Concept for the ideal 16MWth biomass gasification system to feed a synthetic natural gas production process

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Abstract: Biological, synthetic natural gas (SNG) prepared to fulfill the necessary grid feeding guidelines has the potential to keep up with the rising energy demands. Common production technologies for the extraction of natural gas from fossil sources cause relevant carbon dioxide (CO_2) emissions. Biological, synthetic natural gas from renewable energy sources is discussed as an alternative option to replace the traditional extraction process and can therefore be part of a low carbon energy system. This paper describes an optimized process for a biomass gasification system to feed a synthetic natural gas production process. The described investigations include the state of knowledge and the state of the art technology of large scale plants, simulation results from the software IPSEpro, economic analysis, and suggestions for an optimized equipment. The economic analysis shows promising results as well as measures to enable positive revenue surpluses for the optimized novel process concept. Furthermore, a guideline for an overall economic operation of an $16MW_{th}$ biomass gasification system to feed a synthetic natural gas production process can be derived from the economic analysis. The max. investment costs may not exceed 36 mio. Euros while the operational costs, for the optimized process concept, should be reduced by 50%. The highest share of the operational costs is represented by the fuel costs and so the most challenging task will be, to find an appropriate low-cost or negative-cost opportunity fuel available the whole year with low compositional fluctuations. Facing the challenges of climate change in general respectively on a global level the implementation of the Clean Energy for all Europeans Package on a more regional level the optimization of developed technologies needs to gain more effort.

Keywords: biomass - gasification - synthetic natural gas - SNG – process concept

1. Introduction

The worldwide coverage of electricity, heat and fuels demands further research on alternative feedstocks and technologies to enable a sustainable production in the future [1]. Thus, the thermo - chemical conversion of biogenic fuels with the dual fluid gasification technology provides a unique method for the production of eco - friendly and sustainable energy supply [2]. Furthermore, the dual fluid gasification technology has the potential to make another step forward to meet the **European political agenda** for circular economy and renewable energy strategies and therefore, can be named as a promising technology to support the set energy and bioeconomy strategies [3]. Traditional dual fluid gasification enables in comparison with other gasification technologies a favorable product gas composition and so supports various utilization possibilities like hydrogen-rich gas, Fischer-Tropsch fuel, mixed alcohols and synthetic natural gas [4]. The methanation process enables a further improvement of the gas composition and leads to a high share of methane in the product gas stream. The methanation process itself demands very high product gas qualities and less catalyst harming impurities [5].

For the realization of a low carbon energy system, the development of new energy carriers is needed because most energy carriers today are based upon fossil energy sources. For this reason, synthetic natural gas produced from renewable energy sources is discussed as an alternative to fossil energy carriers [6]. The production of synthetic natural gas by the usage of the dual fluid gasification technology, has the potential to bind biogenic renewable carbon (C). Synthetic natural gas can be used as an energy carrier, for energy storage applications, to feed the gas grids or as fuel for combustion engines.

Previous experimental setups, test works, demonstration plants and large scale plants for the production of synthetic natural gas had to deal with certain problems. The desired fuel flexibility combined with the high product gas quality demand, especially forced the attention on the product gas cleaning and upgrading technology. The goal is to provide a product gas suitable to feed a synthetic natural gas production process. Therefore, the following important question occurs:

What does the ideal industrial scale biomass gasification system to feed a synthetic natural gas production process look like?

The following paper contains a novel process concept based on important technical, commercial and legal aspects. As a part of this precise evaluation the paper discusses:

- the state of knowledge and the state of the art technology of large-scale plants,
- simulation results from the software IPSEpro investigating the energy and mass balances for the novel process concept,
- equipment improvements to further enhance the performance of traditional used equipment,
- an economic analysis of the dual fluid gasification with a subsequent methanation.

2. Concept and methodology

The following investigations describe the evaluation of a biomass gasification concept to feed a synthetic natural gas production process. Therefore, the most important technical, commercial and legal aspects were taken in account and harmonized. For this purpose, a comprehensive literature research was made first. This research contains the most important information of the gasification technology as well as the state of knowledge and the state of the art technology of large - scale plants. The investigations focus in particular on increasing fuel flexibility and the associated increased need for gas cleaning and preparation utilities.

