Modelling of Synthetic Natural Gas Production via Biomass Gasification for Renewable Gas Grid Injection

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Introduction

Ireland relies heavily on imported natural gas, which is used for electricity generation, heating and cooking. Therefore, grid injection of renewable gas is very attractive. Replacing heat from fossil fuels with heat from renewable sources is a significant challenge. Due to Ireland's favourable growth climate, bioenergy is expected to play a major role in meeting renewable heat (and transport) targets; however, to date its uptake has been very low. Barriers include: low efficiency of conversion technologies; high capital and biomass fuel costs; absence of large heat loads (no district heating networks and very little heavy industry). Synthetic natural gas production via biomass gasification (BG-SNG) with subsequent grid injection can overcome these barriers. With reference to Fig. 1, a BG-SNG plant comprises a gasifier followed by gas cleaning (removal/conversion of impurities) and upgrading (methanation and inert gas removal) steps.

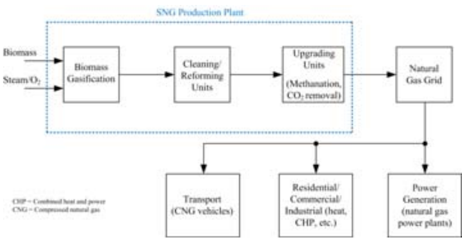

Fig. 1 BG-SNG plant and applications block diagram

Development of these plants is at an early stage; 1 MW_{SNG} (SNG output) pilot plant tested in Austria and 20 MW_{SNG} demonstration plant operating in Sweden (refer to Fig. 2 and Fig. 3).

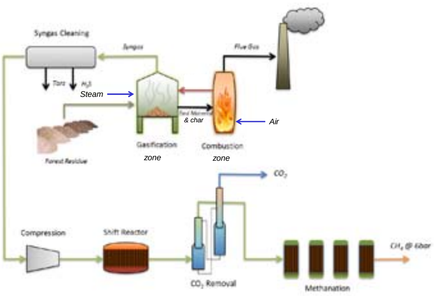

Fig. 2 Simplified schematic of GoBiGas 20 MW_{SNG} demo plant Gothenburg Sweden [1]

Fig. 3 Photo of GoBiGas demo plant [2]

The GoBiGas plant began injecting bio-SNG into the natural gas grid in late 2014. The plant ran almost continuously during 2015. The plant operates at an efficiency of ~65% (biomass fuel to bio-SNG) [3].

Commercial BG-SNG plants are expected to be of the scale 20-200 MW_{SNG}. Scale has a strong impact on cost and therefore large scale is preferable; however, scale will be limited by biomass supply logistics. In Ireland plant scale will likely be limited to 30-50 MWth (biomass fuel input) to ensure a sustainable indigenous supply of biomass fuel.

SNG production via BG could be pivotal in ensuring Ireland achieves future renewable heat and transport targets (2020 targets unlikely to be met). Gas Networks Ireland (formerly Bord Gáis Networks) hope to achieve ~10% renewable gas supply within 10 years [4].

Gasification

Gasification is a process in which a carbonaceous fuel is converted to a combustible gas. It occurs when a controlled amount of oxidant is reacted at high temperatures with available carbon in a fuel within a gasifier. It offers the possibility of conversion to heat and power (CHP), liquid fuels, chemicals or SNG. Thus, it enables biomass to contribute to all three types of renewable energy targets, i.e. heat, electricity and transport. The main chemical reactions that occur during the process are listed in Table 1.

Table 1 Main gasification reactions [5, 6]

Reaction	Heat of reaction[a]	Reaction name	Reaction number
Heterogeneous reactions:			
$C + 0.5O_2 \rightarrow CO$	(-111 MJ/kmol)	Char partial combustion	Eq. 3.3
$C + CO_2 \leftrightarrow 2CO$	(+172 MJ/kmol)	Boudouard	Eq. 3.4
$C + H_2O \leftrightarrow CO + H_2$	(+131 MJ/kmol)	Water-gas	Eq. 3.5
$C + 2H_2 \leftrightarrow CH_4$	(-75 MJ/kmol)	Methanation	Eq. 3.6
Homogeneous reactions:			
$CO + 0.5O_2 \rightarrow CO_2$	(-283 MJ/kmol)	CO combustion	Eq. 3.7
$H_2 + 0.5O_2 \rightarrow H_2O$	(-242 MJ/kmol)	H_2 combustion	Eq. 3.8
$CO + H_2O \leftrightarrow CO_2 + H_2$	(-41 MJ/kmol)	CO-shift	Eq. 3.9
$CH_4 + H_2O \leftrightarrow CO + 3H_2$	(+206 MJ/kmol)	Steam-methane reforming	Eq. 3.10
NH_3, H_2S and HCl formation reactions:			
$0.5N_2 + 1.5H_2 \leftrightarrow NH_3$	nr[b]	NH_3 formation	Eq. 3.11
$H_2 + S \leftrightarrow H_2S$	nr	H_2S formation	Eq. 3.12
$Cl_2 + H_2 \leftrightarrow 2HCl$	nr	HCl formation	Eq. 3.13

[a] Negative sign indicates an exothermic reaction and a positive sign indicates an endothermic reaction.
[b] nr = not reported.

