Fuel Cell Technology: Gasification Game Changer?

Waste to Energy is increasingly attracting column inches as a potential solution to two major UK challenges: namely renewable energy production and heavy reliance on landfill. Peter Jones explores how integrating alkaline fuel cells into a WtE plant can boost net output of electricity by a minimum of 60%.

Traditionally, electrical power generation has relied on combustion. Fuel is burnt (oxidised) either producing heat to boil water for steam or directly expanding as gas, and generates enough pressure to move a piston or a turbine blade. In other words the chemical energy of the fuel is first converted to mechanical energy before it can generate electrical energy. At each of these conversion steps energy is lost, chiefly as heat. But what if you could cut out the middleman and generate electrical power directly from the fuel without using a mechanical engine and so avoiding energy losses?

This is the world of electro-chemistry and the role fuel cells play – generating electricity from chemical reactions without combustion. Batteries have traditionally occupied this space, cells of chemicals which can release electricity on demand wherever we are. This is fine for small scale applications, but a real challenge when it comes to sustained generation and megawatt scales. One contender to fill this space is the fuel cell, which has recently seen rapid development.

Origins in space

Fuel cells were first demonstrated in the 1830s, by Welshman, Sir William Grove. It took another 120 years before GE demonstrated the first commercial fuel cell application as part of the U.S. Gemini space mission. During the 1950s, English scientist Francis Bacon developed a 5 kW alkaline fuel cell for stationary power generation and the technology was licensed to Pratt and Whitney for use in the U.S. space programme.

The majority of fuel cells use hydrogen (H2) as feedstock which reacts with oxygen to form water, electricity and heat. Although the chemistry seems simple, developing fuel cells capable of sustained operation has not been trivial. Those with chemistries greater than 100 degrees centigrade are capable of producing steam as a by-product, but have to be engineered to withstand pressure and prevent surfaces becoming so hot that they become an ignition source. All of this adds to the cost of the fuel cell system. Alternatively, more recently developed fuel cell systems can operate below 100 degrees centigrade and be manufactured from low cost materials including plastics.

As the chemical reaction producing electricity is exothermic, heat can build up within the fuel cell stack. Unless controlled, this will lead to failures due to temperature gradients and thermal cycling. Some fuel cell systems use a solid electrolyte to manage this unwanted heat with blowers and heat-sink materials. However, keeping the fuel cell stack within the desired temperature range detracts from the potential efficiency of the system.

One way around this is to use a liquid electrolyte, as in the alkaline fuel cell system. This liquid electrolyte (usually potassium hydroxide) can be circulated through the fuel cell stack at the rate required carry away sufficient heat to keep the fuel cell operating at a specific temperature. Although the pump required to do this will use some of the power produced, a liquid electrolyte can also be used to transport the water produced away from the stack, where it can evaporate from the electrolyte and condense.

Another aspect requiring significant attention in the fuel itself is the hydrogen. As the smallest molecule, sealing hydrogen within the fuel cell system can be problematic. First, the system must be constructed from materials that will retain the hydrogen and not react adversely with it. Sealing the hydrogen within fuel cell systems that operate at high temperatures and pressures is an engineering challenge.

Unlocking hydrogen's efficiency as a fuel

So where does all the hydrogen come from? Well it is the most abundant element in the universe, it is all around us. The question is how can it be unlocked efficiently to be used as a fuel? There are several methods.

The first is electrolysis of water, H2O. The chlor-alkali industry typically electrolyses brine to produce chlorine, caustic soda (NaOH) and hydrogen. This hydrogen is an excellent potential source of fuel for fuel cells and several companies are targeting this market, with global potential for more than 3000 MW of power generation. Electrolysers can also be used to generate hydrogen from water using surplus electricity from renewable sources such as wind, wave and solar. One of the challenges of these forms of renewable energy is that they are intermittent – you can have too much at one time and not enough at others. By converting the surplus, low value, electricity into hydrogen there is the possibility of using it later to generate electricity with fuel cells at peak times when electricity is more valuable.

