



NATURALHY is an Integrated Project funded by the European Commission's Sixth Framework Programme (2002-2006) for research, technological development and demonstration (RTD)

# The Role of Life Cycle and Socio-Economic Assessment in the Naturalhy Project

## Future of Hydrogen

In the face of mounting economic, energy and environmental crises, various technological options have been put forward as major solutions to the combined challenges of global climate change, energy security and sustainable development. The use of hydrogen as an energy carrier is one such option. Hydrogen has been promoted as a solution to these problems because it can be generated from diverse sources and, through use in fuel cells, it might provide a feasible alternative to oil-based transport systems. However, hydrogen will have to be transported from its sites of production to points of demand. Whilst this can be done by tankers or newly-constructed pipelines, the existing natural gas network offers the enticing possibility of a means of transportation which uses an extensive and established asset. In this way, hydrogen could be transported through current network with natural gas for subsequent separation at vehicle filling stations or sites with stationary fuel cells. Alternatively, it could be utilised in the "greening of gas" by burning it as a mixture with natural gas in conventional appliances.

## Assessing Options

Whether hydrogen or any other future option is technically and commercially viable will depend on many factors. In particular, realistic options will have to demonstrate that they can deliver significant reductions in greenhouse gas emissions, such as carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>) and nitrous oxide (N<sub>2</sub>O). Such potential benefits must not result in further energy resource depletion, as measured by primary energy consumption. Neither must there be appreciable increases in other environmental impacts, such as deteriorating air quality, as indicated by levels of sulphur dioxide (SO<sub>2</sub>), oxides of nitrogen (NO<sub>x</sub>) and particulates (PM), or releases of ionising radiation. Finally, practical future options must be economically competitive and capable of maintaining or expanding employment. All stakeholders, including policy-makers, energy utilities and the general public, will have to be convinced that these and other objectives can be met. This can only be achieved, with confidence, by undertaking comprehensive life cycle and socio-economic assessments which are publicly accessible.

## Workbook Development

In the NATURALHY Project, life cycle and socio-economic assessment is conducted by means of MS Excel workbooks. These are produced by the partners involved in Work Package I. They have a regular structure which assists their application in representing different energy and transport systems. Additionally, they are fully transparent so that all details of calculations, assumptions and sources of data can be examined and, of necessary questioned. All completed workbooks will be available as "stand-alone" files. However, they will also be embedded in the Decision Support Tool (DST) which is being developed by Work Package 6 to assist gas utilities in assessing their own networks for possible use with hydrogen. This will involve generating results for existing natural gas networks and comparing them with results for hydrogen transportation in these networks or by alternative means. Comparative results will indicate differences in energy resource depletion, prominent environmental impacts, levels of employment and economic performance. In order to do this, an extensive library of workbooks is required.

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## EDITORIAL

This is the eighth and penultimate newsletter of the NATURALHY-project. The project contributes to the transition towards a more sustainable energy future by defining the conditions under which the natural gas network could be used for the delivery of hydrogen and of mixtures of natural gas and hydrogen (containing gases). Within this context, hydrogen could be pure and produced, for instance, from electricity generated by wind turbines, or it could be a part of a gas mixture produced from the gasification of biomass.

