TESTING OF RENEWABLE FUELS IN A 80 KWE DOWNDRAFT GASIFIER

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Contractor

Biomass Engineering Ltd.

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EXECUTIVE SUMMARY

Biomass Engineering Ltd. have demonstrated that their downdraft gasification technology is capable of producing very low tar levels in the producer gas, as independently measured, and have four gasifiers in operation. Developments in the gasifier configuration have led to a very low tar gas, allowing a simplified hot gas filtration system to be used. Recent independent analysis of the ''tars'' from the Mossborough Hall farm gasifier at Rainford, NW England has shown that over 80wt% of the condensable organics in the gas are benzene, toluene, xylene and naphthalene and that problematical tar components in the gas were less than 20 mg/Nm^3 under prolonged operation. The gasification technology of Biomass Engineering Ltd. is therefore close to a warrantable commercial reality.

Biomass Engineering Limited has succeeded in developing a downdraft gasifier capable of producing a very low tar, low particulate gas of consistent high calorific value [> 5 MJ/Nm^3 for wood feedstocks]. However, with the development of a technology capable of handling a well-defined wood, there is a requirement to assess the possibility of using other non-standard fuels, especially as these are more readily available in some locations and where other disposal and transportation options are not economical. To this end this work was concerned with testing a variety of fuels in an existing 80 kg/h (80 kWe) gasification system and measuring a range of process emissions and assess whether they could possibly be used in a downdraft gasifier for gas production for use in a boiler or engine. The fuels used were: dried papermill sludge [briquetted], dried leather wastes [briquetted], palletwood wastes [and some demolition wood], medium density fibreboard [MDF], panel board and other chipped pallets], pine/bark mixed waste strippings and renewable biomass fuel [RBF] produced from the organic fraction of MSW.

The Biomass Engineering Ltd. technology is a throated downdraft gasifier and it can be operated using different gas cleaning systems, including cyclones for dust removal, hot gas filter for very high dust capture efficiencies [>99.9wt%] on low tar gases and a wet scrubbing system for contaminated [volatile metals] and high tar gases. Wastes with high ash contents are more prone to high levels of tar formation. Tests of over 60 hours on each fuel were carried out, except for the RBF, of which there was only a limited quantity and of highly variable quality, which caused various processing difficulties.

Tests on the fuels showed that the high ash feedstocks [>15wt%, RBF and papermill sludge] were problematical in gasifier operation and not unexpectedly gave a producer gas with low heating values in the range of 1-3 MJ/Nm^3. The buffings dust, pine/bark mix and the palletwood could be satisfactorily gasified to give a gas with a good lower heating value of 4-5 MJ/Nm^3. This is the expected value for low ash feedstocks with low tar levels in the gas. Extensive analyses of the feedstocks, the by-products chars and ashes, the producer gas and some of the condensates were made. The RBF fuel was prone to clinker formation on the grate possibly by the formation of low melting eutectic of SiO_2 and CaO [or a derivative]. The chars exhibited high carbon conversions of typically over 85wt%.

Preliminary analyses of the condensate from the gasification of the leather wastes demonstrated that the disposal of this, and therefore any wet scrubbing medium used to remove tars, would be problematical. The component tars contain polyaromatic hydrocarbons, which are generally regarded to be toxic and possibly mutagenic or carcinogenic, depending on exposure and concentration.

The palletwood fuels and other wood related fuels are acceptable as gasification fuels; however the high ash fuels are not particularly suitable beyond their use as a fuel gas for use in a boiler. Further work is essential on the gas analysis for volatile metals to assess whether are likely to be deposition issues in the system.

The costs involved in the preparation of dusts and powders, as typified by the RBF, leather and papermill residues into a densified fuel for downdraft gasification will add significantly to the cost of the process in terms of the additional capital and operating requirements for a system [~10%] and for power production approximately 1.5-2.5 p/kWh on the electricity production cost, or 0.75-1.5 p/kWth on heat use. The final decision on whether a system would be economical will depend on a variety of factors including waste disposal options and costs, transportation restrictions on wastes, useful or valuable by-products and the end use of the gas whether for heat or power generation.

The use of a dry hot gas filtration process for leather wastes and the RBF is highly unlikely due to high tar levels in the gas. The other wood wastes could utilise hot gas filtration for particulate removal.

No engine testing was carried out, partly due to unknown tar levels in the gases; however some engine testing was carried out in the pine/bark derived gases at Mossborough Hall Farm, Rainford. The tests demonstrated that the Iveco engines could run satisfactorily on the gas. The use of clean wastes in the gasifier is achievable and increases the scope of the gasification process to accept other non-uniform wastes.

Further work on assessing tars, particulates and trace metals emissions would help to improve the long term viability of operating dry gas cleaning systems if the levels of metals are acceptable for removal in the hot gas filter. There is a need to develop UK expertise in tars and particulates measurement so that the industry has access to several companies offering such services. At present, the industry is reliant on independent testing from other countries, which is not a satisfactory position. Further work on optimising briquette density is required for the leather dusts and other related wastes such as the RBF. This would ensure that the gasification process operates smoothly and efficiently to gasify the organic components and avoid the formation of hard ahs agglomerates which do not flow through the gasifier.

There is a need to complete further fuels testing and carry out engine tests with the fuels and measure the engine emissions. There may also be a need to assess the use of engine catalysts for CO abatement in the engine exhausts.

