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Trends in Hydrogen Projects

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Trends in Hydrogen Projects

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Trends in Hydrogen Projects

by

Mary Gillie, Susan Schoenung,
IEA HIA Task 18 Representatives

Summary

The International Energy Agency's Hydrogen Implementing Agreement Task 18 "Evaluation of Integrated Hydrogen Systems" studies the development of hydrogen demonstration schemes. There has been work in many parts of the world developing roadmaps, strategies and targets for the development of hydrogen systems. This piece of work takes a different approach by studying the trends in projects over the last few years. This is used to identify the barriers that have been overcome and those that still pose a problem. This helps to identify development strategies that have been successful, the most significant issues that will have to be tackled for hydrogen systems to be commercially viable and whether the proposed targets are realistic.

Whilst the targets for national programmes, in, for example, Canada or the USA may be challenging, from the experience of the last few years, they are achievable and would enable products to become commercialised. There have been significant advances in hydrogen and fuel cell systems in the last 5 years that have improved efficiencies, performance and economic viability. Nevertheless, further cost and performance improvements are essential. However, technical improvements alone will not suffice to achieve these targets. Mass production is required to reduce costs. Government and public bodies can assist via public procurement and supporting mass role out of small units such as vehicles and domestic CHP. Users of large transport fleets can do likewise.

Fleets of buses and vehicles are expanding with more undergoing 'real-life' driving tests. For this growth to continue:

- Local and national governments will need to plan and co-ordinate the roll out of the refuelling infrastructure.
- Maintenance and service companies will require support both financially and with training. This could be a joint effort between national governments and vehicle manufacturers.

As well as cutting capital costs, a key area for improvement is hydrogen storage to improve vehicle range and efficiency and this should be an area of focus for research.

With the exception of the niche markets of UPS systems, stationary applications are much less advanced. There is a danger of becoming trapped in a loop of demonstration projects

that do not expand or significantly move the technology on. One-of-a-kind projects that are often characteristic of stationary projects do not encourage redesign of components or mass production. Where larger scale projects have been implemented (for example domestic CHP in Japan), technical problems seem to be addressed and capital costs fall. When working at smaller scales, it is important to focus on characteristics that are generic to systems in general rather than those linked to the small scale of the demonstration.

Consistent long-term political support is essential to ensuring projects are able to continue and achieve all their goals. To accelerate the development of stationary projects and encourage transport applications, key areas to tackle are:

- Creating a clear safety and permitting process.
- Agreeing on safety standards appropriate for the size of project, preferably accepted internationally.
- Raising the awareness and understanding of the public and decision makers.
- Designing electrolysers and reformers appropriate for the application and for mass production. That is, of the appropriate size, able to operate at part load or with intermittent power input from renewables.
- Developing whole systems with components that are designed to operate together.
- Adapting energy markets and regulations to allow the creation of hydrogen from electrolysis or reformation of fossil fuels to help link and control of energy networks rather than exacerbating bottlenecks.
- Supporting the development of service and maintenance networks to give consumers the confidence to adopt hydrogen technology.
- Building hydrogen systems into the development and planning of cities and regions so that projects are not ‘one off’ projects but part of a planned expansion.

Mechanisms to take into account the hidden costs of fossil fuels should be encouraged to provide a fair cost comparison with hydrogen systems.

Generally, projects that become operational on time according to the original project plan have worked with the public and all relevant stakeholders from the inception of the project. This has enabled them to resolve and allay concerns.

Contents

1 Introduction

The International Energy Agency's Hydrogen Implementing Agreement Task 18 studies the development of hydrogen demonstration schemes. The Task has drawn together experiences from the participating countries to form case studies and a database of information on projects, organisations and reports on hydrogen systems. It has also carried out modelling and evaluation of selected projects. Its third remit is to draw out lessons that can be learnt to progress hydrogen systems. This work covers the economic and social aspects of developing hydrogen systems as well as the technical aspects.

There has been work in many parts of the world developing roadmaps, strategies and targets for the development of hydrogen systems. This piece of work takes a different approach by studying the trends in projects over the last few years. This is used to identify the barriers that have been overcome and those that still pose a problem. This helps identify development strategies that have been successful, the most significant issues that will have to be tackled for hydrogen systems to be commercially viable and whether the proposed targets are realistic.

2 Report Structure

The report looks at developments since 2003. The first section gives an overview of the political and commercial landscape and the resulting opportunities and barriers for the development of hydrogen systems. An assessment of how this affects the time from conception to operation of projects is given. The report looks at the trends in transport applications and stationary applications and the niche markets that are developing ahead of more mainstream applications. The work gives particular attention to the production of hydrogen and trends in electrolysers and reformers. It identifies key barriers to the commercialisation of hydrogen systems. From the trends in the last six years, an assessment is given on whether the targets set by national and international governments are realistic. Lessons from successful and unsuccessful approaches to development are drawn and recommendations made.

3 Political and Commercial Landscape

This section provides an overview of the political and commercial landscape in which the hydrogen industry is operating and discusses some general factors affecting its development.

3.1 Political and Commercial Support and Funding

Whilst there are many technical barriers to the development of hydrogen systems, softer political, social and economic issues play a very large role. Local political circumstances can affect how quickly projects develop and engender enthusiasm and engage the local population. Political climate can cause support to wane or increase over the lifetime of a project. Iceland reported that changes in government at both a regional and national level accelerated and slowed progress on projects at different times. A more recent example is of a proposed island renewable/hydrogen power system. An expert reported that there was a sudden enthusiasm to fund the project at a national level even though a similar scheme on another island had been refused funding for years. There is concern however that a change in government may put the project on hold part way through its development. A change in government in the USA resulted in uncertainty over the future support for hydrogen when a proposed new budget removed the funding stream dedicated to hydrogen. Political support is therefore an ongoing problem. The solution is probably contracts that are longer than electoral terms, but this is hard to achieve.

Delays in projects can also occur due to companies being taken over. This can mean that the focus of a company changes and projects are no longer a priority. For example, in Canada, a smaller hydrogen and fuel cell company and larger gas company were involved in a multi-partner fuelling station project. Both the fuel cell company and the gas company reorganized and changed their focus before and after company mergers. As a result, there was a delay and reduction in support for a period. Fortunately, in this case, the project was successful; all parties found it beneficial to continue to support the station until the funding and contracts ended. As the market becomes more consolidated and established, hopefully, this will become less of a problem.

It is useful for projects to have a 'plan b' if political or commercial situations change. This could include alternative suppliers of equipment or possible different locations. As an example, the Hydrogen Office eventually built in Fife, Scotland moved location to attract funding. It also found a more appropriate site for redevelopment with hydrogen start up companies nearby.[1]

3.1.1 Government and Company Focus

Some countries and companies are concentrating on niche markets to get commercial products to market, e.g. fork lift trucks, whilst others are concentrating on mass markets, for example developing fleets of cars. The USA is concentrating on improving the performance of fleets of standard cars in the DOE National Hydrogen Learning Demonstration Program[2]; the cities Malmö in Sweden and Vancouver in Canada are both concentrating on developing fleets of buses. Scotland has focused mainly on the niche market of hydrogen and

[1] The Hydrogen Office www.hydrogenoffice.com Accessed 24th August 2009

[2] DOE National Hydrogen Learning Demonstration Program http://www1.eere.energy.gov/hydrogenandfuelcells/tech_validation/fleet_demonstration.html. Accessed 24th August 2009

renewable for remote locations with projects in the Hebrides and Unset. The company PURE was created by the inhabitants of Unst (an island northwest of mainland Scotland) and pioneered an early renewables/hydrogen energy project. This is an example of local action steering national or regional governments' agenda.

3.1.2 Safety Issues

There are references to safety issues for particular applications throughout the document. Below is a short overview.

Processes for permitting and installation of hydrogen systems are still often dependent on local regulations that are out of date or are derived from older international directives. This leads to unnecessary costs and delays. The need to allay city planners' or the public's concerns about safety (that are often due to a lack of understanding of the technology) can lead to the installation of very expensive safety systems. The need for education and awareness raising is often highlighted by project developers and was identified as an issue in the US Department of Energy Hydrogen Program Peer Review in 2009.[3]

In the last few years, there has been considerable work on developing safety and performance standards for hydrogen and fuel cells. Amongst others, the British Standard Institute developed and published standards between 2004 and 2008 for the installation, safety and performance testing of stationary and micro fuel cells as part of BS EN 62282. For fuel cells, working groups have been set up by the International Electrotechnical Committee (IEC) and CENELEC (the European counterpart to the IEC) to develop a suite of documents. These will cover:

- Terminology
- Performance, safety and installation of stationary power systems
- Safety and performance of micro fuel cell systems
- Propulsion and auxiliary fuel cell power systems

In Canada, the development of the Canadian Hydrogen Installation Code has helped to move projects to the provincial technical approval stage even though the code has not been officially adopted. Provincial technical codes and standards adoption takes several years. The Code is accepted since several of the provincial technical safety experts were involved in its development and there is significant research, development, modelling, simulation and data to support it.

As well as the need for Codes and Standards, in the UK, the process for approval is unclear. Coupled with wary officials who are unfamiliar with the technology, this can lead to considerable delay. There is therefore a need for general education and a clear procedure to follow.

3.1.3 Time from Conception to Operation/Permitting

The time taken from the conception to operation of a project has changed little over the last ten years (Table 1 and Table 2). Most projects take around 3 years although those that experience serious delays can take much longer. Until there are clear planning and safety approval processes and 'off the shelf' components are available this is unlikely to change. Note, however that projects are often larger now than five years ago and therefore in some respects more is achieved in the same time. Furthermore, most mainstream energy projects of a similar size will take a similar time to install.

[3] Education; Safety, Codes and Standards; and Technical Validation, US Department of Energy, FY 2009 Merit Review and Peer Evaluation Report.

The HyCute bus fleet project collated experiences of getting planning permission for the first refuelling stations for hydrogen buses. This identifies the key stakeholders that should be engaged and at what point in the process, to prevent delays in planning[4]. HyCute developed a list of Do's and Don'ts which are listed below. Whilst they may appear onerous, if a system of engagement is developed, they can be managed and incorporated into a project.

Do's:

1. Recognise that stakeholders' perceptions are important and need to be addressed.
2. Spend at least as much time listening as talking
3. Engage in a way that allows all stakeholders to be heard
4. Develop mutually-agreed processes for engagement
5. Give time for social and informal contact before and after consultations to enable trust to develop.
6. Recognise the time stakeholders give up to participate in consultations
7. Follow up with stakeholders after meetings rather than wait for them to follow-up
8. Maintain records
9. Provide clear boundaries of what is and is not possible

Don'ts

1. Engage if you are not going to listen
2. Try and develop all the answers before starting engagement
3. Base engagement on pre-existing personal contact instead of a systematic process to identify issues and stakeholders
4. Assume silence means consent
5. Assume that one engagement approach works with all
6. Assume stakeholder have your timeline
7. Rely on technology to substitute for face to face communication
8. Use external consultants to manage the process
9. Engage only with friendly stakeholders

These are not only applicable to hydrogen but are particularly important when there are considerable concerns over the safety of hydrogen (whether justified or not).

