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A new process concept for highly efficient conversion of sewage sludge by combined fermentation and gasification and power generation in a hybrid system consisting of a SOFC and a gas turbine

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Abstract

Sewage sludge can be disposed of by fermentation, incineration or **gasification**. Conversion of the resulting **biogas**, combustion heat or **gasification** gas into electricity is often employed. Since **sewage sludge** cannot be fermented completely and due to the significant heat requirements for drying it in the incineration plant or before the gasifier, the electrical output in all cases is very low. Consequently, this work seeks to investigate a combination of fermentation and **gasification** in which dried fermentation waste is converted in a gasifier. With the aim of combining these two **biomass** conversion processes with power generation in an efficient manner, a hybrid system consisting of a **SOFC** and a **gas turbine** is investigated. This combination of a **biogas** plant and a gasifier has the advantage that waste heat can be used as a heat source in drying the fermentation waste. Another advantage is the combined conversion of **biogas** and **gasification** gas in the **SOFC**. As steam from **gasification** gas is used for internal reforming of methane out of **biogas** at the anode of the **SOFC**, the complexity of the plant is reduced and the efficiency is increased. A configuration including a pressurized **gasification** process was identified as most efficient in terms of electrical output.

Keywords

Biomass, sewage sludge, biogas, gasification, SOFC, gas turbine

1. Introduction

The disposal of sewage sludge is difficult due to the pollutants it contains. As there are high quality requirements for its deployment as fertilizer in agriculture, its use has stagnated at 30 % in Germany in the years 2006 to 2010. Most sewage sludge (50 %) is disposed of by incineration [1] (after a fermentation step). The first step in sewage sludge conversion is always fermentation. Mechanical dewatering of fermented sewage sludge reduces the water content to approximately 70 %. The biogas formed during fermentation is flared or converted in a combined heat and power plant, whereafter the fermented and mechanically dewatered sewage sludge can be disposed of in a waste incineration plant [2]. Only little or no heat is supplied by the combustion process and additional fossil fuel is required due to the high heat demand of evaporating the humidity in the sludge. Another option is to co-fire the fermented and dewatered sewage sludge in a coal-fired power plant [3, 4]. An advantage of this concept is that the sludge can be dried by the waste heat of the power plant and thus the dried sludge can replace part of the coal. A disadvantage is the energy expenditure for the transportation of un-dried sludge.

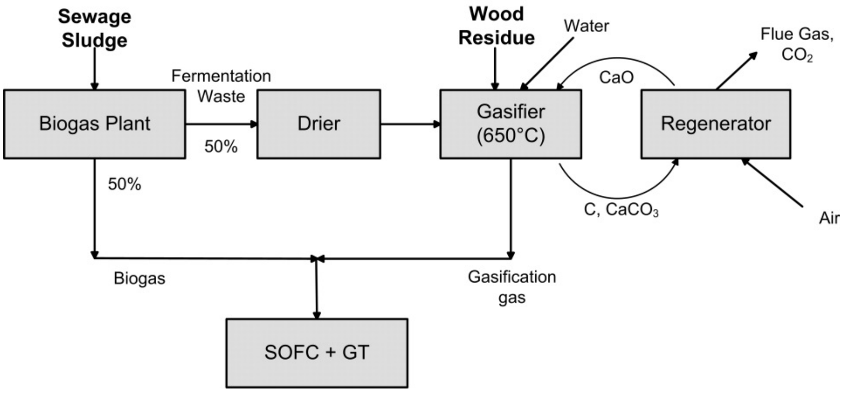

Figure 1: Innovative process concept of combined fermentation and gasification of sewage sludge and wood

This work proposes an innovative concept of combined fermentation and gasification of sewage sludge and wood as seen in Figure 1 [5]. With a two-stage, high-performance digestion [6-8], an energy conversion of 50 % of the sewage sludge into biogas is attainable. Fermentation waste (fermented sewage sludge) is dried and subsequently converted in a gasifier into a gas with high hydrogen content [9, 10]. Since gasifiers are built for higher energy flows, wood residue has to be added to the sewage sludge in the gasifier. Both the biogas from the fermentation and the gasification gas are converted in a SOFC (solid oxide fuel cell), which has a high electrical efficiency potential [11, 12]. Fermentation and gasification are combined, as waste heat from the gasification process can be used to dry the fermentation waste. The absorption-enhanced reforming (AER-) process is based on a fluidized bed gasification where CO_2 is absorbed at the bed material CaO [13-18]. Thus, high H_2 concentrations of about 75 vol% (based on dry gas) and small CO_2 and CO concentrations are achieved. The reforming process consists of two reactors. In one reactor, the endothermic gasification of biomass (dried sewage sludge and wood) with steam takes place, while in the other reactor, the bed material is heated by burning the coke, which is not converted in the gasification reactor. Thus the loaded bed material $CaCO_3$ is regenerated to CaO and the formed CO_2 leaves the reactor with the flue gas. Converting the gases in a SOFC, an electrical efficiency of approximately 45 % (from gas to electrical energy) can be achieved at a fuel utilization rate of 80 %. A hybrid system consisting of a SOFC and a gas turbine raises the electrical efficiency to approximately 70 % [19-26]. An important difference in comparison with conventional fuel natural gas is that there is less of a cooling effect from the internal reforming of methane at the SOFC anode, and therefore more air is required for cooling the SOFC.

Several experimental investigations combining two of the above mentioned components can be found in literature: gasification of fermentation waste [27], power generation in SOFC from biogas [28] and gasification gas [29, 30] as well as power generation in a hybrid system of SOFC and gas turbine with natural gas [31].

Gas quality is important to prevent degradation of the electrodes of the SOFC. For biogas, desulfurization with a charcoal filter is sufficient. Gas treatment of gasification gas is more complex. Particles, chlorine, sulfur and undesired higher hydrocarbons, so called tars [32], must be removed. State of the art is cold gas cleaning in filters and scrubbers. Thus, the steam in the gas is also condensed. Hot gas cleaning, however, has the potential to improve energetic efficiency by using the energy content of the tars and preventing the loss of sensible energy in the scrubber. It also has the potential to reduce the complexity of the system by eliminating heat exchangers and other components. Although hot gas cleaning is not state of the art, there are several research activities in this field. The Fraunhofer UMSICHT report [33] gives an overview of gas cleaning processes for both biogas and gasification gas in general. Aravind [34] summarizes several possibilities for hot gas cleaning of gasification gas for fueling a SOFC. The present work implements hot gas cleaning.

