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Title: GASIFICATION OF SOLID FUELS FOR PRODUCTION OF ADVANCED BIOFUELS: UPDATE	
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Abbreviations

SO	Biomass sorghum
GR	Giant reed
EUC	Eucalyptus
BAG	Bagasse from sugarcane
ar	as received
nd	not determined/measured
db	dry basis
daf	dry ash free basis
PG	Product gas
MSR	Methane steam reforming
FT	Fischer-Tropsch
HDS	Hydrodesulphurisation

1. Introduction

In the BECOOL project, entire value chains including biomass harvest, collection, upgrading and conversion to transportation fuels are studied. With the aim of promoting the development of resilient and robust supply chains for advanced biofuels. For the biomass conversion, both the centralized conversion of (solid) biomass via gasification and the decentralized production of intermediate energy carriers, for subsequent gasification, are included.

Biomass and residual biomass considered in BECOOL include eucalyptus (EUC), giant reed (GR), biomass sorghum (SO), bagasse (BA) and a lignin-rich residue (RL) from a biomass refinery plant. More information on the considered value chains can be found in D2.1 [1]. A short overview of the different BECOOL feedstocks, including properties relevant for the thermochemical conversion, can be found in Table 1.

Table 1: Relevant properties of BECOOL feedstocks for thermochemical conversion [D2.1].

Biomass type	Type/Harvest	Average moisture at harvest	Ash content and ash melting point	Cellulose/hemicellulose /lignin [%]
Eucalyptus	Short (2-3y) medium (4-5y) rotation	50%	2%, MP depends on fertilization and harvest time	43/25/23 (BW: 48/22/24)
Giant Reed	Perennial grass	50-70% (~30% on field)	5%-6%, 954°C	33/27/18
Biomass Sorghum	Annual energy crop	70%-80%	4%-9%, 953°C	40/25/9
Bagasse	From sugar cane	40%-50%	1%-15% [2], 1237°C	39/27/18
Lignin rich residue	From bioethanol plant	50%-60%	5%-15%	50-60% lignin
Lignin rich residue	Fabiola fractionation [3]	50%-60%	0.5-25%	>95% lignin

For the conversion plants, an integral part of the entire value chain, two types of gasification plants are considered [4]. These are;

- Entrained flow gasification at high temperature (>1000°C) for which (decentralized) biomass pretreatment is required. Fast pyrolysis is one of the pretreatment options that provides a bio-oil for EF gasification.
- Low temperature (steam) gasification, in e.g. a fast circulating fluidized bed gasifier at 700-900°C. This low temperature gasification can be followed by tar reforming at high temperature, or tar scrubbing at low temperature. A graphical representation of the gasification process including the tar scrubbing, which is the focus in this work, can be found in Figure 1. It includes the required gas cleaning (tar removal, water wash, HDS), gas upgrading (MSR, CO₂ absorption) and FT synthesis. The MILENA

[1] D. Chiaramonti et al., 2018, BECOOL Deliverable D2.1, “Description of full biomass supply chains”.

[2] Phyllis biomass database, <https://phyllis.nl/>.

[3] K. Damen, A.T. Smit, W.J.J. Huijgen, J.W. van Hal, RRB 13 Conference, 2017, Fabiola: fractionation of biomass using low-temperature acetone.

[4] I. Hannula, V. Nikkanen, E. Boymans, M. Saric, 2020, BECOOL Deliverable D3.6, “Models for biomass to liquid fuels”.

gasifier was chosen as the fast circulating fluidized bed (steam) gasifier, which is commercially licensed by SYNOVA in collaboration with TNO [5].

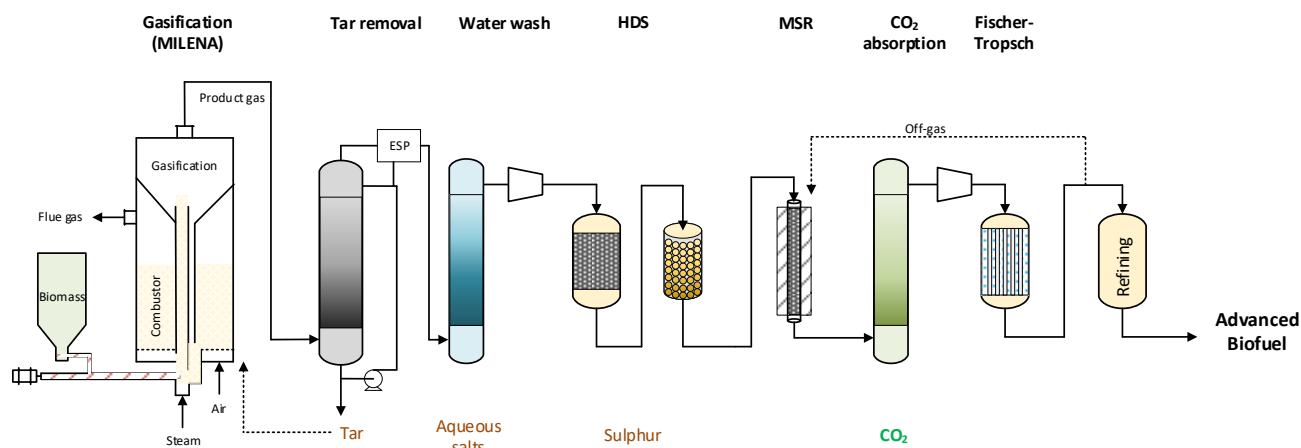


Figure 1: Simplified PFD of the low temperature steam gasification followed by PG cleaning, upgrading and FT synthesis.; one of the BECOOL conversion processes.

