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Hydrogen Energy Communication Services (HYCOM)

Hydrogen Energy - A List of 22 Arguments

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1. Hydrogen is the lightest element in the Periodic Table of Elements; its ordinal number is 1.

2. Pure hydrogen is very seldom on Earth; predominantly, it is found in chemical compounds such as water H_2O, methane CH_4, ammonia NH_3, hydrocarbons C_nH_m, ...

3. Hydrogen is not really something new. It was discovered by Henry Cavendish (1731-1810) and almost at the same time by Antoine Lavoisier (1743-1794). Industrial hydrogen chemistry began about 150 years ago. Prior to the usage of natural gas, so called town gas was used in order to heat homes, cook meals or light streets; it contained up to 70% hydrogen.

4. Hydrogen is not a primary energy. Hydrogen is a secondary energy carrier (like electricity or water steam,...); for its production, primary energy is needed.

5. Like electricity, the other dominant secondary energy carrier, hydrogen can be produced from almost any primary energy raw material or any primary energy. Presently, hydrogen is produced almost exclusively from fossil fuels, through steam reforming of natural gas or partial oxidation of hydrocarbons. Only a few percent come from electrolysis of water. Low temperature electrolysers are state-of-the-art, high temperature/high efficiency electrolysers are still subject of research and development.
   For the time being, the bulk of hydrogen is captively handled in refineries for hydro-treating of oil fractions. In addition, 600 - 700 billion norm cubic meters of hydrogen are traded annually worldwide. That seems much; it represents energetically, however, only about half of the end energy demand of a country like Germany alone. Consequently, from a world energy economy standpoint, hydrogen energy is at its very beginning!

   So far, there is only one industrial branch using hydrogen energetically, the space launch industry, and furthermore, it is dependent on it, because, although hydrogen needs three to four times more volume per unit of energy, it has, however, only one third of the weight, compared with hydrocarbons in use like gasoline, diesel or the like. - Non-energetically, hydrogen is used for fat hardening, cooling of electrical generators, in methanol synthesis, in the electronics or glass production, ...

6. On principle, from a technological standpoint there is nowhere and at no time absolute safety; that is also true for energy technology safety. Each energy carrier has its specific safety risks dependent on its physical/chemical/technological nature. - Hydrogen has a high affinity to air or oxygen (O_2); the ignition range of a hydrogen/air(oxygen) mixture is wide, the ignition energy is very small. The diffusivity of hydrogen in air, however, is very high, so that hydrogen leakages or hydrogen flames diffuse quickly vertically up into the air.
   The energy carrier hydrogen, however, has two inherent safety advantages relative to all other energies:

- per se, long time follow up casualties of unknown extent are impossible, because (radio-)toxicities and radioactivity are inexistent and

- hydrogen is not capable to contribute to the anthropogenic Greenhouse Effect (under the one condition that future hydrogen airlines operate below the tropopause where natural water vapour is abundant).

The Hindenburg incident 1937 in Lakehurst/USA was <u>not</u> causally related to hydrogen!

A complete hydrogen safety sensorics system is on the market.

7. Never in the history of the energy supply was only one energy form in use, never an additional energy form replaced fully its predecessors; the energy demand of a growing human population needed them all:

   - Up until far into the 18th century exclusively renewable energies of the 1st solar civilization were in use

   - The 19th century was the century of coal, with complementary mineral oil at its end

   - The 20th century saw the emergence of natural gas and nuclear fission

   - Many plausible arguments indicate that the 21st century is on the verge to becoming the century of energy sustainability, energy and, above all, exergy (energy = exergy + anergy, with exergy being converted into any other energy form) efficiency, conservation of energy, all sorts of renewable energies of the 2nd solar civilization, and the secondary energy carrier hydrogen.

8. The history of anthropogenic energy of the last two centuries, the 19th and 20th, was clearly dominated by the primary energy raw materials coal, oil, natural gas, and uranium: The energy supply system was - and as before still is - energy raw material-oriented. The 21st century, on the other hand, is expected to be different: It will be technology-oriented, because energy efficiency and conservative energy usage limit the amount of primary energy necessary; they help to provide more energy services with less energy raw materials. For renewable energies, operational primary energy raw material is even inexistent, and the secondary energy carrier hydrogen is the lightest element, we said it already.

