Hydrogen as transport fuel in Iceland. The political, technological and commercial story of ECTOS

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Abstract: Through the political, the technological and the commercial story of the early phases of the ECTOS project and its background, the implementation of hydrogen as transport fuel in Iceland is analysed. The presence of large amounts of geothermal energy is the resource basis for the governmental plans for converting Iceland into a hydrogen economy. Strong political commitment has established the framework for this transition. The goal of replacing the import of fossil fuels by 2030–2040 has provided motivation and support for hydrogen R&D projects. The early public scepticism turned into general support when large multinational companies entered the scene.

Keywords: hydrogen; alternative transport fuels; renewable energy implementation; barriers; socio-technical issues.

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1 Introduction

For some years now Western Norway Research Institute has conducted research into the conditions for implementation of hydrogen-based energy systems for use in transport applications. This research falls within the larger scope of implementing systems for alternative transport fuels. The approach taken in this research is to gain knowledge from previous and on-going demonstration projects. The focus is on socio-technical issues connected to the implementation processes and projects. In the current article we have

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selected for presentation the ECTOS hydrogen implementation and demonstration project in Iceland.

The project ECTOS is supported financially by the European Commission. It covers demonstration, evaluation and research of a system for transportation in Reykjavik, based on the use of hydrogen fuel cell buses. The project started up in 2001 will run until the end of 2005. A hydrogen filling station opened in April 2003. The first two hydrogen buses started running in October 2003, while all three buses were in operation by the end of November 2003. In March of 2004 the author conducted interviews with central actors connected to the ECTOS project. This article thus presents the first and middle phases of the project, but not the conclusive phase.

2 The political story of ECTOS

For understanding the political conditions for implementation of hydrogen energy in Iceland it is important to take a look at this country's development of energy utilisation. The Icelandic Ministry of Industry and Commerce divides this into five distinct phases (Pétursson and Bjarnarson, 2004):

- First phase – until the 1970s
  - Electrification of the country was the main task (mainly by hydroelectric power)
  - Harnessing most of the accessible geothermal fields
- Second phase – after 1965
  - Development of power intensive industry
- Third phase – after 1973/1974
  - Replacement of fossil oil by renewable energy resources (hydro and geothermal), especially for space heating
- Fourth phase – after 1995
  - Further increase in power intensive industry
- Fifth phase – after 2000
  - Work towards a sustainable hydrogen economy.

The fifth phase implied that policies were developed and directed more towards renewables energies, with hydrogen energy as one central element.

These policies have resulted in that Iceland today has the highest use of renewable total primary energy use in the world (72%). The remaining energy must be imported in the form of fossil oil, of which about half supplies the fishing fleet and the other half the road-based transport (mainly private cars). Electricity production in Iceland is today all carbon-free, while fossil fuels also have been eliminated from space heating, and been substituted by geothermal energy.

However, the energy consumption per capita in Iceland is close to the highest in the world. This is partly owing to cold climate, but more significantly to the strong increase in power intensive industry in the country the last 35 years. Iceland now has the highest installed aluminium production capacity per capita in the world, over 900 kg per capita. This energy intensive industry is however powered by electricity from renewable sources only.

The potential for further electricity production from the two sources hydro- and geothermal power is large in Iceland. Today only 23% of the total hydro power production capacity is utilised. This figure is based on utilisation of only what is considered today as economically feasible and environmentally benign. The corresponding figure for geothermal energy is as low as 7%.

2.1 The historical steps

The historical steps leading up to the Icelandic hydrogen policy can be traced back about 25 years connected to the research conducted at University of Iceland by professor Bragi Arnarson. One important step was a 1990 meeting between University of Iceland and various German companies and institutions including Hamburgische Electricitäts-Werke AG (HEW). This was a result of the many years of research on hydrogen energy in Iceland, which other countries now were beginning to be aware of.

