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Energy Efficiency and the Hydrogen Energy Economy's Contribution
An Aide Mémoire[1]

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- Higher energy efficiencies reduce the demand for primary energy raw materials and mitigate environmental and climatic challenges. No energy conversion link in the energy conversion chain can be ignored, from primary energy raw materials to primary energies, from there to secondary energies and further to end energies and useful energies, finally to energy services, which are the sole reason for undertaking the way through the energy conversion chain; since all the prior links are only the means to this end, their efficiencies must be as high as possible.

- As an illustration: Germany's national energy efficiency is a little more than 30%, that of the world not more than 10%; consequently, the potential to increase energy efficiencies is very high; a factor of 2 for Germany (Enquête-Commission of the German Bundestag "Protection of the Earth's Atmosphere") and a factor of 3 to 4 for the world are technologically doubtlessly feasible; what they need for their operationalisation is political will and marketability.

- What is the contribution of the upcoming hydrogen energy economy? - Here also: no link of the energy conversion chain can be excluded, from the production of hydrogen to its storage and transport, finally its utilization. In any case energy is always divided into exergy and anergy: energy = exergy + anergy. By definition exergy is convertible into any other form of energy, anergy is not. Germany's exergy efficiency is some 15%, that of the world, only a few percent, is almost negligible. What will be shown is that hydrogen energy and its technologies exergize the energy system; they provide more exergy from the utilized energy. The output of today's energy system, consisting of much too much heat of the wrong temperature regime or at the wrong place (e.g., the high-temperature exhaust of thermal power stations or the combustion temperature in central home heating systems = anergy), will be reduced in favour of electricity and heat of the right temperature regime supplied at the right place = exergy. – Let us go through the different stations of the hydrogen energy conversion chain:

- <u>Hydrogen production:</u> For the time being hydrogen is produced predominantly by reforming natural gas or in refineries through partial oxidation of oil fractions; hydrogen from electrolysis of water is of minor importance; the amount of hydrogen

