Biomass based Hydrogen Economy

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The world wide energy supply on a fossil and atomic basis is now in an economical, ecological and political crisis: the end of the fossil energy is foreseeable, as is an increase in price and in dependence on imports from abroad. What is needed in this situation is an alternative source of energy and a convincing concept that meets at least three minimum requirements:

- **CO_2 -Neutrality,**
- **Sustainability and Availability**
- **Affordability.**

This can be achieved by implementing a green hydrogen economy in which hydrogen is produced from biomass by thermo chemical gasification, according to the simple recipe

$$\textbf{Biomass} + H_2O = H_2 + CO_2$$

Since biomass is available at about 1 to 2 €ct/kWh, half the price of fuel oil or natural gas, this is an affordable energy source. It will be shown below that, as distinct from the process of anaerobic digestion of biomass, the biomass energy can be transformed to hydrogen energy almost without any loss. So the benefit of the low price of the feedstock can be passed on to the consumer.

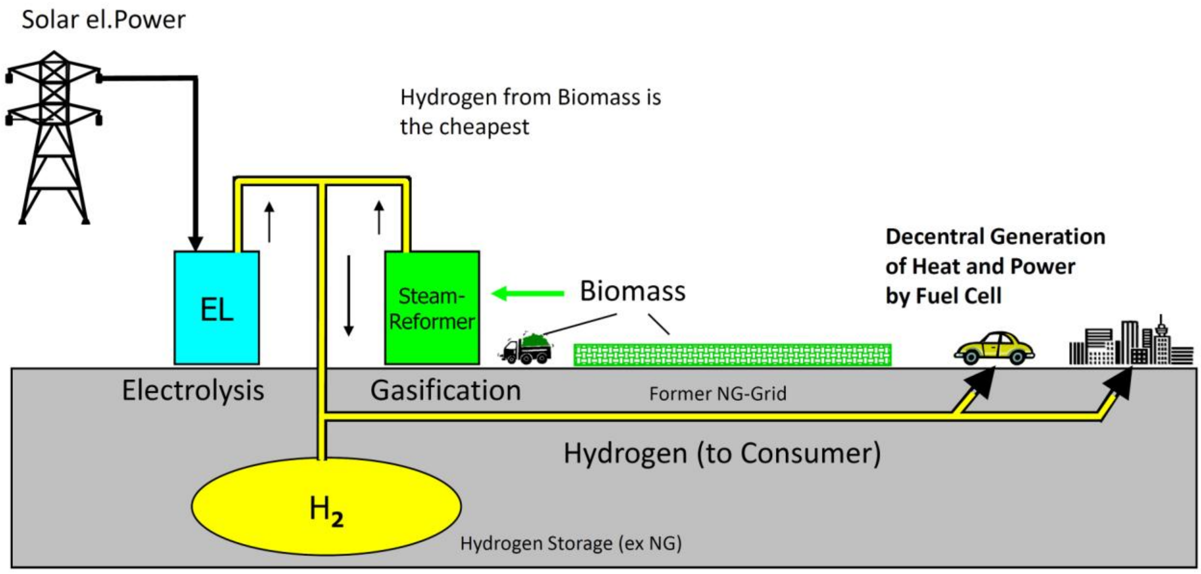

Fig. 1 Genuine Hydrogen Economy

According to the concept suggested the hydrogen produced is pipelined to the user and fed to fuel cells for decentralised generation of electricity and heat, thereby establishing a cogeneration of heat and power (CHP). Although this is not essential to the concept, it is a further advantage of this system that renewable sources other than biomass can be integrated without problems as shown in Fig. 1 and Fig. 3. Calculations below are based on the assumption that in Germany about 33% of the total energy required stem from other renewable sources.

The implementation of this system immediately raises three core questions:

- **How much biomass does it require?**
- **Is this much biomass available?**
- **What are the technical problems?**

Amount of biomass required

In the **electricity guided** system existing presently only a fraction of the primary energy input is converted into electricity and distributed at high costs. The greater part of the primary energy put in is either lost or is liberated as heat energy as a difficult to utilise by-product.

