

# COMBINE

Converting Organic Matter from  
European Urban and Natural Areas  
into Storable Bio-Energy



**Study on combustion characteristics of  
blended regional fuels**

**- 9 test runs -**

## 1 Target of the study

The combustion performance of grassland fuels is of crucial importance for the implementation of the IFBB approach in the COMBINE regions. The technical feasibility of the combustion process and the compliance with legal regulations in terms of emission thresholds are preconditions for the successful introduction of COMBINE briquettes.

To reach this target, this study investigated selected fuels from the COMBINE partner regions for their combustion behaviour. Three batches of briquettes processed at the sedentary plant in Baden-Baden (PP 3) and originating from 3 COMBINE partner regions were assessed by using a large scale boiler of the externally contracted company Ökotherm®. This company is known as one of the most experienced manufacturers of boilers for the combustion of herbaceous biomass types like for example Miscanthus. The tests have been performed with the test unit at Ökotherm® under supervision of LP (UNI KASSEL).

All of the 3 batches were subjected to 3 test runs each to ensure a high level of accuracy of the statements derived. Test runs were performed for heat-up phase, partial load and full load operation for each batch investigated. Thus, altogether nine test runs were performed in this study. Investigation parameters were the flue gas components particulate matter (PM), carbon monoxide (CO), nitrogen oxide (NO<sub>x</sub>), sulphur dioxide (SO<sub>2</sub>) and oxygen (O<sub>2</sub>). Furthermore, technical feasibility was assessed considering ignition behaviour, ash slagging behaviour and the ability to remove the ash.

As results from former experiments and tests with IFBB fuels showed consistently good results for emissions below the legal thresholds, it was decided not to blend the IFBB material with wood, but to burn it solely. Thus, the IFBB biomasses from the Partners in Wales, Belgium and France were combusted in 9 test runs, including tests at heat-up phase, full load and partial load of the combustion unit.



## 2 Methodology

### 2.1 Biomass fuels

Three biomass types from the COMBINE project regions were selected for the combustion tests. The investigated fuel samples originated from Belgium (INAGRO), France (CG22) and Wales (National Trust). The Belgian biomasses consisted of grassland silage, predominated by grass species, especially *Alopecurus pratensis*, *Arrhenatherum elatius*, *Holcus lanatus* and *Poa trivialis*. The French biomasses consisted of road side cuttings harvested in July at the second cut of road side maintenance consisting mainly of *Agrostis x murbeckii*, *Holcus lanatus*, *Anthoxanthum odoratum*, *Galium spec.*, *Rumex acetosa* and *Urtica dioica*. The Welsh biomasses were collected at fields of the National trust and consisted of wetland vegetation species. Most common species were: *Deschampsia cespitosa*, *D. flexuosa*, *Holcus lanatus*, *Carex leponina*, *Juncus acutiflorus*, *J. effusus*, *Luzula multiflora*, *Lotus pedunculatus*, *Plantago lanceolata*.

Raw materials were processed at Baden Baden as described in the “Analysis of mass and energy fluxes” report. After briquetting, fuels were transported to Ökotherm® and combusted.

### 2.2 Combustion tests

The combustion experiments were carried out with an ÖKOTHERM®-Compact plant C1L with a nominal output of 120 kW on the ÖKOTHERM® test bench which meets the criteria according to DIN EN 304. The output of the boiler is continuously adjustable in the range of 30-100% of the nominal load. The heating system is stoke-fired and has a cooled combustion cavity; automated lambda ( $\lambda$ ) control is included. The experimental procedure was carried out in accordance with DIN EN 303-5.



Biomass boiler



Combustion



Measuring equipment

To capture the gas and dust emissions a standardized emission test section was installed in the exhaust gas line. The detection of gaseous and vaporous emissions of oxygen ( $O_2$ ), carbon dioxide ( $CO_2$ ), carbon monoxide (CO), nitrogen oxides ( $NO_x$ ) and sulphur dioxide ( $SO_2$ ) was carried out using the compact analyser ecom-J2KNpro. The detection

of dust emissions was done using the measurement system testo-380. The emissions were recorded from a flue gas temperature higher than 70° C. The compact instrument ecom-J2KNpro rinsed every hour for about 5 minutes with fresh air to avoid damage. These values were excluded from the evaluation. Furthermore, the values were also excluded when the condensate trap was manually emptied.

