Final Report

ECTOS-project

(Contract no: EVK4-CT-2000-00033)

Content

1. Introduction

This 4½ year project started on March 1st 2001 and ended August 30th 2005. The objective of the ECTOS project, as stated in the DoW:

The overall objective of the ECTOS project is to tackle the problem of local urban pollution, by offering the solution of using hydrogen for powering part of the transport sector that is with hydrogen fuel cell buses. The purpose is to demonstrate and evaluate a hydrogen based infrastructure for public transport vehicles and the operation of pollution free hydrogen buses in a CO_2 free environment in Reykjavik, Iceland.

The overall defined strategic goal of the project is also clear:

- *to prove that it is possible to operate a hydrogen fuel cell transportation system, including hydrogen infrastructure as well as hydrogen vehicles in the city of tomorrow,*
- *to show that it will have benefits for the society at large to operate the future transport system on hydrogen, including socio-, environmental and economical factors.*

Earlier the government of Iceland had declared its ambitious goal of becoming the first hydrogen society in the world. For that purpose Icelandic New Energy Ltd. (INE) was founded as a public private partnership (a private company). INE also became the coordinator of the ECTOS project.

The project was a logical first step in evaluating the potentials of hydrogen in a modern urban society. The project became a European (world) leader in this aspect and was followed shortly by the CUTE Project program.

This final report specifically focuses on the development and results of the project. A number of "Deliverables[1]" have already been handed to partners and to the EC regarding specific aspects but this report will give a full overview of the project.

2. Contractual development within the ECTOS project

During the progress of the project two amendments where made to the contract. The first amendment focused on changes of partners and responsibilities within the partner group and equipment at the hydrogen refuelling station including operation and maintenance of the station. A second amendment was done later as with the establishment of the CUTE Project program, the delivery of buses was delayed approximately 6 months and to compensate the project applied for an extension of the project for 6 months.

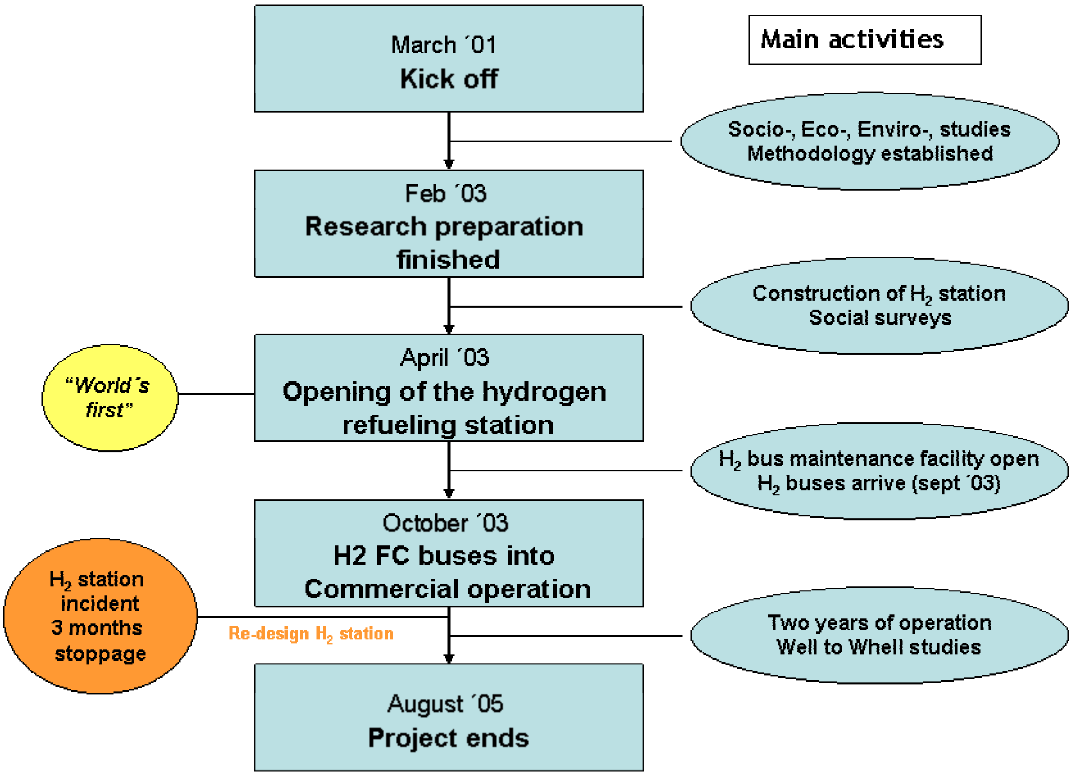
It should be noted that the working relationship with the European Commission was very strong and beneficial for the project and the scientific officer of the project has shown talent and vision beyond sometimes the bureaucratic level that affects EC projects.