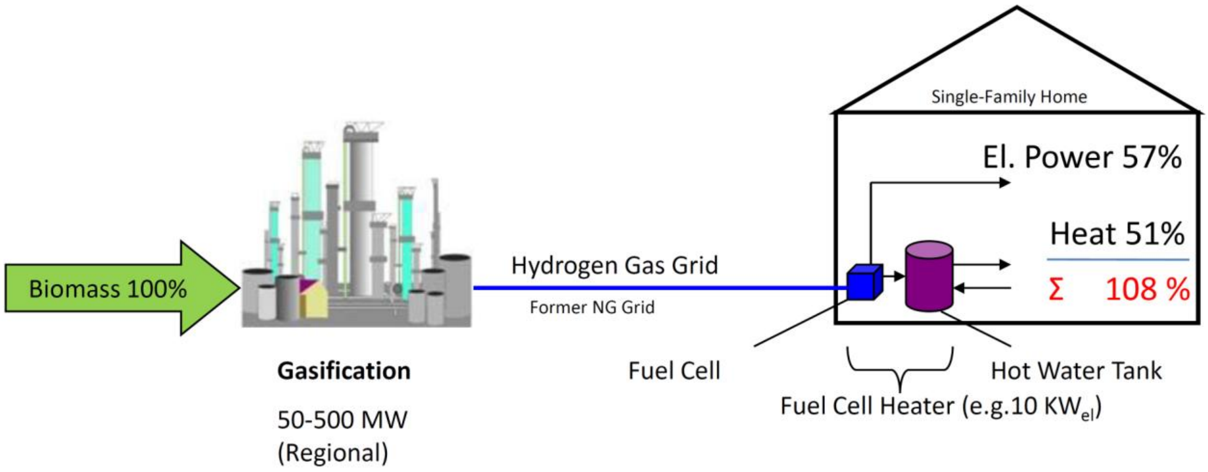

Fig. 2 Supply Scheme

With a **decentralised generation of electricity** as depicted in Fig. 1 it's the other way round: the object is to produce **heat not electricity** since the economy needs three to five or more **times as much heat as electricity.** Fuel cells produce electricity with an efficiency of 50%-60% (Fig. 2) although less than 30% are actually needed to meet the demand. Therefore, in such a system, which is called a **heat guided economy**, there will always be a surplus of electricity- **unavoidably**. This by-product "surplus **electricity"** can readily be converted to heat without incurring any loss at all.

