap, we need to delve a little deeper into the technology. Conventional solid polymer membranes are based on fluorocarbons. They have very long polymer chains in an entanglement network – a bit like a bowl of spaghetti. Attached to the spaghetti are a series of shorter, pendant side-chains holding on to sulfonic acid groups. It is these groups that render the material ionically conductive (when hydrated in water).

ITM's material is quite different (**Figure 2**). It is based on hydrocarbons, which are an order of magnitude lower in cost and easier to handle than fluorocarbons. Furthermore, the polymer is crosslinked, giving it defined structure in three dimensions and important mechanical characteristics. It is possible for the material to be rendered acidic or alkaline, providing another level of flexibility not possible to capture in this article.

They key thing here is that ITM's material is in fact a suite of materials. By varying the ratio of the four main components in the formulation, the ultimate material properties may be varied over a very wide range.

While it is obvious to strive for an optimum where all key properties are simultaneously maximised, unfortunately the real world doesn't usually allow for that, forcing some tough trade-offs. This is where ITM's material and formulation experience comes into its own – providing a unique ability to modify the formula to effectively pick and choose the properties that make the biggest impact (**Figure 3**). This is an area where ITM has concentrated some serious effort, and the benefits are becoming very clear indeed.

Power density

In early 2011, André Martin and Ludwig Jörissen reported for NOW GmbH – the organisation responsible for the rollout of hydrogen infrastructure in Germany – on the fuel cell supply chain.[1] There were three main conclusions. The first was that increasing power density is a prerequisite to reducing the cost of fuel cells (we know this already). The second was that there is consensus in the automotive industry that 1 W/cm^2 (1.5 A/cm^2 at 670 mV) is an aspirational power density target (this is an extremely useful benchmark). The third conclusion was that the supply chain for membrane-electrode assemblies (MEAs) – i.e. the membrane plus the catalyst electrode structures – was unable to reliably supply against the 1 W/cm^2 power density target.

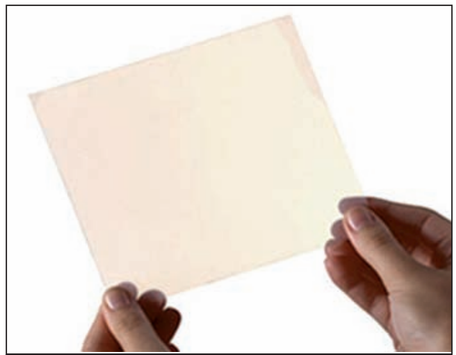

Figure 2. ITM Power's membrane is based on hydrocarbons, which are an order of magnitude lower in cost and easier to handle than fluoro-carbons.

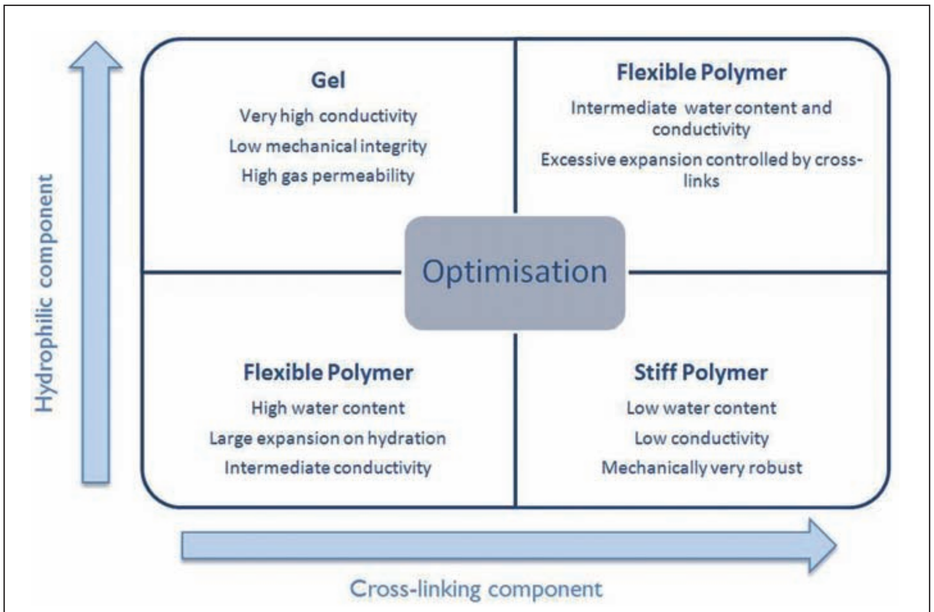

Figure 3. ITM Power's membrane offers a unique ability to modify the formula to effectively pick and choose the properties that make the biggest impact.

