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Towards sustainable energy systems: The related role of hydrogen

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Abstract

The role of hydrogen in long run sustainable energy scenarios for the world and for the case of Germany is analysed, based on key criteria for sustainable energy systems. The possible range of hydrogen within long-term energy scenarios is broad and uncertain depending on assumptions on used primary energy, technology mix, rate of energy efficiency increase and costs degression (''learning effects''). In any case, sustainable energy strategies must give energy efficiency highest priority combined with an accelerated market introduction of renewables (''integrated strategy''). Under these conditions hydrogen will play a major role not before 2030 using natural gas as a bridge to renewable hydrogen. Against the background of an ambitious CO_2-reduction goal which is under discussion in Germany the potentials for efficiency increase, the necessary structural change of the power plant system (corresponding to the decision to phase out nuclear energy, the transformation of the transportation sector and the market implementation order of renewable energies (''following efficiency guidelines first for electricity generation purposes, than for heat generation and than for the transportation sector'')) are analysed based on latest sustainable energy scenarios.

Keywords: Hydrogen; Sustainable energy systems; Energy efficiency

1. Why thinking about new fuels—''business as usual'' is unsustainable

If the current global trends of primary energy consumption and CO_2-emissions increase are not changed, if the developing countries (DC) try to copy the unsustainable production and use patterns of energy systems in the North and if energy policies remain ''business as usual'' (BAU), the risks of climate change *or* of nuclear accidents *or* of resource wars will increase. Depending on the amount of increase of energy demand even all three global risks may be cumulated. Mankind is at the crossroads: within the next 10 years it has to be decided whether we want to rely on the current more or less risky and unsustainable patterns of energy use. If not, we have to switch to sustainable energy paths, putting highest priority on energy end use and supply efficiency and fostering the market introduction of a broad mix of renewable energies. Sustainable energy paths should be based on the following principles:

- Access to energy services for all and fair partnerships with developing countries.
- Effective conservation of resources and protection of environment, climate and health.
- Social acceptability now and in accordance with the needs of later generations.
- Low risks, fault tolerance and contribution to mitigate international conflicts.
- Cost-effectiveness (including external costs).

Based on the principle of common, but differentiated responsibilities, industrialized countries (IC) should take the lead in climate mitigation: To reduce the global CO_2-emissions by about 50% up to 2050 according to the UNFCC, an ambitious reduction target of 80% for IC seems to be necessary in the long run.

But how can we achieve this goal?. For many people, even among politicians, at a first glance, a ''hydrogen

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economy'' seems to be the solution and a vision to fulfil these principles. Several reasons are that hydrogen

- can be converted from all traditional primary energy sources (coal, natural gas, biomass) and, by electricity, from all renewable energy sources (via electrolysis) and from nuclear (via electrolysis or high temperature cracking);
- can be used in stationary and mobile applications without damaging emissions especially by using fuel cells;
- could be made available everywhere and could substitute oil and gas and could be burned without changing the climate.

Therefore, few people doubt *whether* hydrogen will play an important role in sustainable energy systems. But the crucial questions to answer are: Where do we get hydrogen from? How much hydrogen do we need, at what time, at what costs and instead of which alternatives? These questions have to be answered *before* putting large sums of capital into the start up of a ''hydrogen economy''. Hydrogen is only a secondary energy source (a ''storage carrier'') and must be produced from a primary energy source. Because of physical reasons there will always be losses from these conversion processes and therefore in any case the costs of hydrogen must be higher than the costs of the energy used to produce hydrogen. This simple physical reason makes the decision on priorities and time scales for the introduction of hydrogen extremely complex. It is the same simple methodology leading to a higher CO_2-mitigation effect while using the input energy carrier for the production of hydrogen directly.

On the basis of some recent scenario analysis in the following chapters, a short overview on the role of hydrogen within sustainable energy systems can be made. Although scenario analysis cannot give answers to all related and complicated questions, one can argue that there is no need to speed up the introduction of a hydrogen economy. On the contrary, within at least three decades, we will have more environmentally and economically benign alternatives to hydrogen. However, the market introduction of these alternative technologies must not be seen as an opposite strategy, because in many cases the development of these technologies pave the way to hydrogen in the long run. There are some crucial prerequisites and necessary first steps to be taken, before hydrogen becomes the dominant fuel of the future, otherwise there will be no ecologically and economically promising path to a hydrogen economy. On the other hand, if we do not prepare us systematically for the introduction of a stepwise market introduction of hydrogen within the next 30–40 years, mankind will probably not be able to switch to sustainable energy systems in the long run.

2. Future uncertainties: a great range of hydrogen in world energy scenarios

Under BAU there seems to be no entry point for much hydrogen within the next 30 years. Taking the latest Reference Scenario of the International Energy Agency (IEA, 2004) as an example and as an indicator of possible developments of the world energy system under BAU-politics, the perspectives would be like this: if current policies were not to be changed the world's energy demand in 2030 would be 60% higher and the CO_2 emissions would increase by even more than 60%. Though a cumulative amount of \$ 16 trillion would have been invested between 2003 and 2030, the number of people without electricity will fall only slightly (from 1.5 to 1.4 billion) and those using only biomass for cooking and heating in unsustainable ways will even grow from 2.4 to over 2.6 billion in 2030. This energy future is a threat for mankind, because it accelerates the risks of climate change, geo-strategic struggles on scarce oil and gas and nuclear accidents and proliferation. On the other hand, a look into the future based on alternative scenarios and a growing number of good practices in many countries show that this gloomy development does not have to happen. Putting only a recently considered set of new policies into practice, the perspectives could be changed to a ''more sustainable'' world energy system e.g. IEA's ''World Alternative Policy Scenario''(WAPS). In WAPS hydrogen from reformed natural gas is used in fuel cells producing 530 TWh (which is only a doubling compared with BAU) in 2030. In the transportation sector only natural gas and biofuels play a significant role in WAPS. Nothing has been said about costs, but the IEA assumes that fuel cells become economic in some cases in 2015, rather than by 2020, as in the reference case.

As other world energy scenarios show that the WAPS does not include all the cost-effective potentials of more efficient use of energy and the huge potentials and learning effects of decentralized technologies based on renewable energies and co-/trigeneration.

Therefore, let us broaden the picture: more than 400 long-term global energy scenarios (2050/2100) have recently been charted out (Schrattenholzer, 2005) They differ greatly in terms of methodology (e.g. forecasts, projections, scenarios), technology mix, economic and population growth, as well as concerning the resulting CO_2 emissions. If we take the IPCC-SRES-scenarios (Nakicenovic and Swart, 2000) as being representative for the range of possible energy futures, the CO_2-emissions in 2100 may differ between 5.7 GtC (B1-IMAGE) and 27.8 GtC (A2 ASF)—this is the difference between keeping climate change within a ''tolerable window'' or projecting catastrophic impacts of climate change, which mankind never should allow to happen (Fig. 1).

A comparable range has been projected for the use of hydrogen: In the scenarios A2, A1G and B there would be no or only a tiny contribution from hydrogen in 2100. On the other hand, in A1T more than 300 PJ and in B1/A1B about 100 PJ of hydrogen would be used via fuel cells.

What are the messages for decision-makers coming out of these scenario exercises: Everything is possible in an uncertain future? Wait and see, let the markets find the