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Potential Of Emerging And Future CO_2-Neutral Hydrogen Sources On The European Scale

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1 Introduction

Hydrogen is seen as an important and significant energy vector for the future. It not only provides flexibility in the production, but also offers manifold applications for energy generation and energy use. Moreover, it can serve as a transport fuel where it produces no emissions at the point of use. Although there are a number of fossil fuel based production pathways available from which hydrogen can be produced, including nuclear power, one of the great advantages of hydrogen lies in its capability to relatively easy utilise renewable energies in the existing power systems. It allows the use of intermittent sources and thus helps to integrate fluctuating renewable energies into the supply grids. We have investigated the potential that renewable energies and other CO_2-neutral sources could have in Europe for the production of hydrogen in the future within in the frame of the European project Roads2HyCom. Roads2HyCom (R2H) is a project supported by the European Commission's Framework Six program. Its purpose is to assess and monitor Hydrogen and Fuel Cell technologies for stationary and mobile energy applications.

2 Material/Methods

Various renewable energy sources (biomass, wind, PV, solar thermolysis, photo-electrochemical, hydro, geothermal) and CO_2-neutral fossil conversion technologies (nuclear and carbon-based, the latter with carbon capture and sequestration (CCS) technology scenarios), were analysed for their potential to produce hydrogen in Europe up to the year 2020/2030. This time frame refers to the possible start of large-scale demonstration projects in Europe. Only the renewable sources are being presented in this paper. Analysis also took into account the thresholds from which renewable energies actually produce excess energy that could be used for the production of hydrogen as up to a certain percentage, depending on the renewable energy source, power fluctuations can be compensated by the grid.

3 Results

Biomass is first converted to syngas containing mostly methane. From the syngas then hydrogen is produced via steam reforming. This use of syngas is in strong competition with other applications relying on syngas like biofuels or the 'greening' of natural gas. Apart from this competion there is also the question of how much biomass can be used for the production of hydrogen in one place. Generally, larger plants can operate more economical, but biomass raw materials have a low energy content which makes transport to central plants expensive. This will have direct effects on the price and competitiveness of hydrogen as an energy carrier. On the other hand, small, decentralised installations can rarely be operated economically due to the high capital costs and the lack of small-scale gasifiers, making especially large sources of waste as feedstock, like papermills, ideal locations for the production of hydrogen. Another aspect of the use of biomass for energy uses is the increasing awareness of the problems that may arise from the intensive utilisation of biomass and the affect this might have on food production. As one can observe on a global scale, even today there have been steep rises in food prices in poor countries that are caused by the export of biomass from these countries to industrialised nations which need those raw materials, mainly wheat, for their own biofuel production. Although studies for Europe identify vast areas of land currently uncultivated, which could be brought back to agricultural use, the problem may persist, also for hydrogen, depending on the amount of hydrogen envisaged for production, or other problems, like monocultures with high-yield, but non-native plants.

If the renewable energy is provided in the form of electricity, like in the case of **wind energy**, hydrogen can directly be produced via electrolysis. Due to the nature of the wind, however, the best resources are to be found in open space or offshore areas so that most of the large installations are likely to be far away from the demand centres. There will then be two options to produce hydrogen: either the electricity is being transported and electrolysis takes place in centralised plants close to the demand centre, or hydrogen is being produced locally at the wind farm from where hydrogen is then transported as gaseous hydrogen to the end-users. This decision will depend on hydrogen production and storage costs.

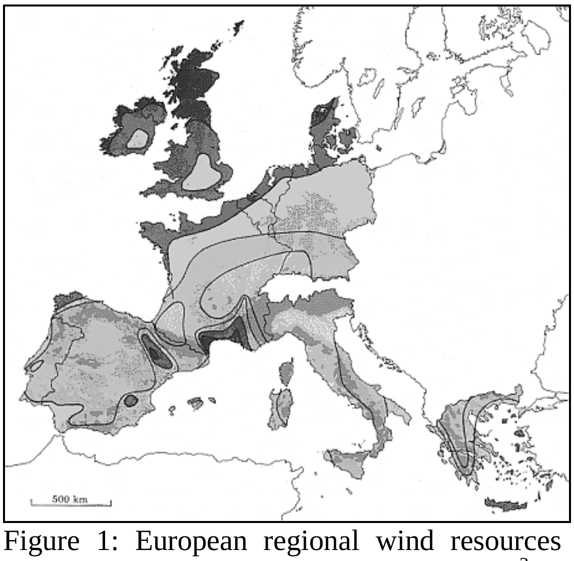

Figure 1: European regional wind resources (light-grey to dark-grey from 50-800 W/m^2 at 50 m height depending on the characteristics of the terrain (from sheltered to open sea).

