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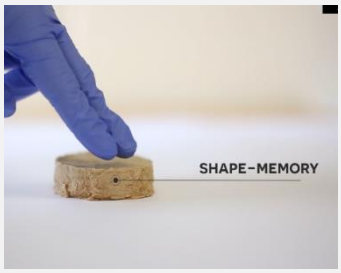
We can help to determine the value of your feedstock for the production of advanced biofuels. We determine sugars in cellulose and hemicellulose, as well as lignin, extractives, and ash. We provide data in one day with our unique rapid analysis models.






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.



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* 12-15

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* 16-19

These pages detail 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* 22-23

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.

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.

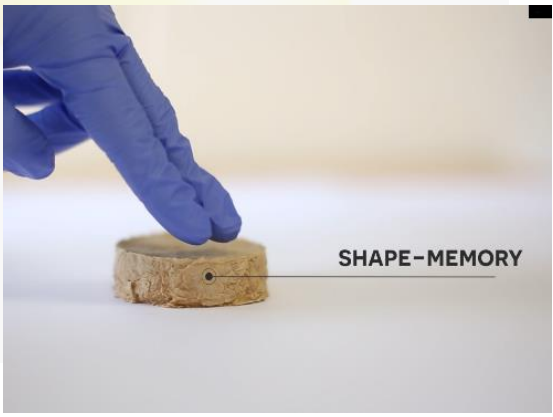
## 1 EXTRACTION AND PURIFICATION OF BIOPOLYMERS

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.

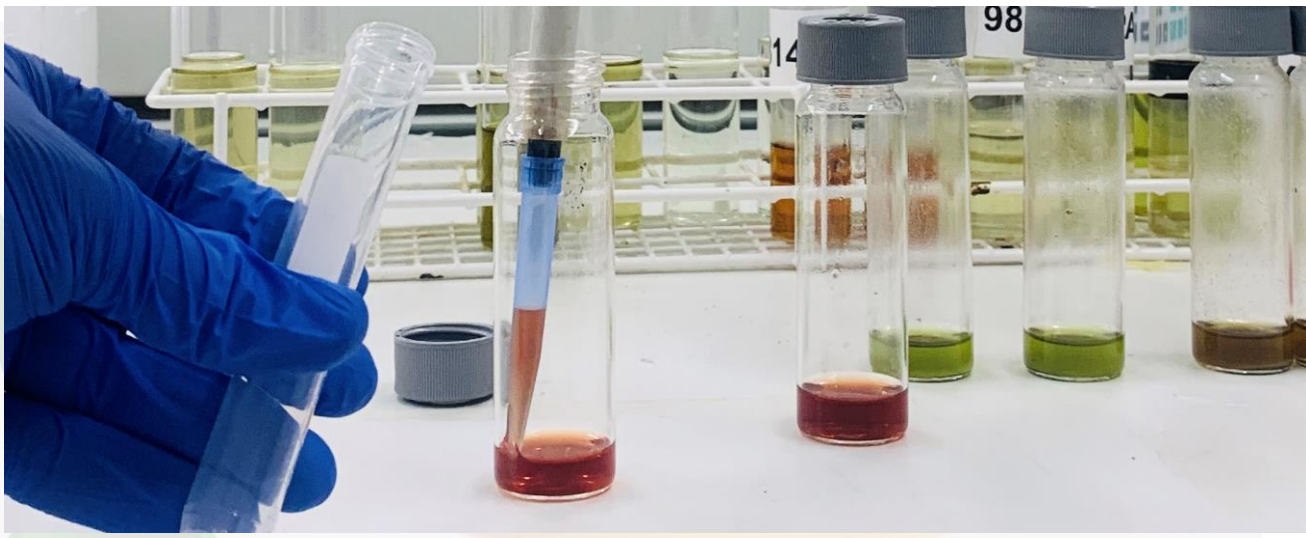
## 2 DESIGN AND TESTING OF BIOMATERIALS

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.



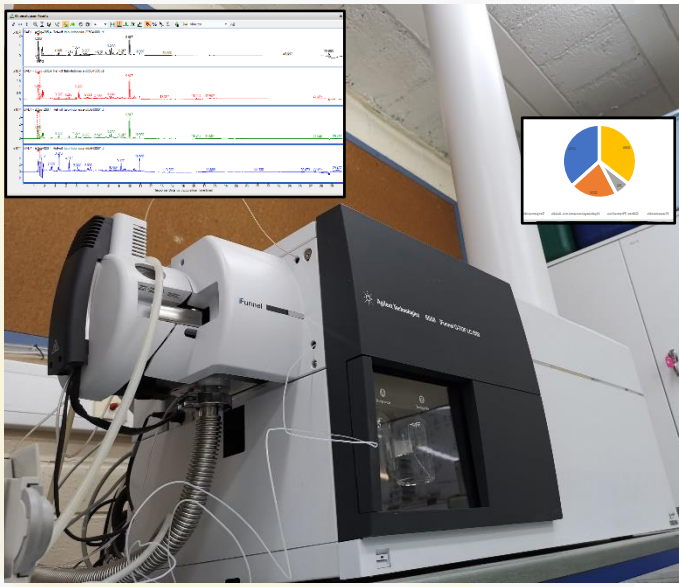
# 3. High-Value Biomolecules



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.

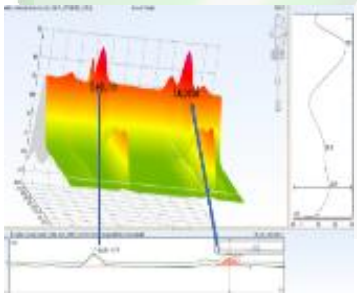
## DISCOVERY, EXTRACTION AND PURIFICATION

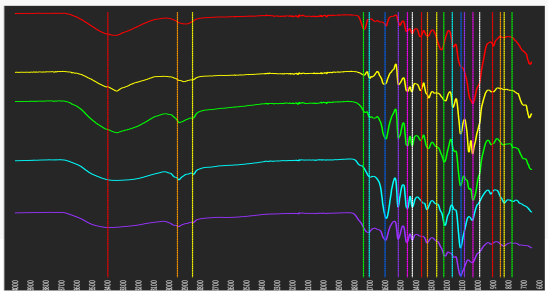
Our multi-disciplinary team of biomass chemists, analytical chemists, and microbiologists work together to discover the novel molecules from biomass and microbial sources. Discovery of molecules from biomass involves multiple extractions in a range of polar and non-polar solvents. The extracted fractions 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.

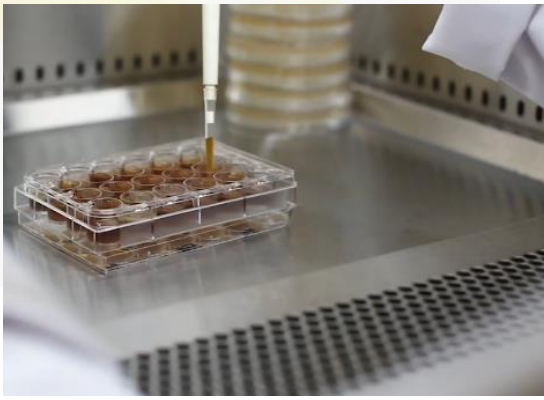


## STRUCTURAL AND FUNCTIONAL CHARACTERISATION

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







SERVICES TO INDUSTRY

# 4. Bioprocess Development

We develop and refine processes to efficiently valorise biomass. We can work on individual process stages, or develop a bespoke vertically-integrated technology for your feedstock or desired end-product. This can be done at lab-scale up to the $1m^3$ level. Our understanding of biomass chemistry, our extensive array of bioprocessing equipment, and the biological, engineering, and commercial experience of our Bioprocess team, all play crucial roles in ensuring that our projects are well-designed and focused on our clients' end-goals.

## 1 Biomass Extraction Processes

Biomass can be rich in bioactive compounds of high value for food, feed, cosmetic, and pharmaceutical applications. We develop bespoke extraction methods suitable for your needs with high selectivity, efficiency and low environmental impact.

## 2 Pretreatment Processes

The choice of pretreatment method varies with the type of biomass and the end-product requirements. At Celignis we can determine the most suitable pretreatment for your feedstock and determine the optimum conditions in lab-scale trials followed by higher TRL scale-ups.

