Summer 2004

Bellona's vision for the hydrogen society

A clean energy chain

In this policy paper, Bellona addresses the opportunities and challenges facing the transition to an economy driven by clean energy.

Today the world economy is addicted on fossil fuel as it provides 90 percent of the world's energy consumption. Emissions from industry and fossil fuel energy use constitute the man-made part of the green house gas emissions and heavy local and regional air pollution. The price we have to pay for this manifests itself in the form of natural disasters, unreliable access to food, the spread of tropical diseases and severe health and ecosystem impacts.

To remedy this situation, the ultimate goal must be to enable an energy system based on clean and renewable energy sources such as solar, wind, hydro, wave, geothermal and bio. An integrated approach to these demands is to introduce energy carriers that do not pollute during distribution or usage, which at the same time introduce flexibility with regard to energy sources. These energy carriers are hydrogen, electricity and thermal (such as district heating and cooling systems) as illustrated in figure 1.

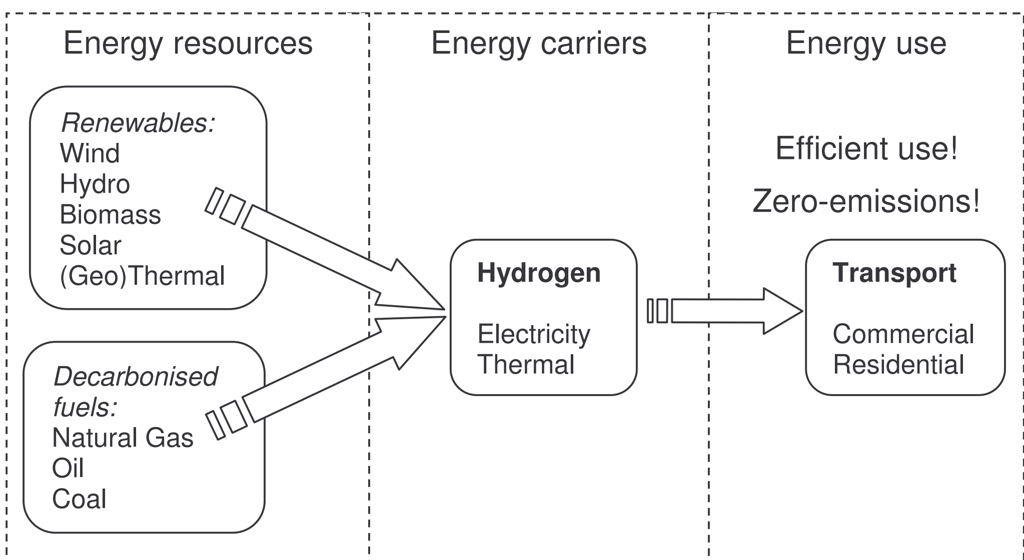

Figure 1: *Bellonas vision for a clean energy chain in the hydrogen society.*

For hydrogen, the challenge today is the large gap between supply of renewable energy sources and the demand for energy needed to kick-start the hydrogen economy. Renewable energy sources only constitute a very small part of today's energy production and compared to fossil fuel, present renewable pathways to hydrogen are scarce and costly. De-carbonised fossil fuel can therefore play a key role in the transition to an all-renewable energy economy.

Bellona Europa
Clos du Parnasse 10B
B-1050 Bruxelles
BELGIUM

Ph:
+32 2 648 3122
Fax:
+32 2 648 3122

e-mail: europe@bellona.org
http://www.bellona.no

Paradoxically, since producing renewable energy sources such as solar panels and windmills is energy intensive, replacing polluting energy production with renewable alternatives will require an increased use of energy during a transition period. A key challenge is to accelerate this transition as quickly as possible and without a parallel increase in emissions.

Renewable energy sources will accomplish what fossil fuels are incapable of in the long term while fossil fuels can accomplish what renewables are incapable of in the short term.

Over the past five years The Bellona Foundation has undertaken extensive work in this field through the energy project entitled "Searching for solutions". In this paper we present the results of our work, laying out Bellona's vision for accelerating the transition towards the hydrogen economy. The transition will lead to a considerable reduction of CO_2-emissions, while at the same time allow for sustainable economic growth. In this way, the energy sector can go from being part of the problem to becoming part of the solution.

