# ECTOS
# Ecological City Transport System

(EVK-CT4-2000-00033)

## Deliverable no 17

# Total Impact Assessment

## Responsible partner: UNI

HÁSKÓLI ÍSLANDS

ENERGY, ENVIRONMENT AND SUSTAINABLE DEVELOPMENT

## List of acronyms

| | |
|---|---|
| $H_2$ fc-bus | Hydrogen fuel ccell-bus |
| fc-bus | Fuel Cell bus |
| AP | Acidification Potential (Environmental Impact Category) |
| CNG | Compressed Natural Gas |
| CO | Carbon Monoxide |
| $CO_2$ | Carbon Dioxide |
| CUTE | Clean Urban Transport for Europe (EU NNE5-2000-00113) |
| ECTOS | Ecological City Transport System |
| EP | Eutrophication Potential (Environmental Impact Category) |
| FC or fc | Fuel Cell |
| GWP | Global Warming Potential (Environmental Impact Category) |
| $H_2S$ | Hydrogen Sulphide |
| LCA | Life Cycle Assessment (following ISO 14040) |
| LCI | Life Cycle Inventory (following ISO 14040) |
| LCIA | Life Cycle Impact Assessment (following ISO 14040) |
| $N_2O$ | Nitrous Oxide |
| NMVOC | Non Methane Volatile Organic Compound |
| NHE | Norsk Hydro Electrolysers |
| $NO_X$ | Nitrogen Oxide |
| PE | Primary Energy |
| POCP | Photochemical Ozone Creation Potential (Environmental Impact) |
| $SO_2$ | Sulphur Dioxide |
| TTW | Tank-To-Wheel |
| WTT | Well-To-Tank |
| WTW | Well-To-Wheel |
| socio-eco-enviro: | Social, economic and environmental issues |

**EVK4-CT4-2000 00033**

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# 1 Abstract

A hydrogen fc-bus test was carried out in the social settings of Reykjavik between March 2001 and August 2005. A hydrogen fuel station was built in 2003 and operated to fuel the 3 test buses. Data was collected on the performance of the buses and the station and issues such as reliability, costs, benefits for the society and learning were compiled and will be used to integrate in the following generations of hydrogen energy technology.

The ECTOS total impact assessment describes and discusses most outcomes from the project. Issues include aspects of building and running the infrastructure and the bus-techniques, organisation and management, impacts on the environment public benefits as well as further applications and extension of the learning only to name a few.

**Key words: Socio-technical demonstration, Hydrogen technology, high pressure electrolysis, fc-buses, sustainable energy chain,**

## 2 Executive summary:

**The ECTOS or Ecological City Transport System was a two-year test involving the construction and running of an electrolytic hydrogen station, using three fc-buses within the public transportation system and sampling data on various aspects of this service system. The electricity to run the electrolytic hydrogen station only comes from renewable sources: hydro-power and geothermal electricity from the national grid. ECTOS started on 1st of March 2001 and ended by 31st of August 2005.**

**The goal of this ECTOS deliverable – *Total Impact Assessment Report* is to evaluate how this bound socio-technical project influenced the local society in three main categories: *the economic, the social and the environmental areas*. The evaluation is done along the lines of a cost-benefit-analysis and describes prices and income as well as values of the social benefits and drawbacks of the tested energy system. Only a few of the impacts can be accounted for in the conventional accounting approach. Social and environmental benefits are described in more detail, because those are the main drivers for undertaking projects like the ECTOS. It refers for more details to the ECTOS deliverables.**

**The performance of the equipment proved to be reliable. A few components had to be redesigned in the hydrogen station and a few of the satellite components in the bus systems were replaced to prevent mishaps or boost the performance. The public approved highly of the tests.**

**The environmental benefits of a transportation based on the tested system are huge. Greenhouse gas emissions are cut drastically compared to a public bus system that runs on fossil fuels. Also, when the hydrogen is made with renewable energy then the environmental impacts are shifted to the manufacturing phase of the station and the vehicles. With careful supply chain management and responsible material selection it may be feasible to cut the environmental impacts even further. Using hydrogen fuel cell buses in city transportation is a very promising option to enhance air quality in urban areas.**

**The energy efficiency of the fuel chain can be optimised further within the current system, for example by introducing more vehicles and new consumers that use the hydrogen from the station or by integrating energy saving components within the station and the buses. The lessons are already being integrated in the next generation of hydrogen buses and stations.**

**The bus passengers and the drivers showed a positive attitude towards the demonstration. New educational material based on the tested system was developed for three levels of the school system. The international media, the public as well as specialists showed high interest in ECTOS and have helped to disseminate information out to the international society on a voluntary basis. The learning from ECTOS has helped to raise awareness for hydrogen as an energy carrier within the transport sector both locally and internationally. The necessary steps that need to be taken towards an increased hydrogenization have been outlined accurately and an Icelandic hydrogen road map has been drawn up. The ECTOS must be regarded as highly successful undertaking and its effects are echoing across the Atlantic.**

## 2.1 *List of lessons learned*

**The consortium was asked to write their answers to the question: What did we learn from ECTOS? In short the lessons of the ECTOS project are as follows:**

# On the technology

1. **The main outcome of the project Ecological City Transport System is that it is feasible to run public fc-buses and an electrolytic hydrogen fuel station with the state of the art hydrogen technology.**

2. **The reliability of the Citaro fc-buses is perfectly comparable to conventional buses with other types of drive trains**

3. **That it is relatively easy to build a hydrogen infrastructure in Reykjavík so if there is a will there is a way**
4. **A few problems came up during the operation of the electrolytic fuel station but all these were successfully overcome and the redesigned electrolysis system operated under pressure should be tested further for optimal operation. Yet the station will most probably be ready to for public service within a few semesters.**
5. **Where we have weather condition like here in Iceland, gas cooling at the HRS can be done in much simpler way, e.g. by circulating the coolant in a snow melting pipes around the station. Probably more effective and cheaper.**

## On energy efficiency

6. **With minor organisational and management changes the efficiency within the tested system has been raised considerably and more energy savings can be made.**

7. **The life time of the current fuel cells has not been exceeded and they need prolonged testing hours. The life time of the fuel cell is expected to be extended considerably in the upcoming technology generations and the power of the cells to grow at the same time rendering the work performed cheaper**

8. **The fuel economy for the entire fuel train proved not to be as good as for electrolysis under atmospheric pressure (Well to Tank part) and the fuel economy for the Tank to Wheel will need improvements to become satisfactory. The costs for running the pre-service equipment used in ECTOS and the monitoring during the project will not be revealed at this stage. Currently installed $H_2$ infrastructure and used fc-busses, both designed for reliability rather than for efficiency, show significant improvement potential in terms of**

**energy efficiency. Optimisation of this $H_2$/fc package has to be addressed within the next technology generation.**

**9. A few hybrid options will be incorporated in the next generation of fc buses. The final selection of for example energy saving options has not been passed at this stage but ultra capacitors, fewer hydrogen storage bottles to decrease weighed, flywheels or batteries are amongst the options.**

## On eco-efficiency

**10. Materialising the environmental superiority of the $H_2$fc system rests on two pillars:**

- **Maximising the energy efficiency of the complete energy chain, $H_2$ production, dispensing and operation of fc vehicles,**
- **Utilisation of renewable resources especially for the $H_2$ production**

**11. The auxiliary electric systems in the fc-buses should be designed to match the fuel cell drive train. Energy is lost because of transformers and similar step down or step up procedures**

**12. The environmental benefits of using hydrogen made from renewable energy are very large. The buses themselves only emit steam and the hydrogen production only emits oxygen. The saving in greenhouse emissions from the project is about 160 tons of CO2 (using three buses part time for 2 years) compared to the average CO2 emissions from conventional bus service in Reykjavik. Running all the public buses and personal transport on hydrogen would give an enormous potential for greenhouse gas savings**

**13. When using hydrogen from renewable energy sources the environmental impacts are much smaller (see 8) and they are shifted to the production phase of the equipment from the running phase. The latter is the situation for conventional public transportation systems and therefore the use of fc vehicles gives huge opportunities for a cleaner urban environment.**

**14. During the driving session far less oil and grease is used for the maintenance of the fc-buses compared to diesel buses of the same age and size. On the other side, lye must be replaced regularly at the production step and costly liquid nitrogen is used during down time at the station. The material bookkeeping therefore touches on whole new categories of materials.**

## On costs

**15. The running-cost of the tested type of infrastructure can be cut considerably especially by augmenting the number of hydrogen customers, remote operation control, continuous operation and only regular maintenance.**

16. **The social benefits have appeared in the form of education, enlightened discussion, new local and international hydrogen projects and more satellite income such as for the Icelandic tourism because of the attraction of the hydrogen initiatives. A needed study would be to map the monetary income of the satellite functions.**

**17. During the test period the consumer price of gasoline has increased by 40% in Iceland. The price of electrolytic hydrogen depends mostly on the price of electricity and the offered price depends mostly on the size of the user.**

**18. The public shows a very positive attitude towards not only the test with hydrogen and fuel cells but further hydrogenization of the economy. A small majority is ready to accept hydrogen even at a higher price than gasoline.**

## On social aspects

**19. Difficult to have one political party in charge in the government and a different one in the city, because everyone wants to take the glory out of the project and make sure the other party is not. Perhaps politics and innovative programs do not go hand in hand, private entrepreneurship can bring the developmet fast forward but sound political commitment is essential**

**20. Finally the utilisation of renewable resources as it is demonstrated in Iceland is the key to achieve sustainable mobility[it eases a bit the importance of the energy efficiency in environmental terms, never the less in economic terms an increased energy efficiency always leads to reduced operating costs, for both HRS and vehicle operator**

**21. On the organisation level the involvement of the local authorities should be more agitated and clear communicational routes and task division to enhance more active participation. The communication channels should be well defined with clear roles for information spread at some levels and closed channels at other levels.**

**22. It's vital to have safety first and handle safety concerns in a mature and organised way and active rehearsing. The operators have to have an active HSE system, Emergency Response Plans and Crisis Management Plans that all the staff knows and exercises.**

**23. The international interest surpassed all expectations. This has already led to many international spin-offs such as the founding of similar companies as Icelandic New Energy in the Faroe Islands, the Cap Verde Isles and the North Atlantic Hydrogen Association (NAHA) – a platform for the smaller economies that have similar local conditions as Iceland in the North Atlantic to discuss the opportunities to use hydrogen as fuel.**

## On needed further studies

24. **At the hydrogen station an exercise should be simulated or tested in order to maximize the output/investment and make the current system more flexible. Three components play a part here: supply, demand and storage. A larger storage would be needed or a better storage management to maximise the utility of the current storage at the station. That could be done by dividing it into smaller storage banks and allowing flow of hydrogen between banks for optimisation purposes or perhaps a second compressor within the chain**

**25. We need better understanding how the technology works under more commercialised conditions where each player tries to maximize his outcomes.**

## Other

**26. Offering different fuel alternatives at a single retail site is possible**

**27. That the quality and commitment of the team running the project was crucial and turned out to be one of the critical success factors in ECTOS. That means bringing very different people together with different motives turned out to be very successful. Therefore it is essential that this team gets to further its capabilities and disseminate the lessons.**

# 3 Introduction to the ECTOS project

The Ecological City Transport System (ECTOS)[1] was a pilot project undertaken during the time period 1st March 2001 – 31st of August 2005 in Reykjavik, Iceland. The European commission granted the sum of 3,8 million€ to the project from the programme Sustainable development, City of tomorrow, DG Research. The partners were the following (in alphabetic order): DaimlerChrysler, EvoBus, Icelandic New Energy, Icetec, IKP at the University of Stuttgart, Norsk Hydro, Shell Hydrogen, Skeljungur, Straeto bs, University of Iceland, Vinnova. Icelandic New Energy was the promoter, organiser and saw to the project management. The ECTOS was prolonged for further 6 months to 31st of August 2005. The equipment will furthermore be tested in new modes within the Hy-Fleet CUTE project during 2006. There was a good deal of exchange of information and common research approaches with the CUTE project (Clean Urban Transport for Europe[2]) the similar yet much larger fc-bus project undertaken throughout Europe, in Perth Australia and later in China. The initiative for the ideas came from Iceland and can be traced back to the oil-price-crises in the 1970s.

The reader should notice that at this stage costs, income and prices are not given as concrete figures. The technology is at a very sensitive stage for the competing businesses and this information is neither considered as public domain nor the main outputs of ECTOS. These figures are only relevant indicators for the consortium and benchmark how much this project cost, given that the main goal was:

***To learn from the utilization of the state of the art hydrogen-technology***

This report has been compiled into a holistic document based on the ECTOS especially deliverables 7, 14 and 16 on the Environmental Impacts, the fuel chain and Life Cycle Assessment, Deliverable 12 on the Public Acceptance and social benefits, and 15 Cost Benefit Analysis of the Infrastructure. The main paper contains short introductions, description of the outcomes and discusses the lessons learned from each aspect. It combines conclusions in the three main themes: Social aspects, environmental aspects and economic aspects.

The report attempts to present ideas of what should be included or accounted for as all influences on society; a modified costs benefit analysis. These may be represented with general prices which are to be found under bookkeeping in the economic sense, material balance and life cycle analysis which is categorised as an environmental approach, how the public evaluates the initiatives as read from public surveys, new public assets arising from the

[1] The project has a home page: www.ectos.is
[2] The website for the CUTE project is: www.fuel-cell-bus-club.com

project, all of which fall under the social sciences. An example is taken on how energy education has gained momentum from the ECTOS experience; these count as benefits which cannot be price-tagged. A satellite income comes from the added attraction of Iceland for tourists and study groups, who add to the income of the hospitality service.

## 3.1 *Approach to value estimations*

In a socio-technical demonstration project such as ECTOS all the invoices and receipts could readily be compiled and thus the costs added up to a single figure. The real challenge is to estimate the total income and benefits, pinpoint what should be included and what should be left out as irrelevant outcomes of the project. Figure 1 gives and overview of the categories that are added up in the total assessment report.

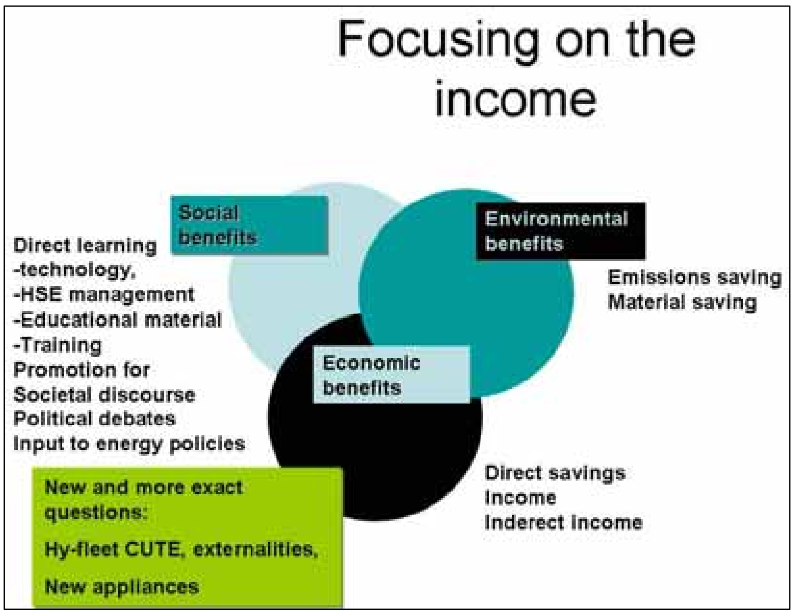



**Figure 1 An overview of income and benefit categories within ECTOS. Most of the issues listed here are discussed in the report**

When discussing costs and benefits it is customary to use the concept costs to describe prices where environmental or social externalities are rarely incorporated. Whereas the clean technology which is put to the ultimate test in ECTOS is driven by a more holistic – value bases, the ***main emphasis in the Total Assessment Report is to highlight and evaluate the other types of benefits, - the external income and savings***. Price tags can be put on either the cost of equipment or savings of material and workload. Recently a lot of work has been done to internalise the environmental damage from energy utilization and put price tags on a few categories of pollution for example.[3] But here, value is also put on social income and environmental savings. The interpretation in the report is recognised as highly disputable but leaving out the main values of the results would be equally disputable, even though the costs of all the preparations from the design phase throughout every step of the undertaking are extremely high.