This work focuses on the experimental validation of biomass gasification using the freshly harvested BECOOL feedstocks in the lab scale MILENA gasifier (25-30 kW). The deliverable (D3.9) serves as an update to the earlier D3.5 and provides the progress in recent months. Where in D3.5 SO and EUC were considered, here GR and BAG will be studied for their performance in the MILENA gasifier.

[5] <https://synovatech.com/our-technology-platform/>

2. Experimental and methods

Here both giant reed (GR) and bagasse (BAG) were applied as feedstock in a 25-30 kW MILENA gasifier. As a continuation of the solid biomass gasification, EUC and SO, reported in D3.5. The aim was to demonstrate the successful gasification (steady state), including the carbon and energy balance at different temperature (700-850°C range) and different steam concentrations.

Two 150 kg GR bales, as shown in Figure 2, were kindly provided by UNIBO after a recent harvest at a site approximately 20 km from the university. The bales were received at TNO Petten in the first week of March 2020. GR gasification were carried out during 2 days of experiments; 24th and 25th of March 2020.

The BAG pellets, Figure 3, originated from Brazil and were kindly provided by RWE-Geertruidenberg, the Netherlands. In total 300 kg of BAG pellets were received in September 2020. BAG gasification was carried out on the 10th and 11th of November 2020.

2.1 Pretreatment

Giant Reed

Moisture content measurements revealed an average 23% moisture for the as-received material. This indicates that a pre-drying must have been performed, as the harvested GR contains 50-70% moisture. Indeed, the moisture content was lower, as after harvest the material was dried naturally in the field for 3-5 days, after which it was baled. The bales contained large stalks, i.e. they were cut upon harvest, but not chipped.

About 170 kg of this GR, including the larger stalks, was shredded over a 10 mm sieve. This shredded material was then pelletized in a pellet mill equipped with a 6x20 mm mould. The desired temperature was obtained by heat generated through milling in combination with water addition (3 kg total). Pellets from the first batches crumbled so all material had to be pelletized several times (8x) before strong pellets were obtained. The ideal temperature for the water/biomass mixture in the pellet mill was found to be 80°C, measured at the outlet. In total 120 kg of pellets (6 x 20 mm) were made. These pellets were ground over a 6 mm screen to provide ≤ 6 mm particles. Even though the ground pellets contained fines, as shown in Figure 2, no additional sieving was applied before gasification. The final moisture content was 9% (see also Table 2).



Figure 2: Photos of the as received giant reed (top), pelletized (bottom left) and ground pellets (bottom right).

Bagasse

The bagasse pellets were only ground over a 6 mm screen before being transferred to the feeding bunker of the gasifier. Figure 3 shows the as-received pellets (in plastic bags) as well as the ground material.



Figure 3: Photos of the as received bagasse pellets (left) and ground pellets (right).

2.2 Feedstock analysis

The feedstock analysis was performed by for both materials (after pretreatment/as fed to gasifier) is included in Table 2. Methods used: B.N035; chloride, nitrate, sulphate and bromide via ion chromatography, B.N202; gravimetric determination of moisture, volatiles and ash, B.N203; calorific value, B.N211; CHN analysis, B.N213; O analysis, B.S231; ICP-AES, O.N203 and O-SB08 (ash composition).

Table 2: Ultimate and proximate analysis of GR and BAG pellets.

Analyse	Unit	GR pellets	BAG pellets	Eucalyptus	Sorghum
LHV	[MJ/kg], ar	15.8	17.7	16.0	15.8
LHV	[MJ/kg], daf	18.6	17.8	17.8	17.4
Volatile content	[%], db	74.1 (78.4 daf)	82.3 (85.2 daf)	77.8	74.3
Ash content	[%], db	5.6	3.4	1.5	5.0
Moisture	[%], ar	8.5	0.3	7.9	3.8
C	[%]	46.3	47.5	47.4	44.8
H	[%]	5.8	5.4	6.1	5.9
O	[%]	42.1	45.8	44.0	41.8
N	[%]	0.60	0.24	0.40	0.90
S	[%]	0.19	0.027	0.034	0.10
Cl	[%]	0.36	0.024	0.13	0.15
Al	[mg/kg]	297	974	42	210
As	[mg/kg]	< 1	< 1	<1	<1
B	[mg/kg]	5	2	6.1	6.6
Ba	[mg/kg]	5	13	14	6.7
Ca	[mg/kg]	2015	734	6200	3700
Cd	[mg/kg]	< 0.1	< 0,1	<0.1	0.21
Co	[mg/kg]	1	4	140	8.4
Cr	[mg/kg]	13	9	<0.9	2.2
Cu	[mg/kg]	4	4	11	4.8
Fe	[mg/kg]	561	1701	46	240
K	[mg/kg]	12198	1412	3100	12000
Li	[mg/kg]	< 0.3	< 0,3	<0.3	<0.3
Mg	[mg/kg]	727	465	740	3100
Mn	[mg/kg]	38	59	12	25
Mo	[mg/kg]	< 0.8	< 0,8	<0.8	<0.8
Na	[mg/kg]	99	45	230	84
Ni	[mg/kg]	7	2	3	1.4

P	[mg/kg]	844	218	450	1200
Pb	[mg/kg]	< 0.6	4	0.84	<0.6
Sb	[mg/kg]	< 3	< 3	<3	<3
Se	[mg/kg]	< 1	< 1	<1	<1
Si	[mg/kg]	13833	8679	150	11000
Sn	[mg/kg]	< 0.9	< 0,9	<0.9	<0.9
Sr	[mg/kg]	12	7	35	24
Ti	[mg/kg]	10	284	1.5	4.9
V	[mg/kg]	< 0.2	6	<0.2	<0.2
W	[mg/kg]	< 1	23	9.8	11
Zn	[mg/kg]	22	10	20	37
All on dry basis (db) unless as received (ar) or dry ash free (daf).					