9. Energy utilization means proceeding simultaneously through the energy conversion chains and the chains of energy material conversion: From primary energy raw materials to primary energy, and further to secondary energy to end energy to useful energy, and finally to energy services; their environmentally responsible supply to cost and time is the exclusive reason for proceeding through the chains; all preceding and follow-up chain links have no meanings in themselves, they are means to an end. - In parallel, the energy materials' chain is run through: it begins with the primary energy raw materials taken out of Earth's crust and ends - after a number of physical and chemical conversions - with the residues and their release into the bio/geosphere. It is not really the energy conversion which is of environmental relevance; it is the material conversion chain with its numerous open ends to environment and climate which causes conflicts with them. The renewable energy conversion chains have no operational material conversion chains at all; consequently, all potential operational material influences on environment and climate must be inexistent! - What is left is the investive material for the construction of

the plant, its lifelong maintenance, the demolition, recycling and final deposition which is comparatively of minor influence.

10. Coal, mineral oil, and natural gas are hydrocarbons whose atomic hydrogen/carbon-ratio H/C is

Coal : Oil : Natural Gas = <1 : 2 : 4

For a prospective hydrogen energy economy it tends to become infinite. The switch from coal to oil and further to natural gas and hydrogen goes along with the decrease of the carbon content finally to zero, and an increase of the hydrogen content to a maximum.

11. In the last 120 years the carbon tonnage relative to the unity of energy in the anthropogenic energy supply decreased by 35%; the decrease continues. Thus, a decarbonisation (relatively less carbon) process is under way, along with hydrogenation (more hydrogen), and - since the atomic weights of carbon and hydrogen are 12 and 1, respectively, a dematerialisation (less weight). With the transition from coal to oil to natural gas and - in a prospective hydrogen energy economy - further to hydrogen, energy gets lighter and lighter.

12. Gaseous or liquefied hydrogen transport via pipelines, in tanker ships, in railcars or tanker trucks is state-of-the-art; likewise is hydrogen storage in high pressure flasks or in containers, in metal hydride or liquefied hydrogen storage; the same applies for filling or emptying devices. Recently, a robot LH2 filling station has been put into operation in Munich, Germany, and a GH2 filling station is operable in Hamburg, Germany. – For comparison, in 1922 the first gasoline filling station was opened to the public in Germany; since the 1960s, with some 16.000 stations saturation may have been reached. 1999 the afore mentioned two first public hydrogen filling stations were opened, consequently, if each and everything goes comparably right, a fully integrated hydrogen supported surface transport may be expected in the coming 2030s or so.

13. Hydrogen liquefaction follows the traditional Claude process. Magneto-caloric liquefaction offers higher efficiencies; it needs, however, still much more R+D.

14. Catalytic burners are well understood and can be purchased on the market.

15. The H_2/O_2 steam generator for spinning reserve applications in the 100 MWe range is readily developed, and so is the H_2/air internal combustion engine for stationary applications or on-board usage.

16. The utilization of hydrogen and air or hydrogen and oxygen in aircraft engines or engines of space launchers is reasonably well understood. Legendary are the numerous operable space launchers using liquefied hydrogen LH2 and liquefied oxygen LOX; in the 1980s a TUPOLEW 155 was operated successfully with one hydrogen engine at the rear.

17. The great challenge of today is the fuel cell which was published for the first time by William Grove (1811-1896). It is a chemo-electrical energy converter not dependent on the high-temperature material restrictions of the heat engine, which for higher thermal efficiencies needs higher temperatures and, thus, better and more expensive materials. - The fuel cell is a modularised energy converter with a unit capacity of watts to ten megawatts over a total range of 7 orders of magnitude, it operates w/o noise, is compact and - without moving parts - free of vibrations. It utilizes - with or without a reformer - a multiplicity of chemical energy carriers such as hydrogen, natural gas, coal gas, methanol, biogas, even gasoline or diesel. The fuel cell is highly efficient with a total

energy utilization of 90% and more, with a comparatively high electricity yield. The fuel cell exergizes the energy system, its emissions are low or even almost zero, with literally no pollutants when operated on hydrogen and oxygen; in this case, only warm air and water vapour are exhausted.

Fields of application are

- Heat-power-blocks in the range of a few kilowatts up to a few (ten) megawatts
- as the chemo-electrical energy converter on board electric busses and automobiles, either as a replacement of the rather inefficient electrical generator or of the prime mover itself
- as topping cycles of gas turbine/steam turbine combined cycles with expected overall electrical efficiencies of 70%
- as mini power plants in portable electronic devices.

