Potential of Bio-Hydrogen and Constraints of its Utilisation

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Summary
A world-wide energy economy on the basis of biomass has significant benefits to the economic conditions of every country. The potential of the technology is explained using examples from developing and developed countries. Technological barriers are mentioned as well as the water issue. In the long run the switch to a solar hydrogen economy with biomass leads to a significant reduction of energy costs. There are several reasons for this:

- Halving the energy requirement through higher efficiency
- Energy from biomass is cheaper than energy from crude oil
- Cheaper energy distribution through use of pipelines.

Clean cheap energy produced locally is a prerequisite for independent development, which leads to peace.

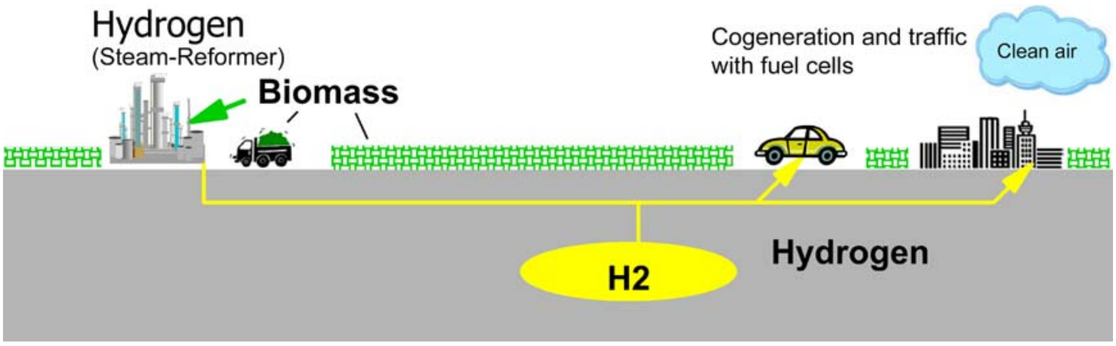

Fig. 1 Infrastructure for a solar hydrogen economy

Introduction

The developing energy crisis can be fully resolved by the creation of a hydrogen economy – the hydrogen itself being produced from agricultural biomass. This energy source causes zero emissions, no global warming, and would end the risk of conflict over oil reserves. Almost all countries can completely satisfy their power requirement with biomass. This bio-energy is less expensive than oil. It can be produced locally and gives developing nations better conditions for their political and economic development. Sale of agricultural biomass would enable the farmers of developed nations to prosper without the need for agricultural exports at give-away prices.

Infrastructure

Agricultural biomass is simply stored solar power. Instead of distributing electricity through wires, the hydrogen produced from agricultural biomass can be more economically distributed through pipes. No electrical national grid is required. Such a hydrogen network would be universal: supplying power, heat and transport fuel through one network. Electricity must be generated at the same time as use. Hydrogen can be used on the spot, on demand, thanks to the storage capacity of the hydrogen network. In many countries a large part of such a network already exists – in the form of the natural gas network, including existing underground storage space.