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1. INTRODUCTION

Biomass gasification in the UK has met with limited success at large scale, primarily with the very limited success of Project ARBRE and a lack of implementation of other NFFO bio-energy projects utilising gasification or pyrolysis. There has been some success at small-scale with several small commercial and R&D units operating at capacities less than 150 kWe, although recently some of these have abruptly stopped. There are less than 10 small-scale gasifiers operating in the UK with a total installed capacity of less than 2 MWe.

Biomass Engineering Ltd. have demonstrated that their downdraft gasification technology is capable of producing very low tar levels in the producer gas, as independently measured, and have several gasifiers in operation as indicated in Table 1. Recent results from the Mossborough Hall farm gasifier has shown that 80-wt% of the condensable organics in the gas are benzene, toluene, xylene and naphthalene and that problematical tar components in the gas were less than 20 mg/Nm^3. The gasification technology of Biomass Engineering Ltd. is therefore close to a commercial reality.

Table 1. Biomass Engineering Ltd. Gasification systems

Client/ Location	Plant capacity	Feedstocks	Fuel use	Hours of operation	Status
Ballymena ECOS Centre, Northern Ireland	55-65 kWe 55-65 kWth recovered	Willow, pine, spruce, poplar, bark strips, sawmill wastes	• Power generation and heat recovery for building	> 3500	Operated over winter season
Biomass Test unit Newton-le-Willows, England	80 kg/h Maximum 80-85 kWe 160-200 kWth	Spruce, poplar, willow, papermill sludge, demolition wood, leather wastes, buffing dust, palletwood, beech, RDF	• Particulate filtration trials • Capstone C-330 testing • Gas engine testing • Scrubber trials	> 2000 on power generation > 2500 on feedstocks	Available for testing
British Leather Corporation, Leeds, UK	50 kg/h 100 kWth boiler use	Leather dust Sludge cake	• Boiler use • Cr III metal recovery from char/ash	>450	Dormant
Mossborough Hall Farm, Rainford, England	250 kWe 250 kWth for drying	Mixed conifer, poplar	• Power generation	> 1000	Operational
Jepsons, Culcheth, England	85 kWe 170 kWth	Mixed woods	• Power generation		Awaiting grid connection

Notes: RDF – Refuse Derived Fuel

Biomass Engineering Limited has succeeded in developing a downdraft gasifier capable of producing a very low tar, low particulate gas of consistent high calorific value [> 5 MJ/Nm[3] for wood feedstocks]. However, with the development of a technology capable of handling a well-defined wood, there is a requirement to assess the possibility of using other non-standard fuels, especially as these are more readily available in some locations. To this end this work was concerned with testing a variety of fuels in an existing 80 kg/h/80 kWe gasification system and measuring a range of process emissions and assessing whether they could possibly be used in a downdraft gasifier. The fuels used were:

- Papermill sludge
- Leather wastes
- Palletwood wastes [some trials were also done on demolition wood with medium density fibreboard [MDF] and panel board and chipped pallets].
- Pine and bark mixed waste strippings
- Renewable biomass fuel [RBF] produced by Fairport from the organic fraction of MSW.

The 80kg/h test has a waster scrubbing system or hot gas filter and is coupled to an Iveco G.E.8061SRi25 gas engine [130 kWe on natural gas, 80-85 kWe on producer gas]. This unit was used to test the fuels, subject to amounts available for testing.

The aims of the project were to build on the experiences of the past 8 years and test further feedstocks under controlled conditions and properties and assess their influence on the gas quality in terms of tar and particulate content, gas composition [CO, CO_2, H_2, CH_4 and permanent gases up to C_4's] and lower heating values of the gases. The project aims were:

- Operate an existing 80 kWe downdraft biomass gasifier on four different feedstocks to asses the effects on the gasification process and how the composition of the feedstock influences the gas quality and the char/ash properties from the process.
- Reduce capital cost of process [calculated to be > 10% reduction], by using dry filtration and demonstrate effectiveness of gasifier in producing gas of sufficient quality for use in a SI engine.
- Determine the costs of briquetting fuels that would not otherwise be used for small-scale gasification. This may open up the possibility of using sawdust as a briquetted fuel in a downdraft gasifier, depending on the costs incurred.
- Optimise a dry filtration system for several feedstocks, avoiding water use in process. One fuel, the leather waste would not be suitable for hot gas filtration.

Use of a dry filtration system allows only condensate to be recovered from the process and avoids the need for onsite water treatment. The condensates were assessed for a range of properties including biological oxygen demand [BOD], chemical oxygen demand [COD] and pH. The proposed benefits from the work are:

- Increased flexibility of downdraft gasifier to accept a range of fuels.
- With offset of landfill taxes and reduced feedstock cost, electricity production costs can be reduced by 30%.

- Quantified emissions and monitoring to ensure environmental compliance.
- Confirmation of low tar and particulate levels and gas engine operation on different gas compositions from four feedstocks.
- Increased export opportunities for UK manufactured systems and system elements as a complete power ''island'', with the backup of Biomass Engineering Ltd. and a suitable engine company.
- Increased potential market for biomass gasifiers.

The advantage to UK industry would be in the development of an integrated technology suited for use in locations where a variety of waste wood materials and MSW-derived renewable energy fuels [REF] could be used. The project would develop a niche market for bio-energy applications.

