Aston University
BIRMINGHAM UK

Biofuels and Biotechnology

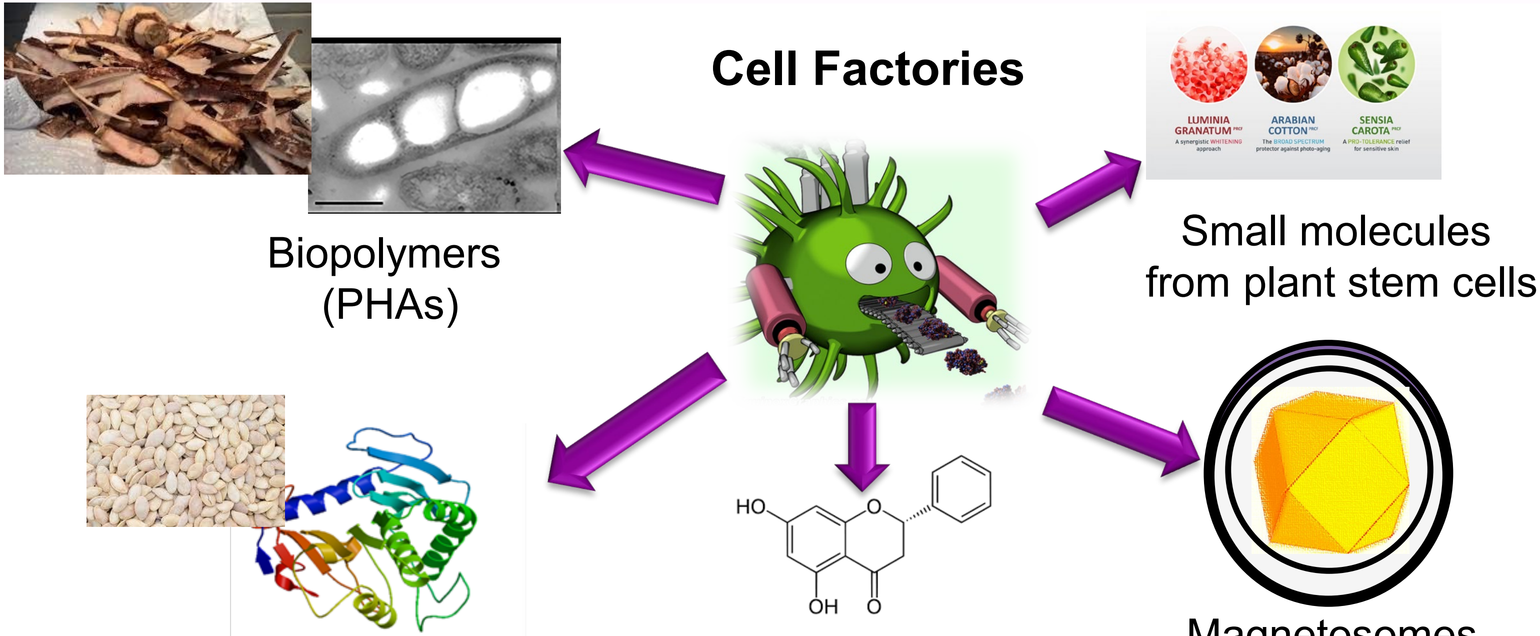
New approaches to biodiesel production

Alfred Fernandez-Castane
Senior Lecturer in Chemical and Biochemical Engineering

ERA Net-Zero Heroes webinar series – 15 February 2023

ERA
ENERGY
RESEARCH
ACCELERATOR

Biological Engineering for bio-based products



Cell Factories

Biopolymers
(PHAs)

Small molecules
from plant stem cells

Lipases
(Recombinant protein)

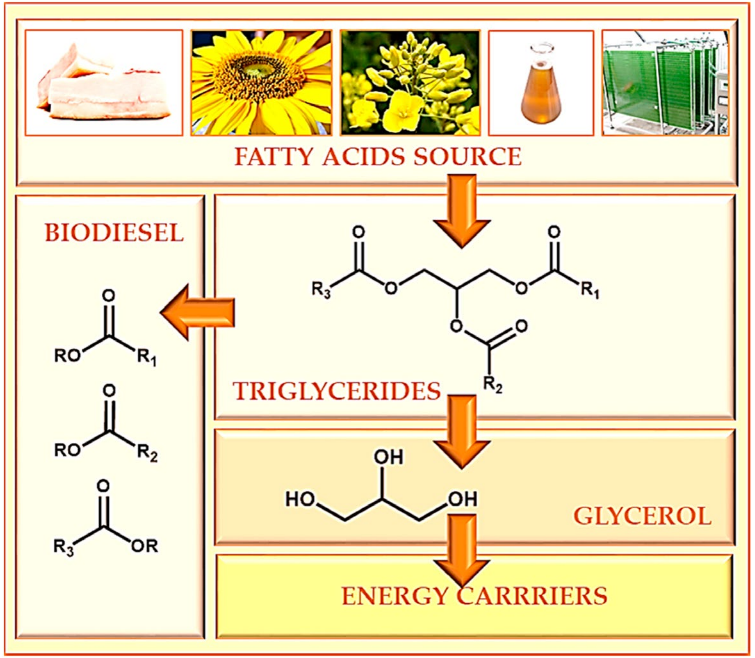
Pinocembrin
(chemical)

Magnetosomes
(bacterial organelle)

Bioprocess development & integration of technologies in biorefineries

What is biodiesel?

Biodiesel is a renewable and clean-burning fuel that is made from waste vegetable oils, animal fats, or recycled restaurant grease for use in diesel vehicles.



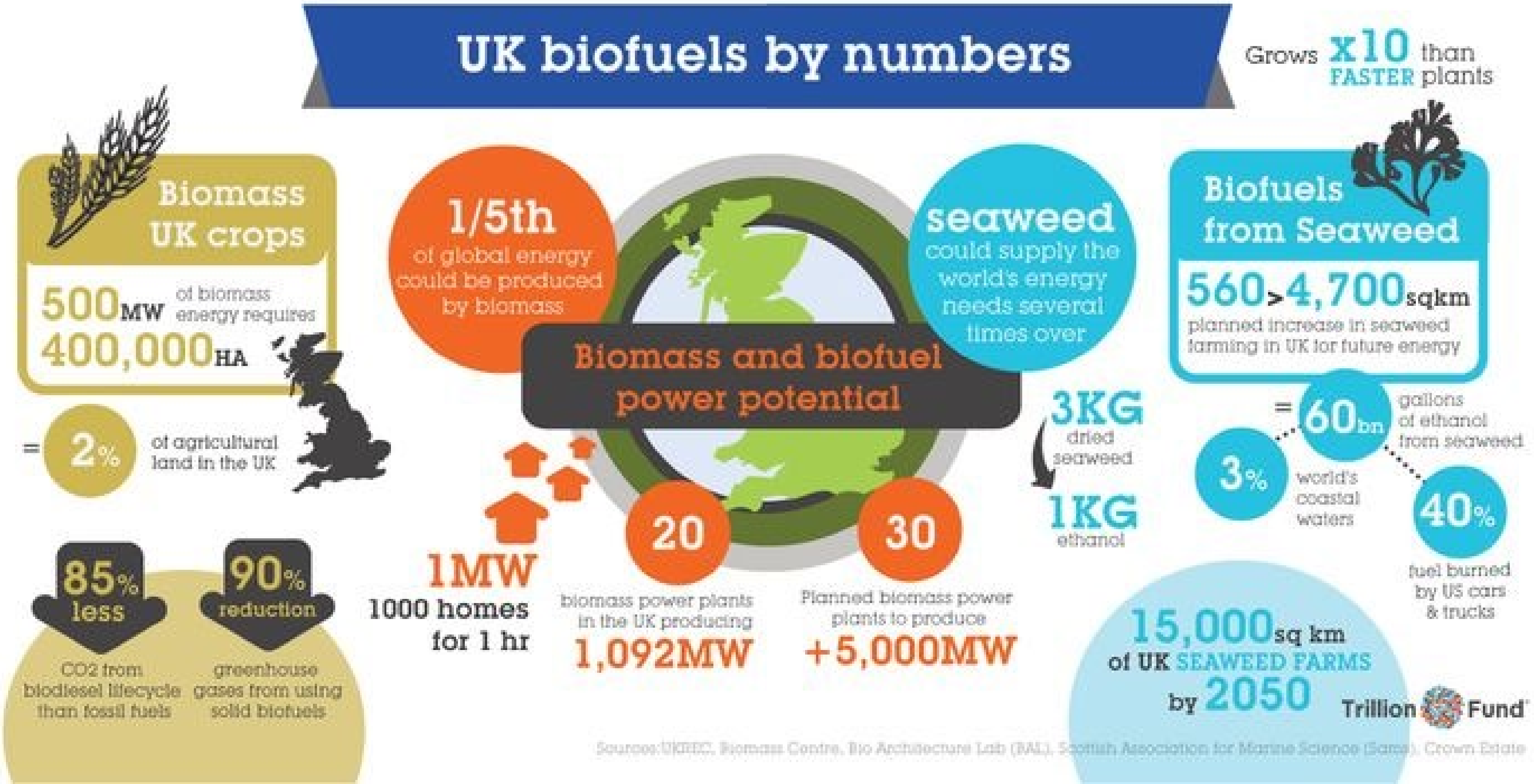
Energies 2017, 10(11), 1817

Diesel vs Biodiesel

Diesel from Fossil Fuels	Biodiesel
Obtained by cracking of petroleum	Obtained from biomass
Consist mainly of long chain unbranched alkanes (C14-C24)	Similar chemical structure (except for the presence of the ester function) of long chain C12-C22
Boiling range 180 – 240 °C	Boiling range 250 – 450 °C
Octane number (ON) of 40-50	ON between 40-80
Heat of combustion of 45,000 kJ/kg	Heat of combustion of 40,000 kJ/kg

Due to the COVID-19 pandemic and Russia-Ukraine War Influence, the global market for Biodiesel Fuel is estimated to grow for the 2023-2028 perdiod