3. Project's Summary

This 4 year project, which later was extended to 4½ year project started at a kick-off conference in Iceland on March 1st 2001. The key elements of the story of the project are shown in the picture here below. Overall the agenda of the project was satisfactory, except for the delayed delivery of the H_2 FC buses. This delay was mostly related to the establishment of CUTE, as the negotiations for CUTE were very long and protracted.

[1] See Annex 1 for a full deliverable list.

THE ECTOS STORY 2001-2005



4. Project Progress

Overall it can be stated that the progress has been as expected for all activities except for the operation of the filling station in the later part of 2004 (this has already been reported in an earlier report). In the following sub-chapters the key aspects of the different elements' of the project will be described as follows:

4.1 Impact assessment (socio-economic-environmental research)

During the first stage of the project, extensive preparatory work was done for the socio-, eco-, and environmental studies. The choice of Reykjavik Iceland, provided an excellent location for gathering data. It is the capital of Iceland, and has a population of some 200,000 highly educated people, and therefore provided a "state of the art" setting for social acceptance testing etc. It should also be noted that another benefit of the location is that the bus fleet in the city is rather small and therefore the 3 hydrogen buses were 4% of the total bus fleet and this made them very visible in the city. Iceland has another unique benefit and that is very strong governmental support for a hydrogen society. It has been stated on numerous occasions by the Government of Iceland the intention to establish the first hydrogen society in the world. Such support is unique when embarking on a RD & D program like the ECTOS. This gives tremendous added value to the project and also community support from the city authorities in Reykjavík further added to the outcome of the non-technical studies.
The impact assessment (socio-economic and environmental studies [so-called non-technical face of ECTOS]) for this miniature study of a ´hydrogen driven society' has three main areas:

- First, the acceptance was estimated on behalf of the operators, bus drivers and the public.
- Secondly, the energy efficiency and environmental effectiveness was estimated and calculated. Several amendments to the system have been suggested in order to prevent losses and streamline the operation.
- Thirdly, is the cost and benefit at large.

The specified methodology has proven to be successful and those that collect and process the data have presented their work in workshops, in meetings and conferences to the international community.

The outcomes of public surveys indicate that the Icelanders are more interested in seeing the results and show impatience for the hydrogen economy. Passengers and other commuters state that they have a positive attitude towards this new locally made fuel, they connect hydrogen to natural concepts such as water but only 30% would be willing to pay a higher price for their commuting during the introduction phases of hydrogen. The bus drivers are very positive towards the technology and enjoy driving the fuel cell buses. They also claim that the passengers make positive comments about the vehicles.

The well to tank efficiency has been calculated by using official numbers for the energy distribution systems and a set of data from the normal operation-sequence of the hydrogen station. The tank to wheel efficiency has been measured twice during set periods of total data collection from fuel cells, passenger counting, mileage driven and fuel use. The first round led to a few small adjustments to the bus-operation.

The total fuel efficiency is lower than hoped for but this generation of fuel cell buses was designed for reliability - and some fuel efficiency was therefore sacrificed. Issues such as purging, idling, etc. are being worked on to increase the fuel efficiency. Learning from such issues are currently being worked on and will be addressed in the next FC bus design and development phase along with countless other items. This is a very important learning for future projects.

