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Hydrogen Production as Part of Sustainable Use of Energy in Wastewater Treatment Plants

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1 Introduction

In its current World Energy Outlook forecast dating from November 2009, the International Energy Agency (iea) warned against a pronounced increase of the worldwide energy consumption until 2030 unless there happened profound changes in global energy utilisation. According to their calculations, about \$ 10,000 billion must be invested around the world in low-carbon technologies and in energy efficiency during the next 20 years.

Thus, Germany too is facing the immense challenge posed by global climate changes, although contrary to the worldwide development this country has a decreasing energy consumption tendency and thus anticipates some of future developments. The challenge can only be met by energy politics which are open to new technologies and market-orientated.

In Germany, energy supply has for decades been based on a well-balanced energy mix. In recent years, there has been a pro-rata change from fossil fuels towards regenerative forms of energy. Sustainable technologies such as wind power and solar energy have particularly been promoted. Other energy carriers bound to play a major role in the 21st Century are hydrogen and fuel cells, which are likely to contribute greatly to climate protection in the future.

The Renewable Energy Law (EEG) has given a new boost to energy generation from wind, water, sun, biomass and geothermal sources. By now, 15% of the electric energy consumed in Germany already stem from regenerative sources [1]. The wind power industry aims at covering approx. 25% of the entire energy consumption by 2020. This necessitates finding a way to deal with the surplus production of electricity on days with strong winds. A reasonable solution may be hybrid power plants which in case of excess capacity produce and store hydrogen.

Prior to the market launch and commercialisation of hydrogen and fuel cells, however, the pertaining hydrogen infrastructure must be established.

Hydrogen as storage medium of electricity is very versatile and utilisable for stationary or mobile applications. It offers solutions for the acceptance of volatile energy surpluses from solar power and wind power and provides a considerably larger vehicle operation range than electro-mobility. Hydrogen supplied from regenerative sources is thus a viable contribution to expanding the spectrum of energy carriers available for individual traffic.

Germany consumes about 30% of its primary energy in the traffic sector. Hydrogen and fuel cells may be playing a major role in traffic by 2050. More than 70% of passenger cars and commercial vehicles could be running with hydrogen-fuel cell technologies [2]. The crucial limiting factor is the distribution degree of hydrogen vehicles and the nationwide availability of hydrogen.

Industrial hydrogen is available in Germany in large amounts, for instance as synthetic gas from coal upgrading. Per year, 19 billion Nm³ are produced or generated as by-product [3], with 3.9 billion in North Rhine-Westphalia alone [4]. This land also sports a 240 km long hydrogen pipeline, which in future might be further expanded to serve as the spine of the overall hydrogen infrastructure. However, the energetic use of hydrogen must be inseparably connected with its production on the basis of regenerative energies.

The general principle of raw material utilisation also applies to sewage sludge. Reserves, resources, and availability as a high-quality product must be considered here. Generally, the availability of this raw material is guaranteed as long as there are human beings, but the upgrading of the sludge will allow for higher levels of value creation.

Water management not only supplies a regenerative energy source – sewage sludge from wastewater treatment –, but also major potentials for the introduction of a hydrogen-based energy infrastructure. Particularly suited are the wastewater treatment plants, which offer themselves as energy supplier for stationary and mobile demands because of their favourable location characteristics. There are approx. 10,500 wastewater treatment plants, predominantly in urban areas, which makes for an excellent connection infrastructure. This network of wastewater treatment plants might provide the starting point for a nationwide local hydrogen infrastructure in Germany.

2 Energy at Wastewater Treatment Plants

Wastewater treatment plants (WWTPs) are both suppliers and consumers of energy. The energy consumption at WWTPs is high and makes for a major percentage of the operation costs. As the processes of wastewater and sludge treatment are very energy-intensive, energy saving and on-site energy production play a crucial role in the operation of wastewater treatment plants. In recent years, Emschergenossenschaft and Lippeverband managed to lower the energy consumption at their WWTPs and to raise the on-site energy production.

One crucial factor of on-site energy production at WWTPs is the utilisation of digester gas in combined heat and power plants (CHPs), a technology which is an established method of internal energy production. Utilising the digester gas through heat-power-coupling in CHPs allows for high energy efficiency degrees, with the mechanical efficiency degree amounting to 30%-35%, the thermal efficiency degree to 50% [5].

In 2006, the production of electric energy in digester gas CHPs in WWTPs in Germany amounted to about 0.94 TWh [6]. At modern WWTPs, the ratio of self-supply with electric energy is approx. 50%-70% (depending on the process technology used). Through co-fermentation – the co-treatment of bio-waste in the fermenters at the WWTPs –, the biogas production and thus the potential of upgraded gas or hydrogen can be increased significantly.

For autonomous combustion, the digested sewage sludge must be dewatered to a degree of at least 45% of dry solids or mixed with other energy carriers (coal fines, shredder fluff); it will then supply further energy, which can be used to cover the demand mentioned above.

In order to reduce the energy demand for wastewater treatment, Emschergenossenschaft and Lippeverband use methods such as area-wide energy benchmarking, energy studies, and load management.

Due to these loops consisting of regular reporting, analysis and measure deduction, which now are run routinely, and the resulting technical measures, recent years have seen a continuous improvement of the energetic situation at the WWTPS of Emschergenossenschaft and Lippeverband. In the long run, it will be possible to cover the energy demand of the WWTPS with sewage sludge utilisation from internal sources [7]. Emschergenossenschaft and Lippeverband strive together for this goal at their respective WWTPs.

