Supplementary Information

The techno-economic viability of bio-synthetic natural gas production utilising willow grown on contaminated land

Jonathan B. Norman[*, 1], Marcelle McManus[1]

Sustainable Energy Research Team (SERT), Department of Mechanical Engineering, University of Bath, Bath, UK. BA2 7AY

* Corresponding author: j.b.norman@bath.edu

Table S 1: Input parameters and their variation as used in the modelling. This is shown in the main paper, but notes and full references are given here. Many of the costs are for a 76 MW output installation, and scaled as discussed in the main paper. Otherwise parameters are identical regardless of installation size. Min and max refer to the variation expected in the parameters and are used in uncertainty analysis.

Parameter	Unit	Value	Min	Max	Notes
Load factor	Proportion	0.9	0.85	0.95	Mode for mature technology and minimum for 1st of a kind based on operating hours given by gogreengas [1], also given by Progressive Energy [2]. Maximum assumed.
Hurdle rate	Percentage	10%	8%	12%	10% for mature technology based on gogreengas [1]. 12% suggested for first of a kind installations [1]. Range of 8-12% used by Progressive Energy [2].
Lifetime	Years	25	20	30	Based on similar installations, for example e4tech [3].
Capital cost for 76 MW bioSNG output installation	£million	150.7	105.5	195.9	Base cost from gogreengas [1] for a 76 MW bioSNG output installation. 30% variation assumed for total capital costs similar to other analyses, for example [4].
Capital cost scaling factor	-	0.6	0.5	0.7	Scaling factor used to calculate capital costs for other size installations. Based on examining cost variation with size for a number of bioSNG installations, as reported by gogreengas [1], Progressive Energy [4] and e4tech [3]. The maximum and minimum reflect the range seen in the estimates from these reports.
Labour cost for 76 MW bioSNG output installation	£million/year	1.8	1.3	2.3	Based on that reported in gogreengas [1]. 30% variation similar to capital costs.
Labour cost scaling factor	-	0.15	0.1	0.2	Estimated from costs for different scale installations given in gogreengas [1]. Minimum and maximum assumed.
Consumables costs	£million/year	3.1	2.2	4.0	Based on that reported in gogreengas [1]. 30% variation similar to capital costs.
Consumables costs scaling factor	-	1	0.9	1	Estimated from costs for different scale installations given in gogreengas [1]. Minimum and maximum assumed.
Maintenance costs	£million/year	2.9	2.0	3.8	Based on that reported in gogreengas [1]. 30% variation similar to capital costs.

Maintenance costs scaling factor	-	0.6	0.5	0.7	Estimated from costs for different scale installations given in gogreengas [1]. Minimum and maximum assumed.
Other operating costs	£million/yr	3.5	2.5	4.6	Based on that reported in gogreengas [1]. 30% variation similar to capital costs.
Other operating costs scaling factor	-	0.6	0.5	0.7	Estimated from costs for different scale installations given in gogreengas [1]. Minimum and maximum assumed.
Gross efficiency	output bioSNG per input of feedstock energy	64%	57%	70%	Gross efficiency is bioSNG output per unit of feedstock energy input from gogreengas [5]. Maximum and minimum based on a 10% variation in the base case gross efficiency.
Natural gas energy demand	input required per unit of bioSNG output	0.01	0.009	0.011	Calculated based on gogreengas [5]. Minimum and maximum 10% variation
Electricity demand required	input required per unit of bioSNG output	0.095	0.086	0.105	Calculated based on gogreengas [5]. Minimum and maximum 10% variation
Wholesale gas price	£/GJ	7.05	3.58	8.73	Based on scenarios from the Department for Business, Energy and Industrial Strategy [6]. Mode is reference scenario in 2030, maximum and minimum based on range seen in scenarios from 2020 to 2035.
Electricity price (retail, industry)	£/GJ	36.01	29.64	39.03	Based on scenarios from the Department for Business, Energy and Industrial Strategy [6]. Mode is reference scenario in 2030, maximum and minimum based on range seen in scenarios from 2020 to 2035.

