Hydrogen - reality in Iceland

International collaboration is facilitating the launch of full-scale demonstration projects using electrolytic hydrogen as an energy carrier.

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Introduction

While several types of alternative fuels that contain carbon, such as methanol, ethanol or compressed natural gas might fit situations elsewhere, the Icelandic society is in a unique situation to head directly for using pure hydrogen as transportation fuel (see fig 1.) Due to the country's volcanic origin, Iceland is deprived of all carbon sources, while renewable energy such as geothermal- and hydropower, are abundant. In Iceland it therefore seems logical to use these non-fossil energy sources for the production of a domestic renewable energy carrier: hydrogen. A logical use of waste-biomass in the country is to facilitate the formation of soil in areas that suffer from severe erosion.

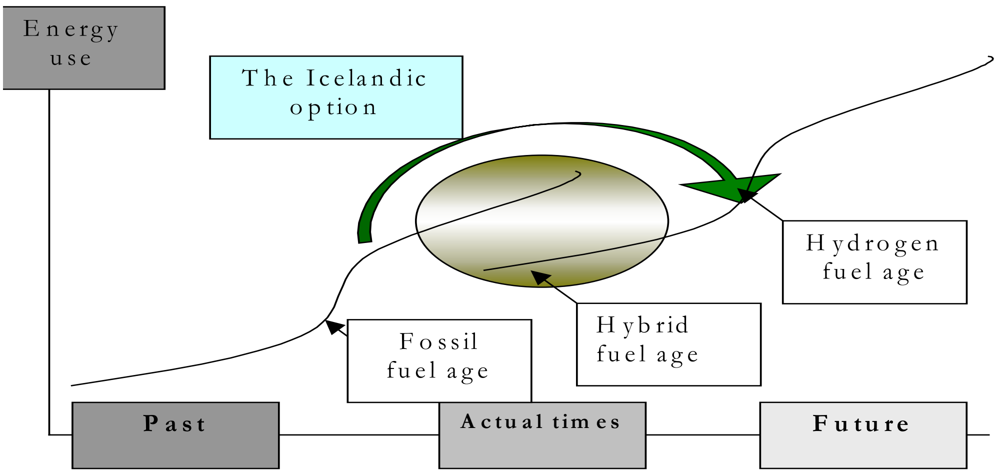

Fig 1: Possible future scenarios: Using renewable energy sources to produce hydrogen by electrolysis could bring Iceland faster into the hydrogen age than most other societies.

The political initiative

The policy of the Icelandic government is to make better use of the domestic renewable energy sources (Policy statement 1999). As a result, investment in energy intensive industry utilising electricity generated by large hydropower-plants, accompanied by highland dams, has been

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[1] Icelandic NewEnergy, INE, was formed in 1999 by Icelandic energy companies, The Icelandic New Business venture Fund, Norsk Hydro Electrolysers AS, Shell Hydrogen and Daimler Chrysler.

promoted during recent decades. However, this approach is being met with growing resistance from environmentally concerned citizens.

Changing scenes

Already 70% of the primary energy sources in use in Iceland are renewable. The main source of electricity is hydropower. Geothermal sources are mainly used for district heating but also for generating electricity. Gaseous fuels have not been used as household energy in Iceland except in a very small measure for summerhouses and highland cabins. All kitchen facilities are run on hydroelectricity and 90% of heating and tap water is provided from geothermal district heating and hot local wells. Cogeneration or cascading has a special meaning in Iceland: generation of electricity from geothermal steam and thereafter the use of hot water in drying or similar industry, then district heating, defrosting and perhaps spin offs like the tourism attraction (www.bluelagoon.is).

Only 30% of the energy consumption is based on fossil fuels (1999, Statistics Iceland, www.statice.is). These imported fuels are mainly used to run the transport system and the fiscally important fishing fleet. The available exploitable hydropower and geothermal sources are estimated by the energy authorities to be approximately 30 and 20 TWh respectively. Of this, approximately 9TWh have been harnessed already and demand for the energy sources is growing.

