Hydrogen: tomorrow's fuel or just hot air? The Icelandic Experience

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Hydrogen: tomorrow's fuel or just hot air?
(The Icelandic Experience of Hydrogen)

Hydrogen is once again in the limelight, with rising fuel prices, the search for fuels beyond petrol and diesel is being debated even more hotly. The European fuel cell bus trial has been extended by one year and there has been much talk about the potential for hydrogen powered vehicles working during the London Olympics. These would bring even more people into contact with future fuels on perhaps boats and buses. The DfT has also announced a major call for more research on hydrogen, clearly indicating a focus on both vehicles and infrastructure. So what is all the hype about this fuel and what does it mean for transport engineers in general? This article tries to address some of those issues by trying to understand hydrogen, and then by looking at how the Icelanders have used this remarkable fuel. There may be some meaningful lessons for the UK and other countries interested in implementing hydrogen.

Understanding Hydrogen

Hydrogen is technically speaking not a fuel which is burned (like diesel) but rather should be seen as an 'energy carrier' which when coupled with fuel cells could lessen the need for diesel and petrol in many vehicles. Fuel cells work by simply by combining hydrogen (H_2) and oxygen (O_2) and converting them into water across a catalytic surface and in this process electricity is produced. The electricity can then be used to power vehicles which are oddly silent compared with traditional engines. This explains why hydrogen is deemed an energy carrier, rather than a fuel which is combusted, just like car batteries are energy carriers. Fuel cells however don't go flat as long as there is steady supply of H_2 and O_2. In general fuel cells have about twice the efficiency of internal combustion engines so large gains in efficiency can be made. These gains however are offset by the relatively low energy content that hydrogen delivers as a carrier when compared to petroleum based fuels on current cars. Some car makers, such as BMW, however are experimenting seriously with using hydrogen as a direct fuel in a combustion engine as a way to sort of bridge the current gap between traditional engines and fuel cells. At the moment fuel cells are still much more expensive than the internal combustion engine, but like any other technological devices further investment in research and development will begin to see these power plants appearing over the next few years. Perhaps the Toyota Prius, the world's first mass produced hybrid car, with its uptake into the consumer market, although considered slow and somewhat costly, shows one way how fuel cells might begin to diffuse into the vehicle parc. At the same time the manufacturer recognises this short-term weakness by balancing it with the long term gains of being first into the market by leading innovation and learning by doing, much as the Icelanders are. But this raises a serious 'chicken-and-egg dilemma' known to many familiar with introducing hydrogen as a new consumer fuel. One country that has taken this challenge on and embraced H_2 is Iceland. Their experience and forward thinking offers us deep insight to the potential of understanding this possible future fuel.

Iceland's first steps into the hydrogen economy

Iceland has embarked on a major mission in the late 1990's to become the world's first hydrogen economy and the transport sector stands clearly as the first piece of this complex puzzle to be put into place. Over the last 3 years the Rekyjavik based New Energy along with DaimlerChrysler, Evobus, Norsk-Hydro, Shell-Hydrogen and the Rekyjavik Muncipal Public Transport operator (Straeto) completed their part of an European funded project with all three demonstrator hydrogen powered buses meeting their main objectives. The CUTE (*Clean Urban Transport for Europe*) is also running three hydrogen powered buses in London, as well as another eight European cities. To understand how all of this has come about it is necessary to know a little bit about the drivers of change in Iceland and also their very special relationship with energy that Icelanders nurture.

Iceland has long been at the renewable energy forefront, having implemented geothermal derived space heating for the majority of houses on the island in the late 1970's using district heating systems. The abundant geothermal energy sources make for excellent supplies of plentiful clean hot water as well as steam to run turbines for 'green' electricity generation. There is also a huge and growing hydroelectricity industry. Today more than 70% of the primary energy needs are met through hydropower and geothermal sources. Thus, the main issue which remains is the transport sector and its strong reliance on imported fossil fuels, which in one sense is similar situation to many other European countries. The Icelandic dilemma is further complicated by the fact that the fishing fleet uses about the same amount of fuel as do the land based vehicles and equipment. Therefore it would seem that although Iceland is very 'clean and green' in some sectors, this contrast places extra pressure on the transport sector to reduce its carbon dioxide emissions. In other words, consumption of petroleum products by cars, lorries and buses needs to be reduced dramatically to significantly alter the CO_2 balance. But there are many Icelandic factors which lend themselves to achieving this difficult goal, and other countries may be to learn from the pioneering experiences taking place there now.

