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VESTA Methanation Applications for Small Scale, Multipurpose, Green SNG Production

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The renewable Green Substitute Natural Gas (SNG) production is one of the most flexible approaches to decarbonise end demand such as residential heating and also transportation systems by using compressed SNG. SNG, produced from Biogas, Power to Gas, and Biomass gasification, is a clean and low carbon alternative to conventional natural gas that can be transported and distributed using the existing grid infrastructure.
VESTA catalytic methanation developed by Foster Wheeler since 2009 to produce SNG provides an efficient, robust, and viable system that can be adapted to any source of syngas, including the CO_2 rich gases typical of biogas upgrading and Power to Gas applications.
Technical and economical assessments were performed and presented in this paper for typical renewable application, including: biomass gasification, biogas upgrading, and Power to Gas.

1. Introduction to Bio-SNG production: three alternative process schemes

The valorisation of biomass and biogas, likewise the Power to Gas application, can produce Substitute Natural Gas (SNG), which is an ultra-clean and excellent energy carrier to be directly introduced into existing natural gas grids. Ruggeri (2012), Mancuso (2015), and Stein and Ray (2016) analysed SNG production from waste gasification and biogas upgrading as a clean and low carbon alternative to natural gas used in the transition phase to a low carbon economy. The applications in the bio based market sector are several, such as residential heating (including cooking), cogeneration, and transportation systems.
The low carbon economy is looking for unconventional methods to produce natural gas and, in this context, the aim of this paper is to show and compare three alternative renewables pathways to produce Green SNG or Bio-SNG, i.e. biomass gasification, biogas upgrading, and power to gas. Both of the last two process schemes deal with the utilization of renewable hydrogen as reactant, which is assumed to be produced in electrolytic cells (i.e. not derived from fossil fuels).
The potentialities of Green SNG are expected to play a key role in the energy sector due to the easy connection of production plants to existing natural gas network and the availability of mature technologies for commercial applications. The innovative schemes presented in Section 2 of this paper are based on the VESTA catalytic methanation process, developed by Foster Wheeler since 2009 and now in Wood portfolio, to produce SNG from the clean syngas. The application scale of Green SNG produced from VESTA methanation is very wide, and this paper focuses Section 4 on three case studies with an outlet SNG thermal power from 4.4 MWh to 200 MWh.

1.1 Biomass Gasification

Biomass gasification is the first pathway to produce a clean gas that can be converted into Bio-SNG by means of a suitable methanation process. Examples of biomass gasification are reported in Mancuso (2015), Domenichini et al. (2016), and Stein and Ray (2016).
SNG can be produced from biomass by using different plant configurations, which depend on the selected gasification technology with an impact on the downstream syngas composition and, subsequently, on the conditioning and cleaning steps (Domenichini et al., 2016).

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A detailed block flow diagram with the major sections of the Bio-SNG production starting from biomass gasification is reported in Figure 1. The process scheme includes the following steps: feedstock preparation and gasification (e.g., with oxygen coming from an Air Separation Unit), tar removal, gas cooling and clean-up with Acid Gas (AG) separation, and clean syngas methanation.