If transportation and the fishing fleet could be run on domestic energy sources as well, with hydrogen as the energy carrier, Iceland would be in a position to strengthen its economic independence from the fossil market and cut its global warming emissions significantly. The first needed steps are to carry out a range of demonstration projects in the field in order to gather evidence on the feasibility of 'hydrogenising' the entire economy. If these experiments become successful they may establish i.e. hands-on experience about technical performance, a basis for socio, economic and environmental analysis of the fuel shift, grounds for estimating the cost of changing the infrastructure and distribution system as well as goodwill in the community for the continuation. Only from these forerunner projects can the future prospects be defined. The coordinator, Icelandic New Energy (INE), is putting ideas that have been promoted since 1970s by Bragi Arnason, professor of chemistry at the University of Iceland, to the real test. INEs mission is: *'to investigate the potential for eventually replacing the use of fossil fuels in Iceland with hydrogen based fuels and create the worlds first hydrogen economy'.*

Projects that have been planned by INE for the next decade are: An experiment with hydrogen-buses within the public transport system (www.ectos.is), building and operating a production-, compression- and storage site for hydrogen; building a fishing vessel that runs on hydrogen fuel cells and exchanging batteries and diesel generators for small fuel cells where feasible. The projects will be described shortly in the following sections and then the focus shifted towards the social aspects of these experiments. But first, an introduction to the scale of the entire fuel conversion.

Amount of energy needed for the hydrogen transition

In 2000 the Icelandic National Energy Authority published a forecast on the need for energy in the next thirty years (Energy forecast 2001-2030,OS-2001/040, www.os.is). The figures from the forecast can be used to compare some aspects of two energy systems: One based on current combustion engines and fossil fuels, where a large portion of the energy content of the fuel is lost as heat and emissions contain carbon dioxide, as well as SO_x and NO_x, especially from the vessel fuels. The other option is a system based on hydrogen produced by electrolysis from renewable electricity sources and converted in fuel cells to electricity. There are next to zero CO_2, NO_x and

SO_x emissions from the fuel cell based system so the carbon emissions in the would be practically eliminated.

The figures shown in table 1 are a rough conversion, based on hypotheses and the current hydrogen, gasoline, and diesel technology. These will probably both be fine-tuned for higher efficiency in the near future. However, they can be interpreted as an indication of the differences of efficiency and the scale that has to be accounted for in Iceland for further plans[2]. The scale of the proposed system is quite modest. The reason for this, of course, is that the Icelandic population is only 286,000 as of the year 2000.

Table 1. A comparison of systems running on fossil fuel and hydrogen as an energy carrier

	Type of fuel	'000s tons	CO2 emission (tons)	Energy content PJ	Energy[3] effectively used PJ	Hydro-gen[4] (tons)	Electricity need for the H_2 pro-duction [GWh]	Energy for com-pression to 400 bar [GWh]	Tot elect-ricity req. [GWh]	Quan-tity of power needed [5] [MW]
Land- transport	Gasoline	142599	437779	6.12	1.28	9056	1090	172	1262	158
	Diesel	47463	150932	2.01	0.42	2972	358	56	414	52
Sea-transport	Diesel	232008	737785	9.81	2.94	20754	2499	394	2893	362
	Crude oil	17246	53118	0.71	0.21	1506	181	29	210	26
	Total	439316	1379614	18.65	4.86	34288	4128	651	4779	597

First steps, the Ecological City Transport System (ECTOS)

The first large hydrogen demonstration project in Iceland, ECTOS was announced 1st March 2001. Three fuel cell buses will be run within the public transport system from the summer of 2003 for two years. This means that 4% of the city's public bus fleet will be run on hydrogen during two years of operation. The partners for the project are INE and its foreign shareholders, Icelandic Technical Institution, Shell Iceland, University of Iceland, Reykjavik's city public transportation company (Straeto), Swedish agency for innovation (VINNOVA) and Evo Bus.

The goal by the ECTOS is to test the performance of a completely new technology in difficult seasonal conditions, yet where hydrogen is produced from renewable, nearly CO_2-free energy where the system tangible, yet contains all social establishments that make the demonstration

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[2] Prerequisites: Electricity needed to produce hydrogen by electrolyses: 51,11 kWh/kg
[3] The calculated amounts take into account the efficiency of the compared technologies; 10 – 21% of the energy is put to work using various types of combustion engines. Efficiency for fuel cells is set at 42,5% for this comparison
[4] This is the amount of hydrogen that contains the same energy as in the proceeding column
[5] The running time for power plants is set at 8000 hours per year

useful as an example that can be extrapolated to a larger unit. Not only will fuel cells be put to trial, but electrolysers, pressure compartments, hydrogen containers, new prototypes of buses and safety equipment such as hydrogen detectors. An important part of ECTOS are also environmental and socio economic assessments, and the formation of a methodology that should give grounds for comparison from elsewhere.

