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Background and motivations.

Iceland with its 290,000 inhabitants is a large producer and user of electricity and perhaps among the largest per capita on the planet. The Electric potential of Iceland has been estimated to be about 55 TWh of which only 8 TWh have been harnessed so far. The primary sources are hydroelectric and geothermal energy.

On the other hand, as a result of the cool climate and the limited vegetation, the country is naturally deprived of fossil energy sources apart from some peat and limited birchwood which served as an important energy source for hundreds of years since the age of settlement. In this way the transport, fishing and general energy sectors are powered by imported fossil fuels.

In 2003 the anthropogenic emission of CO_2 from Iceland was around 3 million metric tonnes or about 11 tonnes per capita per year. This was caused by three roughly equal factors: transportation, fishing fleet and general industry. It should be noted that the use of electricity from renewable sources for aluminium smelting and ferrosilicon production in Iceland still creates considerable carbon dioxide emissions from the carbon electrodes during the process – but saves appreciable amounts of emissions compared with carbon based metal smelting utilized elsewhere in Europe.

Nevertheless, the carbon dioxide emissions from Iceland had already towards the end of the last century created what has been called a Kyoto dilemma in the energy policy of Iceland. Most of the conversion from carbon sources to a geothermal primary source for space heating in Iceland was finished before the Kyoto reference year of 1990. This situation has caused an active debate in Iceland. Along with the heavy imports of fossil fuels these two factors have been major causes of a movement to produce artificial fuels by the use of domestic renewable energy sources, the main theme of this paper.

In 1997 the Ministry of Energy appointed a committee to investigate the possibility of domestic fuel production. The committee was led by Mr. Hjalmar Arnason MP. The committee recommended that efforts should be directed towards hydrogen and hydrogen rich artificial fuels, eyeing the resulting savings on imported oil and greater energy independence.

Hydrogen production in Iceland has already been practised for over half a century trough the production of fertilizers based on hydroelectric electrolysis of water. Hydrogen research at the University of Iceland goes back over three decades to the work of the pioneers Bragi Arnason, Thorsteinn Sigfusson et al. In 1998 the government of Iceland headed by Prime Minister Oddsson declaired its aim for a hydrogen economy in Iceland.
In 1998 a corporation, Icelandic New Enery Ltd. was formed with 51% of the shares owned by a consortium of the main Icelandic corporations in the energy sector as well as two major

institutions. and the Government of Iceland. Three international corporations joined as founding members: Daimler-Chrysler, Norsk Hydro and Shell, rounding up the remaining 49% of the share capital

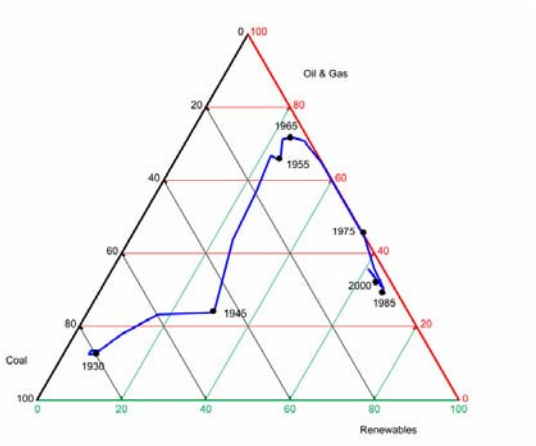

Figure The proportional energy usage in Iceland 1930-2002. The three-phase-diagram shows the proportion of coal, oil/gas and renewables. Initially, the diagram shows how oil took over from coal for the period up to the fourth quarter of the century. Renewables are on a steady increase throughout the century.

The aim of the company was clear: a joint venture to investigate the potential of eventually replacing fossil fuels usage in Iceland with hydrogen based fuels and ultimately create the world's first "hydrogen economy". The Icelandic group devised a roadmap to reach the hydrogen economy, outlining the guiding goal of the nascent Icelandic New Energy. The strategy was to begin with the introduction of a hydrogen-powered bus test-fleet. The next phase was to promote the integration of fuel cell powered vehicles for passenger use. The final phase consisted of examining the possibility of replacing the fishing fleet with hydrogen based vessels.

