Hydrogen for Energy Storage? – Probably, but not in my Car, and preferably not in yours either.

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1. Introduction:

"*WEO 2006 reveals that the energy future we are facing today, based on projections of current trends, is dirty, insecure and expensive. But it also shows how new government policies can create an alternative energy future which is clean, clever and competitive – the challenge posed to the IEA by the G8 leaders and IEA ministers*" [1]. Such a challenge necessarily offers many opportunities, but I have the distinct impression that political and commercial lobbies are seizing these with more mediatic impact than do most scientists or university professors.

Transportation, which most readily relates to public opinion, is receiving widespread attention. Thanks to Governor Arnold Schwarzenegger "*California is investing millions of dollars to line our freeways with hydrogen fueling stations so that low emission cars can travel up and down our wonderful state,*" [2] and Governor Hillary Clinton "*Voted YES on targeting 100,000 hydrogen-powered vehicles by 2010*" [3]. As some of you (or few of you, as this is a October 10, 2007 release) may know, "*The European Union on Wednesday proposed a project worth as much as €1 billion to fund development of hydrogen-powered cars*" [4]. The - questionable, but politically highly attractive - argument is that hydrogen driven cars are environmental friendly because their exhaust contains only water vapour. The question where the hydrogen comes from is of course generally "forgotten" and proponents do not hesitate to claim that (untaxed) hydrogen as a fuel is no more expensive than gasoline, thereby also "forgetting" that public energy prices in many parts of the world consist mostly of taxes.

Hydrogen is bound to play an increasingly important role in the elaboration of sustainable energy policies. But not as a fuel for private vehicles, for which its physical and chemical properties are just not suitable. Europe's scientific community should not, I would think, remain silent when well-organised lobbies are attempting to convince the EC to waste €1 billion on a project [4] that has little innovative content and even less potential benefits.

2. Hydrogen facts rather then myths:

According to the EIA's 2007 International Energy Outlook, world energy consumption should exceed 700 Quadrillion (10^{15}) Btu/year by the year 2030, as compared to the present value of about 500 Qbtu/year [5]. Most of the increase will take place in fast-developing countries in Asia, which will double their energy consumption over that same period. Coal will contribute the major share in meeting these new requirements, especially in China, where new energy requirements are large and where coal is plentiful. The predicted increase in Chinese coal consumption, 47 Qbtu/year, is more than twice as large as present-day coal consumption in the US, the world's second largest coal consumer at about 23.5 Qbtu/year. It is not realistic to expect the people in developing countries to adopt consumption patterns that do not make economic sense. As there is little doubt that oil and –increasingly- coal will remain the main source of energy for several decades to come, the short- and medium term focus should be on saving energy, improving the efficiency of fossil-fuel extraction and conversion, optimising combined-power cycles, and, most urgently, developing CO_2 sequestration processes that are reliable and economically sustainable. When considering different fuel options for private and public transport, the overriding criteria should be overall energy efficiency and global CO_2 reduction rather than showcase ecology. For private transport, hydrogen-driven vehicles are about the least attractive option that one can imagine, especially if it relies on the "good old internal combustion" engine as proposed in BMW's 12 cylinder dual-fuel sedan [6].

Running an Internal Combustion (IC) engine with hydrogen as a fuel is not exactly a new idea: in the first IC engine, patented in 1807 by Swiss inventor Isaac de Rivaz [7], piston motion was achieved by igniting a hydrogen-air mixture. Starting in 1886, French army engineer Charles Renard developed an IC engine designed to propel a military hydrogen-filled airship, fueled by a mixture of gasoline and hydrogen. At the end of WW2, oil shortage prompted the re-discovery of gas-powered IC with bio-fuel generators to produce syngas typically containing 50% hydrogen. On-site generation of hydrogen, advertised as a potential solution for decentralised filling stations, was implemented by the French army at the battle of Fleurus, in 1794.

But running an IC engine on hydrogen results in an energy efficiency of only 10 to 15%, as compared to about 25% for a common-rail diesel, and 30% for a hybrid diesel [7]. The fuel production efficiency can reach 80% for diesel fuel, and 70% for hydrogen obtained by steam reforming of natural gas. Hydrogen liquefaction consumes at least 25% of its useful energy content. Compounding these efficiency figures, an IC engine fueled with liquid hydrogen is found to consume about 3 times more primary fossil fuel than a hybrid diesel. And it produces 3 times more CO_2. Since one can hardly imagine cleaning up our cities by dumping 3 times more pollution in someone else's back yard (or can we?), the best we can expect from this 200-year old invention is to consume 3 times too much fuel while needing to sequester 3 times more CO_2. Who needs a fuel guzzling BMW anyway?

