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PRIMED

Redesigning the Primary Sector for Maximizing Bioeconomy Development

D2.1 Map and Overview of relevant conversion technologies and biomass feedstocks

SINTEF

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1. Content

1. Content 4
2. LLab1: ALC Bio-Lab (ALC) 7
1.1. Biomass feedstock(s) 7
1.2. Conversion technology(ies) 7
1.3. Products/outputs 8
1.4. Technology provider(s) and/or reference plant(s) 8
1.5. Environmental/climate aspects 8
1.6. Societal/social aspects 8
1.7. Economic aspects 8
1.8. Energy aspects 9
1.9. Specific advantages and limitations/challenges 9
1.10. Value chain 9
1.11. Business model 9
1.12. LLab Timeline 10
2. LLab2: Bio-Silica Lab (CeNTI) 11
2.1. Biomass feedstock(s) 11
2.2. Conversion technology(ies) 11
2.3. Products/outputs 12
2.4. Technology provider(s) and/or reference plant(s) 13
2.5. Environmental/climate aspects 13
2.6. Societal/social aspects 13
2.7. Economic aspects 13
2.8. Energy aspects 14
2.9. Specific advantages and limitations/challenges 14
2.10. Value chain 14
2.11. Business model 14
2.12. LLab Timeline 15
3. Llab3: Liguria Bio-Lab (FILSE) 16
3.1. Biomass feedstock(s) 16
3.2. Conversion technology(ies) 16
3.3. Products/outputs 17
3.4. Technology provider(s) and/or reference plant(s) 17
3.5. Environmental/climate aspects 18
3.6. Societal/social aspects 19
3.7. Economic aspects 19

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the European Union

3.8. Energy aspects 19
3.9. Specific advantages and limitations/challenges 19
3.10. Value chain 19
3.11. Business model 20
3.12. LLab timeline 20
4. LLab4: BioEire Lab (IBF) 21
4.1. Biomass feedstock(s) 21
4.2. Conversion technology(ies) 21
4.3. Products/outputs 22
4.4. Technology provider(s) and/or reference plant(s) 22
4.5. Environmental/climate aspects 22
4.6. Societal/social aspects 22
4.7. Economic aspects 23
4.8. Energy aspects 24
4.9. Specific advantages and limitations/challenges 24
4.10. Value chain 25
4.11. Business model 26
4.12. LLab Timeline 26
5. LLab5: CellFactory Lab (VTT) 28
5.1. Biomass feedstock(s) 28
5.2. Conversion technology(ies) 28
5.3. Products/outputs 29
5.4. Technology provider(s) and/or reference plant(s) 29
5.5. Environmental/climate aspects 29
5.6. Societal/social aspects 29
5.7. Economic aspects 29
5.8. Energy aspects 29
5.9. Specific advantages and limitations/challenges 30
5.10. Value chain 30
5.11. Business model 30
5.12. LLab Timeline 30

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Figure index

Figure 1. ALC LLab: From biomass residues to valuable products. 7

Figure 2. SEM image of rice husk (grinded at 0.5 mm) & elemental composition table (XRF analysis, dry basis). *LE: light elements. 11

Figure 3. Reactors at CeNTI – 100 L and 600 L. 12

Figure 4. Bio-silica extraction and functionalization. 12

Figure 5. Overview of LLab VC1. 17

Figure 6. National Bioeconomy Campus in Lisheen, Co. Tipperary. 22

Figure 7. Forestry residues: a possible VC. 25

Figure 8. Dairy by-products possible VC. PLA: polylactic acid (a thermoplastic monomer derived from renewable, organic sources). 26

Figure 9. VTT LLab bioreactor cultivation in the PRIMED project. 28

Table index

Table 1. Biogas generation from ALC feedstocks. 8

Table 2. Products developed by CeNTI. 12

Table 3. Main carbon footprints sources identified. 13

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2. LLab1: ALC Bio-Lab (ALC)

AD biogas plant combined with composting plant co-processing animal & vegetal residues, located in Alcarràs, Catalunya, Spain.

<u>Current status:</u> Composting plant operating; first AD biogas plant to be erected in 2024.

1.1. Biomass feedstock(s)

ALC has been producing compost from pig slurry (solid fraction) and cow manure for several years. It is currently processing 18000 t/y with the ambition of reaching 27000 t/y in 2024. To improve the composting process, 2000t/y vegetal residues (from local fruit tree pruning) are also added, mainly to avoid the compost compaction. The slurry and manure (85-90% moisture) are collected from more than 300 farms. The company was built by the aggregation of 150 farmers from the same municipality: Alcarràs, Lleida, Spain. The feedstocks are produced and collected daily by trucks from the farms. Their properties are not affected by seasonal variations.

In 2024, ALC is expanding its activity by installing two anaerobic digesters (with a volume of approx. 3600 m^3 each) in two phases. They will be combined with the existing composting plant (see details in Section 2). The treatment capacity (first digester) will reach 74000 t/y (12000 t/y cow manure and 62000 t/y pork slurry that will be mixed to ensure homogeneity). In addition, up to 10,000 t/y vegetal streams will be incorporated, i.e., pruning residues, vegetables, and garden/park biomass waste from the region. Given its physical properties (large size), this stream must be pre-treated (sorting/removal, milling/cutting) before processing. During this first phase, the feedstock mixture (manure, slurry, vegetal biomass) will be optimised to get maximal biogas production. In the second phase, the second digester will be mounted, and the biomass feedstocks processed will further increase in amount and diversity. This step is planned for 2026.

1.2. Conversion technology(ies)

ALC LLab will combine the existing composting plant with an anaerobic digester (first phase starting in 2024) to generate biogas. The overall process diagram, from feedstocks to products, is summarised in **Figure 1.** The received livestock waste will be mixed before injection into the digester.

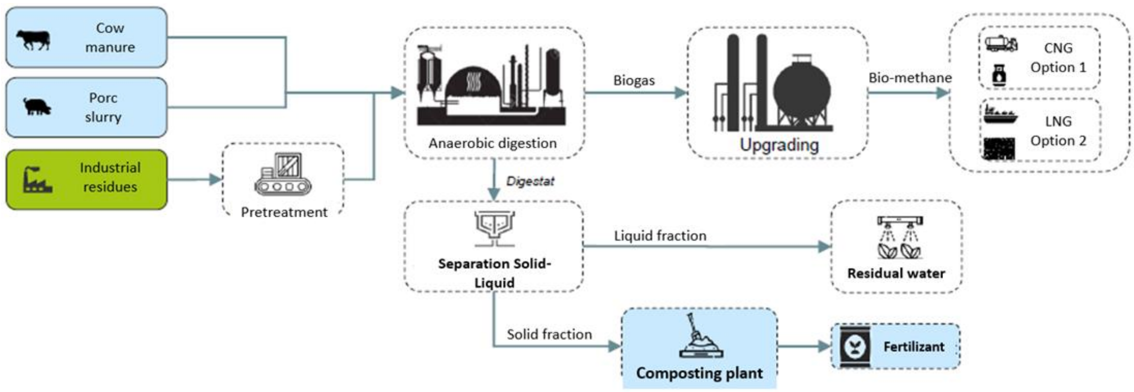

Figure 1. ALC LLab: From biomass residues to valuable products.

The anaerobic digestion will generate biogas and a digestate. The latter will undergo a separation process to recover the solid fraction (10-15%) that will be transferred to the composting plant. The liquid fraction will be collected in a pool and can be used in agriculture after getting the required certifications and respecting the European norms. The biogas from the anaerobic digestion will be upgraded to generate bio-methane. To

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commercialise bio-methane, two strategies are possible: as Compressed Natural Gas (CNG, Option 1) or Liquid Natural Gas (LNG, Option 2).