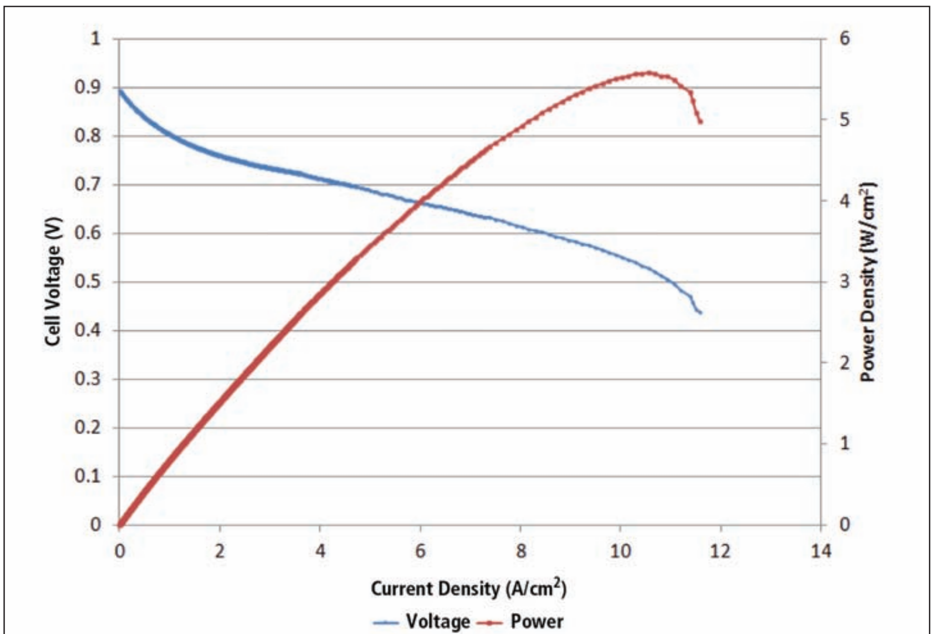

Figure 4. The achievement of power densities above 5.5 W/cm^2 at over 10.5 A/cm^2 (hydrogen and oxygen) shows that the ITM membrane has something special to offer.