When looking at the overall economics of the project it has showed that the maintenance cost and operation of the hydrogen infrastructure is high. It is evident in a project like this that without EU or governmental incentives it would not have been undertaken. The fuel cell buses performed as planned but as is described later in this report the overall maintenance cost and operation of the hydrogen filling station was far higher than expected. Adding the maintenance cost to the capital cost of the filling station resulted in a fairly high hydrogen cost and therefore the price of hydrogen sold only recovered a small fraction of the operation.

However other benefits should be mentioned. Compared to diesel buses, the material balance for motor-oil, grease and brake fluids is much lower for the fuel cell buses and therefore both costs and emissions have been saved during the project period. School groups, young children, interest groups, students in collages and Universities have visited the station and attended presentations on the ECTOS Project. Also, many guests from overseas have visited Iceland during this Project and income gained as well as very positive press can be added as a very important additional benefit in direct and indirect financial terms.

4.2 Bus operation

The hydrogen buses arrived in Iceland in September 2003. The location of Iceland now became a disadvantage as for the first time the vehicles had to be shipped on container vessels over the Atlantic. As the vehicles are delicate equipment the original idea was to ship the vehicles below deck, but due to the height of the vehicles they had to be shipped on deck. Fortunately the rough seas did not affect the equipment and they could be driven from the ship immediately after arrival. Another precaution taken into account in the original shipment was to send only two at once and one later to avoid if a drastic incident would happen, i.e. losing all of them at the same time if the ship sank on its voyage to Iceland.

Figure 1. The fuel cell bus at the filling station

The operation of the buses was always considered as the riskiest part of the project. This was due to the fact that the technology was new and the geographical location and climate of Iceland being subject to extreme North Atlantic weather may influence the operation of the vehicles. However, the buses in Iceland have had extremely high availability with no major incidents and with a very satisfied customer group consisting of the bus company and the passengers. The availability of the vehicles has been high and in total the three buses have had 5.216 operating hours and driven 89.243 km during the project time period. The total availability of the vehicles has been close to 90% which if far higher than the partners originally expected. However the buses have not been in service for all that time as part of the time is holidays, including weekends, and also because of downtime of the hydrogen refuelling station (described later in the report). This is a very similar outcome as the CUTE project in general and the outcome of the operation of the buses between different sites has been similar.
Small technical issues have arisen through out the project, for example failures of the CVM (cell voltage monitor) board early in the project, pumps and inverters. However the project team members, in this case specifically DaimlerChrysler reacted quickly to any issue. In short it can be stated that the vehicles have fully fulfilled the expectations that were originally made for the operation of the buses and beyond. Some developments have also happened on site in Iceland that have proven very valuable and in a number of instances prevented costly damage to the buses. These developments resulted due to the very high dedication of the Iceland team and the vehicles sometimes were treated with as much care as their own children.

4.2.1 Maintenance of buses

One of the original issues in Iceland is that the regular maintenance garage of the bus operator could not be used for the maintenance of the FC buses due to height constraints. Therefore the project group had to establish a specific and dedicated garage for the project. As is explained in the next chapter, the ECTOS project did not build a hydrogen filling station in a bus depot but decided to have a pre-commercial

hydrogen refuelling station, located at a conventional gasoline station in Reykjavík. As a result the team focused on having the maintenance bay as close to the hydrogen dispensing facility as possible. Simultaneously it was decided to sub-contract the FC bus maintenance to Raesir (DC dealer at that time). This set up became very successful. Making the facility safe for the maintenance of the hydrogen buses was less costly than expected and the working conditions fulfilled all required standards.
The maintenance facility has been working as planned and no safety or other issues have arisen with the facility. The technical set-up has been very good which created favourable working conditions. The cooperation between the maintenance team, the bus company, and also the technical team of DC, has been excellent which has resulted in the Iceland team having the fewest maintenance hours on the hydrogen buses compared with all the European cites in CUTE.