1.3. Products/outputs

ALC will generate biogas (Product 1) for Combined Heat and Power (CHP) production. The heat (Product 2) will be used to warm the digesters and reduce the biogas production costs. The electricity (Product 3) will be principally used for internal installations allowing us to build an auto-sufficient energetic community. The remaining electrical power will be sold to the public net. Another alternative will be the installation of charger for agriculture engines fuel. The generated biogas can be upgraded to generate bio-methane (Product 4) that can be commercialised as CNG or LNG. The digestate from the AD process can be valorised as a bio-fertiliser (Product 5). The residual water can be valorised as water for agricultural fields (Product 6). See **Figure 1** for process overview.

Table 1 gives the volumes of biogas that will be produced by the first ALC digester (corresponding to about 734000 m^3 bio-methane). In addition, about 75000 tons of bio-fertiliser will be generated.

Table 1. Biogas generation from ALC feedstocks.

Digester alimentation	t/y	t/day	m^3 biogas/t	m^3 biogas/y
Cow manure	12000	33	60	700000
Pork slurry	62000	173	8	500000
TOTAL	74000	206	68	1220000

1.4. Technology provider(s) and/or reference plant(s)

The main players delivering key parts/equipment for the installation of the first anaerobic digester are Ecobiogas and Biodynamics.

1.5. Environmental/climate aspects

The bio-methane will replace fossil methane while the bio-fertiliser will substitute chemical fertiliser. Locally, dust may be caused by vehicle traffic and bad smells may come from the composting process and digester loads. Corrective measures can be applied if required. The nearest habitable area (house) is about 1 km away.

1.6. Societal/social aspects

The installation of the biogas digester will create new direct and indirect jobs (technicians, workers, drivers, and an engineer). Our intention is to hire and train workforce from the neighbouring villages/cities. The public perception was initially sceptical as many did not know how a composting plant works. Locals (neighbours, municipal representatives) were invited at information meetings and the site was opened to visitors to increase knowledge about how compost allows to reduce the bio-waste and convert it to a valuable product (bio-fertilisers). This strategy of openness worked, and overall perception is good, even supportive. A similar approach will be taken when establishing the digester.

1.7. Economic aspects

The initial investment for the composting plant in 2022 was about 1.5 M€ and was brought by the farmers (partners). ALC's expansion and diversification are under planning and will require both increased CAPEX and OPEX. Revenues will come from sales of energy and bio-fertiliser.

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1.8. Energy aspects

The generation of the biogas and its upgrading to bio-methane to produce electrical and thermal energy will allow ALC to close the loop by enabling an energetically self-sufficient local community. The electrical energy generated will be sufficient to operate ALC's installations while the rest will be transferred (and sold) to the grid. A precise quantification of the expected energy balance cannot be done yet.

1.9. Specific advantages and limitations/challenges

ALC's first digester will manage 74000 tons of bio-waste that will be valorised via anaerobic digestion, a fundamental activity for the development of a circular economy, transforming waste and residues into resources. To ensure success, it is essential that farmers have reliable suppliers of organic fertilisers, who adjust both in quality and costs to the current agricultural reality, especially in a global market with harsh competition. ALC can offer a stable, homogeneous, high-quality bio-fertiliser (compost) to its customers.

Furthermore, legislations are getting stricter every year and biogas digesters cannot process any feedstock without permission. ALC has acquired the permissions to handle animal by-products from the moment they are generated until their final use, guaranteeing that during this process no risks are generated for human health, animal health or the environment, especially to guarantee the safety of the human and animal food chain. ALC also acquired permissions for the treatment of vegetal residues under national registers.

We will design validation and breakthrough experiments in collaboration with the identified technology owners to raise TRL in the target value chains from TRL 3 to 5 as part of PRIMED. In the future, the installation of a second digester will then allow ALC to further diversify and increase the amount of biomass processed.

1.10. Value chain

ALC value chain encompasses various stages from raw materials to final products and services:

- **Raw Material Sourcing:** Acquisition of livestock waste (dejections) from the farms owned by the 150 families of farmers and ranchers in the association.
- **Composting**: Processing and treating the livestock waste to create compost. Categorising the compost into different types/qualities: cow compost, pig compost, and a mixture of pig and cow compost.
- **Biogas Generation**: Using manure/slurry as a feedstock for a biogas installation. Capturing and processing the biogas generated from the compost.
- **Biogas Utilisation**: Conversion of biogas into electricity and/or heat. Distribution or utilisation of the generated energy for various purposes.
- **Diversification of Products and Services**: Exploring and developing new products or services, such as specialised organic fertilisers and soil amendments.
- **Partnerships and Collaborations**: Establishing partnerships with agricultural supply companies, renewable energy companies, local farmers or gardening associations, government agencies, educational institutions, retailers, technology providers, etc.
- **Regulatory Compliance**: Ensuring compliance with national and regional regulations related to compost production, waste management, and biogas generation.
- **Community Engagement**: Engaging with the local community through initiatives, educational programs, or events that promote sustainable farming practices and environmental responsibility.

1.11. Business model

- ALC current business model centres around an agricultural association comprising 150 families of farmers and ranchers who own pig and cow livestock. The association has established a company dedicated to

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treating the waste (dejections) from their farms, converting it into compost. This compost is classified into three categories: cow compost, pig compost, and combined pig/cow compost with predefined proportions.

- The primary revenue stream comes from the sale and internal purchase of the compost. Externally, the association sells the compost to customers, farmers, or agricultural businesses. ALC's business model is more a B2B (Business-to-Business) scheme than a B2C (Business-to-Consumer) scheme. Internally, the 150 families within the association buy the compost to use on their own lands and crops.
- After including anaerobic digestion, ALC will introduce a new product to the market, i.e. biogas, which can be upgraded to produce electricity and/or heat. This not only adds an eco-friendly dimension to the business model but also promotes renewable energy utilisation within the company.

ALC business model in a nutshell:

- **Owners:** An association regrouping 150 family farmers
- **Products:** Compost/bio-fertiliser (different qualities) now and adding biogas in the future (which will be upgraded to biomethane, CNG or LNG, electricity and heat)
- **Customers:** Farmers (in Spain, France) for the compost, and biogas/bio-methane distributors. In the future, innovative SMEs (Small and Medium-sized Enterprises) will be hosted at ALC's site (to form a "bio-economy polygon") and will get access to its renewable energy products (electricity, heat, biogas). The ideal case will be that all involved trucks and cars convert to electrical power.

1.12. LLab Timeline

ALC LLab is currently transforming cow manure and pork slurry into compost. In parallel, it will be expanded with an anaerobic digester to generate biogas. The groundwork started in February 2024 and the first digester installation is to be finalised within 6 months (i.e. Q3 2024). Installation of the second digester will start in 2026.

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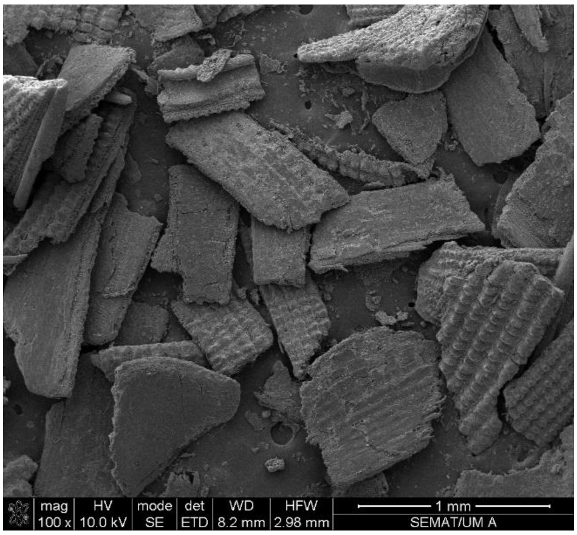
2. LLab2: Bio-Silica Lab (CeNTI)

Bio-silica from agro-industrial residues: Extraction and modification/functionalization, located in Vila Nova de Famalicão, Braga, Portugal.

<u>Current status</u>: Extraction of bio-silica from rice husk using the (alkaline) sol-gel process has been carried out as well as production of modified bio-silica (both at pilot-scale).

