"The world has enough for a man's need,
but not enough for a man's greed"
- Mahatma Gandhi

WHITEPAPER

UPWASTE: SUSTAINABLE UP-CYCLING OF AGRICULTURAL RESIDUES: MODULAR CASCADING WASTE CONVERSION SYSTEM

UpWaste

FACCE SURPLUS
SUSTAINABLE AND RESILIENT AGRICULTURE FOR FOOD AND NON-FOOD SYSTEMS

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Whitepaper

UPWASTE: SUSTAINABLE UP-CYCLING OF AGRICULTURAL RESIDUES: MODULAR CASCADING WASTE CONVERSION SYSTEM

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INTRODUCTION

The goal of the UpWaste project is to create a modular cascading biorefinery system for the upcycling of agricultural residues, to obtain higher-value products of defined composition. An industrial blueprint for such a system will be created based on metabolic modelling and experiments at lab and pilot industrial scale. These will be carried out with the heterotrophic microalga *Galdiera sulphuraria* and insect larvae of the black soldier fly (*Hermetia illucens*), since both organisms have been found to have great potential in the safe utilisation of challenging waste streams as well as promising characteristics for the extraction of valuable compounds. Based on the system design, economic and life cycle assessment (LCA) will be carried out to determine the economic feasibility as well as sustainability of such a system.

Besides development of the system, focus also lies on identification and mitigation of biological contaminations, thus ensuring safety of the produced products even for sensitive food and feed applications.

A range of different waste streams, like for instance manure, straw, hull and other plant parts as well as food waste will be transformable into high-quality biomass in the UpWaste system. High quality lipids, hydrocarbons and proteins can subsequently be used for the production of fine chemicals such as polymers or dyes, energy sources as well as feed or high value food nutritives.

Ultimately, the developed system will create market opportunities for sustainable and economic production and processing of food and non-food materials whilst at the same time reducing pollution and resource use by closing loops in the circular bioeconomy.

PROJECT ORGANISATION

The UpWaste project is set for a timeframe of three years with contributions by six European partners. Whilst the German Institute of Food Technologies (DIL) has oversight of the project, the Institute for Food and Environmental Research (ILU, Germany), University of Warmia and Mazury (Poland), Latvia University of Life Sciences and Technologies (Latvia), Thomas More Kempen (Belgium) and KU Leuven (Belgium) are involved as partners.

It is funded within the FACCE SURPLUS (sustainable and resilient agriculture for food and non-food systems) collaboration, which is committed to improve collaboration across the European Research Area in the range of diverse, but integrated, food and non-food biomass production and transformation systems, including biorefining. FACCE SURPLUS is an ERA-NET cofund (part of the EU Horizon 2020 programme) between the European Commission and a partnership of 15 countries in the frame of the joint Programming Initiative on

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agriculture, food security and climate change (FACCE-JPI). For Thomas More, VLAIO-LA is the national funding agency within the ERA-NET cofund.

RELEVANCE

In an era of climate and other ecological changes, availability and sustainable use of usable biomass is becoming an increasing concern. Thus, the cascading use of underutilised residues, which can increase biomass use efficiency by 40-90% and reduce its environmental impact by 5-70%, is of increasing importance. By up-cycling residues into higher value products, the UpWaste system is going a step further than traditional recycling methods for biomass, which may involve anaerobic digestion to produce biogas and nutrient recycling by spreading residues on the fields. In this way, it makes biomass utilisation not just more economically attractive, but also presents new opportunities for feedstock production and couples diverse sectors such as food, fine chemicals production, pharma, materials and energy.

PROJECT GOALS AND TASKS

The project-associated tasks are divided into six work packages, with the tasks distributed between the partners depending on available expertise and equipment. The work packages are:

1. Modelling and optimisation of productivity
2. Substrate characterisation and cultivation of *Galdiera sulphuraria*
3. Pretreatment of residues and insect cultivation
4. Microbiological safety assessment
5. Socio-economic and environmental analysis of the modular system
6. Management and communication

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INTERMEDIATE RESULTS

Metabolic modelling is ongoing to find out the optimal substrate for and possible uses of the algae and insects. This approach relies on computer driven mathematical analysis of genetics and feeding behaviour to rapidly gain insights into how rearing and cultivation of the insects and algae can be carried out, and what characteristics and utility the end-product will have. To obtain useful data for this model and hints as to practicable design of the process, a range of experiments are currently being carried out by several project partners.

Various substrates have been tested for hydrolysis and subsequent cultivation of the red alga *G.sulphuraria*; straw, potato pulp and biogas digestate were hydrolyzed and characterized, and the alga has been cultivated on digestate and also food waste hydrolysate, yielding knowledge about optimal conditions for alga growth on these substrates.

A range of agricultural and food residues have already been classified as feeds for the black soldier fly. Among them are different byproducts of plant production and processing, such as leaves, stalks and pulp, as well as manure and food wastes from different sources. Knowledge about their nutrient composition will aid in the choice of the best pretreatment methods to ensure efficient utilization by the larvae. Furthermore, microbiological analysis has been the basis of a protocol for microbiological screening and choice of pathogens for testing contamination reduction in the pretreatments in conjunction with optimal growth conditions for black soldier fly larvae.

Results:

ILU

Non-sterile heterotrophic cultivation of *Galdieria sulphuraria* in presence of digestate as well as straw after hydrolysis was investigated. *G. sulphuraria* can be grown in pure digestate at rates of 0.9 day-1 with glucose. However, a proteolytic treatment of digestate resulted in increased growth rates (1.1 day-1) and doubled cell concentrations. Furthermore, *G. sulphuraria* can utilize glucose obtained after straw hydrolysis. Biomass yields in glucose limited cultures were around 0.9 g per g glucose, while only 0.2 g biomass was formed per g glucose in glucose sufficient cultures, probably indicating that amino acids are simultaneously used as nitrogen and carbon sources. The biomass composition (w/w) of *G. sulphuraria* grown in pure digestate supplemented with sufficient glucose was 22%

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carbohydrates, 40% proteins and 8% lipids. The potential to utilize agricultural waste streams to form biomass rich in proteins may pave the way to novel utilization strategies to be implemented in rural areas.