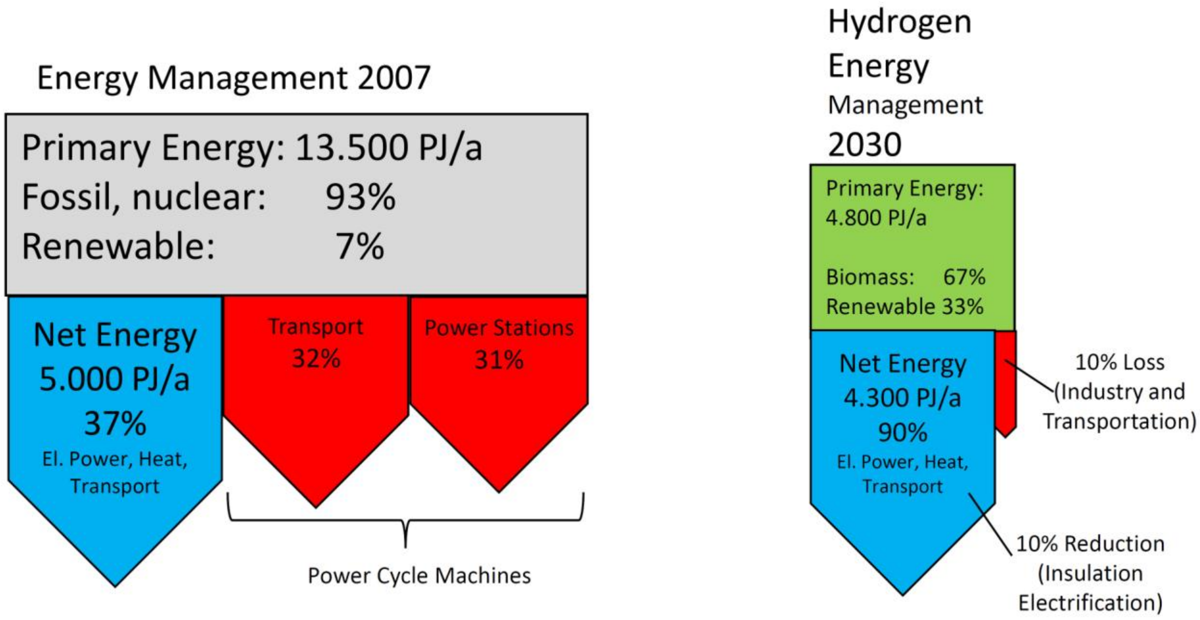

Fig. 3 Reduction of Energy Demand

The resulting increase in efficiency is due to the CHP - the cogeneration of heat and power -, to gains in efficiencies when heating with hydrogen or alternatively with electricity and to improvements in the transport sector. Using official data published by the German government it can be shown that the high efficiency of a **hydrogen economy** implemented as a **heat guided system** (Fig. 3) slashes the amount of primary energy of 13.500 PJ/a presently required for example in Germany to a mere **4.800 PJ/a.** With 33% renewable energies expected in Germany by 2030 an equivalent of **3.200 PJ/a** (67%) remains to be covered by biomass in a hydrogen economy. This reduction is achieved, nota bene, **without a reduction in standard of living** or presupposing extensive measures of energy saving by insulating buildings or changing from cars to bicycles etc.

It is important to note though, that for this system (Fig. 1) in which **electricity** would now **no longer be more expensive than heat,** a **decentralised generation** of electricity is imperative.

Availability of biomass

Knowing now how much biomass based hydrogen energy is needed, the second question is how much is in fact available.

It is estimated that about 2.000PJ/a are available from municipal wastes and lopping, agricultural and forest sewage and refuse. Only 3.200 – 2.000 = 1.200 PJ/a have to be produced by energy crops.

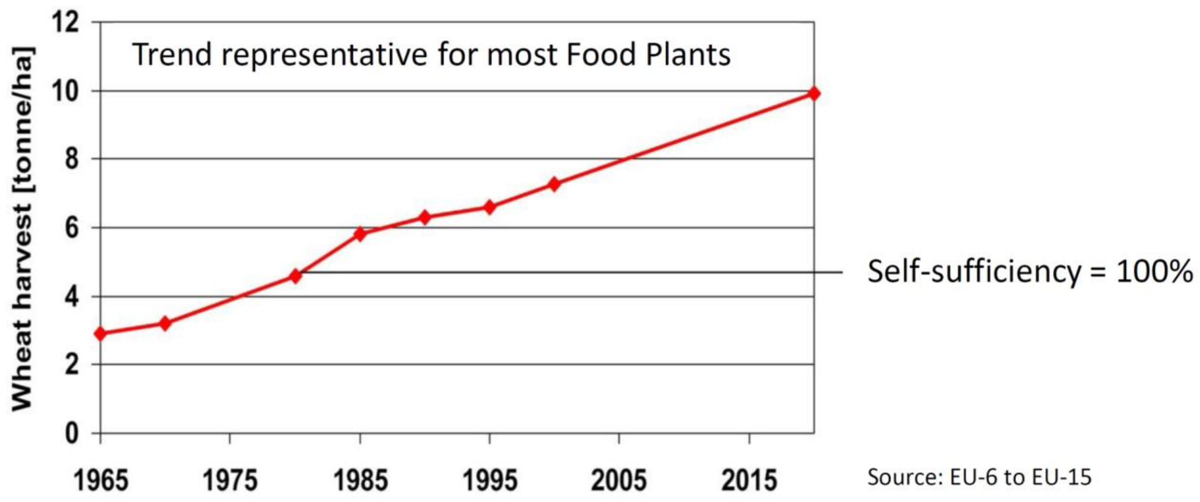

Fig. 4 Competition between Food and Energy?