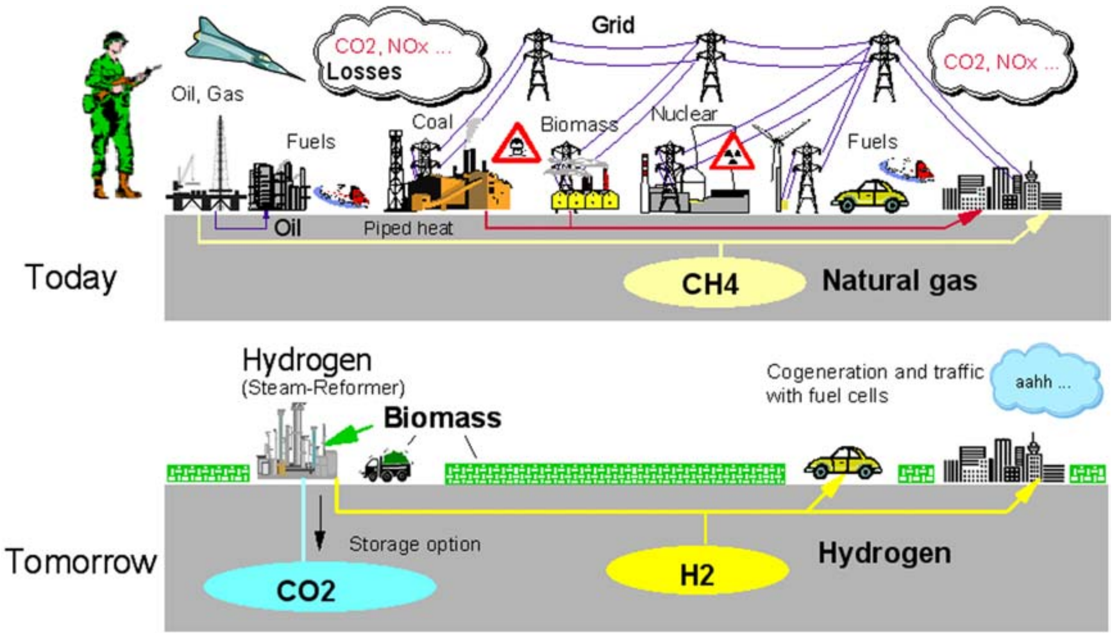

Fig. 2 Infrastructure today and tomorrow

Thus, a hydrogen economy consists of agriculture, hydrogen factories, a pipe system and decentralised users. Neither the generation of hydrogen from biomass nor the use of hydrogen results in any air-born pollutants, while concentrated CO2 arises as a by-product during hydrogen production, and may be stored underground at little extra cost. Depleted gas and oil fields as well as porous geological layers are suitable for this. In this way, the debt we owe to our climate can even be paid back.

Hydrogen factories are industrial plants of a size from 100 to 500 MW. Biomass need only be collected from a catchment area of 3 to 15 km. The factories can be placed at some distance from the consumer, like conventional power stations. This is due to the highly efficient conversion of biomass to hydrogen, where no heat is obtained as a by-product.

Hydrogen technologies

Generation of hydrogen:

All hydrogen technologies are either chemical or electro-chemical energy converters. The conversion of biomass to hydrogen is a chemical process. The first reaction takes place at approximately 850 C: Biomass + H_2O → $\mathbf{H_2}$ + CO + CO_2 + H_2O

Water is added to the process to increase hydrogen yield. Therefore, this first step in the generation of so called “syngas” is also called “steam-reforming”. Because water is needed, wet biomass (silage) is also suitable for processing. Because silage stores well, the biomass can be harvested green. Thus all kinds of plants are available for energy production. In this way several harvests are possible each year, resulting in a high total yield. The same process may also be exploited to generate “syngas” from coal, natural gas and crude oil derivatives (naphtha). The process of the purification of syngas to remove ash etc. requires further optimisation.

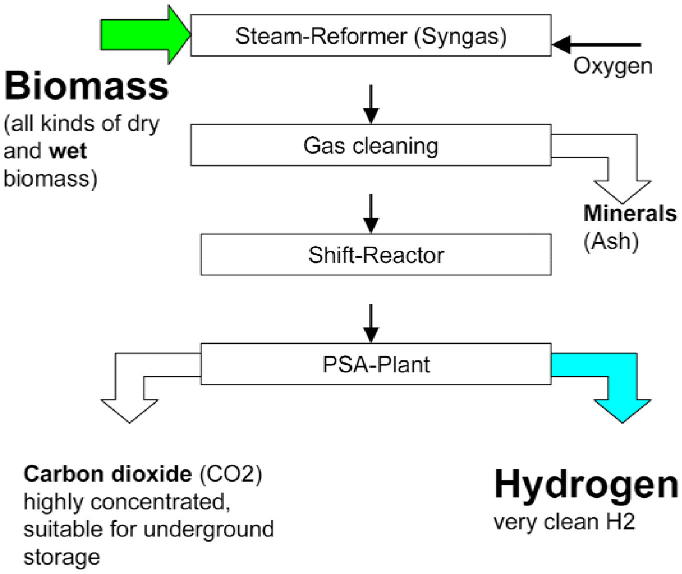

Fig. 3 Production scheme for hydrogen

To date, 20 of the steam reformers for biomass which have been built world wide, can be classed as industrial plants. Development work has accelerated in recent years. Even the US intends to recommence production of hydrogen from biomass. The shift reactor ($CO + H_2O \rightarrow CO_2 + H_2$) and the gas separation (PSA) processes are fully developed and can be added once the purification of "syngas" has been optimised. Incidentally, the ash which arises during gasification can be used as a very good agricultural mineral fertiliser.