1.1 Project Scope

The scope of the project included operation of the 80 kg/h downdraft biomass gasification system on a range of fuels and taking measurements. The objectives and deliverables of the project were:

- Achieve 60-100 operational hours with the gasifier coupled to the gas engine to provide data for a commercial system, operating on a variety of wood residue fuels, including recycled wastes, industrial wood wastes, energy crops and measure all the emissions from the process.
- Demonstrate flexibility of gasifier to handle briquetted materials [REF], chipped material [poplar] and harvested biomass [willow], chipped forestry wastes [log strippings].
- Determine optimal parameters for ceramic filter performance and longevity on producer gas from different feedstocks.
- Confirm environmental compliance by extensive monitoring programme and characterisation of the product, both in-house and by independent companies/laboratories.
- Measure the engine electrical efficiency, emissions, deration and assess performance.

The duration of the project was from October 2004 to April 2005. The project was extended by 6 months to November 2005 due to delays in procuring fuels and a lack of analytical support on the measurement of tars and particulates in the producer gas.

The scope of the fuels to be tested changed slightly due to availability of sufficient quantities and also more commercially relevant, i.e. leather wastes and palletwood. Engine testing was not carried out due to a lack of data on the tars and particulate levels in the gases. Also the leather wastes were prone to visibly high tar levels in the gas, which would be unsuitable for use in a hot gas filter.

2. SYSTEM CONFIGURATION AND OPERATION

2.1 System configuration

The system flowsheet is shown in Figure 1 with the respective equipment codes in Table 2. The delivered fuels were either in sealed drums or delivered as is to site for use. As there is limited fuel preparation possible at the test gasifier, most fuels need to be prepared offsite and brought in the required form, to the correct moisture content.

Biomass is lifted onto the belt [C01] and conveyed to the top of the gasifier [V01], or loaded in manually, depending on the length of the run and the fuel form. A slide valve arrangement allows fuel to be dropped into the gasifier as required. The fuel is then gasified under a slight negative pressure and the hot gases during start-up are drawn through the start-up fan [F01] to a flare [S02] with solids removal in the cyclone [S01].

Char and ash, which fall through the gasifier grate, are recovered in a char/ash storage bin [V02]. When the desired producer gas flowrate has been reached, the start-up fan is stopped and the main gas fan [F02] started and the gases drawn through the scrubber tank [S03] and demister pad mounted on the tank. The tank liquids are cooled by an external cooling loop from a sealed fin cooler [H02] coupled to a cooling coil [H01].

The cooled producer gases are passed through the main gas fan [F02] to the gas buffer tank [V04]. Prior to the engines being brought on line, the producer gas is flared [S04] until the desired flowrate has been reached from F02. The gas engine [E01] is brought on line and started solely on producer gas as required.

Table 2. Codes for the unit operations and equipment in Figure 1

Code	Description	Code	Description
C01	Wood Feed Conveyor	S01	Char cyclone
E01	Gas engines	S02	Start-up flare
F01	Start Gas Fan	S03	Quench tank and demister
F02	Main up fan	S04	Main flare
H01	Producer Gas Cooler	V01	Downdraft Gasifier
H02	Cooling tower and fan	V02	Char/Ash Storage Bin
P01	Quench recirculation	V03	Char/Ash Storage Bin
P02	Cooling tower pump	V04	Gas Buffer

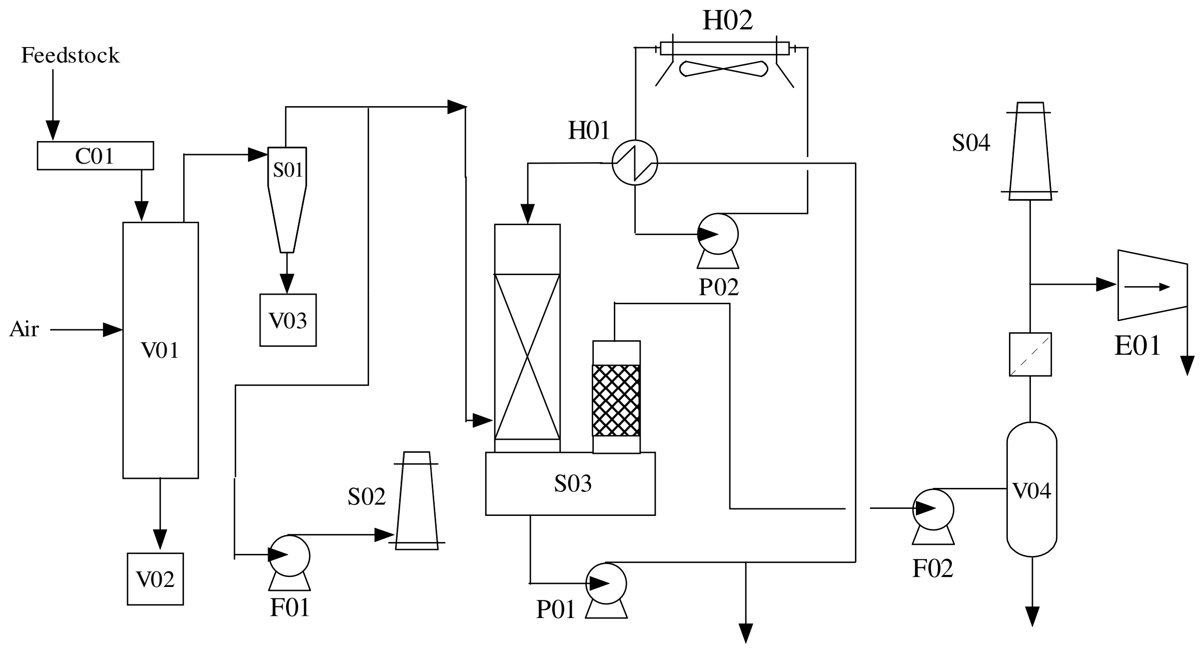

Figure 1. Biomass Engineering Ltd. 80 kWe [net] test gasifier configuration

2.2 Operation on feedstocks

The feedstocks to be tested were provided from various sources and this has led to delays in the implementation of the work, in particular from Fairport and originally Rainworth Fencing had been specified as providing log strippings, however Egni were able to supply strippings in conjunction with other wood deliveries to the Rainford site. There have also been major issues over getting the tars and particulates analysed in the UK and Biomass Engineering Ltd. was unable to schedule CRE to do the required analyses. Despite 2 site visits and repeated contact, CRE were unable to comply with Biomass Engineering Ltd.'s requirements.

