Programme Area: Bioenergy

Project: Energy From Waste

Title: UK Benefit Case Report - Syn Gas for Grid Injection

Abstract:

This report has been produced by the Centre for Process Innovation (CPI) for the Energy Technologies Institute's (ETI) Energy from Waste (EFW) Project that forms part of the ETI Distributed Energy Programme. The project is of a small series of supporting pieces of work that augment the full project reports. This report outlines the opportunity for using syngas produced from the gasification wastes for the injection into the national grid. Natural gas imports to the UK have increased constantly over the last decade, from a net negative value of 100 TWh in 2000 to net positive value of 400 TWh in 2010, while the natural gas production has fallen to 675 TWh from 1200 TWh in the same time period. Syngas from a gasification process of waste has been identified as a potential fuel in some domestic or industrial scenarios similar to the use of Towns Gas in the UK pre 1972. This report looks at the potential for waste to syngas for grid injection by looking at the available technologies and their state of technology readiness. It also considers the scale of operation required for these types of plants and draws on the economic models developed for the core project to explore potential returns.

Context:

The Energy from Waste project was instrumental in identifying the potential near-term value of demonstrating integrated advanced thermal (gasification) systems for energy from waste at the community scale. Coupled with our analysis of the wider energy system, which identified gasification of wastes and biomass as a scenario-resilient technology, the ETI decided to commission the Waste Gasification Demonstration project. Phase 1 of the Waste Gasification project commissioned three companies to produce FEED Studies and business plans for a waste gasification with gas clean up to power plant. The ETI is taking forward one of these designs to the demonstration stage - investing in a 1.5MWe plant near Wednesbury. More information on the project is available on the ETI website. The ETI is publishing the outputs from the Energy from Waste projects as background to the Waste Gasification project. However, these reports were written in 2011 and shouldn't be interpreted as the latest view of the energy from waste sector. Readers are encouraged to review the more recent insight papers published by the ETI, available here: http://www.eti.co.uk/insights

CPI

UK Benefit Case Report

Syn Gas for Grid Injection

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Contents:

Executive summary

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Natural gas imports to the UK have increased constantly over the last decade, from a net negative value of 100 TWh in 2000 to net positive value of 400 TWh in 2010, while the natural gas production has fallen to 675 TWh from 1200 TWh in the same time period[1].

Syngas from a gasification process of waste has been identified as a potential fuel in some domestic or industrial scenarios similar to the use of Towns Gas in the UK pre 1972.

This report looks at the potential for waste to syngas for grid injection by looking at the available technologies and their state of technology readiness. It also considers the scale of operation required for these types of plants and draws on the economic models developed for the core project to explore potential returns. Conclusions are drawn and proposals made for potential projects that could further explore the opportunities for waste to syngas for grid injection, and an assessment is made of potential CO_2 benefits from the displacement of fossil fuels.

The output from this report forms part of the additional work that was commissioned to support the Energy from Waste (EFW) Project Consortium that forms part of the ETI Distributed Energy Programme.

1 Description and Status of the Technology

The term syngas is used to apply to the group of gas mixtures whose composition is predominately made up of hydrogen and carbon monoxide, with a few other additions such as methane depending on the source. The reference to syngas used in this short report is that produced by the gasification of waste. In the previous reports on this project this waste material has been assumed to be similar to biomass in the way that it performs in the gasification process. The trial work that was performed by Cranfield University tended to support this conclusion. In the survey and analysis work performed by Cranfield University the moisture content and the shape and form of the waste were found to be the major waste variables affecting the gas composition.

[1] Office of national statistics DUKES

Appendix A is an extract from the gas grid's website giving details of how the gas system is put together throughout the UK and how the nation wide distribution is achieved. In essence the grid currently takes gas input through nine points in the UK. It operates at between 60 and 95 bar and consists of approximately 6,600 km of steel piping.

The grid cascades down through several pressure stages to 2-7 bar, 75 mbar to 2 bar, and down to domestic use of < 75 mbar. This cascade potentially fits into the large city, large town, small town, and village scenarios developed in the 3.3 report.

The national grid at present has stringent requirements for material that can be injected into the pipeline. A table of which is included in this report's Appendix A.

Two approaches to the use of syngas can be assessed. The first would be use of raw syngas after gas clean up, but predominately the carbon monoxide and hydrogen mix. The alternative approach is the conversion of this syngas to a product that is closer to what is presently in use, which is a predominately methane composition.

