Electricity, Hydrogen - Competitors, Partners?[1]

By

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Visions are more important than knowledge, because knowledge is finite (Albert Einstein)

Abstract

Electricity, Hydrogen - What they have in common, where they are unique

Electricity and hydrogen have in common that they are secondary energies which can be generated from any primary energy (raw materials). Once generated they are environmentally and climatically clean along the entire length of their respective energy conversion chains. Both electricity and hydrogen are grid delivered (with exceptions); they are interchangeable via electrolysis and fuel cell. Both are operational worldwide, although in absolutely dissimilar capacities.
And their peculiarities? Electricity stores and transports information, hydrogen does not. Hydrogen stores and transports energy, electricity transports energy but doesn't store it (in large quantities). For long (i.e., continental) transport routes hydrogen has advantages. The electricity sector is part of the established energy economy. Hydrogen, on the other hand, takes two pathways: one where it has been in use materially in the ***hydrogen economy*** *almost since its discovery in the later 18th century; today, it is traded worldwide as a commodity up to an amount of some 50 million tonnes p.a., e.g., in methanol or ammonia syntheses, for fat hardening in the food industry, as a cleansing agent in glass or electronics manufacturing, and the like. - And along the other pathway it serves as an energy carrier in the up and coming* ***hydrogen energy economy*** *which started with the advent of the space launching business after WW II. Essentially, the hydrogen energy economy deals with the introduction of the, after electricity, now second major secondary energy carrier, hydrogen, together with its conversion technologies, e.g., fuel cells, into portable electronic equipment such as television cameras, laptops, cellular phones, etc., into the distributed stationary electricity and heat supply in the capacity range of kilowatts to megawatts, and into transport vehicles on earth, at sea, in the air, or space-borne. It is never a question of the energy carrier alone, hydrogen or hydrogen reformat. On the contrary, environmentally and climatically clean hydrogen energy technologies along the entire length of the energy conversion chain, from production via storage, transport and distribution to, finally, end use, are what is of overarching importance. Of course, technologies are not energies, but they are as good as energies. Efficient energy technologies provide more energy services from less primary energy (raw materials). Energy efficiency gains are energies! Especially for*

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energy poor, but technology rich countries, efficiency gains compare well to indigenous energy sources!

The trend is clearly visible: increasingly, the world is moving from national fuels to global fuels, and energy technologies serve as their opening valves. – CO_2 capture and sequestration technologies bring hydrogen-dependent clean fossil fuels to life, and hydrogen supported fuel cell technology activates dormant virtual distributed power. Both technologies are key for the hydrogen energy economy which, thus, becomes the linchpin of future world energy.

Mechanization, Electrification, Hydrogenation

The electricity industry began some 100 years ago with Siemens' electrical generator and Edison's light bulb. Electricity is a success story which, truly, is not yet at its end. In industrialized regions, electricity is almost ubiquitous, locally and timely appropriate, environmentally and climatically clean, and more or less affordable.

In the late 18th century, James Watt's steam engine initiated the mechanization of the industry. One century later, electrification came into use; it largely replaced mechanization and permeated into almost all energy utilization sectors such as production, households, communication, and railways. Literally and seriously: "Electricity is readily available at the socket," really never to be worried about! - However, there are weaknesses: blackouts are suffered under, seldom, but once in a while; and many developing nations are still without electricity at all. Further, with electricity you cannot operate an automobile, much less an airplane or a spacecraft. In all those regions where hydropower is not available, home heating with electricity is thermodynamically not justifiable; that is by no means sustainable (exception heat pump). -

The question is: can hydrogen be of help where relative to electricity it has certain advantages, where electricity is useless because it lacks storability, or where electricity and hydrogen together offer solutions which are inexistent for either one? Is it true that, after mechanization in the late 18th and then in the 19th century, after electrification in the 20th, we are now at the start of the 21st century on the verge of **hydrogenation** of the anthropogenic energy system? Answering this question is not too difficult, because developments give a clear signal: historically, with the switchover of the anthropogenic energy centuries from high carbon via low carbon to no carbon, i.e., from coal via oil and natural gas to hydrogen, the atomic hydrogen/carbon ratios showed for coal : oil : natural gas : hydrogen = $<1 : 2 : 4 : \infty$. De-carbonization and hydrogenation increase over time, and, since the atomic weights of hydrogen and carbon are 1 and 12, respectively, de-materialization of energy is growing. Already today two thirds of the atoms of fossil fuels burnt are hydrogen atoms; the trend continues.

Status

What is the status of the hydrogen energy economy? - There are only a few industrial sectors where hydrogen serves energetically undisputedly: in the space business, which would even be inexistent without the highly energetic recombination of hydrogen and oxygen in the space launchers' power plants; in submersibles, where high efficiency hydrogen/oxygen fuel cells guarantee extended underwater travel and low to zero detectability because of the contourlessness of the condensed

water steam exhaust; in refineries for the production of reformulated hydrogenised gasoline and de-sulfurization of Diesel; and in the cooling of large electrical generators.