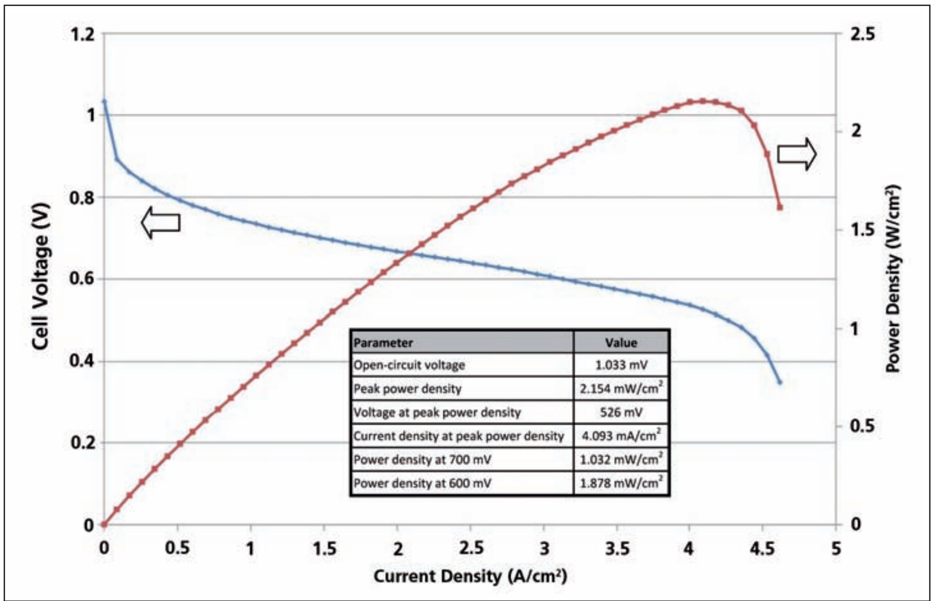

Figure 5. Fuel cells will always show reduced power density when using air rather than pure oxygen, yet the ITM membrane clearly demonstrates a relatively high power density.

When ITM first began investigating its materials for use in fuel cells, hydrogen and pure oxygen were used. This was a logical choice as the company generates both gases from its electrolyser systems, and there is merit in understanding how the two interface with one another.

The achievement of power densities in excess of 5.5 W/cm^2 at over 10.5 A/cm^2 was evidence that the ITM membrane material has something special to offer (**Figure 4**). This is believed to be the highest ever reported power density from any fuel cell, and by some distance. While the company's focus has been (and still is) on electrolysis, the ultra high power density performance justified further development effort. Benchmarking against conventional membrane materials showed the ionic resistance of ITM's material to be an order of magnitude lower than the incumbent membrane technology.

In 2011, ITM benefitted from some funding from The Carbon Trust to explore the chemical stability of the membrane, and to establish if the unusually high power density could be achieved using hydrogen and air (rather than oxygen) – and also at significantly lower catalyst loadings. While there will always be a reduction in power density when moving from pure oxygen to air (owing to dilution of the oxidant with nitrogen), the high power density characteristic of the ITM membrane material was clearly demonstrated (**Figure 5**). It is notable that the 1 W/cm^2 target shared among the automotive community was exceeded.

Catalyst loading

So, high power density – that box is ticked. However, that is of limited benefit if the cost saving is countered by high loadings of expensive catalyst materials. ITM began its fuel cell research using platinum black (the standard catalyst), and at high loading. This was deliberate to ensure it was the membrane itself that was interrogated rather than the catalyst membrane composite.

Simply reducing the platinum black loading resulted in a predictable loss in power density. However, shifting to supported platinum catalysts showed a dramatic increase in performance at lower loadings. Adding a small amount of ionomer coating to the catalysts demonstrated further performance benefits. As such, ITM has achieved an 85% reduction in catalyst loading while maintaining 90% of the power density (**Figure 6**). There is more work to be done in this area, but this is not a bad start.

Couple this with ITM's ability to deliver very low catalyst loadings via its patented one-step membrane fabrication route, and we can see that the technology has a lot to offer.

Sensitivity

High power density – tick. Low catalyst loading capability – tick. But what about the need to carry a lot of balance-of-plant?

An important factor here is the hydraulic stability of the membrane. This relates to the mechanism of ionic conduction within the membrane which requires water to surround the acid sites. Should the membrane dry slightly under operating conditions, the ability to conduct protons will diminish, reducing the performance of the fuel cell. To combat this, it is common for fuel cell systems to incorporate humidification plant, essentially adding water to the input gas streams in order to protect against membrane dehydration.

The ITM material has another trick up its sleeve here, having a hydrophilic (water attracting) moiety tied into the polymer structure. This extra ingredient helps the membrane material hold on to water and minimise the need for hydration balance-of-plant. Elimination of fuel cell subsystems is a good thing! All of the power density data presented in this article were collected using unhumidified feed gases.