Biomass and biofuel power potential: Some figures



UK biofuels by numbers

Biomass UK crops

500MW of biomass energy requires 400,000HA

= 2% of agricultural land in the UK

85% less CO2 from biodiesel lifecycle than fossil fuels

90% reduction greenhouse gases from using solid biofuels

1/5th of global energy could be produced by biomass

Biomass and biofuel power potential

1MW 1000 homes for 1 hr

20 biomass power plants in the UK producing 1,092MW

30 Planned biomass power plants to produce +5,000MW

seaweed could supply the world's energy needs several times over

3KG dried seaweed

1KG ethanol

Grows x10 than FASTER plants

Biofuels from Seaweed

560>4,700sqkm planned increase in seaweed farming in UK for future energy

3% world's coastal waters = 60bn gallons of ethanol from seaweed

40% fuel burned by US cars & trucks

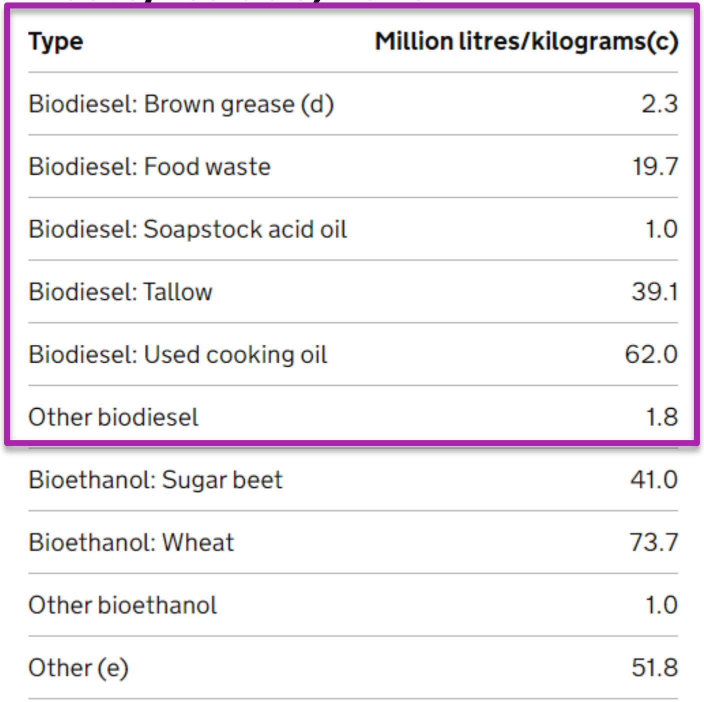
15,000sq km of UK SEAWEED FARMS by 2050

Trillion Fund

Sources: UKERC, Biomass Centre, Bio Architecture Lab (BAL), Scottish Association for Marine Science (Sams), Crown Estate

Some figures

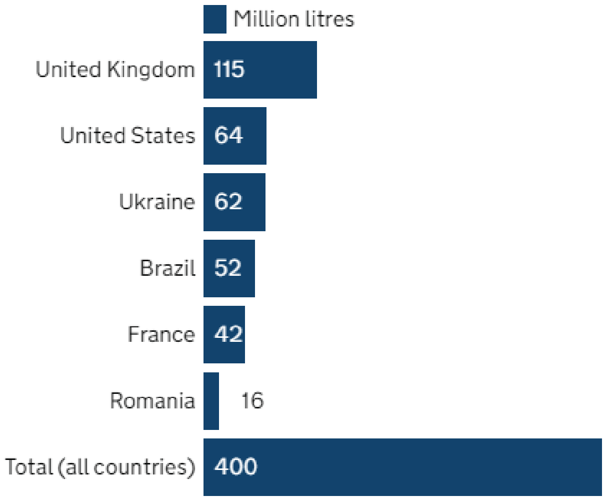
Volume of UK sourced biofuels supplied to the UK road transport market by crop type and waste/residue, 2020



Type	Million litres/kilograms(c)
Biodiesel: Brown grease (d)	2.3
Biodiesel: Food waste	19.7
Biodiesel: Soapstock acid oil	1.0
Biodiesel: Tallow	39.1
Biodiesel: Used cooking oil	62.0
Other biodiesel	1.8
Bioethanol: Sugar beet	41.0
Bioethanol: Wheat	73.7
Other bioethanol	1.0
Other (e)	51.8

43 %

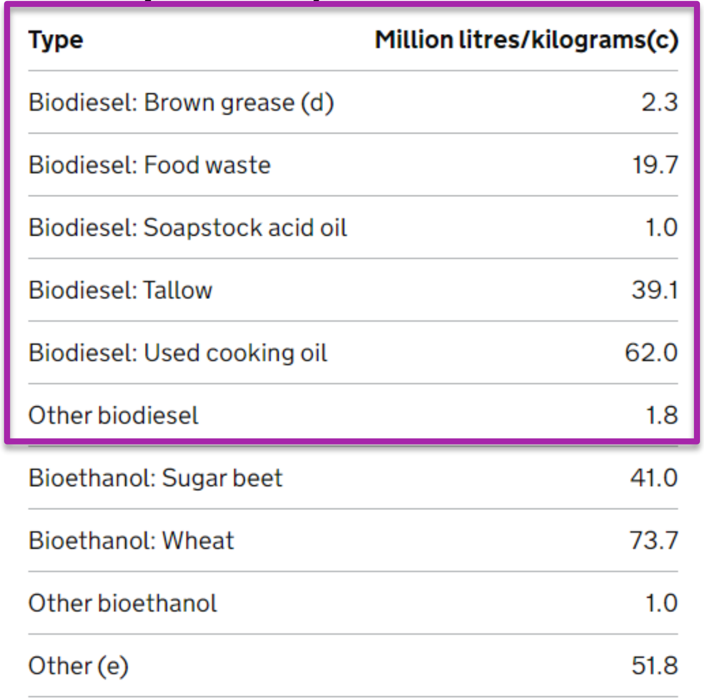
Top 6 countries supplying crop derived bioethanol to the UK 2020



Source: Department of Transport RTFO data

Some figures

Volume of UK sourced biofuels supplied to the UK road transport market by crop type and waste/residue, 2020



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Bioethanol: Sugar beet	41.0
Bioethanol: Wheat	73.7
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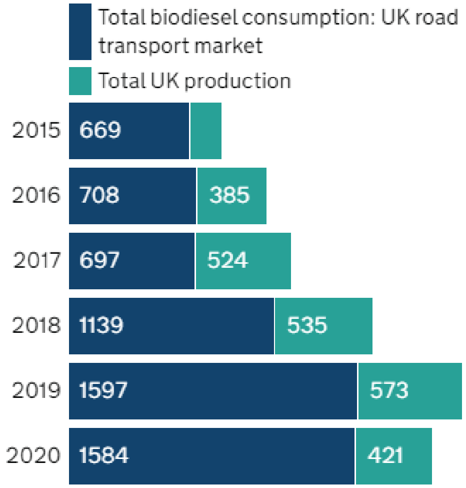
Other (e)	51.8

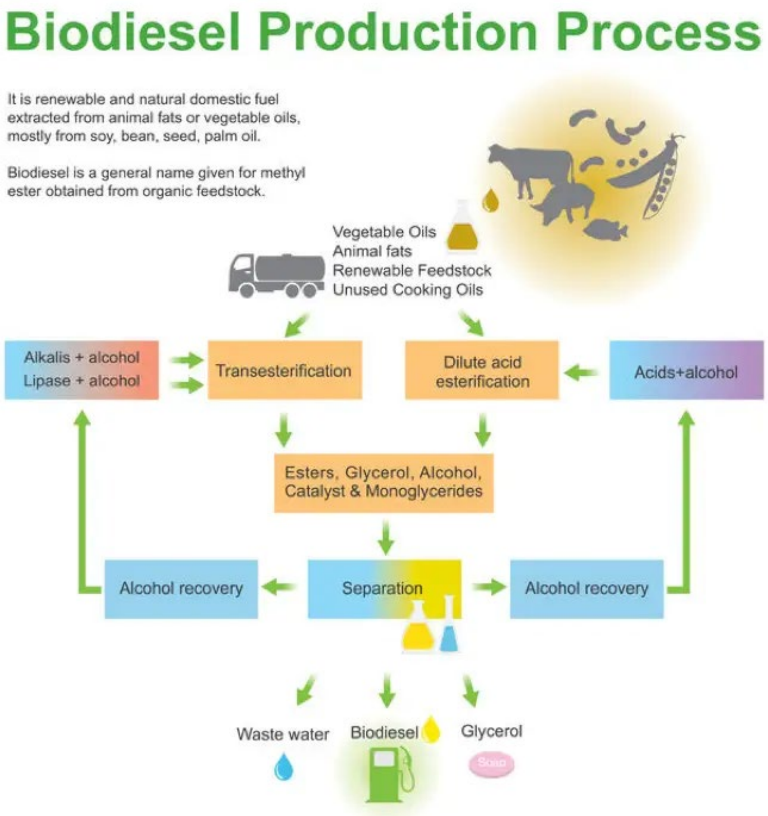
43 %

UK biofuel production and biofuel supply to UK road transport market, 2015 – 2020 (million litres)



Source: Digest of UK Energy Statistics

Routes to biodiesel production



Biodiesel Production Process

It is renewable and natural domestic fuel extracted from animal fats or vegetable oils, mostly from soy, bean, seed, palm oil.

Biodiesel is a general name given for methyl ester obtained from organic feedstock.

Biodiesel

Advantages

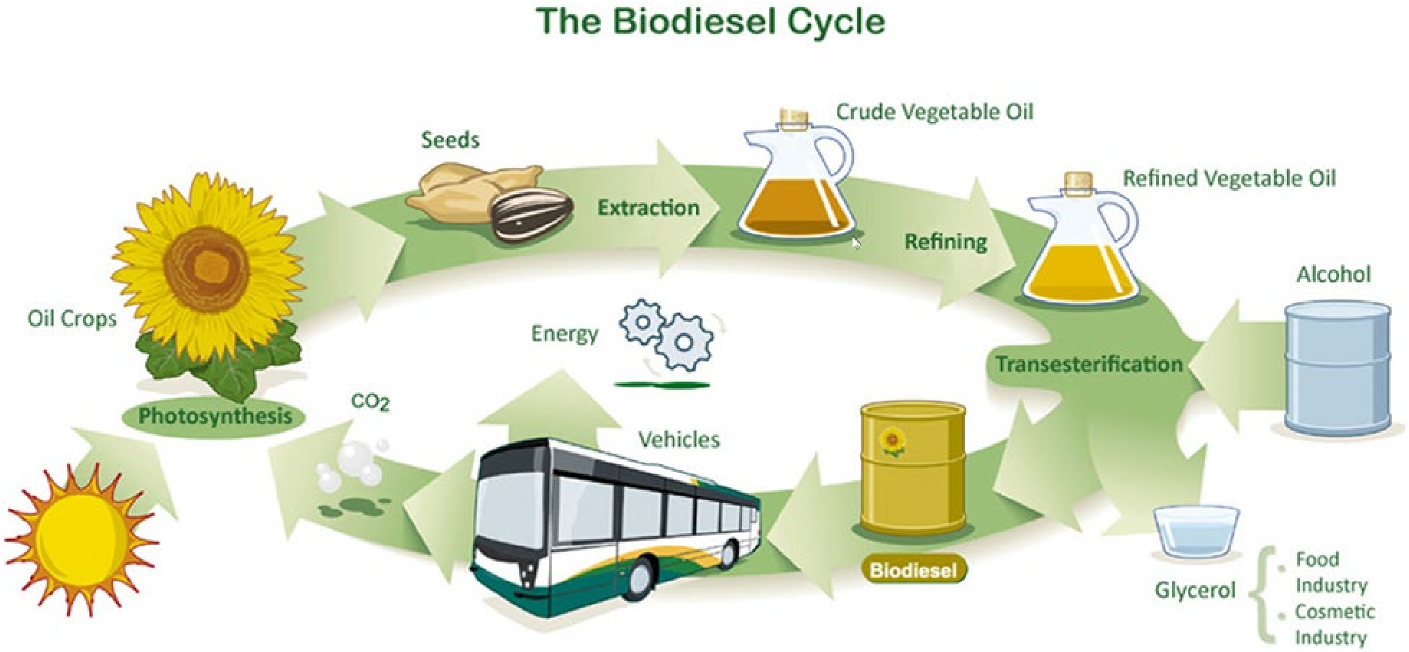
- Produced From Renewable Resources
- Can be Used in Existing Diesel Engines
- Less Greenhouse Gas Emissions (e.g., B20 reduces CO_2 by 15%)
- Grown, Produced and Distributed Locally
- Cleaner Biofuel Refineries
- Biodegradable and Non-Toxic
- Better Fuel Economy
- Positive Economic Impact
- Reduced Foreign Oil Dependence