➊ **Iceland has abundant geothermal and hydroelectric energy sources.**

Some of the factors which contribute to the relative ease which hydrogen may be produced in Iceland are obvious – the experience of switching and promoting renewable energy in previous decades, the rich supply of geothermal sources to provide relatively inexpensive electricity for hydrogen production and the scale of the country all support the transition towards a new fuel. But there are other factors which have also helped significantly. The speed of which a few project champions have put the bus trials into place is impressive along with the unwavering commitment from a highly joined-up cross-departmental agreement. The general public has also been very much involved with successive surveys on the hydrogen buses showing good support for the use of hydrogen powered vehicles. Part of this process of raising the public profile has been the historical process of embedding the idea of a 'hydrogen island' into many of the scientists, technologists and graduates in Iceland by having hydrogen technology as part of the curriculum. This came about due mostly to those academic visionaries who put hydrogen and geothermal energy issues into many of the courses to ensure that students were well briefed and understood the complicated issues at hand. It is clear that this long process has indeed helped smooth the transition start-up phase and has also brought together various experts from industry, academia and government to share their perspectives whilst all working towards a carbon fuel based reduction strategy. There is noticeable acknowledgement that dwindling oil supplies, or even the perception of interruptions this supply, has brought forward the need to be even more self-sufficient for energy and hydrogen is seen as one of the only fuel carriers that fulfils that need within Iceland.

Hydrogen Vehicles or Hydrogen Stations – which comes first?

What should come first: the fuelling infrastructure and associated stations, or the fuel cell equipped vehicles? It is an extremely complex and messy problem with no easy or straightforward answers. At the moment no one really knows what method of hydrogen production will be the most advantageous in terms of technologies, environmental impacts or economics. Many might assume that since this fantastic fuel of the future has virtually no polluting emissions at the vehicle tailpipe that perhaps fuel costs will be lower than current fossil fuels. Early indications show that these fuels might be cost equivalent or even slightly more expensive due to the high cost of compressing and transporting the fuel…which leads us back to which production pathway is most appropriate for the fuel. In some cases making the fuel may end up being more environmentally costly if we are not careful in how the fuel is produced and distributed. The technical and economic barriers which would need to be overcome to replace the majority of say the UK's filling stations and vehicle fleet represent a seemingly enormous obstacle. Yet Iceland in some small way offers some interesting and useful lessons for transport planners, engineers and policy shapers with respect to implementing the hydrogen based economy.

One of the most important key aspects seems to be the high connectivity of all the parties involved within the transition. In terms of government departments there is a clear desire for joined-up thinking which is mirrored in the academic-industrial collaborative efforts. Within these two aligned groups, a consensus has emerged that in their case the only real solution currently seems to be hydrogen. Even though in the long term the infrastructure might be very different to that proposed today for pilot scale projects, it is evident that high rewards or expertise and experience are worth contributing to now. Remarkably when one considers the long term to be some 30-50 years from today, or even up to 100 years according to others, the it is clear that drivers of security of supply, potential shortfall and/or decline of petroleum, reduction of greenhouse gases, energy independence and potentially better economies might all work together to push forward the hydrogen transition. Iceland, and Reykjavik in particular, are focussing on the ecological motivation to become the world's most sustainable capital. This along with a drive for self-sufficiency and a high degree of innovation seem to be the most critical factors for creating a test-bed type atmosphere.

❷ In the long term the infrastructure might be very different to that proposed for the pilot scale projects.