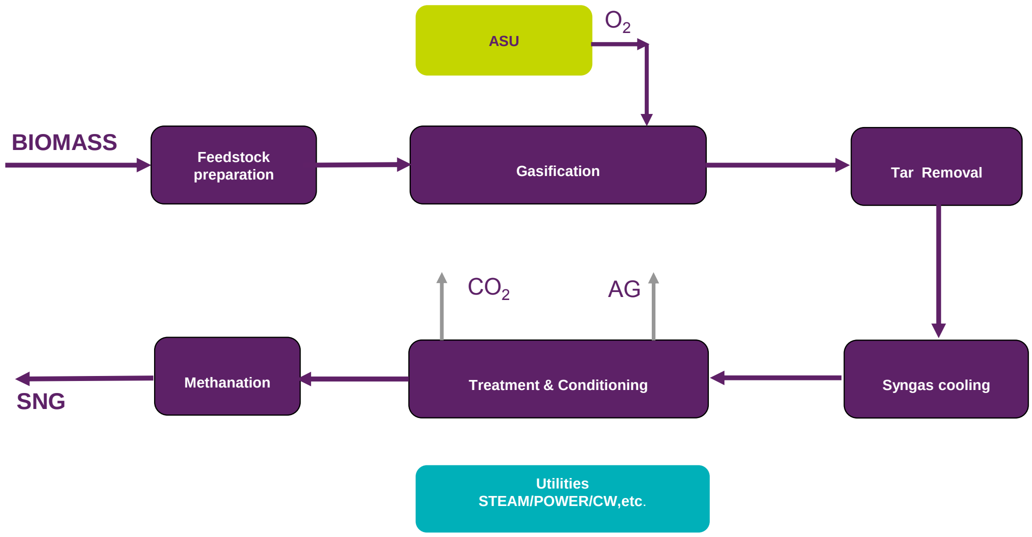

Figure 1: Biomass Gasification to SNG block flow diagram.

1.2 Biogas upgrading

Biogas upgrading pathways to produce Bio-SNG deals with the integrated SNG production from biogas and renewable hydrogen. Likewise the first pathway, the syngas conditioning and cleaning steps can vary depending upon feed gas composition. Figure 2 shows the block flow diagram of biogas upgrading and SNG production from purified biogas and renewable hydrogen, which includes the following sections: biogas clean-up (deep desulphurization, dehalogenation) and compression, clean syngas methanation, and SNG drying system.

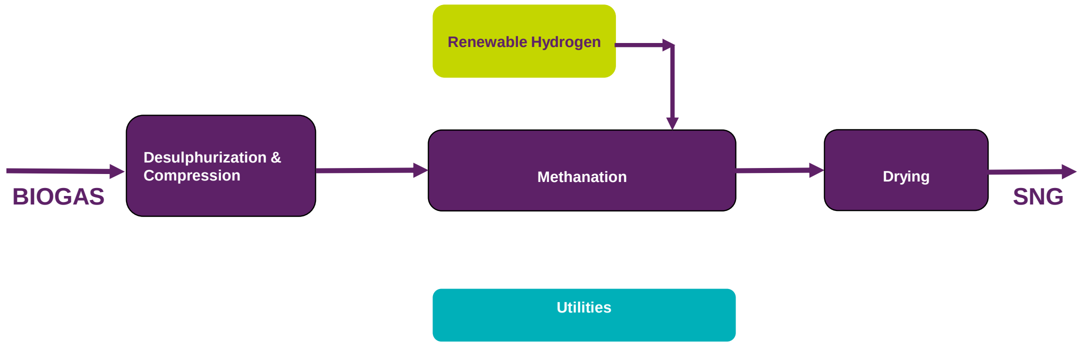

Figure 2: Biogas upgrading and SNG production by renewable Hydrogen block flow diagram.

1.3 Power to Gas

Power to gas applications typically produce CO_2 rich gases that can be adapted for the Bio-SNG production. Figure 3 shows the block flow diagram of this process scheme, which deals with the CO_2 rich gas conversion to Green SNG by using renewable hydrogen and the subsequent drying section.

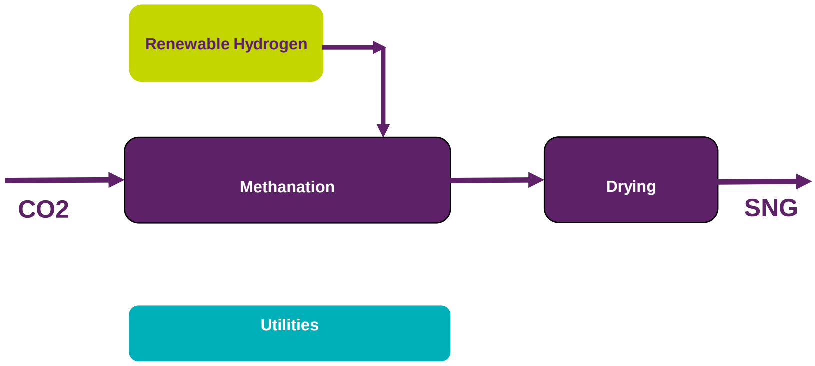

Figure 3: Power to Gas application for the SNG production block flow diagram.