2.1. Biomass feedstock(s)

Agro-industrial residues/waste account for approx. 1300 million tons per year worldwide and includes seeds, hulls, leaves, pulp, and stems. Many of these biomasses contain valuable resources but are not properly valorised. One such fraction extensively studied by CeNTI is rice husk. In addition to their mechanical properties, rice husks are useful materials from which cellulose, hemicellulose, lignin and more specifically silica can be extracted. Silica can be used for various applications, e.g. as adsorbents or fillers. Besides rice husk, several agro-industrial residues can be considered for silica extraction, such as wheat straw, sunflower seeds, corn stalk, corn cob, rice straw, walnut shell, peanut shell, olive stone, wood carpentry, sugarcane bagasse, bamboo leaves, barley, etc. Rice husk was chosen due to its high silica content compared with other biomasses.



Element	Weight %
LE* (incl. C,H,N,O)	84,4
Si	13,1
S,P,K,Ca	1,8
Other	0,7

*Figure 2. SEM image of rice husk (grinded at 0.5 mm) & elemental composition table (XRF analysis, dry basis). *LE: light elements.*

Rice husk is mainly generated in Asia. However, the constraints of intercontinental transport call for the valorisation of local resources and local valorisation. CeNTI's rice husk is currently supplied by Portuguese rice producers. Portugal is the fourth largest rice producer in the EU, after Italy, Spain and Greece. The average quantity of rice produced over the last 5 years has been about 160000 tons of paddy rice (i.e. grain + husk) per year. **Figure 1** shows a SEM image of rice husk and its elemental composition: silicon (Si) represents almost 13% of its weight.

2.2. Conversion technology(ies)

CeNTI's technology to extract silica from agro-industrial residues is based on the (alkaline) sol-gel process. This method is used for the fabrication of metal oxides, especially the oxides of silicon (Si) and titanium (Ti). To obtain silica particles via the sol-gel process, several steps (using standard equipment - **Figure 2**) are needed and illustrated in **Figure 3**. The technology developed is modular allowing system-wide flexibility. CeNTI's process to produce silica from agro-industrial residues is currently at TRL 6-7. Silica extraction from rice husk has been optimised* by the LLab, and a reproducible SiO_2 extraction yield** of approx. 10% was attained. Furthermore,

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CeNTI can produce modified bio-silica with different functional properties, e.g., hydrophobic, flame retardant or antimicrobial properties. Other novel functionalities could be explored at lower TRL (2-3).

Figure 3. Reactors at CeNTI – 100 L and 600 L.

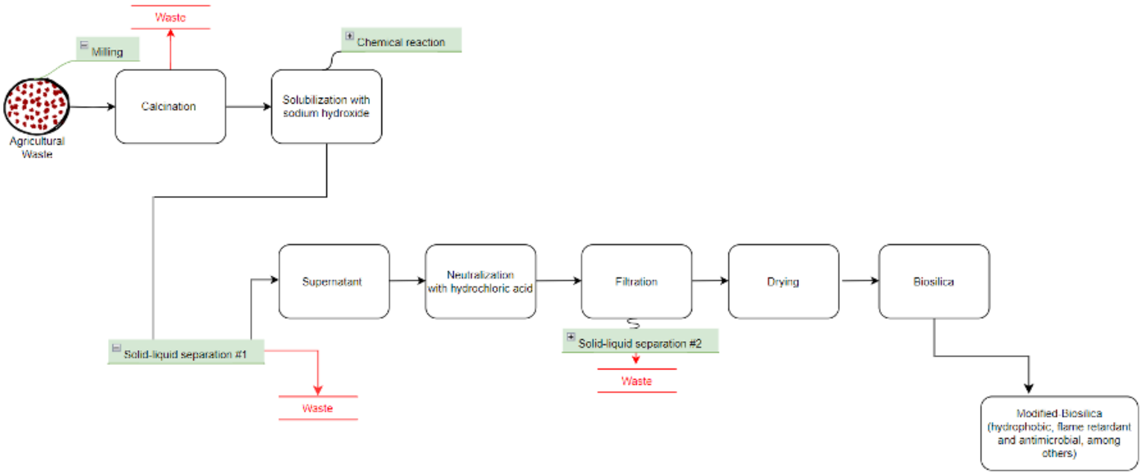

Figure 4. Bio-silica extraction and functionalization.

** Process optimization includes the neutralisation/precipitation solution, temperature, reaction time, drying temperature, and functional agent molar ratio.*

*** SiO_2 extraction yield (%) is defined as: (mass SiO_2 extracted) / (mass rice husk input).*

2.3. Products/outputs

Table 1 presents several products from CeNTI's LLab. Furthermore, CeNTI's know-how shows that the geographical origin of the feedstock, especially for rice husk, has no influence on the properties of the extracted silica and on the performance of the functionalized silica particles.

*Table 2. Products developed by CeNTI. * Minimum amount. The extraction yield refers to (mass SiO2 extracted) / (mass rice husk input).*

Input/Feedstock	Output/Product	Production scale
Agro-industrial waste – rice husk	Bio-silica from acid extraction	540 g/batch* (ca. 10% yield)
Agro-industrial waste – rice husk	Bio-silica from alkaline extraction	1800 g/batch

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		(ca. 10% yield)
Bio-silica + Hydrophobic reagent	Hydrophobic bio-silica	250-300 g/batch
Bio-silica + Antimicrobial reagent + Flame retardant reagent	Flame retardant and antimicrobial bio-silica	250-300 g/batch

The alkaline extraction of silica is more sustainable than the acidic alternative as it generates less waste. The three waste streams (see **Figure 3**) are:

1. Calcination waste: CO_2, H_2O but also N_2, O_2 and minor contaminants
2. Solid-liquid separation solid waste #1: for rice husk, it represents around 35 wt% of the initial sample. EDS analysis shows a material made of C (12%), O (41%), Na (14%), Si (15%) and other elements (≈17%)
3. Solid-liquid separation waste #2: neutralized water

Their possible valorisations will be investigated during the PRIMED project.

2.4. Technology provider(s) and/or reference plant(s)

The equipment employed for bio-silica extraction and modification/functionalisation consists of standard, commercially available machinery that can be readily obtained from suitable suppliers. Specifically, the equipment is used to perform chemical reactions, thermal treatments, milling, and liquid/solid separation processes.

2.5. Environmental/climate aspects

The carbon footprint of bio-silica production and functionalization comprises indirect, direct, and upstream and downstream sources. Carbon footprint will be quantified by the PRIMED project. See **Table 2** for an overview of the main carbon emissions sources identified. Furthermore, bio-silica reduces the dependence on traditional, fossil-based resources needed to produce synthetic silica.

Table 3. Main carbon footprints sources identified.

Product	Transportation	Electricity
Silica production	Rice husk Acid Base	Oven for calcination Stirring reactor Heating reactor Oven for drying
Hydrophobic silica	Hydrophobic reagent Catalyst Solvent	Stirring reactor Oven drying Centrifuge
Flame retardant and antimicrobial silica	Flame retardant reagent Antimicrobial reagent Catalyst Solvent	Stirring reactor Centrifuge Oven drying Ball mill

2.6. Societal/social aspects

The benefits of producing silica from a local, renewable biomass resource should be communicated to society at large. This point will be further explored in the PRIMED project.

2.7. Economic aspects

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The extraction and functionalization of bio-silica is aligned with the Portuguese State's strategy regarding (a) efficient and rational use of local natural resources, (b) reducing dependence on import, (c) creating new economic opportunities and (d) contributing to long-term competitiveness of the economy. The silica obtained from biomass has the potential to be a substitute of commercially available synthetic silica particles in different sectors, such as automotive, construction or textile industries.

2.8. Energy aspects

Consumption of energy is mainly related to the calcination step, as it is a high temperature process, and to the 100 L reactor operation. Additional information will be collected during the PRIMED project.