2.3 Gasification setup and settings

A schematic representation of the gasification setup is shown in Figure 4. Biomass was fed from a bunker via a transport screw into the gasifier. In the gasifier, the biomass contacts with the hot (fast circulating) bed material and steam causing the material to be gasified. The formed product gas (PG) leaves the reactor where it is allowed to cool to 450°C. A slipstream is withdrawn, which passes through filters before PG analysis. After gasification of the feedstock in the gasification zone, the remaining char together with the bed material is transported back to the fluidized bed combustor, where the heat is generated by burning the char with addition of air. The flue gas leaves the reactor separately from the PG and is sent through a cyclone before flue gas analysis.

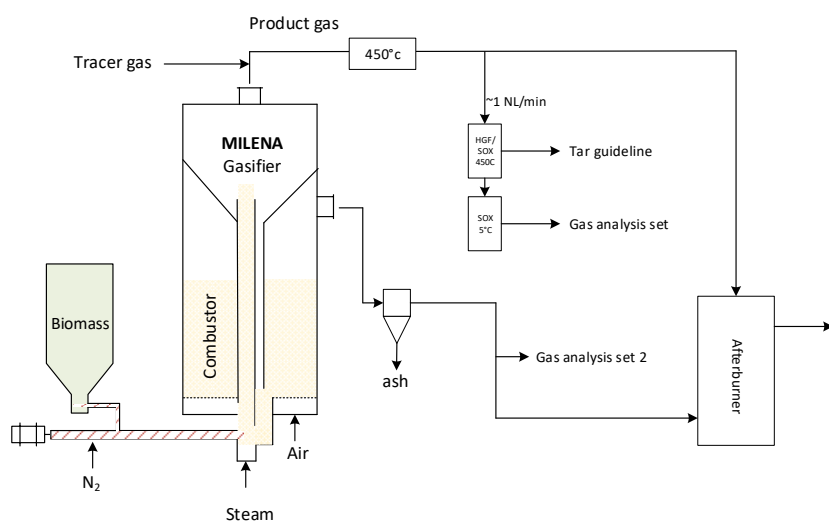


Figure 4: Gasification setup of the 25-30 kW MILENA reactor.

In Table 3, the gasification conditions applied during the GR and BAG gasification experiments are listed. Specific conditions, at which the PG compositions were determined, can be found in the results section.

Table 3: Operating range during the GR and BAG gasification.

MILENA Gasifier		GR	BAG
Bed material		44 kg Olivine (0.3 mm)	44 kg Olivine (0.3 mm)
T gasification in settling chamber	[°C]	750-800	820-870
T in bed combustor	[°C]	800-850	860-910
Fuel flow – GIANT REED	[kg/h]	4.5-5.5	5.15
Steam riser	[kg/h]	0.5-2	1.0-1.1
Transport screw N ₂ flow	[NL/min]	1.0	1.0
Tracer gas Ar, settling chamber	[NL/min]	1.0	1.0/0.5
Tracer gas Ne, settling chamber	[NmL/min]	20	--
Combustion air	[NL/min]	140-160	100-110

2.4 Gas analysis

To determine the PG and flue gas compositions, a variety of gas analyses were performed, see Table 4. These included continuous online analysis with the gas analysis set (including a gas monitor set and μ -GC) and offline analysis. Off-line analysis proceeds via extraction of the gas into a gas bag and subsequent gas analysis and/or via entrainment of the gas in cooled impinger bottles filled with an absorption liquid followed by wet chemical analysis [6]. To determine the concentration of tar, a wet chemical method is used, called the tar guideline as described elsewhere [7]. The flue gas concentration was only monitored by a separate gas monitor set.

Table 4: Gas analysis methods used to determine the PG composition.

Sampling method	Sample measurement type	Measured components
Online Gas monitor set	ABB Advanced Optima analyser.	CO, CO ₂ , CH ₄ (NDIR) H ₂ (TCD) O ₂ (Paramagnetic)
Online μ -GC analysis	Varian CP4900 4-channel micro-GC with TCD.	CO, H ₂ , CH ₄ , C ₂ H ₆ , C ₂ H ₄ , C ₂ H ₂ , C ₆ H ₆ , C ₇ H ₈ , CO ₂ , N ₂ , H ₂ S, COS, Ne, Ar.
Gas bags	Sulphur components using Shimadzu GC17A with FPD detector. C1-C5 using TRACE GC-FID.	All reported sulphur components and C1-C6 hydrocarbons.
Tar guideline	Thermo Scientific Trace 1310 GC with FID for liquid analysis. KF titration.	Respectively all tar components and PG moisture content.
Impinger bottles	Liquid analysis [6].	NH ₃ , HCN, HCl.

[6] G. Aranda Almansa *et al.*, IEA Bioenergy Task 33, Gas analysis in gasification of biomass and waste, ISBN 978-1-910154-43-4.

[7] S.V.B. van Paasen *et al.* ECN-C--02-090, 2002, Guideline for Sampling and Analysis of Tar and Particles in Biomass Producer Gases.