2. The methanation brick: VESTA technology

In the methanation bricks shown on Figure 1, 2, and 3, the methanation process occurs with the conversion of the carbon oxides, mainly carbon monoxide, and hydrogen into methane, in line with the following equilibrium reaction:

$$CO + 3H_2 \leftrightarrow CH_4 + H_2O \quad (1)$$

In conventional SNG processes, the risk of runaway of the methanation reaction is very high, while in the VESTA process such risk is avoided due to the presence of CO_2 and water, which act as temperature dampers. In contrast to other available technologies, CO_2 removal in the VESTA process is performed downstream of the methanation reactors rather before the methanation section, and there is no need of product recycle compressors. This strategy of avoiding the recycle of reaction gases reduces the high operating and maintenance costs associated with the recycle compressor. Moreover, the VESTA process has great flexibility, since it can handle syngas of a wide variety of compositions, coming from different sources. When based on biomass, biogas, or power to gas, the process can help to reduce dependency on fossil fuels and help meet environmental targets. For the sake of clarity, Figure 4 shows schematically the concept of the once-through VESTA process.

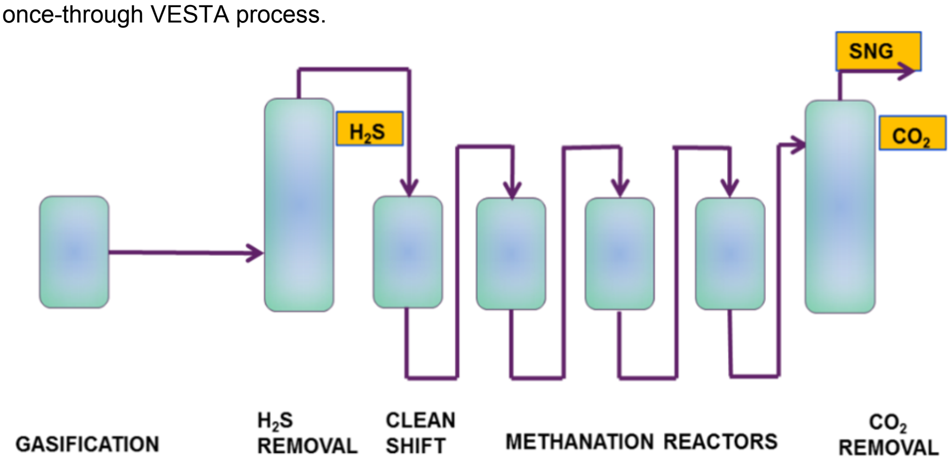

Figure 4: The concept of VESTA process.

The catalyst has already been extensively tested by Clariant, which optimized the chemistry of this catalyst to meet the high quality standards demanded by this new application. Foster Wheeler signed a cooperation agreement with Clariant International, the catalyst supplier, and Wison Engineering to build a pilot plant in China demonstrating the VESTA SNG technology. The pilot plant was designed to completely demonstrate a real plant in addition to the verification of the chemical reactions. It has been erected in Nanjing for a production capacity of 100 Nm^3/h of SNG and conducted two test campaigns in 2014 and 2015/2016 to demonstrate a continuous operation at 100% SNG production meeting the Chinese natural gas grid