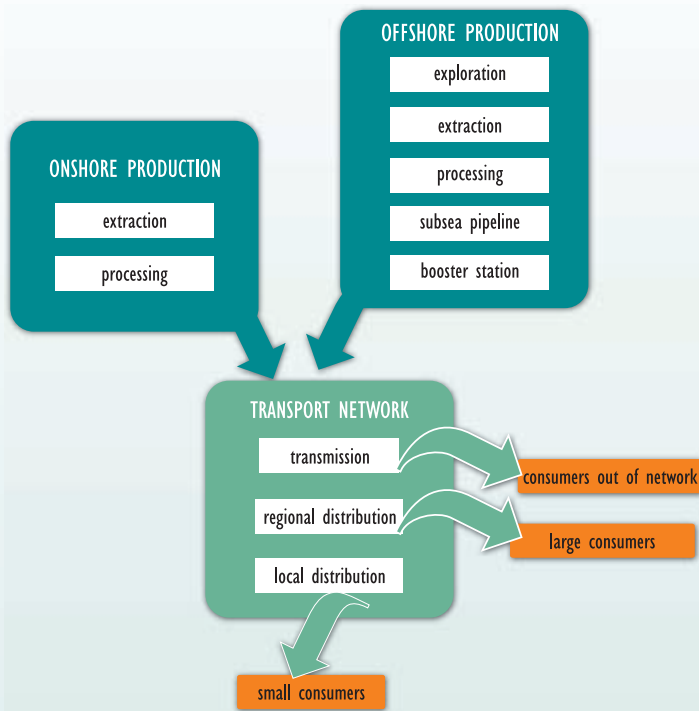
This issue focuses on two important tasks in the project. The main article concerns development and finalisation of workbooks to perform Life Cycle and Socio-Economic Assessment for the situation in which a specified percentage of pure hydrogen is added to natural gas. Amongst aspects, it compares the relative magnitude of carbon dioxide emissions per unit energy delivered by different energy production and delivery chains. One important consideration concerns possible hydrogen losses due to permeation through polyethylene and polyvinyl chloride natural gas distribution pipelines. Investigations carried out to determine the parameters which characterise these losses are the subject in the second article in this issue.

If you have any questions, suggestions or remarks concerning our project, then please do not hesitate to contact us through the NATURALHY project website at [www.naturalhy.net](http://www.naturalhy.net).

*The project coordination team  
Onno Florisson,  
Folkert Koopman  
and Katarina Ondrekova*

Figure 1: Summary of the Existing Natural Gas System

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## Workbook Library

The main series of workbooks that have been developed represent the existing natural gas system, including the extraction and supply of natural gas as well as the transmission and distribution network. A summary of this is shown in Figure 1. In addition, workbooks are necessary for other current energy systems, such as conventional and renewable electricity generation, and transport systems, such as conventional cars and buses. All these workbooks are included in what is known as the “baseline scenario”. Modification of the existing natural gas network to carry hydrogen is based on the important technical data from studies and experiments conducted by NATURALHY Project Work Packages 2, 3, 4 and 6. This enables evaluation of the effects of injecting hydrogen into the transmission and distribution network, and using hydrogen as a mixture with natural gas in existing appliances. For complete assessment of using hydrogen in this way, workbooks are also needed on the production of hydrogen from a variety of likely sources. These workbooks form a collection referred to as the “intermediate scenario”. The “final scenario” workbooks consist of those which represent tanker and new pipeline transportation of hydrogen.

## Provisional Results

The finalisation of all workbooks is currently in its last stages to coincide with DST development. The workbooks are fully functional so that they can generate results using either default or user-defined values of the designated input parameters. Hence, results depend on the characteristics of the actual systems that are being assessed. However, it is possible to illustrate the types of comparisons that can be derived. Such illustrations have been demonstrated to the European Commission during Annual Evaluation, to the NATURALHY Strategic Advisory Committee and at the World Hydrogen Energy Conference in Brisbane, Australia, in June 2008. This illustration is based on estimated net CO<sub>2</sub> emissions savings associated with different options to provide road transport and process heating. In the Base Case, which reflects the current situation, road transport is based on oil and process heating is provided by natural gas. Alternatives to this, which involve hydrogen fuel cell cars, are represented by Cases A to E, which are summarised in Table 1 along with estimated net CO<sub>2</sub> emissions savings. These provisional results show that large CO<sub>2</sub> emissions savings do not necessarily occur in all instances, and that the sources of the hydrogen and the performance of the separation technologies have a substantial influence on these savings. ❖

Author  
Dr. Nigel Mortimer, Loughborough University

Table 1: Illustrated Net Carbon Dioxide Emissions Savings from the Use of Hydrogen as an Energy Carrier

Case	Source of Hydrogen	Transport of Hydrogen	Separation of Hydrogen	Net CO <sub>2</sub> Emissions Savings <sup>(a)</sup> (%)
A	Hydrogen produced from natural gas by steam reformation without carbon sequestration	Hydrogen transported at 10% by volume with natural gas in the existing system	Pressure Swing Absorption separation with current conventional electricity	0.8
B	Hydrogen produced from natural gas by steam reformation without carbon sequestration	Hydrogen transported at 10% by volume with natural gas in the existing system	Membrane separation with current conventional electricity	1.6
C	Hydrogen produced from natural gas by steam reformation without carbon sequestration	Hydrogen transported separately in road tankers	No separation required	2.0
D	Hydrogen produced from wind power by electrolysis	Hydrogen transported separately in road tankers	No separation required	4.0
E	Hydrogen produced from wind power by electrolysis. Separation electricity provided from wind power	Hydrogen transported at 10% by volume with natural gas in the existing system	Membrane separation with electricity provided from wind power	4.6