2.9. Specific advantages and limitations/challenges

The pilot installation has two limitations: (1) the size of a production batch (extraction process) and (2) production time due to the centrifugation step (limited capacity) and the drying stage as low temperatures are employed (functionalization process). These challenges will have to be resolved when further scaling-up the production.

The main advantages offered by CeNTI's process are that they are simple, made of modular, standard equipment and it is robust as it can extract silica from different biomass resources.

2.10. Value chain

Main stakeholders:

Farmers, citizens, coating formulators, end-users of bio-silica from the automotive, construction and textile sectors, among others. At this stage, a Portuguese association of rice producers has expressed its interest in the project results and to establish a collaboration with the bio-silica LLab.

End products:

Value Chain 1 – Bio-silica: 1) Automotive (filler in tires, adhesives/sealants, substitute of carbon black in rubber materials); 2) building and construction (silica sand in concrete and ceramics); 3) other applications / consumer goods (printing inks, fire extinguishing powder, catalysis, water treatment, electronics, etc.).

Value Chain 2 – Modified bio-silica: Additives for 1) coatings; 2) polymers; 3) fibres; among others. The applications are related to the functionalities, e.g. hydrophobic, flame retardant and antimicrobial properties.

2.11. Business model

Key biomass resources providers:

The agro-industrial sector.

Key partners (industrial customers):

Automobile, textile, furniture and bedding, construction and more.

Key processes:

Bio-silica extraction and bio-silica modification as well as testing/consulting both regarding the use of new biomass materials and novel bio-silica functionalities.

Revenue streams (for the LLab):

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- Services (bio-silica extraction and further modification; production of pre-series for validation assessment on relevant industries; development of prototypes for performance evaluation and characterization of relevant properties)
- Consulting (new raw materials for the extraction of bio-silica and new functional properties for bio-silica).

2.12. LLab Timeline

The LLab is currently operational at pilot scale and optimised for bio-silica extraction from rice husk. Aspects related to the value chain, business model, and other relevant topics will undergo further exploration within the context of PRIMED.

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3. Llab3: Liguria Bio-Lab (FILSE)

Bioplastics and value-added products from fishery waste (VC1) and agro/food waste (VC2), located in Liguria, Italy.

Current status: ***VC1 based on EcoeFISHent project pilot plants starting from late 2024; VC2 to be defined.***

3.1. Biomass feedstock(s)

Liguria Bio-Lab is based on an open territorial structure (regional), and works to demonstrate and to develop circular value chains in bioplastics and value-added products from fishery waste (VC1) and agro/food waste (VC2), integrating existing knowledge, capitalizing on new research and innovation and building on public-private partnerships that place sustainable development at their core. The LLab will use the ongoing EcoeFISHent project, coordinated by FILSE (financed by H2020-LC-GD-2020-3) as a starting point to catalyse the development of circular bioeconomy value chains using fisheries waste (VC1). The LLab will also revalorize agro/food-waste (VC2).

- **VC1:** Fishing and fish-industry side-streams.
- **VC2:** Food-waste (urban) and/or agro-waste (e.g. fruit and vegetables, flowers and agro-side-streams).

The specific waste streams to be applied in VC2 has not yet been chosen. The PRIMED project and the LLab will soon be introduced to the EcoeFISHent partners and other VC2 candidates, to explore collaboration opportunities.

3.2. Conversion technology(ies)

LLab conversion technology overview:

New pilot plants are under construction, such as:

- **VC1:** (1) Biomass pre-treatment and bio-actives extraction technology; bioconversion technology (bred larvae); (2) Biopolymer foams (PLA: polylactic acid) production; (3) Cleaning and material recycling of polyamide (from fish nets).
- **VC2:** Biodegradable film technologies (not yet specifically defined).

LLab overall process description:

The LLab VC1 will be based in Liguria and lay its foundations on the activities of EcoeFISHent. The EcoeFISHent project aims to reduce the waste generated by the fish supply chain, through the construction of socio-economic territorial clusters/ecosystems composed of several actors from different sectors. Innovative biomass pre-treatment, extraction technologies and pilot plants developed by EcoeFISHent will be made available to the LLab, enabling sustainable and efficient utilization of fish processing side-streams. The expected process outputs will be bio-actives and gelatine for high value-added food supplements and skin care products, biodegradable and compostable barrier layers for packaging of food and cosmetic products, fertilizers, biodiesel, components for cosmetic applications and polymer-based automotive constituents.

The LLab will connect end user with fish waste processing plants, as well as a fishing net recycling plant (automotive and cosmetic packaging applications), to ensure a closed-loop system in which resources, products, and materials across the supply chain are continuously recycled, reused, or repurposed, in order to minimize waste and maximize resource efficiency.

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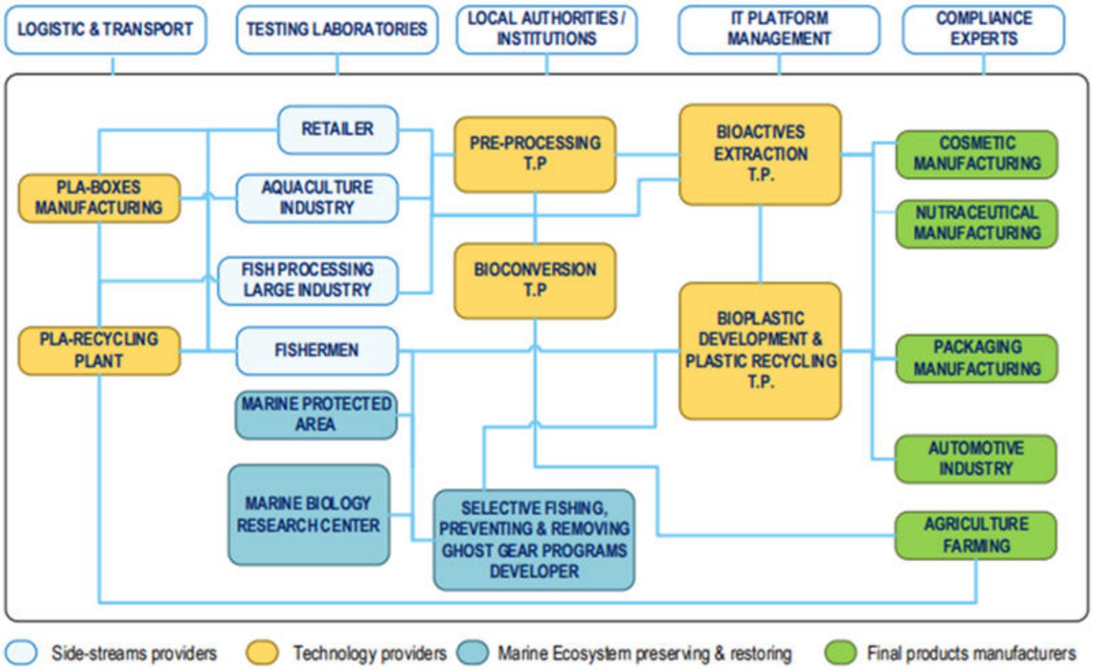

Figure 5. Overview of LLab VC1.

The LLab VC2 conversion technologies are not specifically defined at the current stage, but are soon to be selected in collaboration with partners and technology providers.

3.3. Products/outputs

The potential LLab VC1 products arising from the EcoeFISHent project are:

- Bio-actives and gelatine for high value-added food supplements and skin care products (innovative multi-process technology to obtain products for nutraceutical and cosmetic industry applications).
- Fertilisers and biodiesel: Insect oil and chitin together with soil fertiliser (bioconversion by rearing insects, black soldier fly larvae, with organic side-streams).
- Gas barrier biopolymer coating (based on gelatine extraction technology) for compostable bio-packaging of oxidation sensitive food, substituting conventionally applied fossil-based barrier polymers.
- Eco-FISH-boxes produced from EPLA (Polylactic acid or polylactide polyester made from renewable biomass),) derived by agro-side-stream solution), replacing fossil-based fish boxes.

The LLab VC2 products/outputs are not defined at the current stage, but are soon to be defined in collaboration with selected partners and technology providers.

