March 2011 **Horizon scanning SR025**

HSE Horizon scanning report

The hydrogen economy

Status:
HSE Action

Issue

The health and safety implications of an increase in the use of hydrogen in domestic or vehicle applications.

Background

Hydrogen can be used to generate energy by burning in a boiler or internal combustion engine, or by reaction with oxygen in a fuel cell (see below). Free hydrogen does not occur in nature, so hydrogen is not strictly a fuel, but an energy carrier. Hydrogen can be produced by a variety of means, for example by the electrolysis of water or by algae. Since the residue from hydrogen is just water, it provides energy that is very clean at the point of use. If the primary energy source is a fossil fuel, much of the advantage is lost, but if the primary source is renewable, then a hydrogen based system can provide both a very clean energy source and a means of storing the fluctuating outputs associated with renewable sources such as wind and solar systems.

A Hydrogen Fuel Cell (HFC) is an electrochemical device, which oxidises hydrogen, releasing electricity. Most fuel cells use oxygen from the air and hydrogen from:

- cylinders of compressed gas;
- cryogenic liquid storage;
- metal hydride storage;
- methanol;
- reformed liquid petroleum gas (LPG) ;
- methane.[1]

A key stationary application foreseen for the hydrogen/fuel cell system is the provision of Combined Heat and Power (CHP) for homes and businesses, through “microgeneration” of electricity and heat on site. In the short term CHP will be most likely to be HFC based, but use natural gas or propane as a fuel to generate hydrogen on site, so hydrogen distribution will not be required. Additionally HFCs are likely to replace diesel generators as backup power for data rooms.

The wide variety of primary energy sources, which include fossil fuels, solar, wind and wave sources, nuclear and biomass make hydrogen very attractive as an “energy carrier” or “vector” in terms of enhancing the future security of energy supply.

Hydrogen can also be used to power vehicles by one of two methods: combustion in a modified internal combustion engine or by using a HFC stack to power an electric traction motor.

The industrial use of hydrogen is well established in the UK, where it is used in many applications including the production of chemicals, pharmaceuticals and petroleum

products and in the electronics and metal industries. Currently hydrogen is mostly produced from the steam reforming of hydrocarbons.

Current and Planned Developments

Currently the gap between the state of HFC technologies and successful commercialisation is rather large. However, there are a number of projects ongoing over the coming years, particularly in relation to vehicular applications, that may lead to an expansion in the hydrogen sector. Some examples include:

- AFC Energy has developed low-cost HFCs for electricity generation for large-scale industrial applications. The HFCs, which run at low pressure and temperature, are part of a modular system that can be easily scaled up. The company is currently trialling a 50 kilowatt (kW) unit and is working on a 1 Megawatt (MW) system. The HFC system is a component of B9 Coal's 500 MW carbon capture and storage (CCS) proposal for the Department of Energy and Climate Change's (DECC) CCS demonstration competition. Additionally, B9, Powerfuel and AFC Energy have signed a letter of intent for potentially 300 MW of HFCs to be installed at Powerfuel's planned 900 MW Integrated Gasification Combined Cycle (IGCC) plant and AFC is also in negotiation to supply its HFC technology to Air Products' 49 MW gasification plant, which will convert waste to electricity.[2]
- ITM Power has a hydrogen-powered demonstration home in Sheffield, which is powered by an electrolyser (to produce hydrogen by splitting water) coupled with an internal combustion generator to produce electricity. This removes the need for a hydrogen pipeline infrastructure. In the short term ITM Power initially sees these electrolysers appearing at filling stations to power cars, before later domestic use.[3] The hydrogen can also be used in an internal combustion engine to power a modified Ford Focus car. If mass-produced the electrolyser could be available for a tenth of the current prototype cost of £20,000.[4]
- Intelligent Energy has a joint venture with Scottish and Southern energy to develop Combined Heat and Power HFCs for the UK commercial and residential market.[5]
- In early March 2010 London Hydrogen Partnership (LHP) announced its Hydrogen Action Plan. The ambition is to put 150 vehicles on the roads of London by 2012 along with six refuelling stations; of these only one currently has planning permission. Around 20-50 of the vehicles will be HFC converted taxis in association with Intelligent Energy.[6] Most of the vehicles will be HFC converted cars/motorcycles. The aim is to get fleet users on board. The LHP is currently doing a study of infrastructure and looking at business plans and fleet models.[7]
- The Welsh Government has plans for a series of hydrogen filling stations along the M4 in Wales.[8] There are hopes that this could be linked to a hydrogen 'ring' of filling stations in the Midlands, planned for 2020.[9] However, there has been little in the way of funding for this so far.
- The Cleaner Urban Transport for Europe trial (CUTE) ran from December 2003 to January 2008. Transport for London (TfL) operated HFC powered buses in the centre of London. In 2010 five hydrogen buses will enter service in London, with potentially a further three buses, subject to EU funding.[10] There are plans to construct a hydrogen refuelling and maintenance facility in a First Group diesel bus depot in Waltham Forest London. The hydrogen, refuelling equipment and maintenance will be provided by Air Products.[11]
- Royal Mail is trialling a HFC post van for six months on the Isle of Lewis, along with two hydrogen combustion vans. These have been designed and built by Microcab. This project also involves PostEurop, FuelCellEurope and Cenex, who