In 1997 the Ministry of Industry and Commerce appointed a committee on 'Domestic fuel production', led by Hjalmar Arnason, member of the Icelandic parliament. A policy on hydrogen that gave clear political commitment to development of hydrogen energy was made. This is shown in the introductory statement signed in 1998 by the Prime Minister and the Minister of Industry as well as the Minister for the Environment:

> "Iceland is endowed with vast resources of renewable energy, both hydro and geothermal, in comparison to its small population. These resources are of great importance to Iceland's society and its economy. Power in the country is supplied by these resources and efforts have been made to increase their share in the energy mix, with the result that they have almost completely replaced oil for space heating and in industries and other fields where it is feasible and economically viable. The effectiveness of this energy policy is amply demonstrated by the fact that renewable energy sources account for about 67% of the primary energy consumption in Iceland – a higher share than in any other country.
>
> Future development of the domestic energy resources is on the Icelandic Governments agenda. The aim is to harness these in order to diversify the economy and lay the foundation for higher living standards and prosperity in future. One of the possibilities under consideration is in the production of alternative fuels such as hydrogen. That could replace oil in the transportation sector, i.e., for cars, airplanes and fishing and transport vessels. In addition to diversifying the economy, such use would contribute significantly to reducing the emission of greenhouse gases.
>
> The Ministry of Industry, on behalf of the Government, has appointed a committee to explore the possibilities of replacing oil by alternative fuels and if viable, to promote the use of such fuels in the country. The committee is also to facilitate cooperation among the interested parties of the purpose. The committee is chaired by Mr. Hjalmar Arnason, a member of the legislative assembly. The committee enjoys general support from Government and the Ministries." (Pétursson and Bjarnarson, 2004)

1998 was also the year when negotiations began between Icelandic representatives and large industrial companies Incl. Daimler Chrysler, Norsk Hydro and Shell. The Icelandic ambassador Ingimundur Sigfusson had an important role in these negotiations. The negotiations also included the European Commission, which were approached regarding support for what would eventually be the ECTOS project. These negotiations resulted in governmental support for the forming of the company Icelandic New Energy (INZ),[1] which was to head the ECTOS project. The support was a result of the Government's policy which stated that:

> "It is the Government's policy to promote the increased utilisation of renewable energy resources in harmony with the environment. One possible approach towards this goal is *production of environmentally friendly fuels for powering vehicles and fishing vessels. Hydrogen is an example of such a fuel. The establishment of a company owned by Icelandic parties and several international corporate leaders in the field of hydrogen fuel technology could open up new opportunities in this field.* The Government of Iceland welcomes the establishment of this company by these parties and considers that the choice of location for this project is an acknowledgement of Iceland's distinctive status and long-term potential. The initiative taken by the parties involved in this project deserves to be applauded and respected." (Pétursson and Bjarnarson, 2004)

It is worth mentioning that the long-term political hydrogen commitment of transforming Iceland into a hydrogen economy by 2030–2040, eliminating the need for import of fossil fuels, was one of the reasons why Iceland became one of the founding members of the International Partnership for the Hydrogen Economy (IPHE), established in August 2003. Iceland was actually one of the two countries (together with Germany) invited to share the important chairmanship of the implementation liaison committee of IPHE. Thorsteinn Sigfusson is the current co-chair from Iceland.

2.2 Barriers

Marketing the idea of hydrogen implementation in transport in Iceland constituted a barrier in the early phases of the project. Sceptical voices prevailed among public and authorities while there was a lack of long-term commitment. An attitude common among many politicians at the time was:

> "Well I am only elected for four years; I am not interested in what can be bone after 30 years."

However, when large companies like Norsk Hydro, Daimler Chrysler and Shell came to Iceland and expressed interest in doing business there, the voices shifted to:

> "With these big companies here in Iceland, they must mean something real. They are not coming here just to drink coffee and chat."

3 The technological story of ECTOS

3.1 How did it all start?

The technological story of ECTOS is closely connected to the research strategy of University of Iceland, and the work performed by Bragi Arnarson and Thorsteinn

Sigfusson at this institution. After finishing his chemistry studies in Germany in 1961 Bragi Arnarson came to University of Iceland and for the next 15 years he studied groundwater systems, especially geothermal systems in Iceland. This work led to a good picture of the size of the geothermal energy sources in the country. Based on this research it became apparent that geothermal is an energy source with very large untapped potential. At that time, in the 1970s, Iceland was importing 40% of its consumed energy in the form of fossil fuels. The newly gained knowledge of the large geothermal energy sources sparked the interest in exploring the possibilities of producing domestic fuels to replace the imported fossil fuels. Various possibilities were considered: synthetic gasoline, methanol, even ammonia. Ammonia had been used as a fuel for natural gas engines, with some limited success. Hydrogen was however the possibility that attracted most attention, and after the relatively rapid improvements in the fuel cell technologies in the early 1990s, the strategy for University of Iceland has been to focus its research on this fuel.