Natural gas retail price	£/GJ	10.97	6.15	12.9	Based on scenarios from the Department for Business, Energy and Industrial Strategy [6]. Mode is reference scenario in 2030, maximum and minimum based on range seen in scenarios from 2020 to 2035.
Energy density willow	GJ/odt	18			Mode value from e4tech [7], 25% moisture content.
Policy support RTFC	£/GJ bioSNG	15.2	7.6	22.8	Mode value is based on RTFC price of 20p/litre, minimum and maximum at 10p/litre and 30p/litre respectively (see main text).
Policy support RHI	£/GJ bioSNG	17.3	7.8	10.1	Represents the three payment tiers under the RHI as of May 2018 (see main text).

Table S 2: Contaminant removal required between the concentration in syngas leaving the gasifier and required for the methanation step. Feedstock is clean biomass, adapted from [8].

Components	Unit	Concentration is syngas leaving gasifier	Requirement for methanation
H_2S	ppm	100	0.1
COS	ppm	10	0.1
HCl	ppb	25,000	<25
NH_3	ppm	2830	100
Cd	mg/Nm^3	0.94	0.05
Na+K	mg/Nm^3	1630	1
Dust	mg/Nm^3	10,000	10
Tars	mg/Nm^3	10,000-15,000	5
Heavy metals	mg/Nm^3	<300	<1

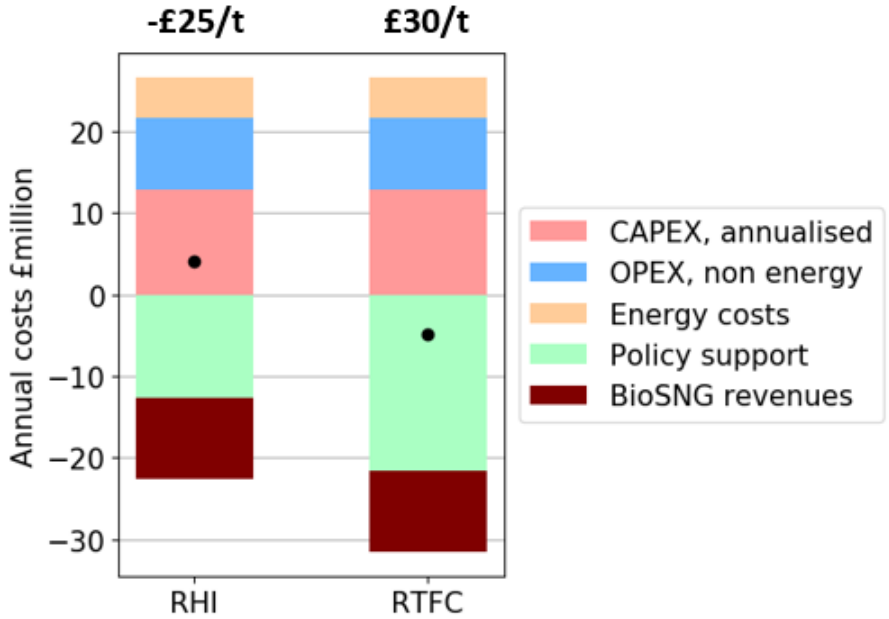

Figure S 1: Annualised costs of bioSNG production for a 50 MW bioSNG output installation. Feedstock costs are not shown. The black dot show the resultant of the annual costs and benefits and the value above the chart shows the required feedstock cost to breakeven. A negative value shows a required benefit from the feedstock (a gate fee). Cases are shown with support under the RHI and the RTFC.