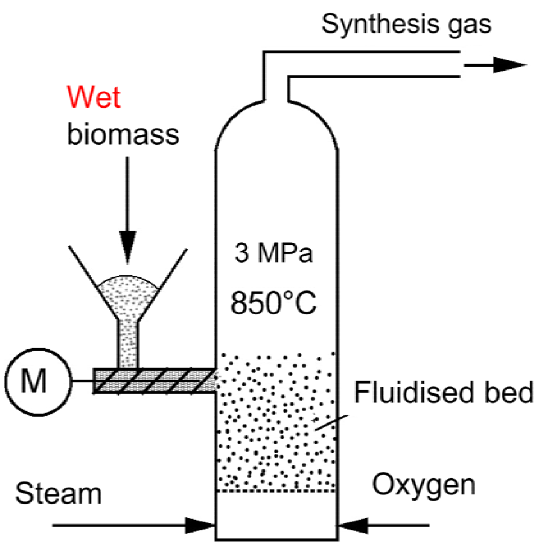

Fig. 4 Steam-Reformer

Fig. 4 shows a steam reformer as a fluidised bed reactor. This is a universal type of reactor which is currently used to burn coal in big power stations. The only difference in the gasification process is that oxygen input is reduced. Steam reformers are normally run under pressure. This makes gas purification easier, and the hydrogen produced then requires no further compression for delivery to the pipe network to the consumer.

Fuel cells

Fuel cells are electrochemical energy converters. They generate nothing but power, heat and water. Their simple structure makes fuel cells ideal for mass production. Fuel cells can be built to any size without loss of their fundamental properties. The cost of a fuel cell system for the production of 0.5 * 10^6 units/y of each 55kW are given by the US government as 12 US $/kW (10 Euro/kW) [1]. In the early market, it would already be competitive to power a car by fuel cells even if the cost were 5 times this, and a fuel cell for stationary energy conversion would still be great at the 100 fold price! The long-term stability of fuel cells both in laboratory and in initial field tests has been satisfactory. Before a more confident statement can be made, mass production has to start and the fuel cell has to prove itself in daily use by the consumer.

In a hydrogen economy there will be a permanent surplus of power over heat, because each fuel cell delivers more power than required. In such a system heat is therefore as valuable as power. This is the case for an energy economy both on the basis of photovoltaic solar cells and for the use of bio-hydrogen. Thus, the primary purpose of a fuel cell is the production of heat. The surplus power can be converted without loss into heat where required. The type of fuel cell will therefore be chosen according to the usable temperature level:

- 200ºC: membrane fuel cell (PEMFC)
- 600ºC: molten corbonide fuel cell (MCFC)
- 900ºC: solid oxide fuel cell (SOFC)

Efficiency and Potential

Hydrogen technologies are efficient technologies. For instance, if hydrogen is used to power a car, then with the same amount of energy, you can drive about 6 times further than with a conventional internal combustion engine (ICE) car. The yield of usable energy is also high for domestic use, due to the technology's decentralised character.