The use of syngas in the national supply grid could be potentially analogous to the use of town gas in the domestic supply to the UK prior to the 1940's. This material was produced from several chemical routes all predominately linked to coal.

Below are detailed the syngas production reactions. The combination of these reactions shows how the calorific value of the production gas can be changed by adjusting the composition of the feed material and use of steam. The adjustment of the product gas can also make it suitable for further chemistry such as the production of methanol or other hydrocarbons. Most Fischer Tropshe (FT) type reactions need higher hydrogen to CO ratio, or for hydrogen production for ammonia.

$$2\ C(s) + O_2 \rightarrow 2\ CO \text{ (Exothermic Producer Gas)}$$

$$C(s) + H_2O\ (g) \rightarrow CO + 2\ H_2 \text{ (Endothermic Water gas Shift reaction)}$$

$$C + 2\ H_2O \rightarrow CO_2 + 2\ H_2 \text{ (Endothermic)}$$

$$CO + H_2O \rightarrow CO_2 + H_2 \text{ (Exothermic Water gas shift reaction)}$$

The reaction that occurs when using a waste or biomass material during gasification would be the following. This shows a similarity the existing syngas reactions; steam can also be used in the gasification process to adjust the mix of products predominately for the increase in hydrogen concentration.

$$CH_{1.4}O_{0.6} + 0.4\ O_2 \rightarrow 0.7\ CO + 0.3\ CO_2 + 0.6\ H_2 + 0.1\ H_2O$$

This is an endothermic process as the energy to drive the reactions (approximately 30%) comes from the use of some of the fuel in straight combustion.

One of the considerations that must be taken into account in the use of syngas (from coal processes) is its low calorific value when compared to natural gas approximately 50% or less. The calorific value for biomass derived fuels has been quoted as low as 5 MJ/m^3 is typical. This is mainly due to the dilution effect of the nitrogen from the air used in the processes. If injected neat the waste derived syngas would considerably dilute the existing mains supply.

For information the following are quoted values for a range of other gases potentially used as fuels. These have predominately been derived from a solid feedstock such as coal.

Lean Reformer Gas 18 Mj/m^3

Rich Reformer Gas 26 Mj/m^3

Natural Gas 40 Mj/m^3

LPG 100 Mj/m^3

The main technologies for the production of syngas by gasification are fixed bed, fluidised bed and entrained flow. Descriptions of how these technologies work and their variations are contained in the main 3.3 report, together with an assessment of their technology readiness levels. When used with fossil fuels the calorific values are noticeably higher.

There are potential options to increase the calorific value of the waste derived syngas. The first option is to perform the gasification with pure oxygen or steam. The use of oxygen and steam can in theory be operated on all the types of gasifier that is updraft, downdraft, fluidised bed and entrained flow. Using steam or oxygen as an oxidant or fluidising medium removes the nitrogen from the system consequently enriching the gas. The fluidised bed and entrained flow types of facility are the most expensive options in terms of capital and are most economical on the large scale.

The other possibility to upgrade the quality of the syngas is to process the material in conjunction with an existing fossil fuel such as coal. An example of this is the conversion of the former town gas plant in Schwarze Pumpe in Germany[2]. This facility takes both fossil fuel and refuse derived materials to produce both power (75 MWe) and chemicals (120,000 tpy methanol).

All the gas produced in the gasification processes will require some amount of clean up, there is will be sulphides, chlorides, tars etc. The economic viability will greatly depend on the extent of the clean up requirements. In recent history the disappointing performance of the gasification processes for wastes or biomass has been linked to insufficient effort being applied to this part of the technology, again as detailed in the 3.3 report.

[2] Syngas and Fuel Gas from Gasification of coal and wastes at Shwarze Pumpe (SVZ) Germany. Dr B Butker and Dr W Selfert SVZ Schwarze Pumpe GmbH Germany. H Hirschfelder and H Vierrath Lurgi Envirotherm GmbH, Germany

The amount of syngas produced per kilo of feed depends on the technology used. For example in a downdraft process there would be ~3.1 m^3 per kilo of feed, the fluidised bed process would produce ~1 m^3 per kilo of feed, but at three times the calorific value.

