Biomass Analysis Services

FROM A LAB DEDICATED TO ADVANCING THE BIOECONOMY

CELIGNIS LOCATIONS

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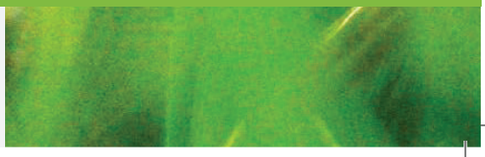

Celignis Analytical

We are a dedicated service provider for the bioeconomy. We provide our clients with the most precise compositional data and highly-informed process expertise in order to allow them to make the best use of their biomass feedstocks and optimise their biomass conversion processes.

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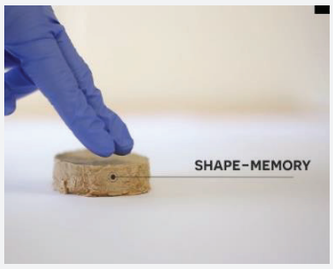
ADVANCED BIOFUELS

We can help to determine the value of your feedstock for the production of advanced biofuels. We determine sugars in cellulose and hemicellulose, as well as lignin, extractives, and ash. We provide data in one day with our unique rapid analysis models.



BIOMATERIALS & BIOCHEMICALS

We are experts in the extraction of biopolymers from biomass and then in modifying these to obtain materials with diverse functional properties. Our team also uses advanced analytical equipment to find high-value biochemicals in feedstocks.

BIOPROCESS DEVELOPMENT

We provide valued analytical services to industrial and academic clients across the globe. We also have a top-class multidisciplinary team that can work with our clients on optimising their biomass valorisation technologies.

Our Philosophy

"We believe that when people have accurate and comprehensive data the opportunities are limitless"

Celignis was born from research that targeted replacing fossil-fuels with sustainable biofuels. We found that feedstock composition was crucial, but that literature data could be highly misleading. There was a critical need for accurate analysis. We are driven to provide the best possible data and want to play our part in the development of the bioeconomy.

Dr Dan Hayes, CEO of Celignis Analytical.

ANAEROBIC DIGESTION

page 12-13

We determine many properties relevant to the anaerobic digestion of biomass. These include the biomethane potential and the composition of the digestate. We also provide bioprocess consultation services to improve digestion efficiency.

BIOCHAR ANALYSIS

page 14-15

This page details our wide-ranging analysis packages for the evaluation of biochar and pyrolysis feedstocks. We are available to discuss these results with you and suggest suitable applications for your biochar and potential process optimisations.

SEAWEED COMPOSITION

page 16

Seaweed has huge potential for the bioeconomy. We understand the unique chemistry of seaweed and the potential applications of polysaccharides and other components, and offer many seaweed-specific packages for sample evaluation.

BIOMASS FEEDSTOCK ANALYSIS

1. Advanced Biofuels Feedstocks

RELEVANT ANALYSIS PACKAGES:

P4 - Ethanol Extractives

P5 - Water Extractives

P7 – Lignocellulosic Sugars: Glucose, Xylose, Mannose, Arabinose, Galactose, Rhamnose

P8 – Lignin Content: Klason Lignin, Acid Soluble Lignin, Acid Insoluble Residue, Acid Insoluble Ash

P10 – Sugars, Lignin, Extractives, and Ash

P270 – Protein-Corrected Klason Lignin

P11 – NIR Prediction

P14 – Starch Content

P15 – Uronic Acids: Glucuronic, Galacturonic, Mannuronic, Guluronic, 4-O-Methyl-D-Glucuronic

P16 – Acetyl Content

P17 – Biomass Amino Acids: Alanine, Arginine, Aspartic, Cystine, Glutamic, Glycine, Histidine, Isoleucine, Leucine, Lysine, Methionine, Phenylalanine, Proline, Serine, Threonine, Tyrosine, Valine

P18 –Lipids as Fatty Acids

P19 – Deluxe Lignocellulose Package

P20 – Lignin S/G Ratio

We can determine all the important parameters for the production of chemicals and advanced biofuels from cellulosic biomass.

Second-generation biofuels, such as cellulosic ethanol, offer huge potential in substituting for fossil-derived transport fuels. Similarly, biorefineries could produce a range of sustainable chemicals and bio-products from low-cost lignocellulosic biomass. The number of suitable feedstocks is massive and includes energy crops, agricultural residues, and municipal wastes. There can be huge variations in composition between different feedstocks and also within the same feedstock grown in different locations and under different conditions. Thus, it is crucial to use a laboratory experienced in the detailed and complex methods of analysis required to fully characterise these materials.

We provide all lignocellulosic analytical data in duplicate so you can see the precision of our work

EXTRACTIVES

These are non-cell-wall components that can be removed using various solvents. Extractives can vary greatly in their compositions and amounts according to the feedstock and its stage of life. We recommend that extractives are removed prior to undertaking the lignocellulosic analysis of samples. We can use water, ethanol, or other solvents for extraction and can determine 14 different water-soluble carbohydrates present in the liquid extract. We also offer detailed analysis of the constituents in ethanol extractives.

STRUCTURAL SUGARS

In lignocellulosic biomass the main structural polysaccharides are cellulose and hemicellulose. These are often the most important constituents when estimating potential cellulosic ethanol yields from the biological conversion of biomass.

We can determine the glucan content of biomass, a good estimate for the cellulose content, and we can also analyse for five other sugars present in hemicellulose (xylose, mannose, arabinose, galactose, and rhamnose) as well as uronic acids (galacturonic, glucuronic, mannuronic, guluronic, 4-O-Methyl-D-Glucuronic) and acetyl content.

LIGNIN

This is a structurally important polymer in biomass and is often the solid residual output of biorefineries after the polysaccharides have been hydrolysed. It can be combusted or used as a feedstock for the production of chemicals and biofuels. In our acid hydrolysis process for liberating the structural sugars, we obtain Klason lignin as a solid residue and also acid soluble lignin which we determine using ultraviolet spectroscopy. With package P270 we can correct the lignin content for residual protein after hydrolysis.

STARCH

Starch is a glucan polymer so we recommend, for relevant samples, that starch content is analysed to differentiate between lignocellulosic and starch-derived glucose.

PRETREATED

Biomass pretreatment is a crucial step for the production of advanced biofuels and chemicals. There are a large number of different processes that can be used and a wide spectrum of potential products. We have a suite of analysis packages designed to fully evaluate the efficiency of pretreatment so that conditions can be appropriately engineered for the particular feedstock and desired end products.

In particular, the starting feedstock should be characterised in detail so that the different sources (e.g. lignocellulose, starch, extractives etc.) of sugars that may be liberated in pre-treatment are known. We strive to get as close to mass closure as possible for the whole pre-treatment process and this involves analysing in detail both the liquid and solid outputs.

We are the Only Company to Provide Lignocellulosic Data within One Day and at Low Cost!

We can follow standard chemical analysis methods for determining the lignocellulosic composition of biomass. However, these chemical analysis methods can be slow, taking up to two weeks for a sample, as numerous steps and items of equipment are involved. To date, the length of this analytical process has meant that the number of samples that can be analysed has been restricted by time and by finance limitations.

But we at Celignis have the solution! As an alternative to our chemical analysis packages you can get your solid biomass samples analysed using our unique rapid-analysis Near Infrared (NIR) method. This involves us scanning your sample and then applying our proprietary algorithms to predict the content of 13 different lignocellulosic parameters. This means that we can provide you with data within one day for as low as €60 per sample. No other company is able to provide this service for advanced biofuel feedstocks.