specification, and to test different operating parameters including all the reactors and control system (Ruggeri and Romano, 2014).
The commercial feasibility of the Bio-SNG processes will be established in the next few months by means of an ongoing Biomass-to-SNG demonstration plant, which was funded by the UK's Department for Transport, as part of a programme to develop and commercialise technologies required to decarbonise the transport sector, and by National Grid Gas Distribution, who own and operate a large part of the UK's gas distribution network. The scope of work of Wood's VESTA SNG technology consisted of a Basic Engineering Design followed by the Engineering, Procurement and Fabrication activities, which include the following sections: final gas clean-up and conditioning (i.e. deep desulphurization and dehalogenation), clean syngas methanation, CO_2 removal system, and SNG drying.
This project focuses on the commercial innovation necessary to enable the construction of commercial plants after years of technical research. Indeed, funders, feedstock suppliers, power off-takers, and construction contractors are generally unwilling to accept the risks associated with a first of a kind plant and require a demonstration that the technology can be operated commercially before developing large scale facilities. Indeed, that 4.5 MWh demonstration plant will produce enough compressed SNG to power 75 heavy goods vehicles and together with the following full commercial scale plant, which is expected to commence operation in 2020, are absolutely in line with the Carbon Plan targets that are the main drivers of the bio-based sector evolution. The results from this Biomass/Waste-to-SNG demonstration plant will be available in the early future.

3. Bio-SNG production: three case studies for technical evaluations

A technical and economic assessment of the three pathways for the Bio-SNG production was performed and the main results collected in this Section. The syngas coming to the methanation section has no specific limitation of undesirable compounds, since adequate treatment can be included in the SNG unit scope. Likewise any other methanation process, inlet syngas must be purified before entering the methanation section, in order to remove organic contaminants (e.g., tar), inorganic contaminants (e.g., H_2S, NH_3) and particulate matter. The purification step is defined according the impurities to be removed in the specific case study. All the required technologies are ready for small scale and multipurpose commercial applications.

3.1 Biomass Gasification

A technical and economical assessment of an industrial scale biomass gasification and SNG plant, using woody materials as feedstock, was performed. The plant configuration chosen was selected according to the following basis. The main input data are relevant to the woody material feedstock and the outlet thermal power of produced SNG of approximately 200 MWh, which correspond to a product flowrate of 21,000 Nm^3/h. Figure 5 shows the Continuously Fluidized Bed (CFB) Gasifier adopted for biomass gasification, which is pressurized and oxygen blown. The final clean-up is based on catalytic reforming for tar removal and physical solvent washing of H_2S, followed by VESTA clean syngas methanation and chemical solvent washing for the CO_2 removal.

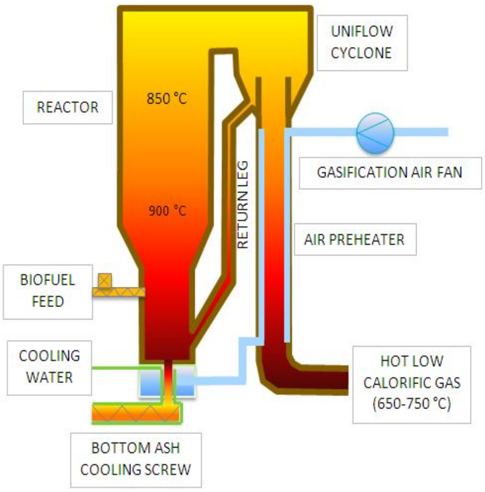

Figure 5: Biomass Gasifier conceptual scheme. The biomass to SNG case study involves a pressurized and oxygen blown CFB Gasifier.

The main technical and economic characteristics and results are reported in Table 1.

Table 1: Performance Data of Bio-SNG production from biomass gasification. Efficiency is defined as the ratio of produced SNG thermal power and inlet biomass thermal power. The SNG production costs is based on the following assumptions: biomass cost of 22€/ton, full equity, I.R.R. 8%.