Fig. 4 shows that the European Union (EU) grows far more food than it needs, the break even point having been reached in the seventies. As the EU is continuing to enforce increasing areas of fallow land, the remaining 1.200 PJ/a could readily be supplied without even having to resort to the vast reserves of fallow land existing in the EU-27 and in many counties in the world (Fig. 5). The yellow areas show the fraction of reserves in form of fallow land in the respective countries. Considering the continual increase in yield observed over the past forty years most countries should require only about 20% of the agricultural area for growing energy plants.

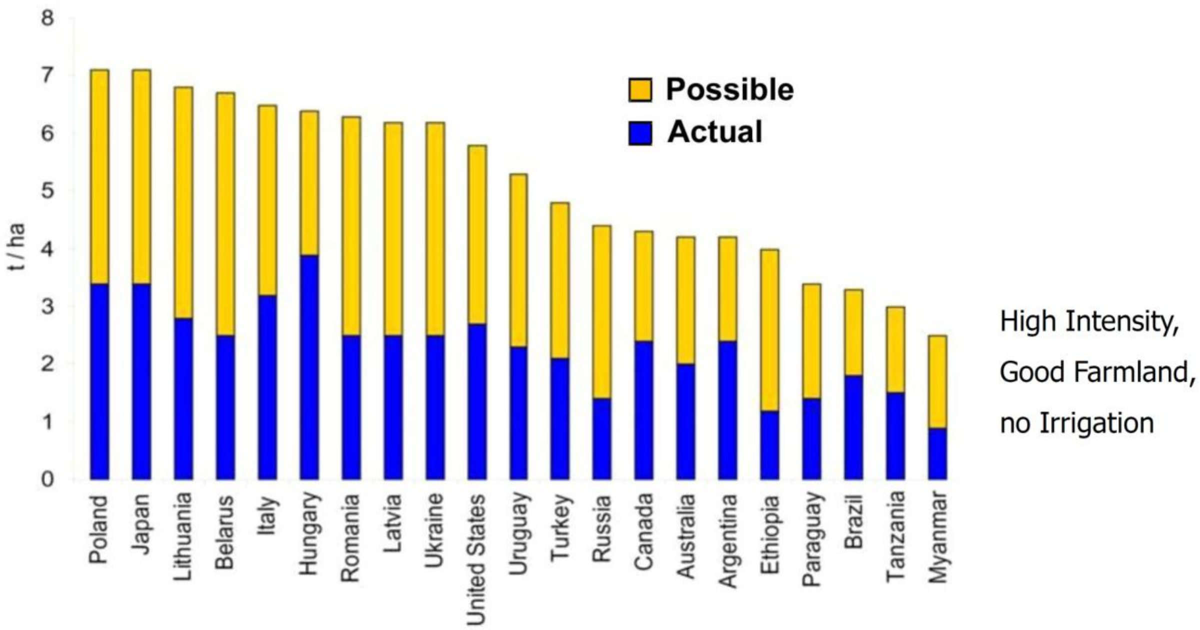

Fig. 5 Agricultural Efficiency

One of the advantages of the thermo-chemical gasification process is that all kinds of biomass can be converted completely to hydrogen irrespective of its chemical nature. This means that lignin containing plants for which agricultural science predicts a tremendous increase in crop yield Fig. 6 can also be used as feedstock. It is for this reason that the federal German government has decided to grant full subsidies to the production of BtL only if the so called 2nd.generation plants are utilised. A competition for land between food and fuel can therefore be excluded.

