1 PROJECT SUMMARY

1.1 Motivation

Within the framework of sustainable development the energy supply system is a crucial topic. Spurred on by the Kyoto Protocol the attention for the definition of energy saving programs and the promotion of environment-friendly technologies as renewable energy is increasing.
In the longer term however additional alternatives have to be found. Especially for the Belgian context the combination of a further decrease of emissions (CO_2, NO_x,...) with a faze-out of nuclear energy is a major challenge.

At the international level hydrogen as an energy carrier is one of the major topics in the discussion on pathways towards a future sustainable energy society. It is expected to contribute both to the reduction of air pollution, CO_2-reduction and energy supply stability.
The reason for this is that hydrogen offers a long term potential for energy systems with almost zero-emission level; it can be based on local and renewable energy sources. In the USA a 'Roadmap to hydrogen' has been developed already and on the European level recently the policy paper 'Hydrogen Energy and Fuel Cells, a vision of our future' has been presented.
Within the Belgian energy policy the knowledge on hydrogen is rather limited and this project intends to be the first step in a scientific assessment of hydrogen in the Belgian context.

1.2 Objectives

Actually the governments of the USA, Japan and the EU are defining energy policies based on hydrogen as energy carrier and the resources for research and development will significantly increase in the coming years. If Belgium wants to play a role in the European discussion and research on hydrogen it will be essential to develop national/regional activities on hydrogen, being complementary to the European activities.

This project is the start of such a Belgian initiative. It gives the Belgian policy makers the necessary international information on hydrogen knowledge and experiences, and tools to evaluate the possibilities of hydrogen in the Belgian energy supply on a scientific way.

The results of the project can be summarized as follows:

* databases with international knowledge and experiences on hydrogen
* hydrogen module within MARKAL-TIMES, illustrated by a scenario calculation
* initial technology assessment on hydrogen, focussed on the scenario
* translation of the progress in foreign legislation and licence procedures on hydrogen
* definition of relevant policy issues concerning hydrogen

1.3 Relevance of methods and proposed approaches

Under 'Objectives' it has been stated that the core of the proposal consists of collecting and analyzing the international knowledge and experience on hydrogen and to develop some tools / opinions to be able to evaluate the possibilities of hydrogen to the Belgian context.

The data gathering is needed while not much information is presently available in a useful way. Databases will be made comprising technologies, regulation and foreign hydrogen experiences. They will not be static but are updated during the project.

Many economical, social and political tools are possible to assist policy making.
In the context of supporting the development of national and regional activities on hydrogen it is useful to cover following three items first i.e. a technic-economic model to characterise the possibility of introduction of hydrogen, a sound opinion of experts to assess a Belgian hydrogen future and a translation of progress in foreign legislation to be able to start public projects.

For the technic-economic evaluation the technic-economic model MARKAL-TIMES has been chosen. It is worldwide used to calculate the economic implications of energy scenarios. MARKAL-TIMES is used in federal studies by the University of Leuven and Vito. Currently the model is not suitable for hydrogen scenarios.

To obtain a sound opinion a technology assessment is a well-suited method. At Vito several of these assessments have been performed on energy-related subjects.

Legislation and construction permit procedures exist of course in Belgium. By lack of public hydrogen projects in the frame of energy supply, it was not worked out specifically for this aim. A translation is proposed of foreign experiences with demonstration projects on the Belgian background.

1.4 Project partners

The project was set up by a consortium of four partners:

* VITO, Centre of Expertise Energy Technology
* University of Liège, Laboratoire de Chimie Industrielle
* University of Leuven, Working group Energy, Transport & Environment
* 3E

The Centre of Expertise Energy Technology of Vito focusses on the introduction of sustainable energy systems and the rational use of energy, both in the sectors of automotive applications and buildings. The combination of hydrogen and fuel cells is one of the major research topics.

The Laboratory of Industrial Chemistry is a research center active in several fields as alternative energies, particularly fuel cells, safety in the chemical industry and environmental concerns. On the basis of the knowledge about hydrogen and oxygen catalysis, the Laboratory developed a pluridiciplinary research program in the fuel cells area, bringing together competences available in the University.

