

Welcome

Biorefining – Clean Growth – Net Zero

Sheffield 10th - 12th April 2024

Session 3: What is waste and why waste is not free

The co-product market in the UK

Richard Evans, AB Agri Ltd



Introducing abagriTM



ABAGRI.COM

ABF Divisions at a glance...



Grocery



Herbs & spices, world foods, hot beverages, sugar & sweeteners, meat, vegetable oils, bread, baked goods & cereals.

Revenue:

£4,198m

2022: £3,735m

Adjusted operating profit:

£448m

2022: £399m

Sugar



Market-leading sugar producer in the UK, Spain, and southern Africa, with substantial interests in China.

Revenue:

£2,547m

2022: £2,016m

Adjusted operating profit:

£169m

2022: £162m

Grocery

Our Grocery division employs more than 15,000 people and comprises brands which occupy leading positions in markets across the globe. In the UK, nine out of 10 households use our brands. Our Twinings and Ovaltins brands are enjoyed in more than 100 countries worldwide.

Sugar

AB Sugar is a leading producer of sugar and sugar derived co-products in Africa, the UK, Spain and north-east China.

Agriculture

AB Agri is a leading international agri-food business operating across the supply chain, producing and marketing animal feed, nutrition and technology based-products-and services.

Ingredients

Our Ingredients businesses are leaders in yeast and bakery ingredients as well as in specialty ingredients for the food, human and animal nutrition, pharmaceutical and various other industries.

Retail

Primark is one of the largest clothing retailers in Europe, the largest by volume in the UK and -has a growing presence-in-the-US. In total, we have 408 stores in 14 countries across Europe and the US.

Revenue

Adj. operating profit

£4,198m

2022: £3,735m

£448m

2022: £448m

£2,547m

2021: £2,016m

£169m

2021: £162m

£1,840m

2022: £1,722m

£41m

202: £47m

£2,157m

2022: £3,593m

£159m

2022: £413m

£9,008m

2022: £7,697m

£735m

2022: £7561m

ABF retail businesses



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Why AB Dairy



About our business...



“Our vision is to help build a dairy ecosystem that delivers sustainable nutrition”

AB DAIRY



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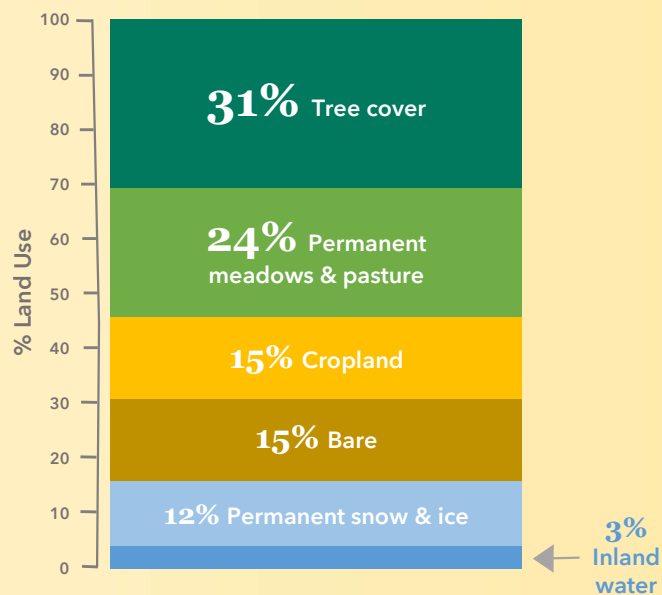
Land use – Not all land is created equal



1.3 billion hectares of the
2.5 billion hectares land used to fulfil
global feed demand cannot be cultivated

(Mottet et al., 2017)