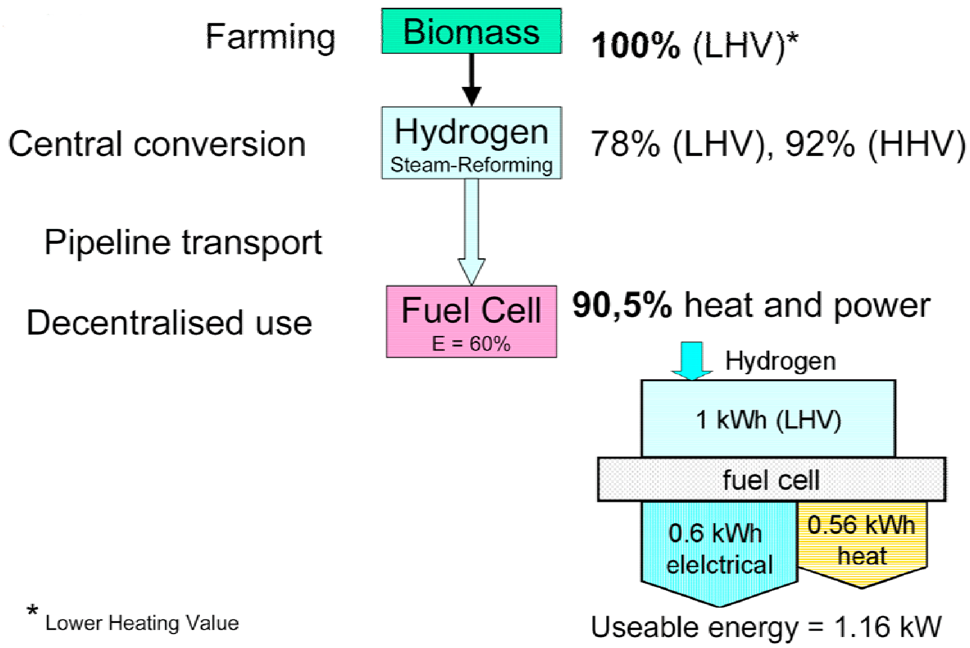

Fig. 5 Efficiency for residential heat and power

In the Fig. 5 it is assumed that most of the reaction water from the fuel cell will be condensed. This is true for the heating of buildings as well as for the generation of hot water.

I will use the German energy economy by way of example to show the consequences with regard to the required primary energy.

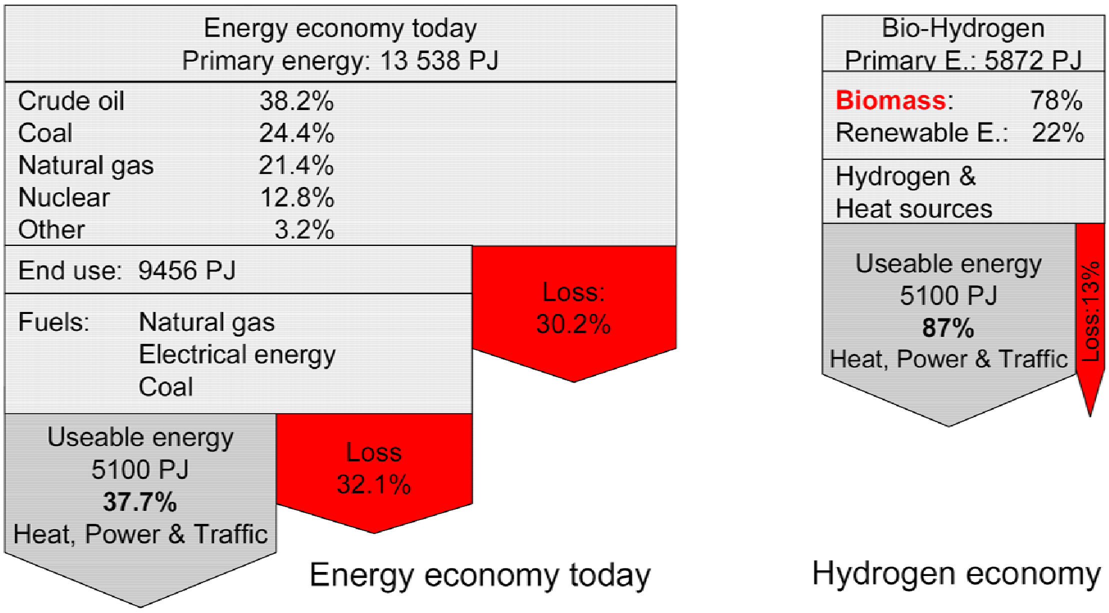

Fig. 6 Energy economy in Germany today and tomorrow

The comparison in figure 6 refers to the year 2001. The usable energy amounts today to 37.7% and tomorrow to 87%. 78% of the primary energy for a future hydrogen economy is derived from biomass, while 22% is derived from other renewable sources such as geothermal and solar heating. Synergistic effects will result in cost reduction. Note that doubling in efficiency also leads to doubling the biomass potential.