[3] Bickel, Peter and Rainer Fredrich (editors) 2005: ExternE Externbalities of Energy, methodology 2005 Update, DG for research ad sustainable energy systems, EUR 21951

## 3.2 *Layout for the ECTOS project*

In ECTOS the hydrogen fuel is produced from water in an a high pressure electrolytic process, stored in cylinders as compressed gas, distributed via dispenser system and tapped into nine gas bottles on top of 3 fc-buses every day. Figure 1 An overview of income and benefit categories within ECTOS. Most of the issues listed here are discussed in the report shows the outline and the connection between the major components.

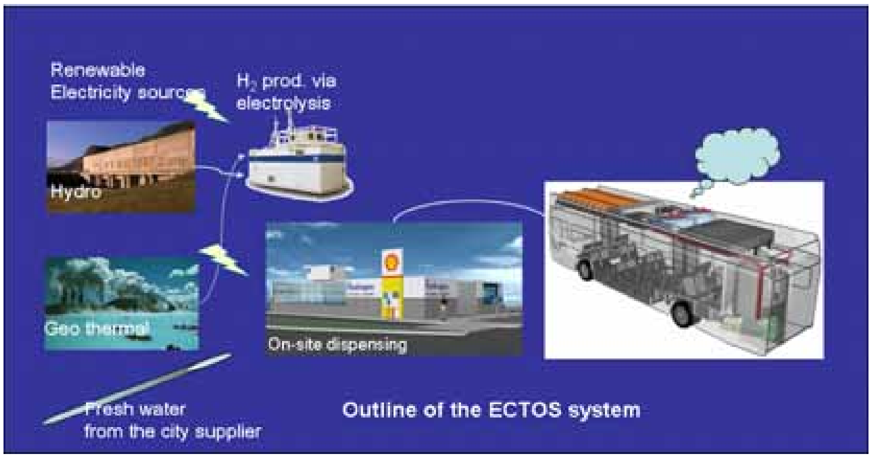



**Figure 2 Layout for the ECTOS project**

## 3.3 *Goals and milestones*

This deliverable reports on the non-technical issues connected to the deployment of hydrogen as a fuel as it appeared during the hydrogen fc-bus tests in Reykjavik. The report describes how various aspects are influenced and at the same time influence the prospects of introducing a locally made fuel, as reflected by social, economic and environmental issues (referred to as: socio-eco-enviro). The design phase, production phase or manufacturing is less emphasised here while the operation of the system and the integration on society is the focus point. The issues touch on the costs, social aspects as well as environmental issues in the same way as indicated by the three filled circles in Figure 1 and Figure 3.

Aspects include local organisation, functions and planning of the infrastructure, new options in environmental effects, current costs and foreseen tendencies within the same context. A recommended foreword to the ECTOS project is the published article 'Implementing the Hydrogen Economy[4]' which appears here as a foreword to the report. It gives a short description of the settings, goals and the preamble to the ideas of using hydrogen as a fuel in Iceland.

Within the socio-eco-enviro studies the aim was first and foremost to:

***obtain knowledge on the implications of the new hydrogen technology on society and the environment.***

[4] Maack, Maria & Jon Bjorn Skulason (2005) Implementing the hydrogen economy, Journal of cleaner production no 14, 52-64. Science direct, Elsevier, available online at: www.sciencedirect.com

***Furthermore to:***

**Set a benchmark within the study of new fuels**
**Give a basis for comparison between options of transportation technology**
**Map the acceptance of the public**
**Map drivers and barriers for a shift to a hydrogen based transport system**
**Facilitate dialogue in society based on the obtained information**
**To facilitate the adaptation of fuel technology for a society aiming for sustainable development.**

***Box 1 Goals for ECTOS revisited***

(ECTOS – CUTE Methodology 2003)

***The overall goal for ECTOS is to learn:***

- **how to organise and run a distribution and infrastructure system to provide hydrogen to vehicles**
- **from the execution of the plan and how to implement refinements**
- **which impacts should be expected for a larger scale system**

**The ECTOS project is a multidimensional study connected to technical tests for specified electrolytic and fuel cell equipment that makes hydrogen- fuel available for current traffic patterns. ECTOS is organised to become a learning experience that can facilitate using hydrogen as a fuel on a large scale, at least within Icelandic conditions. A site dependent frame is therefore given for the goals of the socio-economic-enviro studies in ECTOS, whereas:**

➢ **The government of Iceland has officially promoted its policy to support a continued demonstration phase for using hydrogen as a fuel eventually leading to the world's first hydrogen economy.**

➢ **The outcome of ECTOS will be used to map drivers and barriers within the implementation of a future hydrogen economy and further political decisions**

➢ **Considerations of the transferability of the studies and outcomes will remain a central issue throughout the study period**

➢ **ECTOS is seen rather as a first step towards further hydrogenisation rather than an isolated pilot project. Later steps will yet be based on the real outcomes.**

It is clear that the main goals for the ECTOS project have been met, the learning has been bountiful, often surprising, and either according to organized undertakings or from unplanned moments.

The non technical issues will be addressed in the following order:

- **Costs and benefits of the tested system with emphasis on the savings and income; chapter 4**
- **Public response to the new hydrogen tech-nology and public benefits; chapter**
- **Environmental aspects, the LCA analysis, air quality speculations as well as ideas on the fuel economy, material flow and savings chapter 6**
- **Conclusions include suggestions for further study and in-depth analysis chapter 7**

## 3.4 *Assumptions, boundaries, limitations*

The report is processed from the data which was collected during the drive tests of the three Citaro fc-buses from October 2003 – February 2005. ***Therefore the outcomes are only applicable to the specified pre-service bus models and the pre-commercial fuel station and should not be used as basis for generalisation.*** The fc-buses were designed to be safe and reliable enough to withstand the conditions and demand within a regular public transportation service and several modifications were made for research and data collection. The next bus generation will be made cheaper and leaner in fuel consumption. ***Forecasts based on details of the ECTOS study should be avoided without reference to the specified assumptions.*** The technical details of the buses and the electrolytic station are to be found in deliverables 8 and 5 respectively.

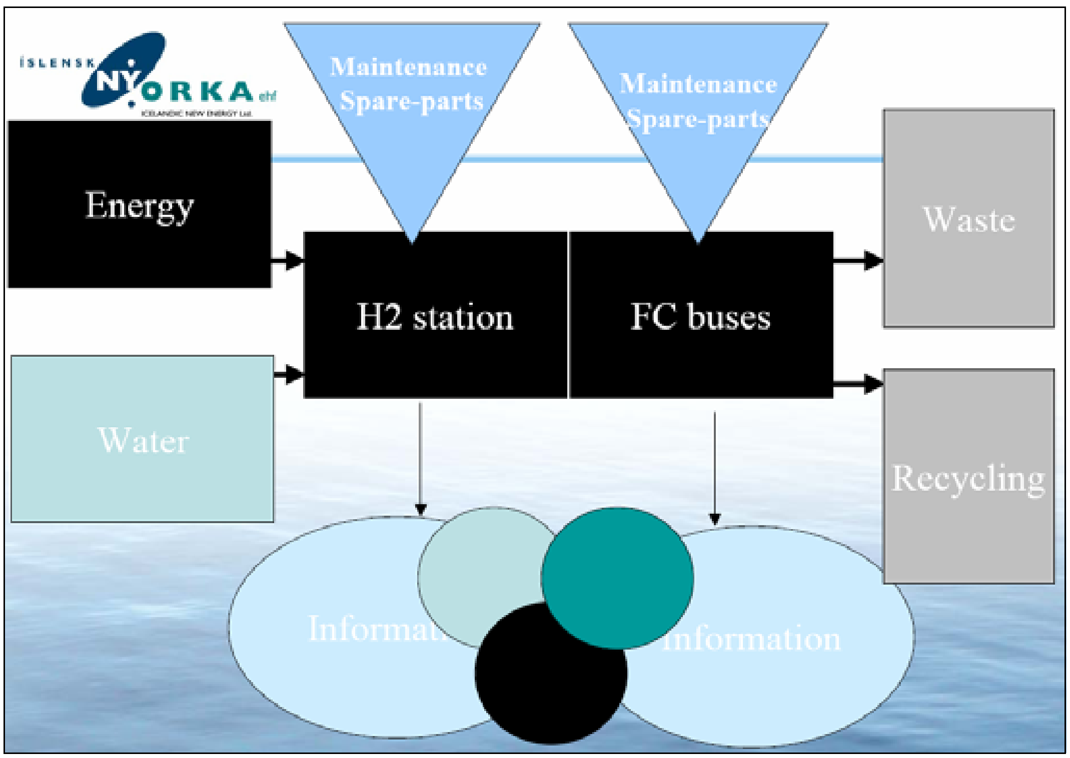



**Figure 3 This is a schematic overview of the material and energy inputs and outputs of the technical system which was tested in ECTOS. The three filled circles indicate the subjects of this report: the social, environmental and economic screening of the collected information.**

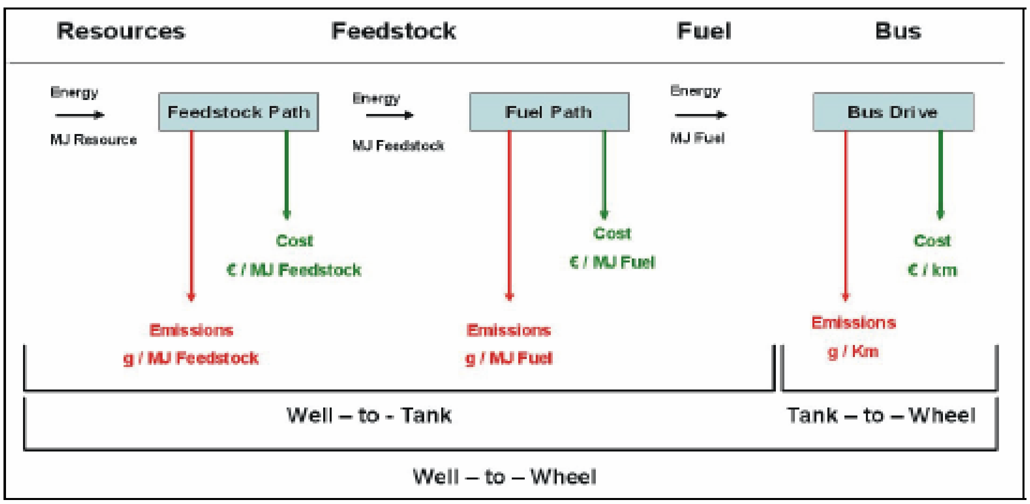
The data was either collected and noted manually or monitored within automatic monitoring equipment[5], such as computers on board the buses or within the hydrogen station compartments. Some of the information obtained during the project is business sensitive and therefore lists of data or detailed information in many categories belong to the

5

partners of the project and are not included here as public information. Yet it is hoped that this basis of data will only be concealed for a finite period of time if interest should arise for further uses or as historical assets.

## 3.5 *Guide for transportation options*

The deliverable 13 from Shell Hydrogen and the additional deliverable 20 from Vinnova – a report on a decision aiding tool for the various types of transportation vehicles, indicate that the outcomes of the ECTOS demonstrations are perfectly transferable to other societies. An overview of the support tool is given in figure 22. The SUSI[6] model was developed within the project for those who need to make choices between all options for public transport systems. Information from more projects and fuel and vehicle options need to be introduced into the model.




**Note:** SUSI is a tool to compare emissions and costs of well-to-wheels pathways including the processes from the *Resource* over its transformation into *Feedstock* and *Fuel* to the wheel of the *Bus*. Considered are the energy use, emissions and cost of each process in the pathway which are aggregated into total emissions and total costs for the whole pathway. The energy use, emissions and cost of the processes are not calculated in SUSI; they are considered as input data that has been calculated in WtW or LCA studies.

**Figure 25: SUSI Concept**

**Figure 4 The SUSI concept, replicated from page 49 in deliverable 20**

The SUSI, described in detail in the ECTOS deliverable 20, Support tool, is a simple decision assistance tool presented as an interactive computer model. The model weighs costs, availability of the fuel, technology options, and environmental effects and combines

[6] Panagiotis, Georgousis & Sönke Behrends, (2005) final thesis for the completion of a Masters degree (2005) SUSI Development of Sustainable Urban Transport System Investigation (SUSI)A Decision Support System for the Usage of Alternative Fuels in Public Transportation

them with the settings that the user selects as input form his own local conditions. The data bases were upgraded from handbooks that already existed in the[7] Transport Research Institute in Stockholm and the traffic and environment department at Chalmers Technical University in Gothenburg in Sweden[8]. The model informs and compares various transport choices so that the user can better understand the differences, opportunities and the stakes that are at hand. At this stage the model is ready for further input from demonstration projects to become really useful but the framework is ready.

## 3.6 *General conditions in Reykjavik*

The fc-bus project was carried out in Reykjavik, the capital of Iceland. During the winter the mean temperature is -2– 0°C in January and +10–12°C in July, the coldest and the warmest months respectively. All traffic must keep the headlights on during all times of driving. The topography is quite even; the highest peak being about 120m, yet the highest driven altitude was only 80m – at the hydrogen station. The relative bus routes are presented in context with the fuel efficiency study but the fc-buses were used on various routes within the whole public transport system most days between 7:00 and 14:00 o'clock, driving the distance of 120 – 200 km/day. Total distance driven between Oct 2003 and Feb 2005 was 65.000 km. In the beginning 15 bus drivers were trained to drive within the ECTOS project but soon the number of trained drivers had reached 30.

[7] TFK Transport Research Institute: *Environmental Handbook for Transport Purchasing*, TFK Transport Research Institute. Stockholm, 1998.

[8] For further details contact Magnus Blinge *Division of Logistics and Transportation* Department of Technology Management and Economics Chalmers University of Technology

# 4 Prices, values, income, benefits

This section describes only the costs and benefits that can be price tagged. The costs of the planning, construction phases and operation of the project are booked in both Euros (€) and Icelandic kronur (Ikr). In this report the cost is only presented in€ and the currency rate is set at 80Ikr =1€. The section contains descriptions and discussion on total cost factors for the infrastructure and the buses and those benefits that are discussed in the following sections can be accounted for in normal bookkeeping and are listed according to the description given in a guide to cost-benefit analysis of investment projects which was prepared for EC's DG Regional Policy[9]. Social benefits and environmental benefits which are probably more valuable than all the costs related to the project will be described in chapters 5-7.