To have the same calorific value at the point of use there would be some requirement for modification of appliances both domestic and industrial to accommodate the fuel change. This is similar to the towns gas natural gas change over in the UK in the 1960's and early 1970's.

When compared to the specification that is required for the grid this is far away from that necessary for direct injection. A view can be made that this is an unlikely option in the near future, but potentially could have application in isolated systems.

Alternatively to create a material that can be directly injected, the syngas could be converted to Synthetic Natural Gas using methanation reactors to convert the CO and H_2 to methane (CH_4), as shown in Figure 1. This is probably the most likely option for a material acceptable to the grid for present use and that which will meet present standards and legislation.

$$CO + 3 H_2 \rightarrow CH_4 + H_2O$$

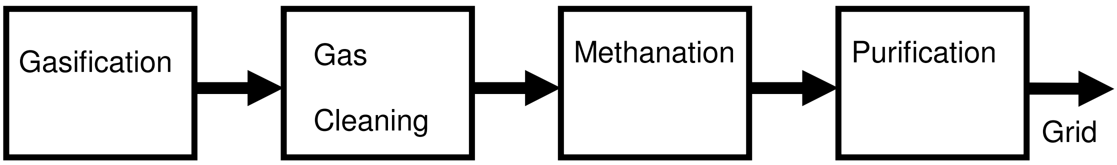

Figure 1: The creation of Synthetic Natural gas from waste which can then be injected directly into the gas grid

As can be seen from the stoichiometry for the process shown above, the hydrogen requirement for the reaction needs to rise from 3 to 1 H_2 to CO. This could be achieved by the use of steam in the gasification process. In some respects there is a tie in to the fuels and production from the syngas as the reactions are similar to the Fisher Tropshe type reactions used for the production of methanol and other hydrocarbons.

The gasification stage is one of the options described in previous work in report 3.3, as is the gas cleaning stage. In the gas cleaning stage contaminants such as sulphur must be removed. This is due to the fact that they can poison the catalysts that are used in the methanation reaction. The methanation reactor is generally a packed bed catalyst system in which temperature control will be critical. For the final gas purification will be required to remove any CO_2, water and other contaminants. This will most likely be a system adjusting temperature and pressures and membrane systems.

This technology, with respect to the use of biomass or refuse derived materials is in early stage development. There are two projects in Europe assessing this technology; REPOTEC-CTU in Austria and ECN technology[3]. The benefit to this approach would be a fuel readily capable for use in the existing systems.

The technology readiness level for this conversion is around the 4 to 5, some organisations are moving into demonstration and pilot.

2 Economic Outline

The UK uses approximately 1000 Twh of natural gas in a year[1]. This equates to, with an assumed calorific value of 40 MJ/m^3, a usage of approximately 100,000 Million m^3. The supply to domestic users alone is approximately one third of this. The gas usage by sector in the UK is shown below in Table 1, derived from data issued by the office of national statistics. To match this calorific requirement based on the low HHV of the air aspirated gasification would require around 280,000 Million m^3. Based on a simplified calculation the amount of dry waste material required to be processed would be ~90 Million Tonnes.

The domestic use for natural gas is 389 TWh. The average gas use of an individual household is on average around 1400 m^3 of natural gas per annum. This figure is calculated using figures from the office of national statistics. Comparing this value to the scenarios that have previously been developed (included below in Table 2) can give a view to the potential options for use of a waste derived syngas as a domestic fuel. A city of five hundred thousand people, on rough calculations, will require ~8000 GWh of natural gas per annum for domestic use only. On an equal calorific basis this would need two million tonnes of feed, which is approximately 5 times the dry (gasification) waste that is expected to be produced by that community. The syngas would therefore only be a potential supplement to any existing grid supply. Consideration that it would be a supplement to an existing supply would lead to the view that methanation of the produced gas is a more realistic option to overcome complicated mixing and multi injection systems.