A much larger increase of this potential is due to the fact that wet biomass can be used for gasification. This biomass can be stored indefinitely in the form of silage. This has an important role to play as a buffer between harvest and energy requirement.
The industrialised nations and some emerging economies can in fact satisfy their need for food using much less land than is currently used for agriculture. This is also true for the European Union (EU-25). The area of arable land which is surplus to requirements can therefore be used to grow plants for the generation of energy. The variety of crop is used for this is not important. What matters is the total amount of dry weight of the harvested biomass per year.

It was in 1979 that the EU attained a level of 100% self-sufficiency in food. Since then, food production has been increasing. The area of arable land no longer required could be used to grow energy crops. Fig. 7 shows the increase in wheat yields by way of example. The picture for other products is similar. In addition to this, modern high sophisticated meat production requires less and less feed.

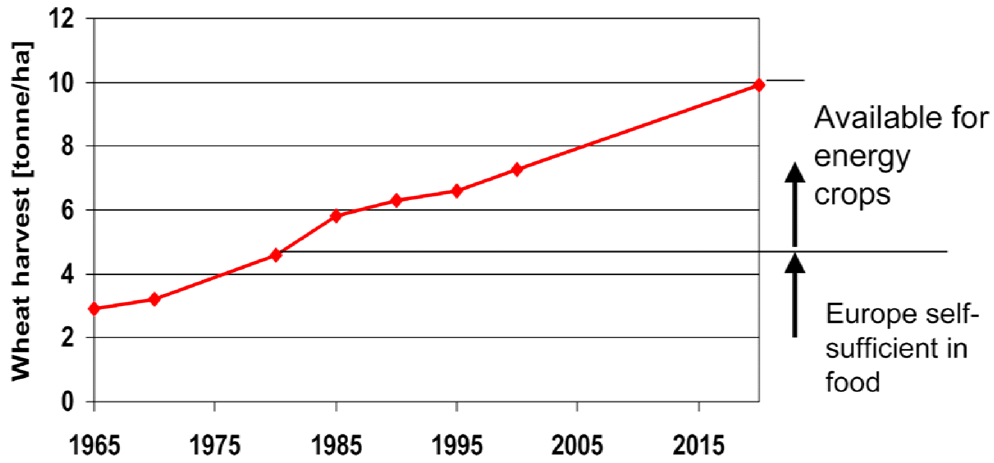

Fig. 7 More and more arable land can be used for energy crops

As yields increase, more and more arable land will become available to grow energy crops, which will also increase in yield. The available energy potential will in the long term far surpass the today's energy consumption. The European Union expects that the energy consumption remains constant or decreases slightly.