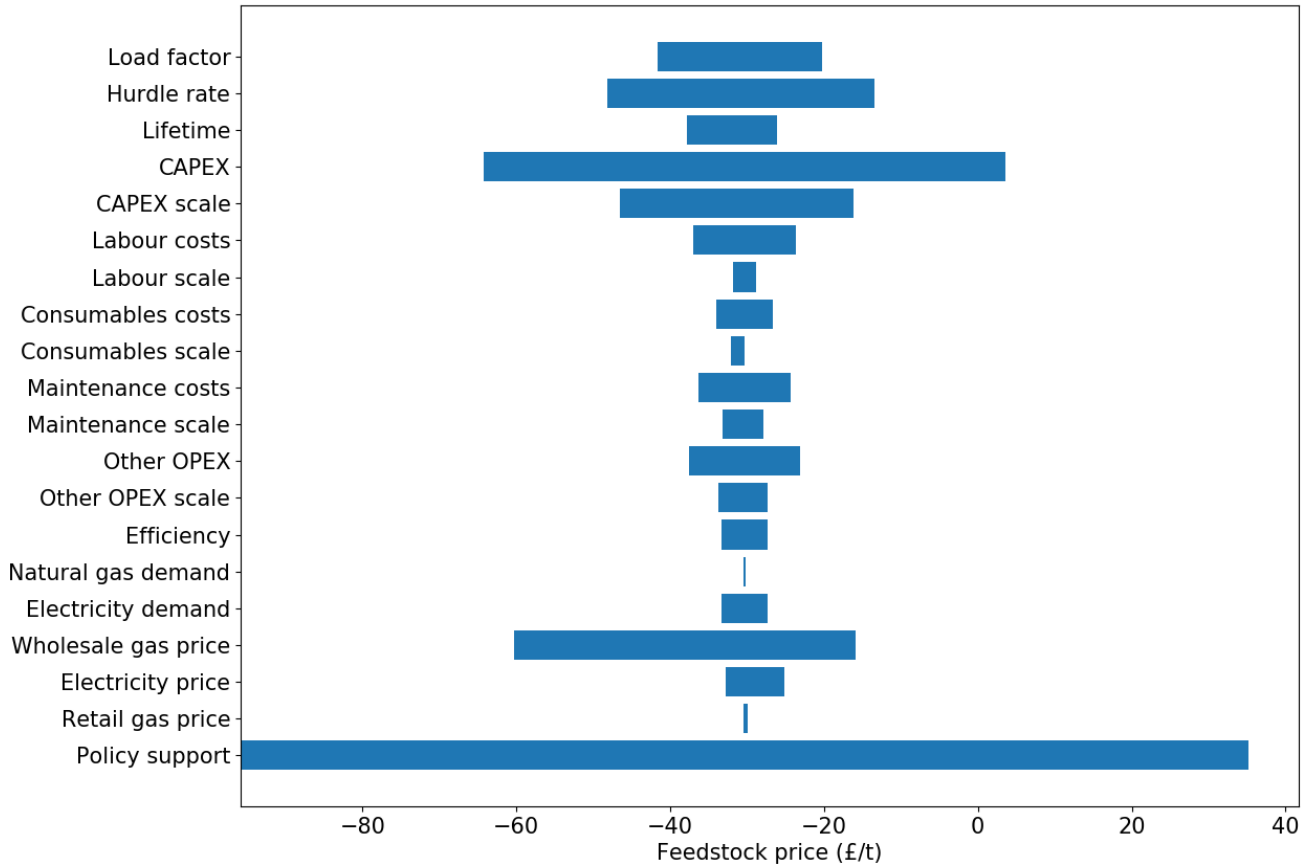

Figure S 2: Sensitivity analysis for a 20 MW output installation. Effect on feedstock price as each parameter is varied between the maximum and minimum values and all other variables held at mode values are shown.