CHEMICAL ANALYSIS METHOD

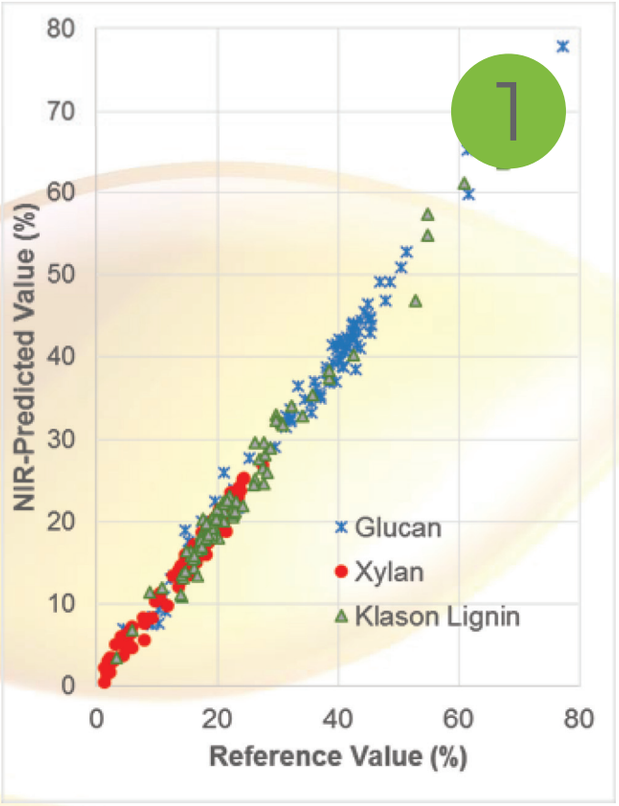
CELIGNIS RAPID ANALYSIS

You are no longer limited in the number of samples you can evaluate!

Benefits of our Rapid NIR Method

1 ACCURATE – DATA YOU CAN RELY ON

When the data from our NIR prediction models were compared with data from standard chemical analyses we found a very close correlation (R^2 of ~0.97 for the main constituents of lignocellulose). Furthermore, as well as providing data for the predicted composition, our NIR package also provides an estimate for the error (deviation) in the prediction and, if we find this to be high, we will undertake the chemical analysis at no extra charge.



2 SUITABLE FOR ALL BIOMASS TYPES

Our models have been demonstrated on thousands of samples covering a wide variety of feedstocks including energy crops, crop residues, organic wastes, pre-treated samples, and process residues.

3 FITS WITH YOUR REQUIREMENTS

The rapid turnaround and low cost mean that you can quickly see the value of your samples or process conditions and make responsive decisions or modifications accordingly. You can also analyse many more samples than before, improving your chances of finding the optimal sample!

BIOMASS VALORISATION

2. Advanced Biomaterials

Advanced biomaterials are designer materials developed by modification and functionalisation of polymers derived from biomass. They are playing important roles in many sectors, from packaging to tissue engineering.

The type of biomaterials range from bioplastics to hydrogels and aerogels. Design and characterisation of these materials require trans-disciplinary knowledge of biomass chemistry, chemical engineering, materials engineering, and molecular chemistry. Celignis's multi-disciplinary team has successfully designed biomaterials from marine and terrestrial biomass for clients and in a number of EU projects.

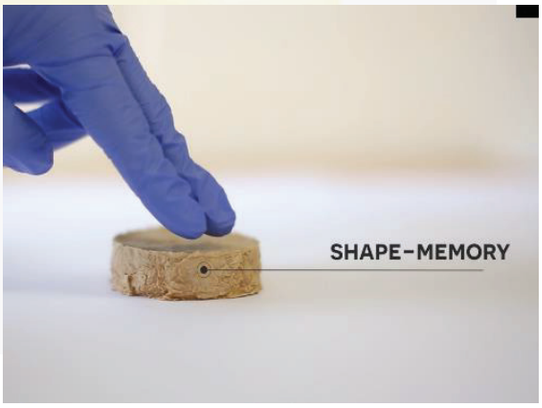
1 EXTRACTION AND PURIFICATION OF BIOPOLYMERS

With the expertise of the Celignis team in biomass chemistry, we design and develop processes for extraction and purification of biopolymers. It involves a multi-stage approach: (1) Analysis of feedstock for desired polymers; (2) Design of extraction strategy to obtain the polymers in the most native form; (3) Establishing proof of concept and process optimisation by lab-scale experiments; (4) Techno-economic analysis and life cycle assessment of the process; (5) Scale-up design and testing.

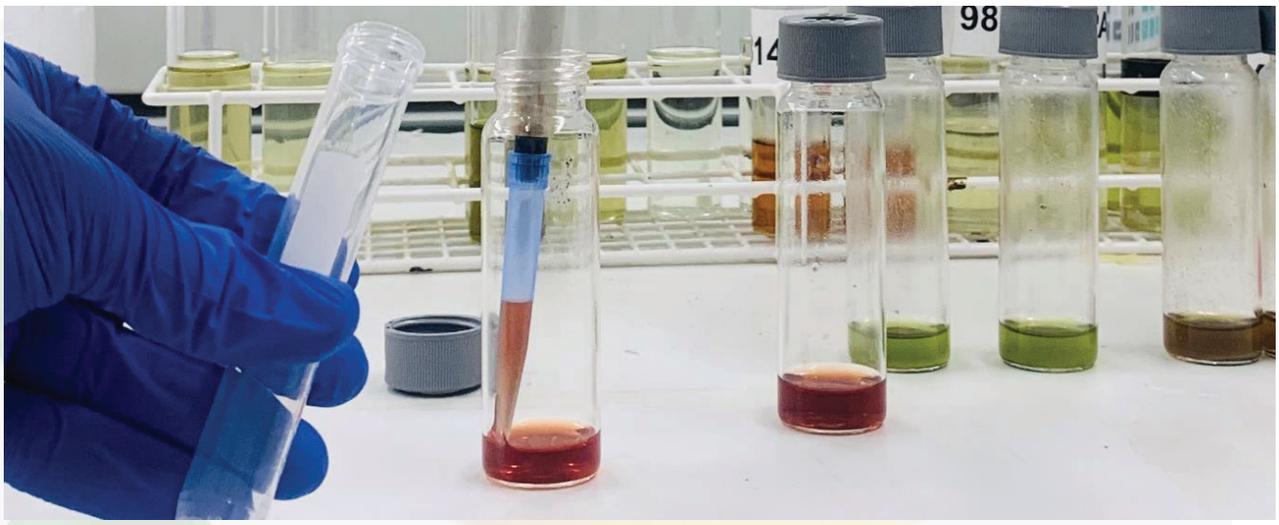
2 DESIGN AND TESTING OF BIOMATERIALS

We offer services for design of biomaterials such as: films, foams, hydrogels, and aerogels with specific functionalities.

Our expert team provides analytical testing for the biomaterials designed at Celignis or at clients' locations. The testing services include thermal behaviour testing; physical, chemical and biochemical functionalities.



3. High-Value Biomolecules



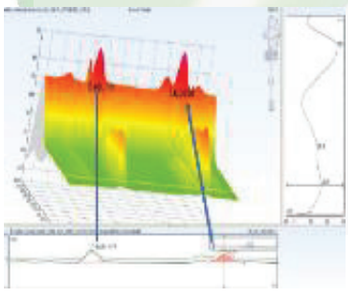
Biomolecules are derived from biomass and microbes. They have a wide range of applications such as cosmetics, paints and coatings, food and nutraceuticals and biomedicine.