hope to use the trial to introduce a universal hydrogen post van design, which will be presented to other European postal companies and then to vehicle manufacturers for consideration. It is hoped that this will stimulate mainstream construction of affordable hydrogen post vans.[12,13]

- Riversimple recently announced a HFC car (which uses ultracapacitors to store and release large amounts of energy quickly) that would be available on lease, hopefully from 2013. In 2012 they aim to run 30 prototype cars in Leicester. BOC will supply the hydrogen filling stations and there are hopes that as cities adopt this technology, a nationwide network of stations will develop. The car designs are 'open source' to allow local manufacturing in small plants.[14,15]
- Major car manufacturers are trialling HFC vehicles. In October 2010 Mercedes began a pilot to lease 200 HFC cars in Europe and America.[16,17] Suzuki has produced a HFC scooter called the Bergman; demonstrators will be rolled out soon, including in the UK.[18] Honda has produced the FCX-Clarity, ten of which were leased in Los Angeles in 2009. It plans to offer HFC cars at similar price to mid-sized petrol cars by 2020.[19] Nissan is testing a new type of car fuel cell[20] and Hyundai is aiming to produce HFC cars by 2012.[21] BMW has loaned 100 Hydrogen 7 cars, which burn hydrogen in a combustion engine; some of these cars were used in London.[22] However, BMW has for now suspended plans for mass production of hydrogen cars.[23] Both Renault[24] and Ford[25] have stopped plans for hydrogen cars, concentrating instead on electric cars.
- The University of Birmingham Fuel Cell Group has a number of pilot projects and demonstrations including: a hydrogen filling station; a hydrogen-powered house; five Microcab vehicles to deliver university post, powered by HFCs; and a HFC CHP device. They are also working on setting up a HFC supply chain in the UK.[26]
- An important new market for HFCs has been fork lift trucks, which have advantages over the current battery trucks. In the United States there are several fleets of over 60 vehicles.[27] HSE has received an inquiry regarding installation of a HFC fork lift infrastructure in UK warehouses; the main safety issue is indoor hydrogen refuelling.

Influencing Factors

Incentives

The Department for Energy and Climate Change (DECC) has provided £7.2 million of funding for the Low Carbon Knowledge Transfer Network for companies to develop hydrogen and fuel cell technologies.[28] However, this level of funding is modest compared to the funding awarded to other alternative energy technologies.

Cenex has been set up with the help of the Department of Business Innovation and Skills (BIS) as the UK's Centre of Excellence for low carbon and fuel cell technologies. Its aims are to promote UK market development and competitiveness in low carbon and fuel cell technologies for transport applications. It runs a number of projects, including the Low Carbon Vehicle Procurement Programme and the Low Carbon Knowledge Transfer Network.[29]

The Policy Studies Institute has carried out horizon scanning activity on the Hydrogen Economy as part of its UK sustainable hydrogen energy consortium.[30]

Barriers and Challenges

The main challenge associated with rolling out a national hydrogen network in the UK is the lack of an infrastructure for hydrogen. Companies are unwilling to invest in hydrogen cars and stationary equipment with no infrastructure in place and no indication of who will build it, so it is likely that government funding will be necessary

to stimulate the building of a hydrogen network. Over the coming decade(s) this may change as petrol and other fossil fuels become increasingly expensive and domestic and EU carbon targets become harder to reach.