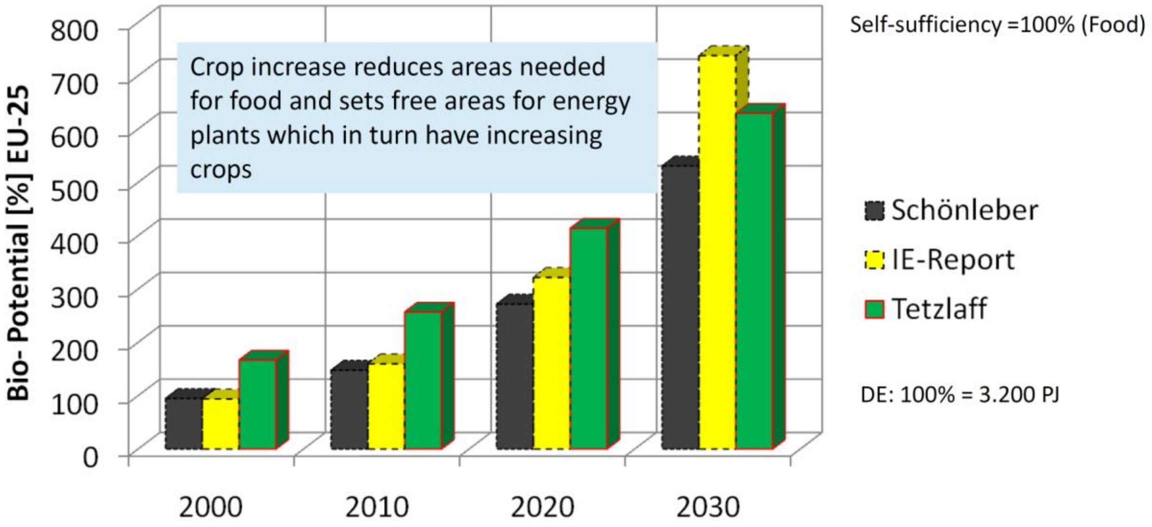

Fig. 6 Estimation of Biomass Potential for a Genuine Hydrogen Economy

The main reason for the expected increase (Fig. 6) is that these plants absorb far less sun energy in growing since they don't exhibit the high content of protein and carbohydrates typical of most food plants. The feedstock doesn't even have to be dry either. On the contrary, a water content of 40 - 50% would be advantageous. Storage in the form of silage in winter presents no problem.

It is an important difference to the process of fermentation that in the anaerobic digestion of biomass to produce biogas about half of the biomass has to be rejected unused, because the bacteria can't completely cope with the chemical nature of the biomass. Moreover, as in this process methane is produced not hydrogen, this dramatically reduces the efficiency of low temperature fuel cells resulting in a poor overall efficiency.

Technical Aspects

The technical implementation of a biomass based hydrogen economy comprises three distinct sectors:

- **the gasification plant itself**
- **the gas grid**
- **the fuel cells.**

Gasification Plant

Worldwide 400 billions of m^3/a of hydrogen are produced by gasification of fossil fuels in the petrol refining and fertiliser industries.

In order to produce petrol, gasification of coal and lignite was practiced in Germany during the war and still is in South Africa today. So, in principle, the gasification of organic material is a proven and well established technology. Fig. 7 shows the principle in a simple scheme.