The framework and conditions in Reykjavik means that results from the bus pilot project, called ECTOS - *Ecological City Transport System*, should inform others about the technological targets that are most important. These should translate into incremental improvements in the future rebuilds of the buses, and lessons about how the buses and refilling stations should be utilised for highest efficiencies. For example, it is clear that for these highly expensive buses that the production cost will be critical when the scales of economy are relatively small. So every saving that can be made in both body weight and fuel gain will be essential, whilst ensuring that the vehicle safety is not compromised. From a practical point of view fleet operators will demand ultra-clean vehicles which operate at the same cost as current vehicles if not more cheaply, so these are strenuous targets. The project has shown clearly that small pilots can have relatively large impacts by the ensuring large public exposure. With only three buses and one station a huge percentage of the population has already been exposed and educated about hydrogen. By the construction of another only another 10 stations, that perhaps up to 90% of the population would have access to hydrogen. With new fuel technologies it is critical that the public is properly consulted as a critical stakeholder, and ultimately the majority user, throughout the entire process; to this end much work has been carried out on the social and economic implications for all the citizens. It is hoped that this work may also shed light on how hydrogen transitions in other countries might be facilitated. The level of goodwill towards the project has been noted by many and it seems a very good sign.

The long term vision using a three step process with each step moving towards a more hydrogen embedded society is viewed with the pilot project being the first step. Eventually it is hoped that the gradual introduction of fuel cells and hydrogen would then progress into the entire bus fleet of the country. The second step would then address a transition for the passenger car vehicles and the third step would tackle the perhaps more challenging fishing vessels. Marine vessels are particularly difficult as space on board is at a very high premium, similar to lorries and buses, but more so, and thus space for fuel storage in place of the daily catch is another trade-off. The sea environment can also be characterised as equally as harsh as the road but with increased water, salt and airborne erosion.

Iceland's Statistics at a glance, 2003

Population 290,570 and density 2.8 people/km^2

Total Area 103,000 km^2

GDP $36,519 /person

Cars 162,000

Motorcycles 2,560

636 vehicles / 1000 people

Vans and Lorries 20,300

Buses 1,700

Marine Vessels 1,135 (77% used for fishing)

Petrol Stations 225 (estimate)

Road network 13,004 km (approx. 1/3rd is paved)

Could Hydrogen solve some of the UK's transport problems?

Although there are still many unknowns with respect to which certain key ingredients are needed entering the hydrogen age the ambitious Icelandic vision is to achieve all this within the next five decades. For the UK those working in transport need to be aware of the developments, yet at the same time perhaps wary, because in many cases our hindsight has shown that the future usually doesn't turn out to be as we initially predicted. The barriers are immense but not insurmountable: which production pathways are best for which region are not yet known or established, fuel cells are still too expensive and don't yet add value for consumers, infrastructure investment, maintenance and replacement and then there is getting the cost right. In the case of Iceland this cost has been previously estimated to be some five billion euros for complete conversion, but this should also be seen in light of the increased earnings that will be present when the system succeeds.

Certainly a different set of ingredients will most likely be needed here due to different energy sources, different transport needs and densities. If one overlays the current concerns, such as congestion, charging for road use and air space, along with vital land use issues then the implementation of hydrogen may seem even further off still. Yet this is no reason for the UK to not engage on an even more practical and larger basis with hydrogen demonstrators beyond the three CUTE buses in London. The Olympics and associated geographical area may be a perfect opportunity for the country to fast-track that area of London and the south east into the hydrogen niche. We need not get caught in the chicken-end-egg trap by ensuring that both vehicles and stations come on-stream simultaneously. The lessons that could be learned from such a programme could be invaluable.

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All three hydrogen powered buses, funded under the EU CUTE framework, have met their main objectives. The bus livery is in both English (left hand side of vehicle) and also in the Icelandic language (right hand side, and boarding side) helping to raise awareness among the public. The battery is being charged in this unit during the off-period.

Further Reading

Hydrogen: the energy source for the 21st century, Technovation 25 (2005) pp 569-585, by B Johnston, MC Mayo, A Khare.

Implementing the hydrogen economy, Journal of Cleaner Production 14 (2006) pp 52-64, by MH Maack, JB Skulason.

Icelandic New Energy Limited's website which describes the hydrogen projects they are working on http://www.newenergy.is/newenergy/en/

Hydrogen cars?..., The Guardian, by M Peters.
http://observer.guardian.co.uk/carbontrust/story/0,,1511916,00.html

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