It had been planned to use chipped poplar, however, The Poplar Tree Company could not provide material to the required specification: one batch of chipped material was contaminated with primer paint and could not be used. Despite repeated efforts to get willow from Coppice Resources Ltd., they also could not supply material in a pre-chipped form to the required specification. The municipal solids waste [MSW] derived material, known as Renewable Biomass Fuel [RBF] was supplied by Fairports. As noted Egni supplied the log strips from pine and this was found to have typically 9wt% bark as a minimum. Other wastes tested to replace the willow and the poplar were papermill sludge, leather waste [the form of which is known as ''wet blue'' and is the dust produced from the buffing of tanned leather goods] and pallet wood [replacement for poplar]. Blends of sludge cake and buffings dust were also tested. The feedstock analyses are given in Table 3.

Table 3. Feedstock analysis

Source	BLC	Fairport	Private	Private	Egni
FUEL	Wet blue	RBF	palletwood	Papermill sludge$^{\$}$	Pine/bark [8wt% bark]
Proximate Analysis (wt% as received)					
Moisture (%)	11.29	5.0	15	13.2	18.9
Volatile matter (%)	67.51	52.4	82.1	59.9	NM
Ash (%)	4.96	16.3	2.5	28.8	1.6
Fixed Carbon (%)	16.24	26.3	NM	NM	NM
Ultimate Analysis (wt% dry basis)					
Carbon (%)	47.80	41.2	47.8	24.3	50.13
Hydrogen (%)	6.40	5.9	6	3.31	5.91
Nitrogen (%)	10.70	NM	0.07	0.4	0.11
Sulphur (%)	1.43	NM	NM	0.14	NM
Oxygen (%)	28.71	33	46.2	43.1	42.25
Chrome (%)	1.34				
Heating Value (as received)					
HHV (MJ/kg)	19.6	19.3	NM	15.6	NM
LHV (MJ/kg)	18.5	NM	NM	14.9	NM

Note: NM Not Measured

Table 4. Detailed metals analysis of the RBF

	RBF Sample 1	RBF Sample 2	Papermill pulp Sample 1	Concentration
Antimony	0.2	34	0.1	mg/kg
Arsenic	0.6	22	< 0.1	mg/kg
Cadmium	0.14	3.1	0.17	mg/kg
Chromium	28500	37100	4.5	mg/kg
Copper	20	104	24.6	mg/kg
Fluorine	23	129	34	mg/kg
Lead	2.9	1940	1.7	mg/kg
Mercury	65.8	27.8	0.04	mg/kg
Nickel	495	634	2.6	mg/kg
Potassium			187	mg/kg
Sodium			549	mg/kg
Vanadium	<5	<5	1.4	mg/kg
Zinc	57	1330	148	mg/kg

The first material provided to Biomass Engineering Ltd. from Fairport was a very poor quality material, with high levels of glass, visible in 7-12 mm pieces and also pieces of Al foil and discrete plastic pieces. This was the lowest quality of RBF and subsequent batches were lower in glass and foil, but the ash content of the materials remained relatively high [> 10 wt%].

3. OPERATION ON VARIOUS FEEDSTOCKS

One of the issues of operating a downdraft gasifier on a variety of fuels are:

- Feedstock preparation – size, moisture and ash contents,
- Flow behaviour in the gasifier,
- Operability and gasification performance.

Comments and observations are made on the various fuels used in the trials below

3.1 Pine wood and pine bark

The pine wood strips with bark proved to be a particularly difficult fuel, which required extensive pre-treatment to remove stringy bark, which was caused bridging of the gasifier on several occasions and therefore chopping of this material to a small size in chipper requires screening of the large strips of bark which are peeled off, but which aren't processed to a smaller size.

Trials on this fuel were carried out on the Rainford gasifier, as there were drying and chipping facilities there. A Laimet HP25 chipper was used to cut the log strips and then this material could be dried using engine exhaust gas to the desired moisture content.

When the material was screened to remove strips and long pieces, the fuel would feed satisfactorily. It was observed however that the bark still attached to the wood pieces tended to be very resistant to drying in the vibratory feeder/dryer and pieces could have moisture contents typically 20-30% that of the dried wood. Upon sorting of the pine/bark chippings from the longer pieces, the material could be satisfactorily gasified.

3.2 Fairport RBF

The Fairport RBF supplied for the first trials was not a particularly suitable feedstock. The material supplied by Fairport was noted to contain a significant amount of glass and large shards of 7-12 mm were visible in the briquetted materials. The material is also very dry for gasification [3-5wt% water] and this adversely affects the gas quality by producing more unreacted carbon. The ahs content was high – over 16% and in some samples over 25wt%. The briquette density was initially too high at over 800 kg/m^3. Very high briquette density leads to incomplete gasification and poor gas quality. Later samples were below 700 kg/m^3 – closer to a hardwood density which was more suitable.