Disadvantages

- Variation in Quality of Biodiesel
- Not Suitable for Use in Low Temperatures
- Biodiesel Could Harm the Rubber Houses of Some Engines
- Biodiesel more Expensive than Petroleum
- Food Shortage
- Increased use of Fertilizers
- Clogging in Engine
- Regional Suitability
- Water Shortage
- Monoculture
- Slight Increase in Nitrogen Oxide Emissions

Routes to biodiesel production (1st generation)

Main disadvantage:
Biofuel production requires intensive soil use, as well as causes raising foodstuffs prices for Europeans and citizens of developing countries.



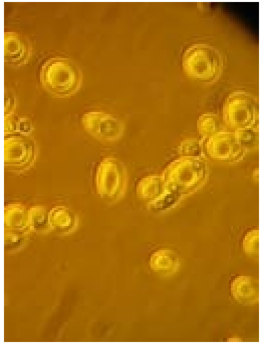
Routes to biodiesel production (2nd generation)

Second generation biofuels, also called advanced biofuels and next generation biofuels, are derived from non-food feedstocks.

Alternative feedstocks?

Case study 1: Wastepaper as feedstock for microbial lipids

Microbial lipids produced by oleaginous microorganisms, which accumulates 20–80% of their dry weight in the form of lipids under nutrient-limitation conditions.



Yeast 2022 Nov;39(11-12):553-606.

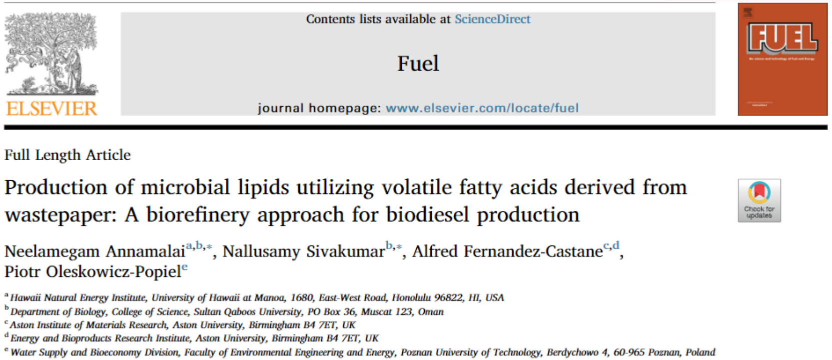
Production **cost** of microbial lipids remains as a major limiting factor due to the carbon sources used for production.
A potential solution to reduce the production cost is to **utilize low-cost or waste biomass** that can be used as a feedstock for microbial lipid production

Wastepaper, a major component of municipal and industrial solid wastes, accounts more than 35% of total lignocellulosic wastes → feedstock for biofuels

5.4 million tonnes were generated in the UK in 2021 (70.6% recycled)*

*Source: Defra Statistics

Case study 1: Wastepaper as feedstock for microbial lipids



Contents lists available at ScienceDirect

Fuel

journal homepage: www.elsevier.com/locate/fuel

Full Length Article

Production of microbial lipids utilizing volatile fatty acids derived from wastepaper: A biorefinery approach for biodiesel production

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[b] Department of Biology, College of Science, Sultan Qaboos University, PO Box 36, Muscat 123, Oman
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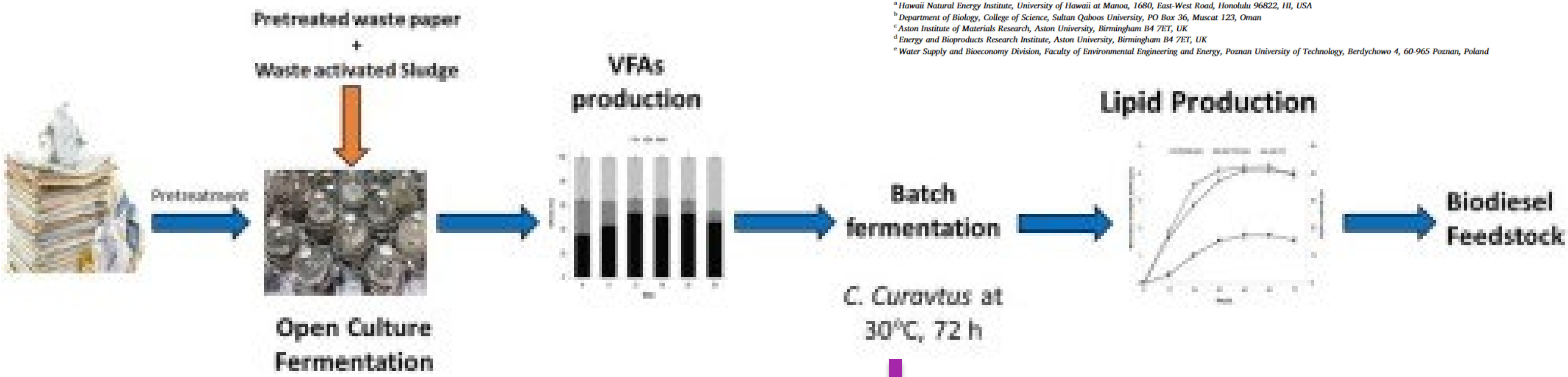
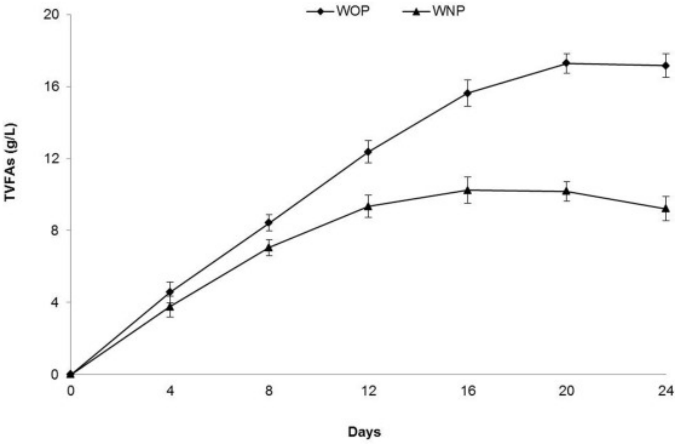
[d] Energy and Bioproducts Research Institute, Aston University, Birmingham B4 7ET, UK
[e] Water Supply and Bioeconomy Division, Faculty of Environmental Engineering and Energy, Poznan University of Technology, Berdychowo 4, 60-965 Poznan, Poland



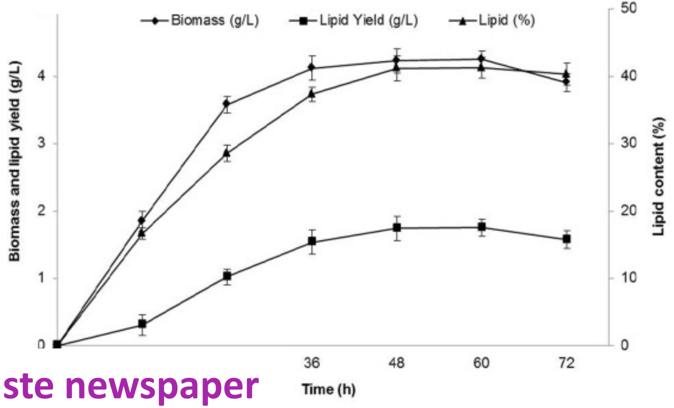
Oleaginous yeasts store above 20% of their dry cell weight as intracellular triacylglycerols.

Case study 1: Wastepaper as feedstock for microbial lipids

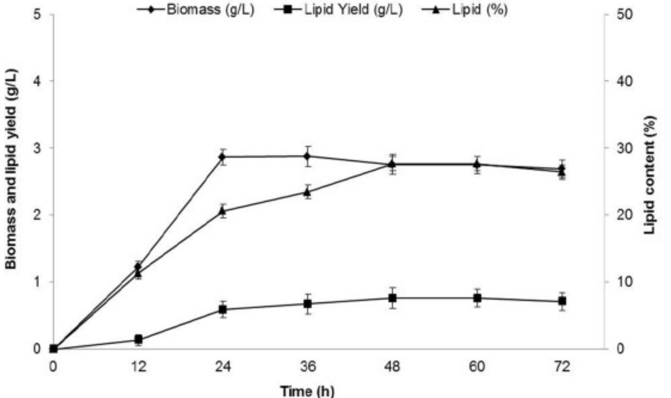
Total volatile fatty acids (TVFAs) production during anaerobic open culture fermentation of waste office paper (WOP) and waste newspaper (WNP).



Waste office paper



Waste newspaper



Case study 1: Wastepaper as feedstock for microbial lipids

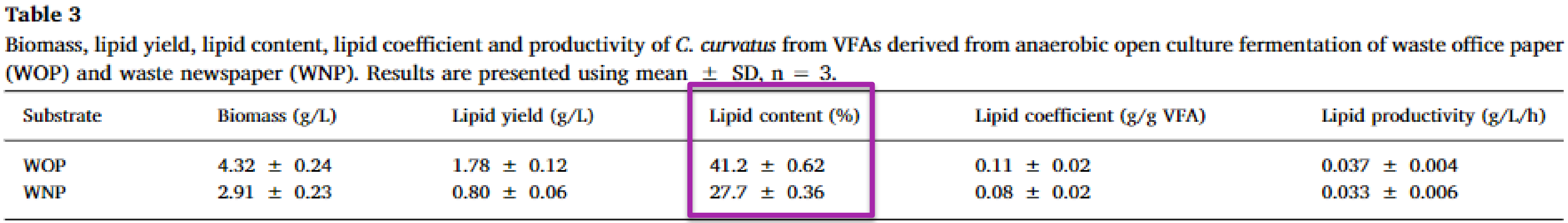


Table 3

Biomass, lipid yield, lipid content, lipid coefficient and productivity of *C. curvatus* from VFAs derived from anaerobic open culture fermentation of waste office paper (WOP) and waste newspaper (WNP). Results are presented using mean ± SD, n = 3.