The technological competence and energy resource situation on Iceland had become known internationally, and 1997 was an important milestone for the country's strategic work on hydrogen. In this year the company DiamlerBenz-Ballard, now DiamlerChrysler contacted the Icelandic ambassador in Germany and asked him if the hydrogen researchers at University of Iceland would like to come and meet with the industrial company. The reason for this invitation was that the company wanted to get information about the opinion of the politicians and the government in Iceland about the country's hydrogen plans. The Icelandic ambassador and Bragi Arnarson met with the company in Stuttgart and presented the plans to convert Iceland into a hydrogen economy in five phases (Árnarson et al., 2001; Árnarson, 2003).[2] The response from the head of the fuel cell project in DiamlerChrysler was: "Well I think we should not discuss more today, we should start to find some basis for cooperation, because you are already producing the fuel". University of Iceland had been producing hydrogen on lab scale for 50 years. DiamlerChrysler had the prototypes and wanted to have them tested. This is how the negotiations started. During the negotiations Royal Dutch Shell and Norsk Hydro wanted to join and the negotiations led to the forming of INE, which is a University spin-off corporation, created to promote the transformation to a hydrogen economy in Iceland.

Another Icelandic technological institution that is closely connected to ECTOS is the Technical Institute of Iceland (IceTec). IceTec is one of the founder members of VistOrka, which is an organisation of all the key Icelandic stakeholders, working together in one single unit. IceTec is involved in the social economic environmental studies of ECTOS, with tasks connected to the environment aspects through LCA studies (Well-to-Wheel) and evaluation of air quality (Skúladóttir and Þórdarson, 2003). IceTec have experienced fruitful project spin-off effects in the form of air quality measurements and air pollution characterisation in Reykjavik, as well as collaboration with University of Stuttgart and VINNOVA in Gothenburg, Sweden. A spin off study was also conducted in collaboration with NILU in Norway on the sources for particle pollution, because IceTec started to wonder what would happen with the air pollution in Reykjavik if diesel is to be replaced with hydrogen.

The fact that ECTOS in many ways serves as a model (and a forerunner) for the CUTE[3] project has resulted in some problems worth mentioning for IceTec. Some studies, which were not originally planned for ECTOS, originated from the work in the CUTE project. For some of the work packages in the CUTE project it became important to include the results from ECTOS. Agreements were therefore made about collecting extra information and data from ECTOS, which were to be used in CUTE because IceTec was doing some of these previously. Getting this extra information has turned out to be more difficult than originally anticipated when these agreements were made. The fact that some of the information required was not easily available at the sources and that some of the information did not exist at all took IceTech by surprise. This caused extra work and costs for IceTec.

3.2 Problems encountered during the first phase of the ECTOS project

When the hydrogen filling station was opened, there was a delay of about nine months in the delivery of the buses. So from April to October 2003 the only hydrogen vehicle which was used was a Mercedes-Benz Transporter, which was borrowed from DiamlerChrysler, mainly for the opening ceremony of the filling station. When the first two buses finally arrived, it turned out that there were problems with the compatibility between the buses and the hydrogen fuel dispenser at the filling station. The coordination of bus specifications and dispenser pump specifications for hydrogen gas pressure apparently had not been good enough, making it impossible to fill the buses properly. The pumps had to be rebuilt, and this caused a delay of about two months in the project.

The maintenance facility for the hydrogen buses proved to also be a main challenge. Finding a suitable location, people for training etc., was a hurdle that had to be overcome. The maintenance is quite labour intensive. One person from DaimlerChrysler works continuously with the maintenance of the three buses. In addition, one person from Ballard comes and inspects the fuel cell stack on regular intervals.

Important knowledge has been gathered from operating the hydrogen buses in Reykjavik, particularly connected to the sensitivity of the electronics components in these buses. It has been the experience that the electronics system components are quite sensitive to salt, which is commonly present in the spray and mist coming with the northern winds from the ocean into the streets of Reykjavik. This is thought to be one of the factors contributing to the frequent breakdowns of the hydrogen buses.