Figure 2. Iceland´s harsh environment.

4.3. Infrastructure

As one of the key elements of the project to evaluate social and economical issues, it was important to integrate the hydrogen infrastructure into the local society as it would be in the future hydrogen society. The hydrogen refuelling station was therefore built at a conventional gasoline station in Reykjavík. As such the station became the "world's first hydrogen refuelling station built at a conventional gasoline station".
Heavy emphasis was placed by the partner group to design the station to be practical and have high visibility.
This development became very successful. During the preparatory stage the construction had to go through a neighbourhood introduction, where most neighbours were very positive towards having the hydrogen station located in the neighbourhood.
The construction was completed during an 8 week period and the opening ceremony was held on April 24th 2003 when a DC H_2 Sprinter was refuelled with hydrogen.

Figure 3 . Layout of the fillin gstation in Iceland.

Shortly after the arrival of the hydrogen buses it became evident that the communication between the dispenser and the vehicle during filling was not adequate. It was then decided that Norsk Hydro would replace the dispenser with their new own design. Since then no major issues have been realised in connection to the dispenser.
During the first months of operation it became evident that more maintenance and service work was needed for the station than in the original plans. Following a few months of operation the team decided to subcontract the operation and maintenance of the station. The operational availability of the station was kept as a priority and the availability of hydrogen was one of the highest in the European bus demo projects. However in August 2004 an incident happened at the station that caused over 3 months of stoppage. The cause of the incident was determined (by a specific task force put in place for the investigation) to be as follows:

1. Level transmitter malfunction,
2. Missing demister, and
3. Manual override of the control system.

As the incident was categorised as serious it went through a formal incident investigation process, with a task force established to investigate. The cause of incident had to be determined and then recommendations and corrective actions implemented to prevent a reoccurrence. Finally, new spare parts were required to be ordered and a redesign of some piping. This took in total over three months. As there is no back-up of hydrogen in Iceland the vehicles were out of service during this period. However since start-up in December the station has been running as expected.

Although serious incidents are never a good thing, the lessons that resulted from the incident have left all partners with valuable learning information. The know-how from the incident has now been fed into other similar operations with similar technology and therefore the project has added valuable technological developments for future hydrogen stations. Other modifications have also been done to the station as a result from other incidents in sister plants, specifically the plant in Hamburg (CUTE) as the Iceland station and the Hamburg stations are almost identical. Furthermore the Icelandic team has developed a crisis management plan, emergency response procedure plan and an incident reporting system as a result from the incident. This is an important feature for future developments and adds security and reduces risk of

further incidents. Also the goal is to install in the future a 24 hour remote monitoring system into the software of the station. This will continuously monitor the station operations and reduce the risk of a serious incident reoccurring to the lowest possible means.
The partners have also installed at the station a small H2 cylinder bottling plant which makes hydrogen accessible for other potential hydrogen projects, i.e. small demonstrations, scientific research, etc.
Overall important information has been collected from the operation of this world's 'first pre-commercial' H_2 filling station. The project has had to struggle a little with the maintenance and service cost of the station, but valuable learning has occurred, benefiting all partners regarding future set-up and technologies (materials, design, etc.). During the latter part of the ECTOS project, it seems that the team has overcome what can be called, "birth symptoms" of the station and it has been running very well in the last 9 months.
During the operation of the station in the ECTOS project the station provided the buses with 17.342 kg of hydrogen and in that sense saved the use of almost 50 tons of diesel fuel. In general the project partners are satisfied with this outcome and the valuable learning from operating the worlds first commercial hydrogen station.

5. Dissemination

Early in the project a dissemination plan was created. Already at that time considerable international and national interest had been shown to the project. However it was important to the project group that information would be readily available for the scientific community as well as the public.
The objective of the dissemination is to get results to the global market so that
the results can and will open a market for the new technology. Simultaneously it is vital that the end user/customer will accept this new technology as a safe, clean and economical for the future transport with in the future urban area.