During the runs on RBF, manual pokering of the bed was required to move the charred briquettes down through the gasifier. The briquettes of material could be seen to be reacting, but the briquettes didn't shrink in size – they retained their original size and shape. Bed avoidance was high, due to the high levels of oxygen in the product gas [up to 8 vol%], which would be expected to be zero in an ideal system. The material therefore did not flow well down the gasifier and grate blockages were a regular problem. Photograph 6 at the end also shows that some fraction of the RBF were prone to melting and forming ''strands'' or clinkers below the grate. This in turn would lead to grate blockage and in one case, damage requiring grate replacement.

Although not ideal, some gasification of the material did occur, however, the char/ash left in the briquettes did not fracture into the expected smaller char pieces and consequently some bypassing of gases occurred through the gasification/reduction zone of the gasifier. Due to the high ash content, the briquettes, only shrank partially and therefore did not flow well within the gasifier.

The material therefore does not gasify particularly well, as the O_2 concentration in the exit gas demonstrates that there is preferential bypassing of the briquettes by approximately 30% of the air, or more, leading to the poor quality gas. A photograph of the briquetted material is at the end of the report [Photograph 3].

3.3 ''Wet blue'' leather wastes

Wet blue or buffing dust is the residual dust recovered from the buffing of the treated tanned leather and consequently contains 1-3 wt% Cr_2O_3. The dust must therefore be briquetted prior to use. This was done internally by Biomass Engineering Ltd. and by varying the die pressure, briquettes of a suitable density could be formed. Briquettes of high density do not gasify well and can lead to reduced gasification and excessive formation of pyrolysis aerosols. The material is also very dry [< 5wt% water], so the water content was below the ideal lower limit of ~15wt% water. A photograph of the briquetted material is at the end of the report [Photograph 4].

Unlike the RBF, the briquettes of buffing dust tended to break up upon gasification and regular riddling could remove the residual char/ash, mostly as fine dust.

3.4 Palletwood

The chipped palletwood did not present any particular difficulty when gasified. Chipping of the palletwood led to ''chunked'' material which fed easily and gasified as expected. A photograph of the briquetted material is at the end of the report [Photograph 2].

3.5 Papermill sludge

Due to the nature of papemill sludge, it can be briquetted relatively easily and this was done on site by Biomass Engineering Ltd. Briquettes of papermill sludge gasified similarly to that for leather dust. The high level of CaO which is present in paper is in the form of finely ground powder. Upon gasification, the briquettes tend to readily fall apart and the find dust could easily be removed through the grate, however this tendency also led to poor gasification of the material.

The papermill sludge is particularly high in ash [28.8wt%] and some sludge can have as much as 50wt% ash in them. This reduces the overall gasification efficiency as the high ash levels mean that a significant proportion of the biomass energy is adsorbed as sensible heat by the ash. A photograph of the briquetted material is at the end of the report [Photograph 5].

3.6 Cost of briquetting fuels

Biomass Engineering Ltd. used a small onsite briquettor to process the dusts and fibrous feedstocks into briquettes. It is expected from this experience that the additional cost of preparing such materials in a form suited to the downdraft gasifier would be in the range of an extra 1.5-2.5 p/kWh on the electricity generating cost. This may in turn be substantially offset by the processor receiving a gate fee for waste disposal or avoidance of additional landfilling and transportation costs for the waste, notably the RBF and the leather buffings dust.

Processing of wastes for gasification systems less than 250 kg/h would not be economically viable due to the additional labour, maintenance and parasitic electricity requirements in the operation of the briquettor.

4. PRODUCT ANALYSIS

The product streams from the gasifier have been analysed to a limited extent, primarily due to cost of analyses and in some cases, difficulties in obtaining relatively homogeneous samples.

- Char and ash recovered from the bottom of the gasifier and the cyclone ash bin,
- Producer gas from the gasifier and after scrubbing and demisting.

Detailed analytical results are given below in Table 5.

4.1 Byproduct Char

Table 5. Product char compositional analysis. Ash on a wt%, dry basis

Feedstock	C	H	N	S	Cr	Cl	Ash
Buffing dust char/ash	15.43	0.22	0.81	0.27	3.50	NM	79.8
RBF char/ash	NM	NM	NM	NM	0.0	NM	85.2#
Papermill sludge	9.6	1.1	NM	NM	0.0	0.08	94.1#
Pine/bark char	27.0	3.5	<0.1	NM	0.0	0.0	75#

Notes # high ash due to oxidation of the reduced metals in air. NM Not measured

The oxygen results are not reported for the recovered materials, as during tests for ash, some samples: samples tended to increase in weight as metal ions oxidised upon reheating in the presence of air. As can be seen, most of the solids had high carbon conversions, with high ash contents [> 75wt%] present in the samples. The ash recovered from the buffing dust had Cr(III) levels of 3.5wt%. Detailed analyses were carried out on the RBF residual char and ash and are presented in Table 7.

4.1.1 RBF Char Leachate Tests

The char produced from the Fairport trials has been extensively characterised and additional tests on its behaviour were made, including leaching, metals and dioxins. The results are presented in Table 6.

Table 6. Leachate test to NRA Protocol

Metal		Leachate rate
Cadmium	Cd	4 µg/l
Lead	Pb	46 µg/l
Zinc	Zn	<5 µg/l
Copper	Cu	25 µg/l
Thallium	Th	<100 µg/l
Mercury	Hg	0.05 µg/l

4.1.2 Dioxin in the RBF Char

A sample of the char from the RBF waste Gasification process showed a dioxin content of 0.837 ng/g. This would be of some concern and needs to be further addressed either by process modifications to ensure no air bypassing and lower levels of Cl and Cu in the material where possible.