For the calculation of the gasification plant parameters, the simulation software IPSEpro has been used. IPSEpro has proven its reliability in many process design simulations in the past. IPSEpro enables an efficient and quick calculation of mass and energy balances for a modeled process design.

The applied process design to feed a synthetic natural gas production process is basing on reported experiences with biomass gasification in Güssing, Oberwart, Senden and Gothenburg. The biomass gasification power plant Güssing represents the first industrial scale power plant using the dual fluidized gasification technology. In 2008 the construction of the Bio – SNG process and development unit (PDU) was finished. The first production of synthetic natural gas was demonstrated [7]. A sufficient gas cleaning and preparation strategy was developed and applied. The three main units were a two stages product gas scrubber based on methyl ester (ME), an activated char coal guard and a zinc oxide (ZnO) bed [5]. The construction of the biomass gasification power plant Oberwart was encouraged by promising results from the demonstration power plant Güssing. In Oberwart a novel cooling concept for the exhaust gas route was developed and demonstrated. Furthermore, some reasonable heat exchanger construction design changes were developed to deal with the high loads of fines [8]. The biomass gasification power plant in Senden is mentioned due to its high availability level. Senden uses new biomass fuel mixtures but nevertheless high availability levels are reached, and even higher availability levels are predicted due to modifications. Therefore, the process concept for the Senden plant represents a favorable strategy to deal with the desire for more fuel flexibility. Especially the fuel preparation and supply equipment represent a sophisticated technology [9]. The construction of the bio synthetic natural gas plant Gothenburg in Sweden was encouraged by the promising results and findings from the bio synthetic natural gas process and development unit (PDU) in Güssing. The Bio - SNG plant Gothenburg represents the first of its kind plant for industrial scale production of advanced biofuels from woody biomass, whereby methane was identified as the desired end product due to local conditions. In **Table 1** and the main operational data from Gothenburg can be seen. The operational results show that 20 MW of synthetic natural gas with high purity can be produced from 32 MW of biomass (based on lower heating value) together with additional electricity and operational resources like lime, scrubber solvent, fresh bed material and natural gas [10].

Table 1: Gothenburg input values [10]

Plant input		
Thermal fuel power	32	MW
Biomass fuel (WP)	6250	kg_{db}/h
Biomass water content	50	wt.-%
Electricity consumption	2	MW
Scrubber solvent	70	kg/h
Nitrogen purge gas	4	Nm^3/h
Limestone	110	kg/h
Fresh bed material	65	kg/h
Active carbon	2.7	kg/h
Natural gas	100	Nm^3/h

Table 2: Gothenburg output values [10]

Plant output		
Product gas to methanation	24.5	MW
Synthetic natural gas	20	MW
	1980	Nm^3/h
District heating gasification	2.5	MW
District heating methanation	1.3	MW

Furthermore, an equipment specification by target costing combined with an economic analysis was used to evaluate the developed novel gasification concept to feed a synthetic natural gas production process. As economic analysis tool the net present value calculation method was used. The net present value calculation considers a time span of 20 years and breaks the investment decisions down to a payment in the presence. The target costing results were used as input values for the optimized option.

3. Results and discussion

Figure 1 shows the IPSEpro simulation sheet for the investigated biomass power plant to feed a synthetic natural gas production process. The IPSEpro simulation sheet was developed out of existing process simulation sheets which origin from the winddiesel_klienIF project and related simulation tasks [11]. These simulation sheets have been continually further developed by various past projects and experiments on this topic and now contain very important and valuable empirical data for the gasification technology process simulation. Thus, the steady growing IPSEpro simulation sheet itself contains a high-quality source for set values. The following main changes compared to the conventional process routes, in terms of the process interconnections, have been made:

- Saturated steam from the methanation process enters the gasification process and is used to heat up the drying air and powers the district heating system.
- The gasification process also provides steam at an elevated pressure level for the methanation process. Therefore, the power demand of the steam generator is high compared to other simulation results from gasification process units. The steam output to the methanation process is realized directly after the steam generator. Subsequently, the raised pressure is relaxed in an expansion valve to the desired steam super heater input pressure.
- A warm water pressure circuit is intended to power the vaporizer and steam generator by using excess energy from the product gas route and the exhaust gas route. In order to prevent tar condensation in the product gas route as well as vaporization in the warm water circuit itself a pressure of 36 bara is used. These conditions require a narrow temperature window between 200 to 244°C and lead to a correspondingly high circulation flow.