[3] The potential for bioSNG production in the UK NNFCC

	UK Natural Gas Usage 2010			
	TWh	GJ	Tonne Oil equivalent	M^3 Nat Gas
Iron and Steel	5.8	20,880,000	498,710	522,000,000
Other Industry	116.1	417,960,000	9,982,803	10,449,000,000
Other Final Customers	88.6	318,960,000	7,618,229	7,974,000,000
Domestic	389.6	1,402,560,000	33,499,570	35,064,000,000
Non Energy Use	8.5	30,600,000	730,868	765,000,000
Distribution Losses	88.1	317,160,000	7,575,236	7,929,000,000
Power Stations	371.1	1,335,960,000	31,908,856	33,399,000,000
Other Transformation Loses	23.9	86,040,000	2,055,030	2,151,000,000
Total	**1091.7**	**3,930,120,000**	**93,869,304**	**98,253,000,000**

Table 1: UK gas usage by sector

Scenario	Population	Dry Waste (kt/yr)	Dry Waste Energy Content (MJ/yr)	Wet Waste (kt/yr)	Wet Waste Energy Content (MJ/yr)	Comment
City	500k	490 (306-673)	$4.8x10^9$ ($4x10^8$-$5.6x10^9$)	408 (255-560)	$9.2x10^8$ ($7.7x10^8$-$1.1x10^9$)	Urban with little agriculture
Town	50k	49 (31-67)	$4.8x10^8$ ($4x10^8$-$5.6x10^8$)	41 (25-56)	$1.0x10^8$ ($8.7x10^7$-$1.2x10^8$)	Residential and commercial
Village	5k	4.9 (3.1-6.7)	$4.8x10^7$ ($4x10^7$-$5.6x10^7$)	4.1 (2.5-5.6)	$1.1x10^7$ ($9.7x10^6$-$1.3x10^7$)	Residential with little commercial
Rural Community	500	0.49 (0.31-0.67)	$5.1x10^6$ ($4.3x10^6$-$5.6x10^6$)	20	$6x10^7$	Mainly farming with residential

Table 2: Scenarios developed in previous reports

The economics that govern the use of syngas in the grid are similar to those already developed in the previous reports. The material produced, whether methanated or not, is a fuel and as such at present has at present a relatively low monetary value. Gas prices at present oscillate between 50 to 70 pence per therm, one therm is approximately equal to 2.6 m^3 of natural gas. A therm would also equate to 20 m^3 of syngas at the lowest calorific value of 5 MJ/m^3 or about 10 kg of feed materials. To have a payback or positive investment case the need for gate fees may be a necessity. The simple profit and loss spreadsheet developed in previous work has been adjusted to look at the grid injection options. This shows that there may be an economic justification that a profitable facility could be built but that the payback would be quite long of the order of ten years. This case still assumes that there is a gate fee for the waste. It is difficult to see that this would be an attractive investment. A print out of the initial print out of the economic case is shown Appendix B.

3 Specification and Regulations

At present to inject materials into the grid a stringent specification is required to be met, for both safety and quality requirements. See Appendix A.

The discussions about the ability to inject direct into the grid from anaerobic digestion have been discussed in previous reports produced for the ETI. The considerations over the use of a syngas derived injection would be similar.

It is at present difficult to envisage how it would be possible for a waste derived raw syngas to meet current specifications. The use of a raw syngas would require a redesign of how a supply would work, not only from an infrastructure basis for the distribution network, but also in the domestic and industrial user appliances which would most likely require a change of burners due to the change in overall gas composition. It can be envisaged how a local area acceptance of direct syngas could be used, or the dedicated supply to a particular factory or facility, such as a brick works or other furnace requiring industry.

As already stated in Section 1, if the development of a Synthetic Natural Gas (SNG) is produced the use in the grid can be seen as a more near term solution. As the gas to be injected would be predominately methane it would be more acceptable as a grid injection product. Even in the use of a methanated material the process may be more complicated with the seasonal variation in waste feed stocks and the fact that they are not likely to tie up with the demand expected from users. For a methantion facility it would be expected to operate at quite a high throughput and up time to maximise return on investment. This leads to the injection at a higher pressure level where the demand is higher and more consistent.

4 Environmental Impact Comments

The use of syngas from waste derived materials as a heating product in industrial or domestic use can have a contribution to CO_2 mitigation. If the waste material is considered already in the cycle, then it can be argued that the waste derived fuel will be displacing fossil fuels. It should be noted that the end use of the material will still create CO_2, as the final use is a combustion process. But if it can be argued that this material would have degraded into CO_2 eventually then it can be considered a trade off. A rough calculation attached in the economic spreadsheet shows that one Tonne of waste would displace 0.133 Tonne of methane if combusted as syngas. The calculation is a little more complicated for the methanation process as CO_2 is created in the production of hydrogen. But again this material is already in the cycle. From rough calculations 1 Tonne of waste material could be converted into 0.22 Tonne of methane. Table 3 below shows how these values relate to the scenarios developed previously.