Another issue is that during the first winter of driving with the hydrogen buses, the slippery roads of Reykjavik made it necessary to equip the buses with winter tires. This was no easy task, as it was not possible to apply the winter tires of the diesel buses normally used on the routes. The hydrogen buses are much heavier than normal buses and therefore require special winter tires. Suitable tires were not found in Iceland. The tires had to be imported, causing the hydrogen buses to be taken out of their routes for a period of two weeks.

Insurance of hydrogen buses proved to be another serious barrier encountered during the project. The reason being that the buses are prototypes and in addition very expensive. The insurance companies were therefore not much willing to insure these vehicles.

3.3 Technology development today

The ECTOS project is perhaps the most well known hydrogen project in Iceland. But the project is connected to a wider strategy for technological development in hydrogen energy conducted by University of Iceland. The hydrogen research at this institution has in the most recent years been focussing on utilising geothermal steam for more economical production of hydrogen. One area that is being looked into is the *harnessing* *of direct molecular hydrogen* in geothermal steam. A significant amount of hydrogen is actually present in the gases emitted from the ground. From single drilling holes in Northern Iceland as much as 50 tons of hydrogen has been measured to come up per year. This is actually as large an amount as what can be produced in a year in the existing electrolyser at the hydrogen filling station in Reykjavik. This is quite promising, as most of the drilling holes that have been made have hydrogen amounts emitted from them as high as this.

University of Iceland is in addition looking into the possibilities of *harnessing hydrogen from volcanic hydrogen sulphide*. In addition to molecular hydrogen, the drilling holes also emit large amounts of hydrogen sulphide. If this is harnessed also, a single drilling hole has the potential for enough hydrogen to fill up the tanks of about 25 hydrogen passenger cars driving the average number of kilometres (15,000) through the year. Hydrogen in hydrogen sulphide is in addition quite loosely bound compared to many other simple compounds. Actually, to split hydrogen sulphide into hydrogen and sulphur it is needed less than 1/10th of the amount of energy required to split water. So when considering the energy requirement, it appears to be very economical to extract hydrogen from hydrogen sulphide. The process currently being looked into for hydrogen production from volcanic hydrogen sulphide is a reaction based on the fact that if ferric chloride is dissolved in a hydrochloric acid solution, the ferric ion (Fe^{3+}) can easily, when reduced to ferrous ion (Fe^{2+}), oxidise the sulphide ion into solid sulphur. When the Fe^{2+} and hydrochloric acid solution is subjected to electrolysis, the Fe^{3+} is reformed at the anode and hydrogen formed at the cathode. The two-step process can be described by the chemical equations:

$$H_2S + 2Fe^{3+} \rightarrow S + 2Fe^{2+} + 2H^+$$

$$2Fe^{2+} + 2H^+ \rightarrow 2Fe^{3+} + H_2 \text{ (electrolysis).}$$

The equilibrium rate of the first reaction is 10^{20}, so it is very favourable.

University of Iceland Research also currently conducts research on *high-temperature steam electrolysis*. This research is based on the utilisation of the very cheap readily available heat source in the form of geothermal steam at about 250°C. This damp is heated further up to 800–1000°C to lower the electric energy needed for the electrolysis of water into oxygen and hydrogen. Feasibility studies have indicated a 20% reduction in the costs to produce hydrogen by water electrolysis this way.

Yet another technology approach being considered for hydrogen production from geothermal energy on Iceland deserves to be mentioned. Actually, the main part of geothermal energy sources in this country is not in the form of geothermal steam feasible for running turbines and produce electricity, but *hot water below 100°C*. The clue to utilising the energy in water at these temperatures is found in solid state physics. With membranes made of certain semi-conducting materials, heating one side and cooling the other, produces a heat flow through the material. The heat flow, when passing through the semi-conducting material, is partly converted into electricity. Research is currently being carried out to upscale this thermoelectric hydrogen production from demonstration at laboratory scale to large -scale commercial production.

3.4 Future technological steps

Further implementation of hydrogen in land-based transport in Iceland would require, in addition to the existing fuelling station in Reykjavik, five other fuelling stations on the main road to drive around the country. In addition, to complete the implementation and provide the possibility to drive everywhere in the country, a minimum requirement would be 15–16 filling stations.