[4] People, Transport and Hydrogen Fuel, Guidelines for local Community Engagement when Implementing Hydrogen Powered Transport. HyFleet Cute, March 2008 http://hyfleetcute.com/data/People,%20Transport%20and%20Hydrogen%20Fuel.pdf accessed

Table 1 Development of Transport Demonstration Projects[5]

Buses, cars and refueling stations	Concept	Funding Agreed	Installation started	System working	Reasons for any delays/Notes
ECTOS (Iceland)	1998	Mar-01	fuelling station Feb. 03	Refueling station April 2003, buses October 2003	No experience in safety and operation of the filling station made the process slow.
Malmö (Sweden)		Autumn 2002		Refueling station Sept 2003. Bus March 2004	At present, progress is delayed as Volvo does not guarantee their buses if run on methane/hydrogen mixes.
Las Vegas (USA)		Jan-96	Staged	Mar-99	Changes in site for refueling station due to residents concerns and changes in local council. This caused 2 years of delays and two changes of location.
California Fuel Cell Partnership (USA)	Jan-99	Apr-99		First station Nov 2000, 3 more stations by 2002, now 15.	Fuelling only carried out by trained staff initially
Berlin CEP (Germany)	2002	2003	2004	2004/5	
Hamburg (Germany)	1996-7	1997		1999/2000	
HyNor (Norway)	2005		2006	2006-2009	
Sunline Mall (USA)	1998	1999	2000	2000/01	Public access
Honda solar refueling station (USA)	2001		2002-2003	2002-2003	The fuelling station was only to be used by trained personnel

[5] Information from IEA HIA Task 18 case studies and information provided by National Experts. Website http://iea-hia-annex18.sharepointsite.net/Public/default.aspx accessed 11th January 2010

Table 2 Development of Stationary Demonstration Projects[5]

Stationary Project	Conception	Funding Agreed	Installation started	System working	Reasons for any delays/Notes
FIRST (Spain)		Mar-00	May-02	Jan-03	2 years for design. Storage too heavy. Had to install air-cooling for summer. Stack failure occurred.
EPACOP (France)	2002	2002	Nov 2002-june2003	September 2003-nov2003	
RES2H2 Canary Islands (Spain)		2001	2002	operation Oct 2007	Changes in co-ordination and funding caused a relaunch in 2006
$RES2H_2$ Keratea (Greece)	2000	2001	2003	2005-2009	Changes in project co-ordination
H2 office (UK)	2004	April 2005 - April 2007	Jan-08	Not finished possibly 2009/10	Delays in finding partners and funding, safety permits, agreements with Water Company, finding the right wind turbine and changes to the cooling process for the fuel cell.
Lolland (Sweden)			2006	1st phase 2007 2nd phase delayed	Delays in later phases due to the right permits not being in place.
Ladymoor Wind Hydrogen project (UK)	2005		Still in planning	Still in Planning	Planning application for wind farm delayed due to objections. Size of wind farm scaled back but outcome to be determined.
Solar House Brunate (Italy)	2005	2006	2007	2009	Delayed due to missing cables to the fuel cell.
HyLink (new Zealand)	2002	2003	2007	2008	n/a
Hawaii Hydrogen Power Park (USA)	2002	2004	2008	2008	n/a

4 Transport Applications

Demonstration projects have moved from one or two prototype vehicles to testing of fleets. Examples of fleets of hydrogen buses are in Iceland, London, Vancouver and Malmö. The USA and Germany are now testing fleets of cars. Hand in hand with these developments is the process of building refuelling infrastructure and overcoming issues with fuel and the filling process.

4.1 Trends in Hydrogen Infrastructure and Refuelling

Introducing a refuelling infrastructure is expensive but essential for the public to adopt hydrogen fuelled vehicles. A filling station must be able to cater for the number of vehicles wishing to refill but, if the station is too large initially, it will be more expensive to build and operate. Predicting where vehicles will want to refill is difficult and may result in stranded assets. This may be the reason why the locations of most of the filling stations are along main road axes, close to large cities, or in places near to the known initial users. Standardising refuelling processes and pressures at the same time as developing technology is difficult but is important so that filling stations can provide for different vehicles.

Earlier projects experienced problems or had limited operation due to planning and safety issues:

- Filling stations could often only be used by authorised personnel e.g. California Fuel Cell Partnership, Honda Solar refuelling station[6]. Hamburg was an example of an early publically available filling station.[7]
- There have been problems getting planning permission for filling stations, e.g. for the Hornchurch station to refuel the London Buses as part of the EU HyCUTE project demonstrating hydrogen powered buses.
- The site for the filling station in Las Vegas changed twice due to objections that delaying the project by 2 years.

There have been problems with designs or caution over the use of hydrogen can also cause problems.

- The design of the Hornchurch filling station was imperfect resulting in unpredictable filling times. The design specification for filling time was 30 minutes but in practice the filling time was three times this long with a lot of variation. 60% of hydrogen was lost through venting.[8]
- Manufacturers can be unwilling to approve the use of hydrogen in vehicles unless they are custom designs. For example, Volvo has been unwilling to approve further use of methane/hydrogen mixes in its internal combustion engine buses in Malmö.

In contrast, there are now publicly accessible filling stations, for example in Scandinavia[9], the USA[14], and Germany[16]. The design of filling stations is becoming more standardised rather than each one being a custom design, although more development is required. For example, Air Products now offers 'off the shelf' small refuelling stations capable of providing

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[6] Honda Solar Hydrogen Refuelling Station http://www.ieahia.org/pdfs/honda.pdf, accessed 24th August 2009.

[7] Clean Energy Partnership www.cleanenergypartnership.de, accessed 24th August 2009.

[8] London Fuel bus Hydrogen Trial, Operational experience and Learning. Ben Madden, H2net 2007 http://www.h2net.org.uk/PDFs/AnnualMeeting_2007/006_BM_H2NET_12_July_2007.pdf accessed 11th September 2009.

[9] HyNor http://www.hynor.no/hynor-1/view?set_language=en, accessed 24th August 2009.

hydrogen for a handful of cars a day[10]. Linde offers a design service for refuelling stations and ‘off the shelf’ mobile refuelling units.[11] This has coincided with a consolidation of the industry in recent years with a number of take-overs. As this reduces the number of providers and designs, this may enable the different components of a refuelling station to be standardised.

Safety procedures in Germany are now clear; the Technical Control Board tests all elements of the filling stations. The standards used are not proscriptive in the methods to achieve. Rather, it must be demonstrated that the design meets the criteria. The standards align with European regulations and German standards for storage tanks and hydrogen technologies.[12]

In Norway, the process of risk assessment and permitting got easier for the later filling stations. This was because by the time the later projects were assessed, the government knew the companies carrying out the work and knew what to expect.

The European project HyApproval developed a Handbook for Hydrogen Refuelling Station Approval[13] working with authorities in France, Germany, Italy, Spain, and The Netherlands. The work is based on the Italian safety standard: ‘The Ministerial decree on Fire Prevention of 4 May 1998, Annex1, for risk assessment’. HyApproval is guidance rather than a standard but could help standardise the safety approval process in Europe.

Welcome additions in the USA are proposal for codes on “Hydrogen-specific separation distances”. It is proposed to include these in NFPA52: Vehicular Gaseous Fuel Systems Code, 2010 Edition and NFPA 2: Hydrogen Technologies Code. The 2010 editions are proposed standards with a new edition expected in 2011.

Engaging with the public, achieving planning permission and safety approval still takes considerable time. It is important to start these processes early and to allow sufficient time and budget. Once one filling station has been installed and vehicles are on the road, extending the system is usually easier to achieve.

Insurance continues to be a problem for both vehicles and stations, especially the liability for the fuel quality. This is improving, however, with the deployment of more fleets and actuarial data.

There is now a focus on developing networks of refuelling stations to make driving hydrogen powered vehicles practical.

- In July 2008, California, which already has the bulk of the refuelling infrastructure in North America, published a report on different strategies to encourage the development of hydrogen refuelling stations.[14]
- In July 2009, Shell announced the opening of its second refuelling station in New York at the airport. This will form a cluster; the first refuelling station opened in 2008

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10 Hydrogen refuelling station for Transport http://www.airproducts.com/Products/MerchantGases/HydrogenEnergy/Products/HydrogenFuelingStations.htm accessed 24th August 2009.

11 http://www.linde.com/hydrogen_flashsite_final/index.htm accessed 24th August 2009.

12 IEA HIA Task 18, Case Study: Clean Energy Partnership, Jochen Linssen, 2009 Task 18 website: http://iea-hia-annex18.sharepointsite.net/Public/default.aspx accessed January 11th 2010.

13 HyApproval Handbook http://www.hyapproval.org/Publications/The_Handbook/HyApproval_Final_Handbook.pdf. accessed 24th August 2009

14 The National Hydrogen Association http://www.hydrogenassociation.org/general/fuelingSearch.asp accessed 24th August 2009.

and the third is due to open in 2010. This could be the first sign of a large multinational oil company starting a strategic roll out of hydrogen refuelling stations to complement its petrol distribution infrastructure.[15]

- The new filling station for the London buses will be incorporated into the standard bus depot demonstrating that it has become more mainstream.
- The Scandinavian Hydrogen Highway already provides enough stations for a hydrogen vehicle to drive around the Norwegian southern coast. The plan is to link the network to infrastructure in Sweden and Denmark[9].
- Germany has the largest number of stations in Europe (26) and as part of its Clean Energy Program aims to develop a 'Hydrogen Region' around Hamburg and Berlin[7,].

The report "California Fuel Cell Partnership Vision for Rollout of Fuel Cell Vehicles and H_2 Fuel stations" (July 2008) estimated the number of refuelling stations needed to roll out fuel cell vehicles in the next decade. It envisages a handful of refuelling stations to provide enough fuel for the few hundred hydrogen powered vehicles and the 10 buses expected in California by 2010. It expects to need nearer a 100 stations by 2013 to provide for a few 1000 vehicles and a few 10s of buses. It is therefore encouraging to see that already California has surpassed the 2010 target and is progressing towards the 2013 target.

Currently in Germany there are approximately 20 filling stations in operation and another 10 filling stations are in planning. Those planned are mainly part of the second and third phase of the Clean Energy Partnership in the Berlin-Hamburg area. Six filling stations have public access. Germany has a large population in the Hamburg–Berlin area so the stations provide a significant population with access to hydrogen for vehicles. It is also on course to have sufficient refuelling infrastructure for the predicted numbers of vehicles in the next few years.