3 Results and discussion

An important property regarding the thermochemical conversion in fluidized beds is the tendency of the ash to melt and cause aggregation together with the bed material (e.g. silica sand). Although in this work the ash melting temperature was not included in the feedstock analysis, typical ash melting temperatures of both GR and BAG are well above 900°C. Additionally to the ash melting point, indicators based on the fuel composition can be used. These indicators predict the alkali-induced agglomeration potential in a fluidized bed at $T > 800^{\circ}\text{C}$ as listed in Table 5 [8]. The higher the indicator ratios, the higher the probability of agglomeration. Indicators 1 and 2 are related to coating-induced agglomeration, which is a slow process as first a coating has to form around the bed/ash particle. Indicators 3a-3d are related to the ash-melting induced agglomeration, which is much faster. For GR, what stands out are the low potassium and high sulphur content leading to a I1 of only 0.1. BAG contains much less sulphur and therefore has an I1 ratio of 1.9. Both GR and BAG give high I2 and I3 indicators, because of their high silicon content. This silicon will most likely be sand that came with the biomass during harvest. Overall, most indicators are suggesting a high potential for bed agglomeration. However, it is important to state that these are only indicators and agglomeration also depends on other factors, such as the type of bed material. Eventually, experimental tests are required to demonstrate whether agglomeration will occur under certain conditions. In the gasification tests described in this work, olivine was used as bed material, and no bed agglomeration occurred with any of the feedstocks.

Table 5: Indicators for prediction of alkali-induced agglomeration potential.

Indicator	Ratio (on fuel basis)	High agglomeration potential if	GR	BAG
I1	$(\text{Na}+\text{K})/(\text{2S}+\text{Cl})$	>1	0.1	1.9
I2	$(\text{K} + \text{Na} + \text{Si})/(\text{Ca} + \text{P} + \text{Mg})$	>2	4.1	7.2
I3a	K / Si	>0.6	0.88	0.16
I3b	$\text{K} + \text{Na} \text{ [g/kg]}$	>1	12.3	1.46
I3c	$\text{Si} \text{ [g/kg]}$	>1.5	13.8	8.7
I3d	$\text{K}_2\text{O} + \text{SiO}_2 \text{ [% in ash]}$	$>50\%$	$>50\%$	$>50\%$

3.1 Giant reed gasification

The GR gasification experiments were carried out on 24-03-2020 (Day 1) and 25-03-2020 (Day 2). Temperature and pressure, as recorded during day 2 of the gasification are shown in Figure 5 and the averaged gas composition under varying settings included in Table 6.

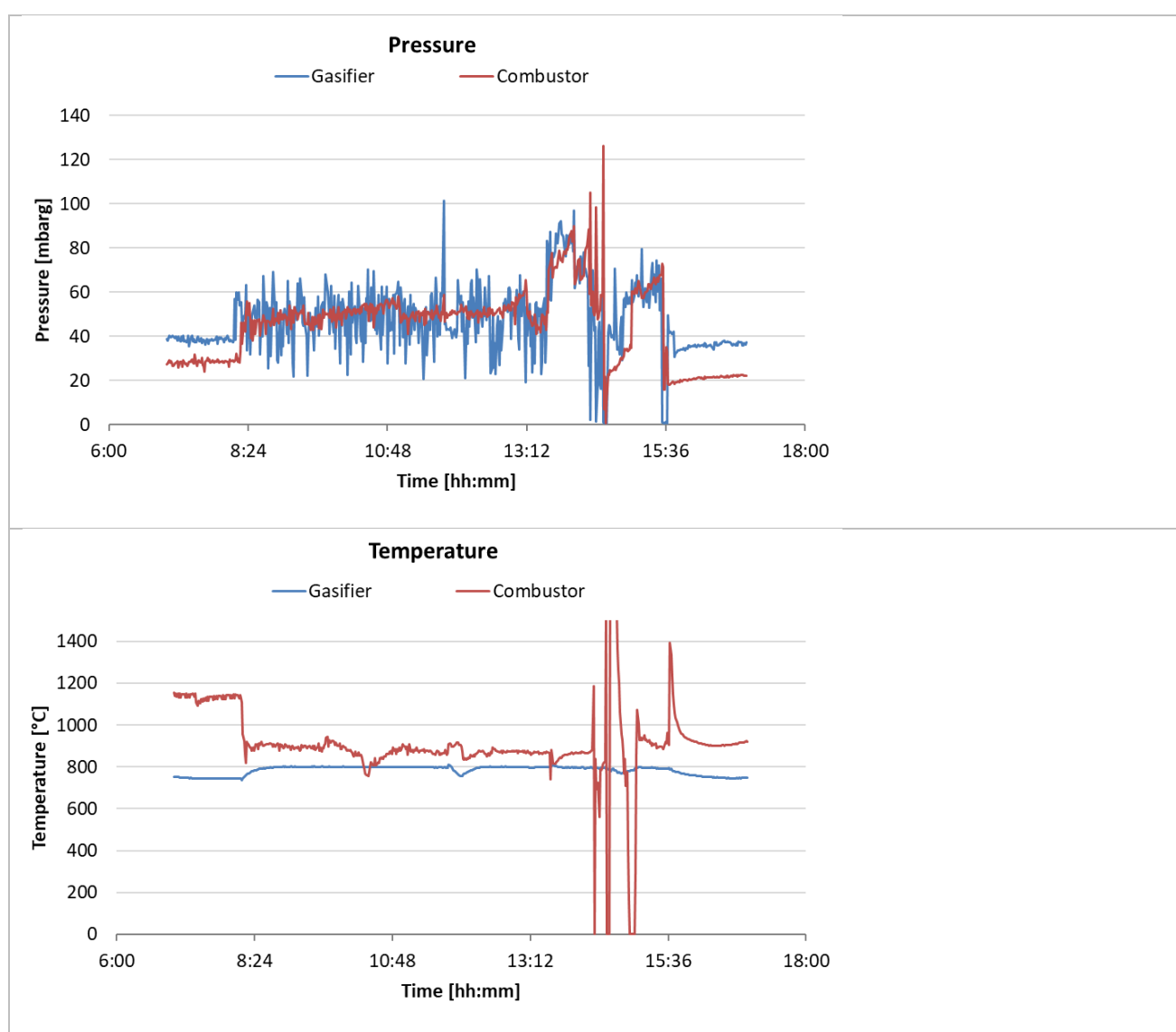
As observed in Figure 5, during day 2 (but valid for both day 1 and 2), the pressure in the gasification zone fluctuated somewhat during the experiment between 40 and 60 mbarg, whereas the combustor pressure was more stable around 50 mbar. The pressure fluctuations are most likely the result of ground pellets being fed instead of chipped biomass. The ground pellets had a wide particle size distribution and contained much fines,