Hydro power installations come in many varieties, some already commonplace for base-load electricity, like dams or run-of-the-river setups, others still in the development stage, like tidal currents, tidal reservoirs, wave energy or marine currents. The availability of traditional hydro power for hydrogen production in the future will be limited. On one hand, the typical European hydro power source are the run-of-river installations which is base-load production with the Scandinavian and Alpine seasonal reservoirs used for balancing the European grids, for instance by supplying peak power. Additional capacities could be developed, but much of this would be decentralised micro-hydro-generation. Hydro power will therefore more likely contribute to increasing the renewable share of grid electricity than be available as excess energy for hydrogen production. The situation for wave power (including ocean currents), though, is totally different. Projects are only currently developing and wave power up to now makes no contribution to the world energy production (and therefore does not feature in the statistics). Growth of wave power exploitation will go alongside with offshore wind development and eventually will be competing for the same grid links. Since both, offshore wind and wave power, have very high potentials in Europe and offshore wind alone is already straining the capabilities of coastal grids, a strong development of wave power may result in grid access limitations that will offer wind and wave power as cheap sources for producing hydrogen.

Geothermal energy also embraces a variety of different technologies aimed at the use of heat from the earth. Geothermal utilisation is divided into two categories: direct use and indirect use. In direct use, heat or heated water (steam) could be used for supporting high temperature processes for the production of hydrogen (e.g. HTE) or support other heat-dependent processes (e.g. biomass drying for gasification processes, heat for steam methane reforming etc.). The indirect use of heat consists of turbines driven by steam which produce electricity. With this electricity hydrogen could be produced via electrolysis. Geothermal energy, though, is currently limited to high enthalpy areas of which only a few exist in Europe. Future technologies (e.g. Hot Dry Rock systems), however, could also utilise low enthalpie areas, thus accessing much larger resources. At this moment, however, it is still uncertain how much geothermal energy could contribute to the production of hydrogen as the geothermal heat source for the direct use would not necessarily be close to any demand centre and supported processes like HTE, or steam reforming would produce hydrogen far off the demand centres, leading to the above mentioned problems with transport. Also, the indirect use of heat which produces electricity would, due the predictability of its output, most likely produce base-load electricity which is usually fully integrated into the grid, not rendering any surplus for the production of hydrogen.

Ocean thermal energy conversion, or OTEC, is a way to generate electricity using the temperature difference of seawater at different depths. With this electricity hydrogen could be produced via electricity. As with offshore wind installations, the restricted access to the plant would suggest the production of hydrogen as a means to store the produced energy on site for any given time. However, to enable an OTEC system to produce significant amounts of power there needs to be a temperature difference of 20°C or more between the sun-warmed surface, and colder waters drawn from depths of about 1000m. This clearly limits its potential use to tropical and sub-tropical countries and not Europe.

Photovoltaic systems could be shown to only generate surplus electricity above a grid penetration of 15 %. Below that all electricity will be compensated by the grid. Especially, because most of the PV-systems in Europe are installed on buildings which are usually grid-connected. Also, the value of PV electricity is generally highest at the point of generation why it is therefore recommended to use the electricity „as it is“ without further energy wasting conversion as long as there are low degrees of market penetration and while costs are still not competitive with bulk electricity.

Other investigated renewable energy technologies are too novel, with immature or prohibitively expensive conversion techniques, thus making it impossible to estimate a concrete potential from the economic point of view, even if physical potentials indicate large resources to be utilised in the future.

4 Conclusions

Proven technologies like biomass or wind energy have a large potential for the production of hydrogen in Europe in the future. They rely on mature and well-understood conversion technologies, but will have to face competition from other fuel demands (biomass) or will benefit from ongoing infrastructure issues (wind). Hydropower and geothermal energy, on the other hand, hold large potentials, but still lack the major technological breakthroughs which will make them widely available. Despite several occasions in which they have shown much progress it is also yet unclear in which form and extent they can be deployed for the large-scale production of hydrogen. PV electricity has still not reached the share in the grid from which excess power for the production of hydrogen can be expected, whereas other renewable energy systems are still in such an immature state of development that reliable estimations to what extent these could contribute to the future hydrogen economy are not possible.