The aim of the present work is a concept that maximizes the utilization of the energy content of sewage sludge. Therefore, three main concepts are presented with combined fermentation and gasification and conversion of the product gases, either in a SOFC or in a hybrid system consisting of a SOFC and a gas turbine. The advantages of heat and stream integration are shown by comparing electrical efficiencies. For the most efficient concepts with power generation in SOFC and gas turbine, different options for compressing the gasification gas for the gas turbine are discussed.

2. Modelling Aspects and Assumptions

Aspen Plus is the software used for process simulation, which includes gas treatment and conversion to electricity. Fermenter and gasifier are treated as black boxes with conversion rates, efficiencies and product gas concentrations taken from literature and project partners [15, 35-37].

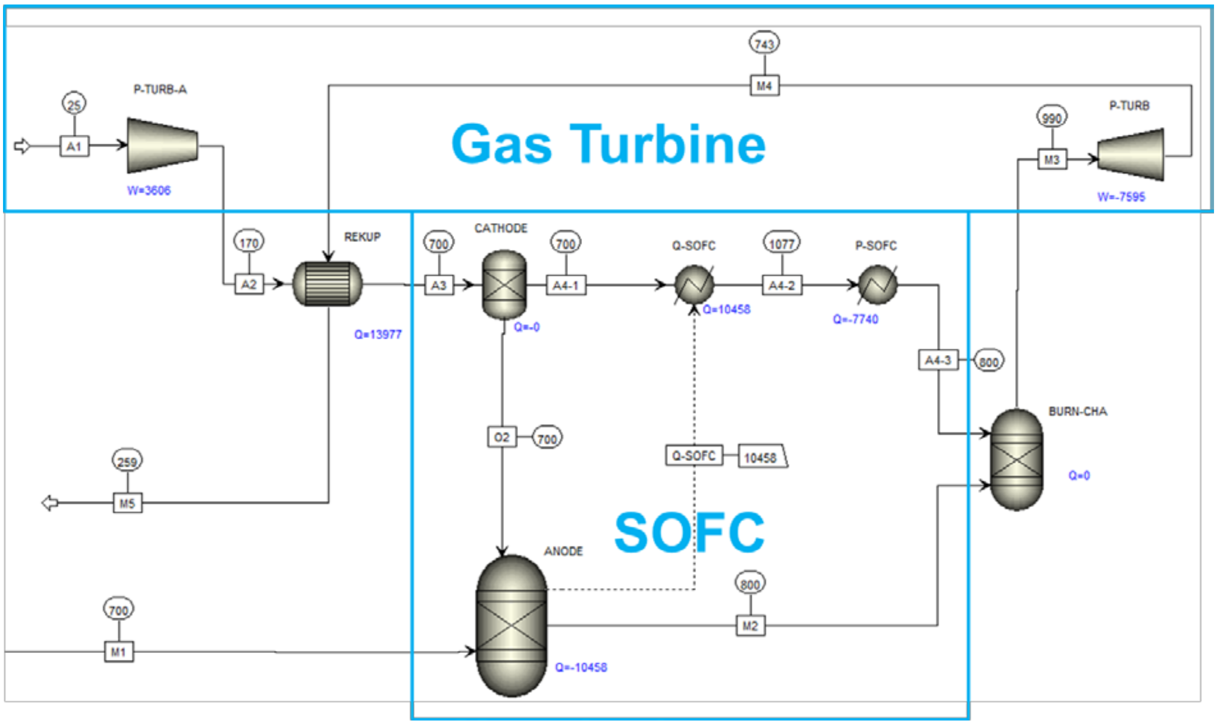

Figure 2: Flowsheet in Aspen Plus for power generation using SOFC and gas turbine

The power generation part of the Aspen Plus model is shown in Figure 2. Preheated air at 700 °C (compare stream A3 in Fig. 2) is fed into the cathode. The required amount of oxygen for the electrochemical reaction in the fuel cell (stream O2) is separated and fed together with the cleaned product gases from fermentation and gasification (compare stream M1) into the anode which is modeled as Gibbs reactor. First all the released heat at the anode-reactor (stream Q-SOFC) is used to heat up the air (stream A4-1). In a second step the generated electrical power in the SOFC is extracted from stream A4-2 in block P-SOFC reaching the actual temperature of the cathode off-gas of 800 °C (stream A4-3). The electrical power is calculated as followed:

$$P_{el,SOFC} = U_f \cdot V \cdot \dot{n}_{M1} \cdot (y_{H2} \cdot y_{CO} \cdot 4\, y_{CH4}) \cdot 2F$$

U_f is the fuel utilization in the SOFC, V the voltage, $\dot{n}_{M1}$ the mole flow at the inlet of the SOFC-anode, y_i the appropriate mole fractions and F the faraday constant. In order to calculate the cell voltage, a one-dimensional simulation tool in Excel is used with respect to local gas concentrations, electrical resistance and temperature along one cell of the SOFC in co-flow configuration. As input from Aspen Plus, the gas concentration, pressure and temperature at the inlet of the anode (stream M1) are required. The tool provides a look-up table for cell voltages, which are dependent on operating pressure, temperature, gas concentration and fuel utilization. The SOFC is standardized to 0.7 V for a typical non-pressurized, reformed gasification gas, which enters the anode of the SOFC at 700 °C and exits at 800 °C. All simulations are based on the same stack size. The anode and cathode off-gas are mixed, burned and used for power generation in the gas turbine.

The simulations in Aspen are based on the following assumptions:

- Peng-Robinson is used as equation of state.