[8] H.J.M. Visser and K. Laughlin, EU-project Biomass/waste FBC with inorganics control “BIFIC”, Deliverable 9, 2004, “Guidelines and recommendations on avoiding/mitigating bed agglomeration/defluidisation and deposition/fouling, emissions control and on ash utilisation options”.

which can lead to intermittent feeding by the transport screw into the reactor. Furthermore, the pellets are densified compared to the original biomass, which coupled with the wide particle size distribution, can result in irregular devolatilization rates.

The gasification temperature was found constant at around 800°C, with the combustor at an average 70°C higher temperature. This dT was somewhat high and was caused by the combustion of the devolatilized material (char). The amount of char was relatively high, which can partially be explained by the low volatile content of the ground pellets at 78% daf (Table 2) in comparison to GR and beech wood, which have reported volatile matter contents of 80-83% and 81-86% daf [2].

In the final graph, the main gas components during the gasification are shown indicating 45-50 vol% of H₂+CO and 12-13 vol% CH₄. At around 12:00 all components drop temporarily to 0%, because the feedstock bunker was refilled at this time.



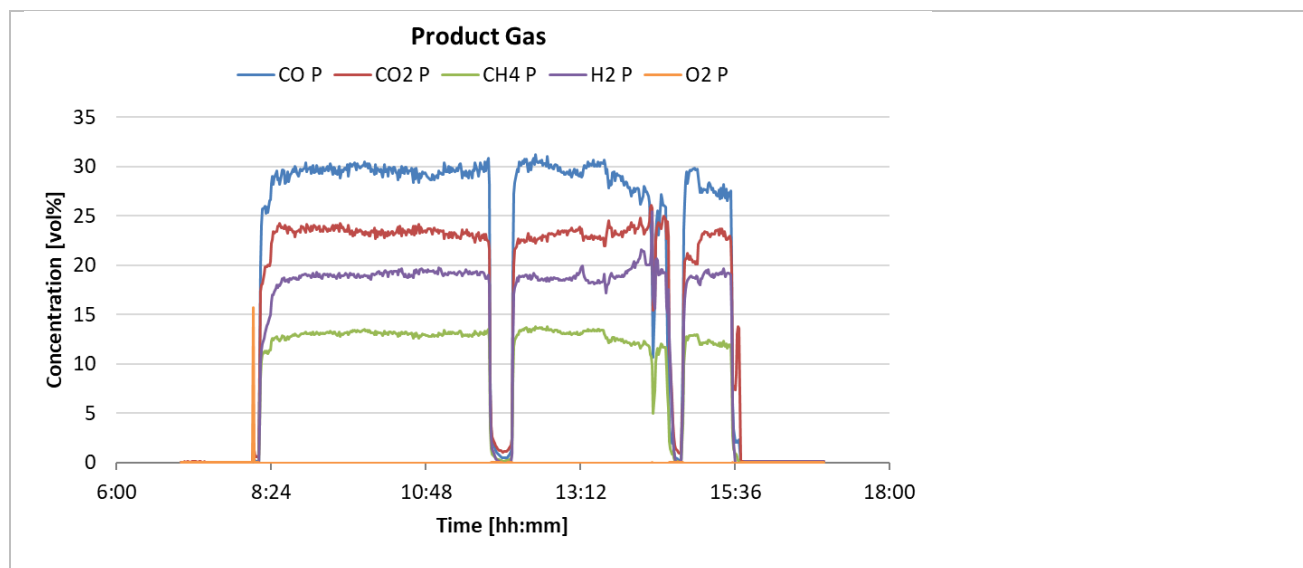


Figure 5: Pressure, temperature and PG composition profiles of the GR gasification during day 2.

The averaged gas compositions, of all the different settings over the 2 days of GR gasification, are reported in Table 6. In total 4 different conditions can be distinguished, one at somewhat lower temperature of 766°C and a steam/biomass ratio of 0.31 (Day 1-1), a second at 800°C and 0.31 (Day 1-1 and Day 2-1), a third with less steam at 0.21 (Day 2-1) and a fourth with more steam at 0.60 (Day 2-3). Total steam as reported in the Table equals the sum of feedstock moisture and steam added to the reactor.

As expected, the carbon conversion to PG is somewhat low with 65% at 766°C, increasing up to 70% at 800°C. A carbon conversion of 70% means that 30% of the fuel-C was left in the char for the combustor. As explained above, this high char content can be related to the low volatility of the as-fed ground GR pellets. Typically, with wood chips the carbon conversion to PG is about 80%. The same trends were also observed for the cold gas efficiency (CGE) and the gas yields.

No markable variations were observed when increasing or decreasing the steam/biomass ratio.

Table 6: GR gasification conditions (temperature and steam were varied), including the PG composition on dry- and tar-free basis.