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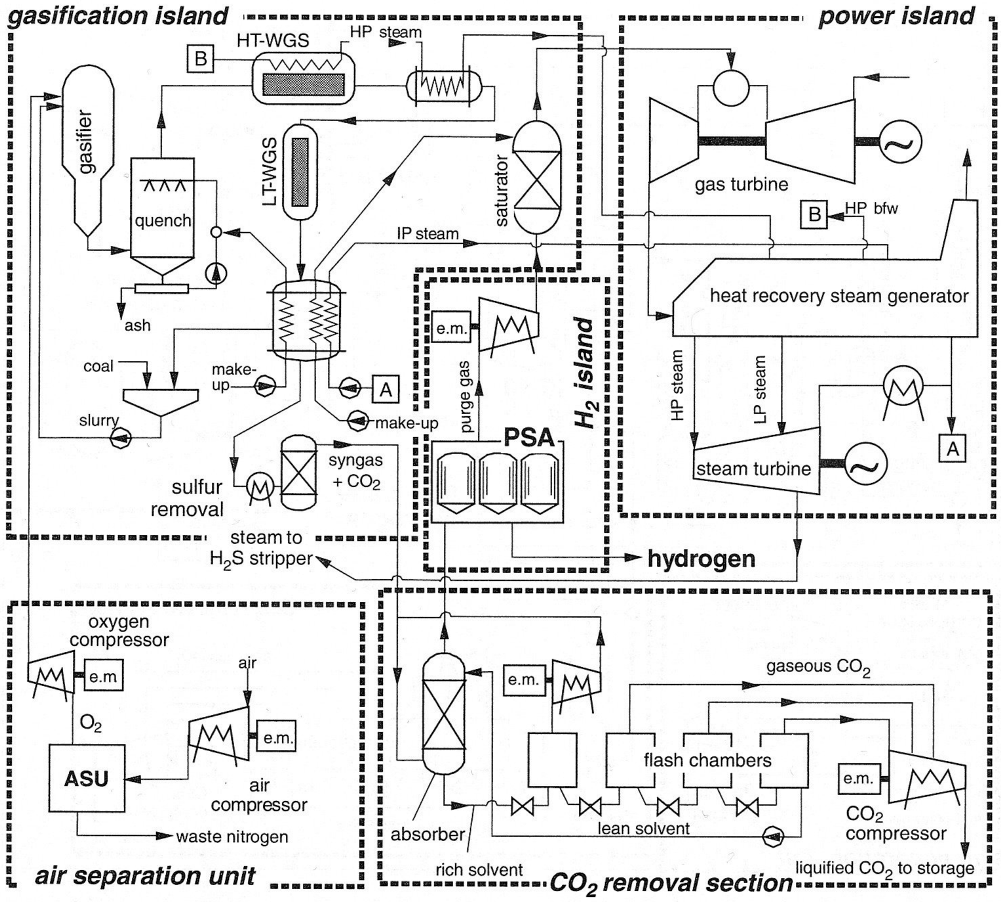
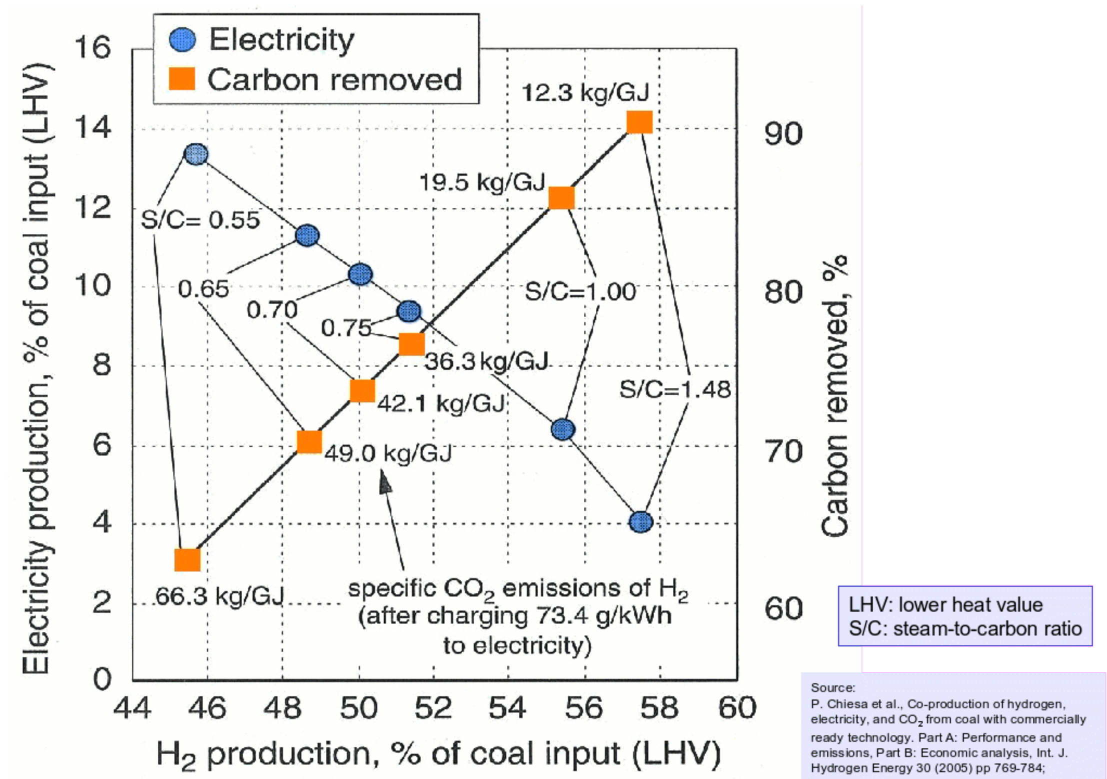
from renewable electricity ("solar hydrogen") or hydrogen produced with the help of nuclear high temperature heat is still insignificant. - Hydrogen from coal has its history (particularly also in Germany); it relies on the continued availability of coal over centuries on all continents of the earth, and can be produced with high efficiency.