Item	Value	Unit
Feedstock flowrate	130	t/h
Inlet thermal power	315-330	MWh
Outlet SNG flowrate	21,000	Nm^3/h
Efficiency	Up to 67	%
Total Investment Cost (TIC)	340-370	M€
SNG production cost	13.0	$/MMBtu

These results prove that the first pathway to produce Bio-SNG from biomass is feasible for large scale bio-based units as well as Stein and Ray (2016) demonstrated that the same conclusion is valid for small scale units.
Today, more than ever, the bio-based sector starting is seeing the interest and investment of the main European Community states' members. Considering these current incentives, the biomass gasification followed by a suitable polishing step and the clean gas methanation is a viable and economically attractive solution to produce Bio-SNG.

3.2 Biogas upgrading

A case study relevant to a small scale unit that involves biogas upgrading and Bio-SNG production with renewable hydrogen was performed and collected in Table 2. The plant configuration deals with 3 MWh of biogas and 550 Nm^3/h of hydrogen as feedstocks and the outlet thermal power of produced SNG of 4.4 MWh. The renewable hydrogen generation involves electrolyzes. The final clean-up is mainly based on either biological or chemical desulphurization, followed by VESTA clean syngas methanation.
According to the results (Table 2), biogas upgrading associated with the VESTA process provides an efficient, robust, and viable system to produce Bio-SNG that can be delivered, transported, and distributed using the natural gas existing grid and infrastructures.

Table 2: Performance Data of Bio-SNG production from biogas upgrading.

Item	Value	Unit
Feedstock flowrate	0.5	t/h
Inlet biogas thermal power	3	MWh
Inlet renewable Hydrogen	550	Nm3/h
Electrical power required for renewable Hydrogen production	2.3	MW
Outlet SNG flowrate	455	Nm3/h
Electrical power to SNG efficiency	61	%

3.3 Power to Gas

The renewable hydrogen generation with electrolysers provides the feedstock also for this case study, together with the CO_2 rich stream coming from the power to gas system.
The design basis are chosen to be the same as the biogas upgrading case study. The plant configuration deals with 141 Nm^3/h of CO_2 and 550 Nm^3/h of hydrogen as feedstocks and the outlet thermal power of produced SNG of 4.4 MWh. The renewable hydrogen generation involves the utilization of electrolytic cells and the final conditioning step is mainly based on either biological or chemical desulphurization, followed by VESTA clean syngas methanation. The main characteristics and results are reported in Table 3.

Table 3: Performance Data of Bio-SNG production from Power to Gas system.

Item	Value	Unit
CO_2 Feedstock flowrate	141	Nm^3/h
Inlet renewable Hydrogen	550	Nm^3/h
Electrical power required for renewable Hydrogen production	2.3	MW
Outlet SNG flowrate	145	Nm^3/h
Electrical power to SNG efficiency	60	%

Power to gas utilization with the VESTA process is as feasible and efficient as biogas upgrading to generate a clean syngas and a subsequent Bio-SNG that can be integrated into the existing natural gas networks for transportation and heating purposes.

4. Conclusions

Green or Bio-SNG production via biomass gasification, biogas upgrading, and methanation of CO_2 rich stream coming from power to gas systems are proven in this paper to be technically feasible with the current available and mature technologies, such as the VESTA methanation technology developed and patented by Foster Wheeler and now in Wood portfolio, which is able to capture the most recent market trend towards Green SNG production by exploiting renewable resources.
The case studies presented in this paper have addressed different sizes, which cover most of the Green SNG application scales. Considering a middle term forecast for the natural gas price of 8-10 $/MMBtu the biomass gasification plant can be economically attractive with an incentive in line with what currently applies in Northern Europe, or alternatively considering a monetization for the low level heat integration (e.g., district heating). Biogas upgrading and Power to Gas systems will allow the widest use of Bio-SNG not only for power generation, but, more important, to provide an alternative for transport, industrial, and domestic demands in all the green economies.

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