Settings/components	Unit	Day 1-1	Day 1-2	Day 2-1	Day 2-2	Day 2-3
		GR	GR	GR	GR	GR
Feedstock flow	[kg/h]	5.5	5.5	5.5	5.5	4.5
Gasification temperature	[°C]	766	800	800	799	795
Total steam/dry biomass	[--]	0.31	0.31	0.31	0.21	0.60
CO	[vol%]	32.2	30.3	29.9	30.3	27.4
H ₂	[vol%]	15.8	17.5	19.1	18.7	19.1
CO ₂	[vol%]	22.3	23.0	23.5	23.2	23.1
CH ₄	[vol%]	13.1	12.8	12.9	13.2	11.8
N ₂	[vol%]	6.5	6.3	4.5	5.0	8.8
C ₂ H ₂	[vol%]	0.2	0.2	0.2	0.2	0.3
C ₂ H ₄	[vol%]	4.5	4.6	4.6	4.5	4.3

C ₂ H ₆	[vol%]	0.7	0.5	0.5	0.5	0.4
Benzene	[ppmv]	7096	8018	8411	8530	7179
Toluene	[ppmv]	1905	1700	1630	1565	1409
Sum C ₃	[ppmv]	2939	2044	1860	807	1901
Sum C ₄	[ppmv]	1104	1360	1222	727	1021
Sum C ₅	[ppmv]	155	185	19	81	176
Sum C ₆ (excl. benzene)	[ppmv]	9	8	8	2	7
H ₂ S	[ppmv]	1505	1676	1756	1811	1775
COS	[ppmv]	251	191	164	130	93
Thiophene	[ppmv]	56	61	59	58	50
Methylmercaptane	[ppmv]	nd	nd	73	43	53
Other S-organics	[ppmv]	24	28	19	14	11
NH ₃	[ppmv]	nd	6890	6762	nd	nd
HCN	[ppmv]	nd	410	593	nd	nd
HCl	[ppmv]	nd	308	388	nd	nd
Tar total (excl. toluene)	[g/Nm ³]	nd	49.0	46.7	nd	nd
Argon*	[vol%]	1.89	1.79	1.79	1.69	2.19
Neon*	[ppmv]	478	416	424	464	463
Total (excl. tar)	[vol%]	98.9	99.4	99.4	98.9	98.9
Water content	[vol%]	nd	52.3	50.1	nd	nd
Time averaged		12:18-13:30	13:30-15:00	9:00-11:00	12:40-13:20	15:10-15:29
Flow db (based on Ar)	[NL/min]	52.9	57.1	57.1	58.1	45.5
Carbon to PG (based on C combustor)	[%]	65	68	69	70	69
CGE LHV basis	[%]	nd	68	68	nd	nd

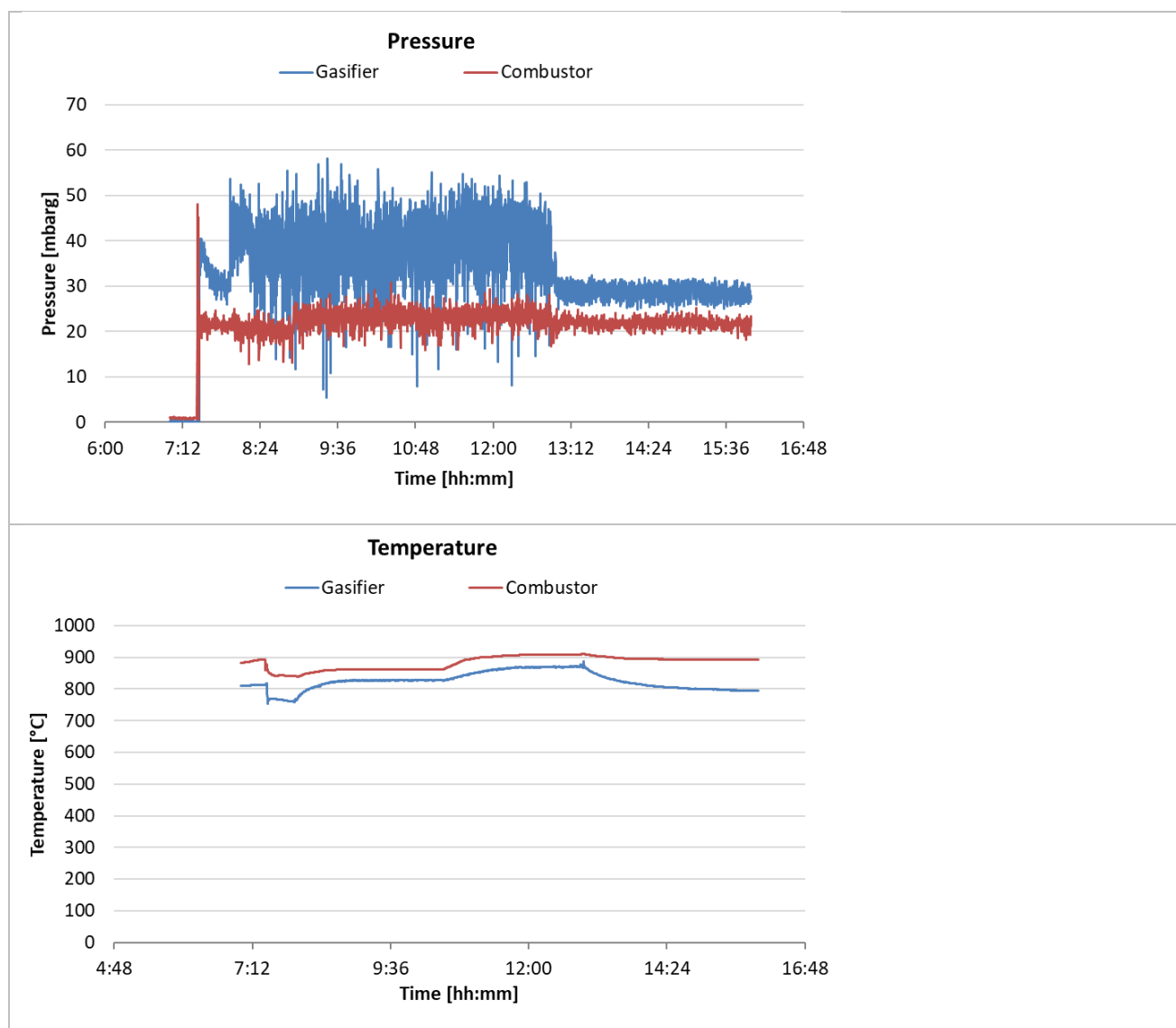
Furthermore, much sulphur (H₂S/COS) was present in the gas as a result of the high sulphur content in the biomass. Parallel for the organic sulphur components a dominance of thiophene was clearly observed. In line with sulphur, also the HCN concentration (400-600 ppmv) and HCl concentration (300-400 ppmv) were determined at 800°C. Naturally, the high level of impurities in the gas will have consequences for the downstream processing (e.g. water wash and HDS).