Scenario	Population	Dry Waste KT/yr	Diplaced Fossil methane by syngas Te	Diplaced Fossil methane by Methanation Te
City	500 K	490	65 K	107 K
Town	50 K	49	6.5 K	10.7 K
Village	5 K	4.9	0.65 K	1.07 K
Rural Community	0.5 K	0.49	0.065 K	0.107 K

Table 3: Amount of methane displaced from the previously developed models

Waste materials processed in these ways would at present be incinerated or sent to landfill. The carbon benefits with respect to these disposal routes are as those discussed in the previous reports. These are the perceived low efficiency of incineration systems and the methane creation that occurs in the landfills. Plus the fact that the landfill availability in the UK is being phased out.

5 The Opportunity for ETI Intervention

The analysis presented in this report shows that the grid injection of waste syngas derived material has potential as a non fossil fuel alternative. The quality of gases produced in contaminants and especially in calorific value may be quite a challenge to the uptake of the technology. The process steps are all well known and have been used for many years. To date the gasification processes have not been proven on wastes although many large scale gasifiers have utilised waste streams at a low level with coal. Early stage work on methanation is underway to make a more acceptable direct injection gas, this technology is similar to that that would be used in chemicals and fuels process routes and there may be some synergy in joint development of the technologies.

- To develop syngas complexes for the production of syngas or SNG for direct injection into the grid. This is unlikely to be a major project for the ETI due to the scale of investment required
- To support the development of novel low cost high yield processes for the production of high quality fossil methane replacement from waste derived syngas.
- To support opportunities for local small community use of raw syngas in domestic use. That is a local small grid, depending on numbers biomass or fossil fuels would need to supplement this demand. Small communities at present that are off grid use local oil or propane storage as their domestic fuel supply.

Both these areas would benefit from the development of gasification technology and gas cleaning technology programmes that were proposed in the core ETI EFW project. This work reiterates the value of the core project proposals.

The UK also has the technological capability to develop low cost high yield syngas to grid injection processes, but to realise the opportunities that have been identified over the years there would be additional benefits from creating a consortium of organisations to come together for this purpose. For example, there are well established organisations in the UK with proven expertise in the following relevant areas.

- Universities – experience with FT reactions and the developments of catalysts;
- Business – the commercial development of catalysts and supply of feedstocks;
- Innovation agencies – the practical development of processes to advance syngas to fuels processes to TRL range 4-7.

There are good prospects for the UK to be able to develop and use such a process but no single organisation is in a position to do so.

As a development programme, work should involve a focus developing a pilot scale plant next to a gasification development facility with the emphasis on the syngas to fuel step. Such a programme would be a significant capital investment. It is highly unlikely that such an investment would be made by business without an external driver. The ETI could be such a driver by issuing a call for technology if it decides that this technology has a high enough priority when compared to its other technology development options. It could invite a consortium to form to undertake a development programme of work with the following objectives.

- To develop and demonstrate pilot scale technology for conversion of syngas into fuel for direct grid injection FT or other processes to advance the TRL to 7;
- To establish the range of biomass and waste types and pre-treatment processes that are required to supply the process with a particular emphasis on the use of waste biomass;
- To undertake environmental, economic and engineering studies into the application of that process in the UK.

The assessment criteria for selecting the preferred consortium should include their capability and intent to further develop and commercialise the outcomes from the work. ETI should expect consortium members to invest their own resources into the project (in cash or kind) although it must recognise that the fundamental role of ETI is to de-risk the development work significantly to enable development to take place.

The benefits of promoting this work would be to catalyse the development of new energy technologies that can convert waste biomass into fuels, thereby reducing emissions of greenhouse gases and consumption of fossil fuels. A successful process would also provide economic opportunities for those involved in its development.

Appendices

Appendix A. Information on the national grid

The Grid[4]

Gas is delivered to nine reception points, or *terminals*, by gas producers.

After treatment, which includes checking the gas quality meets statutory safety requirements and measuring the calorific value (the amount of energy contained), the gas is transported around Great Britain through over 278,000 kilometres of iron, steel and polyethylene mains pipeline.