Substrate	Biomass (g/L)	Lipid yield (g/L)	Lipid content (%)	Lipid coefficient (g/g VFA)	Lipid productivity (g/L/h)
WOP	4.32 ± 0.24	1.78 ± 0.12	41.2 ± 0.62	0.11 ± 0.02	0.037 ± 0.004
WNP	2.91 ± 0.23	0.80 ± 0.06	27.7 ± 0.36	0.08 ± 0.02	0.033 ± 0.006

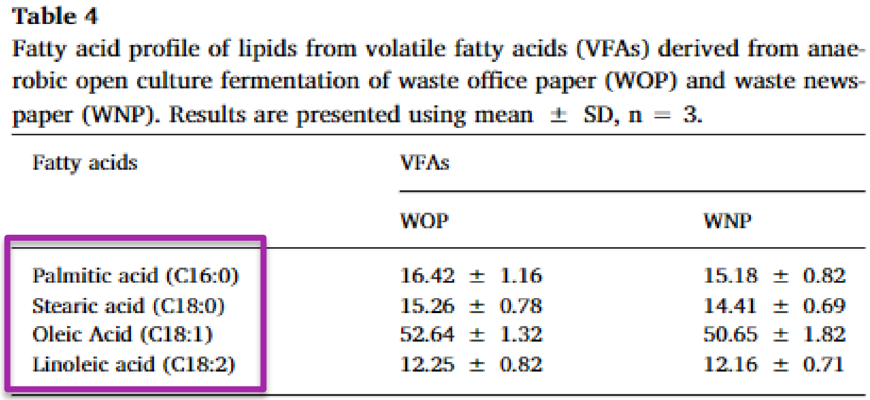


Table 4

Fatty acid profile of lipids from volatile fatty acids (VFAs) derived from anaerobic open culture fermentation of waste office paper (WOP) and waste newspaper (WNP). Results are presented using mean ± SD, n = 3.

Fatty acids	VFAs	
	WOP	WNP
Palmitic acid (C16:0)	16.42 ± 1.16	15.18 ± 0.82
Stearic acid (C18:0)	15.26 ± 0.78	14.41 ± 0.69
Oleic Acid (C18:1)	52.64 ± 1.32	50.65 ± 1.82
Linoleic acid (C18:2)	12.25 ± 0.82	12.16 ± 0.71

Case study 1: Wastepaper as feedstock for microbial lipids

Conclusions

- An integrated and scalable process for microbial lipids production from waste paper was developed
- This biorefinery approach offers a potential valuable and alternative route for management of wastepaper

Future challenges

- Scale up
- TEA and LCA studies

Thank you for your attention!

Any Questions?

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Energy and Bioproducts Research Institute (EBRI)

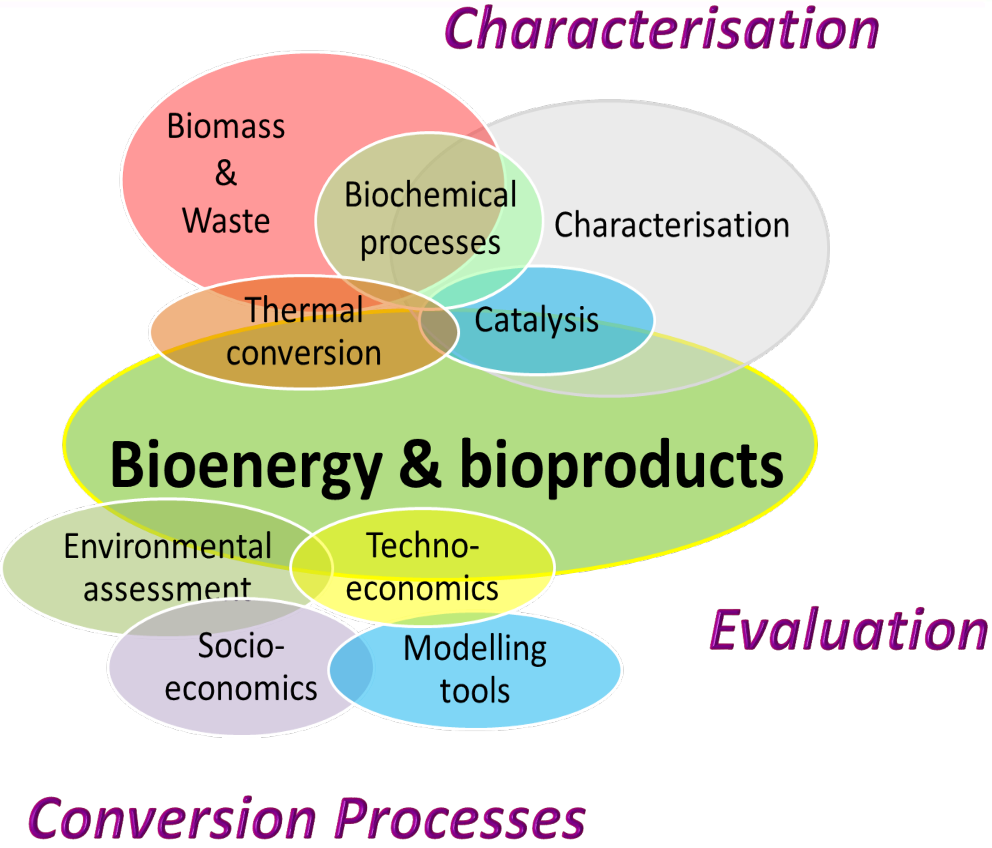
Aston University, Birmingham, U.K.

EBRI: Research Areas

- Fundamental and applied studies on the transformation of **biomass and organic materials** into valuable **solid, liquid and gaseous products**.

- Integration of conversion technologies in **biorefinery systems** to deliver sustainable **bio-products** that are relevant to industry and modern society.

- Wide range of **analytic equipment** for solid, gaseous and liquid samples.



EBRI: Research Areas

- **Process equipment** configurations: batch/semi-batch, fixed-bed, fluidised beds. Processing capacities, ranging from lab-scale (milligram to gram scale) up to a 300 kg/h pilot plant.

- Dedicated **Biotechnology Lab** with general equipment for handling and processing **biological materials**.

Innovation

Bioeconomy

Biorefinery

- Biological conversion of biomass and wastes, algae cultivation, microbial bioprocessing and physiology studies.

EBRI Capabilities

Pyrolysis and gasification

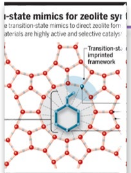
Torrefaction

Biochar production and analysis

Bio-refining and Anaerobic digestion

Microbial and Algae for waste remediation, bio-products and energy

Hydrogen and fuel cells



Catalysis for synthesis of fuels and chemicals

Lifecycle analysis, carbon accounting, TEA

Transport and logistics

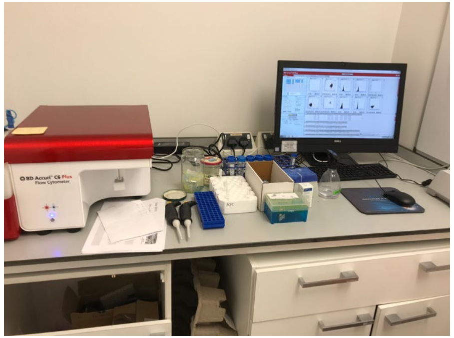
Smart energy systems, vehicle to grid, CHP

Bioenergy and bio-product market opportunities

BioLab facilities

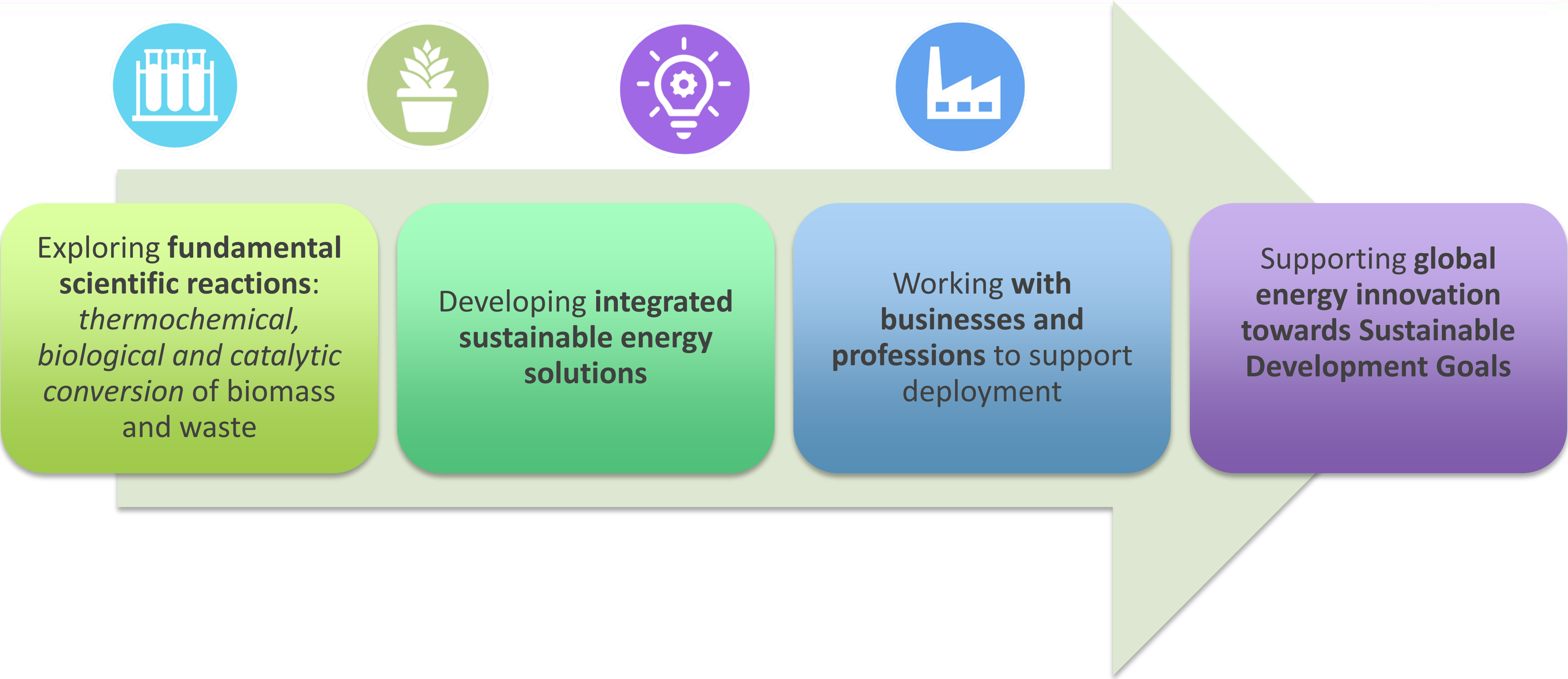
Biotechnology lab (1st floor)

- 6x BiosatatBStirred-tank Bioreactors (1and 5 L vessels) with online monitoring of bioprocessing parameters
- 700 L tubular Photobioreactor
- Fluorescence microscope
- Kit for molecular biology work
- Flow cytometer dedicated to microbial physiology
- General equipment for handling and processing biological materials, biocatalysis, etc…
- Equipment for DSP: Probe sonication, homogeniser and Powerfuge
- Analytical equipment: GC-MS, HPLC-MS, FT-IR, TGA, XAS and time-resolved XPS
- Microscopy: AFM, SEM, ESEM



This laboratory is dedicated to biological conversion of biomass and wastes, microbial bioprocessing, biorefining, algae cultivation and physiology studies for biofuels and biochemicals

EBRI Strategy



Exploring **fundamental scientific reactions**: *thermochemical, biological and catalytic conversion* of biomass and waste

Developing **integrated sustainable energy solutions**

Working **with businesses and professions** to support deployment

Supporting **global energy innovation towards Sustainable Development Goals**

Aston University
BIRMINGHAM UK

Thank you for your attention

Any Questions?