The Energy, Transport and Environment (ETE) division forms part of the Center for Economic Studies (CES – K.U.Leuven), which is the research division of the Department of Economics of the Catholic University of Leuven. The ETE division is specialized in the use of modelling tools to address pricing and investment problems in the transport, energy and environment fields.

3E is an engineering and consultancy company with specialisation in renewable energy and rational use of energy in buildings.

1.5 Results

- **Databases on hydrogen knowledge and experiences**

Hydrogen is traditionally used by the chemical industry in Belgium. Using hydrogen as an energy vector is however new. The advantage of hydrogen as an energy vector is that it is clean (no greenhouse gases are formed at oxidation) and that it can be stored (this is an advantage over electricity).

Hydrogen in its free form does not just exist on earth. It has to be generated. However, it can be made from every primary energy source. The main pathways for carbonaceous fuels are reforming (especially for natural gas) and gasification (in particular for coal) into hydrogen and carbon dioxide. Other energy sources like the sun and wind can be transformed into hydrogen by means of electrolysis. For electrolysis electricity is needed.

The property that hydrogen can be made from all sources makes it a versatile energy carrier able to help the security of energy supply. Hydrogen obtained from the pathway wind/sun – electricity – electrolysis – end use is free from GHG emission. The pathway natural gas – hydrogen – fuel cell car is more efficient than natural gas – internal combustion engine car. If hydrogen production from fossil fuels is combined with carbon capture and sequestration the emission of greenhouse gases could be drastically reduced.

Based on the availability of hydrogen, the use of hydrogen in fuel cells is interesting because of the potentially high efficiency compared to classical energy transformers. There exists five types of fuel cells. High temperature fuel cells can also use natural gas or biogas directly as fuel.

An actual problem is the cost level of hydrogen production and fuel cells. An important explication is the small amount of fuel cells and hydrogen production units that are assembled per year. At the turning of the millennium governments started with demonstration projects, like the CUTE buses in 9 European cities. This stimulates learning by doing. The scale will increase towards complete hydrogen regions. This is the way that automated assembly can start leading to lower costs.

For Europe the desired progress in hydrogen and fuel cells from demonstration programmes towards market introduction is described in the Deployment Strategy, made by the European Hydrogen and Fuel Cells Platform. This strategy is assisted by a Strategic Research Agenda, filling in future performance and costs.

The demonstrations programmes lead to a demand for regulations. The three worldwide standardisation organisations – IEC, ISO and UN/ECE – have specific working groups for fuel cells and hydrogen. They work in close connection. The countries make their own standards too and rules for permitting. An overview of all regulation and standards has been published in this project as a website with direct links to the organisations behind it: www.podopadd.be.tf.

Key Assumptions on Hydrogen & Fuel Cell Applications for a 2020 Scenario[3]

	Portable Fuel Cells For handheld electronic devices	Portable Generators & Early Markets	Stationary Fuel Cells Combined Heat and Power (CHP)	Road Transport
EU H2/FC Units Sold per Year projection 2020	~ 250 million	~ 100,000 (~ 1 GW_e)	100,000 to 200,000 (2-4 GW_e)	0.4 million to 1,8 million
EU Cumulative Sales projections until 2020	n.a.	~ 600,000 (~ 6 GW_e)	400,000 to 800,000 (8-16 GW_e)	1- 5 million
EU Expected 2020 Market Status	**Established**	**Established**	**Growth**	**Mass market roll-out**
Average Power Fuel Cell System	15 W	10 kW	<100 kW (Micro CHP) >100 kW (industrial CHP)	80 kW
Fuel Cell System Cost Target[4]	1-2 €/ W	500 €/kW	2.000 €/kW (Micro CHP) 1.000-1.500 €/kW (industrial CHP)	< 100 €/kW (for 150.000 units per year)

[3] These projections are discussed in detail in the DS Foundation report.
[4] The primary reasons that automotive fuel cells are expected to be produced at a significantly lower cost than stationary fuel cells are discussed in detail in this Foundation report.