However, the converting of Iceland to a hydrogen economy and eliminating the need for import of fossil fuels, the large national *fishing fleet* constitutes the prime challenge. The fishing vessels are responsible for consuming about half of the total fossil fuel consumption by Iceland today. The bottleneck is the storage of the fuel onboard the vessels. These vessels are sometimes on cruise up to six weeks, so they have to carry with them huge amounts of fuel. Hydrogen gas, which is considered as possible energy storage media in private cars, can be ruled out for large fishing vessels. Liquid hydrogen is a possibility, but it is very expensive owing to the high energy requirement for liquefying it. Liquid hydrogen is at least two times more expensive than hydrogen gas.

There is substantial work going on at University of Iceland on storing hydrogen in light metal hydrates, e.g., magnesium hydrates. Theoretically it appears possible to store in this way sufficient hydrogen in the fishing vessels, but this technology is many decades away from being ready. So if Iceland is going to operate its fishing vessels on hydrogen in the next decades, the strategy of University of Iceland is to base the storage on-board the vessels on hydrogen bound in methanol. Then the methanol could be split into hydrogen and CO_2 on board. But then the question rises: How can Iceland produce its own methanol? For this production a hydrogen source and a carbon source is needed. The hydrogen can come from electrolysis of water or from volcanic gases. When University of Iceland was starting to look for carbon sources the attention was drawn to anthropogenic gas emissions, from the country's metal industrie, aluminium smelters and ferrosilicon plants. These gases are mixtures of carbon monoxide, carbon dioxide and small amounts of methane. If one could collect these gases and dilute them, and technically this appears possible, then one could clean them up and react them with hydrogen. From these gases it has been estimated by University of Iceland that, with the addition of hydrogen, one could produce sufficient methanol to replace 95% of the fossil fuels presently consumed by the transport and fishing sectors in total in Iceland. It has further been determined that this replacement would reduce the total CO_2 emissions from these two sectors by approximately 50%.

3.5 Other technological actors

The well- developed geothermal expertise in Iceland is exported and diffused e.g., through the United Nations University Geothermal Training Programme, which has been conducted in Iceland since 1979. This programme assists developing countries in geothermal exploration and offers six-month specialised courses. These courses have been attended by altogether 318 students in the years 1979–2004 (Orkustofnun, 2004). The programme is hosted by Orkustofnun, which is the Icelandic National Energy Authority.

4 The commercial story of ECTOS

4.1 Icelandic New Energy (INE)

In the commercial story of ECTOS a central role must be given to Icelandic New Energy (INE – Ny Orka). When the large companies DaimlerChrysler, Norsk Hydro and Shell heard about government interest in Iceland of transformation into a hydrogen economy, the companies got interested in working in Iceland. The reason for this was that this was the first time a government was taking a clear commitment towards using hydrogen as the main fuel in future. The collaboration started for establishing of a joint project, where DaimlerChrysler, Norsk Hydro and Shell should work together with Icelandic stakeholders and develop a hydrogen project. So, originally it was not a part of the plan to establish INE as a company. But it soon proved very difficult not having anyone to coordinate the work, so in the later stage of the project preparation it was decided to form INE with the main task of coordinating the ECTOS project. The company was formed in 1999 and Jon Bjørn Skulason was hired as general manager with the key task of getting a hydrogen bus project started in Iceland. Later, when ECTOS started in 2001, he became the project coordinator.

INE is owned by four companies: The Icelandic holding company VistOrka and the three multinationals (DaimlerChrysler, Norsk Hydro and Shell).

When INE was established, the goal was that the company should function as an ‘enabler of technology’. There was not a commercial goal of the company at the beginning. It was given a sum of money from the start, to run (operate) the company and for the coordination of the preparation of the ECTOS project. Later a specific budget was created for the work of INE in the ECTOS project. The commercial value of the company was going to be evaluated as things moved on. But during the course of the ECTOS project the goal of INE has shifted into a more clearly commercial type of company, making profits from consultancy and project management connected to other hydrogen activities other than ECTOS.

Because INE is the coordinator of ECTOS, the costs of this project have had a large impact on the commercial situation for INE. The operation of the hydrogen filling station (owned 57% by INE) has been higher than expected. The ECTOS as a whole project has actually been more expensive than expected from the beginning. The whole project was clearly underestimated in terms of costs. The partners thus had to take on the extra costs that were needed for carrying out the various tasks of the project.