Worldwide, no automotive company, no electricity industry or utility company, no home heating systems provider, or other entrepreneurs is not interested or not engaged in fuel cells' R,D&D. It may well so be that in a decade or so the process of replacing home heating boilers or batteries in portable electronics or internal combustion engines under the hood by fuel cells will have resulted in a veritable new cleaner energy industry. The development is fascinating, the race, however, between the "old" combustion engine and the fuel cell in the auto drive train is not yet finally decided.

18. The hydrogen energy conversion chain is environmentally and climatically clean over its entire length as long as the primary energies used are clean. An exemplary chain is the solar hydrogen chain with electricity production in hydropower plants, solar power or wind power plants or biomass converters with follow-up electrolysis of water, transport and storage of hydrogen and, finally, recombination of hydrogen and oxygen or air for the production of heat and electricity.
The two projects HYSOLAR and Solar-Wasserstoff-Bayern, the one a German/Saudi Arabian project in the Arabian peninsular, the other a German national project under the insolation conditions of Central Europe, have experimentally exemplified the direct coupling of solar-voltaic electricity and electrolysis with a unit capacity of up to 350 kilowatt.

19. Clean hydrogen energy chains are also possible when hydrogen is produced from fossil fuels, under the condition that the carbon is captured and the unavoidably co-produced carbon dioxide is sequestered and stored away without risking entering the atmospheric Greenhouse. A typical process is under experiment in Norway: Natural gas from underneath the sea is steam reformed on the platform, and the carbon dioxide is immediately re-injected underground into the emptied natural gas field. So far, 1 million cubic meters of carbon dioxide have been re-injected. - Another highly interesting project is pursued by ZECA – The Zero Emission Coal Alliance: Coal, water and lime react to hydrogen and calcium carbonate; the hydrogen is efficiently converted to electricity in a high-temperature fuel cell, the calcium carbonate is, with the help of the high temperature exhaust heat of the fuel cell, recycled to lime for the entry process and carbon dioxide which is mineralised and deposited of on ground or in emptied mines. Literally, the zero-CO_2 coal plant seems possible! Hydrogen is key.

20. The solar-hydrogen residential home in Freiburg/Germany is an - almost - Zero-Energy-Home (zero= no commercial energy from the market over its entire life) which converts

solar summer electricity into hydrogen and oxygen and recombines them in winter time for electricity and heat. With that experience, even a „Negative“-Energy-Home seems not too far fetched, one which takes more energy from the sun than is needed for its own supply.

21. Energy needs time! Many decades up to half centuries is the reasonable time estimate for a first significant contribution of a new energy or a new energy converter. For example, nuclear fission is more than half a century old and stands worldwide for 7% primary energy equivalent; or the gas turbine was first mentioned in literature in the middle of the 19^{th} century; it was first a power plant of fighter aircraft in the 1940s, and today, more than 150 years later, it contributes to the convincingly efficient and reliable combined cycle installations. – Is there any reason why hydrogen will be any faster? The consequence, “it’s HYtime!” (Hydrogen), it is high time to start the establishment of the hydrogen energy economy and see the process through!

22. Hydrogen technologies on the market:

- Steam reforming of natural gas
- Partial oxidation of hydrocarbons
- Water electrolysis
- Alkaline fuel cell
- Phosphoric acid fuel cell
- Hydrogen engines in space launchers
- Hydrogen compressors and pumps
- All sorts of storage
- All sorts of transportation means
- Hydrogen catalysis
- Hydrogen sensors

Hydrogen technologies on the verge to the market

- Low temperature/high efficiency electrolysers
- Hydrogen internal combustion engines with external and internal mixture formation for stationary and on-board applications
- Robot filling stations
- Fuel cells as a replacement for on-board electrical generators
- Mini-fuel cells for portable electronics
- Proton exchange membrane fuel cells for busses and automobiles
- Solid oxide fuel cells for residential applications
- H2/O2-spinning reserve

Pre-market demonstration necessary

- No-emission city bus fleets
- Fuel cell supported district heating systems
- Molten carbonate fuel cells for industrial application
- Hydrogen production from fossil fuels and supply options
- Transatlantic pilot transport of hydrogen from hydropower, wind power or solar power stations

- Hydrogen pilot airline and on-ground hydrogen infrastructure

Research and Development

- High temperature electrolysers/fuel cells
- The fuel cell as topping cycle of combined systems
- Photochemical hydrogen production
- Material research on membranes
- Reaction kinetics on surfaces
- Low-NOX combustion chambers
- Mecano-catalytic water splitting