## 4.1 *Construction of the fuel station*


**Figure 5 The station on 31st of March 2003, four weeks before the inauguration.**

The first step towards the operation of a hydrogen system was to construct and test a hydrogen fuel station in Reykjavik. At the onset of ECTOS an estimation of costs and operations was presented as shown in Figure 9. It was foreseen that the size of the unit would not be of an optimal size but the initial investment cost would also have to be affordable. The station at Grjótháls makes 60 Nm3/h under approx 14 bar pressure and then a compressor raises the pressure up to 440 bars before storage. The station was said to be of a pre-commercial type that need to be tested before public use. Its construction should not deviate too much from a station of this

[9] Guide to cost benefit analysis of projects Evaluation Unit DG Regional Policy Prepared for the European Commission (Structural Fund-ERDF, Cohesion Fund and ISPA).

type which could be used for public service after the test period. The municipality did not show active enthusiasm towards ideas to test the new energy technologies and make them visible in the city profile. The authorities did not offer new well situated lots for the construction of the hydrogen station according to the retail oil company. This situation is though not considered at all as protest against the hydrogen concept per se but new sites for fuel stations became a sensitive political issue in the late 1990s. Therefore the selection of site took a long time and in the end the oil company Skeljungur had to sacrifice one of its best grounds for the station; a site that had been in high demand from other service companies[10].

The hydrogen station was built at a conventional gasoline station in the outskirts of Reykjavík. As such the station became the "world's first hydrogen refuelling station built at a conventional gasoline station". The partner group put high emphasis on designing the station so that it would be easy to operate, show the state of the art and offer high visibility. It was considered an important PR object for Shell Hydrogen.


**Figure 6 During the inauguration; from left Mrs Valgerður Sverrisdóttir minister of industry, Jeroen Van Der Veer, Shell Hydrogen, Mr Jon Björn Skulason CEO of Icelandic New Energy**

The establishment plans raised public interest. During the preparatory phases the plant was introduced to the neighbouring industrial plants with a letter. The reactions were very positive and no complaints were filed.

The construction took 8 weeks after the site had been prepared and the opening ceremony was held on April 24th 2003 when a DC $H_2$ Sprinter became the first vehicle to be refuelled with hydrogen.

#### 4.1.1 Equipment

The selected equipment for the ECTOS project was so-called turn key solution from Norsk Hydro Electrolysers[11] (NHE), meaning that NHE supplied all the equipment to produce the hydrogen, compress it, store under pressure and supply it at 440 bars to the buses. After installation the station would run without major complications on site. The equipment was delivered in special containers which were simply hoisted on the site (see fig Figure 7and connected to function as a whole. ECTOS deliverable no 10 describes the components in detail, but the general description with an outline drawing is to be found in the second ECTOS newsletter at the website of the ECTOS project: www.ectos.is or more accurately at: www.ectos.is/newenergy/upload/files/utgefid_efni/2nl.pdf. The equipment cost was 1,300,000€.

[10] Personal communication with Mrs Margrét Guðmundsdóttir, retail manager of Skeljungur
[11] Norsk Hydro Electrolysers has a webpage: www.electrolysers.com

#### 4.1.2 Design

As this station was the first hydrogen fuelling station to be build at a commercial gas station site the PR value of it would be significant. Skeljungur[12] in Iceland and Shell Hydrogen[13] decided to add to the stations' appearance in an elegant and modern way on top of meeting the set requirements for technological necessities and maximum safety. The designer's office Conrad in London was appointed to the task and the station became one of the most frequent mentioned undertakings of the Dutch Royal Shell group in 2003 and 2004[14].


**Figure 7 The station seen from the west. The panels in the background to the right carry texts and drawings that explain in Icelandic and English what is hydrogen, how it is made and used in fuel cells**

#### 4.1.3 Buildings

Due to the simplicity of the concept the building structure only consisted of ground preparation and concrete and hard plastic walls around the operational equipment. However the due to the fact that the station is situated beside the highway connecting the city and on a gasoline station where there is quite a lot of heavy vehicle traffic, the health and safety inspection of Reykjavik demanded that walls around the station should be reinforced to withstand an eighteen tons' truck on fire, driving at 30 km/h into the fence. Therefore outer walls and extra effort in the connection phase which exceeded the construction cost budget had to be met by the partners. In addition to this the station needed to have a lightning rod installed and an emergency shower for the workers in case of accident with e.g. lye. These extra security requirements cost approx. 100.000€.

[12] The oilcompany Skeljungur has a website on the station: www.skeljungur.is/category.aspx?catID=275.
[13] Shell Hydrogen has a website at: www.shell.com/home/Framework?siteId=hydrogen-en.
[14] Personal communication from the PR department of Shell


**Figure 8** **The hydrogen station (to the right) was built beside the main highway that connects the city with all rural areas. It stands aligned with a normal gasoline station (to the left) a coffee and snack bar (in the middle)**[15].

### 4.1.4 Total construction costs

The total construction cost for the station exceeded the budged because of the short construction time and the last minute security additions. The total construction cost including equipment was therefore about 1,400,000€ without the PR design which is irrelevant for the ECTOS budget.

## 4.2 *Operation costs*

The Hydrogen station is designed for remote operation and therefore no staff should be needed on site on permanent bases. No major maintenance budget and plans were made because the warranty during the first two years should cover regular and normal maintenance cost, i.e. changing oil in compressor, changing water purifier cartridges etc. This cost was estimated to become approx. 20.000€ during the 2 year demonstration phase of ECTOS.

Skeljungur started their operation on the bases of operating an unmanned station but as time passed the operation of the station showed to be somewhat more complicated. Therefore Skeljungur decided to hire a subcontractor that knew how to handle hydrogen technology to monitor the operation. The operation cost can be set into 3 main categories:

### 4.2.1 Skeljungur internal costs

This includes the cost of Skeljungur staff, travelling cost to and from meetings with the partners, technical designers and project meeting and other indirect operation costs. This amounts to about 207.000€ in total for the total ECTOS period.

[15] Areal photo from the Reykjavik city live viewer: www.Borgarvefsja.is.

### 4.2.2 Energy costs

Reykjavik´s Energy supplies the station with electricity. Cost of electricity during the project period was just over 83.000€. A lower rate than the average public consumer price for electricity was negotiated especially for the project with the wholesaler. The water is provided from the same supplier but instead of charging pr unit used the water tax is a set as a proportion of the real estate taxation.

### 4.2.3 Maintenance costs

The testing of new technology proved to be more costly than expected. Repairs and modifications were needed in addition to regular maintenance costs.

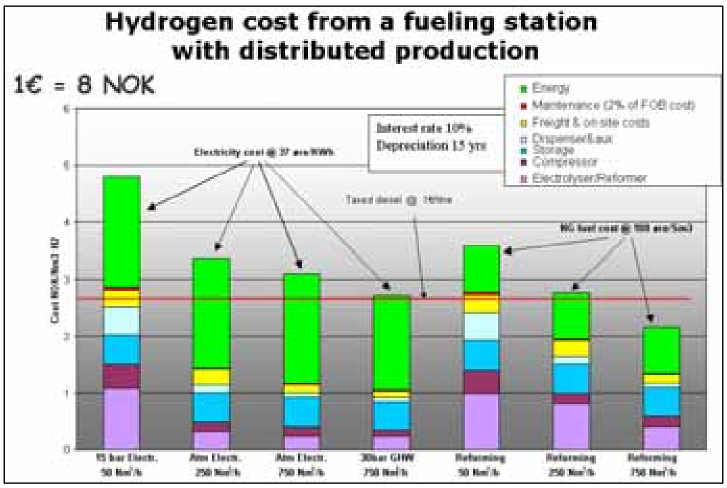



**Figure 9 Composed cost of various hydrogen production options as introduced by Norsk Hydro Electrolysers in 2003. The Grjótháls station is of the type shown furthest to the left where maintenance is hypothetically indicated as only 3-5% of the running costs.**

## 4.3 *Learning procedures*

Unforeseen incidents that occurred in the hydrogen station are well documented but the repairs and inspections raised the maintenance and repair cost considerably. The following factors added to the vulnerability of the hydrogen station:

- Flexibility built into the system which makes in situ experiments possible
- Operator access to override automatic sequences
- Faulty level sensor
- $H_2$ penetration trough diaphragm in the measuring cell
- Missing demister
- Insufficient training of operators
- Moderate sampling frequency made diagnosis difficult

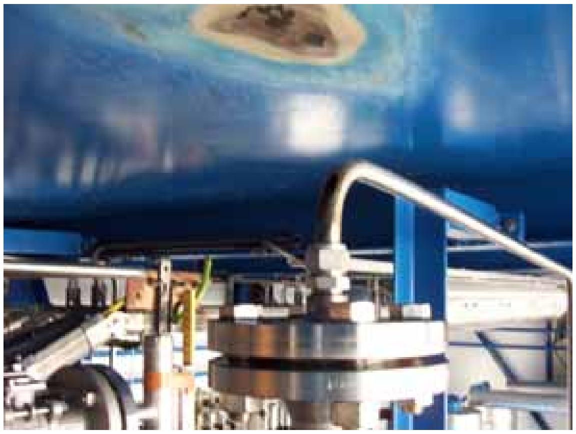


**Figure 10 A pipe gave away in the hydrogen station from pressure and aggressive chemicals. Therefore a thorough and time consuming inspection took place in 2004 followed by and modifications of the design**

The laboratory experience had not indicated the upcoming problems which were not only related to the chemical behaviour of hydrogen.

The lessons documented by NHE are that the organization should have been different; the station could not be run unmanned nor automatically at this early stage, ownership and responsibility for regular inspection and maintenance should have been clearer from the start and the operational procedures and documentation of the normal running phase should have been planned in more detail at the beginning. It can be stated afterwards that the complexity of running the hydrogen infrastructure was underestimated and therefore the learning process became very valuable for later integration at other projects.

The materials' technology was one of the more time consuming issues in ECTOS. The problems demanded new approaches, extra testing longer time and more money than expected. Three incidents were recorded during the ECTOS project time, two in Reykjavik and one in Hamburg in a similar high pressure electrolytic station. They involved both small yet important design failures, mistakes in the installation (missing level regulator) and material fatigue. The learning procedures for these went ***in general*** as follows:

- Investigation team established – a combination of NHE experts and onsite operators Theoretical investigation
- Site inspection
- Analysis of data and incident descriptions
- Final report and action plan composed
- Search within the very limited chemical literature, particularly on the behavior of Oxygen and Potassium lye under pressure
- Specific lab testing, appropriate material procurement – low availability on market both for the relevant material and test results!
- Installation of new parts and welding techniques had to be modified for the purpose
- Full inspection of all repairs and retesting
- Restart and hot testing
- Training of operational staff and new inspection and testing procedures
- Hazopreview

None of these steps was straightforward as the station was truly a pioneering test for the set conditions. A more detailed description of each procedure, the changes in material selection and new approaches in the hydrogen station design was given at the Hy-Pro-Files conference.

The cost composition for running the hydrogen station changed considerably from the initial plans. In light of the experience the inspection of all subcomponents gave rise to detailed discussion between all parties involved. The lessons learned are undeniable extensive and all the findings and new approaches will be built into the next generation of similar electrolytic stations.

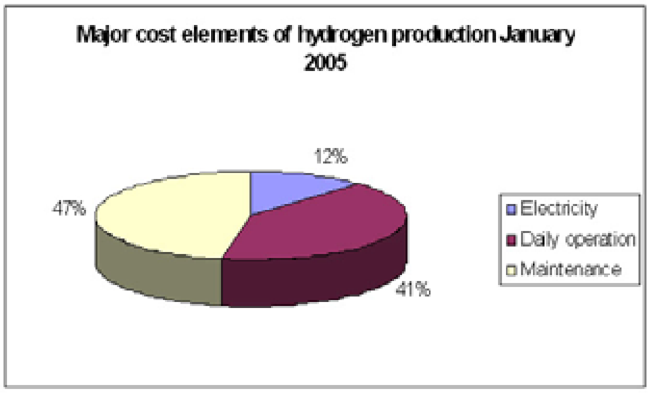



**Figure 11 The actual cost composition of running the hydrogen station. Refer to the suggested brake down of costs in figure 8.**

The underlying reason for the problem is most probable the difference in designing and running a lye-based electrolytic system under pressure and heat compared to a system which is kept at atmospheric pressure.

The strain on the material is considerable and stopping the production causes even more strain than necessary because of eventual minuscule leaks of oxygen into the instalments.

## 4.4 *Price of ECTOS hydrogen*

The unit price of Hydrogen to Stræto, the bus operator, was set at a fixed price in the beginning of ECTOS and should only reflect the variable cost, Ikr 326,14 or approx. 4€ per/kg. The city of Reykjavik decided to bridge the gap between the costs of running a bus on hydrogen compared to one that is run on diesil fuel during the project period. – See also the section 5.7: Conditions for further planning in Iceland which gives insight into which factors need to be considered when speculating on the eventual development of prices of fuel in Iceland.

## 4.5 *Cost related to the fuel cell buses*

Each fc bus cost 1,3 million€. This included warranty and maintenance of 2 years and only for testing. They were delivered with the interior installations except for the payment mechanism, signs to the passengers etc. The exterior design (see Figure 12) was executed by an Icelandic agency and paid again by Skeljungur[16] .

[16] Guðmundsdottir Margret, personal communication Jan 2006

**Figure 12 The exterior design is a play with the concept that hydrogen is derived from water and becomes water when used in fuel cells. A water molecule is displayed on the doors. When it opens the molecule splits into oxygen and hydrogen**

The maintenance league received work orders both from the bus manufacturer and the fuel cell provider. The composition of the work orders are shown in Figure 13. As can be seen a 25% of the work orders is to upgrade either small parts of the systems or the computer system that monitor and synchronise the various systems on board the bus. To name an example: the alarm system to warn drivers about any variations in pressure or load on the batteries etc. The warning system was made less sensitive to normal fluctuations when there was no need to stop the vehicles. As there are many new components that are put under test in the system then troubleshooting – guessing and finding out what the actual problems are the most numerous work orders while real repairs – which can be about any component in the buses accounted for 20%.

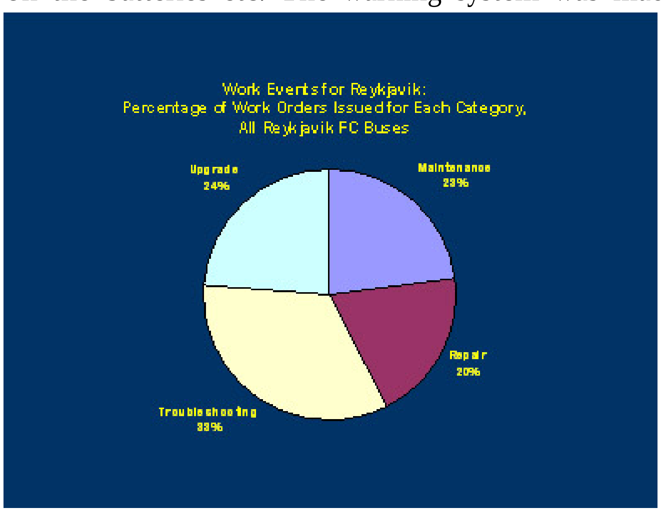



**Figure 13 Reparation of any component within the 3 vehicles were 20% of the filed work orders in the maintenance bay.**

## 4.6 *Lessons learned*

The reliability of the fuel cells grew during the demonstration phase. At the start Ballard, the provider of the fuel cells set a high alarm level for the vehicles in order to prevent any mishaps and protect the most expensive parts within the project. During the first weeks of driving the vehicles sometimes gave a red alert signals for little reasons, and the drivers called in to the maintenance team. In a few cases the vehicles were towed to the maintenance bay but were put back on the streets shortly afterwards because there were no real failures. New upgrades of several sub-mechanism from Ballard were installed continuously and the buses seized soon to give false alarms even if the monitoring computers read any fluctuations of capacity in the various components. Continuous new instalments of hardware and software made the mechanism more reliable and decreased downtime[17] and increased the fuel efficiency already during the first months.

