Advanced Water Electrolysers Powered by Renewable Energy Sources

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The exploitation of any new energy source is forced by the progressive exhaustion of the one previously in use, and costs major efforts for its individuation and development. Any change of energy regime is faced as a burden or as a trouble: renewable energy sources, successors of the mineral resources age, are actually paying this transition duty. This also holds true for hydrogen, their secondary form, which is a *must* for their accumulation, distribution and "clean" end-use.
Our organisation is dealing with hydrogen generation from solar-photovoltaic and wind sources for about two decades, participating in several international projects by designing and building water electrolysis units powered by such sources. This is an effective contribution to the technical development of the "distributed" power generation age, a radically new way of energy handling: electric and hydrogen grids as interacting networks for millions of suppliers-users.
Examples for this groundwork are demonstration systems based on our electrolysers, handling from a few kW up to hundreds of kW. Systems engineering has been developed on the basis of advanced dynamic models, supported by R&D activities in the electrochemical field, as for instance the development of novel electrodes, which are very stable under rapidly fluctuating or interrupted power input. Our output are electrolysers, and related systems, designed and manufactured according to the best criteria of modern engineering, that are efficient and respectful of all applicable safety codes and regulations.

Hydrogen, when, where, why?

About one third of the world population has no electric power available. The total electrification, as per an OCSE estimate, could be reached around the year 2050. However, is it realistic, with the progressive depletion of mineral energy resources? An increase of 1.34% *pro capite* energy production of the last 20 years has been more than offset by the proportionally larger increase in the world population: the present trend is a reduction of that index (- 0.33% in comparison to 1979).
Discussions about the actual oil reserves locate the expected peak of production, give or take a few years, around the end of this decade, while the total availability of oil will have a relatively short life span. In fact 80% of it will be extracted in about 60 years, which is less than the average human life expectation. The year 2007 is the cross over point when the OPEC Countries will become dominant in the oil market, because the non-OPEC Countries will be forced by the progressive exhaustion of their reserves to continually reduce their oil extraction. This century will also take advantage of the so-called "gas economy", based on natural gas, which in turn is expected to reach its

extraction peak around the year 2020. Using the remaining fossil sources such as coal, heavy crude, bituminous earths, etc. could cause a frontal collision with the biosphere, for their "dirty" handling and/or combustion properties.

The carbon dioxide concentration in the atmosphere is 31% higher than two centuries ago; methane is 150% higher and nitrogen oxides 17% higher. Nobody can firmly prove that this largely man-made set of "greenhouse" gases *will not* cause adverse climate changes. This does not mean that such emissions will be accepted politically for much longer.

Nuclear power emits no CO_2, and it is a commercially competitive alternative to fossil energy sources, with reserves sufficient to fuel the growing energy needs for centuries, under the condition that it be firmly demonstrated as a proven, sustainable and ecology-friendly energy supply.

"Renewable" energy resources, rendered available by nature, are the remaining option. Solar energy is abundant and can potentially provide all the energy requirements of humanity for millions of years to come. It is available either directly, or indirectly as wind energy, hydroelectric energy, and even as biomass. Geothermic sources are also a gift of nature, and have potentials in just about every field.

The remaining question is, then, to decide what to do, how much to do, and when to do it. Science, technology and policy share the responsibility to drive this decision process.

With such premises "When?" seems to be the easiest question to answer, because one to two decades are effectively a very short time to remedy against this situation. Actions must be taken immediately or, better, we have to make up for lost time.

As demonstrated by the chain of wood-coal-oil-natural gas, the exploitation of any novel energy resource is forced by the progressive exhaustion of the one previously in use, and the change of energy regime is generally accepted as a burden or a *dilemma*. Nevertheless the current ease in information transfer may be very helpful in directing the public opinion toward a more rational acceptance of the circumstance.

Renewable energy resources have the characteristics of being spread around the world, the opposite of the discrimination of the fossil resources. This means that energy is available to a more diffused exploitation by the mankind.. A reasonable assumption is that the diffusion of the solar-based sources will drive people toward the so-called *decentralised* or *distributed* power generation, with the creation of local production and distribution grids, reducing the discrepancy between the actual consumers and the people not yet knowing the benefits of the power availability. This is "Where".

Solar-based sources are of unsteady type, with either instantaneous, or daily, or seasonal fluctuations and certainly do not match the instantaneous needs of any grid of consumers. This implies that a buffer of energy shall be created between production and consumption, and the general acceptance is that the buffer will be hydrogen, generated where and when power is available, accumulated and re-used to give back power in form of electricity, either for stationary use, or for mobility. Now we have the answer to "Why" hydrogen.