Fuel cells and waste

The second process for generating hydrogen is reforming. Here hydrogen is extracted from hydrocarbons through a chemical reaction, typically accelerated through the use of catalysts. One common process for doing this is steam methane reforming (SMR). In this process methane is reacted with steam at temperature and pressure in the presence of a catalyst, to produce hydrogen and carbon monoxide. Carbon monoxide can then be reacted with water to produce more hydrogen and carbon dioxide. Water from the fuel cell provides the majority of the water required for the production of steam in the reformer.

We could soon see the use of fuel cells with methane from anaerobic digestion technologies. Although reforming uses some of the available energy to generate hydrogen, this is more than compensated for by the efficiency of the fuel cell system, resulting in lower carbon emissions per unit of electricity generated. When the feedstock is bio-methane rather than natural gas, carbon emissions plummet. If the captured carbon dioxide can be used or stored, it could even become carbon negative.

The third source is gasification. In this process hydrocarbons are gasified to produce a synthesis gas. Municipal solid waste (MSW) or commercial waste can be gasified, usually after conversion to refuse derived fuel (RDF) by removing glass, metals and in-organics and potentially some drying and shredding. RDF typically contains plastics, papers and biological derived hydrocarbons.

In each case the synthesis gas is cleaned so that it contains predominantly hydrogen and carbon monoxide. In an additional step the carbon monoxide is reacted with water to produce more hydrogen and carbon dioxide, known as a water-gas shift reaction.

Hydrogen is separated using either a membrane or a pressure swing adsorption (PSA) unit, a device that contains an adsorbent material that will preferentially adsorb one gas from a mixture over another at pressure. As the pressure is released, only one of the gasses is evacuated from the unit. PSAs operate on a batch process.

There are few fuel cell companies targeting markets for multi-megawatt applications. One fast emerging contender is UK based AIM listed company, AFC Energy plc, which as the name suggests focuses on energy generation using alkaline fuel cells. AFC recently delivered and installed two of its commercial scale units at AkzoNobel's chlor-alkali plant in Bitterfeld, Germany.

Known as the Beta system, these units are modular, cartridge-based units which can be installed in phases. When cartridges need replacing they are simply isolated, removed and replaced, or hot-swapped, without having to be turned off. Even the fuel cell cartridges can be disassembled, the electrodes cleaned, re-coated with catalyst and reassembled.

While these systems are still at a relatively early stage of field testing, they have already been designed into several projects. One of these is Air Products' proposed 49MW waste-to-energy plant in Teesside. Waste collected locally will be subjected to extremely high temperatures using gasification and turned into an energy-rich gas which a turbine will transform into electricity for up to 50,000 households. This technology can also produce renewable hydrogen and the facility will be the first to demonstrate Waste2Tricity's fuel cell technology with scrap carbon derived hydrogen. This facility is one of the largest advanced gasification projects planned for the UK and signifies good progress in delivering an alternative to conventional electricity generation.

We have a looming energy gap with or without a second recession. If there is a role for the waste and fuel cell industries to fill part of that gap for efficient heat, electricity and hydrogen or fuel gases, then we must grasp the nettle and widen the horizon of our technological aspirations and delivery.

There is no doubt that the world of fuel cells is progressing more rapidly now than ever before. The drivers include higher fossil fuel prices, incentives for reducing carbon emissions, and achieving greater efficiency from fuel. All of these things will help the commercialisation of large-scale fuel cell systems for the generation of electrical power from waste, perhaps one day replacing conventional engines altogether – truly quite a revolution.

The question that remains, however, is whether local UK councils will have enough budget to replace incineration with more efficient WtE plants, harnessing technologies like advanced gasification and fuel cells and eliminating the issues of air pollution and waste ash. As this ultimately produces at least twice as much electricity for the National Grid for every tonne of waste processed, fuel cell technologies provide a great opportunity for the waste management industry.

Peter Jones is director of Ecolateral and chairman of Waste2Tricity.
email: ecolateraljones@btinternet.com

Stacked: hydrogen is the most abundant element in the universe but the challenge is how to unlock it as a fuel. Could waste gasification processes be the answer?

A proposed facility in Teeside will see waste gasification and fuel cell technologies combining

Tough: cells must be constructed to retain and seal athe hydrogen