Some examples of these minor changes are as follows: A purge line was connected to the exhaust pipe, instead of a diffuser fan, to reduce the noise level. The heating cartridge of the freeze protection was moved from the highest point of the loop where the temperatures measured differently from the lowest position. Temperature control for the freeze protection, was read with a remote device. Thus the night-guard could send an alarm via mobile SMS to the maintenance staff as soon as the temperatures dropped to a critical level during the night. Eventually during the project period the buses were parked inside the maintenance bay for protection.

[17] Jonsson, Gunnar Thor, the head of the maintenance bay, personal communication May 2005

# 5 Assessment of Social Acceptance and Impacts


Most of the information and discussion in chapter 5 are based on the ECTOS deliverable 12: Assessment and evaluation of socio-economic factors.

**Figure 14 The bus drivers took a lively interest in the test drives**

Three surveys were carried out in order to estimate public opinion and acceptance of hydrogen as a fuel.

The ECTOS project started officially 1st of March 2001. The first months were used to plan and organise the upcoming work before the tangible milestones were erected. One of the tasks was an extensive survey made by the Institute of applied Social Science at the University of Iceland to map the public opinion and acceptance of hydrogen before the fc-buses were introduced in the traffic. A second survey was undertaken with commuters at the mid term of the ECTOS project. Short questionnaires were put to the drivers of the buses two times during the project.

## 5.1 *The first public survey:*

The title of the first public poll on hydrogen, conducted via telephone, was: "The opinion of Icelanders of hydrogen in Dec 2001[18]"; notably two years before the $H_2$fc-buses arrived on the streets.

The purpose was to find out if public opinion might become an obstacle to the general introduction of hydrogen as a fuel in Iceland. In the case that that the public opinion would act as a barrier in the implementation then the ECTOS team had planned a strategic launch of information about the emerging hydrogen technology. The strategy was published in Del 4 in 2002.

The outcomes were very informative: The public opinion was very positive and therefore no barriers raised by public fear or reluctance were detected. This outcome made it possible to go ahead with the execution of the project and use it as the source of accurate information from first hand experience. Information was always fed back to those who

[18] Thorolfsson, Aevar (2002) Afstaða Íslendinga til vetnis í desember 2001, Félagsvisindastofnun Háskóla Íslands, Jan 2002, Unnið fyrir Íslenska NýOrku. . Website of Institute: www.fel.hi.is.

showed interest but no „propaganda material" was launched at the onset of the tests; Time and money was saved and yet sound information went to the public through channels that

**Figure 15 One of the best allies in spreading information and exercising the project participants in disseminating education and information were the association of senior citizens. They have time, interest and grand children**

disseminated the material even further such as teachers, newsagents and interest groups that asked for information during the whole project period.

## 5.2 *Public acceptance during the bus demonstration*

Interviews were undertaken in Icelandic in March 2004. Three students from the University of Iceland led passengers on board hydrogen buses, ordinary diesel buses, pedestrians in the street and neighbours to bus routes through a list of 10 appropriate questions, 50 individuals in each category but most of the questions were the same for all 200 interviewees. The response was 99,5%. Only a few of the topics are presented in the following section.

### *Box 2 The main results from a questionnaire*

- **A vast majority of the respondents, 92%, claimed to look positively or very positively upon the tests that are now made with Hydrogen as fuel.**
- **86% of the respondents claimed to be positive or very positive towards the development of using hydrogen as the main fuel for buses, cars and vessels.**
- **36,5% of the respondents say that the price for hydrogen may be set higher than that of gasoline during the introductory stages.**
- **78% of respondents claim not to notice change in the level of noise between the fuel cell buses and normal city buses.**
- **A vast majority of the interviewed connect the concept hydrogen to neutral or rather positive phenomena such as water and clean environment but less than 3% to negative thoughts such as explosions.**
- **48,5% regard hydrogen to be a safe energy-carrier**

## 5.3 *A few examples from the survey*

A vast majority in Reykjavik showed a positive attitude in this survey towards the demonstration with hydrogen buses. Also a great majority (86%) claimed to approve of the idea that hydrogen should take the role of being the main fuel and replaces oil products. Still no fears or barriers on the public side could be detected.

The additional information recognizable from this survey is on one side the positive attitude towards the accepted price range during the eventual introduction of hydrogen as a fuel and the reluctance of the public to notice the effort made to hit the demand for information. Those who were on board the fc-buses for example – even regular customers had not utilized the available short and concise information brochure on board the very same bus they were riding. The respondents also asked for more information for the public school system, - even though an earlier effort had been made specifically to inform teachers and pupils. A conclusion might be that the public expects information to come through the channels they are used to use such as schools, TV or radio channels. Yet compared to the first survey when 93% of the respondents complained that there was not enough information available, then 45% complaining about the same thing three years later can be interpreted as a successful effort.

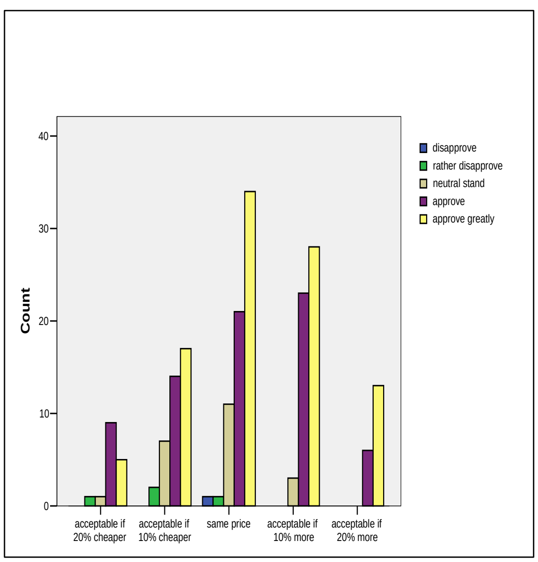



**Figure 16 Correlation of attitude towards using hydrogen as a fuel and the willingness to pay.**

In context with the acceptance of a set price range for hydrogen during the introductory phases several correlation tests were made to find out how various factors influence the general public acceptance. Figure 2 (taken from section 4.1. of the appendix III) the following correlations may be made:

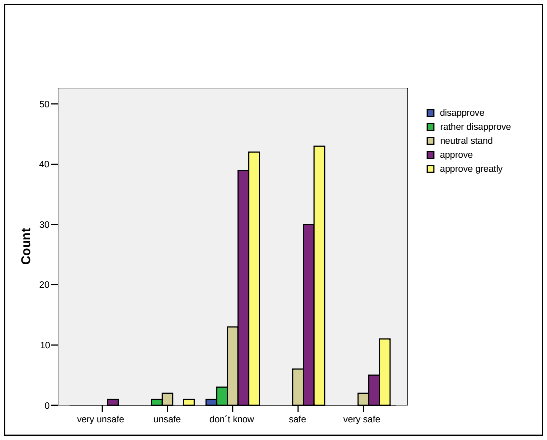



**Figure 17 Correlation of the attitude towards safety aspects of hydrogen and the acceptance of hydrogen as the main fuel for transportation**

**Box 2 *Why water?***

**Two explanations are herby offered as to why Icelanders make the connection between hydrogen and water. One may be the linguistic relation between the words "vatn" (water) and "vetni" (hydrogen). A similar relation is also seen in German; "Wasser" (water) and "Wasserstoff" (watermaterial, water-stuff, hydrogen) and Swedish: "vatten"(water) and "vete" (or "vetgas" as hydrogen gas). Even though the Greek concept hydrogen has the comparable connection to hydro (water) as Wasserstoff has to Wasser, then those roots are not used in English for the common word water; water is again related to the Norse roots in vatn!**

**The other reason may be that the electrolytic technology is well known amongst the public; it has been somewhat of a tradition within the former public fertilizer-plant (in operation between 1945 and 1995) to make hydrogen via electrolysis from water, whilst most other societies would see hydrogen deriving form oil refineries.**

Those who hold a negative attitude towards hydrogen as a fuel (blue) only show up in the category: equal price for hydrogen and gasoline. The green columns stand for those who claim to be fairly reserved towards accepting higher prices for fuels – they would only accept hydrogen if it were to be 10 – 20% cheaper or up to the same price as gasoline. Those who reserve a neutral stand towards using hydrogen as a fuel (sable) show up in all price suggestions except if were to become 20% more expensive than gasoline. Only the violet column (a positive attitude) and the yellow (a very positive attitude) show up in the whole price range.

Analysing the correlation of these answers to the statements about what the same respondents connect to the concept hydrogen then 51,6% connects these to environmentally friendly fuel and 34,7% to water.

The correlations may indicate that those who claim not to know enough about the safety aspects of hydrogen still hold positive attitude towards hydrogen as an energy carrier, probably mostly because of its clean environmental quality.

Finally the respondents were invited to add comments to the questionnaires. Either they could add their own comments and thoughts or they could express what they want to know. The results are shown in Figure 18.

A correlation check was run between a positive response to hydrogen becoming the main fuel for buses cars and ships and the responses concerning hydrogen as a safe fuel. The survey reveals a slight correlation between the two statements. 44,5% of the respondents that consider hydrogen to be a safe or a very safe fuel also claim to be positive towards hydrogen becoming the main fuel for transportation. The percentage that claimed that they did not know if hydrogen is a safe fuel 40,5% still claimed to have a positive attitude towards the issue.

Following is a list of items that respondents mentioned as being of interest to them. The number in brackets indicates how many made that statement.

Three of these issues are actually explained in the brochure that lies at the entrance of the buses freely available for all passengers. In the age group 15-25 many individuals claimed not to know much about safety aspects of hydrogen. Therefore information about this issue should preferably be directed at this age group.

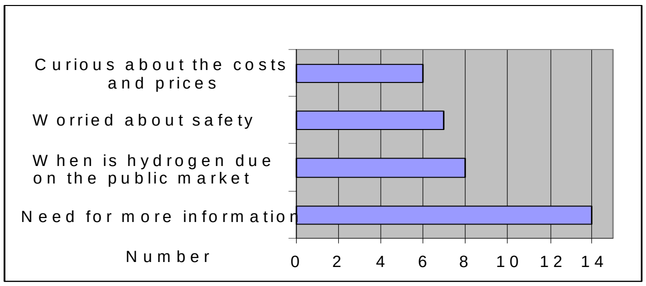



**Figure 18 Respondents free comments**

While asking people about what comes first into their mind in connection with the concept hydrogen then 84,4% of those who mentioned water as their first connection also claimed to hold a positive attitude towards hydrogen as the transportation fuel. 85,1% of those who connect hydrogen with environmentally friendly fuel is also positive towards hydrogen. Therefore those who do take a positive stand towards using hydrogen may do so mostly because of its environmental virtues. Connections to dramatic images of hydrogen such as expensive technology and a burning Zeppelin are quite rare.

A majority of respondents do neither notice the noise nor the emissions from the hydrogen buses. Passengers of diesel buses mostly classified emissions from those as being polluting and very polluting. Again these outcomes indicate that the majority of the public is aware of the difference in nature of these two emission types. The deliverable 12 also describes positive outcomes concerning the fc-buses and sound pollution.

Lastly the public claim that there has been little information available about the hydrogen projects for the public. A few claimed to have noticed the announcement at the onset of the demonstration, but then little information to follow it up. A few respondents wanted to have more information about the performance of the buses and the hydrogen technology. At most people had noticed them in the traffic. Also those who claimed that they had not enough information about the safety of the hydrogen technology asked for more information for the public.

## 5.4 *The outcomes of a questionnaire within the bus drivers' group*

In April 2004, fifteen $H_2$ fc-bus drivers, see Figure 19, were asked about their experience from driving the fc-buses. The survey was an initiative taken by the CUTE project leaders in Luxemburg. The results show that bus drivers in Reykjavik evaluate the test as an important step towards „What eventually has to become". The bus drivers as a whole describe the tests as a pleasant experience, the buses are quicker, more silent and are met with more positive reactions then they expected.

**Figure 19 The happy Nordic champion bus drivers all participated in the hydrogen bus experiments in Reykjavik[19].**

Only one driver lists a negative experience: „I am stressed to know that the bus I am driving is extremely expensive and I tend to get a little anxious during hydrogen bus shifts".

„I am very happy to be one of those who drive a hydrogen bus because the passengers are glad when they climb aboard. I like to surprise my regular customers when I arrive on a hydrogen bus, they take it as granted that a bus arrives punctually and a normal thing that I am the driver, but I notice their smiles when I arrive on a hydrogen bus". – The survey is incorporated in the CUTE reports.

In March 2005 Icelandic New Energy plus one if its major shareholders threw a party for all those involved in the ECTOS project. It was a very pleasant event indeed because all the bus drivers celebrated. They thanked their internal coordinator Rögnvaldur Jonatansson for pulling and pushing for their best performance within the project.

## 5.5 *Comparison to surveys on hydrogen acceptance from other locations*

Box 3 shows a few outcomes from a comparable International survey made in 2003 and focused on hydrogen and energy questions. This survey was conducted in three cities in equally many countries. These locations were particularly selected because of their participation in the upcoming CUTE project[20]. The outcomes were published by the LBST agency in Germany [21].

Similarities between the outcomes from Reykjavik are quite obvious. In all cases a majority claims to have a positive stand in general towards the introduction of Hydrogen as a fuel, the women would like more information and the levels of education influences the claimed need for more information.

[19] Quoting the news on the website www.bus.is.

[20] See the introduction to the paper for reference on the CUTE project.

[21] Altman et. al, 2004 Accept H< Social acceptance survey of hydrogen and fuel cell technology in London, Luxemburg and Perth Australia. LBST

**Box 3 *Results from AcceptH2***

**Within the EU-funded AcceptH2 project, surveys of the general public about perceptions of Fuel Cell buses and hydrogen and the willingness to pay more for riding clean hydrogen buses were carried out in London, England, Luxembourg and Perth, Australia before the start of hydrogen bus demonstration projects in these cities. Preliminary results of these "before" surveys were:**

**The support for hydrogen and fuel cells is generally high.**
**The knowledge about hydrogen and fuel cells is rather low.**
**Males and people with a higher formal education have a higher knowledge on hydrogen technologies than females and people with lower education.**
**Hydrogen is connected to positive (environment, etc), negative (bomb, explosive, etc) as well as neutral associations (physical properties, etc) even though the neutral associations are in majority.**
**There is practically no opposition to the introduction of hydrogen fuel and hydrogen vehicles. Many people are undecided and need more information.**
**In Luxembourg, more than 50% of all respondents would be willing to pay an additional fees to ride a hydrogen / clean bus.**

As in Reykjavik a majority is willing to pay higher fares for a ride in a hydrogen bus than other buses. The questionnaire yet puts hydrogen in a different perspective from what is done in Reykjavik. The accept H-surveys only offer passengers the option of paying a higher price for hydrogen bus rides whilst the options in Reykjavik include use of the suggested fuel also in all vehicles. In these cases it is probably the different energy-cultural context and general ideas behind the formulation of questions that dominates the essence of the public responses. In Iceland, natural gas or products derived from biomass have not been discussed as much as the option of using pure hydrogen as a renewable new fuel.