Thomas More

More than 10 side streams were collected and characterized both chemically and physically. Larvae of the black soldier fly were reared on these streams, where survival, growth, feed conversion and waste reduction were determined. Survival was high on most streams, except for tomato leaves, feather meal, grain middlings and household waste. These streams likely contained substances that were toxic to the larvae or had a texture in which the larvae could not survive. By linking the data from the feeding trial with those from the nutritional and physical analyses, it is possible to determine how these affect rearing of black soldier fly.

KU Leuven

At KU Leuven, 10 sides streams (chicken litter, overproduced vegetables from an auction, corn meal, grain mix, apple pulp fruit puree, food waste from industrial and household sources and tomato and strawberry leaves), which were also studied by Thomas More, were tested for microbial contamination to assess the safety of using these substrates in the larvae rearing system. Salmonella was only found in one sample of grain mix and one of chicken litter, while coagulase positive staphylococci were much more relevant. In general, microbial load appeared to be very diverse. Also, differences in microbial contamination between 2 sampling periods were studied for most of the side streams to determine variations within the same stream. As a next step, the effectiveness of a heat treatment with different durations and at different temperatures will be assessed on supermarket fruit and vegetable waste.

UWM

The University of Warmia and Mazury is responsible for socio-economic and environmental analysis of the modular technology. They have analyzed the technical aspects of rearing larvae as well as cultivating algae, along with legal, social and market issues. On this basis, they have put forth which technologies may be used in the module as well as identified current legal obstructions, especially concerning the use of waste in insect feed, in Europe. From a purely scientific perspective however, no obstacles for the implementation of the system could be identified. From the market perspective, a large and increasing demand for protein on the world market has been highlighted.

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DIL

As project coordinator, the German institute of food technology DIL e.V. is responsible for communication activities, such as this whitepaper. In addition, one joint scientific article with other project partners has been published and three additional ones proposed. Other accomplishments include the development of first schematics and inventory models of the proposed modular processes, which will serve as a basis for sustainability and environmental life cycle analyses.

LUA

Latvia University of Life Sciences and Technologies is responsible for development of *G. sulphuraria* and *H. illucens* metabolic models, analysis of different carbon sources and clarification of best carbon cultivation design sets for high value product bioconversion. Both draft metabolic models have been created and first validation steps have been performed. Metabolic models are able to grow on carbon sources, and both can simulate necessary cell and energetic requirements to generate biomass content from metabolites.

In next steps the high quality, multi-compartment genome scale metabolic model (GSM) of *G. sulphuraria* will be used to analyze and predict different residues carbon mix cultivations data impact on high value product bioconversion and algae genotype – phenotype relationship. While the medium scale metabolic model of *H. illucens* will be used first to perform resource allocation analysis. Next steps will be based on project partner experimental data.

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OUTLOOK

Based on all these results and existing knowledge about algae and insect production, an industrial blueprint for a modular system for producing these organisms is already under development. This blueprint will serve as a basis for economic and sustainability analysis throughout the life cycle of the process. Thus, feasibility of the approach can be ensured and strengths and weaknesses in relation to society, economy and environment will be recognizable. This will enable the prevention of negative side effects and maximization of benefits to stakeholders as well as society at large.

Planned activities as the outcome of annual project meeting:

The recent annual project meeting after the first year of the project has illustrated further collaboration potentials among the project partners and resulted in the planning of additional trials to gather data on the performance of, i.e., *H.illucens* at utilizing different compounds or for the pretreatment of substrates for *G.sulfuraria* rearing. In addition, it is planned to apply multi-criteria analysis to identify the most preferrable substrates for *H.illucens* considering the availability, price and conversion potential of the waste substrate to maximize the efficiency of the modular system. The coming two years of the project will see new insights derived from the exchange of results by different partners concerning the various technical, economic, social and environmental aspects of the cascading biorefinery.

The involvement of stakeholders such as farmers, food producers and consumers across local and international scales is an important aspect of the UpWaste project. Workshops and campaigns will be carried out starting in the second year of the project to make the public aware of the benefits of reusing agricultural side streams of low value and turning them into useful products and how this can be accomplished using the UpWaste system. Involvement of all stakeholders will foster acceptance and implementation of the concept in the future.

Cooperation and involvement by all possible stakeholders from industry and academia is paramount to make the project a success and unlock the full benefits of residue upcycling for society.

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REFERENCES

Pleissner, D., & Rumpold, B. A. (2018). Utilization of organic residues using heterotrophic microalgae and insects. In *Waste Management* (Vol. 72, pp. 227–239). Elsevier Ltd. https://doi.org/10.1016/j.wasman.2017.11.020

Smetana, S., Sandmann, M., Rohn, S., Pleissner, D., & Heinz, V. (2017). Autotrophic and heterotrophic microalgae and cyanobacteria cultivation for food and feed: life cycle assessment. *Bioresource Technology*, *245*, 162–170. https://doi.org/10.1016/j.biortech.2017.08.113

Smetana, S., Schmitt, E., & Mathys, A. (2019). Sustainable use of Hermetia illucens insect biomass for feed and food: Attributional and consequential life cycle assessment. *Resources, Conservation and Recycling*, *144*, 285–296. https://doi.org/10.1016/j.resconrec.2019.01.042

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