Figure 1: Deployment status for applications in 2020 according to the Deployment Strategy Europe.

- **Techno-economic evaluation**

The purpose is to illustrate the use of the MARKAL-TIMES model for the evaluation of hydrogen use in the energy system. In a fist step, the MARKAL-TIMES technology database was updated to take account of the recent state of knowledge about hydrogen technologies on the production as well as on the consumption side.

In a second step, we then made some scenario runs with the model. These were compared with a reference run that includes the current Kyoto target and the nuclear phase-out decision. Two scenarios were considered. In a first scenario, we assume that the transport sector is forced to reduce its CO_2-emissions below the emissions of the sector in the reference scenario. The second scenario then assumes a harsher post-Kyoto constraint compared to the post-Kyoto target that was assumed in the reference scenario.

The simulation results suggest that hydrogen fuelled cars will enter the market in any of these two alternative scenarios, but not in the reference scenario. These results seem to be fairly robust, even when considering a sensitivity analysis with reduced investment costs for hydrogen technologies. In that case hydrogen technologies would from 2040 onwards enter the market in the reference scenario.

However, the scenario runs provide no consensus on the *type* of hydrogen vehicles that will enter. Depending on the scenario and on the market segment that is considered, it will either be hydrogen combustion or fuel cell cars. The results are also rather sensitive for the assumed investment costs. It is therefore best not to draw firm conclusions for as far as the car type is concerned.

Finally, we also found the robust result that hydrogen buses are not to be expected in the time horizon considered by the MARKAL-TIMES model. This result stands opposite to the conjecture by hydrogen experts that one of the first and most important applications of hydrogen would be found in the bus segment.

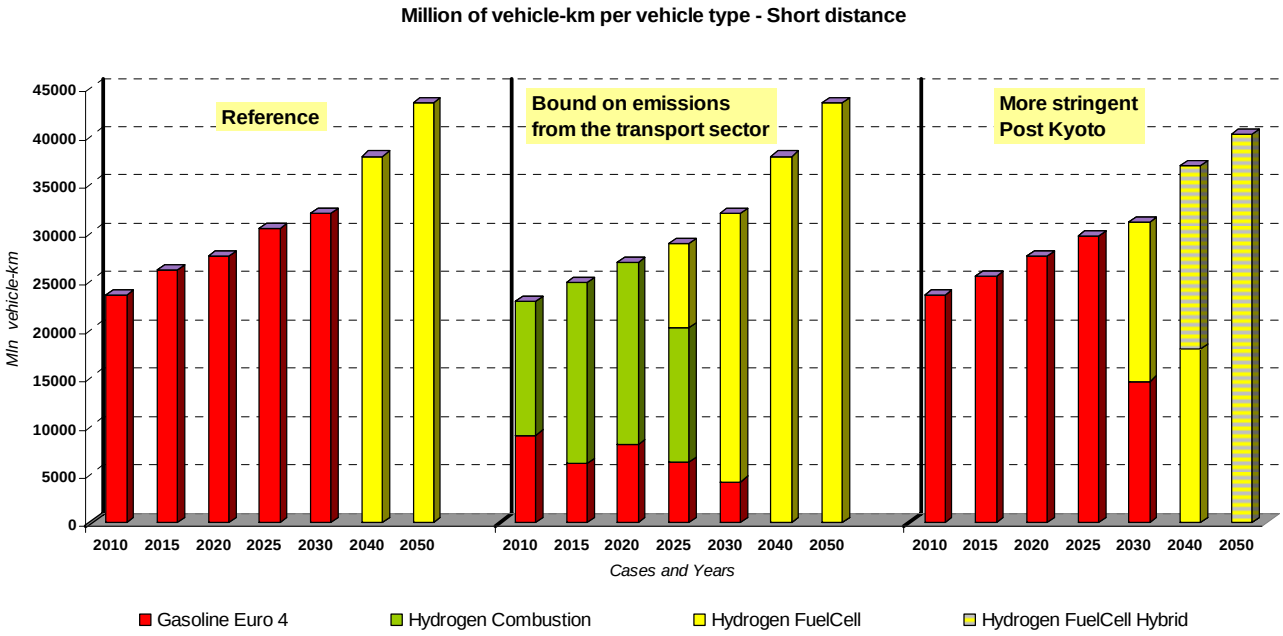

Figure 2: The distribution of car types for the reference scenario and the two more stringent ones.