Fuel cells as replacements for short life batteries in portable electronics such as laptops, camcorders, cellular phones and the like, energized with the help of hydrogen or methanol cartridges; natural gas or hydrogen supplied fuel cells in distributed electricity and heat supply or as replacements for boilers in central heating systems in buildings; fuel cells for APUs (auxiliary power units) in vehicles or airplanes; hydrogen and internal combustion engines or fuel cells on board busses or automobiles; finally, liquefied cryogenic hydrogen instead of kerosene in aviation - one and all, these areas are still in the phase of research and development, at most in their demonstration phase. The technologically driven hydrogen energy economy is at its very beginning and has to face many decades yet before market readiness.

Domains, Partners, Competitors

Now let's come back to our question posed at the beginning: Electricity, Hydrogen - Competitors, Partners? - We distinguish three realms where hydrogen and electricity:

a) have their respective domains
b) are partners
c) compete with each other.

To a) belong aircraft and spacecraft engines; they are/will become undisputable hydrogen domains, simply because you cannot fly or operate an aircraft or a spacecraft with electricity (exception: thermionic engines for deep space applications). Electricity's domain, on the other hand, lies in the communication sector, providing light, and indispensably in all sorts of production. - Under b) you'll find all the chemo–electric energy converters, the fuel cells which convert hydrogen or hydrogen reformat efficiently and environmentally and climatically clean into heat and electricity, in CHP (combined heat and power) applications in industry or in households and office buildings; here hydrogen and fuel cells are an unbeatable combination! - Finally, at c) essentially we find mobility tasks which can be performed with either electricity or hydrogen: rail transport in Europe is electrical grid delivered. For continental distances, however, as for instances in Canada or in Russia, it is questionable whether railway electrification through electrolytic hydrogen powered fuel cells is not the economically more viable solution, replacing the traditional overhead electricity contact wire which, for thousands of kilometers, might be the more costly and irksome investment. – Earlier, the situation in the individual transport realm wasn't as clear as it is today. As long as there was hope to see on the roads efficient, battery supported, marketable electric vehicles in large numbers, it was not too easy for the hydrogen vehicle to make its point. Now, after many decades of development of long range auto batteries in the drive train with only rather minor success, the route for hydrogen surface transport in buses, in limousines, later in trucks and lorries is wide open. Although, the decision is still outstanding as to whether there will be a fuel cell or a hydrogen-adapted internal combustion engine under the hood, because the "novel" fuel cell has not yet won, and the "old" combustion engine still has potential which doesn't force it to give up. The "race" between the two is highly exciting for the thermodynamicist and the mechanical or electrical engineer, but it is not yet decided. The fuel cell needs convincing cost, performance, cleanness, and efficiency advantages in order to

compete successfully with the more than one hundred years of experience of the reciprocating piston engine.

One particular partnership development (b) of electricity and hydrogen is worth pointing out: the stationary fuel cell in CHP (combined heat and power) production or in central home heating systems. It is small with capacities of four orders of magnitude from kilowatt to 10 megawatts. As a decentralized energy converter it tri-generates locally and simultaneously electricity and heat/cold; consequently, the nation's electrical grid losses are nil (which for the time being sum up to some 4% in Germany, in other world regions sometimes significantly more!). The distributed fuel cell park with potentially millions of fuel cells installed compares well with a virtual IT–controlled power station whose capacity easily reaches the capacity of the central installations (e.g., for Germany c.100,000 megawatts). Competition between the traditional energy conversion's front end electricity generation and the novel fuel cell supported back end generation is foreseen. It will be interesting to see which kilowatt-hour will become the less costly one, which the environmentally and climatically cleaner, and which the more reliable!

Exergetization

If it comes true some day that the conversion chain's back end of a national energy system becomes a convincing power generator and, thus, a powerful competitor to the established traditional power plants at the front end, something thermodynamically very important will have occurred: The fuel cells supplied by hydrogen or hydrogen reformat exergize the energy system! What does that mean? Thermodynamically each conversion step converts energy into exergy and anergy: energy = exergy + anergy. Exergy is per definition the availability to perform technical work, it is the maximum work to be extracted from energy. Exergy can be converted into any other energy form, anergy cannot. Historically, it so happened in 200 years of anthropogenic energy development that the national energy efficiency of the more efficient industrialized nations, for instance Germany, is some 30%, and the exergy efficiency is only slightly more than 15% - both numbers really not too impressive! The world is even worse, its energy/exergy efficiencies are around 10%/ a few percent - even less impressive! The technical potential of energy and exergy efficiency improvements with available technologies on the market in industrialized countries is a factor of 2, and in industrializing countries it is a factor of even 3 to 4! What is before us is to make those technologies economically viable; and that needs hydrogen, and time - and money!