Another factor is likely to be public opinion. The public may be wary of hydrogen as a consequence of its historical involvement in airship disasters or through a mistaken association with the hydrogen bomb.

Health and Safety Implications and Discussion

Hydrogen gas is flammable and easily forms an explosive mixture in air. There is a very wide range of hydrogen/air concentrations that will explode. Additionally, a very low ignition energy is needed to ignite a hydrogen/air mix. Methanol, which can be used directly by fuel cells, is highly flammable and toxic. LPG and methane, which can be converted into hydrogen using a high temperature catalytic reformer, often adjacent to the fuel cell, are also highly flammable.[1]

There are implications for safety from all elements of the fuel chain from conversion of the primary energy source, through to possible transport, storage and delivery stages, to use of the hydrogen for power generation.

Vehicles

Before the construction of a hydrogen network, in the short term fuelling stations for vehicles are likely to be supplied by road tankers containing cryogenic hydrogen. [1] As such there will be an increase in the movement of hydrogen on UK roads and an increase in planning applications for the siting of hydrogen storage tanks. There are also safety issues to consider when using hydrogen at such an extremely low temperature, such as spillage and siting of liquid hydrogen tanks in populated areas.

Since hydrogen is of low density, very high pressures (up to 700 bar) are needed in vehicle tanks to give vehicles a reasonable range. These tanks use relatively new technology and there is limited experience of their use or of how they might perform over the life of a car or in an accident. There are also difficulties in preventing leakage of the hydrogen from tanks at these high pressures. Refuelling of high-pressure tanks can also generate heat.[31] These concerns also apply to other types of high-pressure hydrogen storage systems. On 26 August 2010 in Rochester New York State USA, a hydrogen tank exploded during a swap of hydrogen tanks at a hydrogen refueling station. The resulting fire caused a second hydrogen tank to explode and one person received 2nd degree burns from the fire. The area was used by a company supplying GM with hydrogen tanks for its fuel cell car fleet. The cause of the explosion has not yet been found.[32]

Other applications

The movement of hydrogen from an industrial to a more domestic setting will have implications for the safety of members of the public operating car fuelling pumps or CHP with HFCs in a domestic setting. In terms of CHP, currently there is no accreditation scheme for the installation of CHP devices; this may cause a problem if electricity is exported back to the national grid, as this is likely to be beyond the training of most electricians. Additionally, as hydrogen is prone to leak from systems, those working on CHP hydrogen systems will need to be retrained.

[1] Hydrogen kept at an extremely low temperature, in a liquid state.

In addition to the hazards associated with hydrogen itself, the electrical safety implications of its use in fuel cells need to be considered. Electrical hazards within fuel cell installations are from the 240 volts (v) mains supply and the electrical output of the fuel cell stack; this can be around 100-400v and 500 amps. In fuel cell powered vehicles there may be fire and electrical hazards to emergency personnel following road traffic accidents.

In the more distant future, if a hydrogen distribution infrastructure is developed or existing gas pipeline networks are used, there will be materials considerations relating to the use of cryogenic hydrogen or hydrogen mixed with natural gas (Hythane) and gas permeability issues.

There may also be implications for safety arising from the process design of alternative sources of hydrogen production as these are developed. These include projects on hydrogen generation from various sources of biomass (plants, by-products and waste materials).

What is HSE doing?

The risks associated with the storage of hydrogen (under high pressure or cryogenically in liquid form) and its use in fuel cell applications, are well appreciated by HSE and work has been done on various aspects of the fire and explosion hazards at the Health and Safety Laboratory (HSL).