From the terminals, gas enters the national transmission system (NTS), which is the high-pressure part of National Grid's pipeline network, consisting of more than 7,600 kilometres of top quality welded steel pipeline operating at pressures of up to 85 bar (85 times normal atmospheric pressure, over 1250 psi). The gas is pushed through the system using 23 strategically placed compressor stations.

The NTS supplies gas to UK end consumers from over 175 off-take points including large end users which are primarily large industrial consumers and power stations, who receive gas directly from the national transmission system rather than through a distribution network, and the twelve local distribution zones (LDZ) that contain pipes operating at lower pressure which eventually supply the smaller end consumers, including domestic customers.

As well as meeting the standards for quality the systems developed would be required to achieve the pressure requirements.

Table 2: Gas quality requirements for injection into the UK gas grid9,10 Criterion	**Requirement**		**Comments**
Hydrogen Sulphide		< 5mg/m3	
Total Sulphur		< 50mg/m3	
Hydrogen	< 0.1% (molar)		Original syngas is H_2-rich, any left over after the methanation process is recycled. Danish Gas Technology Centre is investigating transmission of high H_2 blends
Oxygen	< 0.2% (molar)		National Grid and Ofgem discussing changes to relax limit to 1% to support biomethane injection. Sweden allows 1%, Germany 3%
Hydrocarbon Dewpoint		< -2°C at any pressure	
Water Dewpoint		< -10°C at 85 bar	
Wobbe Number11	47.20 to 51.41 MJ/m3 (real gross dry)		Important range, to meet gas-air burning safety requirements for UK appliances

[4] "National Grid" About the gas industry: How gas is delivered. http://www.nationalgrid.com/uk/Gas/About/How+Gas+is+Delivered/

Incomplete Combustion Factor	< 0.48	
Soot Index	< 0.60	
Gross Calorific Value	36.9 to 42.3 MJ/m^3 (real gross dry)	Subject to location and volumes, injectors might be set a target within this range. BioSNG can have a lower CV, which may need to be corrected for by adding propane, or through future smart metering/billing
Carbon Dioxide	< 2.5% (molar)	Gas after methanation is mostly methane and CO_2, majority of the CO_2 must be removed
Contaminants	No liquids or solids	
Organo Halides	< 1.5 mg/m3	
Radioactivity	< 5 Becquerels/g	
Odour	Must have a distinctive and characteristic odour at <7bar	
Pressure	> back pressure at Delivery Point, < maximum operating pressure	
Temperature	1 to 38°C	

Appendix B. Base Case spreadsheet for Syngas and methanation injection

CITY OF 500K PEOPLE

WASTES	UNITS	BASE CASE
Dry Waste Weight	kt/yr	490.00
Dry Waste Energy	MJ/Yr	4.79E+09
Cost of Dry Waste	£/t	-30.00
Gasification	%	100.00
Electricity Price	£/KWh	0.06
Gasification		
Capital/kt	£k/kt	350.00
Plant Capital	£M	171.50
Plant Operating Cost	3% Capital/Yr	5.15
Plant Feed	Kt/Yr	490.00
Plant Feed	MJ/Yr	4.79E+09
Feedstock Cost	£M/kt	-14.70
Plant Efficiency	%	70.00
Yield Syngas	Kt/Yr	1162.22
Calorific Value of syngas	kj/kg	4403.25
Price per Kwh		
Kwh available	Kwh	1.42E+09
Syngas in therms		48504856.57
Syngas Price per therm (equal basis with methane)	£/therm	0.50

Value of Syngas	£M/Yr	24.25
Simple Profit gas replacement	£M/yr	16.66
Wastes and Emissions		
Carbon Dioxide	kt/yr	217.81
Char	kt/yr	0.00
Split Syngas		
Electricity	%	33.00
Chemicals	%	33.00
Fuel	%	34.00
		100.00
Methanation		
Capital/kt	£k/kt	100.00
Plant Capital	£M	116.22
Plant Operating Cost	3% Capital/Yr	3.49
Plant Feed	Kt/Yr	1162.22
Plant Feed	MJ/Yr	
Feedstock cost	£/therm	0.50
Feedstock Cost	£M/yr	24.25
Plant Yield	Kt/yr	110.78
Calorific Value	Kj/kg	50000.00
Energy Production	KWh/Yr	1.54E+09
Gas price per therm	£/therm	0.80
Value of Electricity	£M/Yr	42.00
Simple Profit	£M/yr	2.64