## 3 Biomass Hydrolysis

For the hydrolysis of biomass to monomeric sugars either chemical or biological approaches can be used. We can use both methods at scales ranging from flask-level to $1m^3$. We have particular expertise in enzymatic hydrolysis.

## 4 Application of Enzymes

Enzymes are biological catalysts that have a wide variety of applications in the bioeconomy. We are experts in the design and use of enzymatic approaches for the enhanced valorisation of lignocellulosic biomass.

## 5 Fermentations

We're experienced in many fermentations and can help you determine and optimise yields of an array of different fermentation products.

## 6 Downstream Processing

How the various outputs (solid and liquid) of a bioprocess are dealt with is often overlooked until later in bioprocess development, leading to excessive costs and complications.

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

## 7 Lab-Scale Optimisations

We consider that optimising a bioprocess at the lab-scale is the most-cost effective approach to explore a range of different scenarios in search of optimal process conditions. Based on the outputs of these experiments we can then test the chosen set of conditions at higher TRL levels.

## 8 Scale-Up to Higher TRLs

At our dedicated Celignis Bioprocess laboratories we have all the necessary upstream and downstream apparatus to undertake bioprocess projects up to a tehcnology readiness level (TRL) of 6, with reactor and processing capacities of up to $1m^3$.

## 9 Techno-economic Analyses

Our technoeconomic experts can evaluate your bioprocess, considering various scale, tech, and feedstock options. We apply accurate costing models to determine CAPEX/OPEX of simulated and pilot scale processes which are then used to determine key economic indicators (e.g. IRR, NPV).

## 10 Full Project Development

We work closely with you to understand your objectives and timelines. We then propose a project, usually covering a series of deliverables and stage-gates. Often our projects involve optimising conditions at the lab-scale before replicating the conditions at higher TRL levels.

# Types of Bioprocess Projects

## 1 PRODUCT-CENTRED BIOPROCESS

In this scenario the final-product is locked-down and, instead, the bioprocess development can focus on the best approach to sustainably and profitably get it. This means there is some flexibility regarding the feedstock and processing technologies to be employed

## 2 FEEDSTOCK-FOCUSED BIOPROCESS

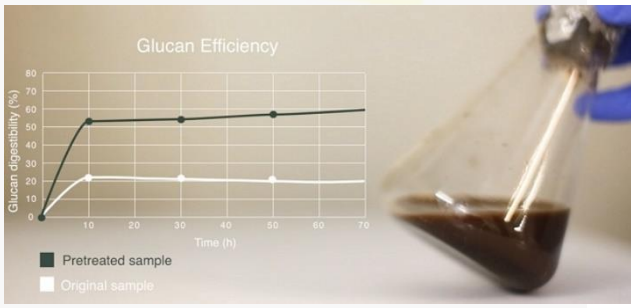
Here the feedstock is locked-down but the technological approaches and final end-product(s) are open. The Celignis team will consider the existing infrastructure of the client when designing the bioprocess as well as any existing chemical demands of their main process.

## 3 REFINEMENT OF AN EXISTING BIOPROCESS

This improvement can target the whole bioprocess or specific nodes. The targets for the improvement can be: product yield, OPEX reductions, and improved product quality, among others.

## 4 NEW FULL-VALUE-CHAIN BIOPROCESS

We can also work on Bioprocess Development for an entirely new bioprocess, covering all stages of the process-scheme. This means we start with the original feedstock and develop all stages involved in processing it and obtaining the targeted product(s). Developing such a comprehensive bioprocess requires considering, and developing approaches for, a number of key aspects, including: Feedstock Selection and Preparation; Primary-Conversion Technology; Downstream Processing Steps; Side-Stream Valorisation; Product-Recovery and Purification; Waste Management; Process Integrations.



SERVICES TO INDUSTRY

# Bioprocess Project Case Studies

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

## Glycerol from Industry Side-Streams

This project focused on the hydrolysis of cellulosic side-streams from an industrial process, followed by the fermentation of the liberated sugars into a variety of products, including glycerol, ethanol, and organic acids. Following the lab-scale work, we worked on a TEA analysis of the bioprocess, considering several different scenarios. The outputs of this TEA informed a follow-on bioprocess development project, incorporating the changes deemed to give greatest impact to the process in terms of commercial and environmental sustainability. The final stages of this project will involve scaling up the developed approach to the 100-litre level.

## Bioethanol from Palm Residues

This was a lab-scale vertically-integrated project covering pretreatment, and separate hydrolysis and fermentation (SHF). The project involved a series of lab-scale experiments focused on optimising the pretreatment conditions so that the yields and commercial viability of the process as a whole could be improved. The next stage involved optimising the type and dosage of enzymes, as well as other factors (e.g. solid-loading), to maximise ethanol yields from the targeted biomass components.

## Sugars from Paper Side-Streams

This project involved the optimisation or process conditions to allow for the production and recovery, in high yields, of monomeric sugars from recycled paper/cardboard streams. The project involved examining a number of important process variables, including: pretreatment conditions; the type and loading of enzymes; and the duration and conditions of the hydrolysis stage. The final outputs of the project were selected optimum conditions for each of the feedstock types and recommendations for further optimisations of the process and future scaled-up activities.

## Oligomers from Biomass

We have undertaken a number of projects, for different clients, focused on obtaining oligomeric sugars from biomass, or biomass-derived polymers. In some cases there have been specific requirements in terms of the preferred oligomer chain length and the ratio of monomeric to oligomeric sugars in the final liquid output. Optimising the bioprocess required a carefully-formulated DoE considering relevant factors (e.g. temperature, enzymes, pretreatment) in the context of the chosen feedstock and the final product requirements. In all such projects that we have undertaken to date we developed an improved bioprocess that allowed for greater proportions of the total carbohydrates in the liquid phase being in the client's targeted product range.

## Other Bioprocess Projects

- Production of Propionic Acid.
- Biomaterials from Caribbean Seaweed.
- Bioactives from Tropical Hardwoods.
- Sustainable Downstream Purification Process Developed.

Through Innovation, Passion, And Determination, We At Celignis Strive To Make A Difference In The Development Of The Bioeconomy


# Relevant Experience & Infrastructure at Celignis Bioprocess

## 1 Dedicated Bioproces Building

Celignis Bioprocess was opened in 2022 and provides a dedicated 500m$^2$ facility for the at-scale (TRL7) processing of biomass. The site is also used for lower-TRL optimisation experiments in order to find the most suitable process conditions that can then be validated in larger reactors. The nearby-located Celignis Analytical building provides all of the necessary analytical support regarding the evaluation of the feedstocks, products, and side-streams.

## 2 Experienced Bioprocess Team

For a commercially-viable bioprocess it is necessary to consider many aspects, both technological and financial, of the value-chain. Celignis Bioprocess is populated by a diverse team with multidisciplinary and complementary expertise. There are biologists, chemists, electricians, engineers, fermentation specialists, technoconomic analysts, and chemometricians. In 2021 Celignis was awarded "Innovation of the Year" (Irish Lab Awards) for one of its bioprocesses.

## 3 Track-Record in Research

In addition to our successful Bioprocess Development Services projects that we have undertaken for our corporate clients, Celignis has a long and impressive history as a valued participant in collaborative research projects. We are a spin-out of a research project designed and written by Celignis founder Dan Hayes and have, to date, participated in 10 research projects, funded by the European Union's Horizon research programme, focused on the development of innovative bioprocesses. Six of these projects are currently ongoing.