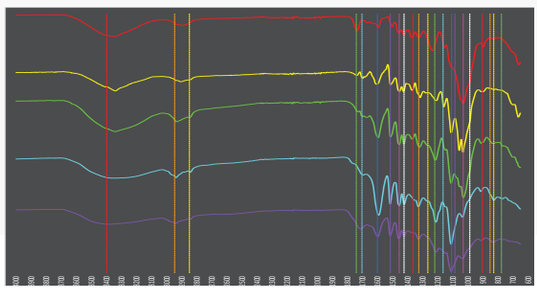
DISCOVERY, EXTRACTION AND PURIFICATION

Our multi-disciplinary team of biomass chemists, analytical chemists, and microbiologists work together to discover the novel molecules from biomass and microbial sources. Discovery of molecules from biomass involves multiple extractions in a range of polar and non-polar solvents. The extracted fractions are subjected to LC-QTOF-MS. The selected molecules, based on the novelty or abundance, are isolated and purified, following the principles of green chemistry, and are tested for purity.

STRUCTURAL AND FUNCTIONAL CHARACTERISATION

The purified biomolecules are analysed for functional groups and linkages using spectroscopic techniques. Functional characterisation of the purified molceules is performed by performing a wide variety of custom-designed microbial, biochemical, and chemical tests.





SERVICES TO INDUSTRY

4. Bioprocess Development

We are proud of the knowledge, passion, and work ethic of our team. They have played key roles in the formulation, optimisation, and commercial evaluation of biomass valorisation processes in industry and academia and, together, we have the multidisciplinary expertise to evaluate all stages of your bioprocess and suggest real improvements

We have a diverse, rapidly-expanding, global array of clients that recognise the expertise that we have with regards to biomass composition and its relevance in designing and optimising biomass conversion processes. We are also key partners in a number of multinational research projects that target significant advances in the state of the art for biomass valorisation.

Accurate data are not enough. We have in-depth understanding of the implications of composition and can design processes to fully valorise biomass

A few examples of our industrially-relevant activities...

1 Fungal and Bacterial Enzymes

Our personnel can investigate strategies for reducing enzyme loadings whilst maintaining, or even enhancing, product yields. We can also, based on our array of existing packages for the enzymatic hydrolysis of biomass and pretreated biomass, determine how efficient a pretreatment technology is in producing a substrate suitable for hydrolysis with enzymes and suggest tweaks in the pre-treatment process that may lead to enhanced yields and reduced costs per unit output.

2 Process Optimisations

We have a very strong understanding of the chemistry of biomass and how to evaluate the conversion and valorisation of the main constituents. We target mass-closure in our analysis so that the conversion mechanisms can be understood. Such knoweldge will be key in developing relevant and effective tools for modelling and optimising biomass transformations. We can also investigate each process node for less energy/chemical intensive alternatives without compromising yield. Our team are happy to discuss examples of our track-record.

3 Microbial Fermentations

Know-how in the area of microbiology, bioprocess engineering and design of experiments (DoE) can significantly reduce the number of experimental runs and time involved in the preliminary screening and optimisation process. We have the expertise to optimise fermentation processes for high yield and productivity in short-time. Our personnel have proven scientific records in producing enzymes, biofuels, biosurfactants, exopolysaccharides and prebiotics through aerobic and anaerobic fermentation.

4 Bioprocess Infrastructure

- Bench-top (1l and 5l) advanced bioreactors.
- Anaerobic fermentation systems (1l and 5l).
- Gas fermentation systems.
- Extracellular flux analysers for metabolic burden analysis.
- Library of industrially-relevant non-recombinant strains.
- 96-wellplate UV-Vis and fluorimetry analysers.
- QTOF-LC/MS for microbial metabolites analysis.
- Ultrafiltration systems for downstream processing.
- Extensive chromatography lab for fermentation products
- 100 litre bioreactor for scale-up studies.

BIOMASS FEEDSTOCK ANALYSIS

5. Anaerobic Digestion

Anaerobic digestion will expand rapidly in the future and we can provide you with crucial data on feedstock suitability and process residues. Our staff have experience in developing and optimising digestion processes for a number of clients across the globe and can work with you on getting the most from your feedstock and technology

Anaerobic digestion is traditionally used to treat biodegradable wastes and sewage/wastewater sludges, but these days it has garnered attention as a source of renewable energy. The process has also been increasingly used as a means by which to generate renewable heat and/or electricity from industry process residues. The biogas produced is either used in a gas engine or it can be upgraded to biomethane that can be suitable, in some cases, for direct injection into the gas grid. Anaerobic digestion involves four key stages (hydrolysis, acidogenesis, acetogenesis, and methanogenesis) and underperformance of any of these stages will have significant impact on the preceding and subsequent stages.

The potential of a process residue or feedstock to produce biogas is tested by the biomethane potential (BMP) test. Though the BMP is considered the maximum biomethane potential of the tested feedstock, the methane production can be further improved by designing optimum feedstock mixes and additives.

We provide analysis and consultation services to help evaluate feedstock and process suitability for maximising biomethane yields and RINs credits

BIOMETHANE POTENTIAL

The biochemical methane potential (BMP) can be considered to be the experimental theoretical maximum amount of methane produced from a feedstock and is expressed in terms of methane per gram of volatile solids (VS - the non-ash component of dry biomass).

We determine the BMP of samples in our lab. It involves mixing the organic substrate with an anaerobic inoculum in a closed reactor that is incubated at a set temperature, with the contents mixed for a set period of time over which the sample is digested and biogas is produced. The volume of biogas is monitored allowing for a cumulative plot over time. Our experiments can last either 14, 21, 28, or 40 days and we can also analyse the biogas for its composition (methane, carbon dioxide, hydrogen sulphide, ammonia).

PROCESS OPTIMISATION

Anaerobic digestion has multiple variables, including: organic loading time, solids retention time, hydraulic retention time, feedstock mixtures, and trace element concentrations. All these variables affect the microbiome of the digester. Hence, for an efficient process optimisation we perform microbiological and biochemical analysis to determine the specific activities of hydrolytic, acidogenic, and methanogenic bacteria. Based on the results, and the historical data provided by the plant operator, variable limits will be designed for an optimum process.

PLANT OPERATIONS

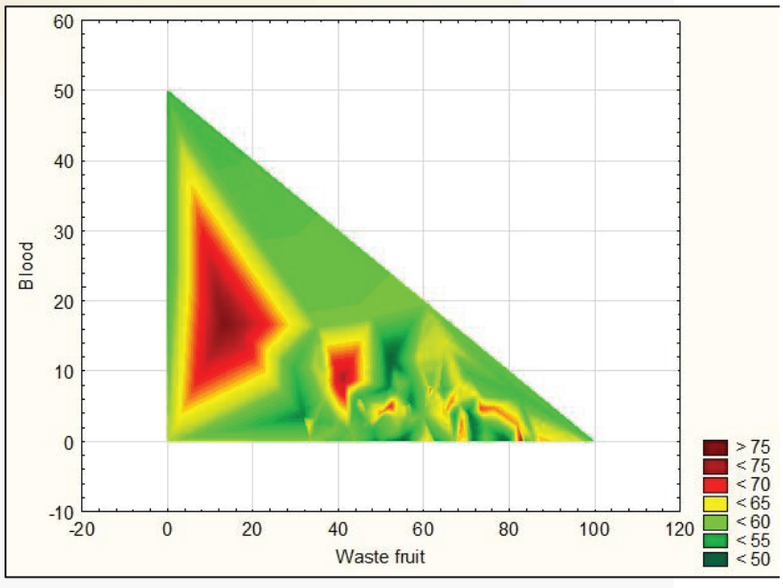
Celignis AD-expert team provide consultation services for plant operations by monitoring the AD plant biogas production and composition data and other key process indicators obtained from the plant operators. In addition, we perform statistical correlations of the process inputs with the process indicators and outputs to define the operational limits for optimum plant operation.