Infrastructure

The building of the first filling and compression station will begin during in 2002. The site will resemble an ordinary service station selling gasoline, diesel and other goods and services. The hydrogen will be produced, compressed, and stored on site in gas-bottles at a pressure of up to 440 bars and provide hydrogen for all the equipment, which will be used in the near future. The choice of site has been an important strategic action, as it will become attraction for media and interested groups, but must be easily accessible for buses in service, as well as being a test for security measures. The partner Shell Iceland has proposed not to keep the equipment in a container but a glass cabin, so that it might be seen but not touched. The cabin will host a 60 Nm3/h electrolyser delivering hydrogen at 15 bar(g) pressure, a compressor station with a capacity of 110-170 Nm3/h and a discharge pressure of 344 bar(g) and 1 storage module of 3 torpedo cylinders with a total volume 2860 l.

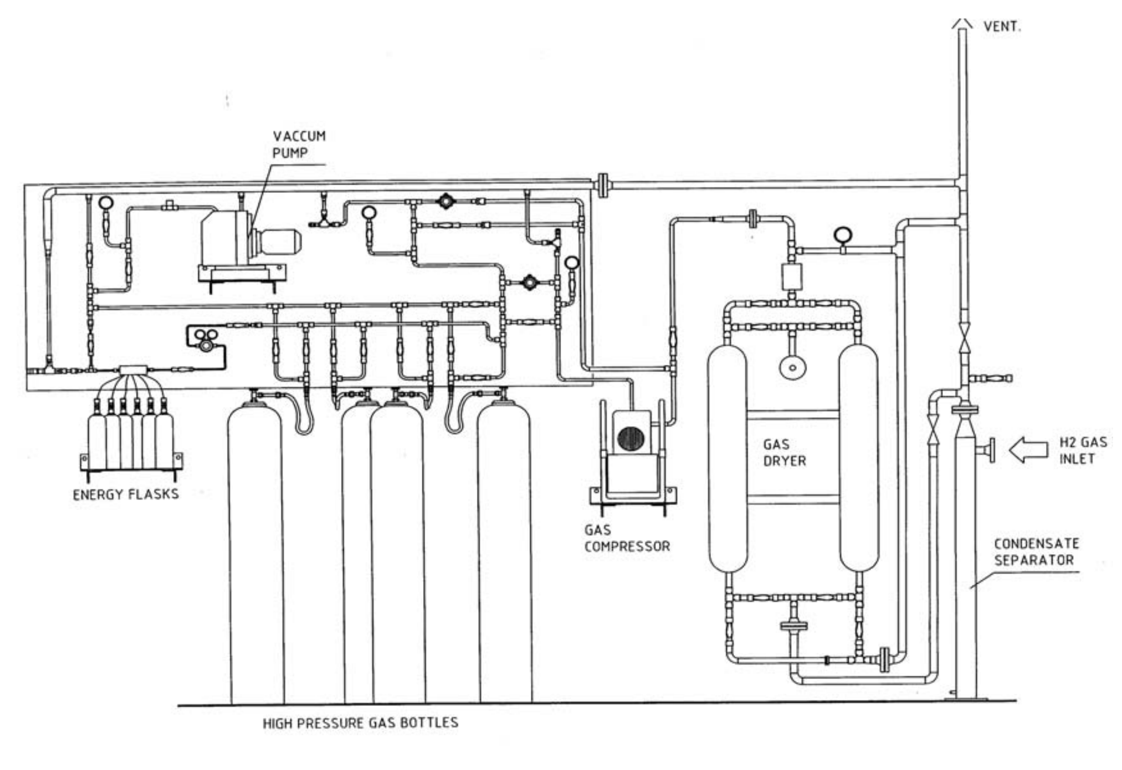

Fig 2. The compression compartment shows that H_2 compression proceeds in several steps.

Water will be provided through pipelines to the station, which is also connected to the local electricity grid. The current is generated by hydropower and to a less extent by geothermal power for example from Nesjavellir, a newly established power plant owned by Reykjavik Energy (www.or.is). The electrolysers will be of a HCU type (a bipolar filter press electrolyser) from Norsk hydro electrolysers.

The gas handling will also be a learning process. The buses' gas bottles will be filled without removal from the vehicles thus minimising all transportation of hydrogen and extra handling.

