Biomass 2 Biochar – Evaluation of biochar for solid fuel use

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Prefix – *The following report is an assessment of the fuel qualities of biochar produced by the project. It is not to advocate for biochar to be used as a solid fuel. If domestic heat were the sole exploitation of the biomass used, then it would be far simpler to densify and burn in pellet or briquette form.*

The data contained in Table 1, is a collation of elemental analytical data from 1) Celignis Ltd, a biomass testing laboratory from Limerick, Ireland and 2) Eurofins Umwelt Ost GmbH, Germany. For clarity, the comparative (before pyrolysis) biomass sample tested was *Juncus Effusus* (rushes) by Celignis and all four biochar samples (after pyrolysis) were tested by Eurofins.

Table 1 - Analytical elemental analysis data for Juncus Effusus (rushes) biomass and Bracken, Ulex, Corylus and Juncus Effusus biochar.

	Biochar***				**Biomass Sample******	***Juncus Effusus***
	Bracken	Ulex	Corylus	*Juncus Effusus*	***Juncus Effusus***	% Difference (+ve/-ve)
Moisture*	14.8	8.5	15.8	8.9	**17.4**	
Ash**	11.2	2.6	9.8	22.4	**3.2**	604.4
Total Carbon**	77.2	92.7	80.2	66.1	**48.7**	35.6
Hydrogen**	2.4	1.3	2.4	1.7	**6.1**	-71.9
Nitrogen**	2.0	0.9	1.3	1.8	**1.4**	25.4
Sulphur**	0.10	0.04	0.05	0.32	**0.06**	433.3
Oxygen**	8.6	3	9.8	10.1	**40.5**	-75.1

*As received sample
**Dry basis
***Biochar analysis tested at Eurofins Umwelt Ost GmbH between June and October 2022
*****Juncus Effusus* biomass sample tested at Celignis Laboratory, Limerick, December 2022

For further comparisons, other typical and currently underutilised biomass types – Hazel mixed chip and cereal straw, were also analysed by Celignis for their elemental composition. Although these products are quite different in physical appearance, their chemical makeup is not too dissimilar. Carbon contents of most biomass types are typically 40-50% and they have a high volatile content – this is defined as the amount of gas/vapour evolution when heating. Volatile content is related to gas evolution when burning and the ease of lighting, and is also an indicator of smoke generation, alongside moisture content.[1]

To avoid nuisance smoke, it is recommended to only burn dry or well-seasoned (<20% moisture) biomass in an approved appliance – a domestic stove or electronically controlled pellet stove or similar. Open fires produce a large amount of smoke, due to the lack of air control needed for complete combustion.[2]

Each of the biochar types vary significantly in their composition, this is related to 1) biomass feedstock type and the elemental analysis (lignocellulosic, protein and inorganic/ ash content), 2) physical characteristics (bulk density, particle size, moisture content) and 3) processing conditions (pyrolysis temperature, reaction time, heat transfer etc.).

For solid fuel use, all the biochar produced would be suitable for domestic combustion purposes, such as open fire or in a stove, provided some form of densification process were employed. This would include methods such as briquetting, agglomeration, or pelletization. Binders may be required, depending on the densification method used.

In terms of solid fuel grading and quality, the carbon, hydrogen, oxygen, and ash content are of highest importance. The carbon and hydrogen content contribute to the highest extent the calorific value of biochar. Oxygen and ash have a negative impact on the calorific value. Sulphur content is a contributor to the formation of sulphur dioxide during combustion which reacts with water to form acid rain. Biomass typically has very low sulphur content, which drastically reduces pollution events related to this.

The fuel ranking for the chars based on composition would be Ulex > Corylus > Bracken > *Juncus Effusus*. The difference between Bracken and Corylus is small due to their similar composition. As a domestic fuel, the user experience would vary depending on the appliance in which it was used, giving a similar performance to fossil coals.