Comprehensive Guidance Notes: HSG 243 – "Fuel Cells, Understand the hazards, control the risks" and Research Report 715: "Installation Permitting Guidance for hydrogen and fuel cell stationary applications: UK version" have been issued.[33]

HSL was previously a member of "Hysafe" an EC funded Network of Excellence set up to facilitate the safe introduction of hydrogen technologies and applications and has contributed to its research.[34] Hysafe has ended and HSE is now a member of the International Association of Hydrogen Safety (IA Hysafe), which is no longer funded by the EU. International ISO standards for hydrogen car refuelling are being developed.

In March 2010 HSE staged a training session for specialist inspectors in order to appraise them of the hazards they might encounter as hydrogen use becomes more widespread.

Recommendation

Over the next 10 years or so the hydrogen sector in the UK seems set to grow, given the number of hydrogen projects and demonstrations running or planned in the UK and Europe. There are likely to be only modest numbers of commercial HFC installations and vehicles in this time period.

However, HSE needs to monitor the growth of the hydrogen sector in order to build on its current early activity and to ensure that legislation and guidance remains appropriate and up to date for future developments in this sector.

Sam Bradbrook
Futures Team, HSL
March 2011

1 http://www.hse.gov.uk/foi/internalops/hid/din/548.pdf Fuel Cells - hazards and risk management , Gordon Newsholme, Technology Division, Dec 2004, TD5-048

2 http://www.afcenergy.com/

3 http://www.timesonline.co.uk/tol/driving/features/article6980876.ece

4 http://news.bbc.co.uk/1/hi/technology/7496331.stm

5 http://www.intelligent-energy.com/index_article.asp?SecID=8&secondlevel=25&artid=3999%20

6 http://www.intelligent-energy.com/index_article.asp?SecID=8&secondlevel=25&artid=4074

7 http://www.london.gov.uk/lhp/

8 http://www.newswales.co.uk/?section=Environment&F=1&id=18756

9 http://www.fuelcells.bham.ac.uk/documents/10Gammon.pdf

10 http://www.tfl.gov.uk/corporate/projectsandschemes/environment/8444.aspx

11 http://www.tfl.gov.uk/corporate/projectsandschemes/environment/8448.aspx

12 http://www.fuelcelleurope.org/relFiles/PR Announcement development of hydrogen fuel cell postal van 23032009.pdf

13 http://www.theengineer.co.uk/news/fuel-cell-postal-vans/310774.article

14 http://news.bbc.co.uk/1/hi/sci/tech/8103106.stm

15 http://www.theengineer.co.uk/news/riversimple-hydrogen-car-to-begin-leicester-trials/1002912.article

16 http://www.autoblog.com/2009/08/28/report-mercedes-benz-launches-b-class-f-cell-leases-to-begin-i/

17 http://uk.ibtimes.com/articles/20101022/mercedes-benz-starts-leasingclass-fuel-cell-vehicles-europe-and.htm

18 http://www.intelligent-energy.com/index_article.asp?SecID=8&secondlevel=25&artid=4075

19 http://www.washingtontimes.com/news/2009/aug/24/hydrogen-powered-vehicles-on-horizon/?page=2

20 http://www.japanesesportcars.com/nissan-testing-vehicle-new-fuel-cell-technology_5298.html

21 http://www.wired.com/autopia/2008/03/hyundai-will-ha/

22 http://www.bmw.com/com/en/insights/technology/efficient_dynamics/phase_2/clean_energy/bmw_hydrogen_7.html

23 http://www.calcars.org/calcars-news/913.html

24 http://www.autocar.co.uk/News/NewsArticle/AllCars/238404/

25 http://current.com/items/90362655_hopes-for-battery-technology-push-hydrogen-cars-to-back-burner.htm

26 http://www.fuelcells.bham.ac.uk/

27 http://www.plugpower.com/newsroom/pressreleases.aspx?action=details&newsid=342

28 http://www.low-carbon-ktn.org.uk/showdoc.asp?doc_id=11610

29 http://www.cenex.co.uk/

30 http://www.psi.org.uk/ukshec/publications.htm

31 http://www.sro.hse.gov.uk/View_Article.aspx?id=147

32 http://blogs.cars.com/kickingtires/2010/08/hydrogen-explosion-deals-blow-to-fuel-cell-advocates.html

33 http://www.hse.gov.uk/research/rrpdf/rr715.pdf

34 http://www.hysafe.org/