In situ analysis of membrane conductivity as a function of relative humidity has shown, firstly, that the ITM class of materials has significantly higher ionic conductivity; and

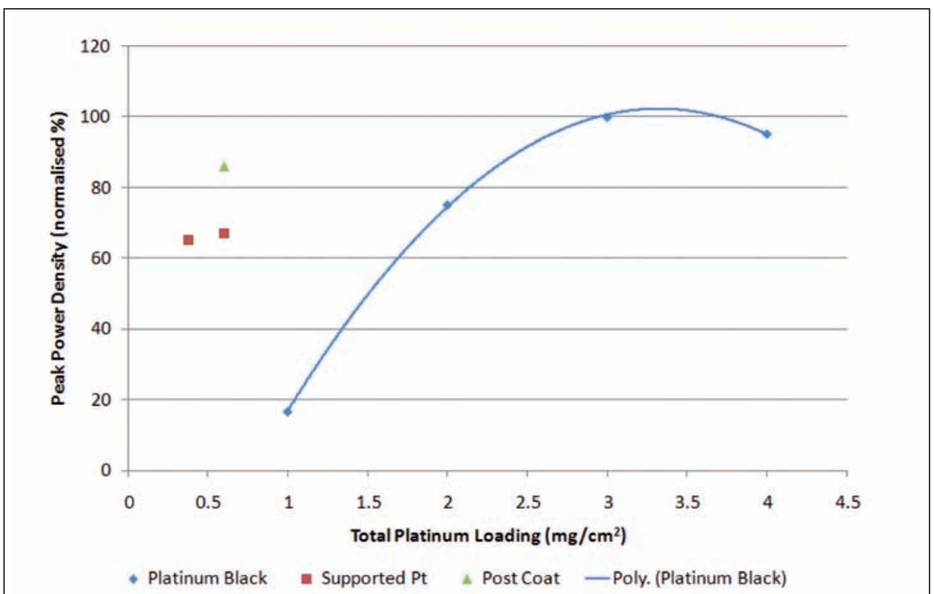

Figure 6. ITM has achieved an 85% reduction in catalyst loading while maintaining 90% of the power density.

secondly, that even at low humidity levels, its conductivity still exceeds that of the incumbent materials (**Figure 7**).

Cost structure

There is always great difficulty in translating significant advances achieved in the laboratory to genuine impact in the commercial world. The same is true here. However, there are tools available to take on this challenge.

The Carbon Trust commissioned an independent techno-economic analysis to quantify the cost benefits of ITM Power's membrane technology compared to the current state-of-the-art.[2] The analysis – which is expected to be published in due course – utilised the TIAX modelling architecture originally developed with and used by the US Department of Energy to project costs of near-term fuel cell technology at high production rates (**Figure 8**). Early indications from the techno-economic analysis suggest that fuel cell technology using ITM Power's membrane and low catalyst loadings could be capable of achieving US$35/kW in manufacturing quantities of 500 000 units per annum, although confirmation will have to wait for the final report. This is particularly relevant, as the analysis identifies the point at which fuel cell electric vehicles become cost-competitive with internal combustion engines is at $36/kW.

A base case projecting the cost of incumbent fuel cell technology under the same conditions, showed a cost of $49/kW. Reducing this cost to $36/kW was shown to be capable of increasing the market share of FCEVs by 10% (160 million vehicles) by 2050, equating to an additional $25 billion of PEM fuel cell market value.