Given Norway's smaller population, its 7 stations should be sufficient for the vehicles likely to be on the road in 2010.[16] These filling stations are part of the HyNor project to provide a network of stations in the south of the country (where the majority of the population lives). The national experts for Task 18 provided the following information on Norwegian trends in storage at filling stations (Table 3).

Table 3 Pressure and amount of hydrogen stored at hydrogen refilling stations in Norway

Station	Year of installation	Lowest pressure storage and amount stored	Highest pressure storage and amount stored
Stavanger	2008	26 kg @ 200 bar	3 kg @ 800 bar
Grenland	2009	150 kg @ 400 bar	1.5 kg @ 900 bar
Oslo	2009	34 kg @ 200 bar	46 kg @ 900 bar
Drammen	2009	34 kg @ 200 bar	46 kg @ 900 bar

15 Shell set to open first cluster of hydrogen filling stations http://www.shell.com/home/content/media/news_and_library/press_releases/2009/hydrogen_stations_14072009.html accessed 24th August 2009.

16 Fuelling Station Map http://www.hydrogencarsnow.com/eu-hydrogen-highway.htm accessed 24th August 2009

Table 4 Examples of refuelling stations in California[17]

Location	Installation	Pressure (bar)	Stored	Car refueled in succession	Cars per day
National Fuel Cell research Center, Irvine	2006/2007	350/700	50kg	4-5	6
Long beach (mobile)	2008		150kg (at about 450 bar)	18	30
Torrance (supplied by pipeline)	2008	350/700	50kg	6	12

Table 3 gives the information on the hydrogen stored at Norwegian hydrogen refueling station. The stations where there is hydrogen at 200 bar pressure get their hydrogen in bottle-packs (12x50 l = 8.5kg H2 in each pack), and a compressor is used to increase the pressure to an appropriate level. The stations installed in 2009 use 250 litres high pressure tanks to top up each filling. Thus, there is a trend towards larger amounts of hydrogen stored at the station. There is also a move to a larger fraction stored at high pressure because of the emerging standard pressure for on-board storage of 700 bar. In both HyNor and California projects are exploring different methods of supplying and storing hydrogen (Table 4). Mobile units may be useful to supplement the size of filling stations as the number of cars grows or to avoid the risk of stranded assets through fixed stations built in the wrong place.

The National Renewable Energy Laboratory (NREL) in the US has monitored filling stations across the USA. The number of fills in 2008 monitored by NREL was the highest since 2005. There were 16300 refills of 400 cars and 24% of the refills were faster than 1kg/minute. The average rate was 0.78 kg/minute. Refilling to 350 bar is still considerably quicker than to 700bar (an average of 0.81 kg/minute compared to 0.59 kg/minute). The average refuelling for both pressures has fallen short of the 2006 technical validation milestone of 1 kg/minute.[18]

For the HyNor project, the time for refueling has been more or less stable throughout the two years since the first installation, and is normally 3-5 minutes for a complete refill. The time elapsed for refueling is very dependent on pressure in the storage tanks and how many cascades are used (there is always a pause in filling when changing cascades). These time scales are similar to those reported by NREL.

None of the stations is particularly large compared to conventional filling stations (that may supply up to 300 cars a day). However most filling stations only have one pump and therefore could be scaled up.

[17] US Department of Energy, Hydrogen Program, FY 2008 Annual Progress Report, California Hydrogen Infrastructure Project, available at http://www.hydrogen.energy.gov/pdfs/progress08/vii_5_heydorn.pdf accessed 11th January 2010

[18] http://www.nrel.gov/hydrogen/pdfs/45641.pdf accessed 16th September 2009

4.2 Trends in Hydrogen Cars

The performance of hydrogen powered cars has improved significantly via large scale fleet demonstrations run by the major car manufacturers. The work 'Trends in Hydrogen Vehicles' carried out by Marcel Weeda for IEA HIA Task 18 studies this in detail.[19] A summary is in the blue box and a selection of statistics is below.

Summary of 'Trends in Hydrogen' Cars by Marcel Weeda

This report provides an update of the latest developments that have recently occurred within car industry within the field of Hydrogen powered fuel cell vehicles (FCVs) to date, October 2009.

The report gives with an overview of the original equipment manufacturers (OEM) that are actually active within the hydrogen vehicle business, and illustrates the intensity of FCV activity per OEM. This shows that there is a distinct group of OEMs that are most active, and that others have tried to get some experience but have not seriously been involved in in-house technology development of FCV manufacturing. Furthermore, some manufacturers have chosen an alternative path when it comes to using hydrogen for vehicle propulsion and developed hydrogen fuelled conventional Internal Combustion Engine (ICE). In the field of FCVs, Honda, Daimler, Opel/GM, Hyundai/Kia, Toyota, Nissan and Ford undertake most FCV activities. Volkswagen has given less priority to FCV development and has not marketed itself as an OEM with hydrogen technology expertise. Mazda and BMW chose to put their efforts in the development of hydrogen fuelled ICE vehicles. Ford has put efforts in hydrogen fuelled ICE vehicles as well as FCVs.

OEMs are assessed by how active they have been in terms of cars produced. It was difficult to come up with reliable estimations based on numbers available to the public. The sum of vehicles produced by all OEMs together was estimated as about 515 vehicles. This estimation however was much lower than the figures published by Fuel Cell Today (FCT). FCT estimates that the accumulated vehicles shipped in 2009 was around 1100 units, double the numbers found by this study. Communication with FCT informed us that FCT has access to confidential information from the OEMs. This was especially relevant for the Asian OEMs who do not publicise numbers of FCVs shipped clearly, however FCT claims to have data in these numbers.

Lessons learned from driving the FCVs are in general encouraging. Durability and reliability are improving with experience. Fuel economy is increasing, range is increasing and costs are still going down. Generally, it can be said that the OEMs are on schedule for delivering the required improvements, though they also warn that they cannot make FCVs a success on their own and call for market stimulation through the development of fuel cell refuelling station networks.

The European project Road2Hycom[20] carried out a review of hydrogen fuel cell demonstration projects in Europe, Japan, Singapore and the USA. The majority of the cars

[19] Available on the Task 18 website: http://iea-hia annex18.sharepointsite.net/Public/default.aspx accessed January 11th 2010.

[20] Roads2Hycom www.roads2hy.com accessed 4th September 2009

were in regular fleet operation from 2003 or 2004 onwards and this has led to the increases in range, durability and reliability.

The availability of the cars ranged from 84% to 88%. Fuel economy varied depending on the average speed however, in the last three years typical values have increased from 38 km/kg to 68 km/kg.[19] The real world driving range is now between 200 km to 690 km with 2000 hours of running time before a significant repair is required. This is close to acceptable levels of performance for customers to use. Range, fuel efficiency and availability are rapidly improving, for example:

- Daimler have increased power by 30% and range by 150% and decreased stack size by 40% and power consumption by 16% between 2004 and 2009. Reliability has also improved (Figure 1)
- GM have produced their 5th series of fuel cells that weigh 100kg less than the previous series, occupy 50% less space and use 50% less platinum.
- Honda has decreased the size of their systems by a factor of 4 between 1999 and 2008 whilst improving performance. The Honda FCX clarity had increased its fuel economy by 20% compared to the previous series.
- In 2008, Nissan had doubled the power density of its latest generation fuel stack whilst reducing the platinum needed by 50%[20]. The volume decreased from 90 litres to 68 litres and yet the power output increased from 90kW to 130kW.

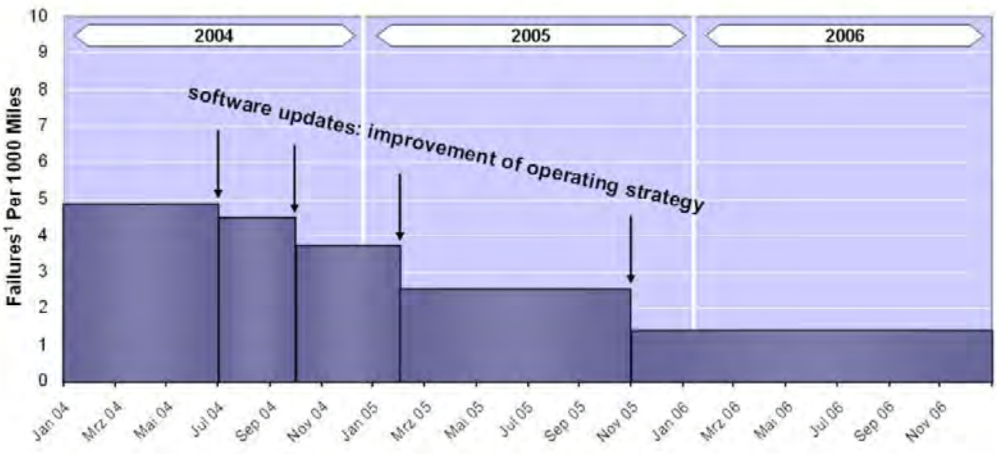

Figure 1 Daimler's Fuel Cell Stack reliability improvements due to control-software changes. (Source: Daimler)

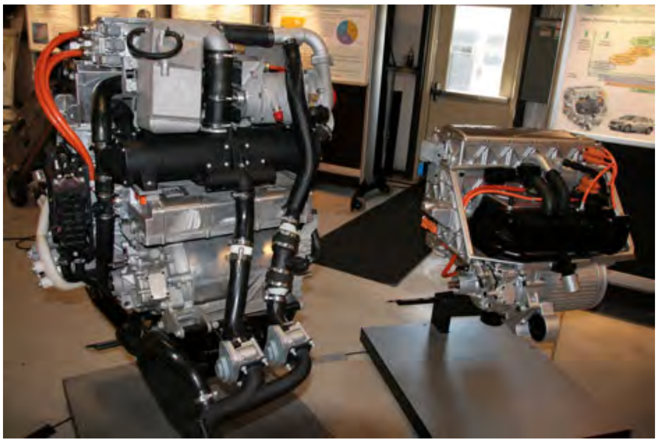

Figure 2 GM's Fifth generation fuel cell system (on the right) compared to its fourth generation predecessor (left), showing a volume reduction of 50%. (Source: GM).

The overall cost of hydrogen vehicles has fallen dramatically. Nissan's latest fuel cell system is 35% cheaper than their previous design. A significant factor in the reduction in cost is a 50% reduction in platinum in the fuel cell. Unit costs for the fuel cells fell from $10 000/kW to $500/kW between 2000 and 2004. An estimate of bulk manufacturing costs for fuel cells is around $100kW at present. The Department of Energy in the US[2] predicted that the cost of a fuel cell would need to drop to $30/kW by 2015 and on-board hydrogen storage would need to achieve a cost of $2/kWh for hydrogen fuelled cars to become commercially viable. Manufacturers have made the following predictions[19]:

- Toyota foresees a cost reduction of a factor 10 due to design & materials, as well as a cost reduction by a factor 10 as the scale of production increases.
- Hyundai/KIA expect cost reductions to be around a factor of 60 when the production increases to 10 000.
- Toyota, Honda, Daimler and Hyundai Motor Co. have expressed the intention to work towards a proposed target of building FCVs that are only $3600 more expensive than normal mid-size gasoline cars.