During the early phases of the ECTOS project other barriers encountered included bureaucracy, tariffs and taxes that needed to be considered when carrying out the various steps of the project. Much work in the years of 2001 and 2002 was done on getting information to and from the regulatory bodies, the taxation representatives, the customs representatives etc. These people were invited to meetings where DiamlerChrysler, Shell and Norsk Hydro explained in details what type of vehicles, components and hydrogen production systems were coming to Iceland. Also how they would be put together was explained to them and to the governmental representatives, who approved the plans. But still INE experienced that when the vehicles and equipment arrived, there were still problems connected to these issues (bureaucracy, tariffs, taxes).

4.2 Skeljungur Ltd

Skeljungur Ltd., the Shell distributors in Iceland, owns 43% of the hydrogen filling station in Reykjavik. Skeljungur Ltd has the full the responsibility of the daily operation of the station. Finding a suitable location for a station of this type proved to be a major problem for the company. The original strategy of Skeljungur for its participation in ECTOS was to build an "environmental progressive Service Station of the Future" in Reykjavik where hydrogen was to be one of the fuels offered on site (Gudmundsdottir, 2003). Reykjavik City was however unable to provide land for this purpose. Much time and money was spent by Skeljungur on this process, without success, and eventually the plan was abandoned. Instead Skeljungur changed the strategy and started looking for other locations. A site was finally chosen next to an existing regular Shell fuel filling and service station in Vesturlandsvegur east of the centre of Reykjavik. However, obtaining the necessary approvals and licences for a hydrogen station at this location also turned out to be a rather troublesome process. A changing of the city regulation plan was necessary. This required that a public hearing was to be conducted, causing delays in the progress of the project. These requirements had not been taken into account in the time planning of the project, and as such took both Skeljungur and INE by surprise. It is quite evident that they did not account well enough for the regulatory requirements they needed to comply with for constructing the filling station. One example was the safety requirements applied to the hydrogen filling station. These were more comprehensive than anticipated at first. The station was e.g., expected to withstand a burning truck roaming into the station areas. Construction permits were not given until the fire protection dept., operating under the guidance of the Iceland Fire Authority, approved the plans. Delays were also caused by necessity of the station to comply with the requirements for safety distances set down by National Fire Protection Agency (NFPA) in their 50A regulations, as well as to the European hazardous locations certification requirements EN60079-10. The time period spent on obtaining these necessary approvals and licences could probably have been reduced somewhat if the community persons responsible for giving out these had been included in the process at an earlier stage. This might have made them more committed to giving out building licenses at an earlier stage than was actually done.

Owing the fact that the hydrogen filling station now was delayed significantly compared to the original progress plan, when the construction started on February 18th 2003 there was strong pressure to complete it in time for the opening date of April 24th 2003. This date had been decided upon much earlier in the project. This caused the total construction costs for the station to be much higher than if the construction project had been carried out at normal pace.

4.3 Strætó bs (Greater Reykjavik Transport)

The operator of the hydrogen buses is Strætó bs. For this company, the ECTOS project might have value in terms of marketing of the company, but it certainly has not been a commercial success yet. There are many reasons for this. First of all, as a consequence of the frequent breakdowns of the hydrogen buses, the bus company had to start devoting one person in a full-time job of bringing the buses back to the garage when they break down, and replace them with regular buses on their bus routes. This implied increased costs for the company, costs which only partially were compensated for.

Initially the plan was that introduction of the three hydrogen buses into the bus route network would make it possible to take three diesel buses out of operation. However, owing to the unreliability of the hydrogen buses, this turned out not to be possible. There has been no saving of the other buses, and the bus company has experienced problems with maintaining the regularity of the bus schedules on the affected routes.

Another factor is the cost of the fuel. The cost per kilometre of the hydrogen consumed by the buses is on the average five times as high as the fuel costs for the diesel buses operating on the same routes. The high cost is partially resulting from the fact that the hydrogen delivered at the station is from a rather small-scale production unit.

The combined maintenance facility/garage for the buses is also quite expensive to operate. One factor contributing to this is that the three hydrogen buses are heated by electricity during the whole night. This is a necessary requirement for the functioning of these buses' fuel cell system.