FEEDSTOCK ANALYSIS

Our expertise in biomass analysis can allow for detailed insight regarding the fate of the different biogenic polymers during digestion. For example, comparisions between the relative amounts of cellulose, hemicellulose, and lignin in the starting feedstock and the digestate can show the extent to which these constituents have been digested. Such data can assist stakeholders in modifying process conditions in order that the specific biomass feedstock can be more efficiently valorised.

DIGESTATE ANALYSIS

Digestate is the residue that remains after a sample has been digested. We can characterise digestate samples for: residual biogas potential; minerals and metals; impurities; and fertiliser properties in order to find the most appropriate end-use and to evaluate digestion efficiency.



FEEDSTOCK TO BIOCHAR

6. Advancing Biochar

RELEVANT ANALYSIS PACKAGES:

P350 – Biochar Production

P51 – Particle Size

P360 – Specific Surface Area

P364 – Pore Size Distribution

P388 – Biochar Plant Growth Trials

P386 – Germination Inhibition Assays

P384 – Polycyclic Aromatic Hydrocarbons

P382 – Water Holding Capacity

P383 – Cation Exchange Capacity

P33 – Ultimate Elemental Analysis (C, H, N, S, O)

P38 – Major and Minor Elements:
Al, Ca, Fe, Mg, P, K, Si, Na, Ti, Sb, As, Cd, Cr, Co, Cu, Pb, Hg, Zn, Va, Ni, Mn

P373 – Thermogravimetric Analysis

P34 – Calorific Value and Elements
Gross Calorific Value, Net Calorific Value, Ash, CHNSO

P42 – Ash Melting Behaviour

P371 – Ash Content (815 °C)

P381 – Electrical Conductivity

We can determine the most relevant properties of biochar and provide a comprehensive assessment of the results

Numerous strategies are being implemented to achieve a neutral carbon footprint, but biochar is one of the few alternatives that has the potential to sustainably meet energy and material needs while potentially being carbon-negative. Biochar is a porous material suitable for being used as: an activated carbon precursor; a catalyst during the production of biodiesel; a soil supplement for improving plant development; or as an additive for upgrading biogas production. These potential applications require a variety of advanced analyses for determining the suitability of each type of biochar for the application of interest. Thus, it is crucial to use a laboratory experienced in the detailed and complex methods of analysis required to fully characterise biochar.

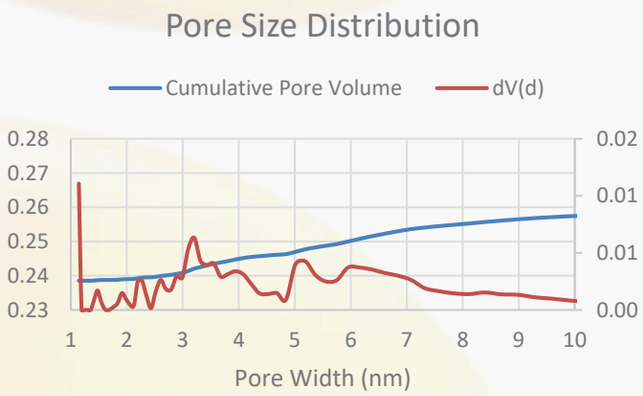
We are equipped to run all the necessary analysis for the EBC and IBI certificate

SURFACE AREA & PORE ANALYSIS

During pyrolysis, the release of volatile components present in biomass provides biochar with a characteristic honeycomb structure with a relatively high surface area. This porous nature makes biochar suitable for applications such as: an adsorbent to decontaminate air and water; a soil supplement for improving plant development; or as an additive for upgrading biogas production. The production of biochar is carried out by optimizing parameters such as residence time, temperature, heating rate, inert gas flow rate, and particle size according to each type of feedstock. This variety of operative parameters results in porous, but also non-porous biochar. Therefore, it is essential to fully characterize the porous profile of each type of biochar to have a clear picture of its potential applications. Celignis offers a wide range of pacakges for such analyses.

THRESHOLD CHECKS

Biochar can have constituents that may prohibit its use in certain applications. We determine the concentrations of 23 different polycyclic aromatic hydrocarbons (PAHs) and several heavy metals. Our reports provide PASS/FAIL tables where the results are compared against threshold values set by the European Biochar Certificate for various end-uses.



Feedstock Analysis - Summary Data

Test	Method Reference	Units	As-Received	Dry Mass Basis	Dry Ash-Free Basis
Moisture	EN 14774-1:2009	%	8.49	-	-
Total Solids	Calculated	%	91.51	-	-
Ash	EN 14775:2009	%	6.85	7.49	-
Volatile Solids	Calculated	%	84.66	92.51	-
Carbon	EN 15104:2011	%	42.25	46.17	49.91
Hydrogen	EN 15104:2011	%	5.23	5.72	6.18
Nitrogen	EN 15104:2011	%	1.83	2.00	2.16
Sulphur	EN 15289:2011	%	0.14	0.15	0.16
Oxygen	By Difference	%	35.21	38.47	41.59
Aluminium	EN ISO 16967:2015	ppm	101	110	-
Calcium	EN ISO 16967:2015	ppm	4,669	5,102	-
Iron	EN ISO 16967:2015	ppm	120	131	-
Magnesium	EN ISO 16967:2015	ppm	3,313	3,620	-
Sodium	EN ISO 16967:2015	ppm	51	56	-
Phosphorus	EN ISO 16967:2015	ppm	2,994	3,272	-
Potassium	EN ISO 16967:2015	ppm	11,853	12,953	-

SOIL APPLICATIONS

Biochar can be relevant in carbon accounting schemes, as it can be considered to sequester carbon whilst also potentially enhancing soil fertility and plant productivity. However, biochar can sometimes inhibit the development of plants. For example, when it is produced from hazardous feedstocks such as municipal solid waste, the presence of heavy metals and other detrimental minor elements can be problematic. Therefore, the starting material and the obtained biochar should always be analysed prior to considering using biochar for soil amendement. We have many suitable analysis packages in this regard and can also undertake plant growth trials in our laboratories, using biochar-amended soil compared against controls.

7. Analysis of Process Liquids

RELEVANT ANALYSIS PACKAGES

P12 – Sugars in Extract:
Glucose, Xylose, Fructose, Sucrose, Mannose, Arabinose, Galactose, Rhamnose, Xylitol, Sorbitol, Arabinitol, Mannitol, Raffinose, Trehalose

P13 – Sugars and Oligosaccharides:
As P12 plus amounts of each sugar in oligomeric form.

P15 – Uronic Acids:
Glucuronic, Galacturonic, Mannuronic, Guluronic, 4-O-Methyl-D-Glucuronic

P22 – Organic Acids and Furans:
Levulinic Acid, Formic Acid, HMF, Furfural, Acetic Acid

P23 - Dimers and Trimers from Cellulose:
Cellobiose, Cellotriose

P24 - Dimers and Trimers from Hemicellulose:
Xylobiose, Xylotriose, Arabinobiose, Arabinotriose, Mannobiose, Mannotriose

P26 – Xylo-Oligos:
XOS from DP2 to DP6 plus Arabinofuranosylxylobiose, Arabinofuranosylxylotriose, Arabinofuranoxylotetraose.

P29 - Oligos from Starch:
From DP2 to DP8

P61 – Sugars in Bio-Oil Water Extract:
As P12 plus Levoglucosan, Cellobiosan, Mannosan, Galactosan

P62 – Sugars and Oligosaccharides in Bio-oil Water Extract

Biomass conversion processes can produce complex liquids containing an array of products. We have the methods, equipment and expertise to allow you to find the real chemical value in your process liquids.

MONOSACCHARIDES

We quantify arabinose, galactose, rhamnose, glucose, mannose, xylose and fructose.

SUGAR ALCOHOLS

Analytes we can determine include mannitol, sorbitol, arabinitol, glycerol, and xylitol.

