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Supplying hydrogen vehicles and ferries in Western Norway with locally produced hydrogen from municipal solid waste

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ABSTRACT

Gibbs free energy minimization has been used to estimate the hydrogen production potential of air gasification of the wet organic fractions of municipal solid waste available in the Bergen region in Western Norway. The aim of this work was to obtain an upper limit of the amount of hydrogen that could be produced and to estimate of the number of vehicles: passenger ferries and cars that could be supplied with an alternative fuel. The hydrogen production potential was investigated as function of waste composition, moisture content, heat loss, and carbon conversion factor. The amount of hydrogen annually available for both gasification and gasification combined with water-gas-shift-reaction was calculated for different scenarios. Up to 2700 tonne H_2 per year could be produced in the best case scenario; which would, if only utilised for maritime operations, be enough to supply nine ferries and ten fast passenger boat connections in the Hordaland region in Western Norway with hydrogen.

Introduction

Norway's contribution to the annual worldwide emission of greenhouse gases is negligible on a global scale: less than 0.15% of the global greenhouse gas emissions in 2015 originated in Norway [1,2]. However, the Norwegian government has set itself and its population the aim of reducing the emission of greenhouse gases to at least 60% or less of the national emissions in the year 1990 by the year 2030 [3]. This means a maximum emission of 31 million tonne CO_2-equivalents in 2030 because the emissions in 1990 were 53.9 million tonne CO_2-equivalents. Compared with 1990, the emissions increased by 2.2 million tonne to 53.9 million tonne CO_2-equivalents by 2015. A decrease by 22.9 million tonne CO_2-equivalents during the next 15 years is therefore necessary. This is to be achieved by increasing the efficiency of energy use as well as a reduction in the use of fossil fuels. As the electricity generated in Norway comes almost exclusively from hydropower (95.8% in 2015 [4]), reduction of fossil fuel use in the transport sector on land and sea is one focus area. For example, cargo trucks, ferries and passenger boats are driven by fossil fuels with the exception of a few local pilot projects like the electric car ferry across the Sognefjord between Larvik and Oppedal in Western Norway. In 2015, 19.1% of the Norwegian greenhouse gas emissions came from road traffic (10.3 million tonne CO_2 equivalents) and about 11.9% from aviation, navigation, fishing, auxiliary motors etc. (6.4

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million tonne CO_2 equivalents) [1]. Further contributors to the emissions of greenhouse gases in 2015 were oil and gas extraction (28.0%), manufacturing industries and mining (22.1%), energy supply (3.2%), heating in other industries and households (2.2%), agriculture (8.3%) and other unspecified sources (5.2%) [1].

The decrease of crude oil prices to below $70 per barrel (Brent) in 2014, has led to a crisis in the Norwegian gas and petroleum industry. Many offshore-related businesses changed their focus towards new markets and products in 2015. One of these new areas of interest is environmentally friendly propulsion in coastal waters. Many communities along the Norwegian coast are connected by fast-going passenger boats with capacities ranging from 10 to more than 100. Car ferries are in many places the only means to cross the fjords, sounds and narrows along the coast. For economic reasons, many of these passenger-carrying vessels use active thrusting while staying in port instead of mooring. This leads to unwanted and avoidable local emissions not only of greenhouse gases, but also particulate and NO_x emissions. Much of the long distant transport of cargo is transported on few long distance train connections or by ship along the coast. The main part of cargo transportation on the road, however, does not travel further than 50 km and is therefore another source for local emissions. While the number of electric passenger cars has increased significantly in the past years in Norway, they are still relatively few compared with the total number of passenger cars in the whole country. At the end of the year 2016 only 3.7% of all registered cars in Norway were pure electric cars [5] even though it meant an increase by more than 40% from the year before. Compared with cars with an internal combustion engine, the limited range of electric cars running on batteries only is still a problem for many people, especially those who live in the outlying districts and regularly have to travel long distances that cannot be done with public transport. Electric cars with a fuel cell running on hydrogen offers the possibilities of a much longer range and faster refill time compared with charging a battery.