Temperature data of flow, return and cold water were recorded by the heater control system AMII. The determination of the hourly amount of cold water took place by repeated weighing over the test period. The hourly amount of fuel was also determined by weighing over the entire experimental period. The calculation of power and efficiency was carried out according to DIN EN 304 + A.7 A.8.

Ash removal is carried out by an ash pusher that transfers the ash into a drawer, giving the possibility to sample the ash to assess its properties.

Per Fuel type, three operation modes were tested within two days:

- a) Heat-up phase
- b) Partial load (50% of nominal output)
- c) Full load (100% of nominal output)

Only the results of the full load mode are shown in this short summary.



### 3 Results

#### 3.1 French fuel

The fuel was combusted in briquette form. Directly after pressing, the briquettes were quite compact and stable, but after loading and transport to the biomass boiler they crumbled into smaller pieces through abrasion (see pictures below). Due to the size of the briquettes and their different content of fine material, the amount of fuel loaded into the boiler varied slightly and with that the performance. Larger combustion units with larger stoker screw diameters can be expected to have more consistent fuel loading.

Tab. 1: Characteristics of French fuel

Ash	% of DM	4.40
Dry matter (DM)	% of FM	97.84
Heating value (HHV)	(MJ/kg DM)	17.57
Heating value (LHV)	(MJ/kg FM)	17.14
Nitrogen (N)	% of DM	0.66
Potassium (K)		0.22
Chlorine (Cl)		0.11
Sulphur (S)		0.06



Briquettes after pressing

### 3.1.1 Technical performance

With automatic hot air ignition the fuel ignited easily. After about 15 minutes a full flame was seen in the combustion chamber and the boiler and flue gas temperature rose continuously.

The fuel burnt with a full and bright flame. Since the fuel consists of pressed fibres and had been destabilized during transport, flying sparks could be observed in the combustion chamber. However, the sparks still burnt up in the upper part of the boiler and had probably no influence on the dust content in the flue gas. Less flying sparks were seen during partial load operation compared to full load operation, since the air blowers ran with lower power and, thus, less fuel was swirled.

In the combustion chamber, slight slagging of the material could be detected (see pictures below). However, the air flow to the fuel was not hindered. The slag could be crushed during the operation of the ash slide and was easily discharged into the ash box. When operating a system including an ash screw and possibly an additional ash crusher this ash fraction would be crushed and discharged without any problems.

During partial load, however, more slagging occurred and the air flow was hindered slightly. This was because less material was reloaded compared to full load.



Ash (combustion cavity)  
– Full load



Ash (ash pan) – Full load

### 3.1.2 Emissions

Emissions were monitored as minimum, maximum and average values and are shown in the table below.

The French regulation for emission limits is depending on the classification of the fuel type. If the fuel type is classified as “virgin biomass”, there are no legal emissions limits for boilers below a thermal output of 2000 kW in France. However, if the fuel is classified as waste, there are emission limits to be kept. In full load mode, the emissions were below the limits; also one has to keep in mind that the measured emissions were related to 11 % O<sub>2</sub> and the emission limits to 6% O<sub>2</sub>.

With regard to German legislation for biomass boilers the emissions of CO and NO<sub>x</sub> were below the thresholds (CO: 250 mg/m<sup>3</sup> (only valid for full load); NO<sub>x</sub>: 500 mg/m<sup>3</sup>). The threshold of PM (50 mg/m<sup>3</sup>) could only be met in full load mode, but in practice a filter would help to be in line with the PM standards.

Tab. 2: Emissions of PM, CO, NO<sub>x</sub> and SO<sub>2</sub> resulting from the combustion of French fuel

		PM	CO	NO <sub>x</sub>	SO <sub>2</sub>
		mg/m <sup>3</sup> (reference: 11% O <sub>2</sub> )			
<b>Full load</b>	Minimum	39.1	2.0	176.0	0.0
	Maximum	49.2	675.0	452.0	148.0
	<b>Average</b>	<b>43.18</b>	<b>75.4</b>	<b>353.3</b>	<b>41.4</b>
<b>Legal threshold France</b>	<b>Regional: Virgin bio- mass / Waste biomass*</b>	<b>- / 50*</b>	<b>- / 250*</b>	<b>- / 525*</b>	<b>- / 225*</b>
<b>Legal threshold Germany</b>		<b>50</b>	<b>250</b>	<b>500</b>	<b>-</b>

\* at 6% O<sub>2</sub>



### 3.2 Welsh fuel

The fuel was burnt in briquette form. Just as the briquettes from France, the briquettes from Wales crumbled into smaller pieces after loading and transport to the biomass boiler (see pictures below). Due to the size of the briquettes and their different content of fine material, the amount of fuel loaded into the boiler varied slightly and with that the performance. Larger combustion units with larger stoker screw diameter can be expected to have a more consistent fuel loading.