Twitter:
@EBRI_UK

https://bioenergy-for-business.org/

Overview of My Research and Research Vision

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Centre for Renewable and Low Carbon Energy
School of Water, Energy and Environment
Cranfield University, Cranfield MK43 0AL, UK

15th February 2023

www.cranfield.ac.uk

Education

Date of Graduation	Degree (Major)	Institute
October 2020	Postgraduate Certificate in Academic Practices	Cranfield University, UK
July 2010	PhD (Biochemical Engineering & Biotechnology)	Indian Institute of Technology Delhi, India
May 2002	M.Sc. (Chemistry)	Indian Institute of Technology Delhi, India
May 2000	B.Sc. (Honors) Chemistry	Hindu College, University of Delhi, India

Professional Experience

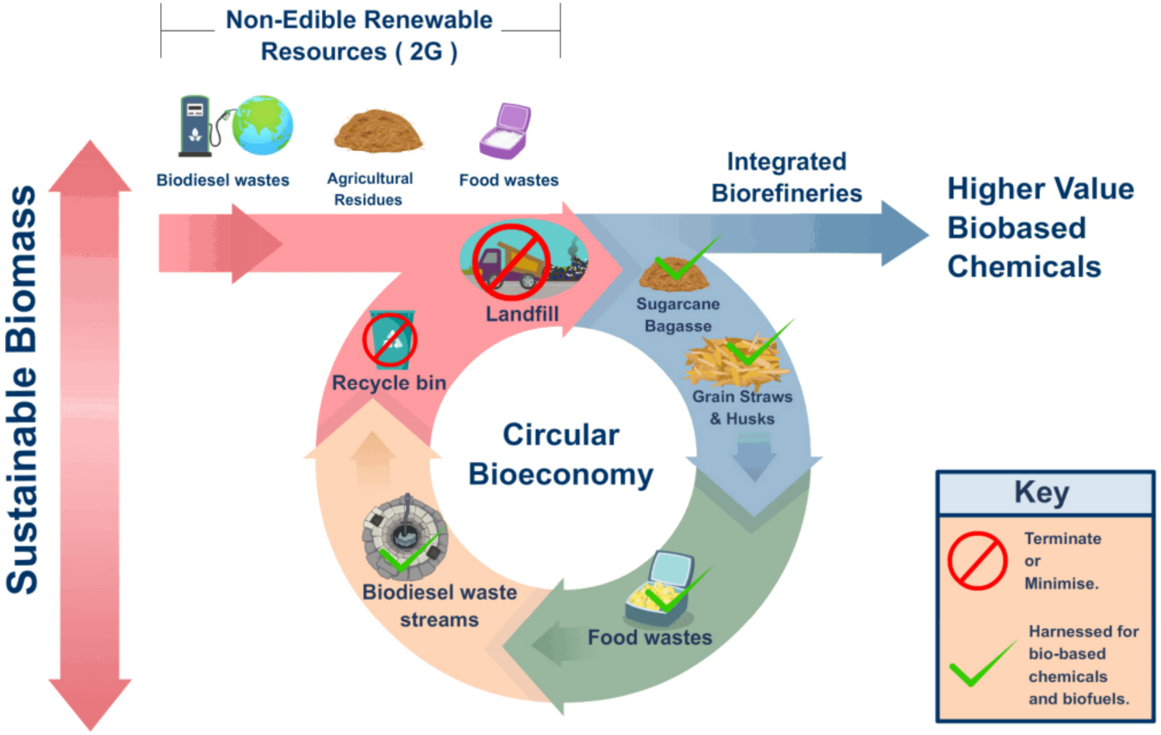
- Since October 2021: **Senior Lecturer in Microbial Technology and Biorefining,** School of Water, Energy and Environment, **Cranfield University**.
- January 2017 – September 2021: **Lecturer in Bioenergy/Biomass Systems,** School of Water, Energy and Environment, **Cranfield University**.
- January 2015 – December 2016: **Marie Curie Fellow,** Synthetic Biology Research Centre at **University of Nottingham, UK.**
- December 2013 – December 2014: **Research Fellow,** School of Biosciences, **University of Nottingham**, **UK.**
- August 2011-November 2013: **Research Professor,** School of Chemical and Biomolecular Engineering, **Pusan National University**, South Korea.
- December 2013 – December 2014: **Post-Doctoral Fellow**, Polytech Clermont Ferrand, **University of Blaise Pascal, France.**

Cranfield
Energy and Power

Current Research Activities

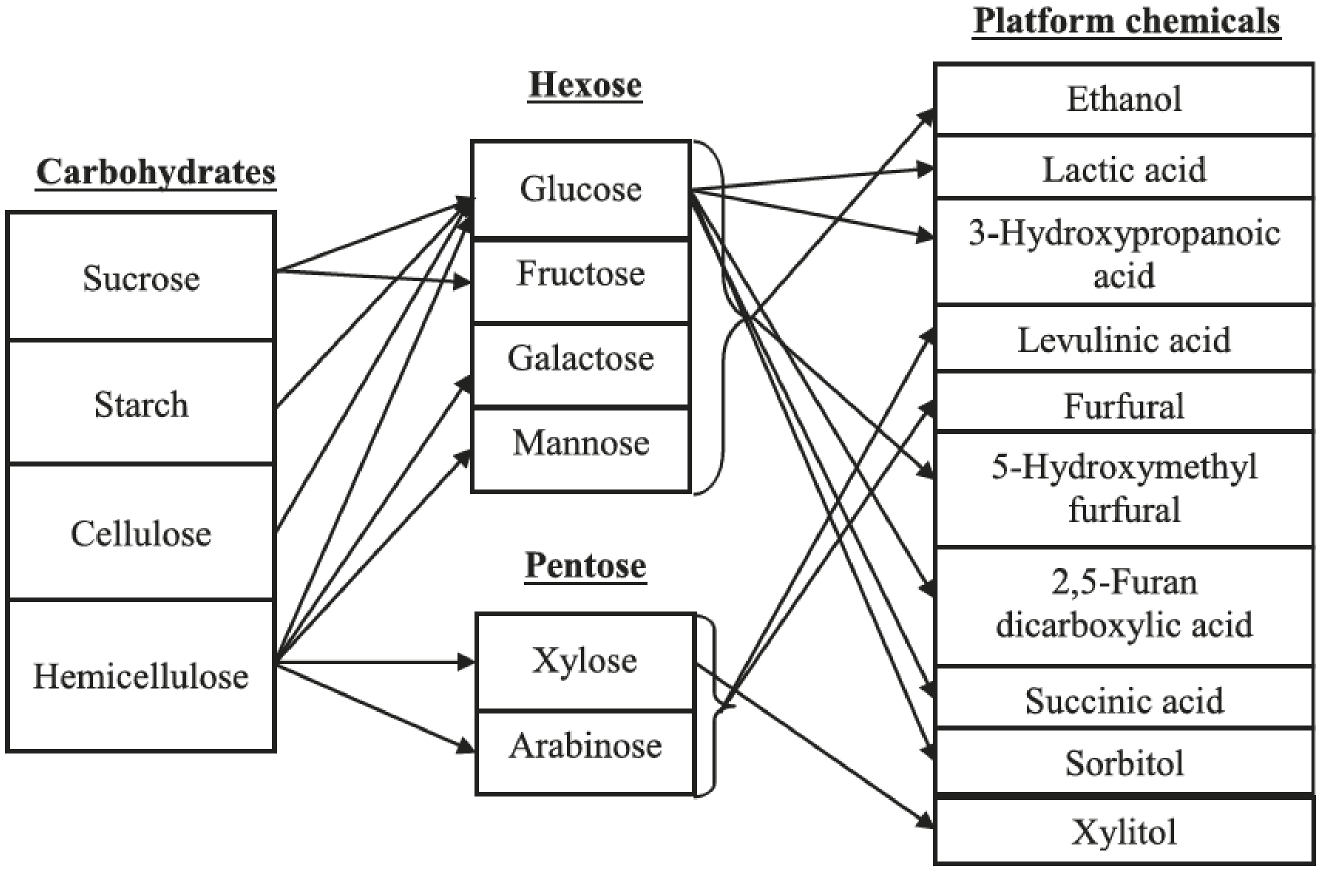
- The current research activities are at nexus of Metabolic/Pathway Engineering, Bioprocessing and Waste Valorisation.

- The work leads to development of low carbon biomanufacturing technologies for overproduction of platform/commodity chemicals and fuels from carbonaceous agro-industrial waste streams rich in renewable carbon, thus enabling a circular economy approach.