Table 3 shows the used input values for the IPSEpro simulation. The foreseen biogenic fuel includes increased levels of sulfur (S), chlorine (Cl) and nitrogen (N) which leads to an increased formation of hydrogen sulfide (H_2S), hydrochloric acid (HCl) and ammonia (NH_3). This measure is intended to represent the use of low-cost or negative-cost opportunity fuels.

Table 3: IPSEpro simulation input values

Plant input		
Thermal fuel power	16	MW
Biogenic fuel	3250	kg_{db}/h
Initial water content	42	wt.-%
Water content post dryer	20	wt.-%
Scrubber solvent	45	kg/h
Limestone	17.5	kg/h
Fresh bed material	50	kg/h

Table 4 shows the output values for the IPSEpro simulation.

Table 4: IPSEpro simulation output values

Plant output		
Product gas to methanation	11.2	MW
	3265	Nm^3/h
Initial water content	42	wt.-%
District heating gasification	1.1	MW

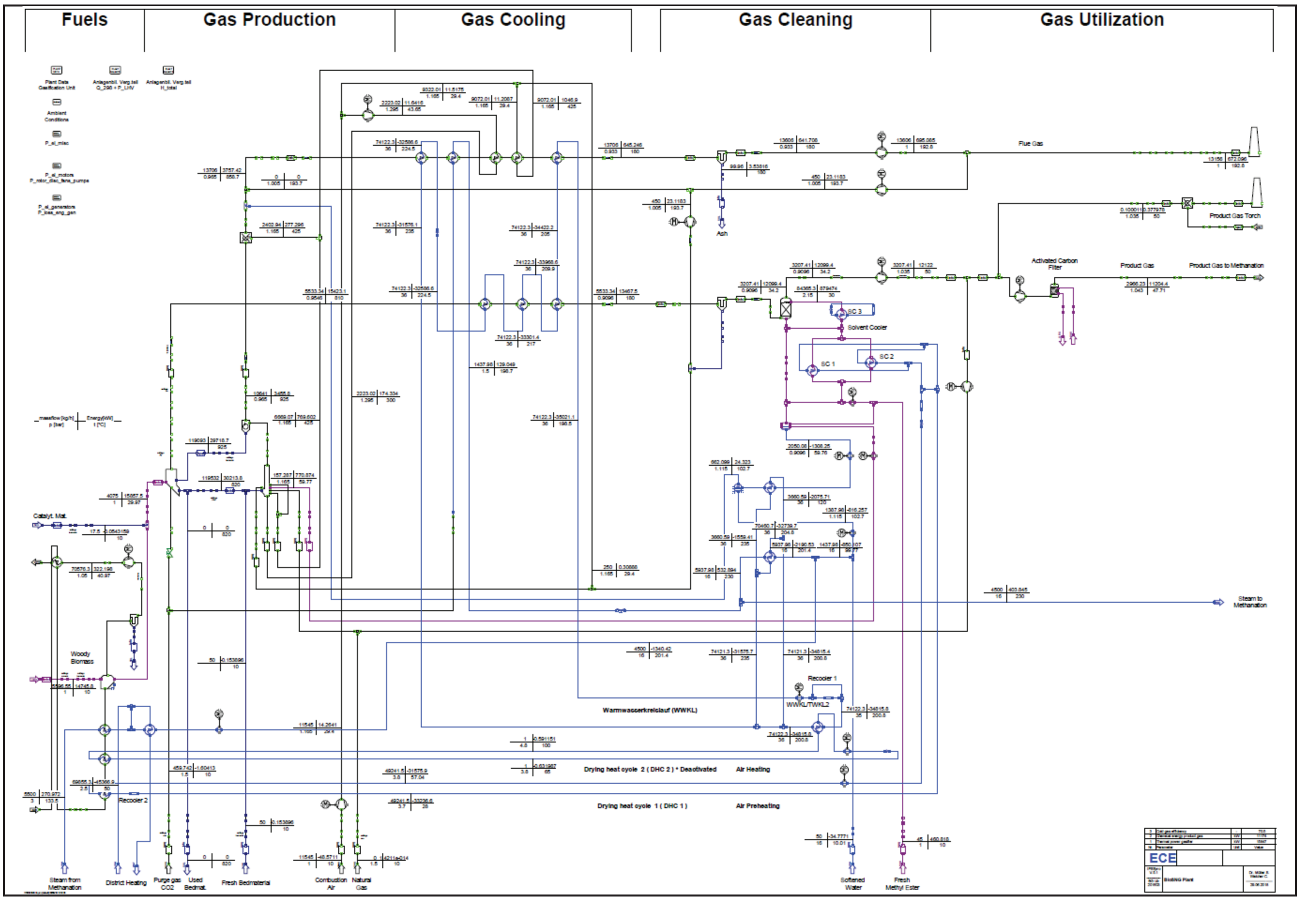

Figure 1: Flow sheet gasification unit to feed the methanation process in IPSEpro

Table 5 shows IPSEpro simulation results across the product gas route including main parameters. The SNG values are derived from the process and development unit (PDU) in Güssing [5] and the SNG output amount origins from the experimental data of Gothenburg [10]. It can be seen that 10 MW of synthetic natural gas can be produced from 16 MW of biomass which indicates an efficiency of approx. $\eta = 64\%$.

Table 5: Product gas route data for the 16MW$_{th}$ biomass gasification system

16MW$_{th}$ gasification unit - product gas route						