Roads2hycom showed that the vast majority of users quickly learned how to drive a fuel cell car and felt safe.[21] South Coast Air Quality Management District in California worked with drivers and maintenance staff to understand the positive and negative aspects of driving and maintaining Prius cars adapted to run off hydrogen. Over five years from 2004 to 2009, improvements to the vehicles, resulted in better driver satisfaction and reduced faults.[22]

Most major manufacturers who are developing hydrogen powered cars have plans for commercialisation in the next five years. Recently:

- A limited number of the Honda FCX clarity was sold in California in 2008.
- General Motors aim to sell 1000 Chevrolet Equinox cars in 2010.
- Mazda introduced leasing of a hybrid gasoline hydrogen ICE vehicle in 2009.[19]

Whilst there are now fleets of cars and buses, communities wishing to integrate vehicles into hydrogen systems (for example with renewable energy) often find it difficult to procure small numbers of vehicles. As a result, an expert reported that projects on the Canary Islands had to develop a custom-made truck. Iceland started seeking hydrogen powered cars in 2005, the project Smart–H2 started in 2007[23] but only around 12 cars were on the road in 2009. The cost of servicing a few vehicles is often too great for manufacturers to consider small numbers a viable proposition particularly when in a remote location. Unfortunately, hydrogen vehicles are often attractive to such remote locations where fossil fuel costs are high and there are abundant renewable resources. In Norway, whilst manufacturers wanted a larger field trial, there was the problem of finding enough drivers whose routine fitted the limited driving range possible because of the limited number of refuelling stations.

4.3 Trends in Hydrogen Buses

Hydrogen fuelled buses have been an area of focus because of the known routes and distances that buses travel. A fixed routine requires fewer refuelling stations that only need

[21] Review of Technical and social Economic and Safety Findings from Fuel Cell Vehicle Demonstration Activities http://195.166.119.215/roads2hycom/r2h_downloads/Roads2HyCom%20R2H6031PU%20-%20Review%20of%20Fuel%20Cell%20Vehicle%20Demonstration%20Activities.pdf accessed 16th September 2009

[22] South Coast Air Quality Management http://www.aqmd.gov/tao/Demonstration/ResearchProject.htm accessed 11th January 2010.

[23] Information on Iceland's hydrogen projects at http://www.newenergy.is accessed 18th January 2010.

be used by a few trained personnel. In addition, the zero emissions and lack of noise from hydrogen fuelled buses is very attractive to municipalities.

Whilst costs have fallen, fuel cell buses are still approximately four times as expensive in terms of capital costs compared to diesel buses. A significant factor in the EU is a proposed EU directive mandating that the health and carbon dioxide costs of diesel buses must be taken into account, which doubles the cost of a diesel bus to 300 000 Euros[54].

In the first trials, buses often had a 'luxurious' regime. The first London buses were not allowed on routes with tunnels and had shorter operating times. The latest buses have identical regimes to conventional vehicles. Whereas the initial trials in London had a dedicated maintenance crew and depot, the latest trials will require hydrogen buses to operate under a standard maintenance regime.[8]

The results from HyFleet CUTE of the performance of hydrogen fuelled buses gave a very good availability of 90-95% of the time expected[24] and over 4000 running hours. Daimler felt that the demonstration showed hydrogen fuelled buses could meet public transport requirements. The fuel efficiency was much greater than diesel powered buses except for very hilly terrain where the consumption was similar.[25] Most drivers were very pleased with the vehicles. As in London, buses in the latest fleets are expected to run whole routes for similar running times per day and maintenance regimes as conventional buses.

Comparisons of efficiency in NREL's buses trials showed that the fuel efficiency of fuel cell buses compared to diesel buses was between 46% and 200% better[26]. Whilst the availability in some of the NREL trials was poor, in the HyFleet CUTE trials availability was between 92-99%. In the HyFleet CUTE trials, the cost per mile, factoring in maintenance etc. was only marginally higher than a conventional bus.

Mass production and greater use of hydrogen vehicles is likely to have a significant impact on the cost of hydrogen and capital investment. It is predicted that PEM fuel cells will drop 6-fold in price if the production increases from 100 to 1000 per year. As noted earlier, fuel cell stack costs have already dropped from $10 000/kW to $500/kW from 2000 to 2004 [54].

The aim now is to increase the running times to 15000 hours, reduce fuel consumption and unit costs. The Hydrogen Bus Alliance (that pools information and promotes hydrogen fuelled buses across the globe) believes it will be possible for hydrogen fuelled buses to be cost and performance competitive with diesel powered buses by 2015[27]. From 2008, each member of the Alliance is purchasing at least 5 new buses to put on trial between 2008 and 2012. For example, Canada tested a prototype bus on the road and ordered 20 buses ready for the 2010 Winter Olympics and for regular transit services afterwards. Likewise, London transport has also recently procured 10 more hydrogen fuelled buses with a new refuelling station[28]. The Alliance has engaged in a co-ordinated procurement plan from 2010 to help reduce costs.

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24 HyFleet-CUTE http://www.global-hydrogen-bus-platform.com/InformationCentre/Downloads accessed 26th August 2009

25 Hyfleet CUTE http://hyfleetcute.com/data/15_Kentzler_Fuel_Cell_Buses.pdf accessed 11th January 2010

26 NREL Hydrogen Fuel Cell Bus Evaluations http://www.nrel.gov/hydrogen/proj_fc_bus_eval.html accessed 14th September 2009

27 Hydrogen Bus Alliance, Industry Dialogue http://www.hydrogenbusalliance.org/dialogue.html accessed 14th September 2009

28 London's Hydrogen Buses http://www.london.gov.uk/view_press_release.jsp?releaseid=14475 accessed 15th September 2009

4.3.1 Type Approval

The EU has published a type approval regulation for hydrogen power vehicles: regulation no.79/2009. This will help ease the route to market for hydrogen powered vehicles.

4.3.2 Material Handling: Fork Lifts, Factory Vehicles

A potential early market for fuel cells is material handling vehicles. These are fork lifts, small factory trucks, etc. Operating schedules can range from 8 to 24 hours a day and 5 to7 days a week. Fast refuelling is therefore required. Battery powered vehicles are quiet and low emission but are very slow to charge and have limited operating times. Internal combustion engines (ICEs) are noisy and emit CO_2 and other emissions. Hydrogen is often readily available on many industrial sites and the rate of refilling is faster than for batteries. In addition, hydrogen powered fuelled fork lifts are clean and quiet in contrast to ICEs. They do not lose power when the fuel is low unlike batteries that lose charge at the end of their charge time. Temperature changes experienced in cooling cells and frozen-storage facilities do not affect the performance of hydrogen fuelled fork lift trucks.

Four years ago, in 2005, Raymond, a fork lift manufacture carried out a comparison of hydrogen and battery powered fork lifts and concluded that assuming:

- 100 trucks driven 15 hours a week for 280 days a year (in 5 hour shifts)
- Pick cycles from 30-90 per hour
- Operator paid $18.50 per hour
- Hydrogen tank size from 1.5-3.0kg
- Hydrogen price of $5/kg
- Electricity price of $0.09/KWh
- Fuel cell price of $4 000/kW
- Battery change time of 25 minutes

4 200 hours were saved per truck with hydrogen, there was a positive NPV and an Internal Rate of Return of over 50%. This calculation was most sensitive to the cost of labour, fuel cell price and shift length.[29] In the last four years, the value of these parameters will have become even more favourable to fuel cell fork lifts.

Examples of trials of fork lift truck show that the demonstration stage is almost finished and they are a proven technology ready for market:

- Trials at Munich airport ended in 2006[30]
- The large companies Volvo Technology AB, StatoilHydro ASA, H2 Logic AS, Powercell Sweden AB and SINTEF are collaborating to develop a fuel cell powered fork lifts.[31,32]
- US Army's distribution centre in Susquehanna (Pennsylvania) tested 40 fuel cell fork lift trucks until 2008 and compared them with the performance of battery powered units.[33]

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29 Application of Fuel Cells in Fork lift Trucks Raymond 2005 http://www.raymondcorp.com/das/PDF_storage/TechnicalPapers/0130FuelCells.pdf accessed 14th September 2009

30 Proton Motor http://www.proton-motor.de/pm-forkliftruck.html accessed 14th September 2009

31 AZoM http://www.azom.com/News.asp?NewsID=18461 accessed 14th September 2009

32 Defence Logistics Agency http://www1.eere.energy.gov/hydrogenandfuelcells/education/pdfs/education_presentation_grassilli.pdf accessed 14th September 2009

33 Senternovem

Commercial orders are now developing. For example:

- NestléWaters operates a fleet of 32 fork lift trucks that are fitted with fuel cells at the company offices in Dallas. The fork lift trucks are fitted with GenDriveTM fuel cells made by Plug Power.[32]
- Linde offer a commercial product.[34]
- Hydrogenics offer a 'Power Pack' to retrofit fork lift trucks.[35]

This is a niche market that should enable fuel cells to achieve mass production in the near future.

4.4 Trends in On-Board Storage for Transport

National experts from Canada reported that the majority of passenger vehicle OEMs have been moving from 350 bar to 700 bar hydrogen storage pressure for their gaseous hydrogen fuel cell systems. Only one OEM continues to support 350 bar as a future pathway. However, bus designs continue to focus on 350 bar hydrogen storage systems due to roof space and weight limitations. An emerging standard of 700 bar was also confirmed by the experiences of the HyNor project reported by the Norwegian National experts (see section 4.1). Figure 3 demonstrates how far hydrogen storage must progress in terms of volumetric and gravimetric density.