- The tar reformer and burning chamber of the gas turbine are modeled as Gibbs reactors for which chemical equilibrium is assumed.
- The gas turbine and the compressors are modeled as isentropic (isentropic efficiency of gas turbine: 85 % and compressor: 78 %).
- All component-related heat losses are not taken into consideration.
- The entry and exit air temperatures for the SOFC are 700 °C and 800 °C, respectively.
- 50% of the energy content of sewage sludge is converted to biogas with gas composition of 60 vol% CH_4 and 40 vol% CO_2 [37].
- Gasification gas composition (dry): 73 vol% H_2; 11.5 vol% CH_4; 7.5 vol% CO; 6 vol% CO_2; 2 vol% C_2H_6 [15] (875 ppmv $C_{10}H_8$); 33.3 vol% H_2O.
- Fermentation waste is dried from 70 % to 25 % water content at 850 kWh per ton water.

It is further assumed that the heat demand for pre-heating the air for the gasification process regenerator and for the steam generation for the gasifier is covered by the waste heat of the regenerator flue gas [35]. Cold gas efficiency of the gasification process is assumed to be 70 % [36]. Gas cleaning of the gasification gas concerning particles, chlorine and sulfur is assumed to take place at a temperature of 650 °C [34]. Energy losses are not taken into consideration. Tars are reformed at 900 °C [38]. Sensible energy of the reforming product gases is partly used for heating the gas before reforming.

3. Combined Fermentation and Gasification Process

Three main process configurations are investigated to illustrate the potential of combined fermentation and gasification of sewage sludge and the conversion of biogas and gasification gas into electricity. In the first configuration, the conversion of gas takes place exclusively in the SOFC, whereas the second and third configurations rely on a hybrid system consisting of a SOFC and a gas turbine. The third configuration differentiates itself by introducing the use of a pressurized gasifier. In order to illustrate the advantages of the combined processes, configurations with separated processes are also introduced at the end of the chapter.

3.1. Process Configuration with Gas Conversion in the SOFC only

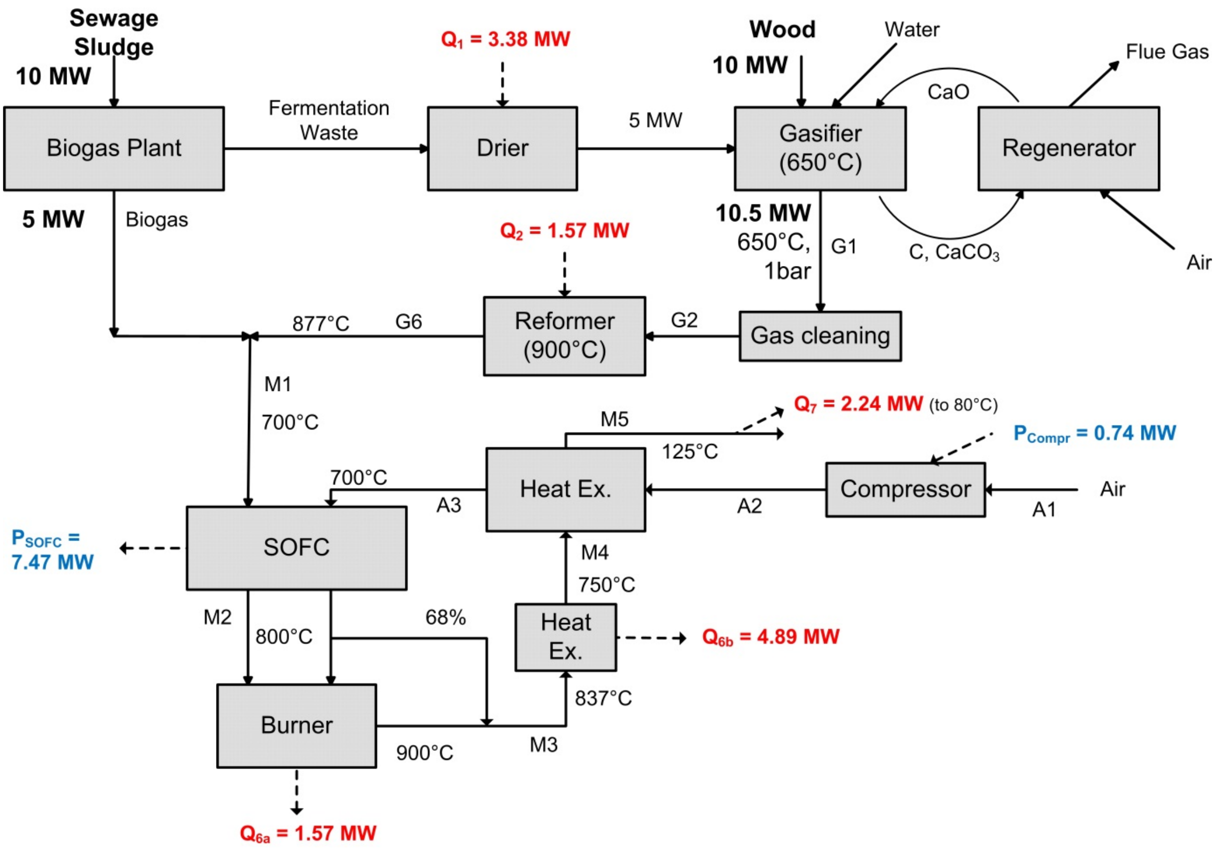

Figure 3: Combination of fermentation and gasification – conversion of biogas and gasification gas in SOFC (Configuration 1) [5]

Figure 3 contains Configuration 1, in which biogas and gasification gas are converted in a SOFC. Sewage sludge with an energy flow of 10 MW is fermented. This energy flow, which is based on the lower heating value, corresponds to the capacity of a sewage treatment plant for a city of about 500,000 inhabitants. The fermentation waste, with a water content of more than 90 %, still contains 50 % of primary energy input. After mechanical dewatering to 70 % humidity, the fermentation waste is dried thermally to 25 % humidity. Therefore, a heat flow rate of 3.38 MW is needed (stream