URONIC ACIDS

We can quantify Galacturonic, glucuronic, guluronic, mannuronic, and 4-O-Methyl-D-Glucuronic acids in biomass/liquids.

OLIGOSACCHARIDES

In our labs we can determine disaccharides and oligosaccharides in two different ways:

- Directly – for example, we can determine xylo-oligos up to DP6.
- Indirectly via acid hydrolysis of the liquid to break apart the oligosaccharides and determine their constituent monomers.

ANHYDRO-SUGARS

Including levoglucosan, mannosan, galactosan, and cellobiosan.

SUGAR DEGRADATION

Analyses for various sugar degradation products, such as organic acids (e.g. formic acid, acetic acid, levulinic acid) and furans (e.g. furfural and HMF).

EXTRACTIVES

We determine fifteen different carbohydrates in water-extracts and fatty acids in organic solvents. Our QTOF-LC/MS system allows us to identify unknown extractive compounds.

PYROLYSIS BIO-OILS

The bio-oil fraction obtained from biomass can also be highly complex but we have packages to determine the important carbohydrates (including anhydrosugars such as levoglucosan, galactosan, mannosan, and cellobiosan) in the water phase of the oil as well as the oligomeric sugars.

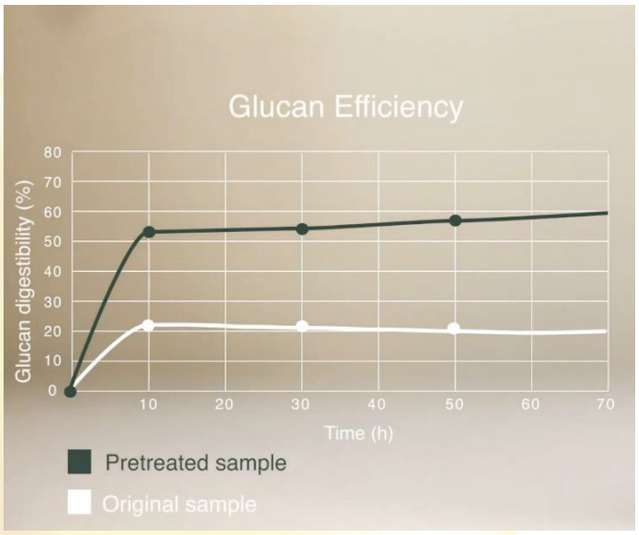
8. Evaluation of Pre-treatments

1 THE STARTING FEEDSTOCK

We offers several packages for feedstock composition. P10 gives detailed data on extractives content, lignin, cellulose, and hemicellulose. P12, P14, P15, and P16 are complementary, providing data on water soluble carbohydrates, starch, uronic acids, and acetyl. All the above are combined in P19 (Deluxe Lignocellulose Package) which also gives a more accurate lignin determination by correcting for protein (P270). The resulting data will help in selecting the right pre-treatment for the desired product/application. The Celignis team can assess the compositional data and design the pre-treatment process for the selected feedstock.

2 LIQUID PRODUCT OF PRE-TREATMENT

Traditionally, liquids from pre-treatments are considered as low value or wastes. However, with advancements in green chemistry and biotechnology, pre-treatment streams are being researched to produce high-value products. For this detailed compositional analysis is needed. Celignis offers analysis packages for sugars, sugar alcohols and oligosaccharides in solution (P13), organic acids and furans (P22) and uronic acids (P15). Additionally, the fermented or chemical conversion products of these streams can be analysed based on custom requirements.



3 SOLIDS FROM PRE-TREATMENT

The solids separated from the pretreated slurry contain the biomass fraction that was not deconstructed by the treatment and adsorbed sugars, phenolics, etc. Depending on pre-treatment type the adsorbed fraction can be significant and so needs to be removed for the analysis of structural components. Pretreatment efficiency is calculated by determining the enrichment of required fraction in the solids (e.g. cellulose) and by determining the improved accessibility to enzymes using analysis packages custom- designed by the Celignis team.

BIOMASS FEEDSTOCK ANALYSIS

9. Seaweed Analysis

The biomass in our seas presents huge potential for contributing towards the future bioeconomy and we have a range of analysis methods suitable for evaluating these complex feedstocks.

Seaweed has been recognised as a potential “third-generation” biomass feedstock. Its commercial utilisation, however, is not without challenges. In particular, the composition of seaweed can be much more complex and diverse than many of the traditional cellulosic feedstocks. Fortunately, we have developed a number of chromatography programs to allow you to see the potential value that seaweed samples may have for a chosen biomass conversion process.

Important Seaweed Properties

1 Carbohydrates and Amino Acids

With seaweed carbohydrate packages, we quantify seaweed specific deoxy sugars, sugar alcohols and uronic acids. For seaweed amino acids, we have developed an in-house chromatography method that quantifies all 17 amino acids present in seaweeds.

2 Seaweed Biomolecules

At Celignis, we employ advanced techniques like accelerated solvent extractor for efficient lipid extraction from complex sample matrices. Vitamins is another analyte that our clients look in seaweeds. Our vitamins analysis packages covers both fat-soluble and water-soluble vitamins in seaweed samples.

3 Pigments and Polyphenols

With our state-of-the-art facilities, we are proficient in extracting and analysing pigments – chlorophylls (a, b and c), xanthophylls (fucoxanthin, astaxanthin, zeaxanthin, violaxanthin, antheraxanthin, neoxanthin, lutein) and carotene (beta-carotene). We are also experts in determining the composition of various seaweed polyphenols and bioactive molecules.

10. Biomass Combustion

RELEVANT ANALYSIS PACKAGES:

P31 – Volatile Matter

P32 – Proximate Analysis:
Moisture, Ash, Volatile Matter, Fixed Carbon

P33 – Ultimate Analysis:
Carbon, Hydrogen, Nitrogen, Sulphur, Oxygen, Ash

P34 – Calorific Value and Elements:
Gross Calorific Value, Net Calorific Value, Ash, Carbon, Hydrogen, Nitrogen, Sulphur, Oxygen

P35 – Chlorine and Sulphur

P36 – Major Elements:
Aluminium, Calcium, Iron, Magnesium, Phosphorus, Potassium, Silicon, Sodium, Titanium

P37 – Minor Elements
Antimony, Arsenic, Cadmium, Chromium, Cobalt, Copper, Lead, Manganese, Mercury, Molybdenum, Nickel, Vanadium, Zinc

P38 – Major and Minor Elements

P40 – Combustion Package:
Gross Calorific Value, Net Calorific Value, Chlorine, Moisture, Ash, Carbon, Hydrogen, Nitrogen, Sulphur, Oxygen, Volatile Matter, Fixed Carbon

P41 – Ash Melting Behaviour (Oxidising Conditions)
Shrinkage Starting Temp., Deformation Temp., Hemisphere Temp., Flow Temp.

P42 – Ash Melting Behaviour (Reducing Conditions)
As P41 but under reducing conditions

P373 – Thermogravimetric Analysis

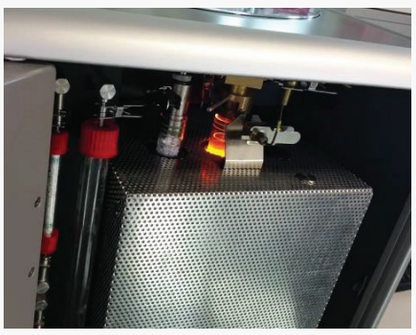
P50 – Ultimate Combustion Package:
P40 plus P38 and P42

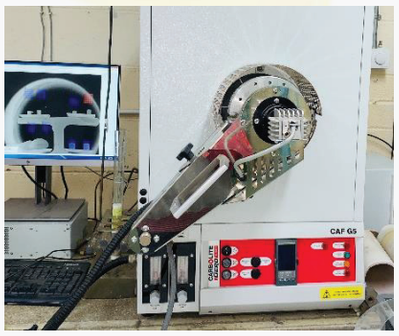
We have a range of packages to help you determine the value of your feedstocks for the production of heat and electricity.