In 2004 a survey was also made amongst the passengers on board fuel cell test buses to estimate Hydrogen acceptance in Stockholm[22], Sweden. The approach to collect the passengers' views was different from the method applied in Reykjavik. Passengers were asked to fill out the questionnaire and send it in the post to the institute in charge of the survey.

The responding group was rather younger than the mean age of passengers and there were slightly more women that sent in their responses. The passengers in Stockholm did find the $H_2$fc- buses more comfortable and less noisy than the buses they ordinarily used. They also marked that they find environmental virtues, comfort, and low noise and punctuality very important assets for public buses. Yet, when asked about their willingness to pay higher bus fares while travelling with a hydrogen fc-bus then 63% of the respondents claimed that they would not accept higher fare- prices. It is not evident from the survey if the passengers connect cleanliness to hydrogen fc-buses. Yet, later news recount that there was a strong public reaction when the city of Stockholm decided not to support prolonged tests with hydrogen and fc-buses in 2005.

22 Harldsson K and Berg H:Passagerarnas upplevelser av brännslecellsbussar i trafik på linie 66. ÅF – infrateknik, Sweden 2004 09 21.

The differences in the outcomes need to be seen in the light of the different local energy and fuel options. In Sweden ideas for new fuels include bio-diesel, natural gas and alcohol from fermented biomass in this country of excessive agricultural wastes and extensive wood-processing within the paper and pulp industry. Iceland has concurrently low biomass productivity and combats local erosion.

## 5.6 *Various public benefits*

Lessons and influences that have spread throughout the society, either as an effort of the project partners or as voluntary dissemination of interest groups, add up to social benefits that are not readily measurable. The lessons and discussions have spread widely and only parts of these can be found as references such as written documents, news, and letters from the public, discussions in political circles, school projects, student projects and further studies only to name a few. How much value might the projects add to the image of Reykjavik as a tourist destination that promotes itself as being the cleanest capital in the world?

**Figure 18 There were many tourists that asked about the hydrogen buses at the city tourist information centre during the tests**

### 5.6.1 List of beneficiaries

The lessons from ECTOS can be organised according to the level of the beneficiaries and will not be subjected to more than necessary speculation; the issues are simply listed in Table 1 along with a category of beneficiaries and general comments. The issues can more or less be listed as effects and spin-offs from ECTOS, even though many separate initiatives have helped the actions and magnified the effects. Deliverable 12 gives 27 groups of beneficiaries that gained in their education, media information, training or general discussions on the hydrogen options. These influences can both be added to social assets in Iceland and other countries because of the foreign visits.


**Figure 20 Kids that attended one out of three hydrogen summer courses thrown by INE and the University of Iceland.**

**Table 1 Influence on society from the ECTOS project**

| Cate-gory | Level | Beneficiaries | Output | Comments |
|---|---|---|---|---|
| Admini-stration | Govern-ment | Icelandic officials and researchers | Hydrogen road map to be announced 27th of Jan 2006 | Leading researchers and institutes have supported an outline for the integration of hydrogen as a fuel for the future in Iceland |
| | Govern-ment | Icelandic politicians | Discussion in Parliament and political parties | The support crosses political boarders. New law that facilitates import and tests of cleaner vehicles passed in 2005. Hydrogen policy is built on the existing renewable energy policy |
| | International parliament members | Nordic, Australian, Japanese, Korean, Chinese, German, American, Indian | High level international involvement, IPHE, UN and EC | Pressure on Icelandic and international governmental bodies |
| | Muni-cipality | Community leaders and administration in Reykjavik | Participation in international policy discussions | Good financial support for further tests |
| | Com-munity | Politicians and officials | Interest and active curiosity – | Borrowing equipment and payment for presentations |
| | Com-pany | Staff of INE buscompany staff Maintenance staff | Skilled workers and researchers Trained drivers Trained engineers | The trained staff are a completely new social asset that can disseminate their speciality |
| Education | Academic | 28 Groups of international students from University level and colleges | 5 Masters' students within INE / University of Iceland Input into small projects, masters' students | MSc students, Icelandic, Greek and German. Phd course: 7 natioinalities, more than 50 indvideuals |
| | Academic | 5 PhD level | The themes are socio-technical | Icelandic, Belgian, German, Italian and American |
| | Academic | | BSc level in Mathematics | Study of the energy flow in the hydrogen station as basis for later comparison within the IEA[23]. |
| | Academic, metho-dology | students | An article on the comparison of social surveys | This one is in the process phase and will be offered to int. journals |
| | Academic | International scholars and the University of Iceland | Input to scientific papers and a book | Example: Journal of Hydrogen Energy and the Int. Journal of Cleaner Production; Book written by Th. I Sigfusson |

[23] IEA stands for the International Energy Agency more specifically; the hydrogen implementation agreement and the task 18 – integrated hydrogen systems.

| Cate-gory | Level | Beneficiaries | Output | Comments |
|---|---|---|---|---|
| | Academic | Icelandic scholars | 2 new surveys on public acceptance | New aspects of public opinion on energy matters have been collected, They are useful for the social and political sciences |
| | Didactics; education al institutes | Academic course for students and teachers at the Uni. of Iceland | Student papers | 7 nationalities |
| | College | Students and teachers | Presentations and discussions | Lively input from the audience |
| | Vocational college | Course for teachers | Training in a fc-laboratory | Icelandic Teachers in Germany trained in new technology and disseminating to their students |
| | Youngster s | Summer course | Trips, course, discussion | Voluntary summer school hosted by the University of Iceland |
| | Middle stage | Educational text on hydrogen as a fuel | Chapters in two public text books | One book is used for 5th grade the other for 8th grade pupils |
| | Pri-mary Schools | Animated film on hydrogen as a renewable energy carrier | A CD rom disk now offered on the web to the national school network | The disc was developed within the supported measure: € HYPORT ENK6-CT-2001-80449 sponsored partially by the EC, but has roots in the system that was used in the ECTOS |
| | Kindergart ens | Young children | Awareness raising even in the | Ride on the fc-buses, simple concepts on the environment |
| | Safety – alarm groups | Fire brigade, officials | Safety codes, training for health safety and environmental response | The HSE- plan and response to alarm can be used on further contexts and expanded to new ventures. These procedures is a new asset for society |
| Public Media | TV | The public – in the international meaning of the word. | Documentaries in French, German, Korean, Japanese, Finnish, Swedish, Danish and Norwegian, Icelandic | The renewable Icelandic energy chain seems to have a strong attraction on international media |
| | Journals | International readers | Articles made by staff from Newsweek, the Economist, die Stern, etc etc etc[24] | Journals and magazines in very high international esteem have used the ECTOS as a case study |
| | Children programs | The youngest audience | Our – Happy –Hour | A fun technical input to the most popular children's program in Iceland. |

[24] A detailed list of all media relations is given as an appendix see Annex V

| Cate-gory | Level | Beneficiaries | Output | Comments |
| --- | --- | --- | --- | --- |
| Spin-offs | National | Training course for vocational teachers | 15 teachers with specif training to teach about fc | |
| | National | Training facilities for further training and tests | National $H_2$ laboratory at IceTec | Several institutes joined forces and applied for research hydrogen laboratory and demonstrations to establish a laboratory |
| | Inter-national | Hy-FleetCUTE | | The social assessment will be applied to a broader spectrum |
| | Case study | IEA, hydrogen implementation agreement | Input for international learning | Systems from Canada |

### 5.6.2 Hydrogen tourism

During the ECTOS project many groups of people and of various origins wanted to have guided tours to the project facilities and presentations from the project partners. The University joined hands with Icelandic New Energy to organise presentations for the public and experts. Visitors from Japan were the most numerous, but groups from the EU, USA, Korea and the Nordic countries were also amongst those who paid INE a visit. The lists of visitors are available at Icelandic New Energy.

The Hydrogen tourism may have left up to 1.1 Mi€ in Iceland given the above figures.

### 5.6.3 Promotion for the public transport system

The bus operator Straeto surveyed the public discourse and media concerning the public transportation system. An increase in passenger count was not measured, but public buses were mentioned in the media more often during the years 2003 and 2004 when the hydrogen buses became visible, refer to Figure 21[25]. Therefore the ECTOS project may have had a positive effect at least on the image of the local public transportation company. Subjects like „modern and high tech" were mentioned, the media gave good coverage on the test drives and about 90% was positive coverage which is not often the case.

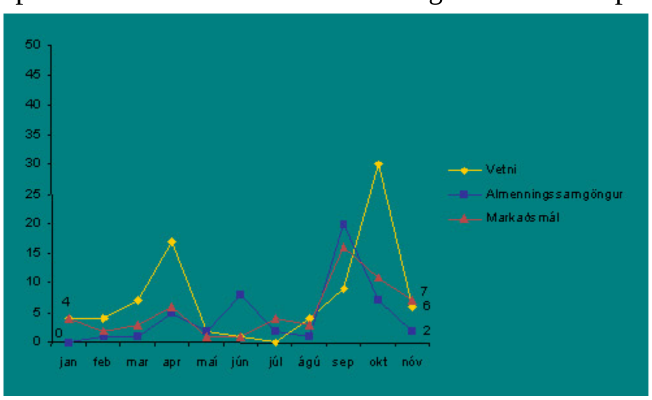



**Figure 21 The bus company was mentioned more often than before in the local media from October 2003 in context with hydrogen (yellow line) public transport (blue line) and marketing issues (red line)**

### 5.6.4 Saving the cost of emissions

As a final cost / benefit estimation the cost of emissions will be added to the list. In chapter 6 describes shortly the environmental savings, yet a few environmental issues could be accounted as cost savings. The Report Extern –E suggests a multiplying factor for the emissions that usually follow transportation. As discussed in later sessions on the impact on the environment, tons of SOx, NOx as well as CO2 emissions were saved, corresponding to

[25] Eiriksson, Asgeir April 2005 presentation at the HyProFiles

average emissions from diesel buses run for 65.000 km. This amounts to minimally to 4.300€ and the grease management in safe disposure for recycling 1.500€.

## 5.7 *Conditions for further planning in Iceland*

No direct price comparison will be made in this report between the current fossil fuel infrastructure nor to the world wide fuel market. Yet at this stage, a few figures will be use to present the general energy profile and economics within which ECTOS was carried out. The source of the information is the Icelandic Energy Authority along with the Ministry of Industry and Commerce.

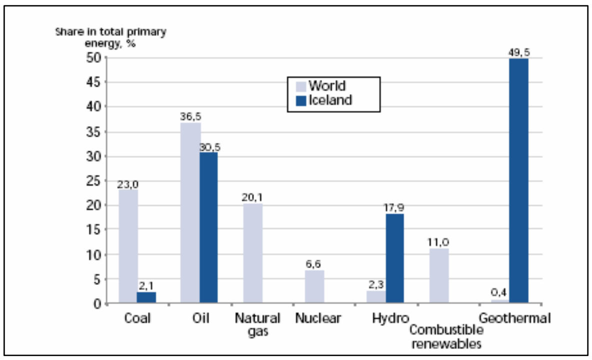



**Figure 22 The energy mix in Iceland compared to the world profile. As can be seen hydropower and geothermal energy play an unusually large role in the energy profile while natural gas and nuclear power do not show up. Oil still adds up to about 30% of the energy**

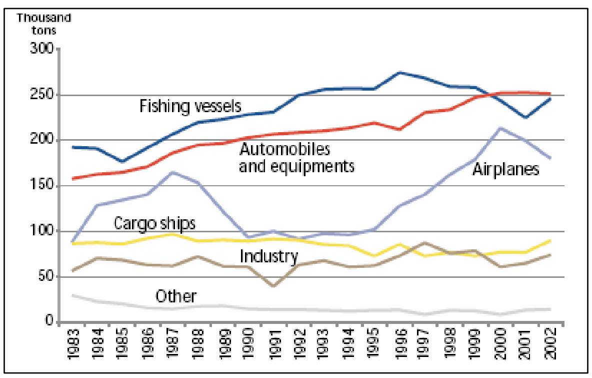



**Figure 23 The use of petroleum products by sectors from 1983 to 2003. The growth in demand comes from personal vehicles and transportation. A considerable amount is used by the fishing fleet, while industrial demand is meagre at the same time the industrial consumption of electricity grew a great deal[26].**

With the presented conditions it becomes a simple and logical extension of the local energy profile to make hydrogen from water via electrolysis from renewable electricity. Oil, coal, gas, even wood must be imported to Iceland as these sources do not exist locally.

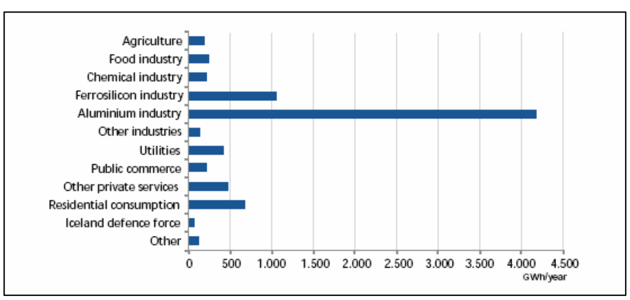



**Figure 24 Electricity consumption as divided between the various sectors. The first aluminium Industry was established in the 1970s and issues instead variations in the average price**

The history of using hydropower to run utensils began in 1904. Most urban communities had been connected to local grids in the 40s, rural areas got their electricity from regional hydro-power plants distributed on the national grid and after 1970 industrial plants have become the largest single users of electricity in Iceland. The demand from that sector will most likely double before 2020 but

[26] The National Energy Authority and ministries of Industry and Commerce. (Feb 2004): Energy in Iceland. Historical perspective, present status, future outlook. Available online at: www.os.is/Apps/WebObjects/Orkustofnun.woa/swdocument/932/EnergyinIceland.pdf

aluminium smelters need constant intensive electricity. The largest power plants are only constructed after long term contracts with the Aluminium companies have been signed.

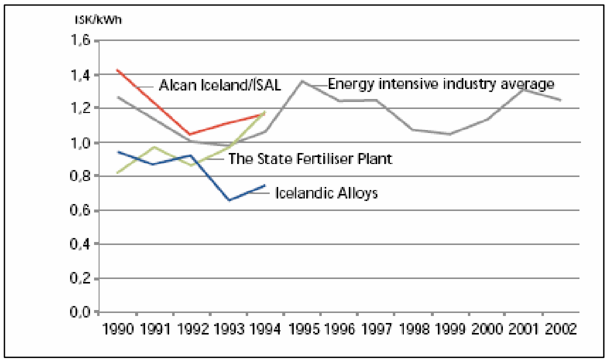



**Figure 25 Electricity prices for the metal industry from 1990. In 1994 the National power company seized to publicize the individual prices.**

The needed amount of energy to provide for a hydrogen economy in Iceland via electrolysis in optimal systems' conditions is estimated to be in the same size range as the electricity consumption of the metal industry in 2003; about 5 GWh annually. The bargaining power for small hydrogen stations is very different from that of the large industries.