The dissemination strategy is more or less separated into two main disciplines:

1. *Hydrogen related issues (technical)*
2. *Socio-economic and environmental related issues (non-technical)*

In the dissemination plan different target groups were identified and a strategy made to approach them at different levels.

Already in 2001-2002 (i.e. during the preparatory stage), a number of international publications were made, specifically through media and scientific magazines. However during the preparatory stage of opening the world's first hydrogen refuelling station, dissemination went to a different level.

The ECTOS team was not prepared for what came. During the opening of the hydrogen refuelling station over 80 international media people showed up plus all the domestic media. This includes roughly 8-10 TV stations etc.

Figure 4. Media at the opening of the filling station April 24th 2003

Through out the project between 300-400 international media people have visited the project (note, on average 2 per week for the whole project period) as well as a number of articles being published in the Icelandic media.

Adding to this, more than 10 international scientific documentaries (longer than 30 min. shows) have been made. These documentaries have been shown in different languages and all over the world, including Asia, Europe and the US.

The project was not prepared for this in the beginning but with strong support from the international partners ie DaimlerChrysler, Norsk Hydro and Shell Hydrogen, the team slowly but surely learned to handle the large international attention.

As planned, brochures were made for different target groups. Also there has been an open web-site and an annual newsletter made available. The traffic on the website has also been well above the project's estimate. In this sense the project also benefited from the cooperation with CUTE. CUTE published a number of specific brochures which were also made available to the ECTOS group, and a joint website was also open www.fuel-cell-bus-club.com. Specific information flyers were made for the public in Iceland and special material provided to the media in Iceland to inform the Icelandic public about the new technology. Also in another European project (EURO-HYPORT) special educational material was made which was distributed to all the schools in Iceland and has been aired on national TV. All of this information flow seems to have reached the public as the positive acceptance level of the Icelandic public was above 90%[2].

Technical study tours to Iceland also reached a stage where it became difficult to handle the number of visitors. In a joint effort lead by the University of Iceland, the team established a seminar schedule, including a technical tour of the ECTOS bus facilities and the hydrogen refuelling station. These seminars have been very successful and hundreds of people (scientific, corporate, teachers, bureaucrats) have participated. In total over 3000 people have visited the project.

The original goal was also to give a number of international presentations. The largest dissemination was during the two ECTOS conferences, in April 2003 and in April 2005. Over 50 other international presentations have been made by the ECTOS group and the project has also been introduced by CUTE partners at other

[2] In a social surveys more than 93% of the public states it is very positive or positive towards replacing fossil fuels with hydrogen in Iceland.

conferences. These presentations cover every continent of the globe except Africa. These presentations have been made on various occasions covering both technical and non-technical subjects.

The ECTOS project has also been visited by number of dignitaries, among them a few presidents, ministers, senators, MP´s, ambassadors and other VIPs.

Figure 5. US Senators visiting INE regarding hydrogen

The dissemination level of the project is still very high, and that will probably continue for sometime into the future. In short the dissemination of the project is well beyond the original objective. All target groups have been reached and if the dissemination of CUTE and ECTOS would be combined this must be two of the highest known profile EC projects. Partners have also been very positive to give out detailed results and therefore both the technical and non-technical info gathered in the projects have been made available for all.

6. Interaction with European Commission

From the beginning of the project the interaction with the EC has been to the benefit of the project. This is both in resources and also in dissemination. The contractual issues have also been in very good hands as twice during the project the partners have asked for amendments which both were accepted by the EC. The project group is thankful to the EC and specifically the scientific officer who has performed work of highest quality.