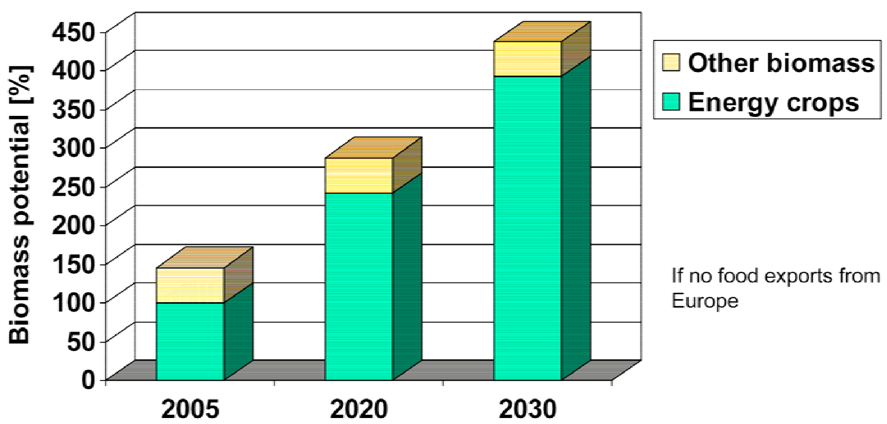

Fig. 8 Energy potential in Europe is higher than consumption

By producing energy rather than just food, agricultural profits will increase such that it will no longer be necessary to subsidise farming. The knock-on effects are immense. Consider this: An energy price for biomass of 73 Euro/tonne (this is equivalent to an oil price of 24 Euro/barrel or 30 US $/bbl) will give the farmer a higher income than would the production of subsidised wheat. This will influence food production such that there will be no place for food export at give-away prices. Even if the oil price were to fall to zero, this would still be too costly for industrialised nations.

Third world countries are increasingly bemoaning the high price for energy acquisition. In reality, it would be sufficient to replace their primitive form of energy conversion (for example simple fireplaces made from 3 stones) with exceedingly more efficient hydrogen technologies in order to build up a complete energy supply from local sources. The most important "sources of energy" are hence awareness and education. Of course help from outside, and this includes financial aid, is still indispensable. This would be more effective than any debt cancellation, as the ever rising oil price would soon lead to new debt.

The water issue

Water is the source of all life. Water is also a source of energy. In many countries, dams and reservoirs serve to generate electrical energy by way of turbines. When water is short, a conflict of interest ensues between energy economy and food production, as farmers also require some of the dammed water to irrigate their fields. By using hydrogen technologies, it is now possible to generate from the dammed water much more energy and at the same time, more food. Instead of running the water through turbines, it is more efficiently used to irrigate fields of energy plants, which are then converted by gasification to hydrogen. Using fuel cells to convert the hydrogen obtained in this way to electrical energy, the same amount of water will now yield 10 to 100 times more electrical energy than if it had been poured through water turbines. This obviously leaves much more of the water to grow food.

An other extreme example of what this new approach could do is the desalination of sea water for irrigation of energy plants. Modern processes make use of reverse osmosis for this. Here, sea water is pumped through thin membranes against an osmotic pressure of roughly 2.7 MPa. To pump the required water to field above sea level, an effective pressure of 7 MPa is generally calculated. Irrigation (in addition to any rainwater) of 0.3 m/y (corresponds to 0.75 m/y rain) will allow a biomass yield of 20t/ha (2kg/m^2). Use of hydrogen technologies converts this into 3 times the energy employed in the first place to desalinate the required water. Thus, desalination of sea water is no more expensive than gaining water by creation of big dams and reservoirs. Even if in some cases the local conditions have to be evaluated on-site, it can generally be said that production of bio-energy is not in conflict with food production. In fact, in many cases it is the generation of bio-hydrogen which will enable the production of food in the first place. It is, of course, a prerequisite that artificial irrigation will allow improved yields, and that there is land available for irrigation. However, this is the case for many countries which are currently suffering from a shortage of energy and food. And this is also the case for China. For instance, a transfer of water from south to north plus transport of desalinated sea water to arid regions will in the long term allow a similarly high energy consumption per head of population as in today's industrialised nations. Naturally, such projects require a high financial input. Still, this is cheaper than waging a war for the last drop of oil. It may take some time to get used to the fact that rivers will, literally, flow backwards. But look at the old Romans. They got used to aqueducts bringing their drinking water to Rome.

Costs

The energy costs of a solar hydrogen economy using biomass are dependant on the costs for generation biomass. The highest costs would be found in countries with high wage costs which are located in temperate zones. Let me elucidate this by comparing Europe and countries like China.

Europe:

A price of 73 Euro/tonne dry biomass (60 US $/tonne or 730 RMB/tonne) gives the farmer a high enough income to make subsidies unnecessary. This price is equivalent to a crude oil price of 30 US $/bbl (24 €/bbl or 0.015 €/kWh). Assuming a return on capital typical for industry, the overall production costs of bio-hydrogen can be calculated as 0.025 €/kWh. This refers to the Lower Heating Value (LHV) before tax.