	Gasifier out	Filter out	Scrubber out	A-Carb out	SNG	Unit
Chemical energy	12083	12083	12083	11186	10000	kW
Volume flow	6174	6174	3526	3265	990	Nm³/h
Water content (H_2O)	46.3	46.3	5.9	5.9	0	vol%
Hydrogen (H_2)	38.6	38.6	38.6	38.6	0.78	vol%$_{db}$
Carbon monoxide (CO)	24.0	24.0	24.0	24.0	0.13	vol%$_{db}$
Carbon dioxide (CO_2)	23.3	23.3	23.3	23.3	0.03	vol%$_{db}$
Methane (CH_4)	10.0	10.0	10.0	10.0	94.4	vol%$_{db}$
Ethene (C_2H_4)	2.5	2.5	2.5	2.5	0	vol%$_{db}$
Hydrogen sulfide (H_2S)	0.05	0.05	0.05	0.0001	0	vol%$_{db}$
Hydrochloric acid (HCl)	0.01	0.01	0.01	0.001	0	vol%$_{db}$
Ammonia (NH_3)	0.3	0.3	0.3	0.0001	0	vol%$_{db}$
Tar	5.0	4.5	0.1	0.1	0	g/Nm³

Figure 2 shows the basic flow sheet for the desired process concept to feed a synthetic natural gas production process. The green area marks the biogenic fuel supply to the gasifier. In order to deal with the desired fuel flexibility an appropriate fuel storage, drying, discharge and conveying concept needs to be implemented. As already mentioned, low-cost or negative-cost opportunity fuels lead to the formation of undesired components in the gasifier. Therefore, the product gas route in blue needs an improved product gas cleaning and preparation strategy. The flue gas route in red has to deal with the mostly increased dust contents of cheaper fuels. The overall target is to produce high quality product gas which has a sufficient H_2 to CO ratio and not contain any catalyst harming substances to feed the subsequent methanation process.