NOTE: <sup>(a)</sup> Relative to conventional crude oil-derive petrol for approximately 1,300 cars which travel an aggregated total of 17 x 10<sup>6</sup> km/a and natural gas supplying a continuous heat demand of approximately 35 MW or 1.1 x 10<sup>9</sup> MJ/a

## Permeation measurements through polymers within the Naturalhy project

### Introduction

The integrity of polymer pipe networks marks a significant improvement over grids made of older pipeline materials such as cast iron. Nevertheless polymer pipelines allow a certain amount of the transported gas (e.g. natural gas) to diffuse through the pipe wall even if the integrity of the pipe is fully given. The whole transport process including adsorption on the pipe wall, absorption into the material, migration through the material and desorption from the outer pipe surface is called permeation.

For the Naturalhy approach (transportation of hydrogen together with natural gas through the existing gas grid) the effect of the hydrogen concentration in the natural gas on the gas losses caused by permeation must be assessed. The aim is to be able to compare the gas losses of the natural gas service in comparison to the transportation of hydrogen rich gases depending on the hydrogen concentration.

To obtain the needed information on the transport properties of hydrogen through the wall of polymer pipes four partners of the Naturalhy consortium (IFP, CEA, ISQ and DBI) have performed permeation measurements on polymers. Continuum (a Dutch gas distribution company which is now called Alliander) has joined the project in 2006 and supported the testing of PVC-HI (ductile PVC) pipes and fittings, which are widely used in the Netherlands. In the following the results of DBI and IFP are highlighted:

### DBI part

For the tests carried out in the DBI laboratory pipe specimens (from the manufacturer) have been used for most of the investigations as this provides results gained under conditions close to the operational parameters of the pipes without the need for subsequent interpretation. Therefore a test bench was developed which could hold pipe sections up to a length of 1.2 meters and diameters up to 160 mm. After a testing period the initial set up was improved by slight changes and the introduction of controlled space. The modifications led to a more accurate determination of the gas volumes permeated through the pipe wall. The general set up of the test bench is shown in figure 1.

DBI has performed tests on pipe specimen made of PVC-HI and PE 100 material with diameters of 110 and 160 millimetres. The tests were performed with a mixture of methane and hydrogen at a total pressure of 10 bars and a temperature of 16°C. Baseline tests were performed with pure methane.

From the results obtained it can be concluded that the transport of hydrogen through polymers is significant elevated in comparison to methane. In particular the transport of hydrogen through PE pipes turned out to be 6 to 7 times higher than for methane.

The permeation of hydrogen through PVC-HI pipe walls is also higher than for methane but still very low in total. Displaying absolute ratio-figures for the material PVC-HI is not possible as the transported methane gas volume through the pipe wall is so small (current business case) that proper determination of a permeation coefficient through PVC-HI, with the applied test set up is not possible. However, the permeation coefficient for PVC-HI determined for hydrogen is about 70-75% of the coefficient measured for PE100 with hydrogen, which marks a significant increase over the methane case but is still low.

The fittings of PVC-HI pipes (plug connection with lip sealing) per-

form very well for methane. If hydrogen is introduced the connections make a greater contribution (factor 30 in comparison to methane) to the overall losses.

It can be concluded that the investigated polymers show elevated transport properties for hydrogen. This will cause higher gas leakage rates with increasing hydrogen concentrations in the distributed gas. The increased gas losses are caused by higher permeation through the pipe or hose wall and for the PVC-HI pipes by a combination of elevated permeation through the wall and larger fitting leakage.