- **Technology assessment**

Methodology: evaluation of the technology assessment

1. The workshop approach proved to be an efficient tool to collect information from the experts.
   On a structured and interactive manner the different experts could explore each others perceptions and assumptions. It was not the intention to reach a consensus on the four statements. It resulted in an overview of, sometimes differing, visions on how to realize a feasible and probable introduction of hydrogen in Belgium.
   The outcomes of the workshop were very valuable and turned out to be decisive for the further development of the project.

2. The well-balanced selection of experts resulted in a very productive discussion in which a variety of perspectives was covered. Sixteen participants was an ideal number: it gave the possibility to work in small groups of four people, but it also allowed to have a good and interactive discussion with a broad scope in the plenary session.

3. The face to face interviews were very crucial to the success of the workshop. They allowed each participant to make more explicit his own position on the 4 statements in a very fast and efficient way.
   The reactions of the participants after the workshop confirmed this positive conclusion.

4. The choice of a professional facilitator seemed to be a good decision. Being not an hydrogen expert, the facilitator was not involved in any technical discussion, and so, he was able to moderate the discussion in a impartial and unbiased way, paying attention to the right methodological approach.

Results

1. The major strong points of hydrogen in Belgium

* A lot of competence and experience on industrial hydrogen is available in Belgium.
* An extensive hydrogen and natural gas distribution network in Belgium for large industrial consumers already exists.
* The size of the country, the dense population and road network and consequently the high concentration of potential consumers result in lower costs for distribution of hydrogen to end-users.
* The existing natural gas network can be used for new projects for a mixture of natural gas/hydrogen.
* There is a real opportunity for meeting CO_2 and other greenhouse gas reduction requirements by production of hydrogen.
* Hydrogen is able to produce/generate useful energy for a variety of applications, this means less dependence on fossil fuels.
* Efficient energy use by fuel cells: a fuel cell has a potentially high efficiency compared to conventional energy converters.
* Hydrogen as storage capacity can result in a more efficient use of renewable energy and nuclear energy.

2. The most likely chances of application of hydrogen in Belgium within 20 years

The most likely chance of application of hydrogen in Belgium within 20 years is in public transport, because central refuelling point and in UPS (Uninterruptible Power Supply), because its good reliability and its cost is less important.
The production of hydrogen has to be based on rational energy use and greenhouse gas reduction.

3. The major impediments to the introduction of hydrogen in Belgium

* High costs
* Lack of Belgian roadmap
* Lack of coordination of R&D
* Lack of acceptance by public and industry

4. Suggestions for the government to introduce hydrogen in Belgium

* Apply favourable taxation on hydrogen as energy carrier, based on positive contribution to energy/environment/CO_2 requirements.
* Active participation in international (EU and UN) organizations:
  – push for EU wide, or better worldwide, certification standards for products (e.g.) vehicles using hydrogen,

– promote the development and implementation of consistent standards and regulations in accordance with EU standardization and legislation.

The introduction of a new energy vector in the Belgian economy can only succeed and have impact if it is in line with a broad EU and even worldwide public and industrial consensus (type of applications, technological choices).

* Play an active role in the definition of a European R&D agenda (7th Framework programme).
* Harmonize regional and federal efforts on legislation and licenses before implementation.
* Initiate large-scale demonstration projects.
* Support public acceptance of hydrogen.

- **Translation of foreign progress in legislation**

Concerning the database on regulation we opted for an internet-site, being currently http://www.podopadd.be.tf/. A combination of Belgian and international information has been compiled and integrated in this web-site. The regulation database was checked with good success : however some legislation texts and links were added in the web-site.