Our laboratory is equipped with a number of state-of-the-art items of equipment that allow us to determine the most important combustion-related properties of biomass.

We recognise that it is important that you have confidence in the analytical data that you receive. That is why we follow internationally-recognised standard analysis methods and undertake most analyses in duplicate, reporting values for each of the replicates analysed, along with the average and the standard deviation. This allows us to repeat the analysis (at no extra charge) if the deviation values are high.

Moisture and ash contents are of crucial importance for combustion. This is reflected in our online, Excel, and pdf reports where data for bioenergy-related parameters are expressed on dry-mass, as-received, and dry-ash free bases, according to standard method EN 15296:2011.





ACHIEVE A PROFITABLE AND SUSTAINABLE PROCESS!

11. Technoeconomic Analysis

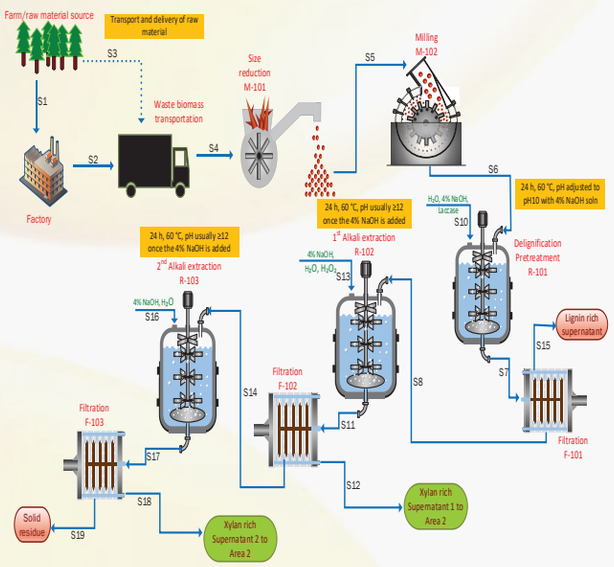
Lab-scale data provide a valuable departing point in the Technology Readiness Level (TRL) spectrum. However, a Techno-Economic Analysis (TEA) is crucial for the successful commercialization of a developed technology. Our staff possess the expertise to develop industrial-scale simulations of lab and pilot scale technologies which are futher evaluated to ascertain the economic feasibility of the identified technology.

METHODOLOGY

Technical modelling and engineering design of pilot and industrial-scale processes are carried out using the experimental data obtained. Rigorous simulation provides reliable mass and energy balance data which constitutes the foundation for equipment design, sizing and specification and utility demand estimations.

The facility design information enables the estimation of capital and operating costs of the proposed production facility using reliable costing models. This is followed by a thorough evaluation of the economic performance of the process. All the technical and economic hotspots in the process flow are identified and modulated to improve the robustness of the process.

A thorough techno-economic evaluation provides more clarity which guides decision making especially in the case of making a significant financial commitment, such as the establishment of a production facility. TEA is valuable in ensuring appropriate resource allocation and identification of main influencing paramters.



PROCESS SIMULATION

Process simulation enables the model-oriented representation of chemical, physical, biological, and other technical processes as well as unit operations using the appropriate simulation software. This allows for the technical evaluation of a process for the design development, analysis and optimization without having to physically build the process.

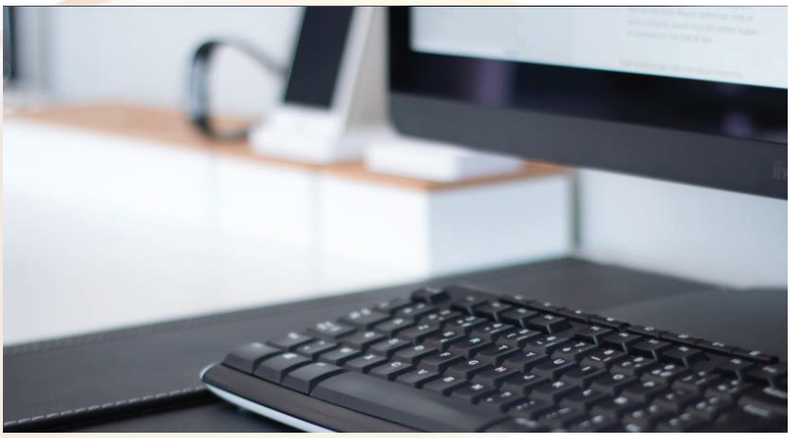
With our thorough understanding of chemical, biological, and physical systems, we are able to develop realistic and accurate industrial-scale simulations of lab and pilot-scale processes to find optimal operating scenarios of examined technologies without wasteful expenditure of time and resources. The simulated process largely consititutes the foundation for energy, economic, and sustainability assessment of a technical process or product system.

WE MAKE IT EASY TO ACCESS YOUR DATA

12. The Celignis Database

CONCEPT

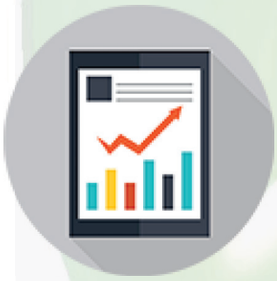
We realise how important your samples are and your need to access data as quickly and as easily as possible. That is why we created the Celignis Database. This is a password-protected website where you can place your orders and view the results of our analysis, even when the order itself has not been fully completed. The database is responsive to use on laptops, tablets, and mobile phones and helps to take the complexity out of the process of selecting which of our analysis packages are the most suitable for your samples.



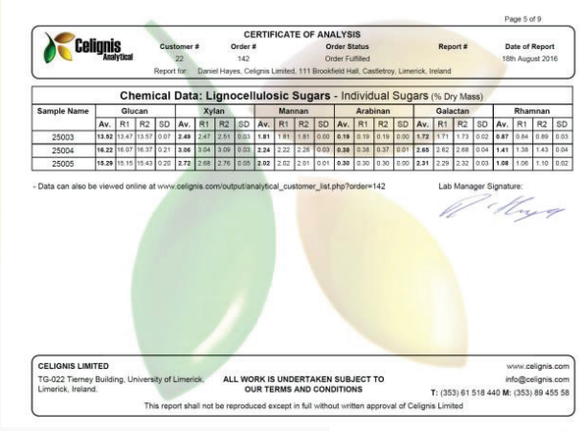
DETAIL

We present summary results as well as detailed data for each sample with results represented in tabular and graphical forms. We also use the compositional data to estimate the potential biofuel yields from your samples. Data relevant to thermal processing are shown on dry-mass, as-received, and dry-ash-free terms.

REPORTS



You can download the data any time from the Database as Excel and PDF reports. We also send you final reports by email once we have completed our analysis. These reports provide data for each of the duplicates analysed, the average, and the standard deviation, so that you can see the precision of our analysis. You can view example data on our guest account, enter user test@celignis.com and password celignis at www.celignis.com/output/login.php.