The situation looks more realistic when considering a vehicle powered by a hydrogen fuel cell, rather than by an IC engine. Neglecting the substantially higher energy impact of distributing hydrogen rather than diesel fuel, and optimistically assuming a fuel cell efficiency of 50%, one obtains comparable overall efficiencies, about 25%, for the hydrogen car and for the hybrid diesel. Running prototype public vehicles to develop reliable, efficient and cost effective fuel cell does make sense, not only for hydrogen, but also other liquid fuels, in particular methanol [8]. But it is not necessary to line our highways with hydrogen filling stations to develop sustainable fuel cell technology.

3. Hydrogen in an E Economy:

Hydrogen will become an even less realistic option for private vehicles when electric power from nuclear plants or from renewable resources will gain in importance, a scenario which will probably be favoured by several European countries to meet increasing energy demands. Producing hydrogen by electrolysis to power a fuel-cell vehicle provides an overall energy efficiency of at best 23%, while a battery powered electric vehicle could yield an efficiency of 69% [9]. Electric vehicles, in particular plug-in hybrids ("PHEV's"), have the major advantage of being able to charge their batteries during night when electricity demand is low. They can also contribute to buffering local distribution grids with a relatively high proportion of discontinuous electricity sources, such as solar cells and wind turbines. Equipped with a fuel cell, they can provide electricity back-up for private homes and provide power in remote locations [10]. They will facilitate the evolution towards a sustainable E Economy [9] without requiring costly investments in a new hydrogen distribution network. SEEC© cars make much more sense than hydrogen-powered private vehicles.

Battery technology, however, certainly needs many improvements to fully meet the specific demands of electric vehicles [10], including the vital need for sustainable manufacturing and recycling practices. Several recently announced R&D projects [11] and scientific advances [12] are witness to the growing awareness that improved battery technology is key to providing energy efficient transport that significantly decreases CO_2 emission.

Several major European companies have world-class expertise in generating and distributing electric power. ITER is without doubt the most ambitious and the most challenging project one can think of when striving to radically depart from what we have been doing ever since we learned how to light a fire [13]: use or waste solar energy from the past without worrying too much about the energy resources available to the next generations. Europe cannot afford to miss this unique opportunity to be world leader in developing fusion technology, even if industrial implementation within the next decades is not at all certain. Innovation in public and private transport technology should, I would think, be coherent with the ambition to increase the share of sustainable electric power in our energy portfolio. If the EU wishes to invest an additional € 1 Billion in transport R&D, let us opt for fuel cells and batteries.

Hydrogen is used in increasing amounts in oil refining, ammonia synthesis and the production of methanol and other base chemicals, and it is mostly produced by steam-reforming of natural gas [14]. As access to oil and natural gas becomes more difficult and costly, hydrogen will increasingly be produced by gasification of coal under the form of syngas (a mixture of hydrogen and CO) which is burned in a gas turbine to drive an electricity generator [15]. Such IGCC (Integrated Gasification Combined Cycle) technology can also be fueled by asphalt, refinery waste or petroleum coke. The syngas can also be converted by Fisher-Tropsch technology to produce synthetic high-quality diesel fuel, naphtha, LPG and methanol. The methanol can be used as base chemical, it can power fuel cell vehicles, or it can be upgraded to high-octane gasoline. South Africa's SASOL perfectioned the production of synthetic fuels when the country had limited access to oil, and to-day successfully competes on the market for low-sulphur fuels when crude oil quotes at $ 70 or more [16]. At time of writing, crude oil exceeded $ 90 a barrel. Coal-based power generation and fuel synthesis, however, generate large amounts of CO_2, and are sustainable only if the carbon dioxide is efficiently captured and sequestered. Industrial sites that integrate coal gasification, power generation and the production of syngas-derived chemicals with reliable sequestration of CO_2 will provide opportunities for buffering electric power requirements through large-scale storage of hydrogen. Such storage facilities may also serve to fuel buses and other transportation vehicles for which the low energy to volume ratio of hydrogen is not as serious a problem as for private cars. In addition, safety precautions required by the characteristics of hydrogen (low ignition energy, broad flammability range, risk of destructive shock-wave detonation when confined) will be more reliably mastered in an industrial site than at a highway gas station. Preparing a possible future for hydrogen as an energy carrier does not require highway filling stations, but technology for large-scale sequestration of CO_2, development of industrial fuel cells and efficient electrolysers for power buffering, and large-scale, safe storage of hydrogen that preferably avoids energy-intensive liquefaction.

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