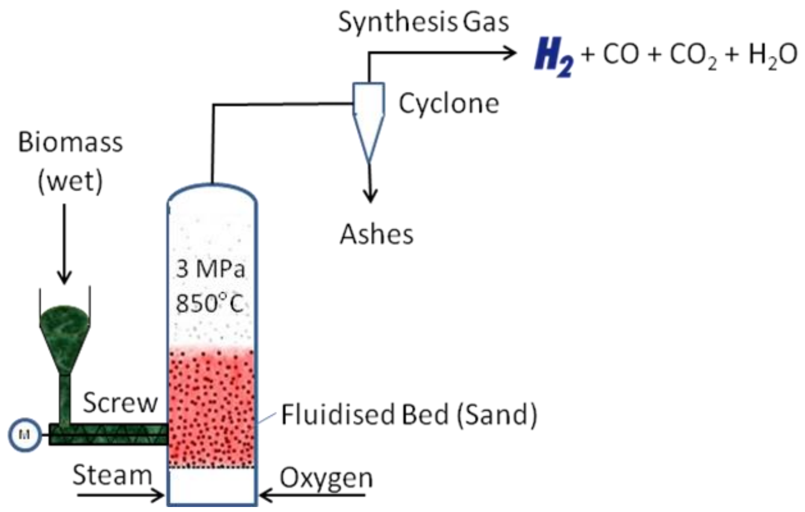

Fig. 7 Hydrogen Production

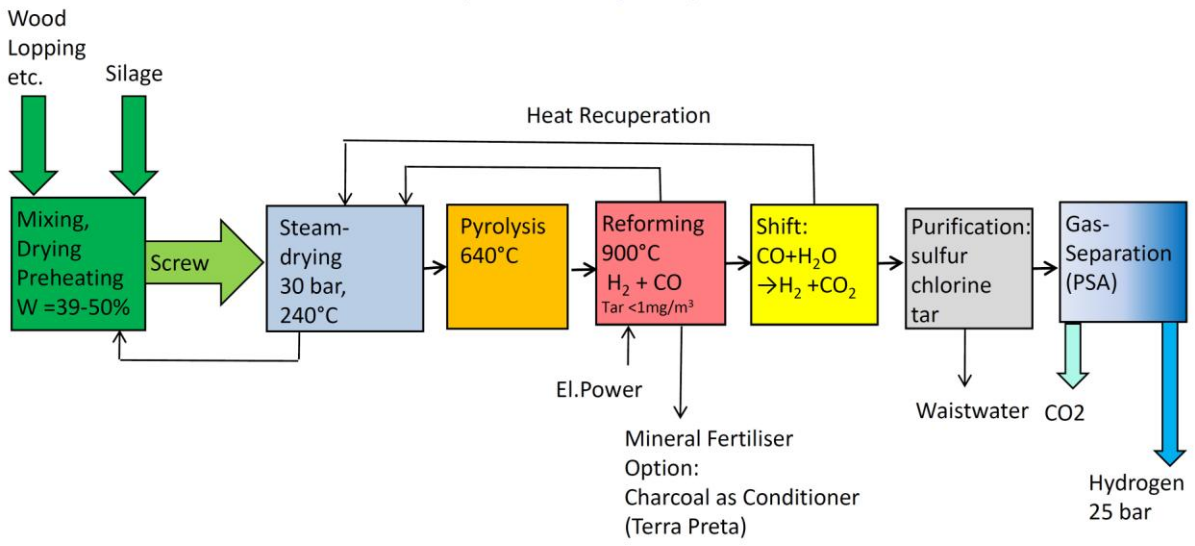

Fig. 8 Block Diagram of Hydrogen Production

Fig. 8 shows more details. The gasification plant consists - apart from the reactor itself -, of conventional straight forward unit operations commonly found in chemical industry e.g. disintegration of the biomass, conveyance of solids, drying and gas purification and separation.

But, since biomass is inconsistent and inhomogeneous in composition (water content, ash content and composition, melting point of ash etc.) and since a modern concept of a **pressurized (25bar), cascaded fluidized bed technology** is aspired, a pilot plant (50 MW) is considered necessary in order to enable reconstruction and optimisation work to be performed.

The gasification reactor itself again consists of three sections (Fig. 8)

- pyrolysis stage (300 to 650 ^{0}C), in which the volatile components contained in the biomass, accounting for about 80% of its mass, are liberated
- reforming stage featuring temperatures of not more than (900^{0}C). This serves to ensure that a melting and thereby glassing of the ash is prevented in order to be able to return the ash to the field as fertiliser (Fig. 9). Inventions in this section aim at the decomposition of tar and the conversion of the soot which otherwise constitute a serious obstacle against the recuperation of heat apart from impeding the subsequent processing of the gas. Although energy has to be imported in order to attain the 900^{0}C, (about 14% of the thermal output), this is not lost, because in an endothermic reaction the energy input is incorporated in the product (in this case hydrogen). The efficiency based on the lower heating values of biomass and hydrogen is about 93%.
- shift reactor (homogeneous water gas reaction) at temperatures of about 350 ^{0}C.

