Efficient production of fuel from biogenic residues

Natural gas is a more climate friendly fuel than raw materials such as coal and petroleum. Nevertheless it is also a fossil fuel that generates anthropogenic CO$_2$ emissions. In a collaborative project at the Karlsruhe Institute of Technology, scientists and engineers are concentrating on finding out how biogenic residues and waste materials such as wood, sewage sludge and biomass mixtures can be turned into alternative gaseous fuels. The innovative approach involves using carbon from different types of biomass as completely and efficiently as possible. In addition, the heat generated by converting the biomass into methane will be integrated into biomass gasification and electrolysis processes. The hydrogen thus generated can then be used for producing methane while oxygen serves as gasification agent. The goal is to make the overall process highly efficient.
The idea of producing regenerative natural gas from sewage sludge, straw or wood pellets, feeding it into the existing natural gas grid and using it as fuel in the form of very heavily compressed natural gas, known as CNG, is quite tempting. In addition, this regenerative natural gas can be converted to liquid form (Bio-LNG, liquid natural gas) and as such has huge potential, especially for heavy goods vehicles. Scientists from the German Technical and Scientific Association of Gas and Water (DVGW) Research Centre at the Engler-Bunte-Institute, which is part of the Karlsruhe Institute of Technology, are pursuing another idea: instead of turning carbon monoxide into methane and removing carbon dioxide, which is the current procedure, the researchers’ goal is to convert absolutely all carbon contained in the biomass into methane. They start by producing synthesis gas from biogenic residues and waste materials using a method known as fluidised bed gasification. In order to convert all CO\(_2\) into methane, the researchers use hydrogen gas provided by way of an efficient high-temperature electrolysis. The gas mixture is then converted into methane, which is the major component of natural gas, in methanation reactors. After purification, it can be fed into the existing gas grid.

The joint three-year “Innovative production of SNG (synthetic natural gas) and CNG from biogenic residues (Res2CNG)” project is coordinated by Dr. Frank Graf from the DVGW Research Centre and has been up and running since September 2015. Other project partners are the EIfER European Institute for Energy Research EDF-KIT EWIV, the Institute for Combustion and Power Plant Technology (IFK, University of Stuttgart) and the Institute of Energy Industry and Rational Energy Application (IER, University of Stuttgart).

Wood, straw and sewage sludge as feedstock for fluidised bed gasification

In order to tackle the experimental and theoretical aspects of methane-based fuel generation, the project partners have drawn up a stringent work plan consisting of five work packages. The first two work packages comprise project coordination and analysing the gasification of various biogenic feedstock materials, up to the stage of hot gas cleaning. In order to determine the best possible method, both in terms of material and energy production, different process chains are being tested with different input materials and compared with each other. The elemental composition, water and ash content as well as the calorific value of numerous biogenic waste and residual materials have already been analysed. In addition to state-of-the-art non-pressurised gasification, the project also involves researching a method of gasification at elevated pressure.

The researchers use wood or a mixture of wood, straw and sewage sludge as gasification feedstock. The synthesis gas produced is treated in a hot gas cleaning process, which, unlike conventional processes, does not require the gas to be cooled down before further processing. High-temperature electrolysis means that steam can be used instead of liquid water for generating hydrogen, considerably increasing electrolysis efficiency. The subsequent methanation step generates a gas that corresponds to the legal guidelines for use as a CNG fuel. “We have developed special methanation reactors that convert the synthesis gas effectively into methane,” says Graf. Alternatively, LNG can be produced in a subsequent liquefaction step using a refrigerant circuit.

In order to find out how plant operation can be made more flexible, the researchers are investigating a scenario involving the generation of CNG from the biomass mixture according to perspective thresholds (90% methane, 10% hydrogen). Graf emphasises the perspective alignment of one of the different process chains aimed at running gasification and electrolysis optionally in the partial load range. “Combined with an additional storage facility for the captured CO\(_2\), we can make full use of
the carbon. When electricity prices are low, CO₂ can be introduced into the system and electrolysis be run at maximum load.”

Generation of synthesis gas for methanation

So far, the team has collected data from a twin-bed steam-gasification process. In this case, the energy required for gasification is generated in a combustion reactor and fed into the gasification reactor by way of circulating bed material. The CO₂ released in the combustion section of the gasifier is usually discarded. “As our aim is to use all the carbon in the process chain, it does not make sense to remove the CO₂ generated in the process, something that is standard in other SNG generation process chains,” explains the project coordinator. The project therefore plans to establish a so-called single-bed water vapour oxygen gasification process which will use the oxygen that is produced during electrolysis. The project partners have established an infrastructure with an atmospheric fluidised bed plant at the IFK in Stuttgart for this purpose. The high discharge temperatures of 800 - 850 °C can be integrated into the subsequent high-temperature electrolysis.

As far as methods to separate tar are concerned, the team plans to integrate a hot gas cleaning step into the process. “The temperature for gas cleaning should not dip below 300 °C, so that it does not have to be reheated in the methanation step.” Using currently available technology, gas scrubbing needs to be carried out at temperatures below 100 °C, which considerably diminishes the overall efficiency.

Water vapour oxygen gasification is being studied in an atmospheric fluidised bed plant. Using the experimental data that has been collected, the researchers have developed a gasification model with which they can simulate optimal operation at pressures of up to 20 bar. This helped them calculate
material balances of scenarios involving the complete conversion of carbon. In the subsequent work package, i.e. the performance and analysis of experiments related to methanation technologies, the project partners also made significant progress. The gas mixtures derived from the gasification step were used as raw materials. Parameters such as temperature, pressure and composition of the resulting product gases were determined and one- and two-step methanation concepts that are suitable for future application were developed.

Graf and his team have reached the first milestone. “We have been able to demonstrate the feasibility of all individual work packages. We theoretically calculated and experimentally validated the conversion of the various feedstock materials into synthesis gas as well as the cleaning of the gas that is used for methanation. The resulting data and models will now be integrated into an overall process.”

In the next step, the resulting process chain will be thermally integrated, further optimised and then evaluated in technical and economic terms in comparison to the current state of technology. Graf clarifies: “We have gained initial insights. However, as no megawatt range plants are yet available, for the time being it is difficult to carry out reliable cost analyses. Our goal is to be able to determine the fuel production costs by the time the project comes to an end in September 2018. As far as the provision of biomass-based fuels is concerned, we also want to perform a valid cost comparison with other power-to-CNG methods.” These findings are likely to make a decisive contribution towards the generation of fuels from biobased materials as alternatives to fossil-based raw materials.
The article is part of the following dossiers

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