4.2 RBF Clinker deposits

As noted, gasification of the RBF led to the formation of ''clinkers'' on the grate and as deposits below the grate. Deposits formed in the gasifier were analysed and the results are in Table 7. The test for ash reduces the various carbonates, hydrogen carbonates, etc. to oxides, therefore these are not indicative of the original compounds which can lead to low temperature eutectics and cause clinker problems. Lowering of the ash content should reduce this problem.

Table 7. Fairport RBF char/ash analysis

	ash analysis RBF		
Elemental Oxide	Sample 1	Sample 2	clinker
SiO_2	6.9	8	44.7
Al_2O_3	6.3	5	10.1
Fe_2O_3	1.7	1.2	9.9
TiO_2	0.4	0.4	0.9
CaO	47.2	47.3	17.3
MgO	2.1	2.6	1.8
Na_2O	0.5	0.2	6.1
K_2O	0.1	<0.1	1.2
Mn_3O_4	0.1	0.1	0.2
P_2O_5	2.6	2.3	1.1
SO_3	13.5	22.7	0.4
Total analysed	81.4%	89.8%	93.7%

The additional processing requirements for the fuels containing metals, or those prone to forming chars/ashes which may be classed as wastes may also need to be carefully considered – see Table 6.

4.3 Producer gas analyses

From the initial commissioning through to the end of the contract, gas samples were regularly taken and analysed by Aston University for a full range of gases. Typical results are given in Table 8 overleaf. These results are typical of downdraft biomass gasification systems.

Table 8. Producer gas compositions [vol%, 20°C, 101235 Pa] [averages]

	Papermill sludge Average [vol%]	δ_{dev}	Buffing dust Average [vol%]	Pine/bark Average [vol%]
H_2	3.4	2.96	11.1	15.49
CO	2.4	2.26	15.06	17.68
CH_4	0.5	0.43	1.1	1.80
C_2H_4	0.2	0.17	0.3	0.45
C_2H_6	0.0	0.03	0.01	0.05
C_3H_6	0.0	0.03	--	0.03
C_3H_8	0.0	0.03	--	0.00
n-C_4H_{10}	0.0	0.01		0.01
CO_2	18.7	4.49	8.6	14.32
N_2	74.7	1.60	58.65	50.16
HHV [MJ/Nm^3]	1.06		3.9	5.28
LHV [MJ/Nm^3]	0.96		3.7	4.88

The papermill sludge gives a very poor quality gas, in terms of heating value, due to the high ash content. This was expected and shows that as a fuel, it is not particularly well suited to gasification. The buffing dust is acceptable and has a LHV approx 20% lower than that of the pine/bark mixture.

Table 9. RBF and wastes producer gases analyses [averages]

	Palletwood		RBF		Demolition wood	
Gas component	Average [vol%]	δ_{dev}	Average [vol%]	Average [vol%]	Average [vol%]	δ_{dev}
H_2	7.9	1.9	9.6	9.74	11.3	0.8
CO	19.2	3.3	11.9	13.63	23.0	1.6
CH_4	1.0	0.5	0.6	0.45	1.0	0.3
C_2H_4	0.0	0.0	0.1	0.08	0.0	0.0
C_2H_6	0.0	0.0	0.2	0.19	0.0	0.0
C_3H_6	0.0	0.0	0.0	0.00	0.0	0.0
C_3H_8	0.0	0.0	0.0	0.00	0.0	0.0
n-C_4H_{10}	0.0	0.0	0.0	0.00	0.0	0.0
CO_2	15.4	1.3	10.4	10.24	12.6	1.0
N_2	56.4	1.7	67.1	65.67	52.1	1.4
HHV [MJ/Nm^3]	3.6	0.4	2.1	3.1	4.4	0.2
LHV [MJ/Nm^3]	3.4	0.4	2.0	2.9	4.2	0.2

The papermill sludge gave the lowest LHV gas at 1.1 MJ/Nm^3. This would only be suitable for boiler use and not engine use. RBF was next and gave similar results to the papermill sludge with a gas LHV of 2.1-3.1 MJ/Nm^3. This poor result was in part due to the bypassing in the gasifier and the poor quality of the RBF.

4.4 Wastewater

Wastewater samples were sent for specialist analyses to the Institute of Wood Chemistry, Hamburg, Germany to assess likely organic contamination, but not quantification, at this stage indication of the potential chemicals was considered important. The sample was condensate from gas fan using buffing dust as feedstock [see Figure 2].

Although a full wt% analysis of the main chemicals was not possible, the GC-MS analysis gives the relative areas for the identified chemicals and this is a crude indication of the particular chemical's concentration in the liquids. The results from IWC were not very encouraging, indicating the presence of several carcinogenic and toxic chemicals. The indicative chemicals that were identified are summarised in Table 10.

The gas fan condensate drained after running on buffing dust contains a few chemicals, which are partially oxygenated and should be more susceptible to treatment for subsequent disposal. Further work on the BOD, COD, total organics carbon [TOC], pH and dissolved metals needs to be carried out. It is unlikely that the condensate, the scrubber residues or tars could be sent to a conventional biological treatment facility.