The two most suitable gasifier types for bio-SNG production are: indirect/allothermal steam blown BG technology and direct/autothermal pure O_2 blown BG technology. Both technologies produce a gas well suited to SNG production (low inerts and high hydrocarbon content). Table 2 displays typical dry gas compositions for steam and O_2 blown BG technologies.

Compound	Oxygen Gasification (Entrained Flow)	Oxygen Gasification (Fluidized Bed)	Steam Gasification
CO (vol %)	40–60	20–30	20–25
CO_2 (vol %)	10–15	25–40	20–25
H_2 (vol %)	15–20	20–30	30–45
CH_4 (vol %)	0–1	5–10	6–12
N_2 (vol %)	0–1	0–1	0–1
LHV (MJ/Nm^3)	10–12	10–12	10–14
Tar content (g/Nm^3)	<0.1	1–20	1–10

Table 2 Gas compositions for steam and O_2 blown BG [7]

A major disadvantage of the O_2 blown BG technology is that O_2 production is expensive (cryogenic air separation) and therefore large scale plants are required (typically a few hundred MW). The sustainability of such large scale bioenergy plants is questionable.

The main suppliers for the steam blown technology include: Repotec/TU Wien FICFB technology (fast internally circulating fluidised bed implemented at GoBiGas plant), Silvagas technology, ECN MILENA technology (4 MW BG-SNG demonstration plant in planning [8]), Agnion Heatpipe Reformer technology.

The main suppliers for the O_2 blown technology include: Foster Wheeler pressurised CFB (circulating fluidised bed) [9] and Carbona/GTI pressurised BFB (bubbling fluidised bed).

Methanation

The main chemical reaction is the reverse of Eq. 3.10 in Table 1 ($CO + 3H_2 \rightarrow CH_4 + H_2O$). A catalyst is required, typically nickel based, at the reactor conditions. The two main reactor types are: a series (typically 2-3) of adiabatic fixed beds and the isothermal BFB reactor. The Paul Scherrer Institute supplies the BFB technology. Different variations of the fixed bed technology are available from Lurgi, Haldor Topsoe (TREMP) and Foster Wheeler (VESTA).

Research in Ireland to date

To date, research in Ireland has focussed on anaerobic digestion (AD) systems for biogas production, upgrading and grid injection. Numerous articles have been published by a research group at UCC. In 2010, a Bord Gáis report titled "The Future of Renewable Gas in Ireland" based on the results of research carried out at UCC was published [10]. It highlighted the potential production of renewable gas from grass and waste via anaerobic digestion in Ireland. Under the baseline scenario (i.e. realistic potential), there is the potential to meet 7.5% of Ireland's natural gas demand with renewable gas by 2020 (shown in Fig. 4).

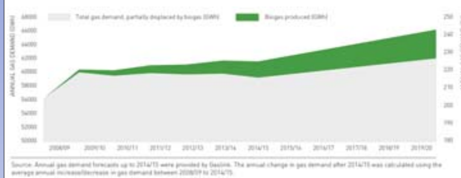

Fig. 4 Fossil fuel based natural gas displacement by biogas in Ireland [10]

Biomass gasification has many advantages over anaerobic digestion with respect to renewable gas production:

- BG is a more efficient process (70-80% versus 20-40%)
- AD is limited by scale to ~1 MWth (economics of collection and transportation of wet biomass)
- BG exhibits greater potential for improvement in biomass to SNG performance (e.g. pressurised steam blown BG would enhance methanation process efficiency)
- BG is a much faster process and allows greater control

Considering gas injection quantities (in Ireland), it will be necessary to connect BG-SNG plants to the high pressure transmission natural gas grid; whereas, small scale AD plants would be connected to the low pressure distribution grid. It would not be financially viable to connect small scale AD plants to the transmission grid (gas compression costs). As a result, AD plants will be limited by residential/commercial heat demand meaning they would have to shutdown during summer. BG-SNG plants connected to the transmission grid would not be affected by this drop in demand because natural gas power plants operate year round. A combined effort of anaerobic digestion and gasification will be required to deliver sufficient renewable gas to replace a significant level of fossil natural gas.

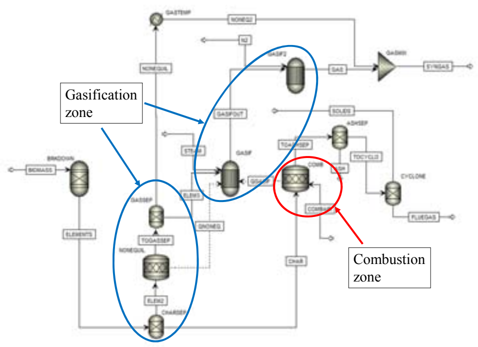

Fig. 5 FICFB gasifier model Aspen Plus flowsheet

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