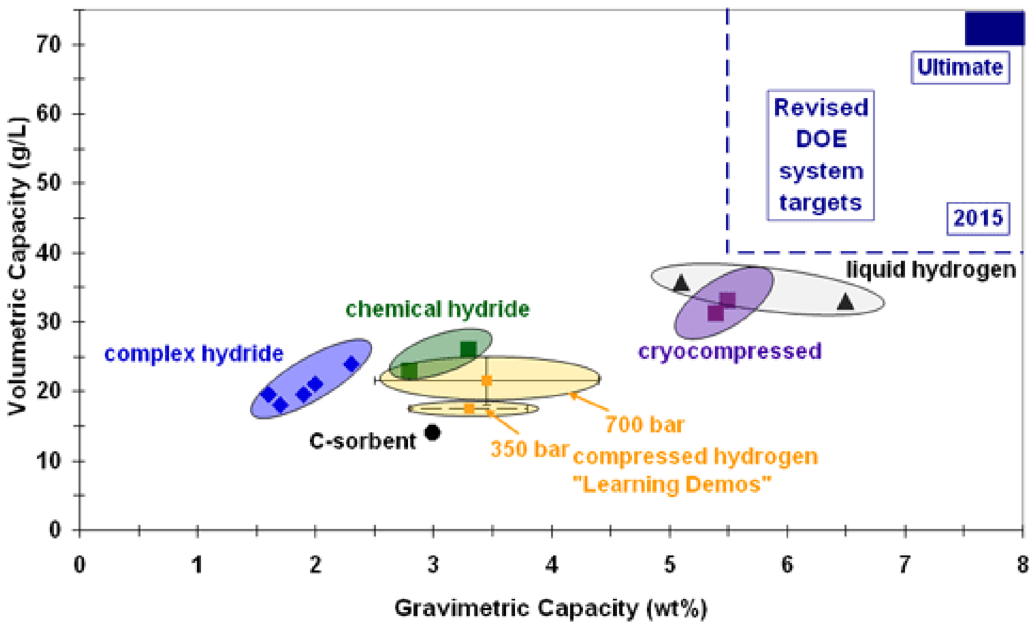

Figure 3 Graph of the Gravimetric and Volumetric Capacity of different types of hydrogen storage and US DOE targets.[36]

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http://www.senternovem.nl/gave_english/nieuws/hydrogen_for_forklift_trucks_is_excellent_alternative.asp accessed 14th September 2009

[34] Linde http://www.linde.com/international/web/lg/us/likelgus30.nsf/0/f14c118a5cb5299885257583005889O7 accessed 14th September 2009

[35] Hygenics 'Power Packs' http://www.hydrogenics.com/fuel/material_handling Accessed 17th November 2009.

[36] From US Department of Energy website, Status of Hydrogen Storage Technologies, http://www1.eere.energy.gov/hydrogenandfuelcells/storage/tech_status.html accessed 19th November 2009.

Metal hydride is too heavy for transport applications in most cases at present. However, fork lifts and similar vehicles could use this storage in future, as the need for a weight to balance the load (on the fork lift) is important.

In the past few years, researchers have developed cryogenic storage whereby pressurised or liquid hydrogen is stored at a low temperature to reduce its volume and increase its density. Lawrence Livermore National Laboratory demonstrated a cryogenic tank in a converted Prius. Using low pressure liquid hydrogen (stored at 20k and 1 bar) it achieved the 2007 US Department of Energy target for weight (1.7 kWh/kg) and achieved the volume target (1.2 kWh/L) using high pressure compressed hydrogen (stored at 20K and 200 bar). The car was driven for 650 miles on one tank of hydrogen. One issue is leakage of hydrogen if the vehicle is stationary for a number of days. The car was left for 6 days before the temperature rose significantly and the pressure became too high. Researchers have identified methods to improve this via better seals. Overall, the performance is much better than any other storage processes to date.[37] It also offers additional flexibility as liquid or compressed hydrogen can be used. Lowering the temperature can also improve the performance of the filling process.

[37] US Department of Energy Hydrogen Program FY2008 Progress Report Automotive Cryogenic Capable Pressure Vessels for Compact High Dormancy (L)H_2 Storage.

5 Stationary Applications

In general, the technology for stationary applications is not as advanced as that for transport applications apart from a few exceptions. Hydrogen and fuel cells are under development for uninterruptible power supply (UPS systems), remote power supplies and various CHP applications.

5.1 Commercial/Mass Produced Products

There are few mass produced or commercially available stationary products:

- UPS and back up systems
- Power supplies for remote mobile phone station
- Biomethane powered fuel cells at sewage stations.

5.1.1 Uninterruptible Power Supplies and Back Up Systems

There is a growing market for fuel cell UPS systems either for buildings or remote telecommunication stations. For back up systems in buildings, fuel cell UPS and back up power are often cost competitive with battery only systems. This is particularly true when their longer run times and higher quality power are taken into account. The energy density of hydrogen is higher than battery storage and can potentially be refilled without the restoration of a power supply. For remote outdoor locations, fuel cell systems are cost competitive with battery/generator systems. In naturally sensitive areas such as national parks, they have the advantage of being quiet and producing no pollution. Their reliability is around 99.9%.

The development in different parts of the globe is rather disjointed. For example, UK Upssystems offer a range of UPS systems from 5 kW to 400 kW using a range of fuels such as methanol, natural gas or renewable power[38]. Hydrogenics provide 'off the shelf' fuel cell back up systems from 2-200kW AC power or 2-30kW DC power. These are modular and 55% efficient.[39] Dantherm Power provide a small unit at 1.676kW[40]. Helion provide back up systems in the range 20-80 kW DC power and 100-200kVA.[41] However, as part of the PAN-H programme, France funded a demonstration project of a UPS system until January 2009, despite the fact there are commercial systems.

5.1.2 Power for Remote Systems

For a few years, there have been commercially available systems to power remote mobile phone stations (not subsidised by grants)[42,43,44]. However, projects such as EoLhy[45] are carrying out a demonstration project of a wind hydrogen system in a remote location in

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38 UK UPS Systems www.upssystems.co.uk accessed 24th August 2009.

39 Hydrogenics www.hydrogenics.com, accessed 24th August 2009.

40 Dantherm www.dantherm-power.com accessed 15th September 2009

41 www.helion-hydrogen.com/indexuk.php accessed 7th December 2009

42 Example of a remote power system: www.idatech.com accessed 19th November 2009

43 Example of a remote power system: http://www.zoomteam.com/Fuel_Cell_UPS_files/Eco-ee_ElectroPS_Intro_english.pdf accessed 19th November 2009

44 Example of a remote power system: http://www.allbusiness.com/energy-utilities/oil-gas-industry-oil-processing/5637604-1.html accessed 19th November 2009

45 EolHy Project http://www.dta.airliquide.com/en/our-offer/hydrogen-energy-1/partnerships-2/eolhy-1.html accessed 7th December 2009

hostile conditions. Wind energy systems are mainstream and have been combined with hydrogen. Whilst there may still be a considerable amount to learn from demonstration projects, it raises the question of whether the progress and lessons learned in different parts of the globe are sufficiently shared and built upon.

5.1.3 Examples of Hydrogen Systems at Sewage Plants

In the US, there are fuel cells for combined heat and power at sewage stations or using other sources of biomethane. For example in Santa Barbara, El Estero[46], Tuscon Arizona[47], City Tulare[48].

5.2 Renewable/Hydrogen Power Systems

Renewable hydrogen projects are mostly still custom designed although there is some knowledge sharing between different communities. There has therefore not been a reduction in cost via mass production.

There are still some serious concerns about the implementation and integration of these technologies. As well as capital costs still being high, systems still struggle with the intermittent nature of renewable energy sources. Demonstration projects have not yet achieved technological breakthroughs in key areas such as:

- The integration of fluctuating renewable energy sources with electrolyser systems,
- The intermittent operation of the electronic equipment due to fluctuating renewable energy power sources.
- The communication between the different commercially available components.

Development effort should focus on these areas.

Some of these projects are still suffering from parts that fail or are unavailable (even when the products are supposed to be sufficiently available to be sold commercially). Examples are:

- The FIRST (a PV-hydrogen) project (2000) experienced electrolyser and stack failure; however, it started in 2000 and therefore is a relatively old project[49].
- Hydrogen house in Brunate Italy started in 2007 (a solar-hydrogen system) was delayed by missing parts (cables for fuel cell).
- RES2H2 in the Canary Islands, which is a wind-hydrogen system, has been delayed by failures in equipment (the inverters and electrolyser).
- Remote hydrogen energy link in New Zealand (the Hylink project see Table 3) – this project is testing micro-scale renewable-hydrogen energy systems in a very remote environment. It has found that most failures have been due to the integration of non-compatible electronics components and assemblies, rather than the hydrogen technologies themselves.

Service support may not be available in some countries, which makes sourcing replacement parts difficult. The Centre for Renewable Energy Sources (CRES) in Greece found that the cost of shipping replacement sensors for their electrolyser was more expensive than the

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[46] Stationary Fuel Cell Installations http://www.fuelcells.org/info/charts/FCInstallationChart.pdf accessed 24th August 2009.
[47] Municipal Wastewater Treatment Facilities http://www.epa.gov/CHP/markets/wastewater.html accessed 24th August 2009.
[48] Fuel Cell at a Water Treatment Plant http://www.fuelcellenergy.com/files/FCE_Tulare_070208-LR_1.pdf accessed 24th August 2009.
[49] FIRST project Case Study http://www.ieahia.org/pdfs/FIRST.pdf accessed 24th August 2009.

parts themselves. A pump for electrolyser failed twice in three years and each time took a month to replace. Another example was that replacement fuses were a different size to those available in Greece.

Projects such as PURE on Orkney (operating since 2005), the wind-hydrogen system on Utsira (2004), the Hawaii Hydrogen Power Park at Kahua Ranch (2007)[50,51,52] and the HyLink in New Zealand (2008) either have encountered fewer problem or are now operating well having overcome problems. Lessons have been learned from all projects whether or not they are still in operation[53] and as a result, there are plans to replicate the projects. More recent projects have solved some of the problems encountered in earlier projects and have brought the technologies closer to commercialisation. For example, PURE required a much greater level of custom design compared to later projects and PURE now offers consultancy and system design. The Hydrogen Office in Fife[1] was able to adapt an existing control system rather than have to have an entirely custom design. The Kahua Ranch developed its own control system, which it aims to license for use elsewhere or as a training programme. Despite the difficulties, the project run by CRES was very successful in that the experience gained through the assessment and optimisation of the plant is now applied in new projects and other consultancy services.

Nevertheless, the progress is slow and major hurdles still remain. Projects are small in scale in contrast to transport programmes. As a result, care must be taken to study and optimise the characteristics that arise from the hydrogen systems themselves rather than from small scale of the project.

Safety and permitting are still a major cause of delay in many of these projects, as is funding.

5.2.1 Combined Heat and Power Over 50kW

Combined heat and power units over 50 kW have a proven track record and have been deployed in buildings such as schools, leisure centers- and hospitals. The vast majority operates off reformed natural gas but reformation of a range of liquid fuels is also available. Technology is proven with up to 60 000 running hours. Availability is above 90%. The greatest challenge is to reduce the unit price of the technology[54]. The Canadian Fuel Cell Road Map (updated in 2008) sets target sales of 35 000 kW by 2010 and 300 000 kW by 2015 for fuel cells over 200 kW to become commercial.