Table 10. Chemical analysis of the gas fan condensate

RT	Area%	Library/ID
6.58	2.07	Propane, 2,2-dimethoxy-
11.53	0.65	Pyridine
13.81	16.71	Furan, 2,5-dihydro-2,5-dimethyl-
13.89	0.62	Ethanone, 1-(2-methylcyclopropyl)-
15.27	0.56	Pyrrole
18.78	5.36	2-Pentanone, 4-hydroxy-4-methyl-
20.44	0.65	2-Pentanone, 4-methoxy-4-methyl-
23.08	0.5	Pyridine, 2,4,6-trimethyl- or Pyridine, 2,3,6-trimethyl-
26.52	0.27	Aniline
52.05	1.13	2,4-Imidazolidinedione, 5-methyl-

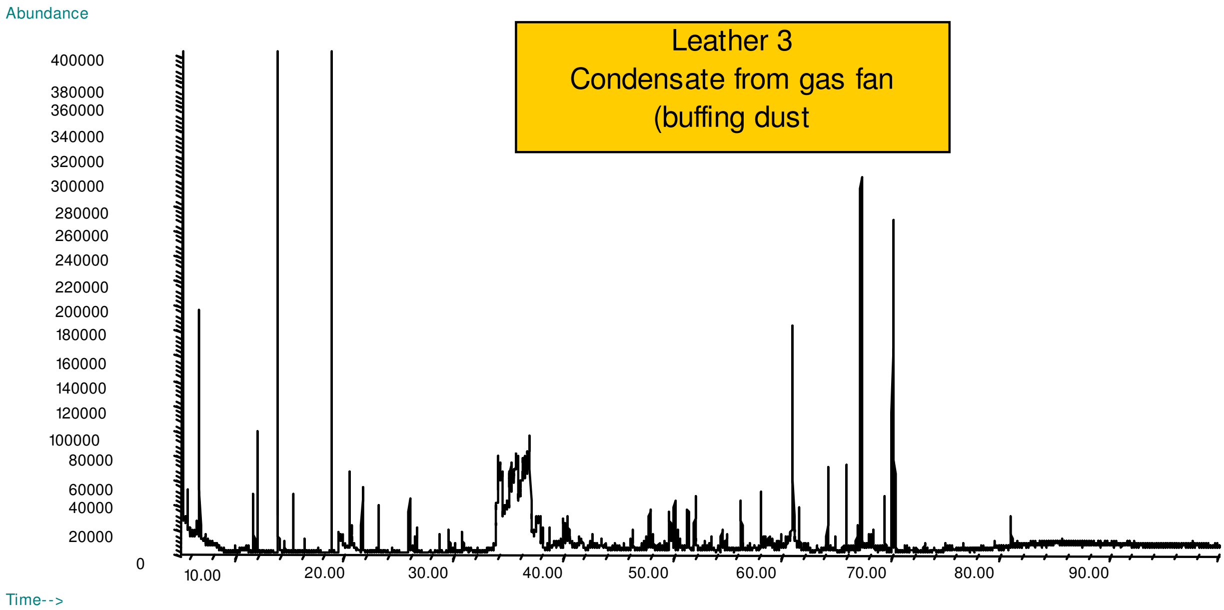

Figure 2. Scrubber water operating on sludge cake

The wastewater therefore needs to be chemically treated prior to discharge and it is unlikely that one unit operation will be sufficient to remediate the entire chemical spectrum present. Further work on the COD and BOD of the wastewaters is required. No analysis of the metals or solids content of the wastewaters or condensate from the gas fan was made.

Some work was carried out on a detailed analysis of the condensate produced at Rainford from mixed conifer, which has been reported elsewhere (1). The total emission level of organics were polyaromatic hydrocarbons [PAHs] at 4.6mg/l of condensate and 197mg/l of phenolics. The majority of the phenols were phenol, the ortho-, meta- and para-cresol forms.

4.5 "Tars" and Particulates

One of the crucial aspects of the work, as this was a scale-up of the Biomass Engineering Ltd. technology, was the measurement of the "tars" and particulates. Tars are in parenthesis, as there is some debate in the gasification community about the applicability of the EU "tar" protocol to biomass gasification as although high levels of organic chemicals may be measured, they do not have a negative impact on the quality of the gas, in fact they can increase the heating value of the gas.

In June 2005, after CRE Casella were unable to meet the requirements of the measurement campaign timescale and no other organisation is qualified in the UK to carry out such analysis. ECN of the Netherlands could have done the tests, but the costs were considerable [€25,000 for 3 days work] as the equipment and personnel would have had to be transported to the UK. This aspect of the work was therefore not carried out.

5. CONCLUSIONS

- Biomass Engineering Ltd. was capable of gasifying a range of feedstocks in its 80 kWe downdraft gasifier. Fuel feeding issues meant that some feedstocks did not gasify well and resulted in gas bypassing and low quality gas.
- Extensive analyses of the fuels were carried out on the chars/ashes, producer gases and the condensates. Further work is required for more detailed specific chemicals and proper tars and particulates analyses in the gases were not carried out.
- The high ash containing waste such as the RBF and the papermill sludge gave the lowest gas heating values as a significant portion of the energy generated during flaming pyrolysis being adsorbed by the ash heating up. Lower ash feedstocks such at the pine/bark mix and the woods gave producer gases with LHVs in the expected range of 4-5 MJ/Nm^3.
- The use of high ash fuels has always been problematical in small downdraft gasifiers and consideration should be given to their use in fuel blends. Unfortunately no tar and particulates data could be obtained. The determination of tars and particulates is essential to assess whether a wet or dry gas scrubbing process is required. It would be preferred if a dry process can be used as it has lower operating costs and less material for disposal.
- The use of a dry hot gas filtration process for leather wastes and the RBF is highly unlikely due to high tar levels in the gas. The other wood wastes could utilise hot gas filtration for particulate removal.
- No engine testing was carried out, partly due to unknown tar levels in the gases, however some engine testing was carried out in the pine/bark derived gases at Mossborough Hall Farm. The tests demonstrated that the Iveco engines could run satisfactorily on the gas.
- Briquetting of fuels for throughputs of less than 250 kg/h is not economic and would be likely to increase net electricity production costs by 1.5-2.5 p/kWh.
- The use of clean wastes in the gasifier is achievable and increases the scope of the gasification process to accept other non-uniform wastes.