There is a large variation in the ash/ inorganic content of the biochar samples. This variation is marked when comparing the biomass and biochar samples of *Juncus Effusus*, with a >600% increase. It is the authors opinion that this sample were somehow contaminated, or a non-homogeneous sample was taken for analysis. The reason for this would be not only comparing the ash content, but also the sulphur content. During pyrolysis, the elemental organic components (carbon, hydrogen, oxygen, and nitrogen) are released as gases such as carbon dioxide, organic compounds, and tars. Generally, the ash and sulphur fractions increase marginally as a proportion of remaining material – depending on the pyrolysis conditions, so for example, if the raw biomass ash was 10% on a dry basis, this would increase to 15% in the biochar, with a 33% decrease in the overall organic mass. The fact that both ash and sulphur are almost a factor higher for *Juncus Effusus*, would point to some form of irregularity.

Ash content is also related to the 'user experience' as this is the material remaining in the grate, following combustion. High ash materials are classified as lower-grade, due to the volume of ashes building up and requiring frequent removal.

Another way to classify solid fuels is by use of the Van Krevelen diagram (Figure 1). The carbon, hydrogen and oxygen contents of all fuels can be plotted by using atomic ratios of oxygen: carbon (x-axis) and hydrogen: carbon (y-axis). All untreated biomass types are in the top right of the chart, with thermally processed materials, and naturally occurring coal, and oils much closer to the origin. This is due to the vastly reduced hydrogen and oxygen content of fossil fuels, compared to biomass.

Displayed in the Van Krevelen diagram in Figure 2 are the five samples (four biochar and one biomass) from Table 1, with their atomic ratios plotted as per their composition. As can clearly be seen, the four biochar samples are located close to the origin, with the untreated biomass (*Juncus Effusus*) located firmly in the top right. The direct reaction pathway is oxygen and hydrogen reduction largely though dehydration or dewatering, which is the removal of chemically bound water and the evaporation of free moisture.

Two major benefits of the pyrolysis process are the removal of biomass volatile components and a drastic reduction in moisture content – factors are largely responsible for smoke generation during the combustion process. Pyrolyzed biomass for solid fuel use are an excellent short to medium-term solution for the transition to a renewable energy future.

In conclusion, all the biochar produced would be suitable for domestic combustion and have improved combustion characteristics over the untreated starting materials, resulting in reduced particulate and smoke emissions.[3] Biochar produced from the pyrolysis process forms a stable product, resistant to further degradation. Following a suitable densification step to reduce logistical costs, biochar from residual biomass types could open new, local Irish solid fuel markets.