This paper will address the following issues:

- Introducing hydrogen: Barriers and possibilities in the transition phase.
- The role of CO_2-handling: How Europe can be the cradle for the hydrogen economy.
- The role of energy efficiency
- The compatibility of renewable energy sources and de-carbonised fossil fuels

Introducing hydrogen

Hydrogen and fuel cell technology is beyond any doubt the bridging technology to a renewable energy system. Fuel cells are energy conversion devices that use an electrochemical process to transform hydrogen into both electricity and heat. Using hydrogen in a fuel cell system gives zero carbon or other gas emissions harmful to the environment. Bellona believes that hydrogen and fuel cell technology must be introduced as rapidly as possible with full market penetration already at an early stage.

Hydrogen produced exclusively from renewables is, and remains, the overall goal. However, as we shall see, this paper identifies a substantial gap in supply and demand of renewable energy for the production of hydrogen. In addition, state-of-the-art renewable generation for hydrogen is through electrolysis, one of the most costly sources of hydrogen at the present. This situation serves as a barrier for the deployment of hydrogen and fuel cell technology, and will cause serious delays in the transition to the large scale all renewable hydrogen society. Bellona believes that neither the environment nor society at large can afford to wait until renewable energy sources come close to replacing fossil fuels. This is why it is vital to look at mechanisms that will accelerate this transition. It is in this context that de-carbonised fossil fuel for hydrogen plays a key role as a "bridging" energy source.

First introduced in road transport

The debate concerning the hydrogen society is often quite wide in terms of both hydrogen applications and sources of hydrogen. Due to recent technological development it is more likely that hydrogen technology will initially be commercialised in the transportation sector. In a first phase, hydrogen will therefore gain the environment and society best as a fuel for road transport (illustrated by bold text in figure 1).

The renewable energy gap

To document the gap in supply of renewable energy, Bellona has asked the following question: What will be the demand for renewable energy assuming all vehicles in the EU run on hydrogen generated form renewable electricity in 2030?

As shown in figure 2, the International Energy Agency (IEA) has established two future scenarios for supply of electricity based on renewable energy. The first scenario encompasses all current policy measures for producing renewables and is indicated as scenario A. In scenario B, future policy measures for renewables are added. Finally, scenario C indicates the energy demand from an entirely hydrogen-driven transport sector in the EU.

The gap in figure 2 is equivalent to about 1,3 million 1MW windmills. Today, there are 24000 MW installed wind power in the EU – which would meet only 1.8 % of the total hydrogen demand.

Even though we should be able to increase energy efficiency and the introduction of renewable sources further compared to IEAs scenarios, this illustrates that we are faced with a huge gap between supply and demand of renewable energy in a hydrogen society.

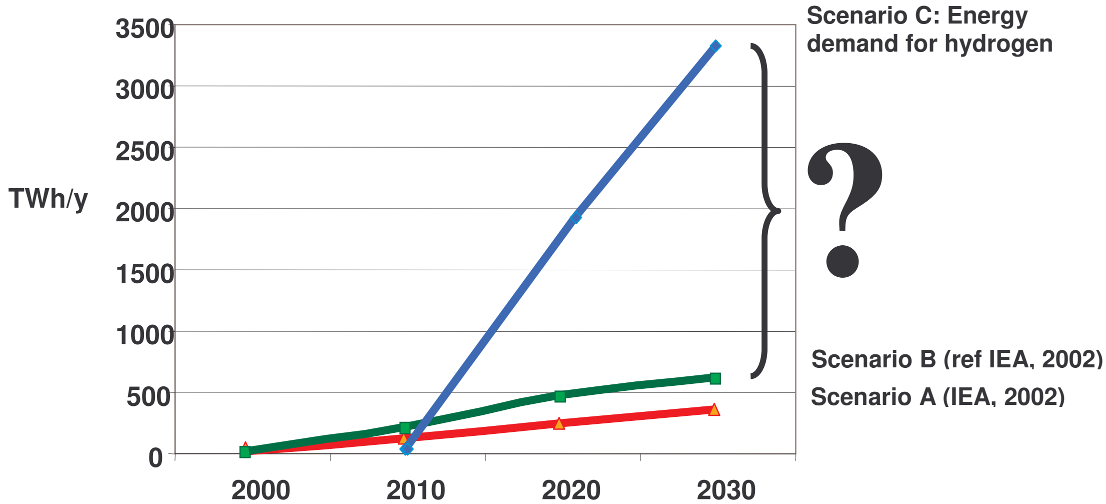

Figure 2: *Calculated annual electricity demand for hydrogen related to expected renewable generation (wind, solar, biomass, tide, wave, geothermal). Based on IEA (2002) & GM (2002)*

There are other ways to produce renewable hydrogen apart from electricity-based pathways, such as directly from biomass. However, the potential in these resources could constitute somewhere between 15% and 50% of total hydrogen demand[1], still leaving a significant gap.