3.4. Technology provider(s) and/or reference plant(s)

The technology providers will be from the EcoeFISHent territorial cluster (centred in Liguria and extending to North-Western Italy), composed of technological and industrial partners, production companies, raw material suppliers, service providers, companies in related fields and public institutions. The pilot plants will be realized by technological and industrial partners within the EcoeFISHent cluster. The LLab ambition is to reach a final TRL of 7-8 for the pilot plants described below.

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Pilot plants under construction are:

- **EcoeFISHent pre-processing pilot units:** Preserving the biochemical properties of bio-actives during dehydration, concentration, stabilization and condensation of fish side-stream processing, creating food supplements, cosmetics and biopolymers.
  The pilot plant will be scaled up by an EcoeFISHent partner.

  Location: Liguria and Sardinia
  Technology provider: THEMIS
  Earliest planned installation: June 2024

- **Larvae Bioconversion Pilot Unit:** Converting fish waste into insect biomass (insect oil for biodiesel, chitin and soil fertilizer) through breeding of rearing insect larvae (black soldier flies). The pilot plant will be scaled up by an EcoeFISHent partner.

  Location: Liguria
  Technology provider: Nasekomo
  Earliest planned installation: February 2025

- **EcoeFISHent RC-Fix Boxes Plant:** Producing biodegradable and compostable fish boxes from agro-side-streams (designed for soil deposition, providing nutrient-rich soil improvers for agricultural applications). The pilot plant will be scaled up by an EcoeFISHent partner.

  Location: Liguria
  Technology provider: GreenEvo
  Earliest planned installation: September 2024

- **Fish Net Recycling Pilot Plant:** Recycling fishing nets from fishing and aquaculture industry for application in automotive industry and cosmetic packaging. The pilot plant will be scaled up by an EcoeFISHent partner.

  Location: Piedmont
  Technology provider: AIMPLAS/PROPLAST
  Earliest planned installation: September 2024

3.5. Environmental/climate aspects

The LLab will contribute to spread new circular side-stream management concepts, connect blue and green economies, and reduce the risks across the fishing industry and its supply chain. Some potential LLab contributions are listed below.

- The LLab potential greenhouse gas emissions reduction (in terms of global warming potential) has been estimated to 25.7% based on Bom *et al.*[1].
- Bioplastics can substitute 65.8% of all conventional plastics (current technical substitution potential), saving 241-316 MtCO_2e per year[2].

[1] S.Bom, H MRibeiro and J Marto, Sustainability Calculator: A Tool to Assess Sustainability in Cosmetic Products, Sustainability Journal, 14 February 2020
[2] J. Brizga, K. Hubacek, K. Feng, The Unintended Side Effects of Bioplastics: Carbon, Land, and Water Footprints, 2020; LCA available: http://dx.doi.org/10.17632/gsfp9c3zyy

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- Production of BioFoam fish boxes can reduce CO_2 emissions by 40% compared with fossil-based polystyrene containers[3].
- Biodiesel can reduce CO_2 emissions by 78% compared with fossil diesel fuel[4].
- The use of pure biodiesel reduces the formation of toxic/carcinogenic compounds, and can reduce the risk of cancer by up to 94%[5].

3.6. Societal/social aspects

The LLab will contribute to job creation, spread circular values tough education and public involvement. It will also formulate policies briefs and recommendations, emphasize the use of energy-efficient tools and technologies, and contribute to the reconciliation of human industrial and economic activities with marine ecosystems.

3.7. Economic aspects

The efficient use of biomass feedstocks will contribute to industrial and economic growth, and reduce the dependency towards fossil-based resources.

3.8. Energy aspects

The LLab will improve the efficiency and sustainability of blue and green economies.

3.9. Specific advantages and limitations/challenges

Regarding existing regulation[6], there is no clear definition of *'food loss'*; an inefficient definition of *'food waste'*; poor quality of Member States reporting of *'food waste'* amounts; and no inclusion of *'upcycling'*. A better definition of *'food waste'* is necessary to accurately distinguish (for instance) differences in edible and inedible parts, possible applications which may decide if food is wasted or not, the fitness of consumption, and the reasons behind waste. The inclusion of *'upcycling'* would promote the valorization of wastes and by-products, obtaining new products for e.g. food, feed, cosmetic, medical and veterinary applications.

3.10. Value chain

Liguria Bio-Lab is based on an open territorial structure (regional), and work to interconnect research, technologies, processes and results mainly related to bioproducts. The results of the activities progressively carried out in the EcoeFISHent project (concerning the exploitation of fish supply chain waste) will be capitalized together with other projects developed by stakeholders (such as universities, research centres and public and private companies related to the valorisation of vegetable waste) within the regional ecosystem.

The LLab will involve the most important players in Liguria Region within circular economy and recycling, including industrial partners, farmers and agriculture, fish industries, citizens, startups, research/technology institutes, urban general markets, and cleaning companies.

Main stakeholders currently involved:

- Liguria Region Body
- Genova University (DISTAV, DIFAR Departments)

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[3] SYNBRA LCA tool 2.0, Prepared by Tobias Borén AkzoNobel Sustainable Development, Sweden Peer reviewed by Martin Patel, Utrecht University, October 8th, 2010

[4] U.S. Department of Energy (DOE) by the National Renewable Energy Laboratory

[5] https://www.cti2000.it/biodiesel/

[6] EU Waste policy – 2023/0234 (COD) – 2017/C 361/01 – 2018/C 133/02

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- Italian Institute of Technology (IIT)
- AMIU (waste management company of Genoa Municipality)
- ARPAL (Regional agency for environmental protection)
- Confindustria Liguria (main enterprises association in Italy)
- Società Genova Mercati (SGM)
- Genova wholesale fruit and vegetable general market

The LLab will additionally benefit from the collaboration with EcoeFISHent partners located outside the territorial cluster.

3.11. Business model

The LLab will conduct analyses to assess opportunities and threats and to understand market development in coherence with the EcoeFISHent project and in accordance with additional technologies related to VC2.

3.12. LLab timeline

The VC1 start of operation is expected by January 2025, reaching its full capacity by January 2027. The VC2 start of operation is yet to be determined in collaboration with partners.

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4. LLab4: BioEire Lab (IBF)

Chemicals from dairy by-products via fermentation and energy products from forestry residues via pyrolysis, located in N ational Bioeconomy Campus, Lisheen, Co. Tipperary, Ireland.

***Current status:** Laboratory-scale tests carried out; pilot-scale facility about to be funded.*

4.1. Biomass feedstock(s)

The BioEire Lab will work with two feedstocks: dairy by-products and forestry residues. These feedstocks were selected using the results of the national project ABC Economy.

Dairy by-products:

The LLab aims to convert dairy side streams, including whey permeate (WP) and dairy sludge, into high-value products through fermentation. WP, a by-product of cheese production, and dairy sludge, resulting from dairy processing, are targeted for conversion into organic acids, bioactive compounds, fatty acids, and bioplastics (PHA). Around 290,000 t of cheese are produced annually in Ireland (2021[7]), corresponding to 72,500 t of WP. WP is used today mostly in feed ingredients or in protein powder for humans. WP is a by-product derived during the production of whey protein concentrate (WPC) and whey protein isolate (WPI) from whey, which itself is a by-product of cheese or casein manufacturing. Whey permeate is obtained after the removal of protein and fat from whey, leaving behind a solution rich in lactose, minerals, and vitamins.

Forestry residues:

Around 11% of Ireland's land area is covered by forest. The primary products made from Irish forests are saw timber for construction and composites (like MDF, chipboard, OSB). Main tree species planted currently are the Sitka Spruce, Norway Spruce, Lodgepole Pine, Larch and Douglas Fir. Native trees (Oak, Ash, Alder, Hazel, Willow) are also being grown commercially. The estimated amount of forestry residues being generated is 3,980 million cubic meters per year, with 700 million cubic meters per year identified as not being utilized[8] and hence possibly suitable for valorisation.