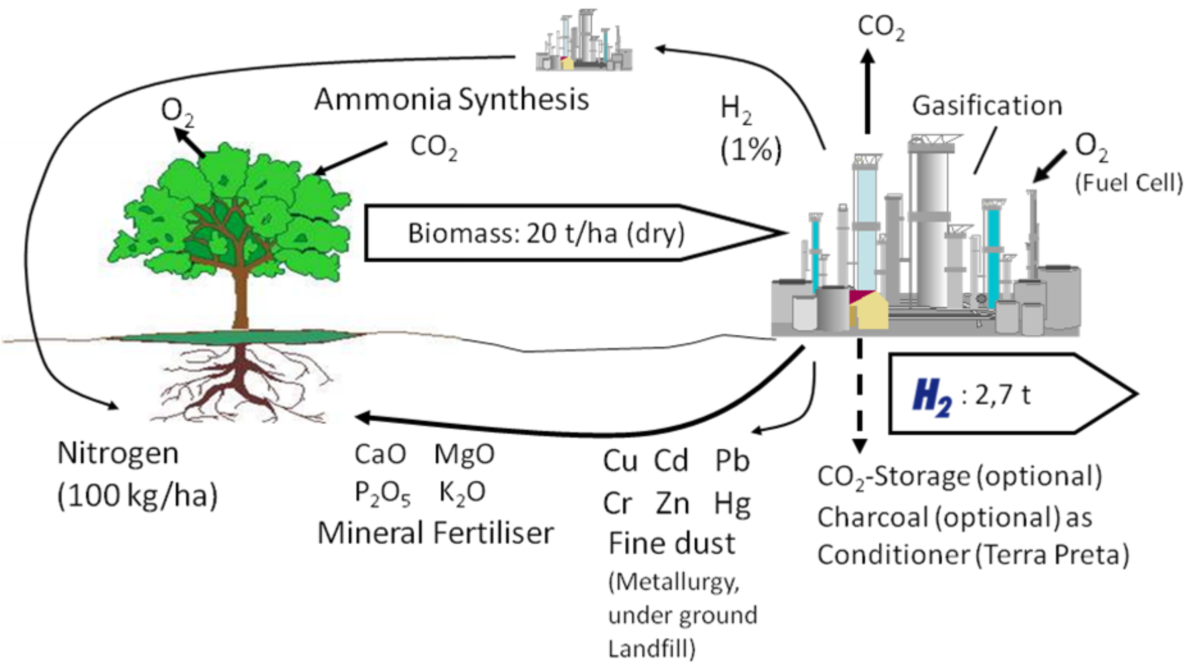

Fig. 9 Material Recycling

Optionally, the process can be controlled in such a way that part of the carbon introduced into the reactor can be discharged partially unconverted as charcoal and returned to field. As charcoal in the soil is not subject to bacterial decay this reduces the CO_2 concentration in the atmosphere and at the same time significantly (20 - 50%) enhances the crop. Obviously, this option can only be realised at the expense of the thermal output, but it is considered both economically and ecologically superior to the sequestration of the gaseous carbon dioxide under ground, although this could accomplished too because carbon dioxide accrues automatically as a concentrated gas.

As mentioned before, the unit operations are straight forward. The screw-conveying of the biomass into the reactor is an exception. This piece of equipment has to seal off the 25 bar reactor pressure against the atmosphere and is subject to some development work. Neither disintegrating and crushing of the biomass are expected to pose problems, since expertise exists from fermentation plants, nor does the gas purification task break new grounds.

Nevertheless the capital investment for the gas cleaning and gas separation stages might exceed that for the gasification reactor itself, as high gas purity is vital in order not to impede fuel cell performance. The gas separation is accomplished by PSA (pressure swing adsorption).

It is estimated that smaller plants (50 MW) cost another 1 (variable cost)) + 2 (capital, battery limits) = 3 ct bringing the total to 5 €ct/kWh (big plants (500 MW): 2,5 €ct/kWh).

Finally, it is not unimportant to note, that because of the high operating pressure, the reactor is relatively modest in size compared to competing concepts, and that, assuming equal energy production, a biomass digesting plant requires much more space than a corresponding gasification plant of the kind described above.(Fig.10)

Fig. 10 Digestive and Chemical Plant Compared

Gas Grid

The gas grid deserves attention, because it must be remembered that presently energy is distributed in three ways:

- **electricity per electric grid**, which, incidentally, accounts for about 60% of the production cost
- **fuel oil and petrol by road (**truck)
- **gas per gas grid**.

It is obvious that this aspect alone of requiring a single gas grid only (Fig. 11) constitutes a **significant cost reduction**, particularly as half of the private homes, at least in Germany, are linked to the gas grid already, (which can be used for methane as well as for hydrogen.)