Q_1). The 5 MW fermentation waste (fermentation waste with an energy flow rate of 5 MW based on the lower heating value) is combined with a 10 MW wood feed and converted in the fluidized bed of the gasifier. Absorption-enhanced reforming provides a gas at 650 °C with 73 vol% H_2 in the dry gas (stream G1). After being cleaned of particles, chlorine and sulfur, the product gas reaches the tar reformer at a temperature of 650 °C (stream G2). In order to maintain the high quality of the gas with high concentrations of H_2, low concentrations of CO_2 and no N_2, an allothermal reforming process is considered. Since tars are present, a reforming temperature of 900°C is required [38], which is also sufficient to reform any other hydrocarbons present (methane, ethane, etc.) as well. As the reforming reaction is endothermic, heat at a high temperature level is required (stream Q_2). Subsequently, the reformed gasification gas is mixed with biogas and the resulting mixture (stream M1) is converted at the anode of the SOFC at a temperature of 700 °C. Methane from the biogas is reformed directly at the anode with steam from the gasification gas and the products CO and H_2 are converted into electricity. A fuel utilization rate of 80 % in the SOFC is assumed which leads to a cell voltage of 0.68 V. Air (stream A3) is required at the cathode of the SOFC in order to provide the oxygen for the electrochemical reaction and to cool the stack. Because of these cooling requirements, an excess of air is supplied to the SOFC ($\lambda = 9.5$).

The SOFC off-gases (stream M2 and parts of the cathode off-gas) are burned in a combustion chamber. Thus energy at a high temperature level is available, which is used for the energy demand of the tar reformer (Q_2) and for pre-heating air for the SOFC. An additional heat flow rate of 4.89 MW at more than 750 °C (stream Q_{6b}) is also available and has a high potential, but remains largely unleveraged in this process configuration, apart from being used for drying the fermentation waste (Q_1) and for district heating. The gas exiting the heat exchanger (stream M5) is cooled to 80 °C in a second step and the heat is also used for district heating.

3.2. Process Configuration with Gas Conversion in a Hybrid System of SOFC and Gas Turbine

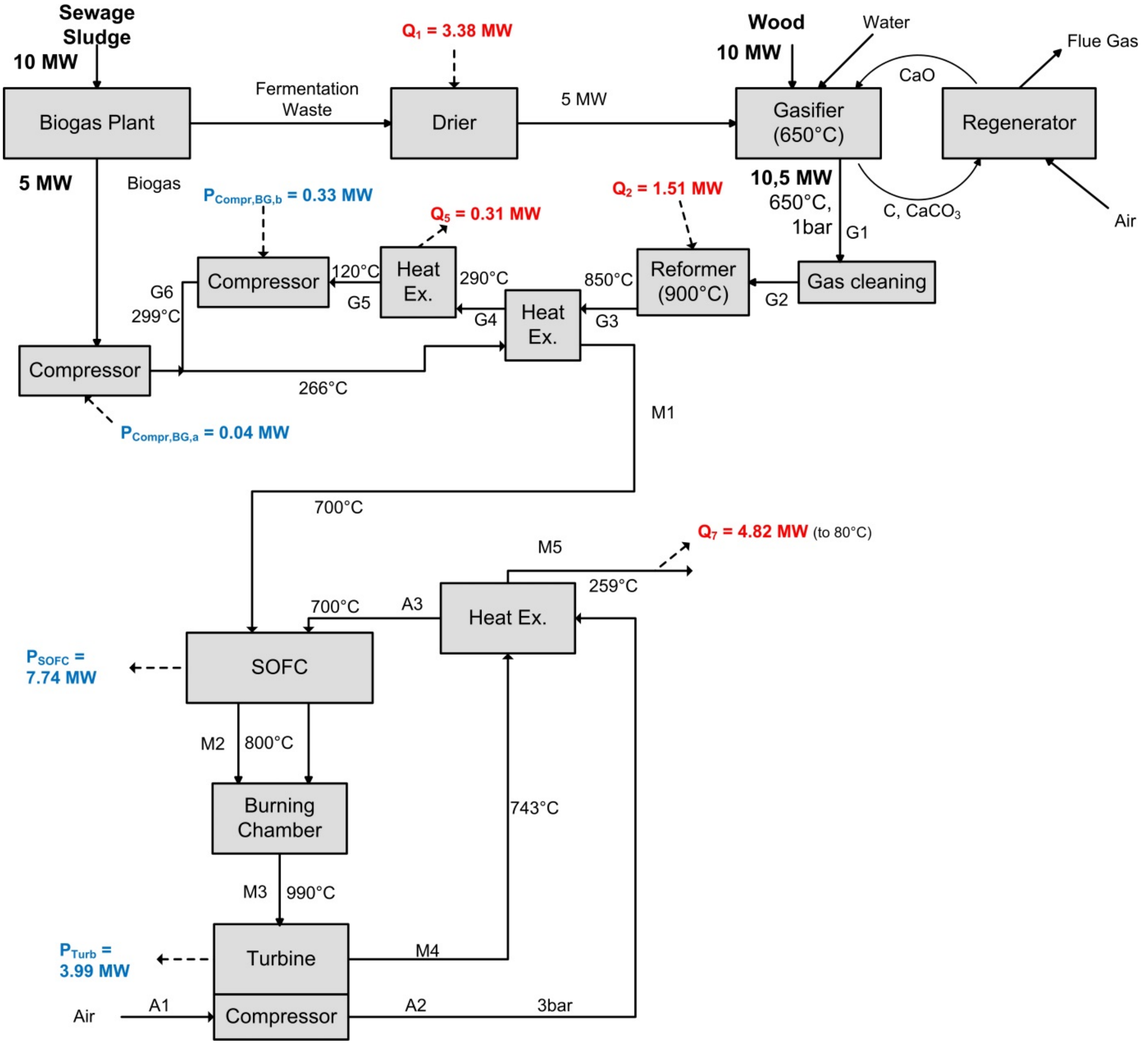

Figure 4: Combination of fermentation and gasification – compression of biogas and gasification gas to 3 bar absolute pressure and combined conversion in a hybrid system of a SOFC and a gas turbine (Configuration 2) [5]