Revised List of Platform Chemicals by US DoE

Ethanol	Lactic acid
Furfural	Succinic acid
HMF	Biohydrocarbons
FDCA	3-Hydroxypropionic acid
Glycerol	Levulinic acid
Isoprene	Sorbitol
	Xylitol



Carbohydrates

Sucrose
Starch
Cellulose
Hemicellulose

Hexose

Glucose
Fructose
Galactose
Mannose

Pentose

Xylose
Arabinose

Platform chemicals

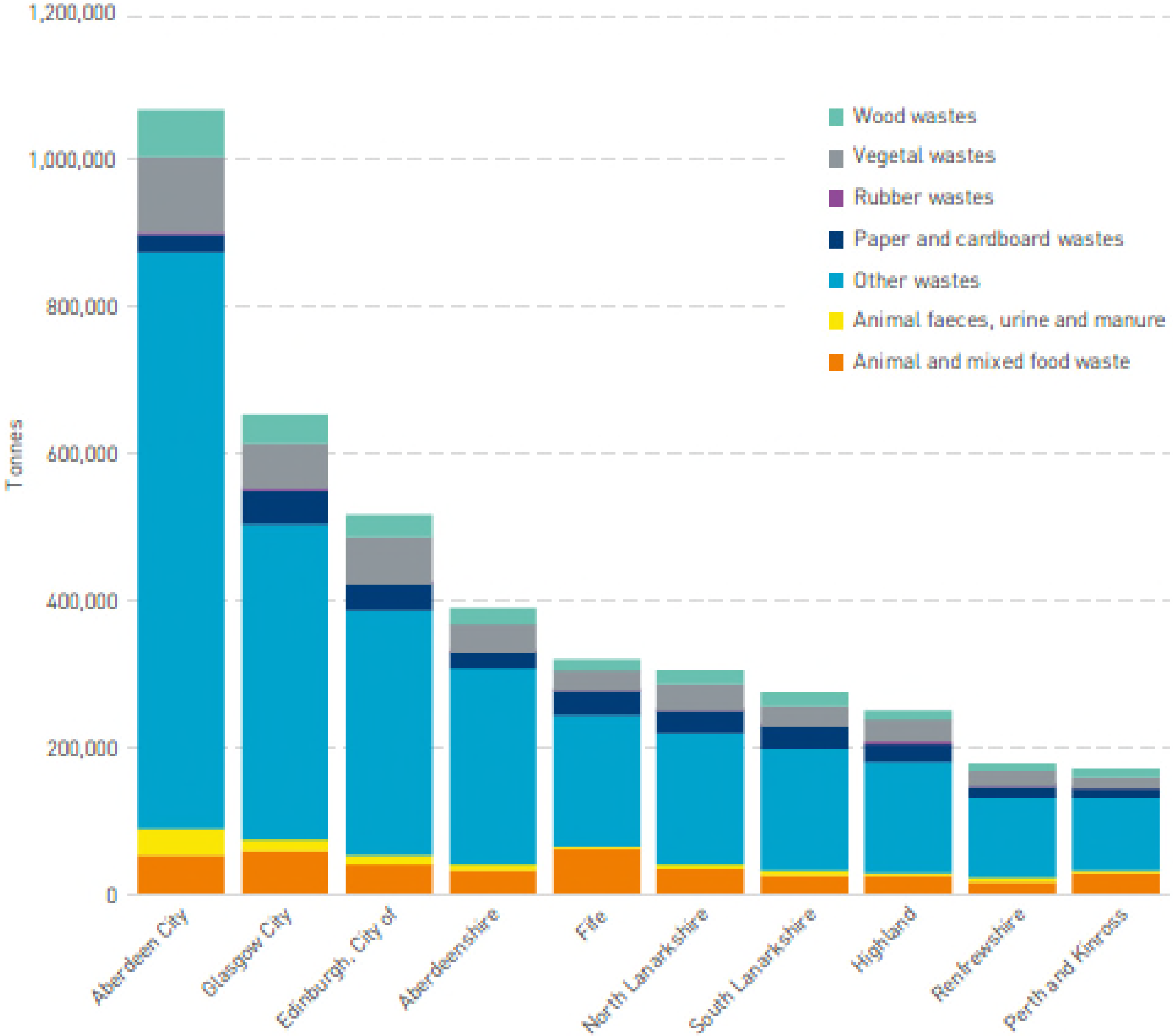
Ethanol
Lactic acid
3-Hydroxypropanoic acid
Levulinic acid
Furfural
5-Hydroxymethyl furfural
2,5-Furan dicarboxylic acid
Succinic acid
Sorbitol
Xylitol

Bozell and Petersen (2010) Technology development for the production of biobased products from biorefinery carbohydrates—the US Department of Energy’s “top 10” revisited. Green Chemistry 12:539–55.

UK Top Bio-based Chemicals Opportunities, A Report by LBNet (BBSRC), 2017

Biorefining Potential of Scotland, Zero Waste Scotland, 2017

- There are 27 million tonnes of bioresources arising every year in Scotland which could be turned into high value chemicals, biofuels and other renewable products across many industries.



Major Sectors/Industries in EU Generating Renewable Feedstocks

Biodiesel (Crude Glycerol)

Spent Coffee grounds

Paper and Pulp Industries

Wineries

Breweries

Organic Fraction of MSW

Sugar beet Processing

Fruits and Vegetables Processing

Ioannidou et al. (2020) Sustainable production of bio-based chemicals and polymers via integrated Biomass refining and bioprocessing in a circular bioeconomy context. Bioresource Technology 307:123093.

Current Research Activities

- My current research includes production of various bio-based products like xylitol, 2,3-butanediol, itaconic, lactic and succinic acid from waste streams like sugarcane bagasse, brewer's spent grains, crude glycerol, unconsumed food, bread & bakery waste etc using preferably GRAS (generally regarded as safe) microbes.

Sugarcane bagasse

Sugar beet pulp

Brewer's spent grains

Bread waste

Crude glycerol

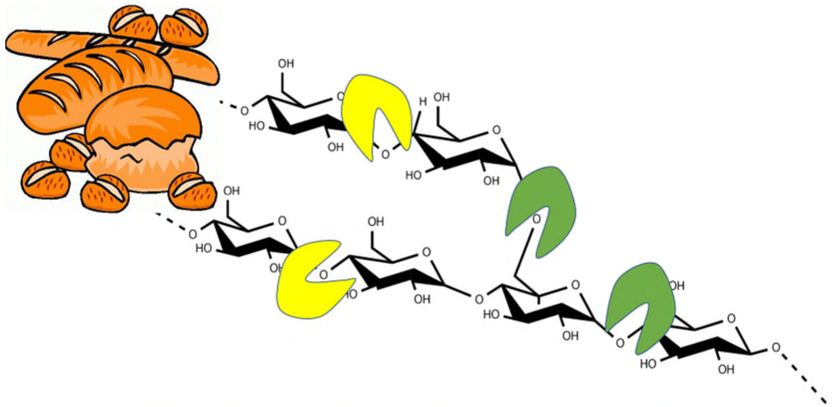
Bread wastage – A serious global problem

- The global annual production of bread is >100 million tons. According to global bread market split analysis, Europe dominates the market with a share of 53.6%. It has been approximated that, globally, ~ 10% of all manufactured bread is wasted.

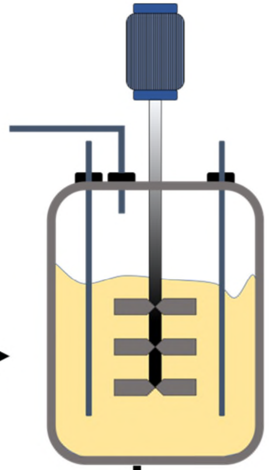
- Bread is the second most wasted food in the UK after potatoes, with the equivalent of 20 million slices of bread thrown away daily leading to an annual wastage of ~900,000 tons, corresponding to 1,200,000 tons of CO_2 equivalent emissions.

- Unless modern techniques like anaerobic digestion (AD) is adapted for food waste management in most of the developing countries, the bread or food waste ends up in the landfills due to limited resources, and infrastructure