Tab. 3: Characteristics Welsh fuel

Ash	% of DM	3.54
Dry matter (DM)	% of FM	92.71
Heating value (HHV)	(MJ/kg DM)	17.85
Heating value (LHV)	(MJ/kg FM)	16.37
Nitrogen (N)	% of DM	0.79
Potassium (K)		0.16
Chlorine (Cl)		0.11
Sulphur (S)		0.08



Briquettes after pressing



Briquettes after storage

#### 3.2.1 Technical performance

Concerning ignition, flame characteristics, flying sparks and slagging, the fuel from Wales showed similar behaviour as the French fuel.



Ash combustion (cavity) – Full load



Ash (ash pan) – Full load

### 3.2.2 Emissions

Most visible differences to the French fuel were increased emissions of  $\text{NO}_x$  and  $\text{SO}_2$ , but lower emissions of CO. This fact could be attributed to the slightly increased nitrogen content in the fuel.  $\text{SO}_2$  emissions were again highest in the full load operation mode. All in all, average emissions were below the legal thresholds in German legislation (except CO in partial load and PM). Concerning UK legislation, the Renewable Heat Incentive (RHI) is the most important law to look at, which is a tool to provide financial support for using renewable heat instead of heat from fossil fuels. Within the RHI there are two important thresholds formulated concerning emissions. Thresholds of 150 g / GJ of  $\text{NO}_x$  and of 30 g per GJ of particulate are given. As these thresholds are given as grams of pollutant per gigajoule of net energy input, one has to recalculate these thresholds to convert it into emission concentration data ( $\text{mg}/\text{m}^3$ ). According to the Guideline: “Conversion of biomass boiler emission concentration data for comparison with Renewable Heat Incentive emission criteria” these recalculation has to be done as follows:

It is possible to convert an emission concentration to a g/GJ emission factor using a specific dry flue gas volume factor (SDFGV).

Essentially :

$$EF = [\text{Conc}] \times (\text{SDFGV}) \div 1000$$

Where :

*EF* = Emission Factor, g/GJ net heat input

*[Conc]* = Pollutant concentration,  $\text{mg}/\text{m}^3$  dry flue gas at  $0^\circ\text{C}$ , 101.3 kPa and at a defined Oxygen concentration

*(SDFGV)* = Specific dry flue gas volume per GJ net heat input,  $\text{m}^3/\text{GJ}$  - for dry flue gas at  $0^\circ\text{C}$ , 101.3 kPa and at the same defined oxygen concentration as the pollutant concentration.

The specific dry flue gas volume is given in the guideline, of course not for the IFBB press cake but for hay. As the calorific value of hay and dried press cake is pretty similar, we took the values given for hay to calculate the thresholds to boiler emission data. These thresholds are therefore not hundred percent fixed, but should be a good guideline. From

a look at the data, it becomes clear that the NO<sub>x</sub> emissions and PM emissions are too high for receiving the RHI bonus. However, the boiler was not fitted with a filter system. If fitted with a filter, the PM values should be easily achieved. The NO<sub>x</sub> values can also be lowered by a better adjustment of primary air. If it is possible to reach the guideline value will have to be evaluated in further tests.

Tab. 4: Emissions of PM, CO, NO<sub>x</sub> and SO<sub>2</sub> resulting from the combustion of Welsh fuel

		PM	CO	NO <sub>x</sub>	SO <sub>2</sub>
		mg/m <sup>3</sup> (reference: 11% O <sub>2</sub> )			
<b>Full load</b>	Minimum	46.3	7.0	265.0	0.0
	Maximum	62.3	505.0	533.0	124.0
	<b>Average</b>	<b>50.8</b>	<b>38.2</b>	<b>405.6</b>	<b>58.5</b>
<b>Legal threshold for bonus payment (calculated from RHI)</b>	<b>Regional</b>	<b>58</b>		<b>290</b>	
<b>Legal threshold</b>	<b>Germany</b>	<b>50</b>	<b>250</b>	<b>500</b>	<b>-</b>



### 3.2.3 Belgian fuel

The fuel was burnt in briquette form. Just as the briquettes from France or Wales, the briquettes from Belgium crumbled into smaller pieces after loading and transport to the biomass boiler. Due to the size of the briquettes and their different content of fine material, the amount of fuel loaded into the boiler varied slightly and with that the performance. Larger combustion units with larger stoker screw diameter can be expected to have a more consistent fuel loading.