Most units at this scale are molten carbonate or phosphoric acid fuel cells and operate at a high temperature. There are developments to include a turboexpander to improve the electrical efficiency to 60%. Already the heat to power ratio is lower than conventional CHP units, resulting in the technology being applicable to situations with smaller heat loads. In addition, if the price of electricity is considerably higher than that of heat, generating a greater proportion of electricity compared to heat is more profitable. Traditionally CHP units

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50 Case study available at http://iea-hia-annex18.sharepointsite.net/Public/default.aspx accessed 11th January 2010.

51 Severine Busquet, Richard Rocheleau, Mitch Ewan, Final Report, Hawaii Hydrogen Power Park, 2008 Accessed 11th January 2011

52 Hawaii Natural Energy Institute www.hnei.hawaii.edu/hhppasp

53 Benefits and Barriers of the Development of Renewable/Hydrogen Systems in Remote and Island Communities, Shannon Miles and Mary Gillie, report for IEA HIA Task 18 available at: http://iea-hia-annex18.sharepointsite.net/Public/Annex%2018%20papers%20reports%20and%20presentations/Forms/AllItems.aspx Accessed 11th December 2009

54 Canadian Fuel Cell Commercialisation Road Map Update 2008 http://www.chfca.ca/files/IC_FC_PDF_final.pdf accessed 14th September 2009

fulfill the heat demand and produce a corresponding amount of power. In future, units could be electrically led. That is, a fuel cell could operate to fulfill the electricity demand rather than heat demand and produce a corresponding amount of thermal energy.

5.3 Residential/Building Systems

Smaller CHP units are still at the demonstration stage, particularly at the domestic scale. Most use proton exchange membrane (PEM) fuel cells. The largest demonstration programme is in Japan, with over 3300 units in domestic properties (see below). Reliability and availability are not as good as for larger units over 50 kW. Note that the performance demand in terms of running hours for a fuel cell of this size are greater for a stationary application than for transport. The expected running hours for a CHP unit is in the order of 10 000s of hours compared to a few 1000s for a car. However, the operating cycles are generally more benign for a CHP unit. Once installed in a domestic home, the number of hours for which the unit is run and its cycle is dictated by the consumer, unless it is remotely controlled. Reducing the unit cost and improving the availability and efficiency of units under 50 kW are the key challenges.

There are some combined heat and power installations such as:

- Large scale trial in Japan,
- Berwick Housing Association Ltd[55],
- Unst UK[56],
- CHP in Woking in the UK[57],
- 64 student apartments in Birk Denmark[58].

Still, the technology for this type of application has yet to become an ‘off the shelf’ commercial product. MicroCHP fuel cells are beginning to scale up with expanding trials notably in Japan and Denmark. These are described below in more detail.

In Denmark, the Distribution Network Operator (DNO) is involved in expanding microCHP fuel cell trials from an initial 10 units to 100 units. The DNO is involved as it wishes to use electrolysis and remote control of the CHP units to balance the network. The project stopped for period as it was discovered that some safety permits had not been obtained.[59]

Japan has over 3300 CHP fuel cells running off various reformed fossil fuels. These installations have been successful as most of the faults are not associated with the fuel cell. Fault rates are at around 0.29 per system per year, which is around the upper threshold of what is acceptable for a product to be commercialised. Each unit is receiving a very large government subsidy as manufacturers move into commercial production post-2009.

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[55] Bewickshire Housing Association, Fuel Cell Markets http://www.fuelcellmarkets.com/fuel_cell_markets/member_view.aspx?articleid=7019&subsite=1&language=1# accessed 24th August 2009

[56] Hydrogen Houses Unplugged http://iea-hia-annex18.sharepointsite.net/Public/National%20Projects/United%20Kingdom/Hydrogen%20Houses%20Unplugged.doc accessed 24th August 2009

[57] Woking Park Fuel Cell CHP http://www.woking.gov.uk/environment/Greeninitiatives/sustainablewoking/fuelcell.pdf accessed 24th August 2009

[58] Hydrogen and Fuel Cell, the Danish Partnership for Hydrogen and Fuel Cells http://www.energymap.dk/Cache/3e/3eea6187-be40-4c5d-9465-9b2b78280aa5.pdf accessed 24th August 2009

[59] Hydrogen Community Lolland http://www.hydrogen-community.dk/index.php?mod=main&top=0&parent=0&id=90 accessed 24th August 2009

However, the subsidy per unit has been reduced by two thirds between 2005 and 2008. Manufacturing costs have reduced in line with this reduction in subsidy. The units have demonstrated a carbon saving even in summer when the heat load is lowest (compared with typical emissions from domestic energy in Japan). Average electrical efficiency has improved slightly since 2006 to 32%. Units operating at part load had the lowest efficiency but this was still 26%[54].

Baxi Innotech and Ceres power are also trialling fuel cell microCHP, therefore is it anticipated that at least some of the designs by the different manufacturers will be commercially available in the near future.[60]

5.3.1 Hydrogen Storage for Stationary Applications

For stationary applications, gravitational, and in some case volumetric density is less important compared to storage for transport applications. If a system is converting excess renewable energy to hydrogen and then back to electricity, its round trip efficiency is important for a scheme to be viable. Unless off-grid, the alternative would be to simply export and import power to and from a public electricity network. However, if the times of excess renewable power are not frequent, the capital cost of hydrogen storage may be too high to justify a renewable-hydrogen scheme. Storage can therefore be at lower pressures, in order to increase the round trip efficiency as energy is not used for compression. An example of a low pressure system is the Hylink system in New Zealand where a plastic pipe transports hydrogen from a remote wind turbine to a few houses. The pipe also acts as a low pressure storage medium (the maximum storage pressure is 4 bar). The Kahua Ranch project[50,51,52] in Hawaii abandoned additional compression and stores hydrogen at 12 bar (as delivered by the electrolyser). This reduces the energy required to store the hydrogen.

5.3.2 Safety Processes

The European project HyPer[61] produced a guidance document for safety and permitting for stationary fuel cells up to 10 kWe. The work was based on existing documents from EU countries. The Health and Safety Executive in the UK have used this document to produce a UK guidance document[62] available at http://www.hse.gov.uk/research/rrhtm/rr715.htm. Unfortunately, it carries less importance as it is a guidance document rather than a standard. Other countries do not appear to have utilised the work as yet.

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60 Baxi-Innotech http://www.baxi-innotech.de/ accessed 24th August 2009
61 HyPer Project website www.hyperproject.eu accessed 11th January 2010
62 available at http://www.hse.gov.uk/research/rrhtm/rr715.htm. accessed 11th January 2010.

6 Hydrogen Production: Trends in the Use of Electrolysers and Reformers

6.1 Development of Reformers and Electrolysers

The development of efficient, cost effective means to create hydrogen is important for almost all applications. Whilst there is research into direct conversion of water into hydrogen and oxygen using solar radiation, this technology has only been demonstrated at a laboratory scale. Therefore, this assessment focuses on the two main methods to create hydrogen at present, reformation from fossil or biofuels and electrolysis of water.

6.1.1 Reformers

Until recently most reformers were built for industrial uses and are therefore large scale, with plant capacities in the range 20 000 – 200 000 Nm^3/h Hydrogen in a single unit. They can however be manufactured at smaller capacities down to 200 Nm^3/h. Indeed, the HyCUTE reports there are recent new technologies that allow designs as small as 50 Nm^3/h. The bus project in Madrid installed a 50 Nm^3/h sized reformer and the Stuttgart bus project uses a 100 Nm^3/h sized reformer.[63] IEA HIA Task 16 identified the need for a set of standards related to each component constituting units for on-site small-scale reforming. Task 23 'Small scale reformers for on-site energy supply' has taken on the work to provide a harmonized approach to reformer capacity. This harmonisation is important for vendors and users and should enable manufacturers to concentrate on cost reduction and mass production.[64] Natural gas is the normal choice but methanol and other hydrocarbons such as landfill gas, biogas are now being considered. Some of these fuels do not occur naturally but are by-products of industrial processes or agriculture. Multifuel and biofuel reformers are now being developed. Reducing the price of reformers is critical.

6.1.2 Electrolysers

The two electrolyser technologies available on the market are alkaline and PEM technologies. Alkaline electrolysers use an electrolyte solution of potassium hydroxide. PEM electrolysers use a solid membrane. Both require de-ionised water, but PEM technology requires a higher purity. An alternative technology may be solid oxide electrolysers but these are not commercial.

There is a wide range of electrolysers in the market. PEM technologies tend to be more compact. Commercial PEM electrolysers also tend to have faster response times, although there is no technical reason for alkaline electrolysers to respond more slowly than PEM electrolysers. Designs suitable for domestic use tend to be PEM technology whilst larger units tend to be alkaline. However, these designs were not initially for hydrogen energy systems. Designing units for use with renewable energy may result in PEM and alkaline technologies being used at different scales to those at

[63] HyCute On-site reforming http://www.global-hydrogen-bus-platform.com/Technology/HydrogenProduction/reforming accessed 14th January 2010
[64] Task 23 Small-scale reformer for on-site hydrogen Supply Semi-Annual report May 2009 Dr. Ingrid Schjoelberg (Operating Agent). Available at http://www.h2-info.dk/iea/pdf/Task23_statusrapport.pdf accessed 14th January 2010.

present. Often, electrolysers with higher efficiencies (and therefore lower operating cost) are more expensive in terms of higher capital cost. However, at present, price is not a good measure of the cost of electrolysers as many are designed for niche markets where price reflects the market rate and not the capital cost. Nevertheless, Danish research of alkaline electrolysers showed that the cost per kW was almost logarithmically proportional to the size of the unit.[65] The Danish technology review also concluded that alkaline electrolysers were the most mature and likely to be the technology used for the large scale electrolysis needed for grid balancing.[65]

Theoretically, it requires 39.4 kWh and 8.9 litres of water to make 1 kg of hydrogen at 1 atmosphere and 25°C and is the higher heating value of hydrogen. The higher heating value is when all the energy - thermal and electrical - is taken into account. The efficiency is the energy used by the electrolyser divided by the higher heating value. Electrolysers vary in efficiency from around 52% to 82%. Some manufacturers quote efficiencies using the lower heating value that is equivalent to 33.4kWh. Experience from users shows that the efficiencies supplied by the manufacturers represent the maximum values, or only consider the stack itself, without taking into account the losses in auxiliaries. For example, in the case study on the Hawaii Power Park[50,51,52], the maximum efficiency was lower than specified by the manufacturer. In the CRES[66] wind-hydrogen plant, the electrolyser stack efficiency varies from 80-90% (using the higher heat value) at partial load, but the losses in the power supply cabinet are around 20% and may be even higher at partial load giving a mean overall efficiency of around 60% including all auxiliaries.

The cost of electricity is a key factor in the cost of hydrogen produced by electrolysers (less so for small units where the capital cost is proportionally higher).[65,67] Therefore, if the efficiency of units is increased, electrolysers could produce a fuel that is of similar price to electricity in the same energy market. If hydrogen is produced at times of excess renewable power and low market price, the cost of hydrogen could be relatively low.