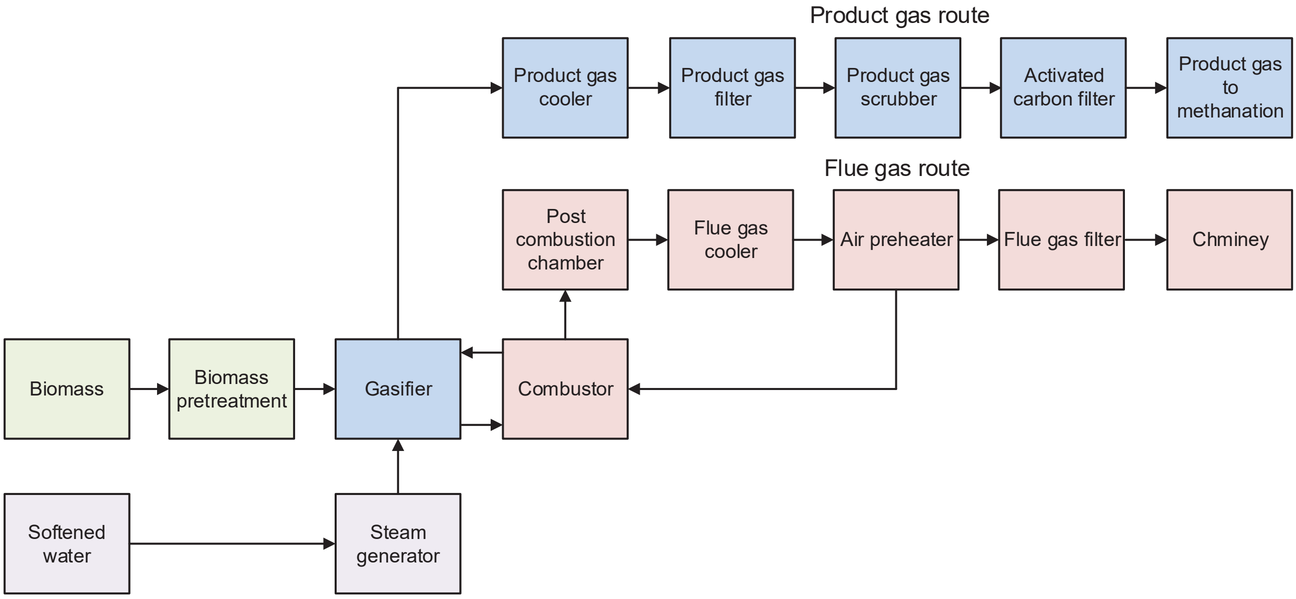

Figure 2: Basic flow sheet

The economic analysis is based on the development strategy, the target costing goals, the mass and energy balances and evaluated cost rates. The development strategy for the novel process concept, marked as "optimized", contains ambitious goals. The total investment costs, for the combined gasification unit and methanation unit are reduced to 15 mio. Euros while the fuel costs, maintenance costs, insurance costs, labor costs and operation supply costs were decreased by 50%. The ash disposal costs were increased by 25% to consider the usage of low-cost or negative-cost opportunity fuels. These measures were derived out of the target costing goals, discussed in internal meetings with the TU Wien. **Table 6** shows the net present value calculation for the economic analysis. A reference period of 20 years has been set and a cumulative present value factor of 10 was used. Six options were taken in account for the economic evaluation:

- Option 0: In this case the purchase of natural gas was considered.
- Option 1: The standard SNG powerplant was considered.
- Option 2: The optimized SNG process concept was considered.
- Option 3: The max. investment costs for the optimized concept and 50% fuel costs were calculated.

- Option 4: The max. investment costs for the optimized concept and 67% fuel costs were calculated.
- Option 5: The max. investment costs for the optimized concept and 84% fuel costs were calculated.
- Option 6: The max. investment costs for the optimized concept and 100% fuel costs were calculated.

As can be seen in **Table 6** option 1 cannot compete with option 0. Option 2 has a significantly better result than option 1 and reaches a positive net present value. The reason for this is the novel process concept with the determined improvement ambitions out of the development strategy and the target costing goals.
For Option 3, 4, 5 and 6 the investment costs were raised at different fuel cost levels until the result was equal to Option 0. Thereby the maximum investment costs for the optimized process concept and 50% fuel costs were calculated with 36 mio. Euros. Increased fuel costs decrease the max. possible invest. costs. Option 3 serves as guideline for an overall economic operation of a gasification unit in combination with a subsequent methanation process unit. Maximum investment costs up to 36 mio. Euros and 50% reduction for the fuel costs, maintenance costs, labor costs and operation supply costs can be derived. The highest share from the reduction of the operational costs is covered by the fuel costs. Therefore, in addition to achieve the given investment costs, the most important task will be to achieve the desired fuel flexibility by the use of low-cost or negative-cost opportunity fuels. It is important to find a biogenic fuel which is available over the whole year and is not subject to high costs and compositional fluctuations. In addition, mixtures of traditional fuels and cheaper fuels could also be considered.