## 4 Bioprocess Infrastructure

- Array of bench-top (1-20 litre) advanced bioreactors.
- Anaerobic fermentation systems (1-20 litres).
- 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 Services

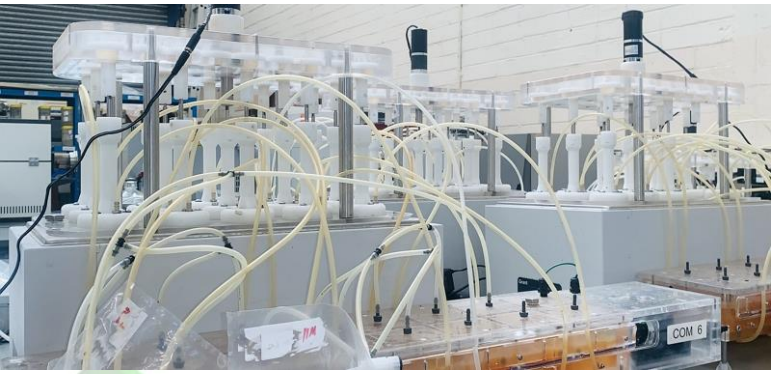
We provide a wide range of analysis & consultation services to the anerobic digestion sector. Our multidisciplinary expertise spans feedstock chemistry, biology, process optimsation, and techno-economics. It's the interaction of all these factors that will allow for feedstocks to be efficiently valorised and for the most impactful RNG projects

## BIOMETHANE POTENTIAL

The biomethane potential (BMP) can be considered to be the experimental theoretical maximum amount of methane produced from a feedstock. In our laboratory, we have six BMP systems, comprising 90 reactors, that allow us to digest your samples and determine the biogas yield over periods of between 14 and 40 days.

## CONTINUOUS DIGESTIONS

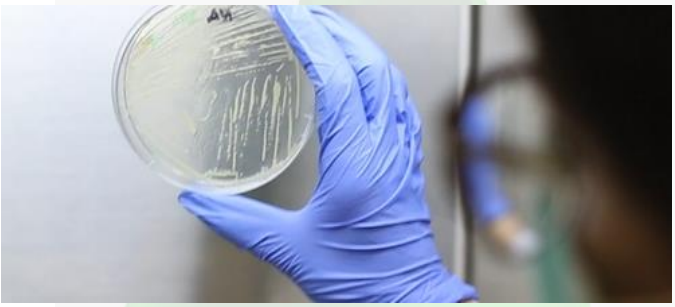
To help you evaluate how well your anaerobic digestion feedstocks will behave in real-world conditions we can undertake continuous digestion experiments. These operate at scales up to 12 litres and typically run for 3 months. We target maximum achievable organic loading rate (OLR) and biomethane potential.



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

## TOXICITY ASSAYS

The waste streams used in RNG that arise from process industries may contain toxic or bacterial inhibitory compounds (e.g. antibiotics, polyelectrolytes, detergents). Our anaerobic toxicity assays can determine the presence of such toxicities and suggest feeding limits for feedstocks.



## PROCESS OPTIMISATION

There are many factors in running an RNG facility. Optimising these allows for improved plant performance and revenues. We can design and experimentally-validate such optimisations at the lab-scale prior to you implementing them at your facility. This approach allows for greater benefits and lower costs than optimising at the commercial scale. For example, we can suggest optimal values for major and minor elements in the digester as well as upper and lower threshold values. This allows us to formulate a bespoke cocktail of additives according to the requirements of the digester.

## BIOLOGICAL CONSULTANCY

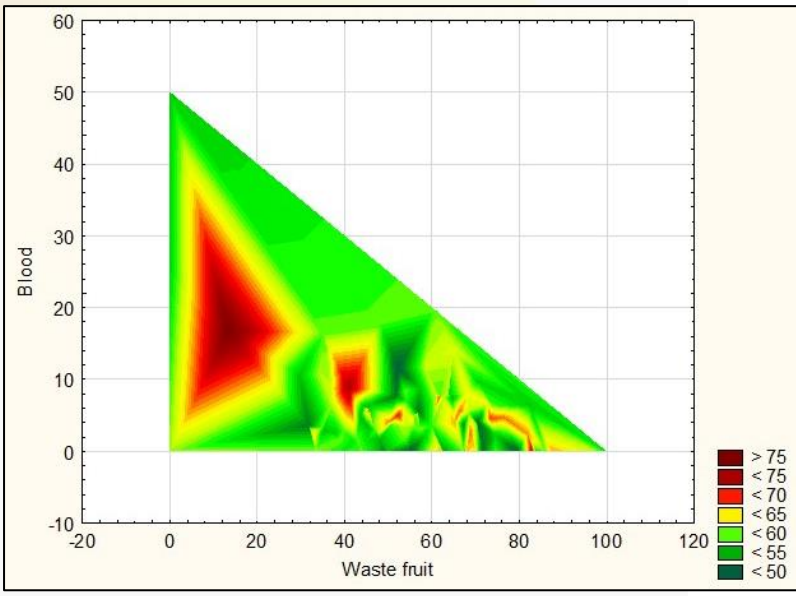
We are experts in the biology of anaerobic digestion. We pour through operational data from biogas plants and identify correlations between process parameters and digester performance. This leads to understanding on the specific biological conditions of the digester and recommendations as to how peformance can be improved and made more stable.

## SPECIFIC MICROBIAL ACTIVITY

AD is a microbial process involving a sequence of stages (hydrolysis, acidogenesis, methanogenesis) to convert a complex feedstock to methane. We analyse samples collected from digesters and undertake tests to investigate how well they proceed with each of these stages of digestion. Tests undertaken include: Specific Hydrolyticl Potential (SHP), Specific Acidogenic Potential (SAP), Specific Methanogenic Potential (SMP). Each test involves 5 days of substrate digestion and monitoring of the biogas produced.

## DIGESTATE ANALYSIS

Digestate can potentially have value as a soil fertiliser. We offer a range of detailed analysis packages for digestate, allowing you to fully assess this resource and to determine the best use for it. Our team can also assist in evaluating digestate valorisation options.



SERVICES TO INDUSTRY

# AD/RNG Project Case Studies

At Celignis, we understand the critical role that accurate and timely data plays in the AD sector. With a decade of expertise in biomass analysis and valorisation, and over 1000 clients, our comprehensive suite of analytical and consultation services will enhance your AD feasibility studies and optimise your AD plant operations.

## Toxicity Assays

A biogas plant started underperforming when a new feedstock was used as co-feed. Since the plant received a gate-fee for this feedstock they did not want to stop using it but instead to use it in a controlled manner. Celignis analysed the feedstock and then custom-designed and ran Anaerobic Toxicity Assays for the waste stream based on the resulting analytical data. This work allowed us to determine threshold feedstock-loadings, in order to avoid toxic/inhibitory effects..

## Biological Advice

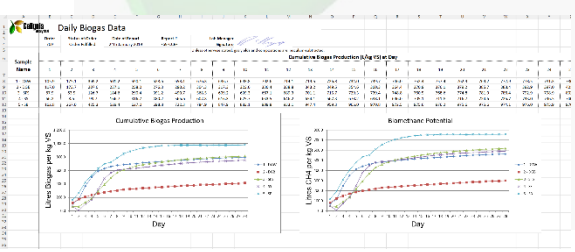
We helped a large AD company to optimise plant operations for more consistent outputs and reduced downtime. Our support involved us analysing process data and providing operational limits and green, yellow, and red zones for each process indicator. We also made a tool to allow self-design of major and minor elements (nutrients) for their plants based on feedstock chemistry. The tool was suitable for mono & co-digestion and allowed for shifting feedstocks and adding a new feedstock to the mix, without lowering plant performance.

## Continuous Digestions

We undertook continuous digestions, for a company producing biogas from the organic fraction of municipal solid waste, to determine the maximum achievable organic loading rate (OLR) and optimum feedstock mixtures. We also determined the minimum OLR to maintain plant health in scenarios of limited feedstock availability. These data, combined with the specific microbial activity tests on the digestate, provided the plant with adaptation strategies for the new feedstock. The full suite of tests and data analysis allowed the operator to understand feedstock limitations, feedstock underload/overload effects, optimum feedstock loadings, and process indicator ranges at different OLRs and feedstock mixtures. This allowed for bespoke adaptive strategies for maintaining plant health under feedstock supply and composition variations.