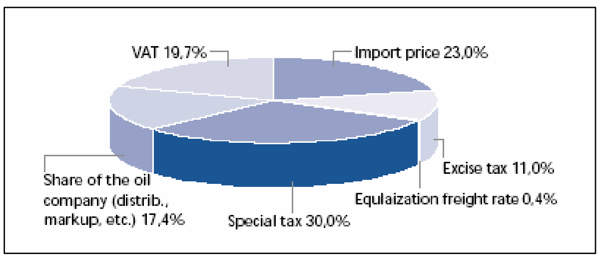



**Figure 26 The composition of the consumer fuel price in Iceland.**

The taxation and charges on petroleum products is quite high and Icelandic gasoline prices are among the highest in the world. When comparing foreseen prices for hydrogen and fuel cells on one hand and prices for equipment and fuel in the current transportation systems it must therefore be stated what is included in the concept price; production costs, initial investments, running costs, maintenance of the distribution systems, taxations and other charges. Changing from one fuel to another would effect the GNP of each country, but it is not possible to extrapolate to future scenarios from ECTOS alone, running a prototype of a hydrogen station to fuel only 3 buses which are also prototypes, not using full capacity of neither the station nor the buses. Many similar learning tests will have to be undertaken until any forecast for costs and prices can be reliably presented. The total system has been streamlined, the components optimised and mass production started. The costs of ECTOS may be high, but the value of the learning is also very high.

## 5.8 *Considering future production costs of hydrogen*

A specific price 2,35 Ikr/ kWh was negotiated for the electricity that was used at the hydrogen station during the ECTOS project. Normal rate for electricity to homes in Reykjavik is Ikr 7,97 pr kWh including 24,5% VAT (10€c). The expected production cost of hydrogen is given in a scenario presented in figure 8 and the following prerequisite: .

The current station produces 60 Nm3/h. It uses 91%[27] of the electricity for the electrolysis and the other 9% go to the auxiliary equipment of the cooling and other satellite

[27] INE (2005) Preliminary results from a study made by Thordarson , S. & Ö. Ulleberg, 2005

uses of the electrolyser. To compress Nm3 for storage at 440bars the compressor uses 1kWh.

The presumptions are the following:

- **Hydrogen production occurs in steadily larger stations, production rate in 2003 is 60Nm3/ h to 3,888 Nm3**
- **The hydrogen is produced in similar high pressure electrolytic station,**
- **The investment cost falls proportionally from 1.666.667 kr/Nm3 to 519.588 in 2020**
- **The price of the electricity is kept the same, e.i. 2,35Ikr /kwh,**
- **the production rate is raised from the current 60Nm3/h up to 3,880 Nm3,**
- **the energy efficiency is presumed the same (5,5kWh/Nm3)**
- **the monthly cost of maintenance is presumed to fall from 33.333Ikr/Nm3 to 2.577 in the largest plant.**
- **The gasoline price is presumed to increase in the same general pattern between 2001 and 2020**

According to this, ***untaxed*** hydrogen (***although NB the electricity carries VAT***) may become similar in price with ***taxed*** gasoline price (consumer price) within 10 years.

The most influential factors are the price of the electricity and the cost of maintenance. But even within the current technology the production cost can be lowered by simply running the station on a more constant basis, except during monthly inspections. During the ECTOS project the station was flushed with nitrogen and shut down during week-ends. No hydrogen was needed during Saturdays and Sundays (the buses were parked). Therefore the price may be sunk considerably during the upcoming semesters simply by using the buses and raise demand.

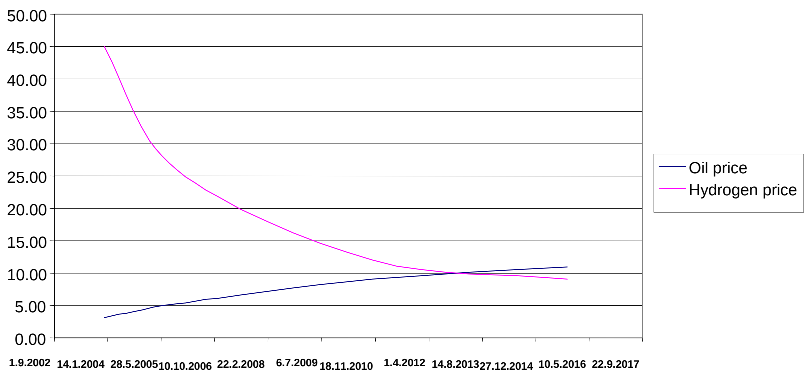



**Figure 27. A <u>speculative vision</u> of the development of fuel prices for the next 10 years in the Reykjavik settings. The presumptions are given above.**

# 6 Impacts on the environment

**Figure 28 Even though newer vehicles have less emissions than older generations, the quantity of emissions from transport is a world wide problem.**

Using hydrogen and clean and efficient technology within the transport sector may be the single most important mitigation action to prevent further effects on the Earth´s climate. How much change can be expected from a total substitution of gasoline and diesel fuel with renewably made hydrogen for buses and other vehicles? This question cannot be answered only using the outcomes of the ECTOS studies, yet they can contribute to the answer; tendencies can be predicted, and emission savings calculated.

ECTOS Deliverables 7 and 14 register the details from the air quality study and the fuel efficiency of the tested equipment. From those the following short interpretation can be given: The pattern for transportation has changed drastically in Reykjavik during the last decades (probably similar as elsewhere in Europe). People use private vehicles and the public transportation is used less and less. Yet the reason for testing hydrogen on buses has two main reasons: A fleet application is easier to monitor and the environmental benefits from bulk transportation is larger. Figure 29 shows the development of transport forms in Reykjavik between 1970 and the year 2000.

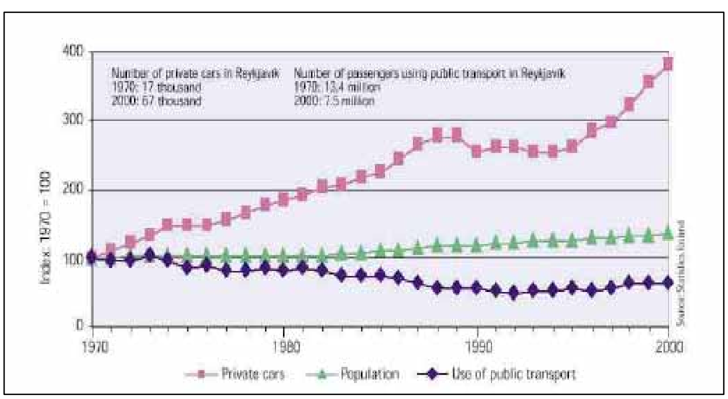



**Figure 29 Indices of the population, number of vehicles and forms of transport between 1970 and 2000. The percentage of commuters using the public transportation system fell down to 5,3 in the year 2005**[28].

Within the ECTOS the environmental study had two phases: Firstly an air quality investigation, secondly a Life Cycle Analysis on the whole energy

[28] The figure appeared in the Delivery 7. mid term Environemtnal report

chain and the current equipment and thirdly a Fuel Economy Analysis which tries to capture the main points in the efficiency throughout the fuel chain; a so called Well-To-Wheel analysis.

## 6.1 *Air quality*

The expected changes in air quality were reported in ECTOS deliverable 7 issued in 2004[29] – The Midterm Environmental Report. One of the relevant outcomes of ECTOS is a forecast of changes in the composition of air emissions from traffic. It is to be expected that only emissions from hydrogen vehicles becomes steam, or water vapour. For the time being fishing vessels and transportation emit about 50% of the $CO2$ from Iceland (see figure and substituting oil and gasoline with hydrogen within those sectors would cut down all air pollutants to a large extent.  The industry uses coal as raw material in the aluminium Industry.

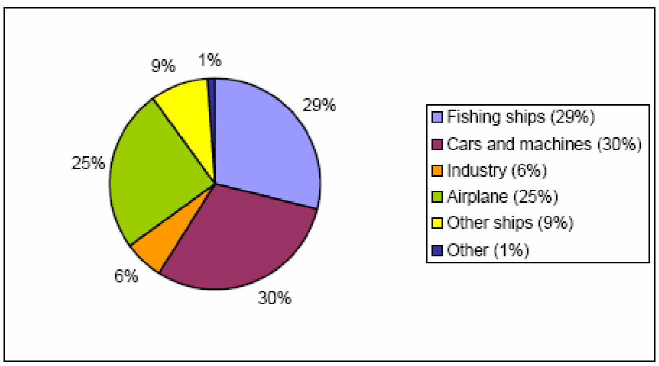



**Figure 30 Total use of fossil fuels divided by sectors in the year 2000[30].**

During the ECTOS project period news in various media reported about new applications of hydrogen and fuel cells. Fork-lifts, Ice rig sweepers, motor-cycles lighting equipment etc: Many machines can now run on hydrogen, still these account only as 1% of the usage in Iceland.

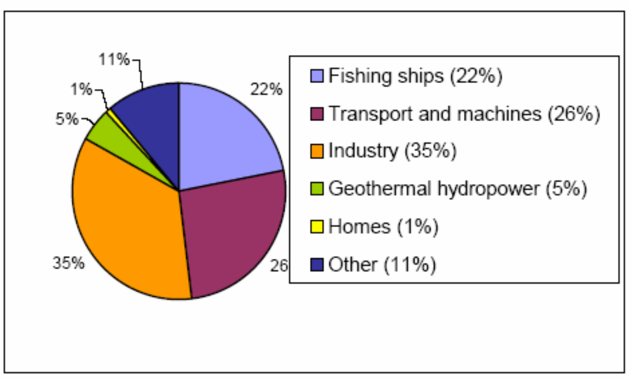



**Figure 31 Total release of CO2 divided by sectors in the year 2000**

The composition of cars in Reykjavik is 86% personal gasoline cars, 8% is personal diesel cars and 6% of the fleet is tucks of various sizes plus buses.

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[29] Skuladottir Bryndis, Hermann Þórðarson Oct 2003 ECTOS Environemtnal Evaluation of Air Quality ECTOS deliverable no 7 available online at: www.iti.is//files/{fa8f9b4d-c451-4b2e-9ca9-e78b536ffddb} ectos delivery7-enviro-midtermreport.pdf

[30] Figures 21 and 22 are taken from Vilhjalmsson, J (2001) the fuel consumption in Iceland. Proceedings from the Energy  convention held in Iceland May 2001, the Icelandic Road Administration

## 6.2 *Environmental aspects and Life Cycle Assessment*

ECTOS deliverable 16 describes the study in detail and the outcomes of ECTOS-LCA is compared to the test sites in CUTE as well, because the same type of vehicles were used in all cases and therefore the comparability is excellent. The fuel chain for the production of hydrogen will be set in focus.

One of the main drivers for using hydrogen within transport is undoubtedly the foreseen savings in emissions of carbon dioxide and other air pollutants from the vehicles operation. Yet, it is not enough to look only at one isolated part of an energy system such as the use phase; it has to be checked if the introduction of a new technology or fuel leads to so called “shift of burdens” which means that the environmental impacts are shifted from one life cycle phase to another place in the process. Therefore only an analysis that registers the inputs and outputs of energy and material from the source of the equipment components and the whole energy chain to the final usage at the exhaustion pipe or landfill facilities can give a comparable insight of the environmental impacts from any fuel or energy chain.

The life cycles of the hydrogen supply infrastructure and the bus system are shown in the following figures. All relevant aspects from resources over production and use to end of life are considered within the system boundary. Life Cycle Assessment (LCA) considers in addition to the energy demand also all other relevant inputs (resources / materials) and outputs (emissions to air / water / soil, wastes). Within the ECTOS LCA the following steps were analysed: the power plants, the electrical distribution system, the hydrogen station with its main components, plus the complete fc-bus system (production, use phase and end-of-life). The calculation of the Life Cycle Inventory (LCI) to simulate[31] and account for material and energy use as well as emissions during manufacturing, operation (incl. fuel supply) and End of life (EoL) for all the technical parts was done. It allows quantifying the environmental life cycle profile of fuel cell, Diesel and CNG buses and to determine the contribution of each system component to the total environmental footprint of the respective bus system in Reykjavik.

A preliminary LCA study was published in 2002 for the equipment and the energy mix in Iceland. The deliverable 16 is an actual case report, completed with all relevant figures from the ECTOS hydrogen tests (see Deliverable 16).

[31] The simulation program used is GaBi 4, description available online at: www.gabi-software.de

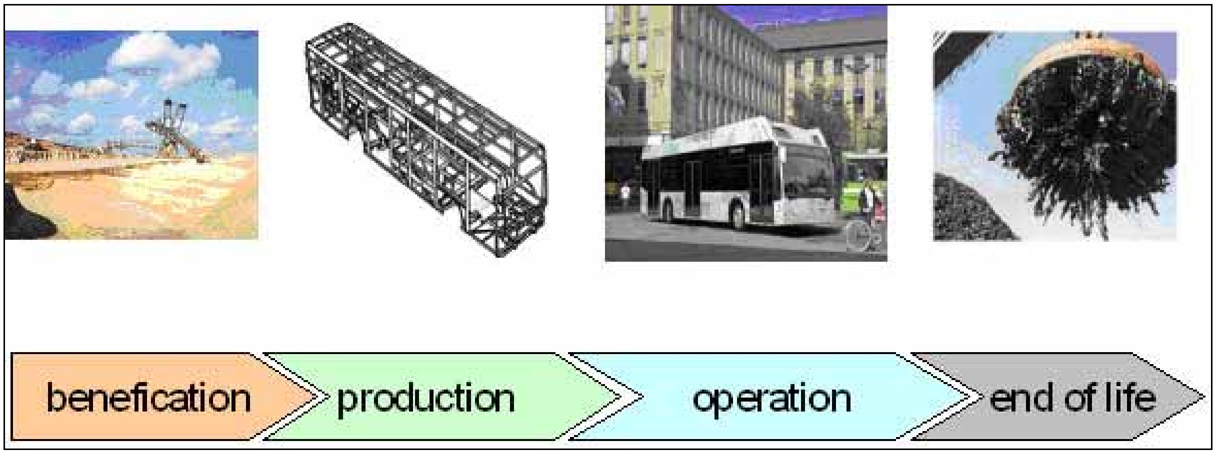



**Figure 32: Life cycle of bus system**

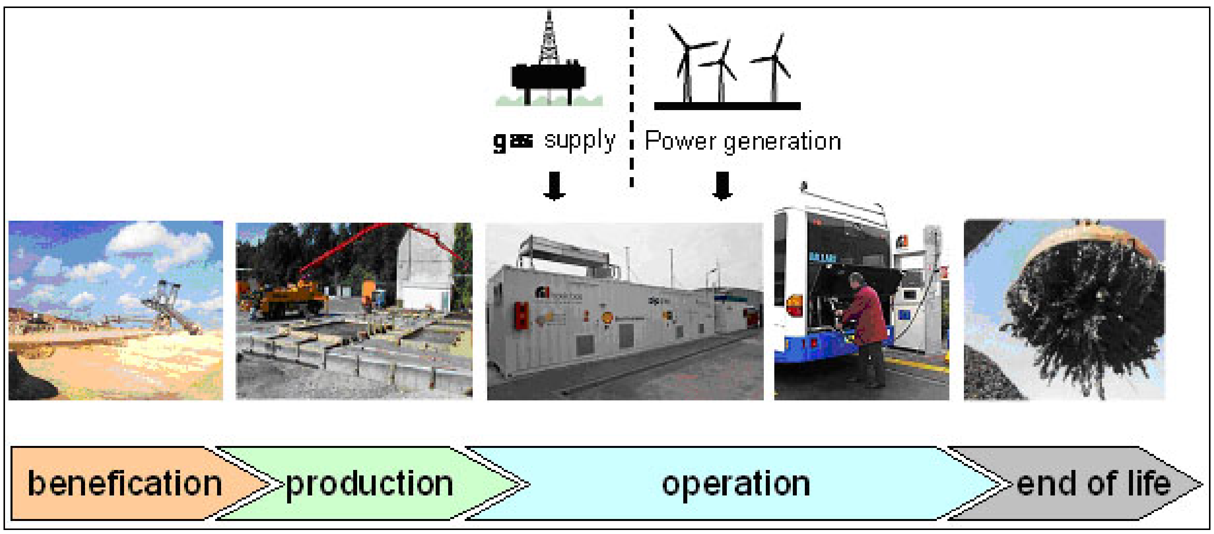



**Figure 33: Life cycle of hydrogen supply infrastructure**

The data for the impact assessment for the driving cycle of bus or fuel Well to Wheel analysis was collected specifically during two measurement periods; a fortnight in May 2004 and again in February 2005. During the measurement periods Ballard provided raw data from the computer that monitors the fuel cells in the buses, Norsk Hydro provided data from the hydrogen station and the bus-drivers filled in the readings that are used as background information from the normal driving cycle on the routes within the public transportation system.