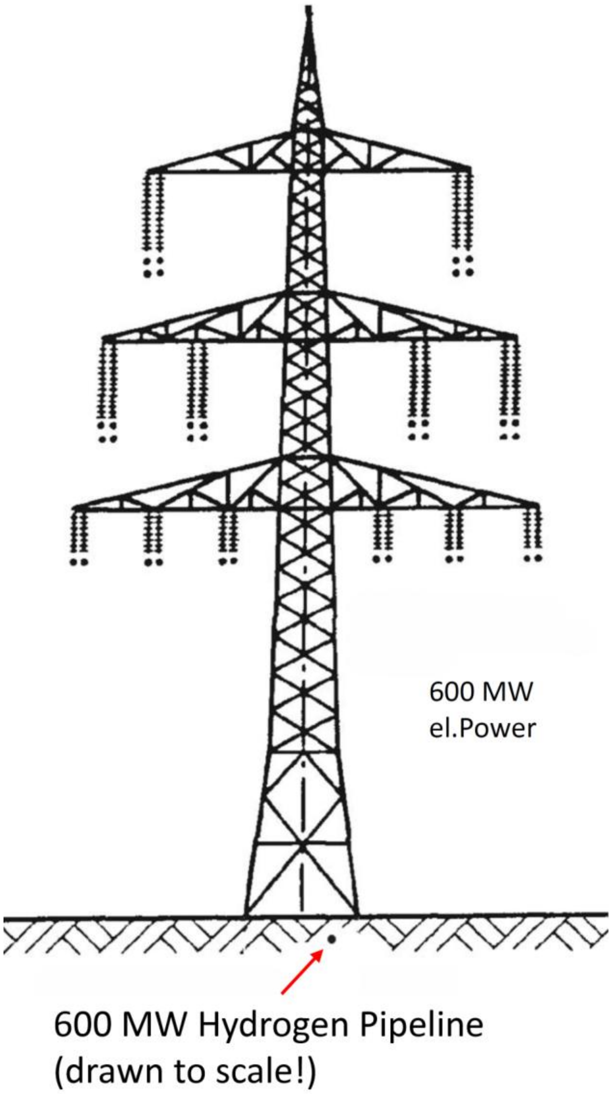

Fig. 11 Energy Distribution

Adaptation of the grid in order to handle the extra load required to meet the demand for electricity is unnecessary. Peak demands especially in winter exceed this by far. In addition, unlike the electric grid, there are no measurable energy losses in a gas grid. Gas pressure drop in the pipeline doesn't pose a problem since the hydrogen emanates from the plant at 25 bars. Besides: the pressure drops of methane and hydrogen in an existing pipeline, equal thermal capacity assumed, are practically the same.

Fuel Cells.

Although presently cheap fuel cells (FC) are not purchasable off the shelf, there can be no doubt that this will soon be the case once hydrogen is available on a large scale. For lack of hydrogen low temperature PEMFC currently have the handicap of having to be adapted to methanol or methane or other hydrocarbon feedstock. This is done by the additional installation of reforming and purification steps preceding the actual FC to produce the hydrogen. These are complicated and cost effective chemical plants en miniature, are limited in the turn-down ratio and are slow in response, requiring some sort of back-up system. (grid).

High- temperature fuel cells (SOFC) don't need this and are well suited to deliver heat (and electricity of course) at higher temperatures but are less suitable for private homes.

To be really effective, FC driven heat pumps no longer have to overcome the poor overall efficiencies of conventional power generation by having to top performance figures of three or so.

Devices other than FCs such as micro turbines, sterling engines etc. have been suggested to perform the HCP. They are expected to be more expensive than FCs, cannot be adapted to liberate heat at significantly higher levels of temperatures and suffer from a poor controllability, meaning that they must rely on some sort of back up system (electric grid or battery). Although efficiency is not that important, because of the excess of electricity generally available by decentralised generation of el. power, sterling engines are in danger of not being able to safeguard this, because their efficiency may be too low.

Fig. 12 Stored Solar Energy has to be a Little Converted

Lower cost of the distributing grid, lower cost of the energy feedstock (biomass), low capital costs, no political constraints due to dependence on foreign energy imports, a CO_2 - neutral, sustainable and available energy source and hardly any ecological draw backs: what prevents us from implementing a green hydrogen economy?(Fig.12)

Presented at Hanover Fair 2009