6.1.3 Applications and Implications for Design

As noted above, in general, electrolysers are more cost effective for small scale applications needing 5-10 Nm^3/hr up to 300-500 Nm^3/hr but larger units are technically possible and there are some megawatt sized designs. At present, reformer technology is most appropriate from around 500 Nm^3/hr to 1000 Nm^3/hr and could service a refuelling station (although smaller designs are now available – see section 6.1.1). 1000 Nm^3/hr would provide hydrogen for approximately 10 cars/hour. It is unlikely that more than two or three such units would be required for a filling station. It is possible to use larger units, if hydrogen is created at a central location, but without a hydrogen pipeline, transportation and storage of the hydrogen is likely to become unmanageable and reduces the economic case for large scale reformation. The price of electrical power compared to natural gas, biogas and ethanol (and its availability) can make electrolysis or reforming more favourable.

In some instances, the two processes can be used alongside each other particularly in the situation where there is a supply of biofuels and intermittent renewable electricity, but neither is sufficient alone. Carbon capture is very difficult for small scale reformers. For electrolysis, either green electricity can be used or carbon capture can be carried out on a large scale at electric power plants. Comparisons of how easy it is to reduce

65 Pre-Investigation of Water Electrolysis PSO-F&U 2006-1-6287

66 Centre for Renewable Energy Resources http://www.cres.gr/kape/index_eng.htm accessed 19th November 2009

or sequester CO_2 should be made as well as the efficiency of electrolysers and reformers.

For both reformers and electrolysers, most designs have been adapted from industrial applications rather than specifically designed for the new uses. This may be appropriate for small numbers of units for demonstration but to reduce costs and improve efficiencies, more appropriate designs are required that can be mass produced. However, an improvement in efficiency may reduce the ease in which a product can be mass produced. For example, an expensive metal or manufacturing process may make production more expensive. A balance may need to be struck between capital, manufacturing and operational costs, but this will be most effectively achieved by designing electrolysers for hydrogen energy systems and for mass production rather than adapting electrolysers designed for other niche markets.[67]

Whole system solutions are required to create a market for small electrolysers. New Zealand researchers have developed a specification for a small electrolyser to be used in remote locations for hydrogen production and distribution by pipeline from intermittent renewable sources such as wind and solar PV.

The efficiency of small units, whether electrolysers or reformers, is always lower than for larger units, due to the relative importance of the auxiliaries and control losses. The power consumption of the auxiliaries and the control systems do not increase linearly with production, so larger units are more efficient than the very small ones. Again, a complete redesign rather than adaptation from larger units may be required to reduce the impact of the losses due to auxiliaries in small units.

Performance of units will vary considerably depending on the application. Variable input or intermittent use, for example, from renewable power or to provide hydrogen for a filling station, may result in more faults compared to when an electrolyser operates continuously with a uniform load.

New combined systems are now being developed. One example uses the oxygen created by an electrolyser in the gasification process for biogas. Another use is to inject the oxygen into sewage plants[68] . There is also the development of a system that uses hydrogen created by internal reforming in a direct carbon fuel cell for alternative applications..[69,70] The hydrogen could be used for transport for example. The waste heat from such a high temperature fuel cell is hot enough for further generation using a combined cycle steam turbine as well as heating or cooling applications[71]. Maximising the heat used and running a reformer at a constant rate creates a very efficient system.

[67] Wind-to Hydrogen Project: Electrolyser Capital Cost Study, Genevieve Saur National Renewable Energy Laboratory, December 2008. Technical Report number NREL/TP-550-44103

[68] F.Haas, A.Jain, et al., The hydrogen-oxygen project in Barth, International Journal of Hydrogen Energy 30 (2005), 555-557

[69] An Innovative Highly Efficient Combined Cycle Fossil Fuel and Biomass Fuel Power Generation and Hydrogen Production Plant with Zero CO_2 Emission by Meyer Steinburg Brook Haven National Laboratory, March 2003 Available at http://www.netl.doe.gov/publications/proceedings/03/dcfcw/steinberg.pdf accessed 14th January 2010

[70] Direct Carbon Progression: Progressions of Power, Barbara Heydorn, Steven Crouch-Baker, Institute of Physics 2006. Available at http://www.sara.com/papers/FCRJanDCFC_SARA_Reprint.pdf, accessed 14th January 2010

[71] Boosting Energy conversion efficiency of fuel cells, SOFC-ST assessment using the EMINENT tool, Petar Varbanov, Ferenc Frielder Univeirsty of Pannonia Hungary available at http://www.aidic.it/pres09/webpapers/190Varbanov.pdf accessed 14th January 2010

Creating hydrogen using electrolysers or reformers has potential implications for the loading of the electricity or gas network although if they are used in a co-ordinated manner they could help to peak shave and avoid reinforcement. The demonstration programme of domestic CHP in Lolland has a long term goal of demonstrating how creating hydrogen via electrolysis from excess renewable power and remote switching of domestic CHP units can be used to help to balance of the electricity network[59]. The concept is to supply the hydrogen to homes and switch on the CHP units when there is a shortage of renewable power.

The production of distributed hydrogen from electricity supplied by a network, along with the production of distributed electricity from gas also supplied by a network introduces a new paradigm. This could be termed “network bridging” where for the first time it is possible to dynamically manage the mix of distributed energy flows from more than one parallel networks. At times of high energy prices on one network, it is now feasible to offset the use of that fuel by direct substitution from the other network.

7 Progress to Commercialisation of Hydrogen for Transport Applications

7.1 Definition of Commercialisation

This study uses the following definition of commercialisation:

> *Commercialization is the* stage *in the* product development process *where the* decision *to order mass* production *and* launch *is made using business methods. At this point revenue is received for the product although initially profit may not be made.*
>
> *From the end-users point of view, the product is economically viable either because it is cost competitive or marginal costs are outweighed by additional benefits compared to alternatives.*

Full scale production launch for hydrogen systems has not been possible due to users' concerns over durability and reliability. This is a particular issue for fuel cells as they compete with conventional technology such as the internal combustion engine (ICE) which has been under development for over a hundred years. Consumers are familiar with fossil fuels and ICE technology and assume its operation is better and more consistent, even though fuel cell technology may meet and exceed it in some areas of performance. Furthermore, the cost is still too high to compete with ICE's for mass market acceptance.

In order to achieve full scale development, there needs to be a value proposition to justify the additional costs. This may mean that niche markets will prevail and until costs are decreased, there will not be mass deployment. On the other hand, the cost savings required may only be achieved through mass production. There is some evidence of early initiatives to encourage mass production (for example joint procurement of buses, fleets of cars for hire or mass roll out of CHP in Japan).

7.2 Barriers and Routes to Commercialisation of Transport Applications

Whilst more R&D funding and purchase incentives may help mass production, for vehicles the areas and range over which they can be used is limited by the location of fuelling stations. Until fuelling stations become widespread, this is a major barrier. Fuelling infrastructure must be in place for mass deployment creating a 'chicken and egg' problem, as the stations are unlikely to be viable until there is mass production.

There is a value proposition for using fuel cell fork lift trucks in warehouses, given the additional benefits they offer. Many warehouses are converting to fuel cell powered fork lift trucks since it reduces energy use and maintenance costs while minimising noise, waste and indoor emissions. Large North American commercial installations include Nestle Waters and Walmart Stores Inc. (see section 4.3.2).

Fuel cell hybrid buses are getting closer to commercialization with many large fleet deployments worldwide (see section 4.3). Fleet applications and use in vehicles with known routes may succeed first since they have dedicated fuelling facilities, therefore avoiding the problem of a limited range due to a lack of refuelling infrastructure.

7.3 Barriers and Routes to Commercialisation of Stationary Applications

For commercialisation of stationary applications, the following approaches could be used:

- Use of niche markets such a UPS systems or proven CHP applications (e.g. at sewage stations) to develop systems to expand into other applications.
- Large scale field trials of increasing size.

Finding suitable properties for field trials may be more difficult compared to testing fleets of buses or cars. However, there are agencies that could provide large numbers of dwellings, for example building developers, agencies for social housing or local councils.

In addition, the particular issue of developing electrolysers and reformers appropriate for the application must be tackled.

7.4 Progress to Date

Fuel Cell Today carries out surveys of the market each year. In 2007, there were commercially available (i.e. unsubsidised) fuel cells marketed. These were targeted at the luxury end of the market. There was a 75% growth in 2007 as the industry shipped 12 000 units. The manufacturing capacity was able to produce 100 000 a year by the start of 2008. Most of the commercial opportunities identified by Fuel Cell Today were for low temperature PEM fuel cells. The costs for these fuel cells vary from around $3000 per kW for a 5 kW unit to $34 000 per kW for a micro 100 W unit. The costs have been dropping by 10-20% each year.[72]

Whilst the drop in price per kilowatt is promising and brings fuel cells closer to being economically viable, during the Road2hycom project that finished in 2009, it only identified one company that was trading profitable solely from fuel cell sales.

Companies such as PURE, Bryte-Energy, and Heliocentris offer a one-stop shop for design and delivery of hydrogen projects and (as described in section 4.1) commercial filling station systems are now available.

7.5 Comparison of True Costs of Different Energy Sources

Whilst hydrogen is an energy vector rather than a resource, a significant reason for developing the technology is to enable a greater use of renewable generation and decarbonise our transport systems. However, it is often argued that hydrogen systems (especially combined with renewables) are too expensive compared to conventional energy systems. However, this does not take into account the true cost of fossil fuels in terms of damage to health and the environment. This lack of a 'level playing field' is a serious barrier to commercialising hydrogen systems.

[72] Fuel Cells: Commercialisation 30 Jan 2008 Fuel Cells Today http://www.fuelcelltoday.com/online/news/articles/2008-01/Fuel-Cell-Commercialisation accessed 11th January 2010

It is hoped that as climate change moves up the political agenda, hydrogen will be able to take advantage of more generous incentives for low carbon energy systems and the true costs of fossil fuels will be reflected at least in part in some kind of carbon trading or tax.

7.6 Opportunities in Energy Network Bridging

A key advantage of hydrogen systems that has yet to be explored and could offer significant value is energy network bridging. That is to say, using hydrogen as an energy vector to reduce bottlenecks or shortfalls in the heat, electricity, gas and transport networks. Hydrogen has the potential to link these sectors and potentially increase their flexibility and reduce the operating margins required. This in turn could help increase the penetration of renewable energy. Furthermore, there are a number of waste treatment processes that either produce hydrogen or products that can be reformed to hydrogen.