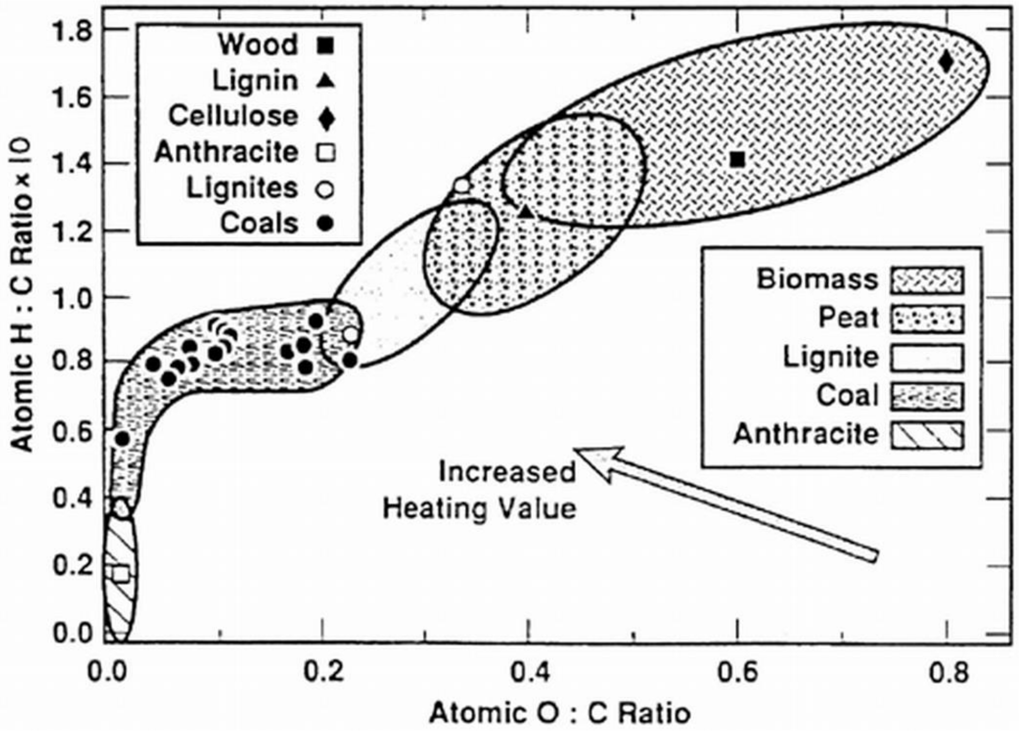

Figure 1 – Van Krevelen Diagram (Source https://doi.org/10.5772%2F25030)

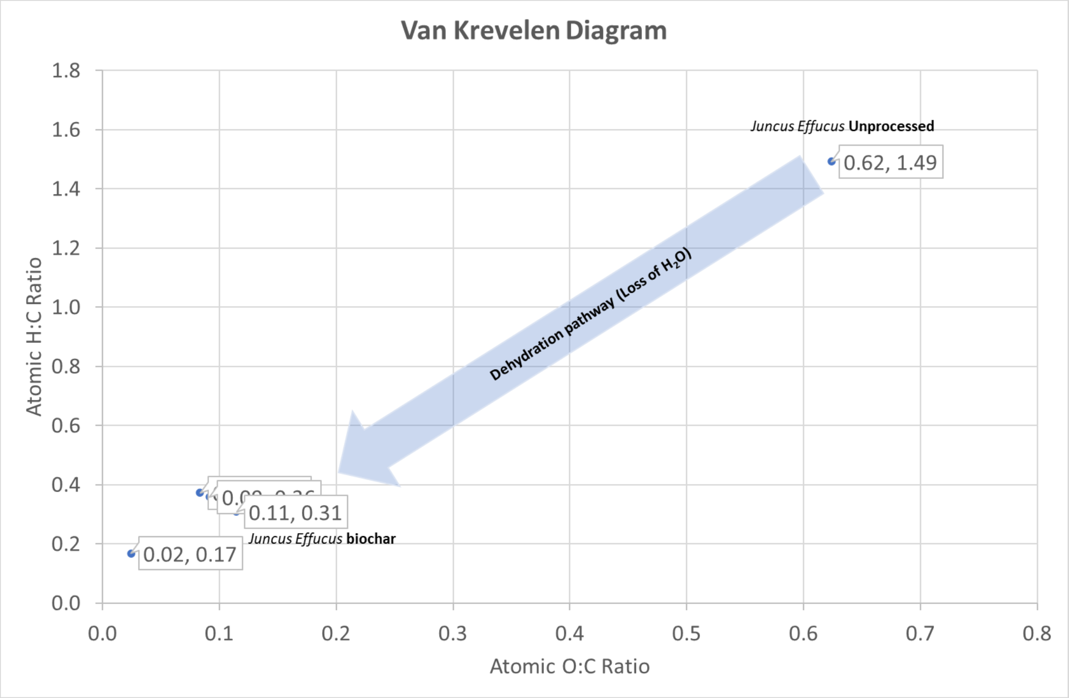

Figure 2 - Van Krevelen Diagram showing thermal degradation (dehydration) pathway from biomass to biochar

References

[1] Yao Bin Yang, Changkook Ryu, Adela Khor, Nicola E. Yates, Vida N. Sharifi, Jim Swithenbank, Effect of fuel properties on biomass combustion. Part II. Modelling approach—identification of the controlling factors, Fuel, Volume 84, Issue 16, 2005, Pages 2116-2130, ISSN 0016-2361, https://doi.org/10.1016/j.fuel.2005.04.023.

[2] https://www.epa.ie/environment-and-you/air/resources/airqualityhomeheatinginfograhpic-2022.php

[3] Study of Emissions from Domestic Solid-Fuel Stove Combustion in Ireland. Anna Trubetskaya, Chunshui Lin, Jurgita Ovadnevaite, Darius Ceburnis, Colin O'Dowd, J. J. Leahy, Rory F. D. Monaghan, Robert Johnson, Peter Layden, and William Smith Energy & Fuels 2021 35 (6), 4966-4978 DOI: 10.1021/acs.energyfuels.0c04148