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CERTIFICATE OF ANALYSIS

Customer #	Order #	Order Status	Report #	Date of Report
22	142	Order Fulfilled		18th August 2016

Report for: Daniel Hayes, Celignis Limited, 111 Brookfield Hall, Castletroy, Limerick, Ireland

Chemical Data: Lignocellulosic Sugars - Individual Sugars (% Dry Mass)

Sample Name	Glucan				Xylan				Mannan				Arabinan				Galactan				Rhamnan			
	Av.	R1	R2	SD	Av.	R1	R2	SD	Av.	R1	R2	SD	Av.	R1	R2	SD	Av.	R1	R2	SD	Av.	R1	R2	SD
25003	**13.92**	13.47	13.57	0.07	**2.49**	2.47	2.51	0.03	**1.91**	1.91	1.91	0.00	**0.19**	0.19	0.19	0.00	**1.72**	1.71	1.73	0.02	**0.87**	0.84	0.89	0.03
25004	**16.22**	16.07	16.37	0.21	**3.06**	3.04	3.09	0.03	**2.24**	2.22	2.26	0.03	**0.38**	0.38	0.37	0.01	**2.65**	2.62	2.68	0.04	**1.41**	1.38	1.43	0.04
25005	**15.29**	15.15	15.43	0.20	**2.72**	2.68	2.76	0.05	**2.02**	2.02	2.01	0.01	**0.30**	0.30	0.30	0.00	**2.31**	2.29	2.32	0.03	**1.08**	1.06	1.10	0.02

- Data can also be viewed online at www.celignis.com/output/analytical_customer_list.php?order=142

Lab Manager Signature:

CELIGNIS LIMITED
TG-022 Tierney Building, University of Limerick, Limerick, Ireland.

ALL WORK IS UNDERTAKEN SUBJECT TO OUR TERMS AND CONDITIONS

www.celignis.com
info@celignis.com
T: (353) 61 518 440 M: (353) 89 455 58

ACTIVITIES AT CELIGNIS

13. SCIENTIFIC RESEARCH

In the bioeconomy if you stand still you end up being left behind. Celignis was born from pioneering research and we are still passionately committed to advancing the bioeconomy.

1 Our Research History

Celignis founder Dan Hayes wrote and managed a project, DIBANET, funded by the EU's FP7 programme. It involved collaborative research between 13 partners from Europe and Latin America to develop biorefining technologies. One output was the development of rapid biomass analysis models which led to Celignis launching in 2014. Prior to that he wrote and managed several other research projects.

2 Our Present Research

Celignis is in six ongoing collaborative EU research projects. These follow on from three successfully completed EU H2020 projects. We take particular interest in the Circular Bio-Based Europe Joint Undertaking (formerly the BBI JU), being in 3 ongoing projects, with another completed. In 2023 Celignis joined the Biobased Industries Consortium (BIC, the CBE-JU steering committee) as a Full Industry Member. We are also active in a number of Irish projects.

3 Our Ambitions for the Future

We are eager to continue to collaborate with partners in research projects that will help to advance the bioeconomy. We have identified a number of areas within the research programmes of Horizon Europe in which we could be valuable partners in future proposals. In particular, our new Celignis Bioprocess facility will allow us to undertake scaled-up biomass processing activities up to TRL 6.

Selected Ongoing Research Projects at Celignis

Enxylascope aims at bioprospecting and producing a novel set of xylan debranching enzymes with high catalytic activity and wide operation conditions, thereby demonstrating its ability to make xylan a key ingredient in a variety of consumer products. Celignis is playing a key role in the project, being the technical lead and responsible for the extraction and modification of xylan from biomass.

VAMOS is a BBI JU demo project producing and valorising second-gen sugars from municipal solid waste. Celignis is leading a work package and is responsible for analysis of feedstocks and outputs and for the development of algorithms to rapidly predict composition using near infrared spectra. We will install NIR equipment at the demo-plant, employing our custom CELDEEP software package.

UNRAVEL, a research and innovation action (RIA) project funded the BBI JU, develops a lignocellulosic value chain based on the FABIOLA fractionation process. Celignis leads a work package and has undertaken detailed profiling, using our QTOF-LC/MS system, of high-value chemicals in the extractives. We then designed a process for separation and purification of a target molecule. We also analysed feedstocks & process outputs, obtaining quantitiative predictive NIR models for these.

PERFECOAT, a RIA project funded by the BBI JU, targets the development of novel sustainable coatings that will ultimately be available to the public. Celignis is responsible for the extraction and modification of polymers (xylan and chitosan) that will be used as binders in these coatings. It is highly commercial, with industrial partners targeting replacing fossil-based coatings with biobased ones.

This demo project involves innovative superheated steam processing of unwanted bush and invasive biomass into high-value, clean-burning, low-cost solid biofuel. Celignis will analyse feedstocks and process outputs, with Sajna, our “Biomass Detective”, using our QTOF-LC/MS system to profile the steam condensate for high value chemicals. She will then develop a method to recover target constituents.

BIO4AFRICA will empower smallholder farmers to generate new sources of income by creating value from locally available biomass. Celignis is analysing a wide range of biomass feedstocks, from a number of African countries, and providing recommendations regarding the most suitable ones, under the best conditions, for the given processing technology. We also analyse the outputs of the various processes.

EXPERTS IN THE BIOECONOMY

14. Meet the Team

Dan Hayes

Dan undertook his PhD at the University of Limerick and was involved in the leadership of several key research projects. He launched Celignis in 2014 to commercialise his work and to offer analytical and process expertise to clients. Since then Celignis has grown to be the premier global provider of these services.

Lalitha Gottumukkala

A serial innovator with numerous years of research experience in: bioprocess development and process optimisation for the production and application of lignocellulose deconstruction and modification enzymes; resource maximisation; and advanced biofuel and biochemical production from 1G and 2G feedstocks.

Saina KV

Sajna has a PhD in Biotechnology with research on production and analysis of biosurfactants and exopolysaccharide from a yeast isolate. Sajna is Biomass Detective at Celignis and has been designing, testing, optimizing and validating robust analytical methods for the identification and quantification of functional molecules.

Oscar Bedzo

A dynamic and purpose driven chemical engineer with expertise in bioprocess development, process design, simulation and techno-economic evaluation. He is passionate about exploring relevant biorefinery technologies through experimental work and process simulations.

Kwame Donkor

Chemical engineer with petro-chemical and bioprocess engineering degrees. His expertise is in the conversion of waste streams and biomass to biofuels. Specialises in process development, operation of bioreactors, biogas plant operation review, process optimisation and mathematical modelling of the anaerobic digestion process.

Edgar Ramirez Huerta

Chemical Scientist with business development skills focused on creating lasting value for bio-based industries. He is currently active in the expansion of Celignis's analytical capabilities for biomass compositional analysis and the products derived from biomass, such as biochar. Particular interest in surface-area analysis and thermogravimetry.

Maitri Patel

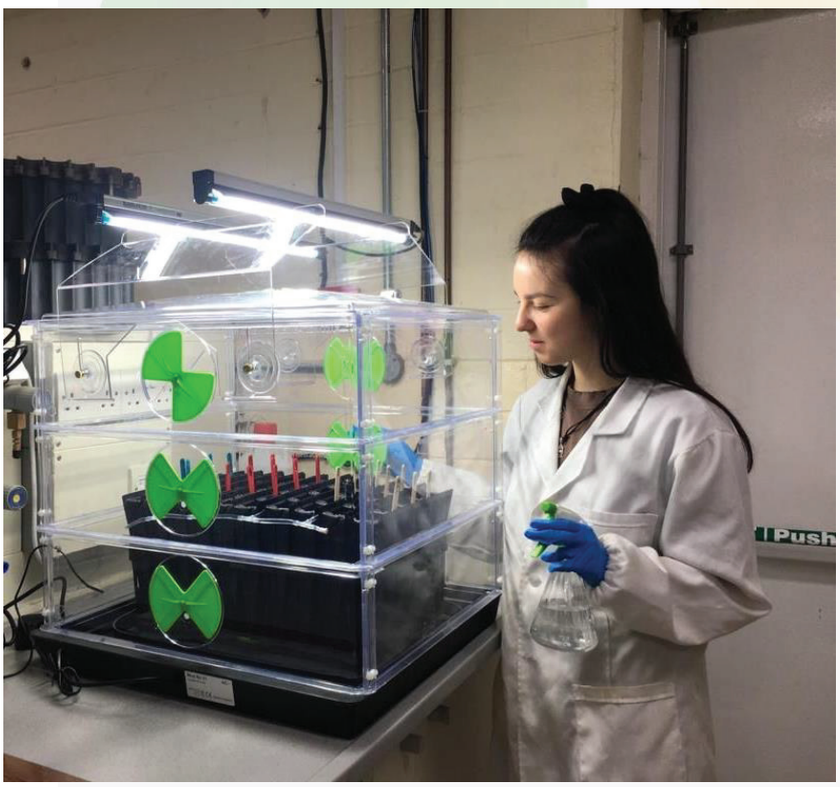
Maitri is an organic chemist with strong leadership skill. At Celignis, she is involved in managing lab activities for thermal and anaerobic digestion analysis. She implements and maintains efficient work flow in the company by motivating, talking, and collaborating with the management, analytical, and bioprocess teams.