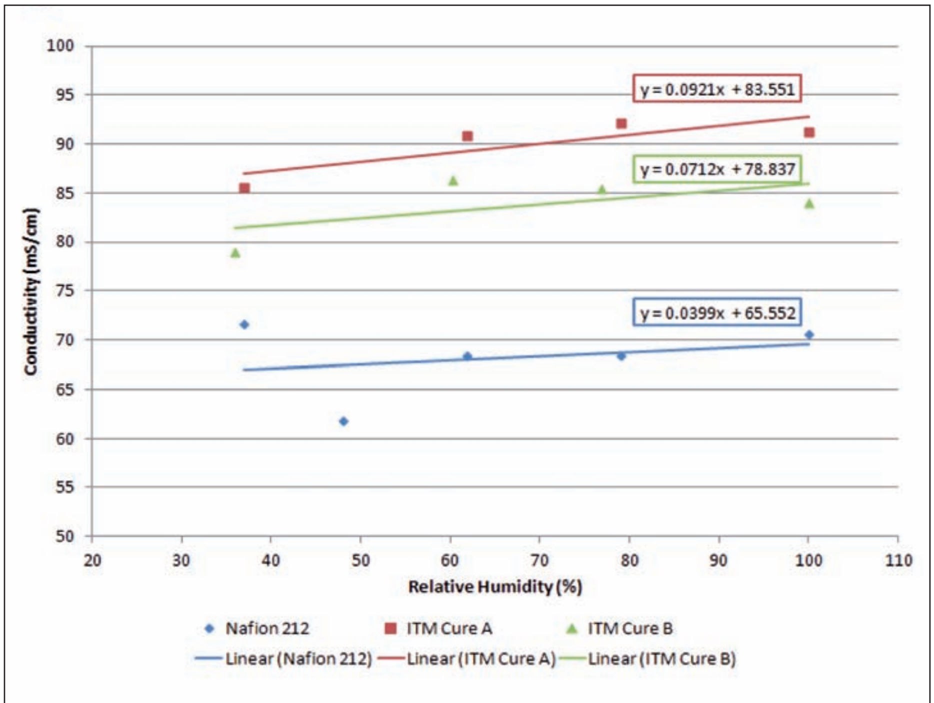

Figure 7. The ITM membrane has a hydrophilic moiety tied into the polymer structure, which helps the material hold on to water and minimise the need for hydration balance-of-plant.

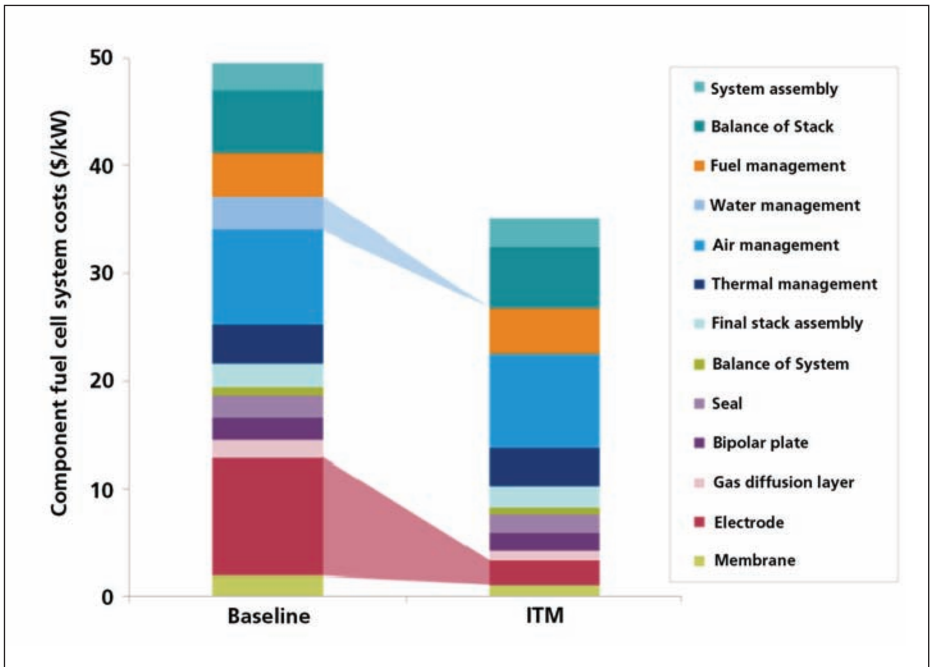

Figure 8. A techno-economic analysis commissioned by The Carbon Trust quantifies the potential cost benefits of ITM's membrane technology compared to the current state-of-the-art.

About ITM Power

ITM Power designs and manufactures hydrogen energy systems for energy storage and clean fuel production. The company has grown from its original platform of novel polymeric electrolytes (for water electrolysis and hydrogen fuel cells) to that of a technology provider. It now has both a strong base of intellectual property and engineering expertise for providing complete hydrogen solutions and CE marked products for sale.

ITM Power Plc was admitted to the Alternative Investment Market (AIM) of the London Stock Exchange in 2004, and raised initial funding of £10 million (US$15.5 million) in its Initial Public Offering. A further funding round of £28.5 million ($44.1 million) was completed in 2006. The company has now made the transition from a research and development company to a product manufacturer and technology provider. A strong set of results in 2012 shows a growing customer base and associated product revenue.

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