3 Production of Green Hydrogen at Wastewater Treatment Plants

The generation of hydrogen at WWTPs is an additional factor of energy production and consumption there. The digester gas which is produced during the anaerobic sewage sludge stabilisation in fermenters is available as renewable resource for hydrogen production, with electrolytic production being a further option. Both ways are described below.

3.1 Hydrogen from biogas through gas reformation

For the production of hydrogen, the biogas is converted in a catalyser at 900° C with addition of steam, analogous to the industrial steam reformation of natural gas. This production path is climate-neutral, as biogas is a renewable energy source.

Being the biggest operator of wastewater treatment plants, the Emschergenossenschaft decided early to test and further develop the processing of digester gas into biomethane and hydrogen in the „EuWaK“ demonstration project at the WWTP in Bottrop („EuWaK“ standing for “Erdgas und Wasserstoff aus Kläranlagen” = “Natural gas and hydrogen from wastewater treatment plants”). The EuWaK project was realised with funding of the federal land of North Rhine-Westphalia and the European Union.

The success of the project depends on a marked problem-solving competence of everybody involved, with interdisciplinary co-operation or „trans-disciplinarity“ being particularly demanded.

The project partners of the Emschergenossenschaft for project development and project realisation are the engineering company Tuttahs & Meyer, the FIW research institute for water and waste management at the RWTH Aachen, the consulting engineers Redlich and Partners, as well as the city of Bottrop. In the pilot project, the digester gas is first converted into biomethane, a component current of which is discharged and supplied at a natural gas filling station to in-house vehicles running with natural gas. In the second step, the remaining biomethane is converted into hydrogen in a steam reformer. The maximum digester gas input currently is 120 Nm³/h, which is equivalent to a dimension of about 10% of the entire digester gas amount. The capacity of the biogas processing amounts to 72 Nm³/h, that of the hydrogen processing to ca. 100 Nm³/h. The generated hydrogen is led via a pipeline to a nearby school centre, where electric energy and heat for the energy supply of the schools are produced in a CHP. In this way, the project succeeded in demonstrating the complete local hydrogen infrastructure from the renewable energy source sewage sludge to the

hydrogen consumer for the first time. A further target of the project is the stable production of high-quality hydrogen, the plan being to supply not only the natural gas filling station, but to provide a hydrogen filling station with hydrogen immediately from the sewage sludge production. Further details of the project will be explained in the report on „Green Hydrogen and Natural Gas from Digester Gas of Wastewater Treatment Plants“.

3.2 Hydrogen from water through electrolysis

Hydrogen can be produced through electrolysis run in a regenerative way (wind power, photo-voltaics, etc.) The oxygen produced at the same time can be used in the wastewater treatment process. This method is employed at the WWTP at Barth in Mecklenburg-Western Pomerania, with the produced hydrogen being used to fuel a fuel cell bus [8].

4 Hydrogen Infrastructure and Wastewater Treatment Plants

The hydrogen production at WWTPs plays a role particularly in building up the hydrogen infrastructure. WWTPs are the first de-central production locations and can supply local vehicle fleets and serve as junctions in the filling station network to be built. The intermediate step of biomethane generation is a bridging technology towards hydrogen and established the WWTPs as filling station locations.

Because of the complex technology and the necessary digester gas amounts, current estimations regard only large WWTPs with a capacity of 100,000 PE onwards as suitable for hydrogen production. In Germany, there are 237 WWTPs of this size. The hydrogen potential of the digester gas on these WWTPs is estimated to be about 260 million m³, which corresponds to ca. 1% of the total hydrogen production in Germany. Another source calculated the hydrogen production potential from the digester gas of all German WWTPs to be 1.65 billion m³ per year [9].

If this hydrogen amount were completely used as fuel, a mileage of 6.2 billion km/a could be achieved. Compared to the total mileage of all passenger cars of 525 billion km/a, this makes for a ratio of 1.2% [9].

The biogas production from the anaerobic sewage sludge treatment at the WWTPs of Emschergerossenschaft and Lippeverband amounts to ca. 45 m Nm³/a, which could be reformed into ca. 60 m Nm³/a of hydrogen. Depending on the frame conditions, ca. 17,000 passenger cars could be supplied with hydrogen.

Even if only a part of this biogas were used for hydrogen production, this part would suffice to satisfy the foreseeable demand for hydrogen-fuelled vehicles in the surrounding area relevant for the refuelling. In the next 15-20 years, the hydrogen supply of vehicles could stem from the potential of the biogas from WWTPs. If a significant market penetration with hydrogen-fuelled vehicles is achieved, it will be necessary to utilise other hydrogen sources.

If only „green hydrogen“ is used, that is hydrogen from regenerative sources, hydrogen-fuelled vehicles can be classified as „zero emission vehicles“. This potential is fulfilled with hydrogen from WWTPs.

The local hydrogen production at WWTPs has one advantage: in case of direct utilisation at the WWTP (filling station), there is no need for an extensive infrastructure to distribute the hydrogen. This allows for the early building of filling stations at the WWTPs which need

neither infrastructure nor distribution logistics. For WWTP owners, hydrogen production as fuel is interesting because mobile utilisation makes for a higher price level than stationary usage. The prerequisite, however, is that the discharged energy of the digester gas can be replaced by regenerative energy sources.

5 Conclusion

In the energy supply of the future, hydrogen will play a major role, provided that the production is based on regenerative energy sources. For the owners of wastewater treatment plants, the hydrogen technology opens up interesting perspectives. Compared with the entire hydrogen amount produced in Germany, the potential of hydrogen production from digester gas must be regarded as low; still, WWTPs will be able to play quite a significant role in the building up of the hydrogen infrastructure, particularly during the extension of the filling station network.

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