## Our Global Client Base

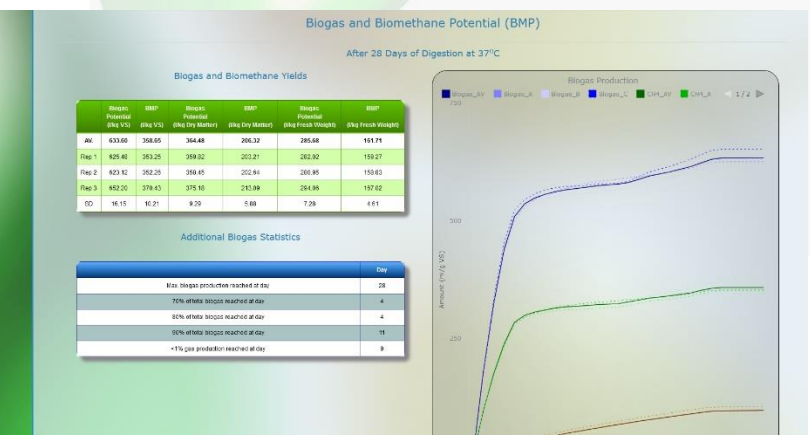
We provide valued analytical and bioprocess services to over 1000 clients globally, including many in the AD/RNG sector. We understand how the focus of AD projects can differ between countries and have advised a global network of clients on their RNG projects.

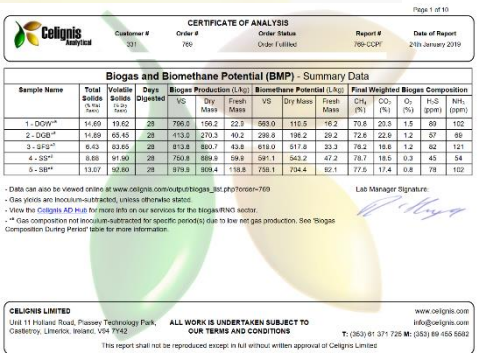



# Celignis AD/RNG Packages

| P# | Package Description | Price per Sample (€/$) | Comment |
|---|---|---|---|
| P38 | Major and Minor Elements | 120 | On feedstock or digestate |
| P81 | Biomethane Potential - 14 Days - Basic | 450 | €1,350 per batch of 4 samples |
| P82 | Biomethane Potential - 14 Days – Deluxe | 695 | €2,330 per batch of 4 samples |
| P84 | Biomethane Potential - 21 Days - Basic | 550 | €1,650 per batch of 4 samples |
| P85 | Biomethane Potential - 21 Days – Deluxe | 795 | €2,630 per batch of 4 samples |
| P87 | Biomethane Potential - 28 Days - Basic | 630 | €1,890 per batch of 4 samples |
| P88 | Biomethane Potential - 28 Days – Deluxe | 875 | €2,870 per batch of 4 samples |
| P93 | Feedstock Chemical & Biological Analysis | 125 | Included in the Deluxe BMP packages |
| P94 | Digestate Chemical & Biological Analysis | 125 | Included in the Deluxe BMP packages |
| P95 | Residual Biogas Pot. – 14 Days - Basic | 325 | Undertaken on digestate |
| P220 | Chemical Oxygen Demand (COD) | 30 | |
| P221 | Biological Oxygen Demand (BOD) | 30 | |
| P222 | Volatile Fatty Acids (VFA) Speciation | 50 | |
| P223 | Carbon Dioxide Evolution Rate | 50 | |
| P224 | Specific Oxygen Uptake Rate | 50 | |
| P225 | Digestate Impurity Content | 100 | |
| P226 | Ammoniacal Nitrogen | 30 | |
| P227 | Nitrates | 25 | |
| P228 | Viable Weed Seeds | 100 | Undertaken on digestate |
| P240 | Specific Hydrolytic Potential (SHP) | 450 | |
| P241 | Specific Acidogenic Potential (SAP) | 450 | |
| P242 | Specific Methanogenic Potential (SMP) | 450 | |
| P243 | SHP; SAP; and SMP | 900 | |
| P245 | Sludge Granule Size Analysis | 75 | |
| P246 | Sludge Activity Test | 75 | |
| P247 | Anaerobic Toxicity Assay | 750 | |
| P249 | Biological Consultation | 650 per day | Alternatively, €90 per hour |
| P250 | Continuous Anaerobic Digestion | 1,500* | per reactor per month |
| P386 | Digestate Germin Inhibition/Stimulation | 100 | |
| P388 | Digestate Plant Growth Trials | 495** | Per set triplicate pots. €295 (bulk) |

** Price is dependent on reactor size (5-100 litres) and on the associated analyses undertaken in the experiments.*
*** Larger (tray) trials using a dedicated greenhouse can also be arranged.*



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

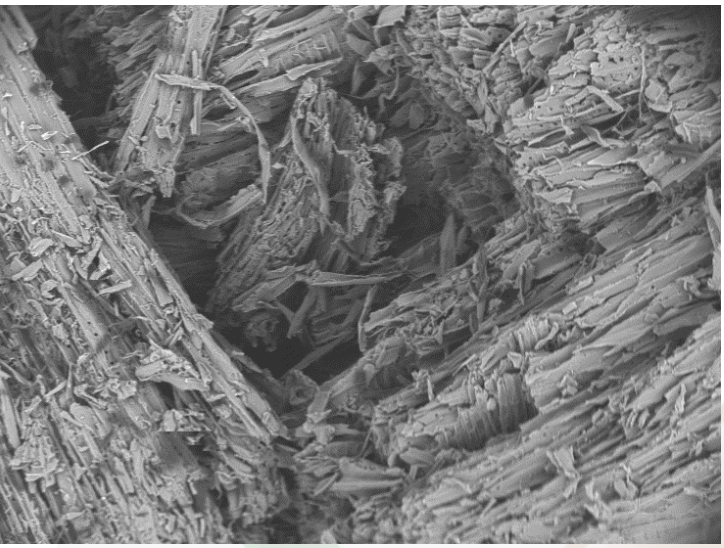
**P42 – Ash Melting Behaviour**

**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.



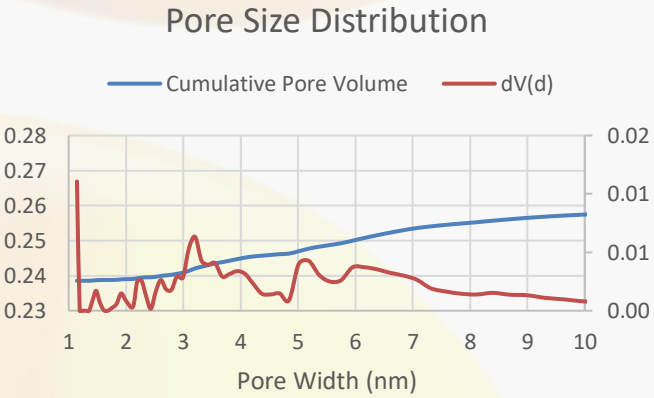
We are equipped to run all the necessary analysis for the EBC and IBI certificate

## 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 packages for such analyses.

## THRESHOLD

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.