A Case History

The development of the carbon-combustion economy was the result of taking the easiest step: resources were available and burnable. The solar-hydrogen economy involves a number of new technologies, many of which have been developed in principle, but require substantial improvements. Other new technologies are in early stages and still require research efforts. Technology developments have a cost, but the generality of the problem is inviting Countries to share costs, and to disseminate results through proper cooperation agreements

Our organisation started to deal with hydrogen production by water electrolysis in the year 1977. The engineering goal was the coupling of large, advanced-type electrolysers (10.000 Nm^3/h hydrogen production size per unit) to nuclear power sources forecasting net thermal efficiencies approaching 40%. Even then the objective was hydrogen generation to constitute a buffer between energy production and end users, accounting for the inherent low flexibility of nuclear plants, and for the simplicity of interfacing the nuclear to the process plant. A ten-year time span was assumed to be necessary for the transition from "conventional" water electrolysers to "advanced" units operating under pressure. These units were to be fully automated, reliable, safe, with 30% investment cost reduction, increased efficiency to reduce the energy consumption down to 4 kWh/Nm^3 hydrogen.

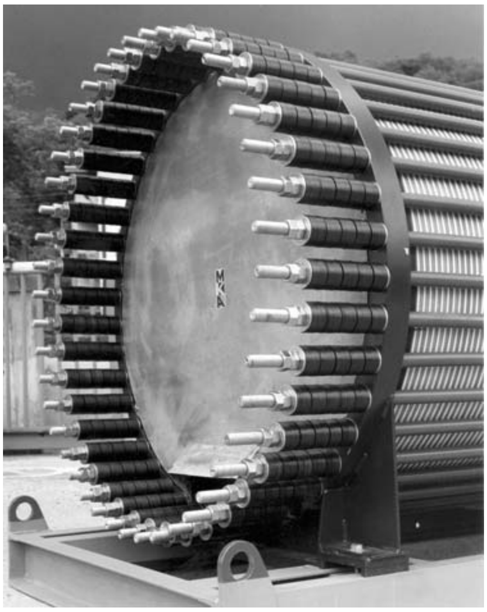
Having accepted the challenge, we have analysed all pros and cons of existing technologies, also in the light of the most recent acquisitions of chemical and materials sciences. This resulted in several innovations and fundamental changes in the electrolysis cells' design. In 1986 we filed the first patent relating to the novel, pressurised electrolyser design, and started the construction of the first prototypes. Part of the goals were achieved, apart from the very large-scale prototype, but came to a halt due to lack of funds consequent to a diffused world-weariness of nuclear plants.

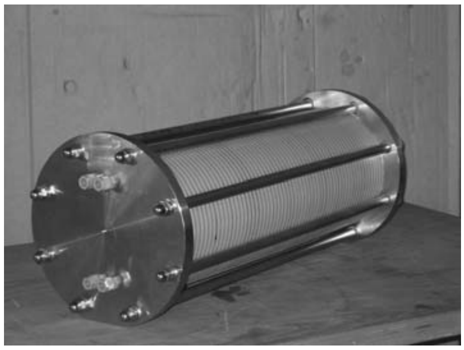
A new deal emerged with the first applications to the exploitation of solar-photovoltaic sources. During the year 1990 we delivered the first 10 kW cell stack to the German institute DLR for the Stuttgart laboratory HYSOLAR project, and later a 350 kW cell stack, operating at 9.5 bar pressure, for the same project, developed through a German-Saudi joint venture, which has been in use for 9 years. Over the following 10 years we have delivered complete electrolysis plant units (operating up to 30 bar pressure) to several research institutions dealing with water electrolysis powered by solar PV fields, including the Pisa University (Italy), ENEA (Italy), Fraunhofer Institute (Germany), INTA (Spain), KFA Jülich (Germany), Fränkische Überland Werk (Germany), Helsinky University (Finland), Naresvan University (Thailand), TBT (France), Panclor (Switzerland), EWI (Switzerland), KACST (Saudi Arabia), and fundamental engineering studies have been prepared for bodies as Bernische Kraftwerke (Switzerland), Paul Scherrer Institut (Switzerland), Ludwig Bölkov Stiftung (Germany), Solar Wasserstoff Bayern (Germany).

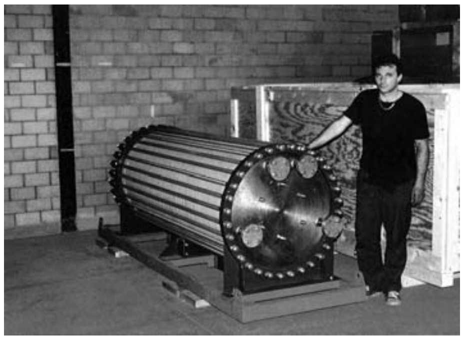
In terms of safety, from the beginning our electrolysers were respectful of all applicable safety codes, regulations and directives, having been also accepted by the most severe authorities, including the Lloyds'of London for installation on offshore drilling platforms.

Then, a reflux tide made the attention to vanish, and the facts were replaced by the words, apparently easier to be funded. Nevertheless we have continued to invest in our R&D programs, waiting for better occasions, further improving the electrolysis cell design, the plant engineering, the energy efficiency, reducing costs and developing new ideas, as for instance electrodes capable to withstanding the severe conditions of power fluctuation and interruption, typically induced by solar and wind power sources. Patents have been filed to protect the fundamental innovations.