Figure 1: DBI test bench with controlled space and casing according to EG 97/23

### IFP part

Permeation measurements were performed by IFP on unaged PE80 material samples in various conditions of pressure, hydrogen content, and temperature. The experimental technique developed at IFP concerns gas or gas mixtures permeation through a polymer membrane in a flowing stream of vector gas and detection by gas chromatography. In that kind of measurement, one or several diffusing species cross the polymer to reach an opened volume swept away by an inert gas stream. This carrier gas serves for pulling the different molecules towards an appropriate detector measuring the present gas proportion. Then, it is possible to determine the intrinsic transport coefficients of each of the gases constituting the initial mixture. It allows us to determine the permeability coefficients of pure gas in numerous polymers but also the permeability coefficients of gas mixtures, such as  $\text{CH}_4\text{-H}_2$ .

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Permeation properties of a polyethylene (PE80 grade) used in pipe manufacturing was studied on this apparatus. Practically, many tests of permeability ( $> 50$ ) were carried out during this study in order to identify the influence of three main parameters:

- Temperature (3 temperatures tested: 40°, 60° and 80°C)
- Pressure (2 pressures tested: 5 and 20 bar)
- Compositions of gases (pure CH<sub>4</sub>, 10% H<sub>2</sub>-90%CH<sub>4</sub>, 20% H<sub>2</sub>-80%CH<sub>4</sub>, pure H<sub>2</sub>).

Most of the experiments have been carried out twice in order to evaluate the repeatability of the tests. All the measurements were performed on PE80 plane sheets, of approximately 2 mm thickness, processed by compression moulding of pellets. The crystallinity rate of the PE samples, determined by DSC measurements, was near 50%.

Nevertheless, no influence of the applied pressure could be detected in the studied range (5 to 20 bar). Moreover, in the case of mixtures of H<sub>2</sub>-CH<sub>4</sub> with PE, no particular interaction could be noticed that is to say no mixture effect. Consequently, for a given temperature, each gas (either H<sub>2</sub> or CH<sub>4</sub>) keeps its intrinsic permeability coefficient whatever the composition of the feed mixture is. As expected, permeability coefficients increase with the temperature and are well represented by an Arrhenius law. This is quite normal because in the temperature range studied, no transition temperature is associated neither to the polymer nor to the gases. Thus, starting from these laws determined for each gas, it is possible to extrapolate and to obtain the permeability coefficients values at lower temperatures such as 10°C or 0°C.

By comparing the behaviour of the two single gases, one can see that the permeability of H<sub>2</sub> is larger than those of CH<sub>4</sub> whatever the considered temperature is. The activation energy of the permeability phenomenon through PE 80 for hydrogen is weaker than that for methane. As a consequence, the decrease of permeability with temperature is slower with hydrogen than with methane.

Regarding the results presented, hydrogen diffuses quicker than methane but the respective amount of gas dissolved in the polymer matrix is smaller. No particular interaction between the two gases was detected while a strong dependence of the diffusion coefficient on temperature was observed. ❖



Figure 2: IFP test bench (2 permeation cells)

Authors

Marie-Hélène Klopffer (IFP)

Gert Müller-Syring (DBI)

## UPCOMING EVENTS

**March 31, 2009:** Presentation of Naturalhy Project to the Committee on Industry, Research and Energy (ITRE) of the European Parliament

**June 9-10, 2009:** 3rd International Symposium on Natural Gas, INGAS 2009, Four Seasons Hotel, Istanbul Turkey

**June 18-19, 2009,** 7th European Forum Gas North Convention Centre of IFEMA, Madrid, Spain

**July 12-17, 2009,** Hydrogen-Metal Systems II Ciocco Hotel and Resort, Lucca (Barga), Italy

**September 16-18, 2009,** 3rd International Conference on Hydrogen Safety (ICHS) Congress Palace Ajaccio Corsica, France

**October 5-9, 2009,** 24th World Gas Conference La Rural Exhibition and Conference Centre, Buenos Aires, Argentina

## CONTACT US

For more information on the NATURALHY Project, please contact:

Onno Florisson

Gasunie Engineering & Technology N.V. Nederlandse Gasunie // P.O.Box 19 // NL-9700 MA Groningen // The Netherlands

email: [naturalhy@gasunie.nl](mailto:naturalhy@gasunie.nl) OR Visit the NATURALHY website: [www.naturalhy.net](http://www.naturalhy.net)