Fossil sources secure supply and increase use

Car manufacturers are hesitant to invest in large-scale production with fuel cell vehicles as long as there does not exist a hydrogen infrastructure and there is an inadequate supply of hydrogen. To close the energy gap, Bellona believes de-carbonised fossil fuels can be a viable short-term solution. Supply is secured if fossil resources are utilised and this will significantly reduce barriers for the deployment of a hydrogen infrastructure. It will enable car manufacturers to introduce hydrogen and fuel cell vehicles. Fuel cell vehicle stocks and hydrogen infrastructure will then develop interactively. Such hydrogen infrastructure will lay the foundation for the distribution and hence the widespread use of hydrogen fuel from renewables in the long term.

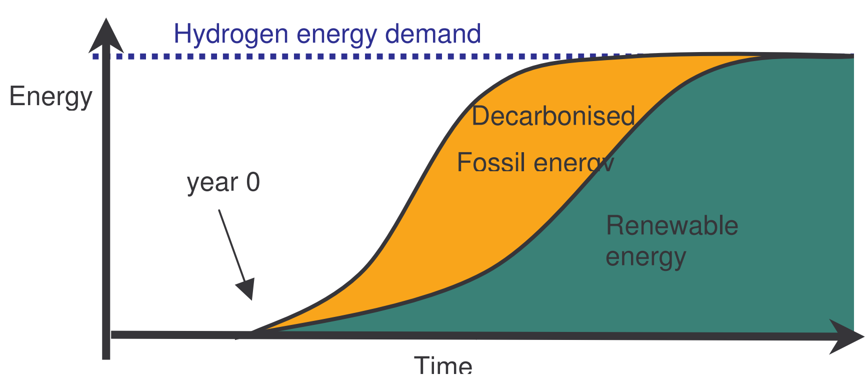

Figure 3: *The transition period to hydrogen.* The transition to the hydrogen economy should be accelerated using fossil energy.

How fossil fuels can secure supply is illustrated in figure 3. At year 0 in the figure 3 production of hydrogen from fossil and renewable resources starts. Fossil energy boosts hydrogen in transports giving benefits to the environment and society at an early stage. At the same time it is extremely important to work as fast as possible for development and implementation of renewable solutions. Over time, renewables can replace fossil resources in order to ensure a sustainable long-term hydrogen economy.

Increasing hydrogen production from decarbonised fossil energy will in the short term accelerate the transition towards commercial and common use of hydrogen, and at the same time safeguard the commitment to the struggle against climate change.

The role of CO_2-handling

A hydrogen economy based on fossil fuels without CO_2-handling will at best give limited benefits due to continued emissions of Greenhouse gasses (GHGs). This calls for identifying practical and environmentally sound handling of the CO_2. It is therefore important to develop safe long-term solution for CO_2 in parallel with the work for more efficient use of energy and increased use of renewable sources.

Europe is in a position to realise a clean hydrogen economy by taking advantage of the availability of fossil resources combined with the large storage potential of CO_2 in the North Sea basin.

Studies Bellona has undertaken show that given practical and environmentally sound methods, the North Sea region is a unique place to create a commercial basis for exploiting CO_2 by depositing it in reservoirs or formations under the ocean floor.

Today natural gas and water are being injected into oil reservoirs for oil recovery. In old oilfields the use of CO_2 for enhanced oil recovery (EOR) may increase the total amount of oil recovered. In many oilfields, natural gas, which have a higher greenhouse effect than CO_2, can be replaced by CO_2 and hence secure a more optimal use of resources. Moreover, by creating a demand for CO_2, petroleum companies would be willing to pay for it, which could pave the way for a large-scale CO_2-structure. An overview of oilfields with a demand for CO_2 is presented in figure 4. More importantly, particularly from an environmental perspective, petroleum companies could invest in emptying existing reservoirs rather than embarking on new oil exploration in sensitive areas like the Arctic[2]. Paradoxically, the problem is to provide enough $CO_{2,}$ in order to meet the demand for EOR in existing and future oilfields in the North Sea. CO_2 can be collected by capture from existing power plants and non-energy industries. Moreover, with a common infrastructure for transportation and injection of CO_2 in the North Sea region, economies of scale and profitability can be achieved.