4.2. Conversion technology(ies)

Dairy by-products:

Using an existing biorefinery, such as the pilot plant in Lisheen (see **Figure 1**), it is possible to create a range of value-added products. WP can be used as a feedstock to produce lactic acid via fermentation, that can in turn be used in the production of Polylactic Acid (PLA) which is a compostable bioplastic.

[7] https://www.irishexaminer.com/farming/arid-40975541.html

[8] https://doi.org/10.1016/j.rser.2018.09.032

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Figure 6. National Bioeconomy Campus in Lisheen, Co. Tipperary.

Forestry residues:

Pyrolysis is the thermal decomposition of biomass at high temperatures (300–700 °C) in an environment devoid of oxygen (except for the one found in the feedstock). The process produces several key products: a liquid known as bio-oil, a non-condensable gas termed syngas, and a solid residue referred to as biochar. The main product produced in BioEire Llab will most likely be biochar. The composition and proportions of the pyrolysis products varies depending on key process parameters such as temperature, heating rate, pressure, and reaction time.

These processes are planned to be demonstrated on a pilot scale (TRL 7) during the PRIMED project, moving from the current laboratory scale (TRL 4).

4.3. Products/outputs

Dairy side streams may be used to produce fatty acids, biochemicals, bioactive compounds and bioplastics, while forestry side streams will be pyrolyzed to produce bio-oil, biochar (most likely the main product of interest) and syngas/biomethane.

4.4. Technology provider(s) and/or reference plant(s)

Irish Bioeconomy Foundation (IBF) plans to use the pilot scale facility at the National Bioeconomy Campus at Lisheen to develop the BioEire LLab. IBF will soon operate a modern Bioprocess pilot plant covering 1,700 m^2 floor area. The facility will contain state-of-the-art and versatile pilot-scale processing equipment. The plant now has a wide range of capabilities for developing bio-based products. IBF is arranging a modular structure of self-contained processing areas. IBF will work with Premier Green Energy which is a Waste-to-Energy, low carbon technology solutions provider.

4.5. Environmental/climate aspects

BioEire Lab will quantify the environmental, economic and social impacts of the processes and products using Life Cycle Analysis (LCA) during the PRIMED project. The LLab will assist Ireland to meet its Climate Change obligations by demonstrating new technologies that can deliver on the Irish Government's Climate Action Plan, EU Green Deal and UN Sustainable Development Goals (SDGs). IBF partners with BiOrbic that have a specific LCA division.

BioEire Lab will increase resource efficiency in Agri-food and related sectors through valorisation of side streams/residues. Through resource efficiency we can reduce imports and improve security of supply of key Irish resources which can decrease exposure to macroeconomic shifts. Data from the Central Statistics Office (CSO, 2015) shows substantial categories of imports that could (partially) be produced indigenously from biobased resources e.g., annual imports of chemicals €4 billion, fertilisers €450 million, plastics €1.4 billion.

4.6. Societal/social aspects

The National Bioeconomy Campus is located at the former Lisheen Mine in Lisheen, Co. Tipperary. The Lisheen Mine produced an average of 300,000 Mt/y of zinc in zinc concentrates and 35,000 Mt/y of lead in lead concentrates employing 350 people before ceasing operations in 2015.

A taskforce was established to replace this industry and Lisheen was subsequently identified as a European Model Demonstrator location which determined that this location was one of six European top locations for bioeconomy investments. The lands were cleared of mining infrastructure in 2016 and 2017 with a vision to create a national bioeconomy campus.

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Irish bioeconomy stakeholders have applied for EU Just Transition Funding to transform the mining site into a bioeconomy campus including a pilot scale facility. The BioEire LLab will use these facilities within the PRIMED project to increase the TRL of dairy and forestry value chains from 4 to 7. The LLab works towards the principle of just transition that states that a healthy economy and a clean environment can and should co-exist. The success of BioEire could potentially lead to investment in a large-scale biorefinery. A single bio-refinery can generate 50-300 direct jobs. However, the indirect employment generated by a biorefinery can be 10-100 times the number of direct jobs[9]. Such as development will offer new employment and wealth creation opportunities in the region.

Other societal benefits include:

- Success will open up international collaboration opportunities.
- This will create rural jobs at Lisheen and grow the campus as a national hub for biobased innovations.
- IBF will be able to showcase the activity and success of the LLab to attract further business, allow further investment into the facility and help build its reputation as an international and national Centre for scale up and innovation.
- The project will enable Lisheen to retain and attract people to rural areas and contribute to rural regeneration.
- Gender and Equality: by committing to an inclusive work environment, this LLab aims to offer equal opportunities for all.
- Training and Education activities will ensure that companies, researchers and the public have the opportunity to upskill across the full value chain.
- Increased public knowledge and understanding: the LLab will engage with educational institutions to incorporate its findings into curricula.

4.7. Economic aspects

Irish Bioeconomy Foundation with Tipperary County Council and 5 Research Performing Organisations (RPOs) applied for funding through the Bioeconomy Demonstration Initiative – EU Just Transition Fund. The Bioeconomy Demonstration Initiative Scheme is co-funded by the Government of Ireland and the EU through the EU Just Transition Fund. The Fund aims to support bioeconomy innovation at the territorial level and will seek the active involvement of local actors (e.g., NGOs, local and regional authorities, community, and local action groups) alongside the bio-based industries.

BioEire LLab will showcase the scale up of biobased innovations at the Lisheen pilot scale facility. The success of the project will form a blueprint for co-operation with RPOs and industry to accelerate the development of other biobased innovations. We will also combine this with our recent successes in European projects to tap into our expanding network and create business opportunities where we can offer to meet the needs of a wider European biobased community seeking to scale up technologies. IBF connections with public and private finance will make up the third arm of our business plan where we engage entrepreneurs seeking to commercialise innovations that require scale up and investment. The Lisheen pilot plant will be able to provide the platform (infrastructure and scientific/technical expertise) for such entrepreneurs to accelerate their business idea towards the market which will be coupled with the extensive network of Irish Bioeconomy Foundation's 'Access To Finance' on a national and global level.

Positive economic aspects include:

- The new products are of substantially higher value than current options providing new outlets and enhance the development of biorefineries in rural locations.

[9] https://biomonitor.eu/wp-content/uploads/2022/02/BioMonitor_D8.3_Biorefinery-case-study.pdf

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- Patents on the processes are envisaged and will be fully explored.
- Licenses to industry of the production technologies for the organic acids, bioactive compounds, fatty acids and bioplastics are expected knowledge outputs.
- Substantial know-how on the operation and integration of operational units to achieve scale up of biobased technologies will create a new level of expertise in Ireland. This knowledge will enable Lisheen to attract international industries and Research Performing Organisations (RPO)s and create a platform for foreign direct investment creating jobs at the National Bioeconomy Campus Lisheen.
- Prototype products that can be market-tested.

4.8. Energy aspects

Energy aspects (consumption, integration) will be investigated during the PRIMED project.

4.9. Specific advantages and limitations/challenges

BioEire LLab will be located at the National Bioeconomy Campus in Lisheen. Tipperary County Council (local authority) have identified the Decarbonisation Zone to be located at Lisheen as part of their Climate Action Plan[10]. Each local authority in Ireland has developed a Climate Action Plan which includes a Decarbonisation Zone 'to act as a test bed for a range of climate mitigation, adaptation and biodiversity measures in a specifically defined area through the identification of projects and outcomes that will assist in the delivery of the National Climate Objective'[11]. The purpose of the designation is to help demonstrate, through stakeholder investment and support, decarbonising and positive climate action at a local level.

Demonstration of the biobased technologies through the BioEire LLab will promote rural innovation and re-industrialisation of the region. By facilitating the scale up and valorisation of new processes and technologies relevant to the bioeconomy we can showcase new business opportunities. It will enable diversification of business activities in the rural economy which will attract and retain workers and businesses in the region which in turn will drive innovation and investment. BioEire Llab based at Lisheen, acts as a "centre of gravity" for industry, entrepreneurs, academics, and ancillary service providers to interact, innovate and create new technologies, processes, products, companies and jobs.