An important way to make hydrogen penetration easier should be to establish dialogue between Belgian Regional permitting bodies in order to avoid that the requiring company or public agency have to collect and organise different information to obtain permit. It should be stranger that, for example, the filling station requirements should be different in the three different Regions of Belgium.

We hold on to items (from experts) to be managed : it is important to carry out an active involvement in international (EU and international) organizations on product certification and standardization and to harmonize regional and federal legislation and licenses.

In order to apply the development of regulations, codes and standards for hydrogen applications in the transport sector, large attention has been paid to CUTE-ECTOS project (30 busses in 10 European cities). One major challenge, from the project, related to obtaining licences or approval from the authorities was :

– the lack of experience in handling hydrogen for non-industrial or public applications, and
– the absence of regulations explicitly expressing the safety requirements for such applications.

Regarding these foreign experiences, it is important to gain experience and to build competence within Federal and Regional administrations to achieve an effective approval process and in order to avoid Nimby reaction, we recommend to join legal procedure and population information in a complete and coherent mode.

- **Policy issues**

At the moment a lot of countries (Europe, United States of America, Japan, Canada,....) are developing an energy policy for introduction of hydrogen in the energy system. In Belgium for the moment no energy policy on hydrogen and fuel cells exists. Therefore the suggestions for

developing a Belgian policy on hydrogen and fuel cells is based on the current European policy.

The main conclusions for Belgian policy makers can be summarized in following statements:

* start thinking/acting on hydrogen
* participate actively in the development of an European Vision
* dialogue with Belgian experts (industry, research,…)
* network with high level international organisations
* define relevant Belgian vision and targets within policies on environment, energy and innovation… and compatible with the European vision
* define a Belgian action plan (demonstration, R&D,…)

Start thinking/acting on hydrogen

Before Belgium can decide to implement the introduction of hydrogen in the energy policy, it is necessary to think about the impact (ecological, economic, innovation, technology development,…) of this on the Belgian society.
Therefore a program has to be defined to calculate/map this impact in an objective way. (calculating specific scenario studies, discussions with international policy makers, discussion with Belgian industry and research,…).

Participate actively in the development of an European Vision

Last years Europe has been very active in defining a hydrogen road map for Europe and recently an European discussion platform has been installed to discuss hydrogen and fuel cells in Europe. Since august 2005 two important European reports on hydrogen and fuel cells are available: 'Strategic Research Agenda' and 'Deployment Strategy'.
Both reports are essential to define a Belgian policy on hydrogen and fuel cells being compatible with the European Vision.
Therefore is it strongly suggested that the Belgian policy makers participate actively in the European platform.

Dialogue with Belgian experts (industry, research,…)

As every country has its own background and ambitions on hydrogen, it is not possible to copy the complete European vision to each country. Therefore Belgian policy makers need to have a clear view on the possibilities/ambitions of industry and R&D in Belgium, in order to synchronise the Belgian efforts to the European targets as efficient as possible.
Presenting specific Belgian possibilities and targets of Belgian industry and R&D to Europe will give a high visibility of Belgium with respect to the development of an European hydrogen and fuel cell policy.

Network with high level international organisations

The European platform is the most important international organisation with respect to the development of a Belgian hydrogen policy.

But an active participating in the International Energy Agency is also a necessity to be able to assess the international context (technological, economics, ecological, policies,...) of hydrogen and fuel cells. Within IEA the implementing agreements 'Advanced Fuel cells' and 'Hydrogen' are most important for this issue. Since several years Belgium is active in the implementing agreement 'Advanced Fuel Cells', but it is recommended that Belgium should become a member of the implementing agreement on 'Hydrogen'. Last year the Belgian participation in the 'IEA Hydrogen Coordination Group' resulted in necessary additional information for Belgian policy makers on hydrogen.