Table 6: Economic analysis

Economic analysis								
		Natural gas	SNG	SNG	SNG	SNG	SNG	SNG
Parameter	Unit	Option 0	Option 1	Option 2	Option 3	Option 4	Option 5	Option 6
			standard	optimized	max. invest. 50% fuel costs	max. invest. 67% fuel costs	max. invest. 84% fuel costs	max. invest. 100% fuel costs
Boundaries								
Natural gas demand	MWh/a	77 770						
Wood chips demand	MWh/a		112 000	112 000	112 000	112 000	112 000	112 000
Investment costs incl. Interests	€	0	37 500 000	15 000 000	35 990 970	33 736 233	31 481 496	29 359 391
Expenses								
Fuel costs (Natural gas)	€/a	1 944 250						
Fuel costs (Woodchips or alternatives)	€/a		2 520 000	1 260 000	1 260 000	1 688 400	2 116 800	2 520 000
Sum fuel costs	€/a	1 944 250	2 520 000	1 260 000	1 260 000	1 688 400	2 116 800	2 520 000
Maintenance, insurance, admin., tax	€/a		3 375 000	1 350 000	3 239 187	3 036 261	2 833 335	2 642 345
Labor costs	€/a		490 000	245 000	245 000	245 000	245 000	245 000
Operating supplies	€/a		1 793 327	896 663	896 663	896 663	896 663	896 663
Ash disposal costs	€/a		93 870	117 338	117 338	117 338	117 338	117 338
Sum Operation & Maintenance costs	€/a		5 752 197	2 609 001	4 498 188	4 295 262	4 092 335	3 901 346
Earnings								
District heating	€/a		343 035	343 035	343 035	343 035	343 035	343 035
SNG earnings	€/a		7 070 000	7 070 000	7 070 000	7 070 000	7 070 000	7 070 000
Costs								
Sum (Expenses - Earnings)	€/a	1 944 250	859 162	- 3 544 034	- 1 654 847	- 1 429 373	- 1 203 900	- 991 689
Net present value calculation								
Cumulative present value factor	-	10	10	10	10	10	10	10
Additional investment costs	€	0	37 500 000	15 000 000	35 990 970	33 736 233	31 481 496	29 359 391
Operating expenses savings	€/a	0	1 085 089	5 488 284	3 599 097	3 373 623	3 148 150	2 935 939
Net present value	€	0	-26 649 115	39 882 843	0	0	0	0

4. Conclusion and Outlook

The present work was carried out to investigate the ideal concept for a 16 MW_{th} biomass gasification system to feed a synthetic natural gas production process. Therefore, the most important technical, commercial and legal aspects were taken in account and harmonized. For this purpose, a comprehensive literature research was made first. This research contains the most important information of the gasification technology as well as the state of knowledge and the state of the art technology of large - scale plants. This resulted in the novel process concept. The presented novel process concept provides a good basis for the development of future large-scale biomass power plants to feed a synthetic natural gas production process. Furthermore, the desired fuel flexibility was also investigated and included in the conceptual design. The new concept serves as a further achievement in the long development process chain of the dual fluid gasification technology and may can provide another performance enhancement towards to an overall economic operation. The economic analysis shows that positive net present values can be reached by the novel process concept and that positive revenue surpluses can also be expected. It should be noted, however, that this analysis is based on an ambitious development strategy and target goals and the used expenses and investment costs should be seen as a guideline to achieve an overall economic performance for the dual fluid gasification technology to feed a subsequent synthetic natural gas production process. In particular the total investment costs for a 16MW_{th} biomass gasification system and a subsequent methanation unit to feed a synthetic natural gas production process, may not exceed 36 mio. Euros while the operational costs should be reduced by 50%. The highest share of the operational costs is represented by the fuel costs and so the most challenging task will be, to find an appropriate low-cost or negative-cost opportunity fuel available the whole year with low compositional fluctuations.

Nevertheless, the thermo-chemical conversion of biogenic fuels still provides a unique method to produce eco-friendly and sustainable energy supply and therefore the technology should be further pushed forward, especially in times of climate change and rising energy demands. Future projects on this topic should further focus on low-cost or negative-cost opportunity fuels to highly valuable synthesis products via gasification. At this point the recently started project ReGas4Industry may be mentioned due to its current research topics in the field of opportunity fuels to highly valuable synthesis products [12]. Furthermore, the development of modern software solutions which can transfer the desired project parameters directly into a finished process conception should be pushed too. Especially the further political strategies, as mentioned the European bioeconomy strategy, offers the opportunity to bring together not only a CO_2 reduced energy source but also a waste treatment facility and a fuel provider for the needed logistics. Indeed, a systemic and more holistic approach is needed to find solutions also for the undoubtable still present economic challenges of this technology.

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