In occasion of the 200th anniversary of the Volta's pile, and with reference to the fact that Alessandro Volta was born (1745) at a short distance from our city, we have filed the trade mark VOLTIANA® for our typical electrolysis cells.







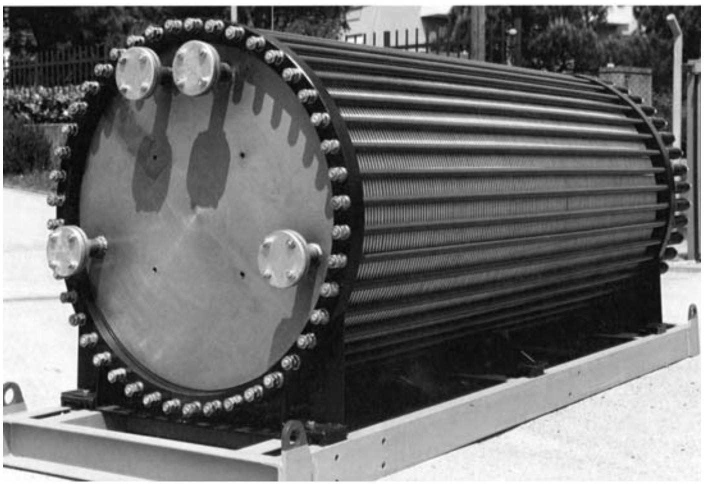
Three views of VOLTIANA cell stacks, respectively for 500, 5 and 350 kW rated power (approx 120, 1.2, 80 Nm^3/h hydrogen production)

A New Deal

As expected, the temporary fog clouding the oil-gas and climate change scenario is now dissipating, and the interest in "clean" hydrogen technologies is re-emerging: the 21st century is now presented as the century of energy efficiency gains, renewable energies, and hydrogen as the only energy carrier candidate.

In continuation of our work, we are now dealing with systems based on hydrogen from renewable energy resources (hydroelectric, photovoltaic, wind), or aiming, through hydrogen, to a more rational use of energy. We would like to inspect here below the main subjects dealt with by our company.

Solar-hydrogen residential units, in modular execution, have a very good hope for a sane future. Hydrogen generated by pressurised water electrolysis, powered by roof-or yard-mounted photovoltaic units, is stored in stationary metal hydrides tanks. When needed, the hydrogen may be reconverted into electricity in fuel cells, or by means of catalytic burners. Costs are still high, but the trend is promising. Additionally, larger systems on a scale applicable to public utility use are important for regional or relatively small utilities, to help smoothing out load patterns. The importance of such problems to be optimised has convinced us to develop dedicated dynamic math models, capable to simulate the complex situations involving the PV field, the energy conversion, and the electrolyser operating in unsteady-state conditions. The results are very useful at the engineering design level, and are later validated on site.
A further instrument available to our R&D people is a programmable solar, or wind load simulator, providing fluctuating DC power to any electrolyser under experimentation. This tool is substantial for testing electrodes and electro-catalysts in simulated solar or wind service.

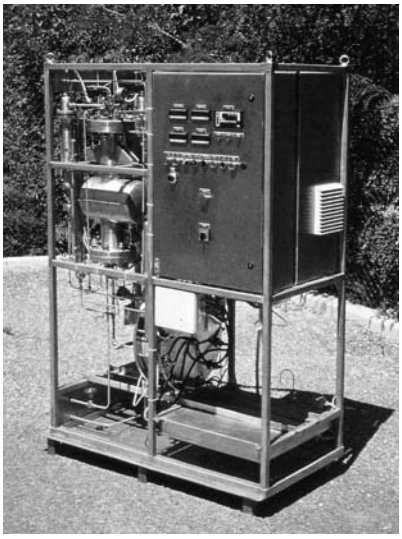


VOLTIANA® cell stack producing 100 Nm3/h hydrogen at 10 bar pressure

Wind energy is the next subject, supported by interesting applications to small-medium grids, especially in connection to adequate power accumulation systems avoiding disturbances to the power-receiving grid. Hydrogen is the ideal carrier for energy, either for re-electrification, or for distribution as such. The last alternative has involved us in the particular case of refuelling stations delivering hydrogen to vehicles, a good perspective for an efficient, zero emission energy chain, a sort of a building block for the future hydrogen delivering infrastructure.

On the subject of energy accumulation and re-distribution we are dealing with power back-up systems, based on water electrolysis, intermediate hydrogen storage and fuel cell, capable of delivering power for a limited, but sufficient time for the final user.
For other applications in larger scale, we have conceived fully integrated units, wherein electrolyser and fuel cell share the same electrolyte, heating/cooling systems and a common hydrogen and oxygen storage.

Our policy is to support all innovative efforts by the current sale of water electrolysers and plants following our proven, but advanced technology, at the same time accepting to risk a part of short term benefits for long term potential in associated fields. This means confidence in the important role of hydrogen as principal means for an abundant and clean energy.



VOLTIANA® electrolysers producing, respectively, 2 Nm^3/h hydrogen at 30 bar, and 7 Nm3/h hydrogen at 6 bar under PV power