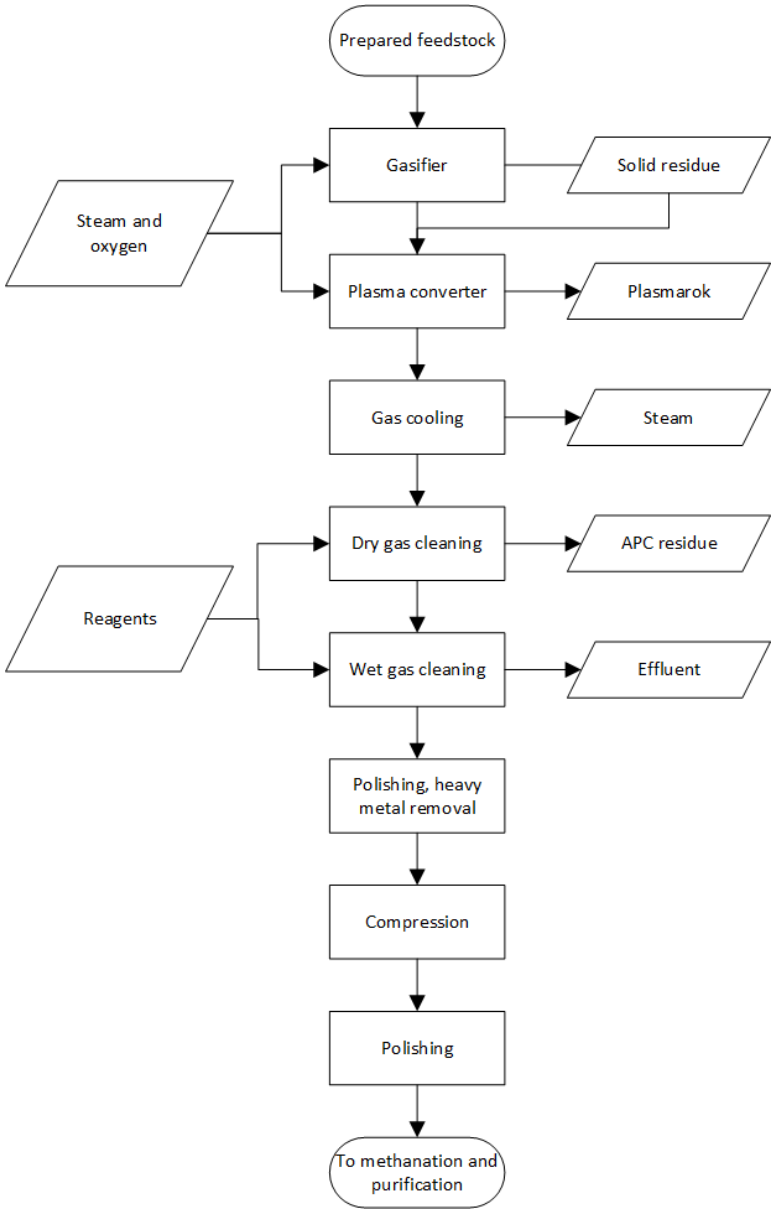

Figure S 3: Thermal treatment, syngas cleaning and cooling steps. Adapted from gogreengas plant design report [5].

Supplementary information references

1. gogreengas (2015) BioSNG Demonstration Plant. Summary of Commercial Results. Commercial model of full scale BioSNG plants. Swindon, UK: gogreengas.
2. Progressive Energy Ltd and Advanced Plasma Power Limited (2017) Biohydrogen: Production of hydrogen by gasification of waste. An NIA assessment of Biohydrogen production and opportunities for implementation on the gas network. Coventry, UK: Cadent Gas Ltd.
3. e4tech (2010) The potential for bioSNG production in the UK. NNFCC D. NNFCC project 10/008 NNFCC project 10/008.
4. Progressive Energy and CNG Services (2010) Bio-SNG. Feasibility Study. Establishment of a Regional Project.: NEPIC National Grid and Centrica.
5. gogreengas (2017) BioSNG Demonstration Plant. Summary of Plant Design. Full scale BioSNG design and asessment of scale-up risks. Swindon, UK: gogreengas.
6. Department for Business Energy and Industrial Strategy (2017) BEIS 2017 Updated Energy & Emissions Projections. Annex M Growth assumptions and prices.
7. e4tech (2010) Biomass prices in the heat and electricity sectors in the UK.: Department of Energy and Climate Change. URN 10D/546 URN 10D/546.
8. Mozaffarian M, Zwart RWR (2003) Feasibility of biomass/ waste-related SNG production technologies. Petten, The Netherlands: ECN-Biomass Systems.