The transition from fossil fuels to hydrogen as a fuel for both fuel cell powered passenger cars and land and sea transport has come into the focus of both government, companies and local industrial interest groups. The aim is to use hydrogen to solve the problems with both emission of greenhouse gases and local pollution. Another driving force behind these activities this transition is the aim to develop both hydrogen-related technology and products as well as hydrogen as fuel to become more independent of the sale of fossil fuels to the global market.

Based on its natural resources, Norway has three main sources for hydrogen. One is electrolysis using electricity generated from hydropower. The second is steam reformation of methane sourced from its natural gas resources in combination with CO_2 capture and storage. The third option is the gasification of biomass with CO_2 capture and storage. The biomass could come from either agricultural waste and forestry or municipal solid waste.

The aim of this work was to obtain an upper limit of the amount of hydrogen that could be produced by gasification of municipal solid waste available in the region around Bergen, which is located in the Hordaland region on the Norwegian west coast. With this annual hydrogen production rate, an estimate of the number of vehicles of different types that could be supplied with locally produced hydrogen as a fuel is to be given.

Gasification is the partial oxidation of a biomass, which results, depending on the process parameters and gasification agent, in a hydrogen and carbon monoxide rich product gas (also called synthesis gas or syngas) [6]. Atmospheric air, pure oxygen and steam can be used as gasifying agents. Among the thermal processing methods for solid municipal waste, incineration of waste in combined heat and power plants is still preferred among the thermal treatment methods. This is mainly due to technical problems with the control of the gasification process because municipal solid waste is a chemically inhomogeneous fuel. However, improvements in gasification technology have been made and along with the possibility to produce hydrogen from waste, a renewable source in the sense that there is a constant to increasing availability of waste, gasification of biomass has seen much renewed interest.

Previous studies of hydrogen production by means of gasification have investigated different fuels and gasification processes. Tian et al. analysed the effects of biochemical composition of lignin, cellulose, hemicellulose and other biomasses on the hydrogen production potential in experiments with an updraft fixed-bed reactor [7]. It was found that biomass with more lignin produced more hydrogen than the other biomasses in the study. The simulations carried out by Ibrahimoglu et al. [8] analysed the hydrogen production potential in coal plasma-gasification with steam injection in a down-draft-gasifier. Favas et al. [9] used Aspen Plus to study the plasma-gasification process of three different types of biomass and validate the results with experimental findings. Microalgae were the biomass used in chemical-loop-gasification experiments conducted by Liu et al. [10] while citrus peels were used as biofuel by Chiodo et al. [11] in a steam-gasification process. The potential of plasma-gasification processes for the treatment of solid wastes in general (not only biomass) was recently reviewed by Sanlisoy and Carpinlioglu [12]. The combined recovery of hydrogen and aluminium from unrecycled plastic waste was studied by Lu and Chiang [13]. High recovery efficiency of high purity aluminium was achieved in a lab-scale fixed bed gasifier. Different types of coal as fuel for a combined gasification and power plant were studied by Seyitoglu et al. [14].

Dincer and Acar [15] have evaluated 14 different methods of hydrogen production with respect to sustainability by comparing the different methods' global warming potential, social cost of carbon, production costs and energy and exergy efficiency. Gasification of biomass into syngas was one of the methods in this comparison. Although biomass gasification has highest energy and exergy efficiencies among the thermal methods, it has also higher social costs of carbon and global warming potential compared with many of the non-thermal methods. The relatively large SO_2 emissions can be dealt with by exhaust gas cleaning and capture and storage or use of CO_2 can reduce the global warming potential of gasification. The production cost of hydrogen by biomass gasification is one of the lowest (less than $2/kg H_2), only beaten by plasma arc decomposition of fossil fuels, coal gasification and fossil