Define relevant Belgian vision and targets within policies on environment, energy and innovation... and compatible with the European vision

Belgium should not just copy all international actions into the Belgian policy framework. It is much better to define a real Belgian vision and targets on hydrogen and implement these in policies on environment (e.g. NO , post-Kyoto-targets, transport,...) energy (nuclear energy, renewable energy,...), innovation (technological developments on hydrogen and fuel cells in Belgian industry and R&D,...).
Of course this Belgian Vision and Research agenda should be compatible with the European initiatives.

Define a Belgian action plan (R&D, demonstration,...)

Based upon a Belgian vision on hydrogen and fuel cells, the Belgian government should define a concrete action plan in close consultation with the regional authorities.
Within this action plan concrete targets on Belgian R&D activities (industrial R&D in close cooperation with the Belgian scientific world (universities, research centres,...)) should be defined. Based on promising introduction markets for hydrogen in Belgium, the Belgian policy makers should suggest the contents and structure of large, visible demonstration projects.

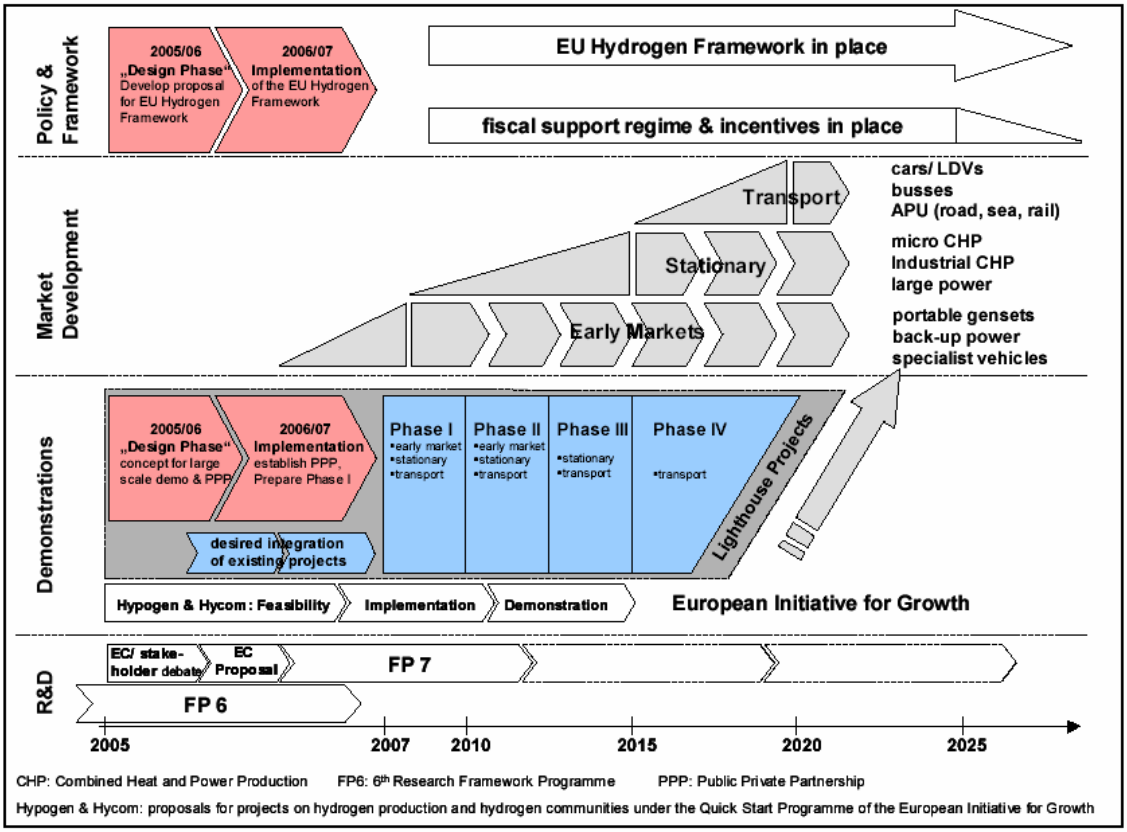

Figure 3: Schedule for a deployment strategy on hydrogen and fuel cells according to the Deployment strategy Europe.