Piotr Dobkowski

Ambitious data manager. He plays a significant role in data processing, data evaluation, and chemometrics. Piotr is very accurate and has a keen eye on big sets of data. He is also present in the ion chromatography department by conducting quality control of chromatograms and results.

Kassiani Pliatsika

Kassiani has integrated masters in agriculture and is Celignis's Analysis Operations Manager for lignocellulose biomass samples. With in-depth understanding of the diverse chemistry of biomass and its relevance to valorisation approaches, she designs the analytical work flow and ensures in providing accurate data to clients.



Further Information on Our Research and Activities

Publications

Donkor K.O, Gottumukkala L.D (2022) Lin R, Murphy J.D. A perspective on the combination of alkali pre-treatment with bioaugmentation to improve biogas production from lignocellulose biomass, **Bioresource Technology**, Volume 351.

Donkor K.O, Gottumukkala L.D, Diedericks D, Görgens J.F (2021) An advanced approach towards sustainable paper industries through simultaneous recovery of energy and trapped water from paper sludge, **Journal of Environmental Chemical Engineering**, Volume 9, Issue 4.

Gottumukala L.D, Sukumaran R.K, Venkata Mohan S. Sajna K.V. Sarkar O and Pandey A. Rice straw hydrolysate to fuel and volatile fatty acid conversion by Clostridium sporogenes BE01: bio-electrochemical analysis of the electron transport mediators involved

Bedzo, O.K.K, Trollope, K., Gottumukkala L.D., Coetzee, G. Görgens, J. F. (2019) Amberlite IRA 900 versus calcium alginate in immobilization of a novel, engineered β-fructofuranosidase for short-chain fructooligosaccharide synthesis from sucrose, **Biotechnology Progress** 35(3)

Bedzo, O.K.K, Mandegari, M, Görgens, J. F. (2020) Techno-economic analysis of inulooligosaccharides, protein, and biofuel co-production from Jerusalem artichoke tubers: A biorefinery approach, Biofuels, **Bioproducts and Biorefining** 13(5): 1274-1288

Gottumukkala L.D, Haigh K, Görgens J (2017) Trends and advances in conversion of lignocellulosic biomass to biobutanol: Microbes, bioprocesses and industrial viability, Renewable and Sustainable Energy Reviews, Volume 76, 2017, Pages 963-973.

Hayes, D. J. M. (2013) Second-generation biofuels: why they are taking so long, **Wiley Interdisciplinary Reviews: Energy and Environment** 2(3):304–334

Hayes, D. J. M., Hayes, M. H. B., Leahy, J. J. (2017) Use of Near Infrared Spectroscopy for the Rapid Low-Cost Analysis of Waste Papers and Cardboards, **Faraday Discussions** 202:465-482.

Hayes, D.J.M. (2013) Biomass composition and its relevance to biorefining, **The Role of Catalysis for the Sustainable Production of Biofuels and Bio-chemicals**, K. Triantafyllidis, A. Lappas, M. Stoker, Elsevier B. V. 27-65

Articles on Celignis and Recent Awards

(2021) **Innovation of the Year Award** (Irish Laboratory Awards) – For our work on the extraction and modification of biopolymers.

(2021) **Laboratory Staff Member of the Year** (Irish Laboratory Awards) – for our CIO Lalitha Gottumukkuala.

(2018) Cutting the Wait Time Involved in Complex Biomass Analysis, **Limerick Leader**, January 19th 2018.

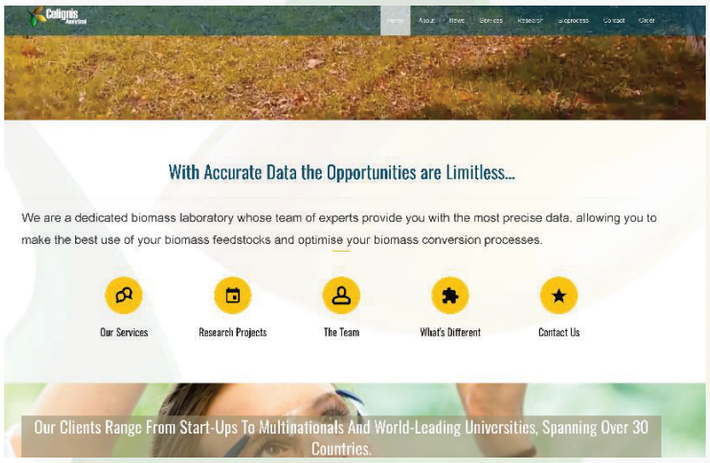
(2015) DIBANET, **Building on Ireland's Energy Research Performance**, Sustainable Energy Authority of Ireland, pp. 8-9.

(2015) New NIR Models Speedup Feedstock Analysis Process, **Ethanol Producer Magazine**, October 2015 pp. 50-52.

(2015) 4 Minutes with…Daniel Hayes, CEO, Celignis Analytical, **Biofuels Digest**, August 2nd 2015.

WE ARE ALWAYS HAPPY TO CHAT ABOUT BIOMASS!

15. Contact Details



WEBSITE

There is lots of information at www.celignis.com on our various analysis packages and the wide range of analytes we determine. We also present more detail on our bioprocess development services and TEA work as well as the many feedstocks we have experience with.

ADDRESS

You are most welcome to visit us! Our analytical labs are in Plassey Technology Park, Limerick, with our bioprocessing activities at Celignis Bioprocess, just a few km away. The shipping documents we provide allow receipt of many samples from all over the world with no customs delays. You receive automated emails from the Celignis Databse when samples arrive and as soon as we obtain any data.

PHONE + EMAIL

Our email is info@celignis.com or call our analytical labs at (+353) 61 371 725 and our bioprocess labs at (+353) 61 545 932. We're also on social media (LinkedIn and Twitter).

TESTIMONIALS

"Arigna Fuels has been working in conjunction with Dan and the team at Celignis for a number of years. Alone and as part of a larger consortium that are members of the International Biomass Torrefaction Council (IBTC), we have been characterising thermally processed biomass and their corresponding raw materials for the purposes of producing a domestic heating fuel. We receive a professional, amiable and rapid service from Celignis and wouldn't hesitate to recommend them to others."

Robert Johnson PhD, R&D Manager at Arigna Fuels

"Celignis has characterised a large number of our complex biomass samples using their NIR method and chemical analysis methods. We have been impressed with both the quality of data generated and the attention to detail employed in their analysis."

Darragh Gaffney PhD, R&D Manager Monaghan Biosciences

Bioprocess Development Services

FROM A LAB DEDICATED TO ADVANCING THE BIOECONOMY

CELIGNIS LOCATIONS

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