Gas containers will be kept on the roof and stored under 350bar pressure. The gas containers will be filled up daily to cover a range of 200 – 300 kilometres' schedule.
The buses will be maintained not by the bus company but subcontracted to Daimler- Chrysler's retailer in Reykjavik, hopefully offering school groups from vocational schools and mechanical work shops to learn about the new technologies. The garage will have to be H_2 safe, equiped by H_2 dectors and have spark free door openings to name two special features for the facility.
During the ECTOS, procedures recommended by the German TÜV agency for safety permits and regulations will be applied for the handling of the hydrogen, but neither Icelandic regulations nor a directory on Hydrogen from the EU has been issued.

Steps proposed for the continuation

Icelandic NewEnergy and Shell Iceland are already implementing a market assessment in cooperation with a fuel cell producer in California (DCHT). They are examining the possibility of replacing batteries and diesel generators with small fuel cells. One test is a portable fuel cell, run on hydrogen that is stored in small energy flasks (metal hydrides) about the size of a soda can, producing a current that can be connected to various electric appliances. The combined portable fuel cell and energy flasks are convenient for safety equipment for example light or heating, to reload mobile phones, or for equipment for research purposes.

The construction of a new fishing vessel that runs on hydrogen fuel is in the commencement phase. The buoyancy and design of a vessel will depend on the storage methods for the fuel, especially if it is to be equipped for long journeys. Therefore a new H_2 vessel is considered an easier approach instead of reforming an old one. The storage form of the hydrogen fuel for this project are currently under examination: Liquid hydrogen, which demands high input of energy for extreme cooling and compression, gas hydrogen under high pressure, even methanol.

Other interesting aspects of hydrogen research and demonstration include a detailed inspection of hydrogen emitted from geothermal vents and studies of the feasibility for Iceland to export hydrogen.

Social aspects

Icelandic New Energy intends to use the outcomes of the ECTOS project to form a basis for further attempts for the 'hydrogenisation' of the Icelandic economy. The socio economic and environmental studies within the ECTOS focus on such issues as: public expectations and acceptance, general knowledge, service performance, drivers and barriers for further applications, environmental monitoring of air pollution, noise etc. A 'well to wheel' inventory for the hydrogen technology used in the experiment will be compared with data available for two other modern types of fuel systems and technology used for similar functions. As there are other projects run parallel or connected with the ECTOS, the approach had to be a strategically modified to fit many situations and adaptable to complex transport or energy systems. A framework is being formed which makes later comparison simpler and useful to simulate how larger units or (i.e. public transport networks in larger cities) would function either using similar or different fuel arrangements. The frame would have to be applicable for example for comparison of hydrogen produced from natural gas using any combination of electricity production from grids in general or with city diesel as a fuel.

As such, ECTOS is implemented in cooperation with a trans European project: the CUTE (Clean Urban Transport in Europe), which is a similar bus project carried out in 9 cities within the EU but where only the technical performance will be in focus. Therefore the social approach of ECTOS will be kept as transparent as possible and not be expressed in numerical indicators unless their significance is evident. The methodology is based on experience and research within

Swedish research institutes for the transport sector and accumulated by VINNOVA. Public surveys will be used to follow some of the social impacts of the ECTOS and environmental data will both be collected and calculated from well-established sources.

Traffic and transport involves many stakeholders and introducing new ideas into a well-established transportation and fuel system is bound raise friction, but generally the introduction of hydrogen is both met with scepticism and curiosity. High interest and positive attitudes are mostly shown by those who are in the environmental, research and investment sectors, as well as the media, - not the least by international media. Public questions are most often raised regarding costs and security, two prime parameters closely linked with the public acceptance.

Considerations on fuel prices

The cost of hydrogen will evidently play a large role in the speed of adoption and acceptance of a new fuel system. But at this moment it is hard to estimate what will be the price for future hydrogen. Water is abundant in Iceland but the prices for electricity for the electrolysis has to be negotiated. The energy market is undergoing deregulation and therefore various deals might be cut. It will be very much up to governments who regulate tax and charges for transport systems and what will become the price of fuels. A policy on charges for carbon emissions or subsidies for clean fuels has not emerged, but INE is in a unique position to remind of the need for governmental decisions. The question society has to answer is whether the pump price of gasoline really reflects the true costs of that fuel taking into account what impacts global warming might have on the economy? After establishing that, it can be determined if hydrogen is a too expensive fuel!