In Configuration 2 the gases are converted to electricity in a hybrid system consisting of a SOFC and a gas turbine (Fig. 4). In order to increase the efficiency of the combined plant, the off-gas of the SOFC is expanded in a gas turbine. This requires a pressurized operation of the SOFC at 3 bar absolute pressure, which also increases the efficiency of the SOFC itself [21]. Fuel utilization in the SOFC is reduced in order to reach a sufficiently high temperature before and especially after the turbine (stream M4) in order to heat the compressed air (stream A2) to 700 °C for the SOFC. The temperature before and after the gas turbine (streams M3 and M4) increases with reduced fuel utilization in the SOFC because less air is required for cooling purposes (stream A3) and because the SOFC off-gas contains more chemical energy, which is converted in the burning chamber. Based on material properties, a temperature of 990 °C is assumed before the gas turbine, resulting in a fuel utilization rate of 67.5 % in the SOFC for Configuration 2. The cell voltage is calculated to 0.835 V. The difference in gas treatment between Configuration 2 and Configuration 1 is that the gasification gas must be cooled for compression. Gasification gas is compressed to 3 bar absolute pressure at 120 °C in order to prevent the steam in the gas (streams G5 and G6) from condensing. The steam is required for the internal reforming of methane from biogas at the anode of the SOFC.

3.3. Process Configuration with Pressurized Gasification and Gas Conversion in a Hybrid System of SOFC and Gas Turbine

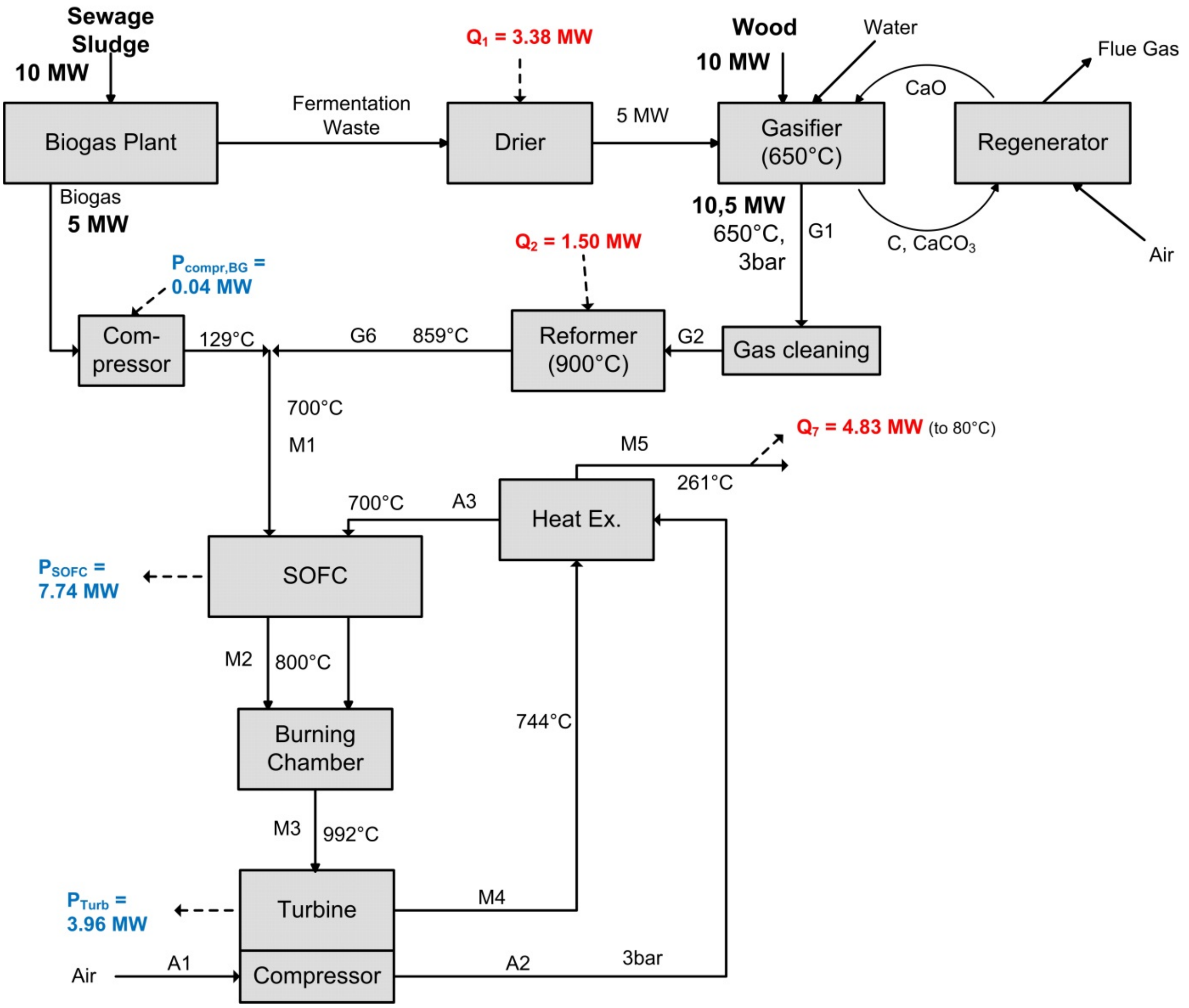

Figure 5: Combination of fermentation and pressurized gasification at 3 bar absolute pressure – conversion of biogas and gasification gas in a hybrid system of a SOFC and a gas turbine (Configuration 3) [5]

In Configuration 3, a pressurized gasifier [39] is implemented (Fig. 5). Gas treatment is simplified, since the gas does not need to be cooled and compressed and the energy required for compression to 3 bar absolute pressure is saved. The following assumptions are made:

- Energy demand for the compression of liquid water before evaporation in the gasifier is negligible.
- Energy demand for pre-heating the air for the regenerator and for vaporizing the water for the gasification process is covered by the regenerator flue gas.
- Energy demand for compressing the air for the regenerator is covered by expansion of the regenerator flue gas.
- Cold gas efficiency, gas composition and gas temperature are the same as in the case of atmospheric gasification.