Payment to the farmer	0.015 Euro/kWh
Loss	0.005 Euro/kWh
Investment	0.005 Euro/kWh
∑	**0.025** Euro/kWh
Industry rate	0.028 Euro/kWh
Household rate	0.032 Euro/kWh
Filling station for cars	0.041 Euro/kWh

Table 1 Cost of bio-hydrogen in Europe

The current household price for natural gas is higher than the price for bio-hydrogen. It would thus be profitable to enter into a hydrogen economy even without the use of fuel cells (though less efficient, of course).

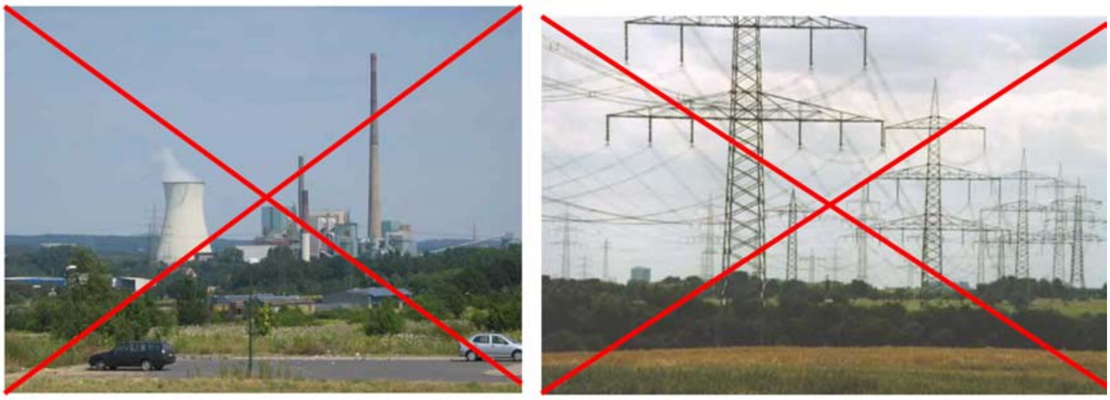

Fig. 9 Uncompetitive old infrastructure

The use of fuel cell heating would put the cost for the generation of electrical energy in a private household at 0.032 €/kWh. In comparison, the current tariff in Germany is 0.18 €/kWh. The fuel costs for future fuel cell cars will also be much lower than today, namely 0.36 €/100km compared to 4 €/100km (all before tax).

Countries like China:
Assuming a price for biomass of 20 €/tonne, the production cost of bio-hydrogen can be estimated to be around 0.0083 €/kWh. This could for instance be the case for China.

Payment to the farmer	0.0041 Euro/kWh
Loss	0.0012 Euro/kWh
Investment	0.0030 Euro/kWh
∑	**0.0083** Euro/kWh
Industry rate	0.010 Euro/kWh
Household rate	0.011 Euro/kWh

Table 2 Cost of bio-hydrogen in countries like China

Unlike today's energy economy which uses fossil and atomic energies, the energy prices given here correspond to the general level of income. This sets good conditions for development.

Energy costs in Germany:

Comparing energy costs of a hydrogen economy with the current situation in Germany puts them to the test, a “worst case scenario” if you so want, especially if you base the comparison on the year 2001, when oil prices were still low.