FEEDSTOCK TO BIOCHAR

# Celignis Biochar Packages

| Pkg # | Package Description | TAT (wks) | Per Sample Price (€/$) | | | | # Samples in Order | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | P1 | P2 | P3 | P4 | L2 | L3 | L4 |
| **Biochar Production** | | | | | | | | | |
| P350 | Biochar Production | 2 | 595 | 495 | 395 | 295 | 5 | 10 | 30 |
| **Biochar Chemistry** | | | | | | | | | |
| P10 | Ligno.Constit., Extractives, and Ash | 2 | 450 | 395 | 350 | | 5 | 10 | |
| P226 | Ammoniacal Nitrogen | 1 | 30 | 25 | 20 | | 30 | 50 | |
| P227 | Nitrates | 1 | 25 | 20 | 15 | | 10 | 30 | |
| **Biochar Physical Properties** | | | | | | | | | |
| P51 | Particle Size | 1 | 35 | 25 | | | 10 | | |
| P53 | Bulk Density | 1 | 20 | 15 | 10 | | 10 | 30 | |
| P360 | Specific Surface Area | 1 | 275 | 250 | 200 | | 10 | 30 | |
| P364 | Pore Size Distribution | 1 | 325 | 295 | 225 | | 10 | 30 | |
| P366 | Pore-Size Distribution Deluxe | 1 | 395 | 350 | 300 | | 10 | 30 | |
| P368 | Pore-Size Distribution Ultimate | 1 | 595 | 495 | 445 | | 10 | 30 | |
| **Biochar Thermal Properties** | | | | | | | | | |
| P2 | Moisture Content | 1 | 20 | 15 | 10 | | 10 | 30 | |
| P3 | Ash Content | 1 | 20 | 15 | 10 | | 20 | 50 | |
| P31 | Volatile Matter | 1 | 50 | 40 | 30 | | 5 | 10 | |
| P33 | Ultimate (Elemental) Analysis | 1 | 45 | 35 | 30 | | 25 | 50 | |
| P34 | Calorific Value and Elements | 1 | 125 | 95 | | | 10 | | |
| P35 | Chlorine and Sulphur (Requires P34) | 1 | 25 | 20 | 15 | | 10 | 30 | |
| P42 | Ash Melting Behaviour (Reducing) | 2 | 100 | 80 | 60 | | 10 | 30 | |
| P370 | Inherent Moisture | 1 | 20 | 15 | 10 | | 10 | 30 | |
| P371 | Ash Content (815C) | 1 | 35 | 25 | 15 | | 20 | 40 | |
| P372 | Inorganic Carbon | 2 | 45 | 35 | 30 | | 25 | 50 | |
| P373 | Thermogravimetric Analysis (TGA) ($N_2$) | 1 | 195 | 150 | 95 | | 10 | 30 | |
| P374 | Thermogravimetric Analysis (TGA) (Air) | 1 | 195 | 150 | 95 | | 10 | 30 | |
| **Biochar Soil Amendment Packages** | | | | | | | | | |
| P38 | Major and Minor Elements | 1 | 120 | 100 | 80 | | 20 | 40 | |
| P381 | Electrical Conductivity | 1 | 50 | | | | | | |
| P382 | Water Holding Capacity | 1 | 95 | | | | | | |
| P383 | Cation Exchange Capacity | 1 | 150 | | | | | | |
| P384 | Polycyclic Aromatic Hydrocar. (PAH) | 2 | 295 | 250 | 195 | 150 | 10 | 20 | 30 |
| P385 | Liming | 1 | 75 | | | | | | |
| P386 | Germination Inhibition | 3 | 295 | | | | | | |
| P387 | Scanning Electron Microscopy (SEM) | 2 | 350 | | | | | | |
| P388 | Biochar Plant Growth Trials | 5 | 495 | 395 | 350 | 295 | 2 | 5 | 10 |

| Pkg # | Package Description | TAT (wks) | Per Sample Price (€/$) P1 | P2 | P3 | P4 | # Samples L2 | L3 | L4 |
|---|---|---|---|---|---|---|---|---|---|
| **Biochar Bulk-Analysis Packages** | | | | | | | | | |
| P390 | Biochar Physical Properties Deluxe | 1 | 450 | 395 | 345 | | 10 | 20 | |
| P391 | Biochar Physical Properties Ultimate | 1 | 650 | 595 | 525 | | 10 | 20 | |
| P393 | Biochar Thermal Properties Deluxe | 2 | 325 | 270 | | | 10 | | |
| P394 | Biochar Thermal Properties Ultimate | 2 | 750 | 650 | | | 10 | | |
| P396 | Biochar Soil Amendment Deluxe | 3 | 695 | 545 | | | 10 | | |
| P397 | Biochar Soil Amendment Ultimate | 5 | 1,200 | 1,075 | | | 10 | | |
| P399 | Biochar Complete Evaluation Package | 5 | 1,995 | 1,745 | | | 10 | | |
| **European Biochar Certificate (EBC) - Equivalent Tests** | | | | | | | | | |
| P2 | Dry Matter | 1 | 20 | 15 | 10 | 10 | 10 | 30 | |
| P370 | Water Content (40 C) | 1 | 20 | 15 | 10 | 10 | 10 | 30 | 20 |
| P33, P372 | Total Carbon, H:$C_{org}$, $C_{Inorg}$, Nitrogen, Sulphur, Oxygen, Ash | 2 | 90 | 70 | 60 | 60 | 25 | 50 | |
| P53 | Bulk Density | 1 | 20 | 15 | 10 | 10 | 10 | 30 | |
| P382 | Water Holding Capacity | 1 | 95 | 95 | 95 | 95 | | | |
| P381 | Electrical Conductivity | 1 | 50 | 50 | 50 | 50 | | | |
| P38 | Major and Minor Elements | 1 | 120 | 100 | 80 | 80 | 20 | 40 | |
| Free | pH | 1 | 0 | 0 | 0 | 0 | | | |
| P384 | Polycyclic Aromatic Hydrocar. (PAHs) | 2 | 295 | 250 | 195 | 150 | 10 | 20 | 30 |
| P364 | Surface Area & Pore Size Distrib. | 1 | 325 | 295 | 225 | 225 | 10 | 30 | |
| P51 | Particle Size Distribution | 1 | 35 | 25 | 25 | 25 | 10 | | |
| | **Combined Package:** | 2 | 960 | 845 | 695 | 650 | 10 | 20 | 30 |
| | Dioxins/Furans & PCBs *Subcontracted | 3 | 490 | 490 | 490 | 490 | | | |
| | **Combined (Incl. PCB, PCDD/F)** | 3 | 1,450 | 1,335 | 1,185 | 1,140 | 10 | 20 | 30 |
| **IBI Test Category A** | | | | | | | | | |
| P2 | Moisture | 1 | 20 | 15 | 10 | | 10 | 30 | |
| P33 | Organic Carbon (Corg) (Incl. P372) | 2 | 90 | 70 | 60 | | 25 | 50 | |
| P33 | H:Corg (Incl. P372) | 2 | 90 | 70 | 60 | | 25 | 50 | |
| P33 | Total Nitrogen | 1 | 45 | 35 | 30 | | 25 | 50 | |
| Free | pH | 1 | 0 | | | | | | |
| P381 | Electrical Conductivity | 1 | 50 | | | | | | |
| P385 | Liming | 2 | 75 | | | | | | |
| P51 | Particle Size Distribution | 1 | 35 | 25 | | | 10 | | |
| | **Combined Package** | 2 | 215 | 190 | 165 | | 20 | 40 | |
| **IBI Test Category B** | | | | | | | | | |
| P38 | Major & Minor Elements | 1 | 120 | 100 | 80 | | 20 | 40 | |
| P35 | Chlorine | 1 | 95 | 75 | | | 10 | | |
| P384 | Polycyclic Aromatic Hydrocar. (PAHs) | 2 | 295 | 250 | 195 | 150 | 10 | 20 | 30 |
| P386 | Germination Inhibition Assay | 3 | 295 | | | | | | |
| | Dioxins/Furans & PCBs (*Subontracted) | 3 | 490 | | | | | | |
| | **Combined Package** | 3 | 1,200 | 1,115 | 1,040 | 990 | 10 | 20 | 30 |
| **IBI Test Category C** | | | | | | | | | |
| P36 | Total Phosphorus and Potassium | 2 | 80 | 70 | 60 | | 20 | 40 | |
| P36 | Available Phosphorus | 2 | 80 | 70 | 60 | | 20 | 40 | |
| P36 | Total Ca, Mg & Sulphur (Incl. P33) | 2 | 125 | 105 | 90 | | 20 | 40 | |
| P36 | Avail.e Ca, Mg and Sulphate-S (+P33) | 2 | 125 | 105 | 90 | | 20 | 40 | |
| P31 | Volatile Matter | 1 | 50 | 40 | 30 | | 5 | 10 | |
| P364 | Total and External Surface Area | 1 | 325 | 295 | 225 | | 10 | 30 | |
| | **Combined Package** | 2 | 595 | 495 | 395 | | 10 | 20 | |

# 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.

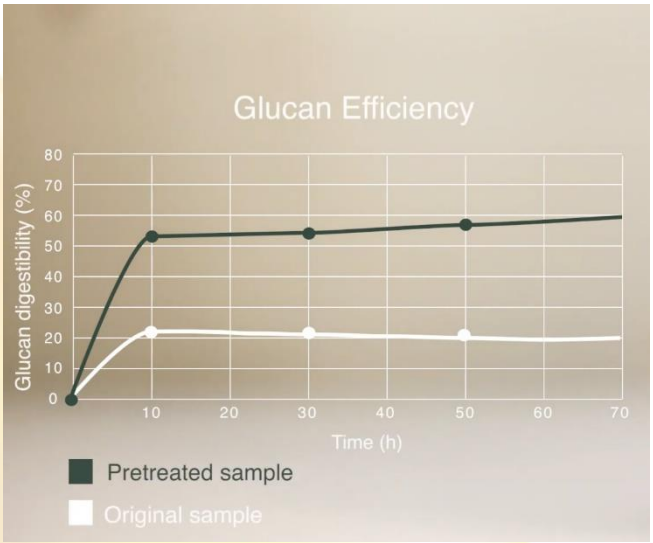
# 8. Evaluation of Pre-treatments

## 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.

## Our Analysis Packages for Seaweed

### P71 Seaweed Carbohydrates

Fucose, Mannitol, Glucose, Xylose, Mannose, Arabinose, Galactose, Rhamnose, Total Sugars, Glucuronic Acid, Galacturonic Acid, Mannuronic Acid, Guluronic Acid.