Let us give some examples in order to see what is meant: in Germany's cellars some 15 million boilers in central heating systems are installed. They have excellent energy efficiencies of nearly 100%, almost the total chemical energy of the fuel (light oil or natural gas) is converted into heat. The exergy efficiencies, however, are miserable, it is thermodynamically simply absurd to generate a flame temperature of around 1,000 °C only in order to supply the room radiators with temperatures of 60 or 70°C. - Or another example: the 700 million vehicles on earth are operated with an exergetic efficiency of not much more than a quintile, c. 20%, 80% of the energy of the gasoline or Diesel fuel is converted into heat. Essentially, autos are stoves which provide some surface traffic, too, with 20% of the fuel's energy - bitter to say! Here, the hydrogen supplied internal combustion engine will provide a change, an exergy efficiency rise in the direction of some 50% is not an illusion. And stationary fuel cells with hydrogen or hydrogen reformat fuel generate exergetically efficiently, and

simultaneously electricity and heat, and meet with their fuel cell-specific temperature regime between 70 and 900 °C the exact relative temperature demand of households, industry, and vehicles, respectively. - Let us never forget that ecological reasoning not only asks for waiving claims and avoiding materialism but also for unparalleled technology development in order to improve the rather poor efficiency of anthropogenic usage of energy, which for hundreds of years was underestimated; hydrogen supported technology is a harbinger of this development!

Traditionally, electricity is produced at the front end of a national energy conversion chain and used at its back end. Thousands of kilometers may be the distance between front and back ends. Now, with some millions of envisioned fuel cells in future distributed supply at the back end, also here electricity is produced, and that's in the vicinity of the electricity users. This is of cardinal importance, because the back end of a national energy conversion chain governs the overall efficiency of a nation: Because each kilowatt-hour of energy services, because of efficiency gains not demanded at the chain's end, results in three kilowatt-hours of primary energy (raw material) which are not necessary for the nation's economy to be introduced at the front end (e.g., Germany's national energy efficiency ~ 30%!). In the world, the relation is 1 : 10 (the world's efficiency ~ 10%). That is it what is meant by the sentence "Hydrogen and fuel cells exergize the energy system!" They make more electrical energy services out of less primary energy. Electricity is pure exergy.

Hydrogen supply

At times one question is repeatedly asked: Where does the hydrogen come from? - There are three answers which would be answered similarly for electricity: (1) from fossil fuels via reformation or partial oxidation or gasification, preferably from natural gas, like today, or from coal, then, however, only with capture and sequestration of co-produced carbon dioxide in order to prevent its release into the atmosphere and, thus, its contribution to the anthropogenic greenhouse effect; so far, electricity and steel kept coal alive, tomorrow hydrogen will keep clean coal alive; (2) from renewable energies via electrolysis, but not before a number of further decades of development and in competition with the direct use of the renewable electricity in the power market; or (3) from nuclear fission, if societally accepted.

Thought experiments

At the end of this talk a thought experiment is given: statistically, Germany's 40 million road vehicles are operated 1 hour per day; they are parked for 23 hours. Let us imagine that they have fuel cells under their hood with a capacity of, say, 50 kilowatt each and are plugged in when parked in the home garage or on the company's employee parking lots. Consequently, only 5% of Germany's cars operated at standstill will provide some 100,000 megawatts, which is exactly the capacity on-line today in central stations. – Thought experiments seldom become real, but mostly they have a true kernel. Here we see two of these kernels. The one reads: in the long run, will it really be compatible with the energy and transport sustainability so urgently needed, to leave useless a whole fleet of "power stations on wheels" with a potential capacity 20 times more than is in traditional use today?! (The engineer knows well that a mobile highly dynamic power station with up to 6,000 rpm and sometimes more, and a service lifetime of 3,000 hours is absolutely something quite different from a stationary station with 3,000 rpm and a life of 80,000 hours before the first full maintenance standstill. However, mutatis mutandis it is not under

the horizon, and climate benignity may become a more powerful parameter than we allow today forcing us to think the unthinkable!) – And the second kernel: mobile fuel cell vehicles will only be filled up with hydrogen fuel, because any hydrocarbon fuel used instead means the necessity of a millionfold mobile carbon dioxide collecting device - a technical and economical impossibility!

The Secondary Energy Sector Ever More Important

To come to an end: electricity and hydrogen - competitors, partner? – None of the aforementioned arguments negates the legitimacy of either electricity or hydrogen, each has its own domain; they compete on certain issues, and here and there they are partners. Relative to the primary energy (raw materials) sector, the secondary energy sector grows more and more in importance. It will consist in future of two secondary energy carriers, electricity and hydrogen, developed in tandem!

In general, novel energies need time! That applies to hydrogen energy and its technologies, too. Many decades up to almost half a century for first significant contributions to the mix are typical. In any case, it seems always to be almost too late to start creating consciousness and further awareness. People live and work downstream and ask for reliable, payable, and clean energy services. Since the hydrogen energy economy moves the centre-of-gravity within the energy conversion chain towards its end, exactly where these people need their energy services, professionalization of their supply is needed; professionalization not unlike that at the beginning of the chain where we are accustomed to the professional operation of power plants, refineries, coal mines and the like.
Delay is the foe of success. Consequently, let's be aware: **www.itsHYtime.de!**