Some still state that methanol will inevitably be the intermediate fuel for vehicles, and further attempts with hydrogen should be postponed until it becomes economically compatible with methanol. A source of carbon in Iceland might be the CO and CO_2 emitted from smelters. By hydrogenising these gases methanol can be formed (Arnason, B.& Thorsteinn I. Sigfusson, 1999) But most authors claim that hydrogen is likely to become the ultimate energy carrier, and for the reformation to methanol hydrogen must be produced anyway. Carrying out real scale tests already on hydrogen in the given conditions, gives valuable answers in spite of high costs. It is inevitable that the change of infrastructure will be expensive, a double infrastructure, taking an intermediate methanol era even more so.

Benefits from hydrogen transport are expected to become less particle emissions (the asphalt and tires still give rise to some), less noise and a more joyful ride due to cleaner consciousness of the passengers who know about its low emissions. The city of Reykjavik and Straeto, the bus company, intend to make use of the experiments to promote public transport in general.

Education and information

The ECTOS will be followed up with public information and education targeted to the municipality, the bus company, passengers, operators, maintenance staff, local schools, the government and public media (example shown in fig2). Local newspapers, schools, the buses themselves and public surveys will be used as well as documentaries hosted by film makers and foreign news agents. The form of information will be websites (ectos.is, ny-orka.is, vetni.is, newenergy.is), newspaper articles written by specialists in various fields, a booklet for schools, CD ROM disc and presentations to name a few.

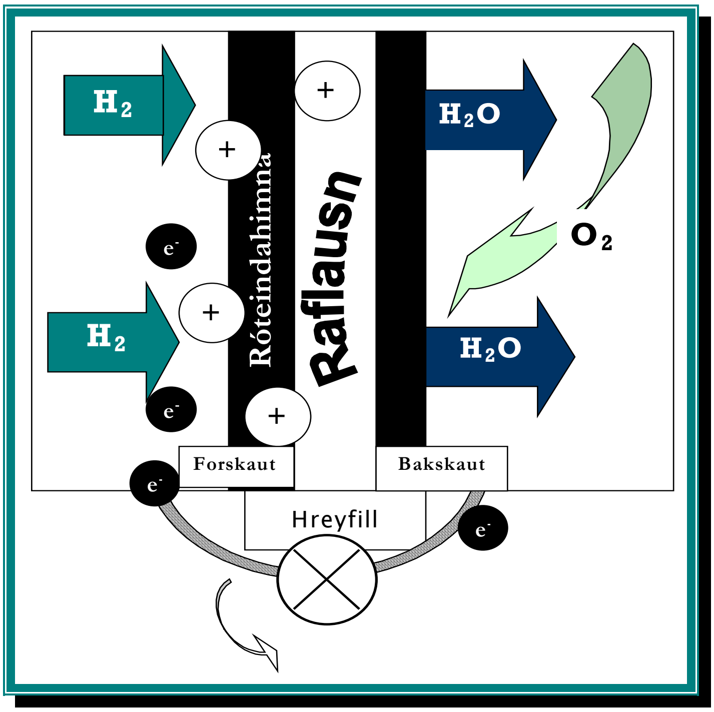

fig 2. A simple overview of the functions of a fuel cell. The terms are kept here in Icelandic as an example of the tradition of making new Icelandic words to facilitate communication in the native language, even on the very latest technology. The meaning of words is: róteindahimna: proton exchange membrane, raflausn: electrolyte, forskaut: anode, bakskaut: cathode, hreyfill: motor

By-products and added values

The organisation and start up for the projects has proven to be as dependent on the goodwill of society as it is upon the technology that will be put to test. The idea of hydrogen-based economy has not reached the general discussion but the interest is slowly growing. Added values are also emerging from the hydrogen projects.

The economies of scale do not regarding the size of the production units does not effect so much the cost of hydrogen. Therefore electrolyses can be carried out in scattered places closest to its usage, also by decentralised micro-hydropower plants or other renewable resources such as wind or waves. A new service system has to be established and therefore new jobs might be created in rural areas. Electrolysis can be shut down in times of high energy-demand, and produced e.g. during the night. Being independent from the oscillations and risks connected to the world oil market is also important, as long as the fishing fleet remains the prime earner of national export income. The fuel cell based technology to be used in the project is also quieter and cleaner than the current transportation technology therefore there is much to be gained as long as the monetary costs will not override the benefits.

An added bonus to the projects, is the knowledge and expertise that builds up in a field, which is in high demand. By drawing upon the best international technology available and mixing it with world-leading Icelandic expertise in geothermal research and technology, the accumulated knowledge becomes a marketable product in itself. International interest for the projects adds directly to other efforts in marketing the country for tourism and investors. At least some of the knowledge can give opportunities to extend assistance to developing economies that need help with cleaner energy technologies.

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