Bread Waste to Lactic acid

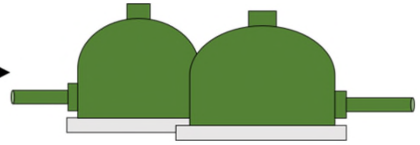


SACCHARIFICATION OF BREAD WASTE

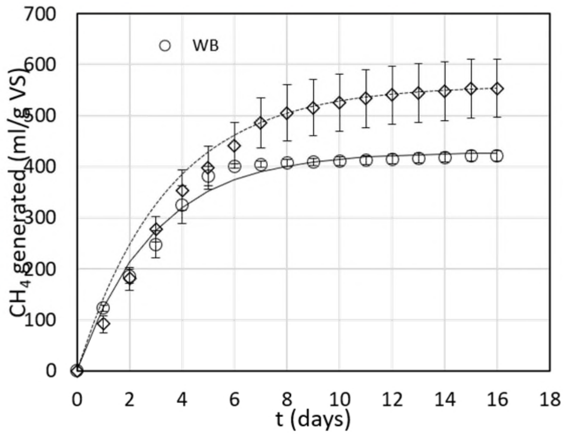


Fermentation by *Bacillus coagulans* DSM1

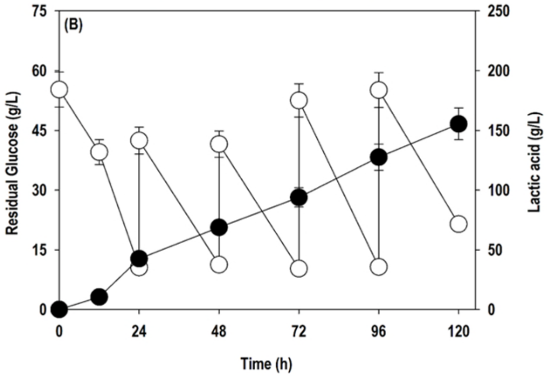
Solid residues



Anaerobic Digestion



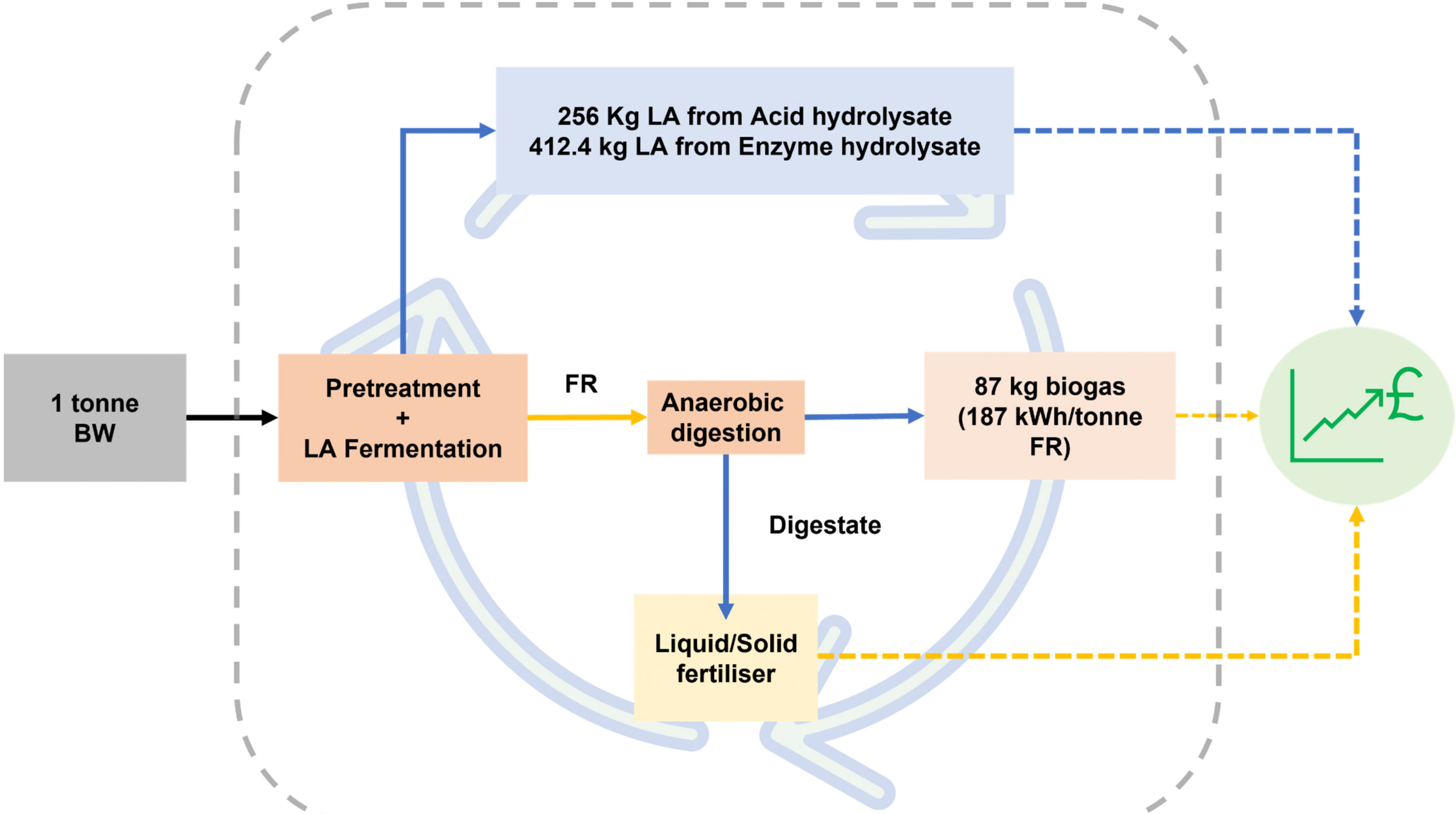
Lactic acid



Lactic acid
Titer – 155.4 g/L
Yield – 0.85 g/g
Productivity – 1.26 g/L. h

Cox et al. (2022) High-Level fermentative production of Lactic acid from bread waste under Non-sterile conditions with a circular biorefining approach and zero waste discharge. Fuel 313:122976.

Potential of BW as a resource in a circular bioeconomy



1 tonne BW

Pretreatment + LA Fermentation

256 Kg LA from Acid hydrolysate
412.4 kg LA from Enzyme hydrolysate

FR

Anaerobic digestion

87 kg biogas (187 kWh/tonne FR)

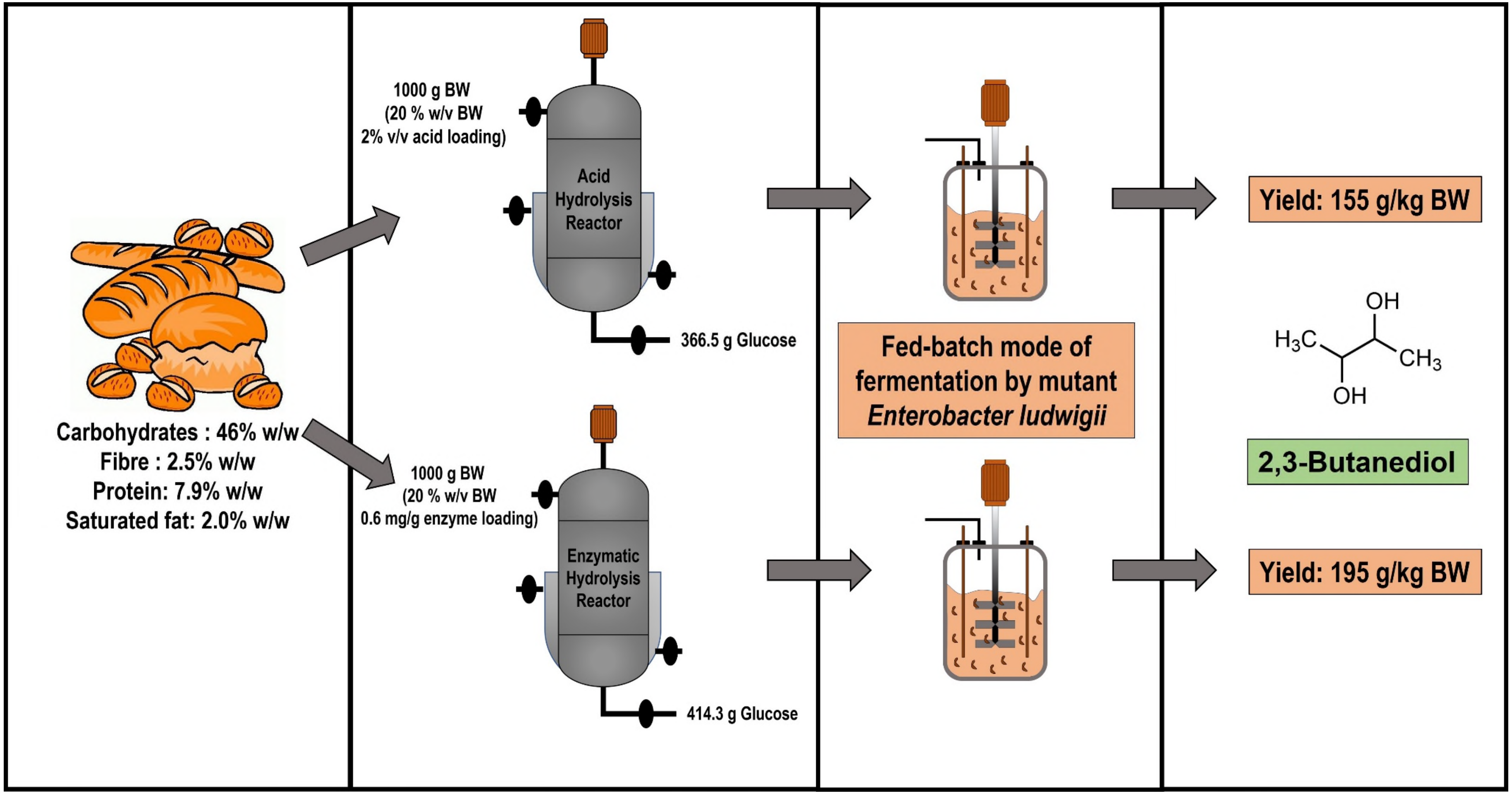
Digestate

Liquid/Solid fertiliser

Bread waste to 2,3-Butanediol

2,3-Butanediol from EBW
Titer – 138.8 g/L
Yield – 0.48 g/g
Productivity – 1.45 g/L. h

2,3-Butanediol from ABW
Titer – 135.4 g/L
Yield – 0.42 g/g
Productivity – 1.41 g/L. h



Carbohydrates : 46% w/w
Fibre : 2.5% w/w
Protein: 7.9% w/w
Saturated fat: 2.0% w/w

1000 g BW
(20 % w/v BW
2% v/v acid loading)

Acid Hydrolysis Reactor

366.5 g Glucose

1000 g BW
(20 % w/v BW
0.6 mg/g enzyme loading)

Enzymatic Hydrolysis Reactor

414.3 g Glucose

Fed-batch mode of fermentation by mutant *Enterobacter ludwigii*

Yield: 155 g/kg BW

Yield: 195 g/kg BW

2,3-Butanediol

Narisetty et al. (2022) Fermentative production of 2,3-Butanediol using bread waste – A green approach for sustainable management of food waste. Bioresource Technology 358:127381

Ethanol Production from Bread waste


Energy Conversion and Management 266 (2022) 115784

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journal homepage: www.elsevier.com/locate/enconman

Process optimization for recycling of bread waste into bioethanol and biomethane: A circular economy approach

Ethanol from EBW
Titer – 114.9 g/L
Yield – 0.49 g/g
Productivity – 3.2 g/L. h

2,3-Butanediol from ABW
Titer – 106.9 g/L
Yield – 0.47 g/g
Productivity – 3.0 g/L. h

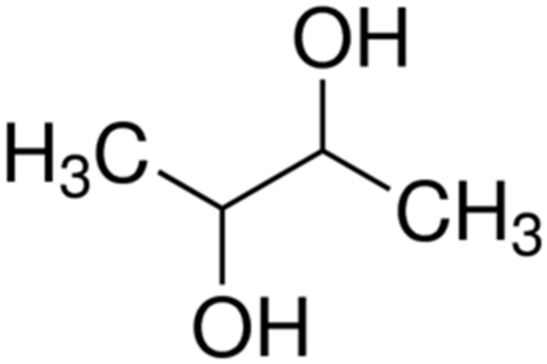
Narisetty V (2022) Process Optimization for Recycling of Bread Waste into Bioethanol and Biomethane: A Circular Economy Approach. Energy, Conversion and Management 266:115784

Brewers Spent Grains to 2,3-Butanediol

- In another work, brewer’s spent grain (BSG), major by-product of breweries worldwide, has been employed as feedstock for bioproduction of 2,3-Butanediol (BDO), a largely fossil-based versatile bulk chemical with multitude of applications.

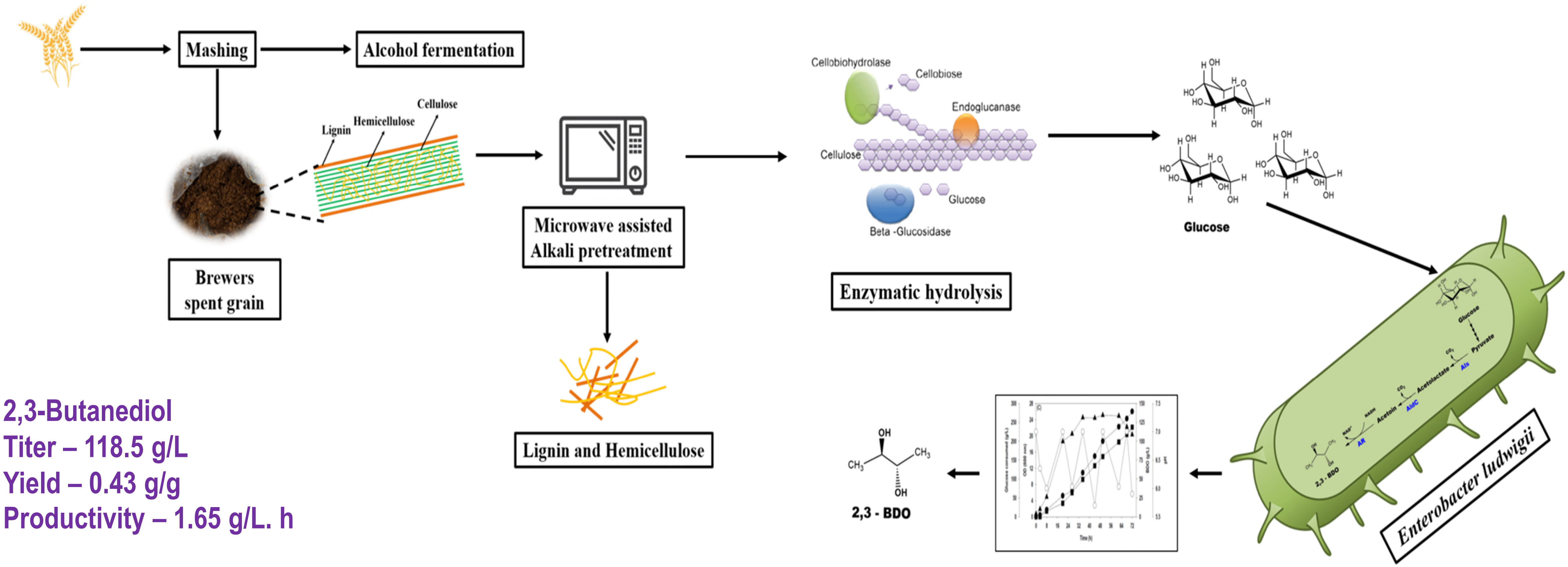
- The high cost of production impedes commercial manufacturing of BDO through microbial route. BSG is an inexpensive source of fermentable sugars and proteins and Europe, USA and Brazil are major producer of it.