## 6.3 *ECTOS – aspects of the fuel use*

The fuel economy is affected by numerous factors. How is the energy distributed proportionally to the demanded service such as lightning, heating, acceleration and to move the wheels of the bus and therefore the passengers? What is the effect of the number of stops and distance between the bus halts as well as the driving behaviour of the bus conductor? How does the load of the bus influence the fuel consumption for example? Or the type of route, the topography of the route and the difference in altitudes, idling, acceleration or other driving phases? All of these topics gave rise to speculations and simple tests but the outcomes are neither reliable nor representative for the hydrogen technology per se. ***Therefore no generalised conclusions will be drawn at this stage from the unscientific measurements and calculations that were undertaken within ECTOS. Still the outcomes will be used internally as benchmarking values within the consortium. The fuel efficiency for the system will not be made public for a while.***

The characteristics and tendencies that are discussed here do not represent the truth about the hydrogen technology in general or its future potential. What the studies can offer is to show specifically points that may be subjected to for further optimisation and what could be done with more accuracy in the research design.

## 6.4 *Learning from the WtW*

The energy efficiency of converting geothermal heat to electricity is only 18% at its best, but when the hot brine is also used for heating purposes then the total efficiency of a geothermal power plant rises to approximately 65%. The energy conversion of hydropower is higher. Given the grid mix for electricity in Iceland when the hydrogen reaches the tank or the Well to Tank part only 47% of the total energy is available compared to the energy from the sources. The hydrogen station has been run sub-optimally throughout the project period. It was built to only service the three fc-buses, and these do not create a demand that urges constant running on full capacity. Therefore the energy efficiency is lower than it might be at full capacity. A better fitting design around a larger production volume can be expected to show increased efficiency. Still the inherent losses in the infrastructure will not be overcome by the hydrogen The allocation of energy to the various components at the station showed that energy expenditure to cooling is higher than expected.

On the fuel cell buses the lack of compatibility of the auxiliary equipment (AC equipment) to the fuel cell system (DC system) seems to take some energy toll. Also, hydrogen needs to be constantly driven through the fuel cell in this design model, demanding hydrogen also during idling times. Therefore the hydrogen use is proportionally much larger per kilometre when there are many stops on the bus route. When driving the fuel cell buses on long distances the fuel economy is considerably better for each driven kilometre.
Yet, the GHG emission for the ECTOS hydrogen power train is only 1/3 of the in GHG emission for the Diesel power train.

**Table 2 CO2 emissions for the hydrogen drive train compared to emissions from the diesel drive train**

| [g$CO_2$ equiv./MJ] | Hydrogen Power Train | Diesel Power Train |
|---|---|---|
| WTW GHG Emission | 24,2 | 81,0 |

## 6.5 *Environmental impacts from the equipment*

The results from the Life Cycle Analysis of the system in ECTOS is presented parallel to other fuel cell bus trials in the CUTE Deliverable No. 5. But a few of the findings are listed in Box no6.

- Box 6 The main outcomes of the Life Cycle Impact assessment

- indicates a fundamental shift of environmental impacts from driving phase of the bus, as is the case when using diesel and gas as fuel, to the manufacturing phase hydrogen.
- The total emissions from FC-buses running on hydrogen from renewable energy are considerably lower than for other drive trains.
- The environmental profile of FC-bus system is highly dependant on the chosen H2 supply route and the total efficiency of the bus energy chain.
- When using renewable resources for hydrogen production, the manufacture of the infrastructure and the FC-bus determines the environmental footprint of the overall system. This means that emissions from manufacturing of hydrogen production facilities have a relevant share for routes using renewable energy sources, however on a significantly lower absolute level.
- A new element in the emission profile shows up H2S – deriving from geothermal electricity production. Its acidifying effects in the Icelandic ecosystem are subject of further research. A main point of discussion is the consideration of H2S which would eventually be emitted naturally from the geothermal fields, however on a different time scale.
- The FC-technology shows the potential to be able improve air quality in urban areas considerably. The FC-bus system shows the most advantages compared to conventional bus systems in terms of local environmental effects.
- Current FC- bus and H2 infrastructure shows significant improvement potential in terms of efficiency.
- FC System: The primary energy demand and CO2 emissions are dominated by H2 storage with a share of 36 % (mainly related to carbon fibre production) and the FC stacks, having a share of 37 %. The manufacturing process is only relevant for the primary energy demand since the electricity used during manufacturing of the FC drive train is based on renewable energy (96 % hydro power for British Columbia, Canada).

## 6.6 *Expected changes for the total conversion to hydrogen*

What happens in the environmental aspects if hydrogen would be used to replace fossil fuels within the transportation sector in Iceland? It is assumed that the total amount of gasoline and diesel that is burned in public and private transportation is substituted by hydrogen and fuel cell technology. Based on the energy consumption of the year 2000 for transportation sector in Iceland the amount of hydrogen for use in fuel cells is calculated.

A scenario about the environmental effects of the change of Icelandic fuel supply for transport from a conventional (fossil fuel based) to a hydrogen based one was analysed within the ECTOS project. The scenario with detailed description of boundary conditions and assumptions is included in the ECTOS Deliverable No. 16 – Life Cycle Assessment of the $H_2$/fc bus system.

The four-step scenarios all imply the full conversion of buses and 50% of the trucks but various portions of the personal cars, as this is the most numerous category. The total emission and the energy demand for the production of the necessary amount of $H_2$ is calculated from the LCA inventory of ECTOS project. The emission figures for the production of fossil fuels for the road transport represents the actual situation in Iceland and is based on inventory data for diesel and gasoline from an average European refinery. In addition to these emissions from the manufacturing phase, emissions from the utilisation of the vehicles are taken into consideration according to the statistical yearbook Iceland 2002. For vehicles and work-vehicles emission limit EURO II or EURO III (share each 50 %) for gasoline and diesel is assumed. The emission factors are weighted according to the mass of fuel consumed. Results are shown in Figure 34.

**Table 3 The scenarios for the figure 34**

| | |
|---|---|
| **Scenario 1** | Buses all hydrogen driven |
| **Scenario 2** | 100% buses, 50% light trucks, 15% petrol pass.cars hydrogen power |
| **Scenario 3** | 100% buses, 50% light trucks, 30% petrol pass.cars hydrogen power |
| **Scenario 4** | 100% buses, 50% light trucks, 50% petrol pass.cars hydrogen power |

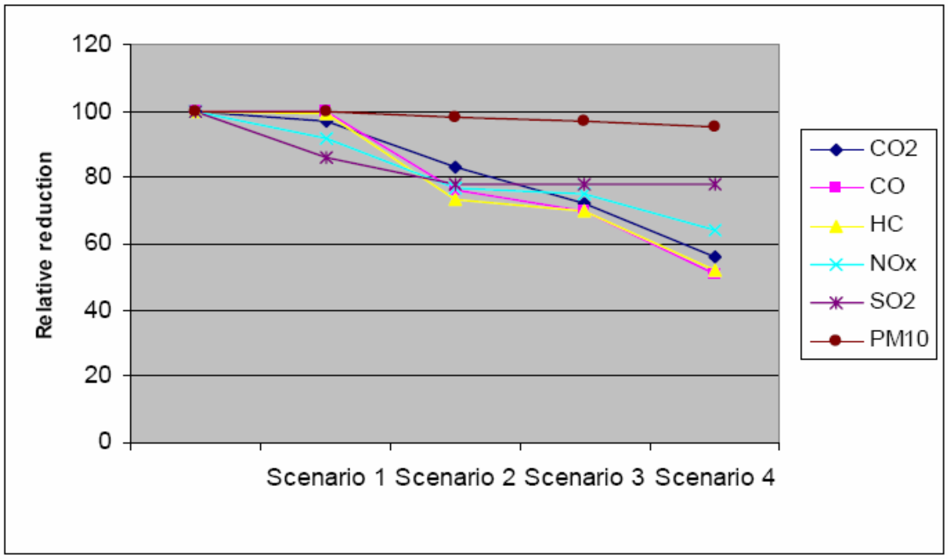



**Figure 34** **Outcome of the simulation from the given ECTOS scenarios refer to deliverable 11**

As can be seen there is a braking point in the concentration of sulphur compounds ($SO_2$ is used here as *pars pro toto*; it includes all forms of sulphur, $H_2S$ as well). It is evident that this happens because to a large extent only the large vehicles use diesel as the main fuel (even though indications are that smaller cars will run to a larger extent on diesel in the near future and in order to gain in fuel efficiency) and the sulphur emissions from geothermal vents within Reykjavik itself and the geothermal energy source used for the electricity generation.

The outcomes of the simulation indicate a drastic change in the concentration of most emission categories, but particulate matter, one of the major health hazards for people who have sensitive pulmonary systems (refer to Table 4), will not disappear in spite of conversion to hydrogen. Actually only 15% of the particulate matter arises from the fuel, the main part comes from the asphalted streets when vehicles with studded tires rip off the surface.

Both particulate matter and sulphur emissions have to be lowered by other means. But changes should be expected in other aspects. Currently hydrogen escapes from industry and refineries but its current effect on the atmosphere has not been followed in detail, yet no impact is currently evident. If hydrogen were to become an item for commercial transactions this loss might even be captured and most losses prevented because of its value.

Out of the tailpipes comes water steam and carbon dioxide, if the emissions will become pure water steam there is always a possibility to capture that in containers and thus prevent the humidity to condense on the streets in cold weather. These considerations are already on the manufacturers options for future vehicles. But the main exhaust gases from vehicles and their health impacts are listed in Table 4

**Table 4 Health impacts from the various traffic emissions. Health and environmental impacts depend on concentration and interactions between them**[32].

| Pollutant | | Health effects | Environmental effects |
|---|---|---|---|
| $NO_x$ | Nitrogen oxides formed by combustion of fossil fuels | Respiratory diseases | Acid rain<br>Visual effects<br>Global warming |
| HC (VOC) | Volatile organic chemicals, due to incomplete combustion of fossil fuels | Respiratory irritation<br>Carcinogenic effect | Global warming |
| PM10 | Airborne particulate matter (0-10 µm) from gas exhaust, asphalt and natural sources. Organic chemicals and heavy metals can adsorb to them | Micro particles entering lungs, can cause respiratory problems and diseases. Indications of carcinogenic effect | Visual effects |
| $SO_x$ | Sulphur oxide formed by combustion of fossil fuels | Respiratory problems and diseases | Acid rain<br>Visual effects |
| $CO_2$ | Carbon dioxide formed by combustion of fossil fuels | | Global warming |
| CO | Carbon monoxide due to incomplete combustion of fossil fuels | Cardiovascular system | |
| $O_3$ | Ground level ozone, formed in chemical reactions in urban environment | Eye irritation, affects lung function and immune system | Global warming, plant growth |

[32] The table is copied from the mid-term environmental report ECTOS deliverable 7 page 7

### 6.6.1 Mistakes in research design

There were many lessons learned during the research actions in ECTOS. Not the least concerning what to measure, how to measure and which significant correlations can be made.

When using equipment that is meant for testing the costs of including measurement monitors is considered too high and does not belong to the standard equipment. It would have been very interesting to measure how the electricity on board the buses is proportionally divided between the drive train and the auxiliary equipment. Also how much electricity goes to each component at the station. But adding these meters could have raised the costs, caused higher failure frequency and not given the accurate readings that are necessary to get reliable results.

**Figure 35 Barrels full of water and sand can substitute passenger load on public buses**

The research team had designed tests that could help to decide the effect of load on the fuel economy of the buses. What could be more appropriate than to take on passengers that have time and interest to volunteer for such measurements and drive a test round? If the hydrogen buses have various loads – full, half and empty and two diesel buses driven the same rout with full load and also empty a good basis for comparison is built. – But then again, who wants to sit in the same seat on an ordinary diesel bus for 90 minutes while others are enjoying the ride in a fuel cell hydrogen bus? The volunteers did not sit as still as the water barrels that were used in the next trial. Also, the outcomes from the second measurement attempt (the water barrels) was so different from the first attempt that none of the outcomes were reliable or useful. Still, a good relation was formed with the audience, keeping the interest in the hydrogen fuel cell projects alive.

**Figure 36 Volunteers on the hydrogen bus. Tiles form half the load, passengers add up to the full load.**

# 7 The road from ECTOS

This chapter contains brief suggestions on how to use the outcomes of ECTOS and how to continue to establish knowledge on all the relevant aspects of the hydrogen technology which is developing rapidly. These are categorized into suggested short term and long term suggestions for actions, in the form of research, demonstration projects, policy measures and private undertakings.

## 7.1 *Future visions derived from the ECTOS*

The ECTOS project came as a remarkably timely input to the social discourse on energy, the price, uses and import of fossil fuels and sustainable development. The public in Iceland appreciated the demonstration of using hydrogen in fc-buses very well. This energy option was perceived and mentioned as a feasible solution to the modern fuel dilemma. Not only was it well accepted and discussed locally but got a remarkable attention in the international media (see Annex I, the list of media relations). A helpful step to make hydrogen and fuel cell initiatives appear less risky for investors would be to foresee a better TOTAL cost/benefit analysis for a society as a whole – perhaps of the size of the Icelandic Economy. Questions such as:

- How much income or transactions would these new energy initiative raise in society?
- How much weight does the environmental and social benefits carry in the decision procedures; should studies be carried further if they bear less weight than the economic and the technical aspects?
- Will there be more new jobs created or lost during the transition from an economy based on fossil fuels to a hydrogen based economy?
- Could regions / communities become self sufficient in respect to all energy needs and road transport of fuel belong to history
- How much value would an island society put in fuel /energy self sufficiency in a globalized market?

need to be answered and supported by real figures. That type of study could use a large portion from the ECTOS project but more details and economic models would be required.

## 7.2 *Usefulness of ECTOS outcomes*

The usefulness of the outcomes of ECTOS is undisputable but can at best be disseminated properly through further work and implementations.

The next generations of buses and hydrogen production stations will be designed differently. The stations will deploy other selections of steel in all pipes, the welding must follow revised particular procedures and pressure will be kept on the system even though production is halted. Also the stations will have larger capacity and yet not take up more space than the current electrolytic station. In table 3 suggestions as to how these outcomes can be used for further planning and testing are listed. Yet as always, when answers have been obtained to the first questions more questions emerge.