BioEire LLab will be a collaboration between RPOs, SMEs and large industry for process development and scale-up of biobased products and processes, enabling conversion of renewable feedstocks into biobased chemicals, biobased materials, food ingredients, biofuels and other bioproducts.

The Irish Government is a strong supporter of the bioeconomy with several policy documents and funding mechanisms to promote the bioeconomy. The National Policy Statement on Bioeconomy (2018, 2022) and the Bioeconomy Implementation Group Progress Report (2019) are two policy documents that demonstrate a clear commitment from the Government to support the development of the Irish Bioeconomy within the context of "rural renaissance" under the Rural Development Action Plan. Irelands Bioeconomy Action Plan 2023-2025 was released in October 2023 to deliver the vision of the 2018 National Policy Statement on the Bioeconomy[12]. The Action Plan contains several pillars including 'Research, Development and Innovation' which highlights the need to support piloting and demonstration to advance research and scale-up knowledge, biobased innovation, and

[10] https://www.tipperarycoco.ie/climateaction/tipperary-county-council-climate-action-plan
[11] https://www.gov.ie/en/publication/f5d51-guidelines-for-local-authority-climate-action-plans/
[12] https://www.gov.ie/en/press-release/595e3-ministers-mcconalogue-and-ryan-publish-first-national-bioeconomy-action-plan/

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bioeconomy solutions. There is also funding available for bioeconomy demonstration projects including EU Just Transition Fund[13] and Shared Island Bioeconomy Demonstration Initiative[14].

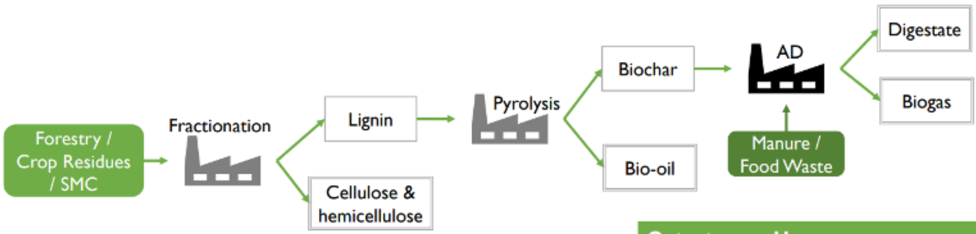
4.10. Value chain

BioEire will be located at the National Bioeconomy Campus at Lisheen. Irish Bioeconomy Foundation (IBF) will be responsible for coordination of BioEire. Other stakeholders may involve Tipperary County Council and RPO's. IBF will leverage its broad membership which includes key stakeholders in the dairy, forestry and technology sectors.

Two value chains (VCs) are developed in the LLab: (1) one pyrolysis VC focusing on bioenergy from forestry residues and (2) one fermentation VC focusing on biochemicals from dairy by-products.

Ireland has an extensive dairy industry. The country is home to large dairy companies and cooperatives that can provide large amounts of WP (Whey Permeate), including Tirlan, Dairygold, Kerry Group, Carbery Group and Dale Farms. There are also research centres including the Dairy Processing Technology Centre (DPTC) and BiOrbic bioeconomy research centre.

BioEire expects to work with semi-state and private companies in the forestry sector including Coillte and Green Belt Forestry. Coillte, a state-owned company, is the largest forestry business in Ireland, managing approximately 50% of the country's forests. Green Belt manages close to 20% of the land under forestry. These are stakeholders that could provide feedstock for the forestry value chain. BioEire lab will likely work with researchers from NXTGENWOOD which is an Irish research program and network for delivery of next generation wood products and increased economic return for Irish wood products.



Output	Use
Cellulose	Textiles, packaging, films
Hemicellulose	Barrier film for wounds, adhesives, seed coatings
Bio-oil	Fuel
Biogas	Heat, power
Digestate	Fertiliser

Figure 7. Forestry residues: a possible VC.

[13] https://www.gov.ie/en/publication/deb47-2023-bioeconomy-demonstration-initiative-eu-just-transition-fund/
[14] https://www.gov.ie/en/publication/shared-island-bioeconomy-demonstration-initiative/

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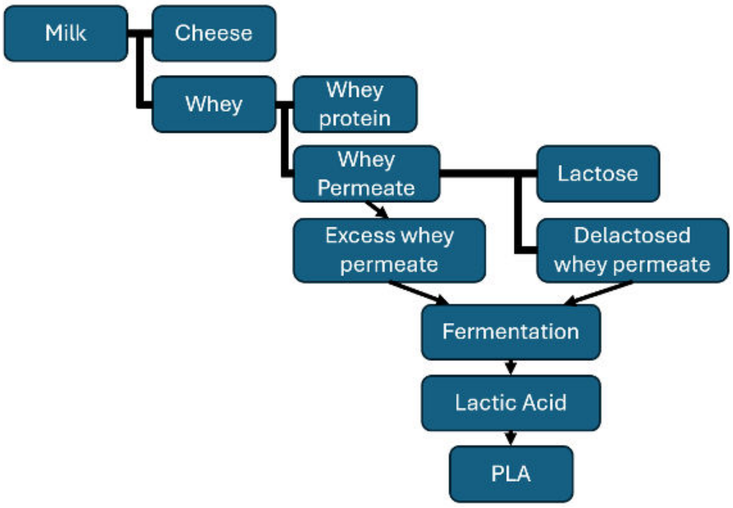

Figure 8. Dairy by-products possible VC. PLA: polylactic acid (a thermoplastic monomer derived from renewable, organic sources).

4.11. Business model

The LLab stakeholders:

- Primary producers: dairy and forestry sector
- Manufacturers/Processors: pyrolysis + energy production (CHP, fuel, biochar); fermentation + biochemicals (various applications with focus on plastics)
- Policymakers, authorities and public bodies: Department of Agriculture, Food and Marine (DAFM), Department of the Environment, Climate and Communications (DECC), Tipperary County Council.
- Industry experts/Research groups (RPOs)
- End-users: General public/consumers, heat and power users, various industries, e.g. film, packaging, textile, adhesives, fertiliser, etc.

Revenue streams for the LLab are twofold: pilot plant rental to industrial clients as well as technical advice and support (including LCA, Development of New Product Concept, Market Analysis, Industry Insights).

4.12. LLab Timeline

Laboratory experiments (TRL 4) of the processes presented here have been carried out. The next step for the LLab is pilot plant tests at the Lisheen site that will be operated by IBF to increase the TRL to 7.

IBF expect to commence operations at their pilot scale facility at Lisheen, Co. Tipperary in Q3 2024 and during 2025 it is expected that the facility will be in a position to accommodate the LLab pilot plant tests. IBF will work with its member and partner Premier Green Energy who has pilot scale pyrolysis testing equipment at their nearby facilities in Thurles, Co. Tipperary. IBF will engage with feedstock providers and technology partners who will contribute to the pilot plant tests.

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5. LLab5: CellFactory Lab (VTT)

Novel plant cell cultures using agricultural/food side-streams as feedstock, located in Koivurannantie, Jyväskylä, Finland.

<u>Current status:</u> Small-scale testing carried out using potato processing residues.

5.1. Biomass feedstock(s)

The ambition of the LLab is to use agricultural/food side-streams as growth medium component for plant cell cultures. These cells, carefully selected and developed by VTT, could be used for a variety of novel applications (cosmetic, food, etc.). However, plant cells do not possess enzymes that would allow for cell walls degradation so sugars and other nutrients (N, P, K, etc.) must be readily accessible, hence the selection of a liquid side-stream, namely concentrated potato cell fluid from potato starch production. This side-stream is provided by Finnamyl Ltd (Finnish company, Kokemäki production site), and is rich in sugars (ca. 95 g/L). As it is a liquid fraction (with a dry matter content of 32-35%), it can spoil easily and must be sterilised (by autoclave) and kept cold (eventually frozen) prior to use. About 5000 to 8000 t/y are available from the selected production site and are produced between September and November. This side-stream is currently used/commercialized as a fertilizer.