### P72 Seaweed Amino Acids

Alanine, Arginine, Aspartic Acid, Cystine, Glutamic, Glycine, Histidine, Isoleucine, Leucine, Lysine, Methionine, Phenylalanine, Proline, Serine, Threonine, Tyrosine, Valine.

### P33 Ultimate (Elemental) Analysis

Carbon, Hydrogen, Nitrogen, Sulphur, Oxygen, Ash.

### P38 Major and Minor Elements

Aluminium, Calcium, Iron, Magnesium, Phosphorus, Potassium, Silicon, Sodium, Titanium, Antimony, Arsenic, Cadmium, Chromium, Cobalt, Copper, Lead, Manganese, Mercury, Molybdenum, Nickel, Vanadium, Zinc.

### P73 Seaweed Lipids as Fatty Acids

Arachidic Acid, Behenic Acid, Decanoic Acid, Erucic Acid, Lauric Acid, Linoleic Acid, Linolenic Acid, Myristic Acid, Caprylic Acid, Oleic Acid, Palmitic Acid, Palmitoleic Acid, Stearic Acid.

### P74 Pigments in Seaweed

Fucoxanthin, Astaxanthin, Chlorophyll-c, Chlorophyll-a, Chlorophyll-b, Lutein, beta-Carotene, Neoxanthin, Antheraxanthin, Violaxanthin.

## P75 Seaweed Phytohormones

Gibberellic Acid, Indole-3-Acetic Acid, Indole-3-Propionic Acid, Indole-3-Butyric Acid, 6-Benzylamino-Purine, Kinetin-Riboside, Abscisic Acid, Salicylic Acid, Zeatin.

## P77 Vitamins (Water-Soluble) in Seaweed

Thiamine, Niacin, Nicotinamide, Pyridoxine, Folic Acid, Riboflavin, Pantothenic Acid, Ascorbic Acid, Biotin.

## P155 Seaweed Polyamines

Dopamine, Histamine, Serotonin, Phenylethylamine, Putrescine, Cadaverine, Norspermidine, Spermidine, Spermine, Tyramine, Agmatine

## P76 Vitamins (Fat-Soluble) in Seaweed

Phylloquinone, Tocopherol, beta-Carotene.

## P78 Seaweed Phenolics Profiling

Acids (Gallic, Caffeic, Chlorogenic, Ferulic, Coumaric, Protocatechuic), Catechin.

## P171 Molecular Weight Analysis - Alginate

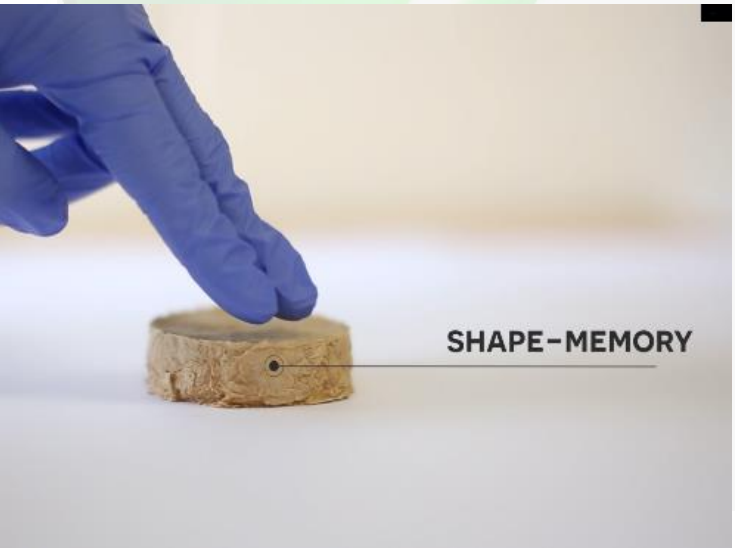
Using size-exclusion chromatography and refractive index detection.

## CUSTOM METHOD DEVELOPMENT

Sajna KV (PhD), our Bioanalysis Developer, has developed new and custom analysis methods, according to our clients' needs, for seaweeds and other biomass. Sajna also took part in the NIST Quality Assurance Program (Seaweed).

## WE HAVE CUSTOMS EXEMPTIONS

We also have customs exemptions for samples sent to us for analysis and research, allowing us to quickly get to work no matter where our clients are based.




## SEAWEED BIOPROCESS

**Isolation of Seaweed Polymers for Production of Sustainable Biomaterials:** This project concerned the development of a new sustainable process for the extraction, and subsequent modification, of alginate from seaweed. The process, developed by Celignis for our client, allowed for alginate extraction without the use of harsh chemicals (e.g. bleaches) and also considered the valorisation of process side-streams (e.g. fucoidan, cellulose etc.). The target of the project was polymers of improved properties for application in a variety of different biomaterials applications. We found that tweaks in the extraction and modification stages of the bioprocess could influence the physicochemical properties of the resulting alginate, allowing the process to be tailored for producing different types of materials for different end-uses.

BIOMASS FEEDSTOCK ANALYSIS

# 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**

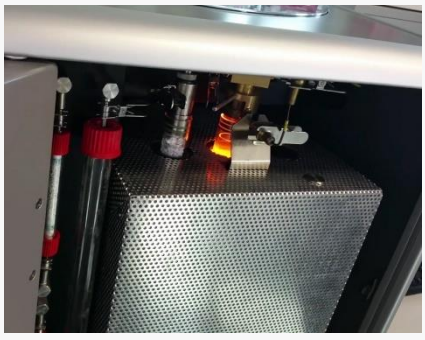
**P50 – Ultimate Combustion Package:**
P40 plus P38 and P42

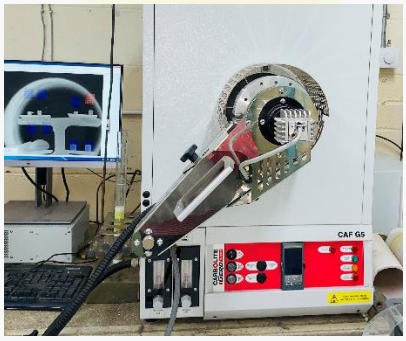
We have a range of packages to help you determine the value of your feedstocks for the production of heat and electricity.

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

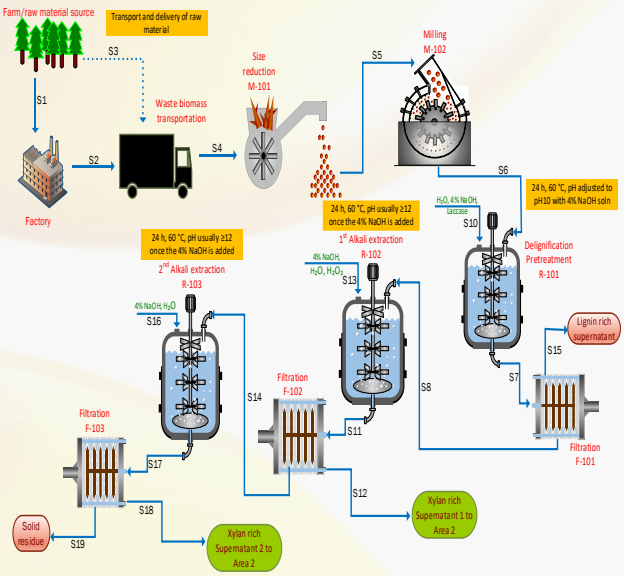
Lab-scale data provide a valuable departing point in the Technology Readiness Level (TRL) spectrum. However, a Techno-Economic Analysis (TEA) is crucial for the successful commercialization of a developed technology. Our staff possess the expertise to develop industrial-scale simulations of lab and pilot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

# 12. Rapid Analysis at Your Facility

The power of Celignis's NIR analysis models is now available for use at your facility for the rapid at-line analysis of feedstocks and the outputs of your pre-treatment and conversion processes.