7. Conclusion

Setting out goals and objectives of a project of this size and nature was a difficult thing 4½ years ago. However the project partners agree that a successful demonstration has taken place, proving that the current stage of technology can be integrated into the modern society of today. In Iceland it has also been demonstrated that this has been done in a CO_2 free nature, i.e. the production of hydrogen and the running of the fuel cell buses add no greenhouse gases to the environment. Integrating the infrastructure has also been successfully proven at a conventional gasoline station, in a pre-commercial way. The strategic goal was also to show in what way the future society might benefit in social, economic and environmental terms by using hydrogen as a fuel instead of conventional fossil fuels. Throughout the project it has been shown that social and environmental benefits are very visible. However, the current stage of technology does not yet make it commercially economical. Indications are though that the cost of the new technology will come down in the near future and therefore not far into the future the city of tomorrow will benefit in social, economical and environmental way by using hydrogen instead of fossil fuels.

Finally the project group is convinced that the ECTOS project will be remembered in the history books as one of worlds first real scale hydrogen RD & D projects, bringing clean fuels and brighter future to all global citizens. This was only possible with the exceptional teamwork, cross border international cooperation, and support from the EC.

ECTOS- project group
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Shell Hydrogen
Norsk Hydro
EvoBus
Skeljungur
University of Iceland
Institute for Technological Research, Iceland
Straeto bs
Vinnova
University of Stuttgart

Sub-contractor
Raesir hf

Annex 1

Deliverable list for the ECTOS-project.

B2. Deliverables list

Deliverable No[3]	**Deliverable title**	**Delivery date**[4]	**Nature**[5]	**Dissemination level** [6]
2.	Establishing methodology for impact and comparative assessment	4	Me	Pu
4.	Dissemination Plan	8	Re	Pu
5.	Delivery of operational hydrogen fuelling station	18	Eq	Pu
6.	Report on maintenance structure and equipment	20	Re	Re
7.	Midterm "Environmental study" (Air quality and CO_2 emission levels from chosen routes in Reykjavik)	24	Re	Pu
8.	Delivery of 3 hydrogen fuel cell buses	24-26	Eq	Pu
9.	Mid-term assessment report + draft of TIP	28	Re	Re

B2. Deliverables list

[3] Deliverable numbers in order of delivery dates: D1 – Dn

[4] Month in which the deliverables will be available. Month 0 marking the start of the project, and all delivery dates being relative to this start date.

[5] Please indicate the nature of the deliverable using one of the following codes:

Re = Report **Da** = Data set **Eq** = Equipment
Pr = Prototype **Si** = Simulation **Th** = Theory
De = Demonstrator **Me** = Methodology **O** = other (describe in annex)

[6] Please indicate the dissemination level using one of the following codes:

PU = Public
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CO = Confidential, only for members of the consortium (including the Commission Services).

Deliverable No[7]	Deliverable title	Delivery date[8]	Nature[9]	Dissemination level [10]
10.	Description of design and operation of the fuelling station	36	Re	Re
11.	Report on specification and features of the fuel cell buses	40	Re	Re
12.	Assessment and evaluation of socio-economic factors	48	Re	Pu
13.	Transferability of technology on European level	48	Re	Pu
14.	Final "Environmental study"	48	Re	Pu
15.	Cost-benefit analysis for the new infrastructure	48	Re	Pu
16.	Life-cycle analysis (fuel cell buses, infrastructure, etc.) for different cities	50	Re	Pu
17.	Complete comparative assessment of fuel cell buses with other alternatives	52	Re	Pu

B2. Deliverables list

[7] Deliverable numbers in order of delivery dates: D1 – Dn
[8] Month in which the deliverables will be available. Month 0 marking the start of the project, and all delivery dates being relative to this start date.
[9] Please indicate the nature of the deliverable using one of the following codes:

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Deliverable No[11]	Deliverable title	Delivery date[12]	Nature[13]	Dissemination level [14]
18.	Final report and TIP	54	Re	Co
19	Final publishable report Cordis	54	Re	Pu

[11] Deliverable numbers in order of delivery dates: D1 – Dn
[12] Month in which the deliverables will be available. Month 0 marking the start of the project, and all delivery dates being relative to this start date.
[13] Please indicate the nature of the deliverable using one of the following codes:

Re = Report | **Da** = Data set | **Eq** = Equipment
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