- BSG is a lignocellulosic material containing cellulose (12-33%), hemicellulose (19-42%), lignin (11-28%), proteins (14-31%) and lipids (6-13%). The fibre constitutes about 50% of the BSG composition (dry weight basis) while protein fraction can be up to 31%.



2,3-Butanediol

Brewers spent grains to 2,3-Butanediol


Mashing

Alcohol fermentation

Brewers spent grain

Microwave assisted Alkali pretreatment

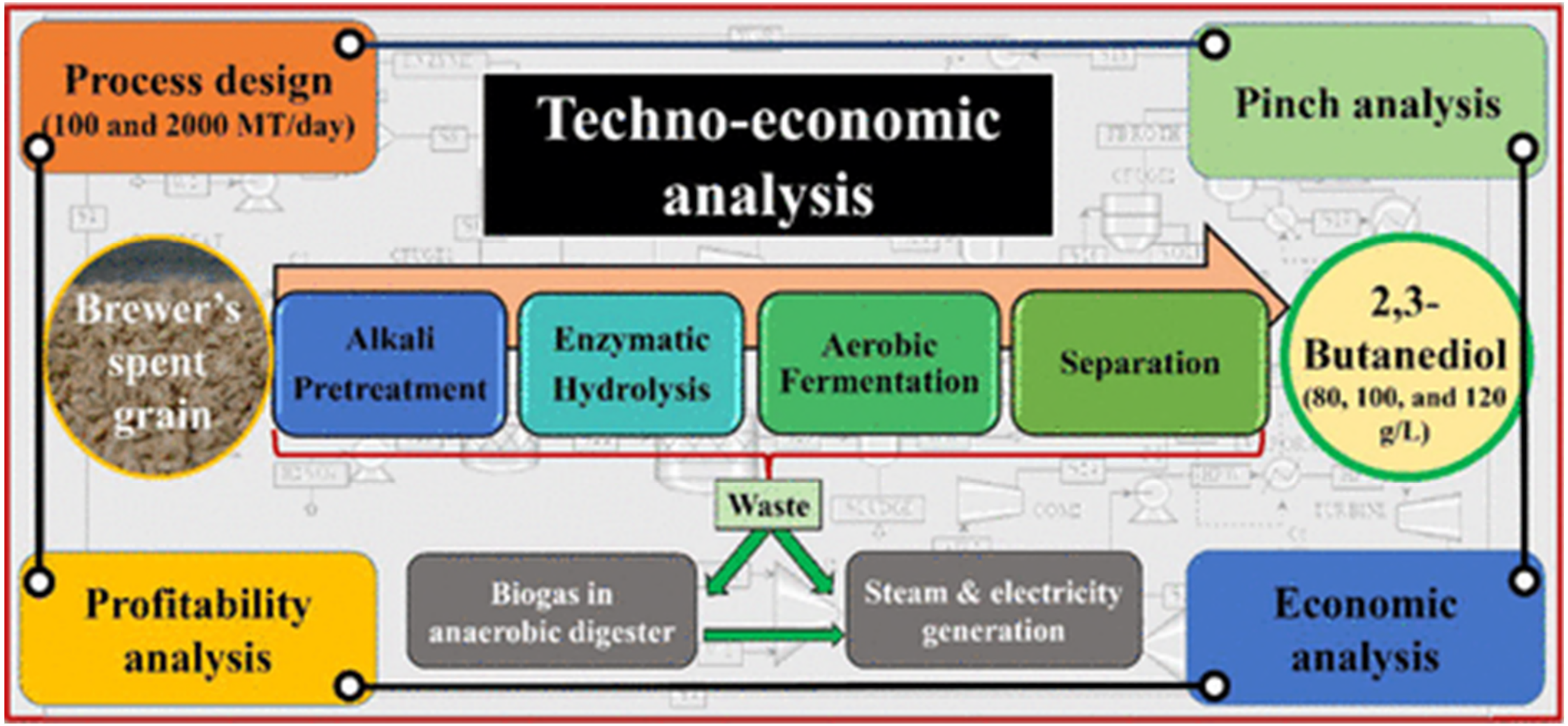
Lignin and Hemicellulose

Enzymatic hydrolysis

2,3-Butanediol
Titer – 118.5 g/L
Yield – 0.43 g/g
Productivity – 1.65 g/L. h

Amraoui et al. (2022) Enhanced 2, 3-Butanediol production by mutant *Enterobacter ludwigii* using Brewers' spent grain hydrolysate: Process optimization for a pragmatic biorefinery loom. Chemical Engineering Journal 427:130851.

Techno-economic analysis for the production of 2,3-butanediol from brewers spent grain



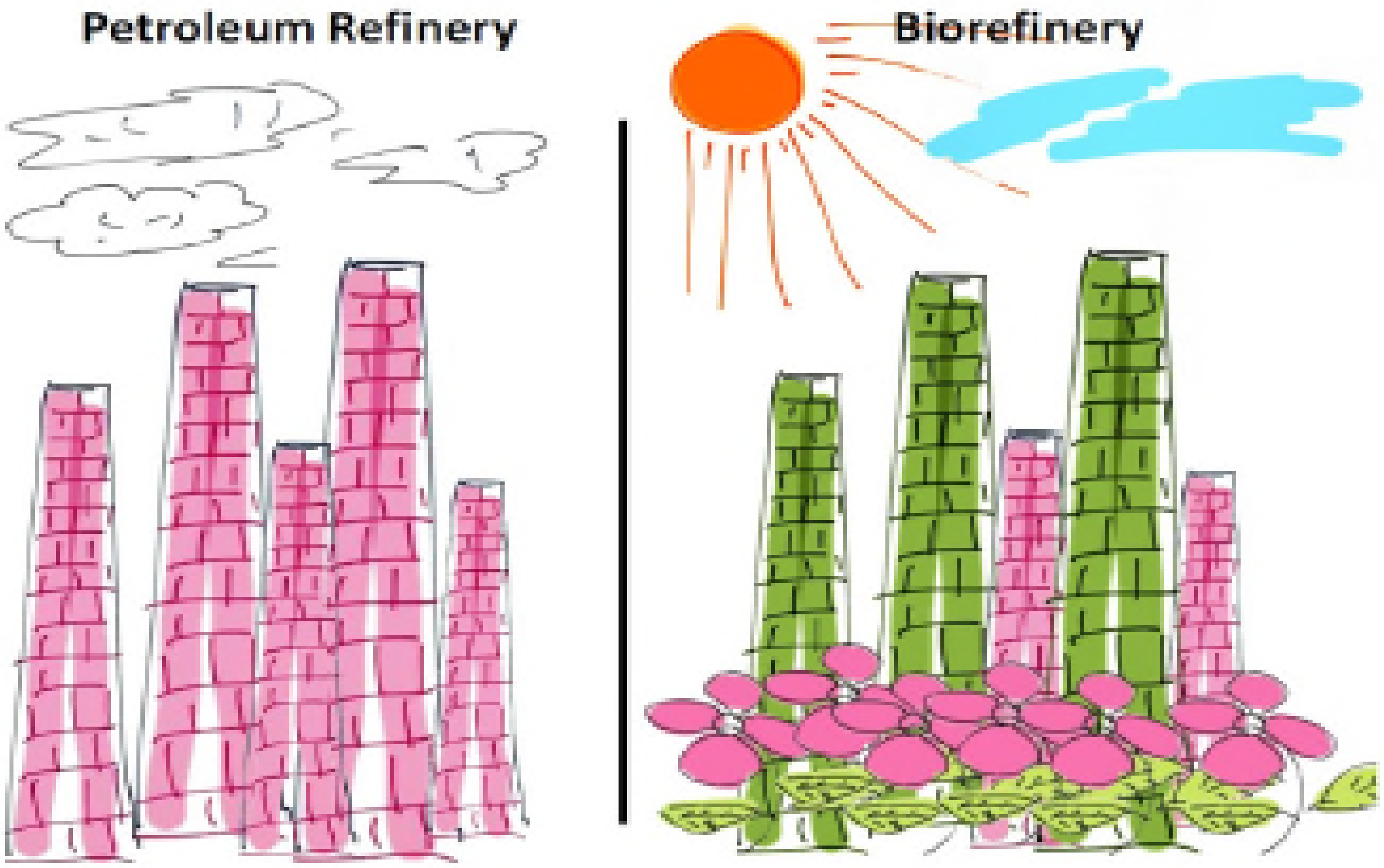
Mailaram et al. (2022) Techno-economic analysis for the production of 2,3-butanediol (BDO) from brewers spent grain (BSG) using pinch technology. Industrial & Engineering Chemistry Research 61:2195-2205.

Vision

- Oil is central to global manufacturing. The petrochemicals sector is greater than £50tn globally.
- Significant progress has been made in manufacturing low carbon renewable sources of heat and power, while the chemicals and polymer sector remain largely dependent on petroleum even today.
- Currently, bio-based chemicals provide only little fraction (<5%) of the chemicals used in manufacturing, indicating big opportunity to develop this area.
- My research vision is to build on core research strength and rapidly growing need and demand for production of a range of bio-based Green Chemicals from non-edible/waste biomass, developing new scientific approaches, tools and techniques to establish a world leading capability and become a global leader in this discipline.

Long term Goals

- Sustainable and Economical Production of Chemical Building Blocks and their Derivatives
- Wealth from Wastes
- Elimination of Biogenic Waste Streams with a Circular Biorefining Approach i.e. Zero Waste Society
- Significant Contribution to National Goal of Zero Carbon Emission



Thank you....