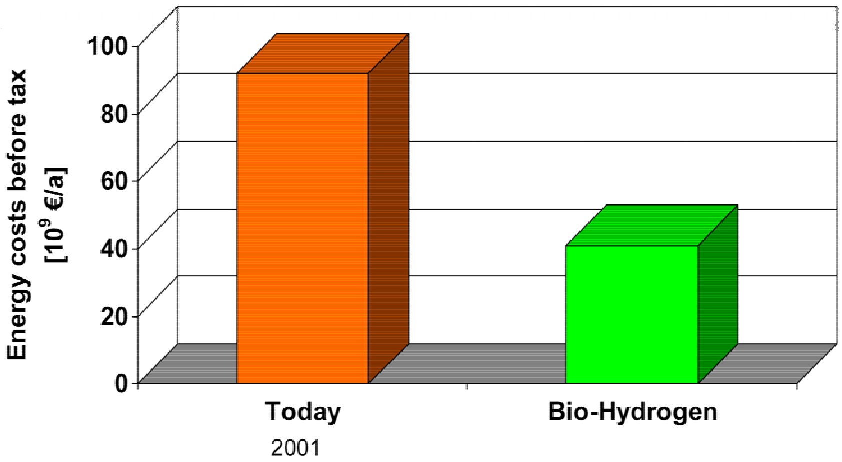

Fig. 10 Energy costs in Germany

The result is no surprise. Suppose the farmer receives for his biomass the crude oil equivalent of 30 US $/bbl (73 €/tonne). Bare in mind also the much simpler infrastructure in a hydrogen economy, plus the fact that the energy requirement will be halved due to higher efficiency. It is then easy to see that the cost for energy in a hydrogen economy will be less than half. This is especially the case if you consider the full costs of energy conversion, including the installation costs at the customers’ premises. Unfortunately there is not enough room to explain all the facts in more detail, but you will find further explanations in my book [2].

In countries with an efficiency lower than 38% (compare Fig. 6) and a lower cost for biomass, the difference between a solar hydrogen economy and the traditional energy economy is even more marked. In the long term, the oil price is forecast to rather rise above 30 US $/bbl. At the time of writing, the price is more than twice this.

How to start?

The aim of this essay is the instigation of a broad debate which should investigate whether a solar hydrogen economy using biomass can be a desirable goal. Of course, if it’s so good, everybody will want to know how to start, and why it hasn’t been done yet. First of all, a few impediments:

- Unknown benefits
- Energy companies are not amused
- There is a big “chicken and egg” problem
- The world thinks only in terms of electrical energy
- Due to the subsidies for electrical energy, every attempt at the use of hydrogen is nipped in the bud

Is it possible to introduce a hydrogen economy within the framework of existing regulations to support the generation of electrical energy from renewable sources, which exist in many countries? No, because the hydrogen economy will make all these other technologies superfluous. Thus a political decision of general principle is required. The problem is not the technical maturity of the technologies, nor the

necessary finance. Rather, it is a problem of social perception. It is not easy to even start a fair debate. This is due to the fact that there is a powerful energy lobby which dominates the agenda in many nations.
It is not appropriate to list here the innumerable ways to introduce a hydrogen economy. Only a few remarks are called for:

- A hydrogen economy serving 100,000 population would already compete with oil and gas even without fuel cells
- Start with a state support
- Use the Kyoto protocol rules

Were an economy to start a hydrogen economy in a big way, then no state support would be necessary. To make mass production of the implementation technologies cost effective, as many customers as possible ought to be won. The construction of a hydrogen infrastructure is especially important. The gasification technology is simple enough for even the developing nations to adapt to their own requirements. It is not necessary for small or poor countries to develop fuel cells on their own. In the long term, the market will be flooded with fuel cells at give-away prices from disused fuel cell cars from industrialised nations.

Outlook

Like all biological systems, a hydrogen economy based on crops is very complex. The connections between energy and politics are equally complex. It would therefore be a mistake to consider the solar hydrogen economy presented here as just a cost-effective alternative to the current energy economy. For this reason, a broad debate with pros and cons, considering all aspects, is so very important. This amounts to no less than a paradigm shift both in the energy economy and foreign relations. A solar hydrogen economy would have the following advantages:

- Wealth through low cost, local energy
- Sustained energy supply
- Full protection for the environment and climate
- No wars over oil
- Independence
- Safeguarding of cultural independence
- Fair structures of globalisation
- Better prospects of development for poor countries
- Remove a source of world wide tension – and potential terror

We all have a lasting obligation towards our children and our children’s children. Let us leave the century of world wars far behind us. Now, wars over oil are more than superfluous. The new emergency is peace, and we all have to prove ourselves within it.

Fourth Global Conference of GCHERA, 12. – 15. September 2005, Hangzhou, China

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[1] Fuel Cell Report to Congress (ESECS-1973); DOE, February 2003
[2] Karl-Heinz Tetzlaff; Bio-Wasserstoff; ISBN 3-8334-2616-0; BoD Verlag Norderstedt, Germany