- Celignis has offered Near Infrared (NIR) predictions of the lignocellulosic composition of biomass since 2014. This reduces analysis time from weeks to seconds.
- We're the only company with robust models for cellulosic feedstocks, covering 1000s of samples.
- Until recently, clients' samples were analysed within our labs and results then delivered by email.
- Recent technological advancements have greatly reduced the cost of suitable NIR hardware.
- Celignis is now able to offer a combined package of equipment leasing and NIR-model development, enabling clients to use Celignis models on-site.

## ADVANTAGES OF RAPID ANALYSIS

- Samples can be analysed in seconds.
- No chemical or statistical expertise required for operators.
- Actionable data can allow for informed process decisions.
- Cost of annual contract significantly less than employing a dedicated chemical analyst. Can be divided across thousands of NIR scans allowing for minimal per-sample analysis costs.
- Equipment and NIR models are updated by Celignis.
- Email and phone support from Celignis biomass experts.
- Models can be adapted to process and feedstock changes.

## PREDICTED COMPOSITIONAL DATA

- Structural sugars (glucan, xylan, mannan, arabinan, galactan)
- Klason lignin content.
- Extractives, ash, and moisture contents.
- Additional parameters possible.
- For each parameter the models provide two values – the predicted amount and the estimated error (deviation) in prediction. High deviation samples are less-well predicted by the models and will be retained for analysis at Celignis.

Our serviced NIR models allow for routine rapid analysis of your feedstocks and products on-site

# Serviced NIR Models from Celignis: Process Involved

## 1 Custom Model Development

NIR models require the development of algorithms that relate spectral data to compositional data, determined via reference (i.e. chemical analysis) methods. Due to the variation in feedstocks and technologies between biorefineries, bespoke algorithms need to be developed for each facility. This is done by the client posting around 200 samples to Celignis's labs where the analysis is undertaken, the results uploaded to the Celignis Database, and the Stage 1 models developed.

### PRICING

- €65,000 per annum.
- Covers the chemical analysis of up to 200 samples in Yr 1, to develop the first iterations of the bespoke models.
- Covers the subsequent chemical analysis of up to 15 samples per month and associated updating of models.
- Includes unlimited scans on-site and access to models.
- Renewal for subsequent years allows for continued access to the models and monthly model servicing.

### SUITABLE SAMPLE TYPES

Solid biomass, slurries, pre-treated samples, enzymatic hydrolysis residues, process side-streams. Models can be developed for wet and/or dry samples.

### CELDEEP SOFTWARE TOOL

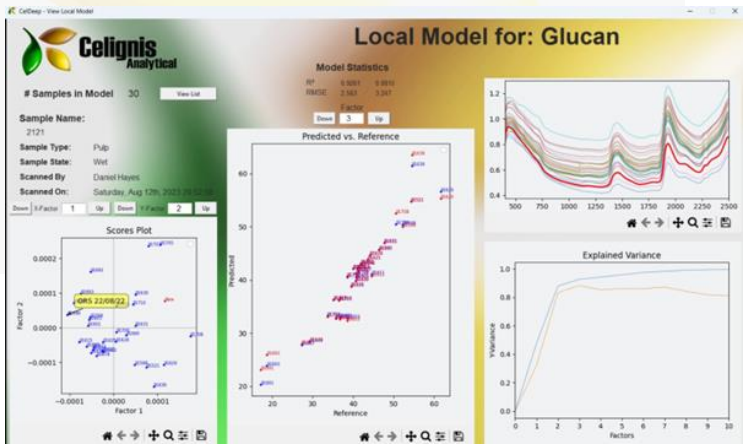
- A powerful tool for viewing the outputs of the NIR models.
- Provides the user with great flexibility regarding which models are applied for each type of sample.
- Allows the user to set threshold values for each property.
- Results can be directly emailed to contacts from CelDeep.
- There is an associated website (CelDeep Process Control) where control plots can be viewed for selected sample types and compositional parameters.

## 2 Routine Analysis & Updates

After Stage 1 the client is able to use the handheld NIR scanner on-site and gain access to the bespoke NIR models developed by Celignis. Data are provided via the CelDeep software and are accessible online on the CelDeep Process Control website. We understand that cellulosic technologies are constantly being developed and improved and that this can lead to new types of samples being produced over time. It's therefore important that the NIR models adapt to these changes. As part of the annual contract, Celignis will analyse up to 15 samples per month in its laboratories and will use the obtained data to iteratively update the models so that their accuracy and robustness improves. The CelDeep software can provide suggestions to the user regarding which samples should be retained for chemical analysis at the Celignis labs.

## 3 Contract Renewal

The contract renews annually, allowing for continued access to the models and hardware



EXPERTS IN THE BIOECONOMY

# 13. Meet the Team

## Dan Hayes, PhD

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, PhD

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.

## Sajna KV , PhD

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, PhD

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. Working on Bioprocess Development Services projects at Celignis.

## Fernando Climent, PhD

Multi-disciplinary env. engineer with pedigrees: reactor design, monitoring, control and TEA. Studied continuous saccharification of urban residues at high-loadings, addressing rheology & microbial contamination. Developed cellulases for biomass and detergent applications. Working on Bioprocess Development Services projects at Celignis.

## Salar Mehdikhani

Salar, Celignis's Electrical Manager, is an Electrical Engineer skilled in working with PCB boards and machinery. At Celignis he has further advanced his capabilities by working on preventative maintenance and optimisation of lab and bioprocess equipment. His contributions have enabled our Bioprocess facility to greatly expand its capabilities and processing scales.

## 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.

## Patrycja Burczynska

Patrycja is a microbiologist with a strong GMP knowledge. Currently, she is responsible for our microorganism collection. She undertakes microbial and biochemical assays and is mostly focused on fermentation and enzyme activity related to Celignis's Bioprocess Development Services.

## Guillermo Langa

Guillermo's role as chromatography manager is to explore and develop biomass analysis methods. He is also responsible for several other analyses at Celignis, including the quantification of major and minor elements in biomass (ICP) and for the production of biochar through pyrolysis.

## Roberto Liberti, MSc

An industrial biotechnologist focused on the valorisation of waste biomass to obtain bioproducts from microbial sources. Starting with the production and extraction of enzymes he is contributing to the development of different bioprocesses focusing on the microbial aspects of the projects. Also involved in the set up and maintenance of bioreactors, Roberto contributes to the operations of Celignis's RNG lab.