Governments should facilitate the creation of a CO_2-market by establishing infrastructure and fiscal incentives that will make CO_2 for EOR purposes commercially viable

CO_2-storage beyond EOR and deposition in saltwater filled formations (saline aquifers) has a considerable potential. Studies suggest there is a capacity to store 100-150 years of EU's present CO_2-emissions. This capacity could be instrumental in further reductions in GHG emissions beyond the first Kyoto protocol. In

---

[1] Zittel & Wurster, 2002

[2] The Bellona Foundation (2003); The Bellona Foundation (2004);

fact, combining CO_2-handling technology with bio based generation of energy will enable a negative net emission of CO_2, which opens the possibility of reversing climate change tendencies in the longer run.

Field	Operator	CO_2(Mt/y)	Start year [3]
Brent	Shell	3-7	2006
Ninian	Kerr McGee	2-3	2006
Forties	BP	3-6	2008
Statfjord	Statoil	4-8	2012
Gulfaks	Statoil	2-5	2008
Ekofisk	Phillips	5-10	2010
Grane	Norsk Hydro	1-2	2008
Piper	Talisman	2-3	2008
Claymore	Talisman	1-2	2006
Brage	Norsk Hydro	1-2	2006
Dan	Maersk	2-5	2010
TOTAL		**26-53**	

Figure 4: *Potential demand for CO_2 for EOR in the North Sea*. Source: The CENS-study. Values are based on best estimates from the respective authorities.

Decarbonisation prevents nuclear pathways to hydrogen

The introduction and future strengthening of the carbon-dioxide emissions trading directive will clearly affect the energy markets and could result in favouring the use of nuclear energy. The European Commission High-level group report also recommends the use of nuclear energy for hydrogen in the mid- and long term. Nuclear power for hydrogen can get a market advantage over fossil energy in this situation. It is not in the interest of the environment to expand nuclear capacity as long as the challenges related to nuclear waste handling remain unsolved [4]. It is thus urgent to promote use of decarbonised fuels with a view to countering this situation.

The Role of Energy Efficiency

Bellona believes that energy efficiency will reduce the demand of fossil fuels and thus constitute an effective way to reduce emissions of GHGs. However, it must be very clear that electricity savings cannot contribute alone to clean production of hydrogen, as long as the liberated electricity is generated from fossil and nuclear sources. If this is the case, the performance of hydrogen vehicles would be very poor in terms of both energy efficiency and GHG emissions (Figure 5: H2 from EU el. mix), as compared with other alternatives in figure 5. The liberated fossil fuels (typically natural gas) resulting from energy efficiency measures should rather be converted to hydrogen directly combined with CO_2-handling. This will ensure efficient production and near zero emissions of GHGs as shown in the column "H2 from NG+CO_2 handle." in figure 5.

[3] Later studies have shown that for some fields the starting year might be some years later than indicated here.

[4] Solli (2004)