In reality, the temperature of the gasification process will be higher and the product gas composition will vary at 3 bar absolute pressure. For example, several more hydrocarbons will exist [40]. After mixing the gasification gas with compressed biogas, the mixture can be converted in the SOFC and the gas turbine as described for Configuration 2.

3.4. Overview of Process Configurations

In contrast to Configurations 1, 2 and 3, as described in the previous sections, in Configurations 1a and 2a, the conversion of the dried fermentation waste takes place in a separate process. No heat integration is possible and each gas is converted separately. In Figure 6 an overview of all Configurations is shown. In Configuration 2b the steam in the gasification gas is condensed and the gas compressed at lower temperatures than in Configuration 2.

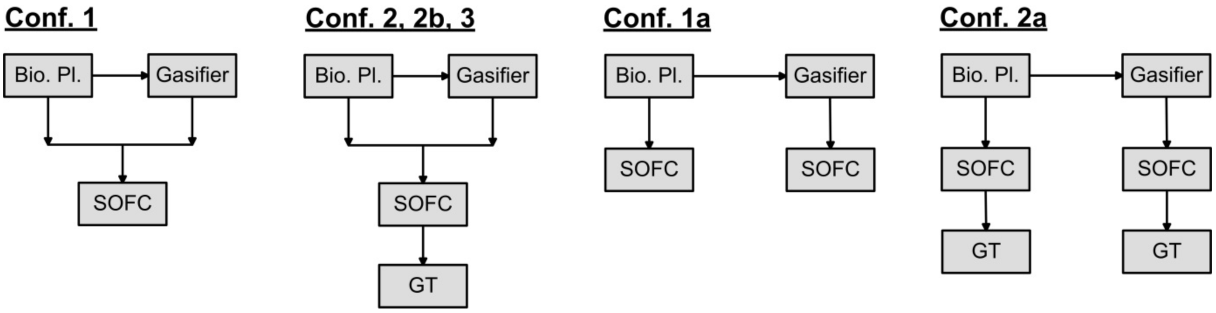

Figure 6: Overview of all configurations: combined-process (Confs. 1, 2, 2b, 3) and separated-process (Confs. 1a, 2a)

Figure 7 shows the fermentation part of Configuration 2a, which consists of the fermentation and conversion of biogas in a hybrid system of a SOFC and a gas turbine. The fermentation waste is dried before being transported to the gasification process. Steam is supplied for internal reforming of methane out of the biogas at the anode of the SOFC and the steam-biogas-mixture is heated to 700 °C (Q3).

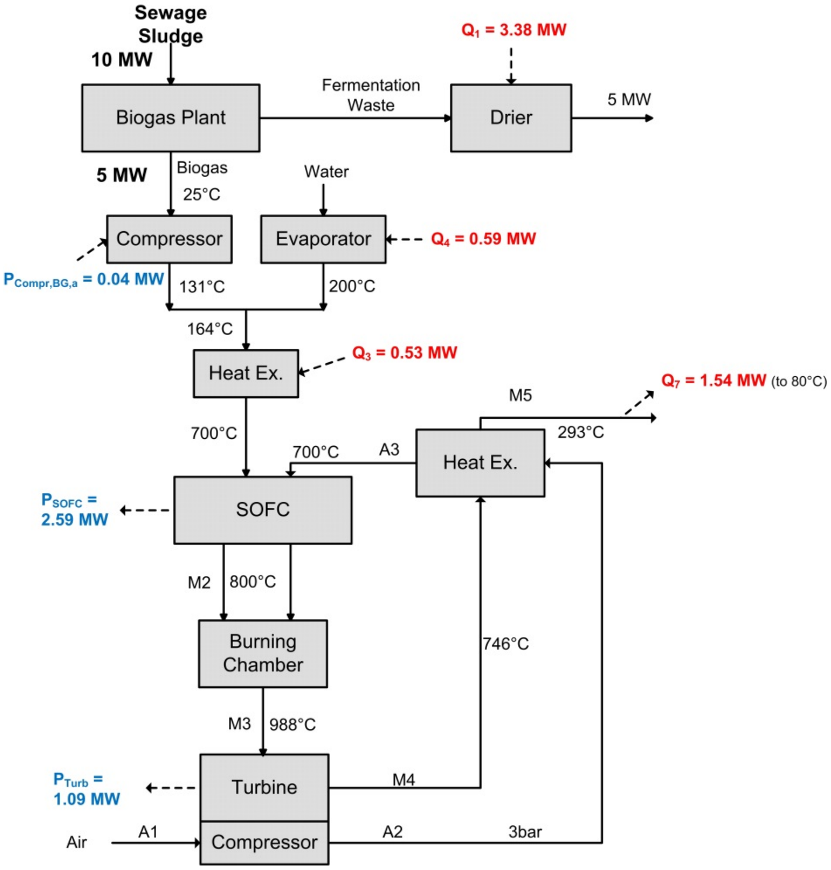

Figure 7: Fermentation of sewage sludge and conversion of biogas in a hybrid system of a SOFC and a gas turbine (left part of Conf. 2a) [5]

The electrical efficiency is defined for all configurations as:

$$\eta_{el} = \frac{P_{SOFC} + P_{Turb} - P_{Compr}}{H_{Sew-Sludge} + H_{Wood} + Q_{external}}$$

Whereas no external heat is required for Configuration 1, an external heat source (Q2) is required for the tar reformer in Configurations 2, 2a, 2b and 3. In the case of Configurations 1a and 2a, external heat is also required for drying the fermentation waste, supplying steam and heating the biogas-steam mixture.

4. Results and Discussion

This chapter comprises two sections. The first section underlines the advantages of combined fermentation and gasification (Configurations 1 and 2) resulting from heat and stream integration compared to two separate processes (Configurations 1a and 2a). In the second part the results for power generation in a hybrid system consisting of a SOFC and a gas turbine are discussed, with special consideration given to the different possibilities of pressurization (Configurations 2, 2b and 3).

4.1. Advantages of Combined Fermentation and Gasification

An advantage of combined fermentation and gasification is that waste heat from the gasification process can be used to dry the fermentation waste.