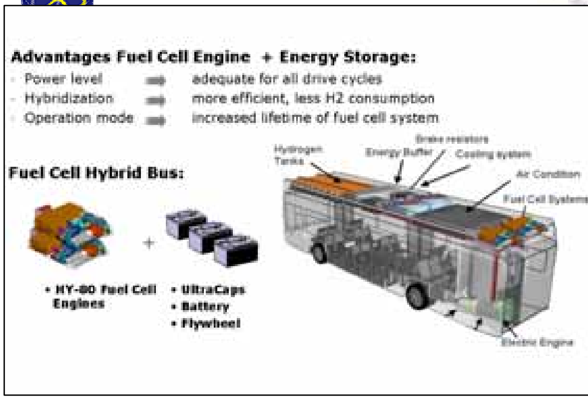


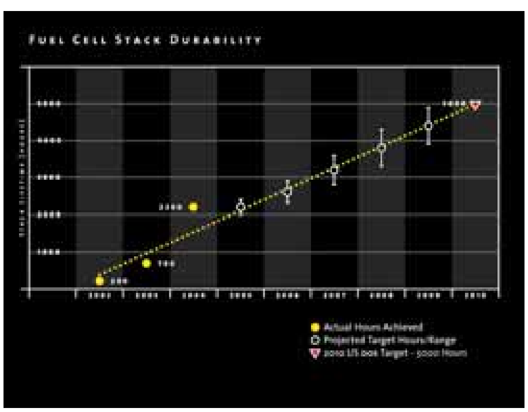

**Figure 37** A few of the suggested changes to be incorporated in fuel cell buses in the future. At the end of the Hy-FLEET:CUTE project a new generation of fc-buses is expected to emerge

**Table 5** Suggested use of the ECTOS outcome as topics for the long and short term research, entrepreneurship and policy formulations.

| | Short term | Long term |
|---|---|---|
| Research and demonstration | Testing the current infrastructure under full capacity – find optimal running modes Planned within the Hy-Fleet CUTE project, Jan – Dec 2006 (EC sponsored)<br>Participation in the NEEDS (EC supported project: New Externalities from Energy Development for Sustainability) which is further work towards incorporating external costs to all energy usage and future energy policies[33].<br>Encourage (EC supported project: Energy corridors to Europe) where hydrogen will also be considered as an actual energy carrier on the continent of Europe. | Launch detailed cost / benefit analysis for the hydrogen economy in Iceland. Two doctors theses have been organised around the subject[34].<br>A total cost /benefit analysis of four power plants, 2 which are currently in use and two new undertakings<br>The public and private costs and benefits in a fishing village fuelled only by locally produced hydrogen. New impressions on established cultures.<br>"Uthrif", Externalities from using renewable energy sources a local master student is working an a project to find methods and exercise calculations the environmental costs of the utilization of geothermal and hydropower sources. This is developing into a PhD project. |

[33] New Externalities from Energy Development for sustainability, EC supported project, Sixth framework Programme, Sustainable Energy Systems; coordinator: Wolfram Krewitt.
[34] PhD student: Nielsen, Kjartan at the department of engineering and environmental science, email address: kdn@hi.is

| | Short term | Long term |
|---|---|---|
| Private undertakings | Spreading the usage of fuel cells and hydrogen storage technology in tests and fleet applications could allow earlier market introduction of fuel cell vehicles, even within the 2010 - 2012 timeframe. The follow up for ECTOS and similar projects will have to catch participants from the private sector. *Negotiations are already promising both with car manufacturers and local companies ready to lease vehicles*<br>Further technological innovation and economies of scale will enable fuel cell vehicles to be fully competitive in the mass market. | Fuel cell engines must be developed to reach ultimate automotive maturity and quality standards, beyond what they are proving on the roads today. Weak points may still be the life time of the fuel cell.<br>Long term investors (perhaps ethical and environmentally minded investment funds) would do well in outlining the business opportunities in hydrogen systems with maturing technology. |
| Policy – national | More $H_2$ demonstration projects and increased governmental funding (National, EC, IPHE) is essential to bring about the practical experience from the technological advantages of hydrogen equipment. Negotiations are underway. | Plan for renewable energy power stations that feed into massive hydrogen production is needed within 10y<br>Regional and municipal planning departments need to consider the criteria that have to be clear before the next steps for the distribution and infrastructure are undertaken. |




As a final comment on what can be expected and achieved from large scale tests is an example from Mr Budds presentation at the closing conference of ECTOS in April 2005. He claimed that learning from tests in the laboratory is very important, but these lessons cannot be trusted until the equipment has been put through practical usage in real surroundings. Demonstration tests are therefore extremely valuable for the manufacturer as well as the operators at each link of the energy chain. The learning curves cannot become any steeper.

**Figure 38 Future vision, actual achievements compared to set goals for the extended life time of fuel cells.** [35]

[35] Budd Geoff, Ballard, HY-Pro-Files Conference Reykjavik, Iceland April 27, 2005

# 8 List of references

## Relevant web-sites

CUTE home page: www.fuel-cell-bus-club.com

ECTOS home page: www.ectos.is

GaBi 4, LCA simulation program; description available online at: www.gabi-software.de

Norsk Hydro Electrolysers has a webpage: www.electrolysers.com

Reykjavik city live viewer: www.Borgarvefsja.is

Shell Hydrogen homepage: www.shell.com/home/Framework?siteId=hydrogen-en

Skeljungur, oil company operator of the hydrogen station website: www.skeljungur.is/category.aspx?catID=275

Straeto, Public bus operator, homepage: www.bus.is

## Relevant articles and reports

Altman et. al, 2004 Accept H< Social acceptance survey of hydrogen and fuel cell technology in London, Luxemburg and Perth Australia. LBST

Bickel, Peter and Rainer Fredrich (editors) 2005: ExternE Externalities of Energy, Methodology 2005 Update, DG for research ad sustainable energy systems, EUR 21951

Guide to cost benefit analysis of projects Evaluation Unit DG Regional Policy Prepared for the European Commission (Structural Fund-ERDF, Cohesion Fund and ISPA).

Harldsson K and Berg H:Passagerarnas upplevelser av brännslecellsbussar i trafik på linie 66. ÅF – infrateknik, Sweden 2004 09 21.

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New Externalities from Energy Development for sustainability, EC supported research project, Sixth framework Programme, Sustainable Energy Systems; coordinator: Wolfram Krewitt, University of Stuttgart

Panagiotis, Georgousis & Sönke Behrends, (2005) final thesis for the completion of a Masters degree (2005) SUSI, Sustainable Urban Transport System Investigation (SUSI) A Decision Support System for the Usage of Alternative Fuels in Public Transportation

Skuladottir Bryndis, Hermann Þórðarson, IceTech Oct 2003 ECTOS Environemtnal Evaluation of Air Quality ECTOS deliverable no 7 available online at: www.iti.is//files/{fa8f9b4d-c451-4b2e-9ca9-e78b536ffddb}_ectos_delivery7-enviro-midtermreport.pdf

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The National Energy Authority and ministries of Industry and Commerce. (Feb 2004): Energy in Iceland. Historical perspective, present status, future outlook. Available online at: www.os.is/Apps/WebObjects/Orkustofnun.woa/swdocument/932/EnergyinIceland.pdf.

Thordarson , S. & Ö. Ulleberg for the IEA and INE (2005) Preliminary results from a study made in 2005 paper in preparation for the World hydrogen conference, Lyon, June 2005

Thorolfsson, Aevar (2002) Afstaða Íslendinga til vetnis í desember 2001, Félagsvisindastofnun Háskóla Íslands, Jan 2002, Unnið fyrir Íslenska NýOrku. . Website of Institute: www.fel.hi.is.

Informers through personal communication

Michael Faltenbacher and Matthias Fishcer, IKP Stuttgart for further information: faltenbacher@ikp2.uni-stuttgart.de

Mrs Margrét Guðmundsdóttir, retail manager of Skeljungur, Personal communication

Gunnar Thor Jonsson,, the head of the maintenance bay in Reykjavik May 2005

PR department of Shell International

Nielsen, Kjartan PhD student at the department of engineering and environmental science, email address: kdn@hi.is

Quoted presentations:

Eiriksson, Asgeir April 2005 presentation at the HyProFiles

Budd Geoff, Ballard, HY-Pro-Files Conference Reykjavik, Iceland April 27, 2005

Vilhjalmsson, J (2001) the fuel consumption in Iceland. Proceedings from the Energyconvention held in Iceland May 2001, the Icelandic Road Administration

# 9 Annex IList of media references on ECTOS

The following table shows all sorts of media publications where ECTOS, Iceland New Energy and/or hydrogen in Iceland is portrayed. The sources that INE has at hand are listed either in English or Icelandic and in a few instances meetings with reporters or other media persons, who have not sent their creations afterwards are included. Interviews are listed according to staff-diaries. The articles may either be written by journalists or by staff from INE or the University of Iceland, officials etc. Presentations at conferences are listed on a separate sheet.

Items that are not listed here are for example are those who have borrowed/bought pictures for text books or administrational reports (The EC publications) No active media scanning is performed at INE, the list is simply compiled from information that the company has listed from people that have sent links and materials on a voluntary basis. It therefore should not be regarded as a finite report on the publications but can give an idea about the span

| | Date. | Author, media, title, ECTOS or INE's representative |
|---|---|---|
| 1 | 20.1.2006 | Land Line Now Radio in the U.S, Road radio in Arkansaw asks for an interview for their main target audience: truck drivers. Jon Björn Skulason |
| 2 | 24.1.2006 | JBlack, Free lance journalist from Ireland requests an interview for dissemination in Irish journals, Maria Maack |
| 3 | 12.1.2006 | BBC international demands an interview at the station, JBS and Gunnar Þór |
| 4 | 20.1.2006 | Science Museum, new Exhibition on Energy and natural resources in Iceland at the London 20th Jan 2006. Press releases, Jon Björn Skulason for a press meeting |
| 5 | 24.1.2006 | CBC radio in Canad requests a direct interview after the hydrogen road map will have been published |
| 6 | Dec 05 Jan 06 | Kopecky, Arno; Water to burn. Iceland's experiment with hydrogen points toward an oil-free world by Arno Kopecky + Poll for the readers: Arno Kopecky asks whether it's time Canada got serious about alternative energy sources. Walrus magazine, Canada |
| 7 | 24.1.2006 | Steinarsdottir, Steingerður, Vikan, 1-51 Interview with Maria Maack. Visonary with the will to act. Pg: 37-39 weekly women's magazine in Iceland |
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| 9 | 1.6.2005 | M. Maack and J.B. Skúlason, 2005. Implementing the hydrogen economy. Internat. Journal of Cleaner Production 14(2005): 52-64. Elsevier |
| 10 | 18.8.2005 | Italian freelance journalist – INE has seen no publications |
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| 12 | 9.2.2005 | Þórdís Icelandic Geographic: Interview for the World EXPO in Japan. |
| 13 | 1.6.2005 | Island på vaeg mot vatgassamhallet. Finlands Natur 3/2005 pp. 12 – 13. |
| 14 | 1.2.2005 | María Maack: Hydrogen – an Independent Fuel, p. 16 Baltic 21 Newsletter. |
| 15 | 26.12.2004 | Ralf Köpfke: Iceland to Spread Green Energy Mantra in Europe. www.dw-world.de<br>Interview with M Maack, Thorstein Sigfusson |
| 16 | 1.12.2004 | Ralf Köpfke: Island vergeudet sein naturliches Kapital. pp 17 -18 Fairkehr, das Magazin fur Umwelt, Verkehr, Freizeit un Reisen – Nr.6/2004 Desember/Januar |
| 17 | 1.12.2004 | Ralf Köpfke: "Eternally Hot" pp 17- 23 New Energy magazine for renewable energy No.6 / December 2004 |
| 18 | 1.11.2004 | Thorsteinn I. Sigfusson et INE: L'ile de Jules Verne, Découverte N°322 Novembre 2004 pp 64 – 73 in connection with Iceland Expo in Paris |
| 19 | 15.9.2004 | Arne Spångberg: Island blir grönt med vatgas, Metro |
| 20 | 25.8.2004 | Roland Knauer, Die Insel der Nachhaltigkeit, Wissenschaft und Technik |
| 21 | 18.8.2004 | Lars Eriksson, "Professor Vete" ar Islands energirevolutionar, Ny Teknik p.1 og pp. 8 - 9 |
| 22 | 24.7.2004 | Tyler Hamilton: Iceland: The fire within, Iceland today planting the seeds of future hydrogen economy, og Prof. Hydrogen gets top marks, pp D1, D4, D5 Toronto Star |
| 23 | 9.6.2004 | Andrew Langkjær: Fuld gas mod 2050, Via Nordica 04, side 3 |

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| 24 | 27.5.2004 | Clemens Bomsdorf: Quellen unter Sonderstatus. Vefútgáfa Rheinischer Merkur http://www.merkur.de/aktuell/do04/ener_042205.html |
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| 26 | 1.3.2004 | - Neues vom Wasserstoff: Island, Wasserstoff-Spiegel, Nr. 2/04 (Marz/April) |
| 27 | 01.03.04 | María Maack: Practical Implementation of Hydrogen in Iceland. T Point- “Notiziario di EniTecnologie”, 1. hefti, 6. árgangur. |
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| 30 | 01.02.04 | Rosalind Griffiths: Hydrogen, the power of the future, today? Grein í Shetland Life bls. 4 -7. |
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| 32 | 10.01.04 | Ivar Grydenland,norska ríkisútvarpið Factaredaktionen.Viðtal við Maríu Maack |
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| 50 | 10.09.03 | CEA, Centre de l' EnergieAtomique, Stutt grein í fréttabréf stofnunarinnar frá Maríu Maack |
| 51 | 10.09.03 | Ragnhild Krogvig Karlssen: Ren energi; Norsk radio (NRK-tv), heimildarmynd.Viðtöl við Jón Bj. Skúlason, Maríu Maack, Þorstein I Sigfússon, Braga Árnason ofl. |
| 52 | 08.09.03 | - The Big H: Hype or Hope? p 20 og The Boiler in the Basement pp 22 – 23 í Northern Enterprise, northern Europe business magazine Volume 5, Issue 27 |
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| 55 | 05.07.03 | Maria Maack; viðstödd opnun 5th Interantional Clean air conference Lissabon, July 5th-7th, 2003. Fjallað var umhreint eldsneyti. Greinar útdráttur birtur sem Abstract: Hydrogen applications and research. Ráðstefnugögn. |
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| 59 | 09.06.03 | Dr. David Hart: Hydrogen energy, a worldwide movement. Minnst er á að Ísland ætli sér að verða fyrsta vetnissamfélagið í heiminum í þessari grein sem birtist í The Globe and Mail, Canada's national newspaper |
| 60 | 07.06.03 | Lydia Murphy, Researcher - with David McWilliams: Newstalk 106, Morgunútvarp írskrar útvarpsstöðvar, (Morning magazine) 5 mín viðtal við Mariu Maack |
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| 62 | 05.06.03 | Carole Venuat / Annie Lassibliere: Europe /Nature – Environnement, Journal de 20 H avec Patrick Poivre D'arvor, L-Hydrogen sert de carburant de substitution. Declaration Margrét Guðmundsdóttir, Declaration Helgi Bjarnason |
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