## Cristóbal Belmonte, MSc

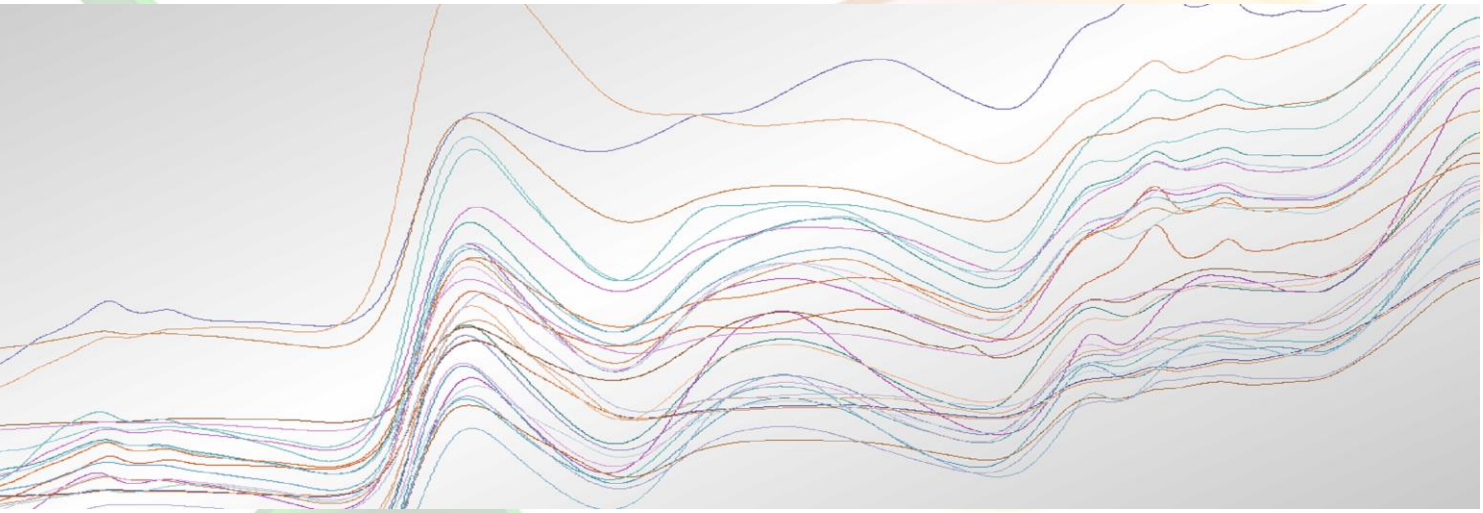
Cristóbal, a biotechnologist that is passionate about biomass, with an MSc in the Circular Bioeconomy. He is responsible for a number of different analyses relating to the thermal characteristics and behaviour of biomass and process residues (e.g. CHNS (Dumas Analysis), Ash Melting Behaviour, Chlorine Content, Calorific Value, Volatile Matter, Fixed Carbon, and Thermogravimetric Analysis).

## Charilaos Bakalis

With an academic backround in Agricultural Technology and Enviromental Science, Charilaos's thesis focused on studying soil nutrients in vineyards. He is really passionate about the Bioeconomy and in his new role at Celignis he is tasked with the extraction of various biomass samples, showcasing his practical application of scientific knowledge and laboratory skills.

ACTIVITIES AT CELIGNIS

# 14. 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 7.

# 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.

PIONEERS IN THE BIOECONOMY FOR A DECADE

# 15. HISTORY OF CELIGNIS

## 1 Celignis Analytical

Celignis was launched in 2014 as a spin-out from Dan Hayes's PhD on NIR analysis of biomass and his work in the research project DIBANET. The initial focus of Celignis was on compositional analysis services for lignocellulosic feedstocks. Over the years the range of analytical services expanded significantly and the company relocated to larger premises.

## 2 Celignis Bioprocess

We started offering Bioprocess Development Services (BDS) in 2020 and these have grown greatly since. In 2022, in response to the increased demand for these services at higher technology readiness levels (TRLs), we took a second location, Celignis Bioprocess, focused on BDS projects. This facility has since been populated with an increasing array of bioprocessing equipment up to TRL7.

## 3 Currently Over 1000 Clients

In 2023 we secured our one thousandth client. Our customers span the globe and have come to depend on the chemical and process expertise that is prevalent within the Celignis team. We are examining options for securing additional labs, both within Europe and beyond, and further expanding our analytical and bioprocess development services, as well as our provisions to the RNG sector.


# OUR CUSTOMS EXEMPTIONS

We understand how important your samples are and also how important it is that you get accurate data promptly. One bottleneck associated with the analysis of samples can be issues related to the delay in samples being delivered to the lab. For example, there can be hold-ups associated with the country's Customs and Agricultural departments taking time to examine the samples and to determine whether fees or additional documentation need to be provided for samples sent from overseas.

Thankfully Celignis has secured **special provisions** from Ireland's Revenue department which exclude samples sent for analysis from customs fees and duties. This means that the samples are no longer held by the courier companies or national departments whilst further investigations taken place. As a result, we now receive samples from as far afield as Australia in a couple of days and samples from the US **within 3 days**. These developments mean that you no longer need to worry about your samples degrading, or their compositions changing, during the delivery and that we can provide data to you much more quickly than before.

Contact us to receive all customs exemption documentation

# Further Information on Our Research and Activities

## Publications

Ravindran, R., Donkor, K., Gottumukkala L.D., Menon, A., Guneratnam, A. J., McMahon, H., Koopmans, S., Sanders, J. P. M., Gaffey, J. (2022) Biogas, biomethane and digestate potential of by-products from green biorefinery systems, **Clean Technologies** 4(1): 35-50

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**, Vol. 9 (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., 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.

## Recent Awards

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

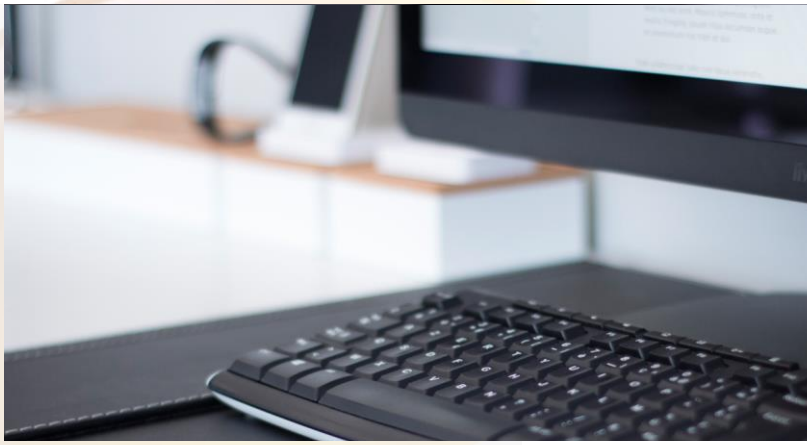
(2021) **Laboratory Staff Member of the Year** (Irish Laboratory Awards) – for our CIO Lalitha Gottumukkuala.

WE MAKE IT EASY TO ACCESS YOUR DATA

# 16. 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.

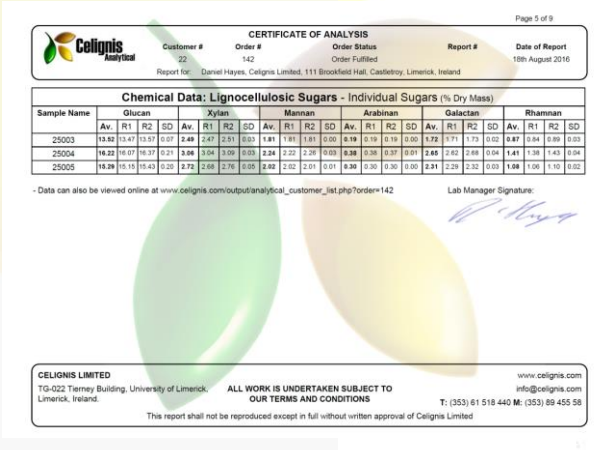



## DETAIL

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.



CERTIFICATE OF ANALYSIS

Customer # 22 | Order # 142 | Order Status: Order Fulfilled | Report # | Date of Report: 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 | 1.81 | 1.81 | 1.81 | 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.

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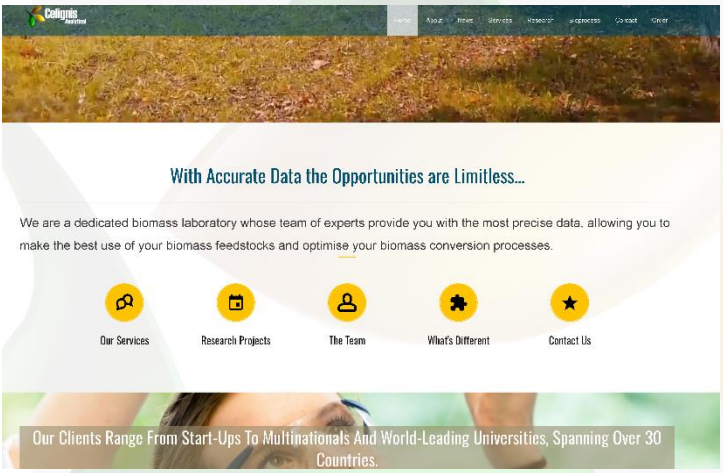
WE ARE ALWAYS HAPPY TO CHAT ABOUT BIOMASS!

# 17. 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


**CELIGNIS ANALYTICAL**

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Plassey Technology Park,
Castletroy, Limerick,
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