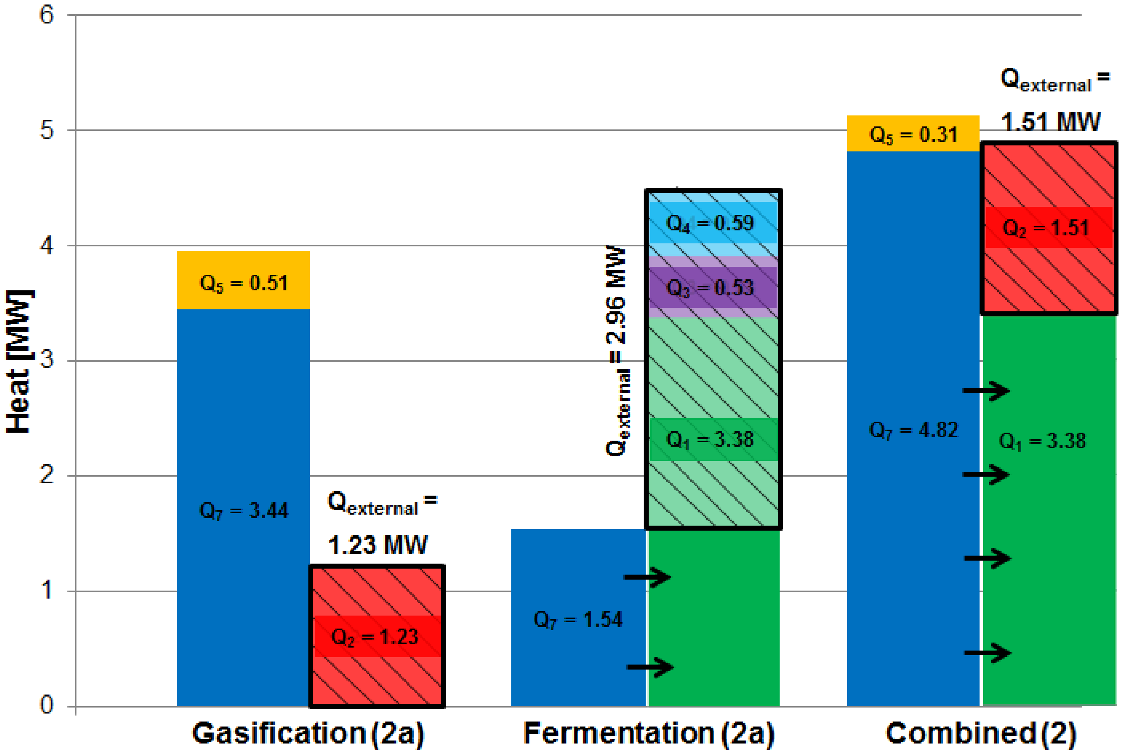

Figure 8: Waste heat (Q5, Q7 at the left) and heat demand (Q1, Q2, Q3, Q4 at the right) for Configuration 2: With separated processes for gasification and fermentation (Conf. 2a) and the combined process (Conf. 2)

Figure 8 illustrates the heat streams for Configuration 2, as well as for Configuration 2a, which consists of two separate processes for fermentation and gasification. For the combined process, heat streams Q5 and Q7 are sufficient for covering the heat demand of drying the fermentation waste (Q1). Operating with separate processes produces significant waste heat during gasification, which cannot be used in concurrent or subsequent processes. The heat required for drying the fermentation waste in the fermentation process cannot be covered completely, requiring the addition of supplementary external heat. This extra heat has to be supplied by a burner, which may be fired with fossil fuels, for example. In all cases, extra heat for the tar reformer in the gasification process (Q2) cannot be provided internally, because the heat requirements exceed 900 °C.

Another advantage besides heat integration is stream integration. The approximately 19 % steam in the 4800 m_N^3/h stream of reformed gasification gas (stream G6 in Confs. 1, 2 and 3) is sufficient to reform the 60 % methane contained in the 840 m_N^3/h biogas stream, which happens at the anode of the SOFC. Containing 9 % methane and 16 % H_2O, there is sufficient steam in the mixed gas to inhibit thermodynamic carbon formation at the anode of the SOFC. If biogas and gasification gas are converted together in the SOFC, neither an evaporator providing steam for the internal reforming of methane, nor a heat exchanger for heating the biogas-steam-mixture is required. No supplementary heat (Q3 and Q4 of the separate fermentation process in Figure 7) is required, which also increases overall electrical efficiency. Comparing Configuration 2 with Configuration 2a demonstrates the effect of heat and stream integration. Additional heat flows of 0.59 MW for vaporizing (Q_4 in Figure 7) and 0.53 MW for heating the biogas-steam-mixture (Q_3) are required. Requiring external heat for Q_3, Q_4 and parts of Q_1 (for the drier) causes the overall electrical efficiency to be reduced from 52.8 % (Conf. 2) to 46.4 % (Conf.

2a). In the case of exclusive use of a SOFC, as in Configuration 1, the overall electrical efficiency is reduced from 33.7 % (Conf. 1) to 29.7 % (Conf. 1a).

Configuration	**1**		**2**	
Processes	**separated (a)**	**combined**	**separated (a)**	**combined**
η_{el} [%]	**29.7**	**33.7**	**46.4**	**52.8**

Table 1: Comparison of electrical efficiencies with separated and combined processes of fermentation and gasification (for Confs. 1 and 2)