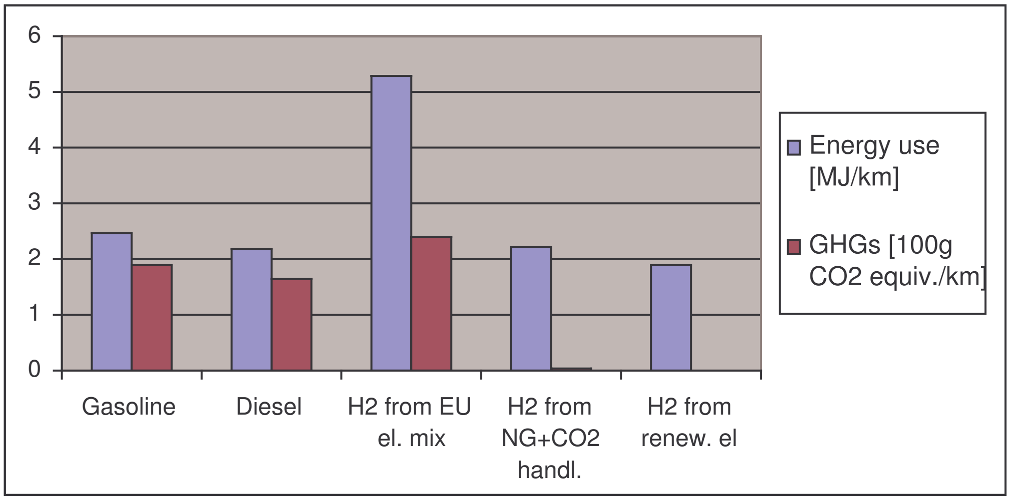

Figure 5. *Performance of different vehicles (fuel cycle included).* Source: GM (2002).
All figures are for compressed hydrogen. Figures for hydrogen from natural gas (NG) with CO_2-handling are collected from SINTEF (2002).

The compatibility of renewable energy sources and de-carbonised fossil fuels

As stated earlier, Bellona sees renewable energy as complementary to decarbonised fossil energy. Renewables will accomplish what fossil fuels are incapable of in the long term, while fossil fuels can accomplish what renewables are incapable of in the short term.

Looking at the energy situation realistically, renewable electricity generation such as photovoltaics, wind power, tide power and so fourth still have a long way to go before they constitute any significant share in terms of electricity supply. These sources must displace an enormous generation capacity in order to dominate the markets. In this situation, society can in the short term choose to use renewable electricity to replace either i) conventional electricity generation or ii) conventional fuels for vehicles. For both pathways, benefits will manifest themselves in terms of increased sustainability and reduced emissions. By choosing the second option, converting energy from electricity into hydrogen via electrolyses, will considerably increase the relative energy costs compared to conventional road fuels. Bellona sees this option as both a barrier for the deployment of hydrogen as a road fuel and the deployment of renewable generation. Renewable generation will suffer as the increased competitiveness towards conventional generation built up over several decades will be lost due to increasing cost of conversion from electricity to hydrogen. In the short term, it is therefore necessary to use decarbonised fossil energy for hydrogen to accelerate the development towards a sustainable energy system.

At present, direct conversion of biomass and bio-waste to hydrogen are the only renewable sources of hydrogen that come close to compete with fossil sources. Improving the competitiveness of these renewable energy sources through the introduction of proper fiscal and other framework conditions will be necessary. Preliminary calculations indicate nevertheless that the energy potential in these resources is limited. As renewable generation starts to dominate the power markets, proper framework conditions must also be implemented to promote electricity-based pathways to hydrogen.

Given an energy system dominated by fossil sources, renewable electricity should preferably be used to replace conventional electricity generation rather than to produce hydrogen.

References

European Commission High Level Group on Hydrogen and Fuel Cell Technologies –A vision for our future. Available at: http://europa.eu.int/comm/research/energy/pdf/hydrogen_summary_report.pdf

GM (2002), GM Well-to-wheel analysis of energy use and greenhouse gas emissions of advanced fuel/vehicle systems, -A European study. Available at: http://www.l-b-systemtechnik.com/gm-wtw/TheReport_Euro-WTW_27092002.pdf

IEA (2002), World Energy Outlook 2002.

SINTEF (2002), Hydrogen som energibærer –Energi og utslippsregnskap for utvalgte energikjeder. Available at: http://www.sft.no/nyheter/dokumenter/hydrogen_energibaerer.pdf

Solli, Christian (2004), FISSION OR FOSSIL? A Comparative Hybrid Life Cycle Assessment of Two Different Hydrogen Production Methods, NTNU, Available at: http://193.71.199.52/no/energi/hydrogen/34843.html

The Bellona Foundation, Hydrogen: Status and possibilities (Report 6: 2002) Available at www.bellona.org/en/energy

The Bellona Foundation (2003), Arbeidsnotat Nr. 1:2003, Utredning av konsekvenser av helårig petroleumsvirksomhet i området Lofoten – Barentshavet, Available at: http://193.71.199.52/no/energi/fossil/nord/barentshavet/32340.html,

The Bellona Foundation (2004), Fakta ark: Nei til olje i nord, Available at: http://www.bellona.no/no/energi/35034.html

Zittel & Wurster (2002), The prospects for a hydrogen economy based on renewable energy, L-B systemtechnik. Available at: http://www.hyweb.de/Wissen/pdf/ireland2002.pdf