3.2 Bagasse gasification

The BAG gasification experiment was carried out on 11-11-2020 (day 1) and 12-11-2020 (day 2). Temperature and pressure, as recorded during day 2 of the gasification tests are shown in Figure 6 and the averaged gas composition under varying settings included in Table 7.

Similar to the GR gasification, also with the ground BAG pellets the pressure in the gasification zone fluctuates substantially between 30 and 40 mbarg. Also here, the wide particle distribution and the presence of fines most likely cause the fluctuations.

As observed in the Figure, the temperature was kept at 827°C and 869°C with the combustor temperature approximately 35°C higher with much less air needed for complete combustion of the char (100-110 NL/min), when compared to GR (see Table 3). This was already an indication that much less char remained for the combustor with a higher conversion to PG in line with the higher volatiles content of these ground BAG pellets (85% daf) in line with reported sugarcane bagasse 79-88% daf [2].



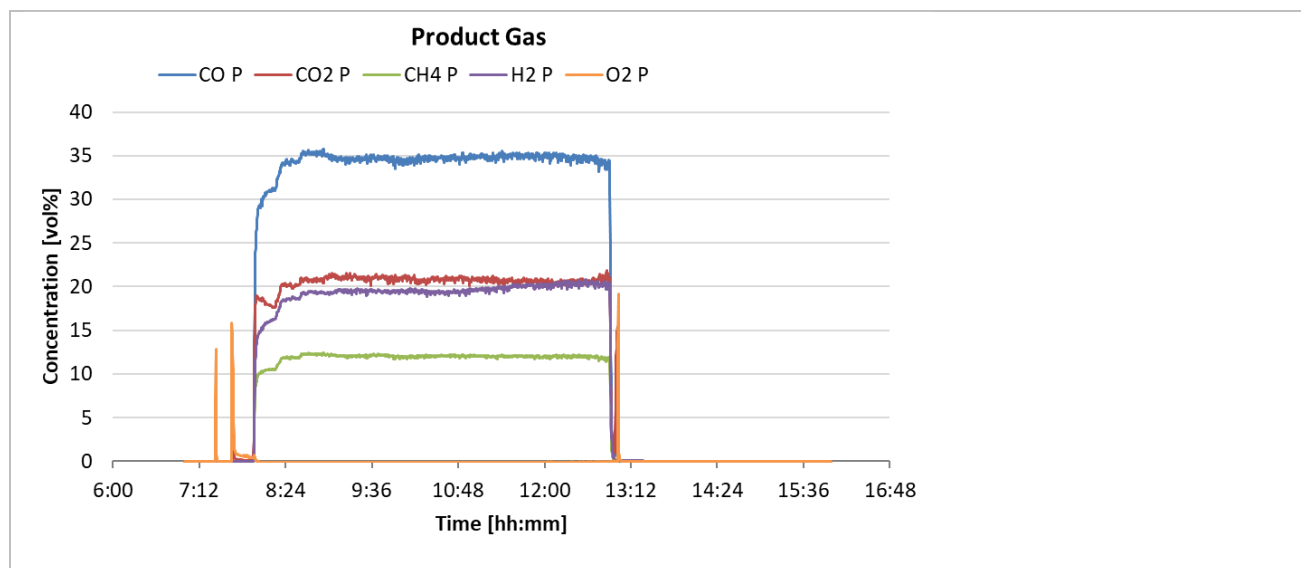


Figure 6: Pressure, temperature and PG composition profiles of the BAG gasification during day 2.

The averaged gas compositions, over the 2 days of BAG gasification, are reported in Table 7. Two different conditions can be distinguished based on the gasification temperature, namely 824-827°C (Day 1 and Day 2-1) and a higher 869°C (Day 2-2) all at a similar 0.26-0.28 steam to biomass ratio.

Carbon conversions for BAG gasification were higher than measured for GR. At 824°C already a conversion of 81% was achieved, which increased slightly to 84% at 869°C. Only 16-19% of carbon, in the form of char, was left for combustion, which is in line with a material with similar volatile content.

Table 7: BAG gasification conditions (temperature and steam were varied), including the PG composition on dry- and tar-free basis.