4.2. Pressurized Operation of SOFC and Gas Turbine and Pressurization of Gasification Gas

With the advantages of stream and heat integration shown in section 4.1, an electrical efficiency of over 30 % (33.7 % for Conf. 1) is achieved. In the case of exclusive conversion in a SOFC, however, a significant amount of energy is inefficiently used or lost as waste heat. As described in section 3.1, not all of the chemical energy in the mixed gas (stream M1 in Fig. 3) can be converted in the SOFC. Due to the fuel utilization rate of 80 %, the high amount of air used for cooling ($\lambda = 9.5$) and the conversion of the remaining chemical energy in a burning chamber, there is a surplus of energy available in the form of heat at over 900 °C. Even after covering the heat requirements for reforming the gasification gas (stream Q2), an excess of 4.89 MW is available at over 800 °C, which is not used efficiently by district heating in Configuration 1. Since this potential is used more efficiently by a gas turbine in Configurations 2 and 3, the electrical efficiency increases from 33.7 % (Conf. 1) to 52.8 % (Conf. 2). In order to maintain a sufficiently high temperature at the turbine off-gas to heat the air to 700 °C for the SOFC, fuel utilization in the SOFC has to be reduced to 67.5 % in Configuration 2. Thus, less air is required to cool the SOFC ($\lambda = 5.0$). At the given conditions – pressure ratio of 3 in the turbine and low cooling effect of internal reforming of only 9 % methane in the gas – the gas turbine contributes approximately 34 % to electrical output. The more methane in the gas, the bigger the cooling effect in the SOFC, the less air required and the more fuel can be converted in the SOFC. Thus, less air in the compression and expansion part of the turbine leads to a smaller contribution of the turbine to electrical output.

If converted in a turbine, the gas must be compressed to 3 bar absolute pressure before the SOFC and the SOFC itself must work under pressure. Therefore, different routes for compressing the gas for conversion in a hybrid system of a SOFC and a gas turbine are discussed. Biogas exists at low temperatures and can be compressed easily. Gasification gas exists at high temperatures and has to be cooled for compression. Thus, there are two options to compress the gas, Configuration 2 and 2b, compared in Table 2.

Configuration	**2**	**2b**	**3**
Evaporator required	**no**	**yes**	**no**
Gas cooling required	**yes**	**yes**	**no**
$T_{compr,g}$ [°C]	120	53	-
P_{compr} [MW]	0.37	0.28	0.04
P_{turb} [MW]	3.99	3.98	3.96
P_{SOFC} [MW]	7.74	7.74	7.74
$P_{overall}$ [MW]	11.73	11.72	11.70
$Q_{biomass}$ [MW]	20	20	20
$Q_{extern\text{-}required}$ [MW]	1.51	1.51	1.50
η_{el} [%]	**52.8**	**53.2**	**54.2**
$Q_{district\text{-}heating}$ [MW]	1.75	1.25	1.45

Table 2: Comparison of Configurations 2, 2b and 3 with different options for pressurizing the gasification gas to 3 bar absolute pressure

T_{Compr} in Table 2 is the temperature of the gasification gas before compression (compare stream G5 in Fig. 4 for Configuration 2). P_{Compr} is the electrical power required for compression of biogas and gasification gas (compare $P_{Compr,BG,a}$ and $P_{Compr,BG,b}$ in Fig. 4). $Q_{extern-required}$ is the required heat input which cannot be covered by internal heat integration (compare Q2 in Fig. 4 and 5). $Q_{district-heating}$ is the waste heat down to 80 °C which can be used for district heating (compare in Fig. 4 or Fig. 8 for Configuration 2: Q5 + Q7 – Q1).

In the case of Configuration 2b, the gas is cooled to 25 °C before being reheated to 60 °C, mixed with biogas and compressed to 3 bar absolute pressure at a temperature of 53 °C. Therefore, most of the steam is condensed and the electrical energy demand for compression is small, due to the small volume flow (see P_{compr} in Table 2). An evaporator is required, however, for providing steam for the internal reforming of methane in the SOFC, as are heat exchangers for cooling gasification gas and heating biogas, steam and gasification gas.

In Configuration 2, the gas is cooled to 120 °C (see stream G5 in Fig. 4) before compression. Thus, due to the higher steam content in the gas and the higher temperature, more electrical energy is required for compression. No evaporator is required, though, resulting in a reduction in the complexity of the whole plant and an increase in the amount of waste heat, which can be used for district heating (see Table 2).

Using a pressurized gasifier as a third option allows the energy required for compressing the gasification gas to be saved. Configuration 3 offers an increase in electrical efficiency from 52.8 % (Conf. 2) to 54.2 %. After hot gas cleaning, pressurized gasification gas is mixed with compressed biogas and converted in a SOFC and a gas turbine at 3 bar absolute pressure. No evaporator and no heat exchangers are required for gas treatment. Configuration 3 is identified as the most promising configuration concerning the electrical efficiency of converting sewage sludge (and wood residue).

5. Conclusion

It was illustrated that the combination of fermentation and gasification coupled with the combined product gas conversion in a hybrid system consisting of a SOFC and a gas turbine enables an highly energetic utilization of sewage sludge. With this innovative concept, sewage sludge is not only disposed of but can also partially replace fossil fuels. Additionally, with wood residue being converted in the gasifier, fossil fuel use is further reduced. In each of the three investigated configurations with combined fermentation and gasification, the waste heat produced by the combined plant is sufficient for drying the fermentation waste. If the fermentation process and the gasifier are considered separately, however, the waste heat from the fermentation part is not sufficient for drying purposes, requiring an external heat source. An hybrid SOFC-gas turbine system, which is investigated at 3 bar absolute pressure in this work, enables high electrical efficiencies. Since gasification gas contains no methane after tar reforming and there is only 9 % of methane in the gas after mixing it with biogas, there is only a small heat sink resulting from internal reforming at the SOFC anode and, as a consequence, a high amount of air is required for cooling the SOFC. Therefore, the SOFC off-gas contains significant amounts of sensible and chemical energy, which are optimal for conversion in a gas turbine. Approximately 34 % of the electrical output is produced by the gas turbine. With the combined conversion of biogas and gasification gas in the SOFC, a heater for the biogas and an evaporator for providing steam for internal reforming of the biogas at the SOFC anode are not needed, because the gasification gas contains sufficient steam. In the case of atmospheric gasification and gas conversion in a hybrid system, this advantage of saving an evaporator however leads to the disadvantage that more electrical energy is required for the hot compression. Overall, a process-wide electrical efficiency of 53 % is calculated, excluding any heat losses. Pressurizing the gasifier to 3 bara maximizes the overall electrical efficiency to 54 % and reduces the complexity of the gas treatment process.

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