The figure shows a typical production process consisting of air separation, coal gasification, carbon separation, and simultaneous electricity and hydrogen generation; all the required technologies are available on the market. – The result (an example): at a separation rate for carbon of 90%, 58% of the energy content of coal (LHV) is converted to hydrogen, and 4% into electricity, for a total of 62% - a convincing result! It goes without saying that the separated carbon has to be stored away without harm to the environment and climate.

- Storage and transport of hydrogen is being accomplished in steps: in the first step reasonable amounts of hydrogen will be utilized which for the time being are flared (e.g., in chlorine electrolysis, in chemical plants of all sorts, etc., in Germany alone c. 950 Mm^3/a (according to the German Hydrogen and Fuel Cells Association 2003). The second step adapts hydrogen to the natural gas infrastructure long in place; 10 to 15% of hydrogen can be pick-a-back co-stored and co-transported in natural gas pipeline systems without major technical modification. Finally, the third step further develops the hydrogen supply infrastructure in place for more than a century, which for the time being stores and transports some 50 million tonnes of hydrogen p.a.: as high pressure gas in steel flasks or pipeline systems, or as liquefied hydrogen in cryo-containers on land or at sea. Potentially more efficient magnetocaloric liquefaction processes will supplement the classical Claude liquefaction process.

- The highest energy efficiency gains are sought in the two end energy utilization realms of residential and office buildings, and transportation, which in Germany together account for some two thirds of the total end energy supply: The typical natural gas or light oil fueled boilers in the country's 15 million home central heating systems have excellent energy efficiencies, since they convert almost 100% of the fuel's energy content into heat. Their exergy efficiency is, however, miserable; it is thermodynamically simply absurd to produce a flame temperature of, say, 1,000 °C, in order to supply only 70 °C to a building's room radiators. Replaced by a hydrogen supplied (reformed or pure hydrogen) fuel cell, first of all 35% of the fuel's energy content is converted to electricity (= pure exergy), and the remaining heat is still sufficient to heat the building over most of the year. A thought experiment tells us that 15 million fuel cells in German central heating systems of, say, 5 kilowatt each sum up to 75,000 MW_e, which approaches the centrally organized 100,000 MW_e now online; welcome competition is expected between the two ends of the national energy conversion chain, with the big power stations located at the start of the chain, and millions of highly efficient distributed small fuel cells at its end.
  The other end energy utilization realm in question, transportation, shows a similar picture: only some 25% (30% in extremely fuel-efficient examples) of the energy content of the gasoline or diesel fuel is converted into traction (= exergy); all the rest leaves the vehicle via the tailpipe or the water cooling system; in exergy terms, the automobile is a rolling stove, which with a small fraction of its fuel provides traction from A to B, too. – Hydrogen vehicles change the picture radically: It is not an illusion to expect highly efficient hydrogen optimised internal combustion engines or low temperature fuel cells including dramatically improved peripherals (in particular the so far exergetically miserable electrical generator) to have a total exergy efficiency of the prime mover system of the vehicle of some 50%.

- In sum: No doubt, energy efficiency campaigns along the entire energy conversion chain of nations are absolutely necessary, important, and indispensable; the energy

systems of nations exhibit huge potentials for efficiency improvements, as is shown by the rather meagre energy efficiency regimes of nations achieved after more than 200 years of anthropogenic energy (e.g., Germany c. 30%, the world 10%).
However: besides system-immanent energy efficiency improvements, what is truly imperative is improvement in so far sadly low exergy efficiencies! Because asymptotical energy efficiency improvements in high temperature thermal power plants or industrial furnaces – to take these examples - are only one side of the medal; thinking and acting in terms of exergy improvements as shown above are on the much more important other side! And these exergy improvements need the hydrogen energy economy and its inherent technologies, like for instance the fuel cell or the optimised ICE. The forthcoming energy/climate catastrophe calls for the permanent solution through hydrogen energy technologies: future energy policy is hydrogen energy technology politics!