6. RECOMMENDATIONS

- Further work on assessing tars, particulates and trace metals emissions would help to improve the long term viability of operating dry gas cleaning systems if the levels of metals are acceptable for removal in the hot gas filter.
- There is a need to develop UK expertise in tars and particulates measurement so that the industry has access to several companies offering such services. At present, the industry is reliant on independent testing from other countries, which is not a satisfactory position.
- Further work on optimising briquette density is required for the leather dusts and other related wastes such as the RBF. This would ensure that the gasification process operates smoothly and efficiently to gasify the organic components and avoid the formation of hard ahs agglomerates which do not flow through the gasifier.

- Test blends of high ash fuels and sawdust in briquette form to improve the gas LHV and increase the overall process efficiency.
- There is a need to complete further fuels testing and carry out engine tests with the fuels and measure the engine emissions. There may also be a need to assess the use of engine catalysts for CO abatement in the engine exhausts.

7. ACKNOWLEDGEMENTS

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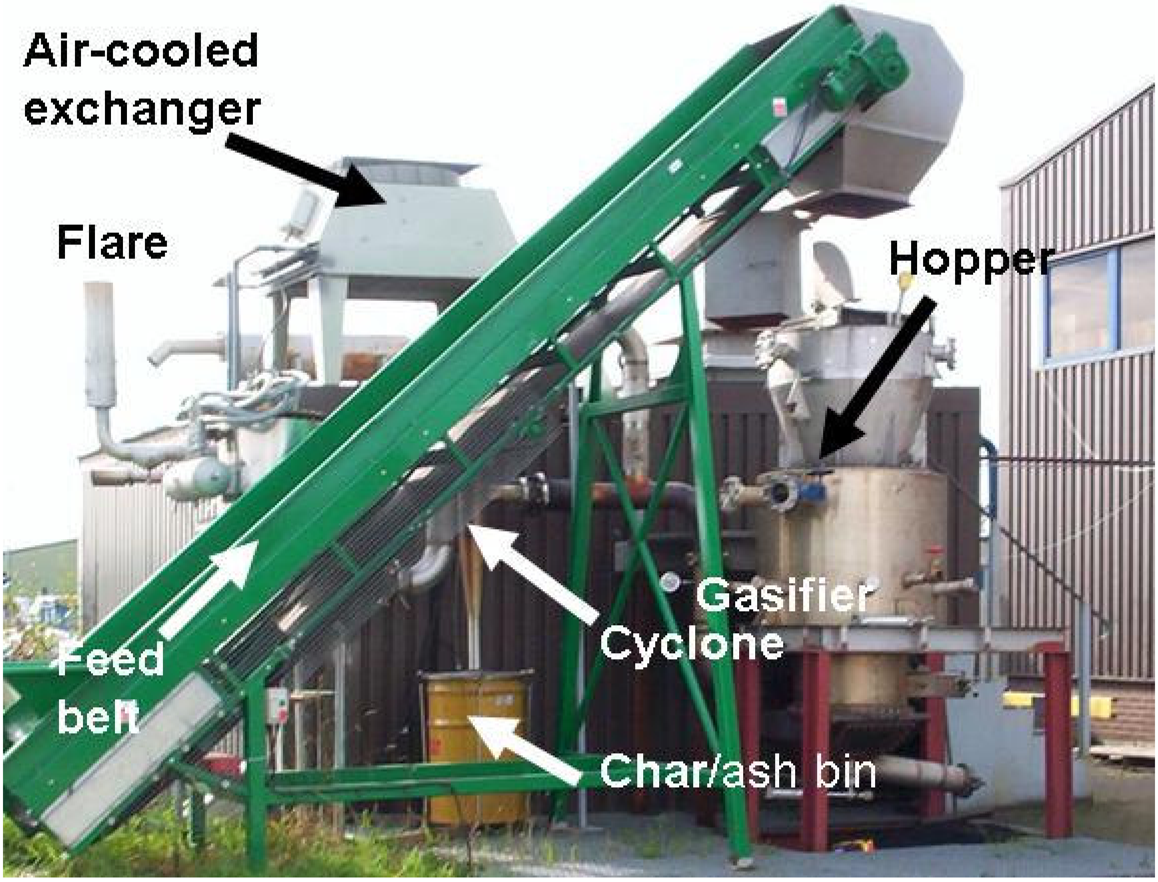
8. REFERENCES

1. Biomass Engineering Ltd., ''Development of a 250 kWe downdraft gasifier for CHP'', contract report under Contract Number: B/TI/00800/00/00 to DTI, 2005.



Photograph 1. Gasifier and Test filtration unit

Photograph 2. Pallet wood prior to chipping

Photograph 3. Fairport RBF briquettes [pressed by Biomass Engineering Ltd.]

Photograph 4. Briquetted ''wet blue'' [pressed by Biomass Engineering Ltd.]

Photograph 5. Papermill sludge prior to briquetting

Photograph 6. Clinker/melt formation with RBF