A second residue from the same production site is also being considered, a solid side-stream collected before potato protein extraction. Its dry matter content before drying and further processing is 16-17% with about 11% protein, 7 % ash and 20% fibre in the dry matter.

5.2. Conversion technology(ies)

Figure 1 presents the steps involved in the culture of plant cells to be carried out in the LLab.

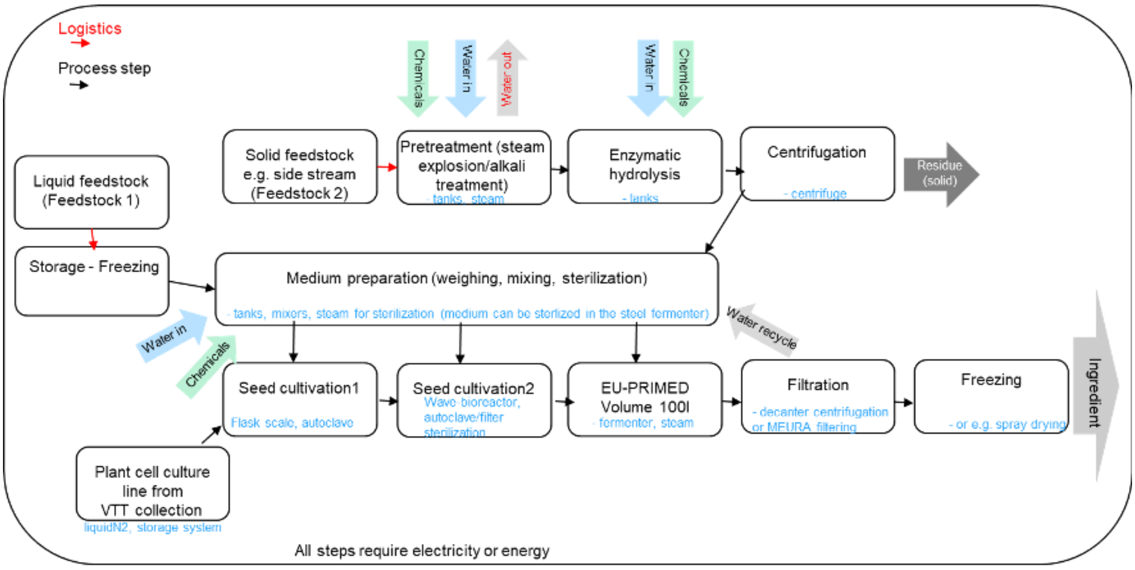

Figure 9. VTT LLab bioreactor cultivation in the PRIMED project.

The main steps (at the current laboratory scale) can be summarized as such:

1. Growth medium preparation (mainly based on agricultural side-streams – "feedstock 1" and/or "feedstock 2") + plant cell line(s) selection from VTT's culture collection
2. Seed cultivation (i.e. cultivation of first plant cell amounts), 2 steps (10+10 days) in shake flasks and wave bioreactors in M&S (Murashige and Skoog) basal medium

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3. Final cultivation step in 100L vessels (7-10 days) in agricultural side stream -based medium. Planned in PRIMED, starting Autumn 2024
4. Harvesting (decanter centrifugation or Meura filtering) and freezing or spray drying before shipping to end-users

The TRL of the LLab cultivation process is estimated to be 3-4. It should be noted that industrial scale operations would need to be minimum 10-100 times larger.

5.3. Products/outputs

The 100L cultivation experiment will be carried out and investigated during the PRIMED project. It is expected to yield 30-40 kg plant cells, fresh weight (some moisture left). This means that the biomass will be multiplied by a factor 20 in about 30 days. Typical data with other cell lines can be found in the literature[15], regarding both biomass yields and energy and water consumption.

5.4. Technology provider(s) and/or reference plant(s)

Standard equipment that can be provided by fermenter and other downstream equipment suppliers.

5.5. Environmental/climate aspects

Specific data (on energy and water consumption) will be collected during the PRIMED experiments. However, a LCA for other plant cell cultures has been carried out[1] and provides general information regarding the environmental and global warming potentials as well as energy consumption.

5.6. Societal/social aspects

It is important to keep in mind that the use of plant cell cultures as food or cosmetic ingredients is a brand-new field. Plant cell cultures was first taken to market by Mibell with their apple cell line technology[16]. The apple cell line got approval for use as a food supplement (but not as a food ingredient) for adults in 2023[17], while VTT has a patented use of cloudberry cell lines in cosmetics[18]. Furthermore, the first applications as food ingredients (with a strong focus on sustainability), e.g. cell-coffee, are taking shape[19]. Thus, it is important to involve consumers in the discussions related to new foods and cosmetics.

Plant cell cultures could replace and add into the portfolio of agricultural commodities but also supplement traditional food production.

5.7. Economic aspects

The target markets are novel ingredients for food and cosmetics. Plant cell cultures are a brand-new field with multiple promising economic opportunities regarding high-value products for niche markets.

Regarding the upscaling of production, equipment for up to 1000L vessels have a current cost estimate of roughly 1M€, including fermenters and downstream treatment.

5.8. Energy aspects

[15] https://www.sciencedirect.com/science/article/pii/S0048969721070662
[16] https://mibellebiochemistry.com/phytocelltectm-malus-domestica-skin
[17] https://www.efsa.europa.eu/en/efsajournal/pub/8065
[18] https://us02web.zoom.us/j/89635455222?pwd=ZDlIUWtPRDk1SEhCTnk0M1hiTkF2dz09
[19] https://doi.org/10.1007/s00253-018-9279-8 and https://doi.org/10.1021/acs.jafc.3c04503

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Data regarding energy consumption by the VTT LLab processes (see **Figure 1**) will be collected during 100L cultivation experiments in the PRIMED project.

5.9. Specific advantages and limitations/challenges

VTT has a strong track record in developing plant cell cultures for cosmetic and food ingredient use. VTT owns a broad collection of plant cell lines e.g. from Nordic berries. VTT has already shown that the flavour of plant cell cultures can be tailored[20]. VTT has also evaluated the safety and sustainability of plant cell cultures as food[21].

The use of plant cell cultures as food or cosmetics ingredients is a novel field opening up a vast array of opportunities, as previously mentioned. However, it also poses challenges especially regarding approval as the Novel Food[22] and cosmetic products[23] regulations apply to products containing novel plant cell culture–based ingredients. Approval would typically take a minimum of four years in Europe.

5.10. Value chain

The current value chain is straightforward: the agri-food side streams from potato and vegetable processing factories (e.g. at the Finnamyl Kokemäki site) are transported by truck to the LLab before storing/processing. The ingredients produced are frozen or spray dried before transport to end-users (food, cosmetics actors).

An industrial scale value chain could presumably be realised by a new bio-tech start-up, possibly with the involvement of existing agri-food actors.

5.11. Business model

Biomass providers: Agricultural/food actors.

Industrial customers: Food, cosmetics.

Key processes: Plant cell selection, cultivation and preparation/conditioning.

Revenue streams (LLab): Sale of plant cell cultures to replace and add into the portfolio of agricultural products but also supplement the present food production.

Further development of the business model will take place during the PRIMED project.

5.12. LLab Timeline

The LLab has been part of VTT Technical Research Centre Ltd infrastructure and facilities since the 1990s. Regarding plant cell cultivation as food/cosmetics ingredients, small-scale testing has been carried out so far (TRL 3-4), with lab-scale experiments ("100 L PRIMED") to be carried out from the Autumn of 2024 – Spring 2025.

Finally, a possible next step could be a spin-out company in the next 5 to 10 years.

[20] https://doi.org/10.1016/j.foodres.2022.111440
[21] https://doi.org/10.1007/s00299-020-02592-2
[22] https://food.ec.europa.eu/safety/novel-food_en
[23] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:02009R1223-20190813

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