Some studies have been carried out as to the penetration of renewable power required before storage as hydrogen is economic. These studies focus solely on the electricity network and to a certain extent DSM and transport. Energienet in Denmark also commissioned a report to assess the best technologies for electrolysis to use hydrogen as a storage medium on a utility scale to balance the electricity network but this again, only considered electricity networks. Studies do not generally take into account the potential benefits of an approach where hydrogen could be produced from electricity, gas or waste streams and used as electricity, heat or transport[73]. One example of early investigations is the demonstration in Lolland Denmark. The development of domestic CHP units is such that the network operator aims eventually to be able to create hydrogen via electrolysis from excess renewable electricity and supply it to homes. The network operator could then switch CHP units on remotely when there is a shortage of power[65]. This at least uses hydrogen as an energy vector to avoid bottle-necks on the electricity network.

Unfortunately, the trend to 'unbundle' electricity markets so that network operators and suppliers operate separately, together with the lack of co-ordination between different energy sectors, inhibits investigations in this area. There are also few economic incentives for different energy and transport providers to collaborate in this area.

[73] Scotland's Hydrogen Future Study http://www.all-energy.co.uk/userfiles/file/Alison_Cavey210508.pdf accessed 19th November 2009

8 Comparison of Targets and Progress to Date

Progress in developing new technologies is not a smooth process and past performance does not dictate future developments. As technology matures, improvements are harder to make but on the other hand, new opportunities for cost reduction such as mass production arise. With this in mind, a selection of targets from the US Department of Energy and the Canadian government were chosen (Table 5 and Table 6) to assess how realistic they are compared to recent performance. There are many more targets; these are just a selection.

8.1 Electrolysers

First, to assess whether electrolysis will achieve the targets set, here is a summary of the state of the art. Using assumptions in an NREL report, the capital costs are $5000/kW for a 10 kg/day unit (domestic), $2000/kW for a 100 kg/day unit and $850/kW for a 1000 kg/day unit (filling station size). This is significantly higher than the US Department of Energy target (Table 5). The US Department of Energy estimated that public procurement of around 1500 to 2000 units per year could reduce the cost of stacks by a factor of three[74]. Discussions with manufacturers showed that most felt that they could reduce the capital cost of electrolysers by improving efficiency and by mass production of key components (e.g. the stack, power electronics and gas conditioning components).[67] Efficiency will have a bigger impact in reducing the cost of hydrogen from larger units than from smaller units as the price of electricity is a more significant factor than capital cost for larger units. Conversely, mass production will have a bigger impact on the price of hydrogen for small units as more the capital costs have a greater impact than electricity price on the cost of hydrogen. Whilst at present efficiencies up to 82% (HHV) for electrolysers are possible, they generally operate at much lower than this, particularly with an intermittent input and if they must switch on and off frequently. The efficiency of electrolyser production in the US Fuel Cell Vehicle Learning Demonstration Program was on average 45%[2] (for other applications the efficiency is often higher). For filling stations, an increase in efficiency of around 10% is therefore needed. However, efficiency is an area where manufacturers see improvements are possible for a number of the components in electrolysers.

In conclusion, a 20% reduction in capital costs for a large unit would achieve the DOE target and may be realistic. Whilst there are predictions of 6-fold reductions in price, achieving the DOE target for small unit capable of 10 kg/day may be difficult even with mass production. A redesign for use with wind power may also be required.

8.2 Vehicles

Here is a résumé of the present costs and performance of hydrogen powered vehicles. It is estimated that the cost of a fuel cell is around $100/kWe if mass produced (or possibly lower[74]). Therefore, further improvements in design (for example reducing the rare metals in catalysts) are required to achieve the US target (Table 5). Even though the target is challenging, this may be possible. The 2009 driving range target for cars has been achieved with some designs achieving the 2015 range. For many trials, the Canadian 2015 target for availability has already been met. Manufacturers' claims that there will be a dramatic fall in

[74] US Department of Energy Hydrogen Program, Annual Progress report, FY 2008, Introduction

the cost of hydrogen fuelled cars in the next few years are very ambitious but consistent across the industry.

Improvements in storage methods will play a large part in improving vehicle storage and range. As noted in section 4.4, whilst most technologies are not meeting existing targets, cryogenic storage could offer a significant improvement.

Manufacturers believe that they can achieve equivalent performance to conventional buses by 2015 so the 98% reliability target should be met. Given the number of buses already on order (motivated in part by the Hydrogen Bus Alliance), the target of 200 buses by 2010 is achievable. Achieving 1500 may depend on a mixture of reduced costs and better efficiency and reliability compared to conventional buses to justify higher capital costs.

Table 5 Table of transport related targets

	DOE Target Cost of FC for transport[32]	**DOE Target Driving range**[32]	**DOE Target Electrolyser**[32]	**Canadian target Transit bus reliability**[54]	**Canadian target Transit bus availability**[54]	**Canadian target No. of sales of Transit buses**[54]
2008			$665/kWe electrolyser that can work with input from wind energy at 62% efficiency when built in quantities of 1000/year			
2009		420 km driving range				
2010	$45/kW FC for transport			95%	90%	200
2015	$30/kW FC for transport	500km range		98%	95%	1500

Table 6 Canadian targets for residential fuel cell CHP[54]

	PEM residential CHP(natural gas or LHV)	**PEM residential CHP (natural gas or LHV). Failures per year**	**PEM residential CHP (natural gas or LHV). Running hours/10 years**	**PEM residential CHP (natural gas or LHV). Target sales**
2010	85%	0.2	40 000	15000
2015	90%	0.05	60 000	250000

8.3 Domestic CHP Units

The most advanced domestic trials of CHP units are in Japan. The Japanese field trial is probably the best example of what is presently possible with domestic fuel cell CHP units. These have achieved a fault rate of 0.29 per year in 2008. Improvement is still required to achieve the 2010 Canadian target of 0.2 per year, but it is realistic. The highest efficiency (in a regime that demanded a high average electrical output) was over 82% on natural gas or LPG but around 70% if the average electrical output was low. Thus it is likely that the Canadian 2010 target of 85% could be met but not for all operating regimes.

With considerable subsidy, the Japanese have demonstrated that it is possible to install significant numbers of CHP units over a few years. Domestic boilers are often an 'emergency purchase', that is, bought quickly when the existing boiler cannot be mended. If CHP units are to replace domestic boilers, installers will need contracts and training so that they are prepared to recommend them as an alternative. Other routes will be via new build or installation in social housing. Energy suppliers or network operators may wish to market them with remote control for electricity network balancing purposes.

By focusing on more than one market for fuel cell stacks, for example small CHP units and transport, it may be easier to justify mass production.

8.4 Conclusions

In conclusion, whilst the targets may be challenging, from the experience of the last few years, they are achievable and would enable products to become commercialised. However, technical improvements alone will not suffice. Mass production is required to reduce costs. Government and public bodies can assist via public procurement and supporting mass role out of small units such as domestic CHP.

9 Lessons Learned and Recommendations

The information and discussions in this report demonstrate that hydrogen systems are moving closer to commercialisation. However, some sectors are much more advanced than others.

The fleets of buses and vehicles are expanding with more used for 'real-life' driving. For this growth to continue:

- Refuelling infrastructure must be rolled out. This will require planning and co-ordination by local and national governments.
- Maintenance and service companies will require support both financially and with training. This could be a joint effort between national governments and vehicle manufacturers.

As well as cutting capital costs, a key area for improvement is hydrogen storage to improve vehicle range and efficiency and this should be an area of focus for research.

To enable mass production, it would help if companies and government agencies or service providers that use large numbers of vehicles collaborated to increase the size of orders.

Consistent political support long-term is essential to ensure project continue and achieve all their goals. Public procurement can play a significant role in justifying mass production, which in turn will allow the cost reductions needed for commercialisation.

With the exception of niche markets of UPS systems, stationary markets are much less advanced. There is a danger of becoming trapped in a loop of demonstration projects that do not expand or significantly move the technology on.

Transport applications may be more advanced than stationary applications due the co-ordinated planned development. Vehicle fleets have expanded, and are driven under increasingly onerous operating conditions. Examples are the CUTE bus programme in Europe and the Vehicle Learning Demonstration Program in the US[75]. Technology has been improved along side these trials. In contrast, there have been a number of 'one off' stationary projects. Some of these do not seem to have built on the lessons learned from previous projects. For example, similar problems with electrolysers and control systems in a number of projects do not seem to have been addressed. One-of-a-kind projects do not encourage redesign of components or mass production.

Where larger scale projects have been implemented (for example domestic CHP in Japan), technical problems seem to be addressed and capital costs fall. It should be emphasised however that larger scale projects only overcome technical and cost issues if there are robust monitoring systems in place, rigorous goals and reporting structures. Larger scale projects often give a more 'real world' setting to evaluate performance. When working at smaller scales, it is important to focus on characteristics that are generic to systems in general rather than those linked to the small scale of the demonstration.

As stationary applications are still relatively small scale, individuals or communities tend to initiate them. To develop large scale programmes larger companies and organisations need

75 US Department of Energy Technology Validation Programme http://www1.eere.energy.gov/hydrogenandfuelcells/tech_validation/fleet_demonstration.html accessed 19th November 2009

to be involved. However, engagement with communities should be maintained and is important for hydrogen systems to gain public acceptance.

To accelerate the development of stationary projects and encourage transport applications at the same time, key areas to tackle are:

- Creating a clear safety and permitting process.
- Agreeing on safety standards appropriate for the size of project, preferably accepted internationally.
- Raising the awareness and understanding of the public and decision makers.
- Designing electrolysers and reformers appropriate for the application and for mass production. That is of the appropriate size, able to operate at part load or with intermittent power input from renewables.
- Develop whole systems with components that are designed to operate together.
- Adapting energy markets and regulations to allow the creation of hydrogen from electrolysis or reformation of fossil fuels to aid the control of energy networks rather than exacerbating bottlenecks.
- Supporting the development of service and maintenance networks to give consumers the confidence to adopt hydrogen technology.
- Building hydrogen systems into the development and planning of cities and regions so that projects are not ‘one off’ projects but part of a planned expansion.

If the environmental costs of fossil fuels are taken into account, the difference in price of hydrogen/renewable systems and conventional energy systems is much less compared to the upfront costs. Mechanisms to take into account the hidden costs of fossil fuels should be encouraged.

Projects should not underestimate the time to find funding and planning approval. Generally, projects that become operational on time according to the original project plan have worked with the public and all relevant stakeholders from the inception of the project. This has enabled them to resolve and allay concerns.

9.1.1 Technology Advances

There have been significant advances in hydrogen and fuel cell systems in the last 5 years that have improved efficiencies, performance and economic viability. Nevertheless, further cost and performance improvements are essential. Some of these improvements will come from mass production, but improvements in technology itself will be required to meet the requirements of industry and consumers.

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Further information is available at the Task 18 website
http://iea-hia-annex18.sharepointsite.net/Public/default.aspx

and the HIA website
http://www.ieahia.org/