In summary the total costs for the bus operator have been higher than anticipated when planning the project. It has been necessary for the bus operator to pay parts of these excessive costs. This has caused some aggravation in the bus company, where it is expressed that this was not well enough thought through and agreed upon in the project planning phase.

4.4 Other commercial actors

There are in addition many other commercial actors connected to the ECTOS project. They include DaimlerChrysler AG, who supplied the three hydrogen buses in the project. For DaimlerChrysler both CUTE and ECTOS are parts of the company's strategy for testing and obtaining input for improving their prototypes of hydrogen based fuel-cell buses.

Norsk Hydro Electrolyser AS has supplied all the equipment for the hydrogen production part of the filling station in Reykjavik. The hydrogen production system, including electrolysers, compressors, storage and fuel dispenser system was built in Norway and shipped to Iceland, as a complete unit. The hydrogen station in Reykjavik serves as an important element of the strategy of Norsk Hydro Electrolyser AS to keep the position as a "World leader in water electrolysis" (www.electrolysers.com).

The company Varmaraf ehf. is an example of a commercial company that has originated as a direct result of Iceland's efforts on hydrogen energy. The company was founded in the year 2000 and produces the thermoelectric generator 'Thermator' which produces electricity from hot geothermal water below 100°C.

5 Conclusions

The implementation of hydrogen as a transport fuel in Iceland has been analysed through the political, the technological and the commercial story of the background and early phases of the ECTOS project. The analysis has focussed on the conditions for conversion from fossil fuels to renewable hydrogen as energy carrier in transport.

The presence of large amounts of readily available geothermal energy in Iceland is the resource basis for the governmental plans for converting into a hydrogen economy. Strong long-term political commitment has established the framework conditions for developments of an economy based on hydrogen energy. The political goal of using hydrogen energy to replace the need for import of fossil fuels by 2030–2040 has provided motivation and support to hydrogen research, development and demonstration projects. The ECTOS project for hydrogen implementation and demonstration in public buses are the most well known of these.

The early public scepticism has turned into general support for the transition into a hydrogen economy. The strategies of the large industrial companies DiamlerChrysler, Royal Dutch Shell and Norsk Hydro in being drivers for conducting hydrogen demonstration projects in Iceland were important in causing this turn in public acceptance.

The early phases of the ECTOS project also faced many other barriers which had to be overcome to move the project forward. Some were connected to safety requirements, codes and standards, tariffs, and taxes. The most serious were probably those connected to the hydrogen filling station, requirements and procedures that were not well enough planned, causing delays, which increased costs.

The largest barrier for the plan of replacing the need for import of fossil fuels by 2030–2040 is likely to be the conversion of the fishing vessels. The storage of hydrogen on board is a major challenge, and even if the boats theoretically could eventually be fuelled by domestically produced methanol, much work remains to facilitate this.

Even though the ECTOS project cannot be labelled a commercial success, the hydrogen commitment it is a part of has resulted in the emerging of new companies, such as Varmaraf ehf. In addition, the large industrial companies DiamlerChrysler, Royal Dutch Shell and Norsk Hydro are using ECTOS actively in their strategies of promoting development of hydrogen energy.

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Notes

[1]Described later in this article, in the chapter "The commercial story of ECTOS".

[2]The five steps in the transition to a hydrogen economy are Árnarson (2003):

Phase 1: Demonstration project with hydrogen fuel cell buses in Reykjavik

Phase 2: Gradual replacement of the Reykjavik city bus fleet and possibly other bus fleets with hydrogen fuel cell buses

Phase 3: Introduction of hydrogen fuel cell cars for private transport

Phase 4: Demonstration project with hydrogen powered fuel cell fishing vessel

Phase 5: Gradual replacement of the whole fishing fleet with hydrogen powered fuel cell fishing vessels

Sometimes a 6th phase is included (Árnarson et al., 2001):

Phase 6: Export of hydrogen from Iceland to the continent of Europe.

[3]CUTE – Clean Urban Transport for Europe is a European Commission demonstration project to support nine European cities in introducing hydrogen into their public transport system: Amsterdam (Netherlands), Barcelona (Spain), Hamburg (Germany), London (UK), Luxembourg, Madrid (Spain), Porto (Portugal), Stockholm (Sweden) and Stuttgart (Germany).