Icelandic New Energy anticipates approximately fifty years of development towards the goal of replacing fossil fuels in the transport and fishing sectors. The company estimates that about 4.3 TWh of energy will be needed to complete the change, using 81,000 tonnes of hydrogen. In the first decade of the millennium, demonstrations of the developing hydrogen technology will be performed. In the following decade fleets of hydrogen driven transport and fishing systems will be introduced. At its steepest part, the development will involve the deployment of mass produced vehicles and engines for applications on land and sea. The completed scenario is expected to be reached around 2050. Considering the fact that Iceland has seen two major infrastructure changes in the twentieth century with hydroelectric and geothermal energy, it is not unexpected to assume fifty years as reasonable for the total duration for the hydrogen economy transition.

Projects.

Icelandic New Energy under the general management of Mr. Jon Björn Skulason MSc, began preparation for a demonstration project which sought financial support from the Fifth

Framework Programme of the European Union. The project was called ECTOS, **E**cological **C**ity **T**ransp**O**rt **S**ystem. Its main objective was to construct a hydrogen fuelling station completely integrated into an urban setting and feed three hydrogen fuel cell busses in the mass transport fleet of Reykjavik for a test period of two years. The project was divided into a first phase covering the first two years involving preparation, establishing infrastructure, a maintenance facility, economic/social research, etc. This was to be followed by the second two years involving the actual demonstration of three H_2 buses and commercial infrastructure. The second phase started in 2003. The total cost of ECTOS is expected to be 7 Meuro.

The ECTOS project has as an additional important ingredient, the analysis of carriers and hurdles for a hydrogen economy in Iceland. The University of Iceland and Ms. Maria Maack are responsible for socioeconomic analysis and a number of polls intended to watch the development of the public acceptance of the new concept. In 2001, shortly after the formation of Icelandic New Energy (INE) a poll was conducted of group of 1200 people who were surveyed of their knowledge about the newly established company. 23% of the people said they had heard of INE. When asked their attitude towards hydrogen as an energy carrier, 93% said they held a positive stance. This figure was unexpectedly high and points towards an unusually positive public opinion which may prove difficult to keep at such a high level. Well to wheel based and LCA, analysis of life cycles, is an important part of ECTOS. This part of the project is done in close cooperation with the University of Stuttgart.

In cooperation with Hambug Elektricitaets Werke Iceland is involved in an ongoing project in the area of hydrogen transport to mainland Europe (ex. Hamburg). Three different scenarios are studied: 2000 tonnes annually, 20.000 tonnes and 200.000 tonnes. The project, called Euro-Hyport is supported by the EU and was reported in detail in 2003.

Creating a new infrastructure is of course a immense task for the hydrogen economy. One has to bear in mind that the present oil/gasoline infrastructure has been built over almost a century. It is expected that the infrastructure of hydrogen will have to be based on new concepts as hydrogen fuelling does not require the density of fuelling depots as in the present Reykjavik gasoline infrastructure. The current infrastructure study involves a comparison of distributed electrolyser stations with centralized hydrogen production facilities connected to outlets by pipeline or truck transport. It is hoped that some guiding principles will be founded during the ECTOS project and related projects in Iceland.

The most recent international project in Iceland is “New – H – Ship” an EU project about hydrogen in marine applications and is just about to kick-off at the time of this writing towards the end of January 2004.

As in all EU projects, Icelandic New Energy has very carefully anticipated the role of dissemination. Dissemination takes place at many levels ranging from newspaper articles to public seminars, summer schools and the publication of web materials intended for education.

In the summer of 2003 the University of Iceland held a one week long instructional conference (summer school) on hydrogen technology and infrastructure, attended by some 50 graduate students from 14 countries. The bulk of the conference was supported by NorFA, Nordisk

Forskarakademi, a Nordic organization on Graduate training. The conference enjoyed internationally regarded professors from Europe and USA and a number of selected graduate students with differing goals and backgrounds within the area of hydrogen.

The Nordic Council of Ministers and its programme, Nordic Energy Research, has supported graduate projects in the area of hydrogen, especially in storage. In these projects, students from the Nordic countries receive assistance for travelling and studies between universities, research institutions and corporations in the Nordic countries.

Also within the Nordic Energy Research there is an interesting project called “Nordic Technology Foresight” which looks closely into the evolving hydrogen society in the Nordic countries through the critical and innovative eye of the “foresight methodology”.

Further reading can be found in a chapter by T.I. Sigfusson in the forthcoming book:

Mitigation and Adaption Strategies for Global Change, Ed. **Robert Dixon** , KLUWER Publishing 2004.