Settings/components	Unit	Day 1	Day 2-1	Day 2-2
		BAG	BAG	BAG
Feedstock flow	[kg/h]	5.15	5.15	5.15
Gasification temperature	[°C]	824	827	869
Total steam/dry biomass	[--]	0.28	0.26	0.26
CO	[vol%]	31.9	35.5	35.5
H ₂	[vol%]	17.2	17.8	18.4
CO ₂	[vol%]	17.4	20.3	19.8
CH ₄	[vol%]	10.3	11.7	11.7
N ₂	[vol%]	12.6	3.6	3.8
C ₂ H ₂	[vol%]	0.3	0.3	0.4
C ₂ H ₄	[vol%]	4.4	5.0	4.3
C ₂ H ₆	[vol%]	0.3	0.4	0.2
Benzene	[ppmv]	6937	7972	8949
Toluene	[ppmv]	897	1008	721
Sum C ₃	[ppmv]	1080	1024	431
Sum C ₄	[ppmv]	848	848	517

Sum C ₅	[ppmv]	149	142	104
Sum C ₆ (excl. benzene)	[ppmv]	4	5	4
H ₂ S	[ppmv]	137	179	194
COS	[ppmv]	9	9	9
Thiophene	[ppmv]	8	10	10
Methylmercaptane	[ppmv]	3	3	3
Other S-organics	[ppmv]	1	1	1
NH ₃	[ppmv]	nd	2142	nd
HCN	[ppmv]	nd	nd	nd
HCl	[ppmv]	nd	8	nd
Tar total (excl. toluene)	[g/Nm ³]	30.2	nd	nd
Argon*	[vol%]	1.3	0.79	0.80
Neon*	[ppmv]	--	--	--
Total (excl. tar)	[vol%]	96.8	96.7	95.9
Water content	[vol%]	35.1	nd	nd
Time averaged		13:44 - 14:31	8:57-10:03	11:54-12:52
Flow db (based on Ar)	[NL/min]	76.2	65.5	64.5
Carbon to PG (based on C combustor)	[%]	81	81	84
CGE LHV basis	[%]	85	nd	nd

As for the specific gas composition, no markable difference were observed compared to the gasification of woody biomass, meaning no substantially higher concentration of impurities.

3. Conclusions

The experimental work has demonstrated that the BECOOL feedstocks EUC, SO (Deliverable 3.5), GR and BAG have been successfully gasified, while fed in solid form in the MILENA gasifier. An important factor was that the materials SO and GR had to be pelletized to meet the requirements of the lab-scale MILENA gasifier and its feeding system. This was mainly to prevent bridging of the feedstock in the bunker as well as to densify the material in order to feed the required amount (~5 kg/h) into the gasifier.

An overview of the results in terms of carbon conversion is shown in Figure 7. Woody biomass was added as reference feedstock (red dotted line), because the lab MILENA was designed for this feedstock and much data is available. As can be observed, a higher gasification temperature results in a higher (carbon) conversion to gas. Furthermore, addition of more/less steam has little impact on the overall conversion as demonstrated by the GR results at 800°C. The conversion of EUC and BAG are in line with the reference feedstock. SO and GR showed a much lower carbon conversion than what can typically be expected from standard biomass feedstocks.

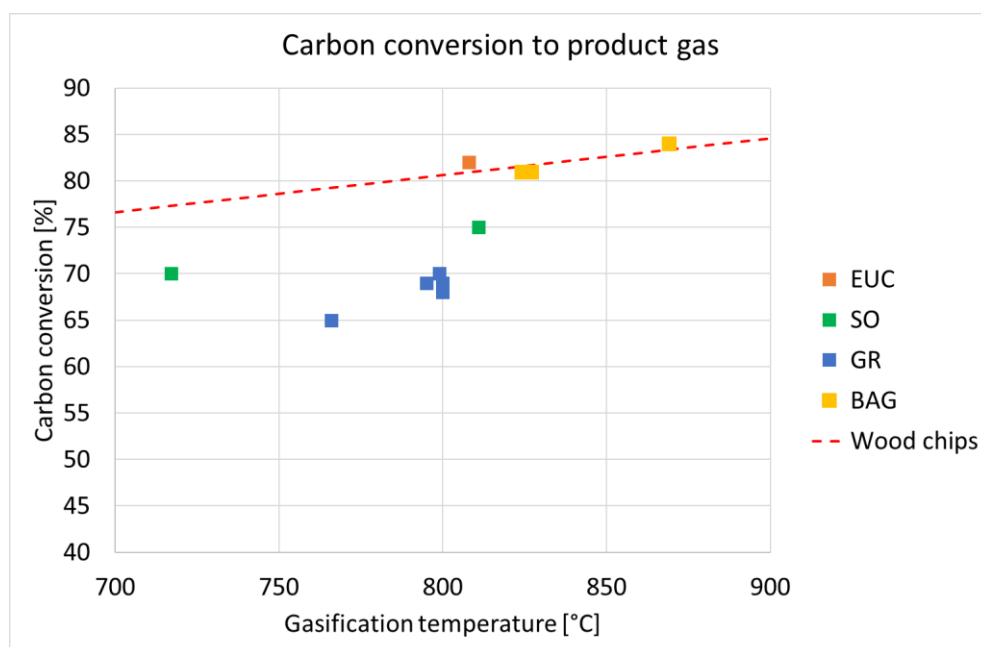


Figure 7: Carbon conversion in the gasification experiments with the BECOOL feedstocks as a function of temperature, including wood chips as reference (red dotted line).

When extrapolating these experimental results for modelling and/or engineering of large commercial-scale plants, care needs to be taken. The experimental work provides expected gas compositions and thereby trends, but the feedstock form (here ground pellets) have an effect on the gasification performance. Naturally on a larger MW scale, the biomass will only be chipped to 1-4 cm and feeding becomes typically more facile. For this reason, wood chips gasification should be used when extrapolation experimental gasification results such as gas conversion and cold gas efficiency to a larger scale. EUC and BAG show that under the right conditions, these numbers will be in line with those for wood chips.

As the feedstock analysis illustrated, the sulphur concentration in GR was very high resulting in a PG H₂S concentration of 1500-1700 ppmv, much higher than the 130-200 ppmv measured in BAG. Also, the 6890 ppmv

NH₃, 410 ppmv HCN and 308 ppmv HCl in GR PG were much higher than for BAG with 2142 ppmv NH₃ and 8 ppmv HCl.

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