Tab. 5: Characteristics of Belgian fuel

Ash	% of DM	3.88
Dry matter (DM)	% of FM	88.75
Heating value (HHV)	(MJ/kg DM)	17.69
Heating value (LHV)	(MJ/kg FM)	15.43
Nitrogen (N)	% of DM	0.89
Potassium (K)		0.08
Chlorine (Cl)		0.04
Sulphur (S)		0.07



Briquettes after pressing

### 3.2.4 Technical performance

Concerning ignition, flame characteristics, flying sparks and slagging, the fuel from Belgium showed similar behaviour as the French and Welsh fuels.



Ash (combustion cavity)



Ash (ash pan)

### 3.2.5 Emissions

Emissions during the combustion of the Belgian fuel showed results that were comparable to the Welsh fuels. All emissions measured during full load operation were below the legal thresholds in Germany. PM emissions were also below the threshold for the partial load operation, and SO<sub>2</sub> emissions were again highest in the full load mode. Concerning Belgian combustion thresholds the situation is more complicated, depending on whether the fuel can be classified as a resource or as a waste and in case of waste which type of waste. If the fuel is classified as a resource and burned in a small combustion unit 0-0.3 MW, there are no emission thresholds. If the fuel is classified as a waste, there are thresholds, depending on the scale of combustion unit and the type of waste. For the IFBB fuel, either a classification as “biomass waste” is possible or as “other non-dangerous waste”. The thresholds for “biomass waste” are easily met for all parameters, not even a dust filter would be necessary. In the case of classification of the fuel as “other non-dangerous waste” a dust filter would be necessary and the emission threshold for NO<sub>x</sub> would not be met, although only barely higher emissions occur, which might be possible to reduce by small adaptations on the combustion unit settings.

Tab. 6: Emissions of PM, CO, NO<sub>x</sub> and SO<sub>2</sub> resulting from the combustion of Belgian fuel

		PM	CO	NO <sub>x</sub>	SO <sub>2</sub>
		mg/m <sup>3</sup> (reference: 11% O <sub>2</sub> )			
<b>Full load</b>	Minimum	32.8	7.0	265.0	0.0
	Maximum	42.6	505.0	533.0	124.0
	<b>Average</b>	<b>37.2</b>	<b>52.9</b>	<b>404.0</b>	<b>58.4</b>
<b>Legal thresholds</b>	<i>Belgium</i>				
	<i>0 – 0.3 MW</i>	<i>200*</i>	<i>375*</i>	<i>600*</i>	<i>450*</i>
	<i>0.3 – 1 MW</i>	<i>200</i>	<i>375</i>	<i>600</i>	<i>450</i>
	<i>1 – 5 MW</i>	<i>50</i>	<i>375</i>	<i>450</i>	<i>450</i>
<b>* not applicable if fuel is considered a resource</b>					
<b>Legal thresholds</b>	<b>Germany</b>	<b>50</b>	<b>250</b>	<b>500</b>	<b>-</b>



## 4 Conclusions

All fuel batches consisted of briquettes which crumbled increasingly into their fiber constituents. This can already be seen in the big bags in which significantly finer material can be found at the bottom compared to the top. The stoker crushes the briquettes even further, which leads to loading of briquettes in varying degrees of comminution. High fiber content mainly led to visible sparks during full load. However, these sparks only had a low effect on the dust content, as they burned out in the burnout zone.

The combustion behavior is very similar for all batches. The ignition is very good; the fuel ignites quickly and without problems. A large bright flame emerged quickly. The rated power of the 120 kW boiler could be achieved permanently.

All batches showed light slagging of the ash. However, there were no problems that impeded the airflow, since the fuel material was loose and the air could disperse through the fuel. The slag was crushed by the ash slide and discharged into the ash box. During operation of the boiler, ash conveyor and ash crusher, the ash fraction was easily crushed and discharged.

The briquettes burned smoothly and with a bright flame.

In respect to the emissions it can be stated that the thresholds from legislation are kept in full load mode on average, only a few maximum values were higher than the thresholds.

Dust levels were comparatively low for an operation without filter. In conclusion, it can be said that this fuel is very well suited for the combustion in the ÖKOTHERM®-Compact plant C1L.