LAND-USE AND LAND COVER CLASSIFICATIONS

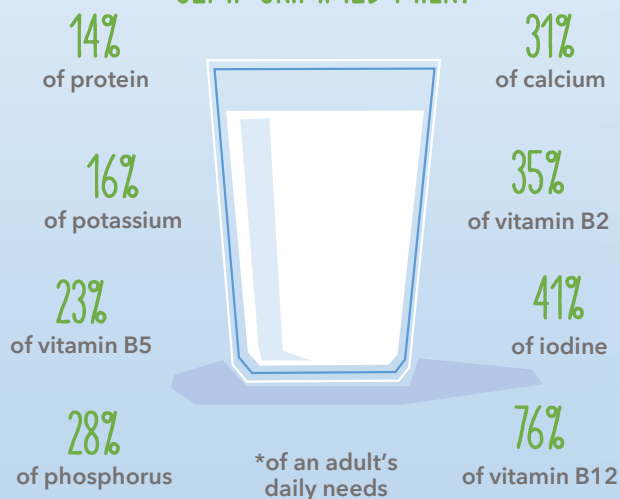


Affordable essential nutrients – an incredible opportunity

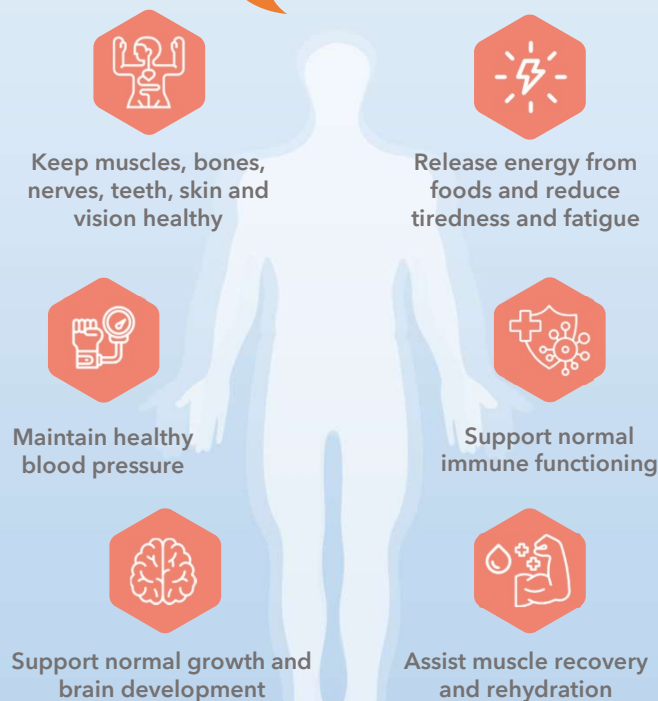


Dairy is a nutritional essential

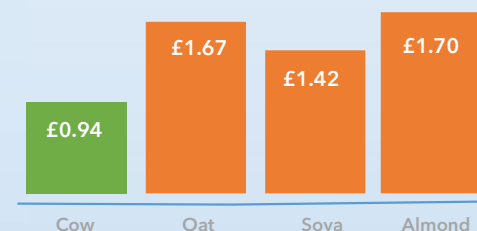
WHAT'S IN A 200ML GLASS OF SEMI-SKIMMED MILK? *



Dairy has proven health benefits



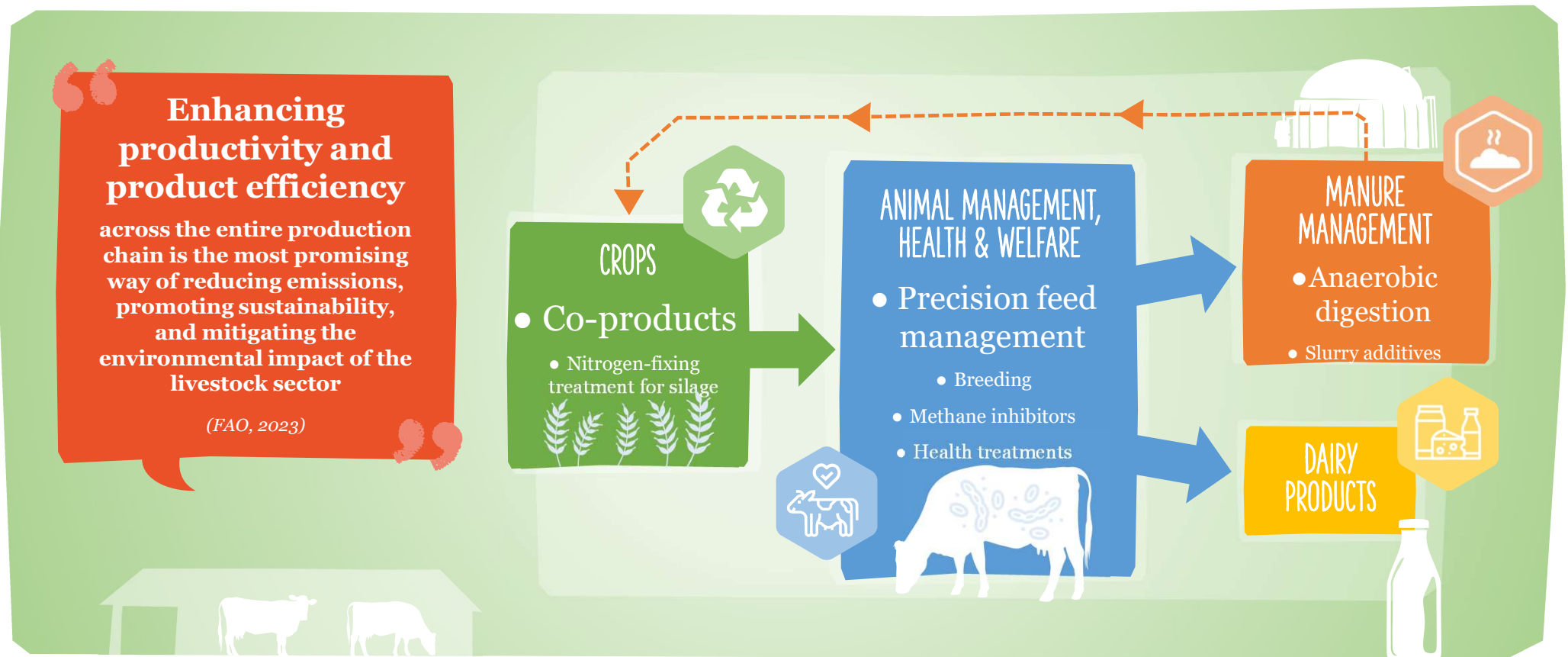
Dairy is affordable



AVERAGE LIQUID PRICES PER LITRE

But... **10%** of world's population are undernourished, rising to **20%** in Africa (UN 2021)

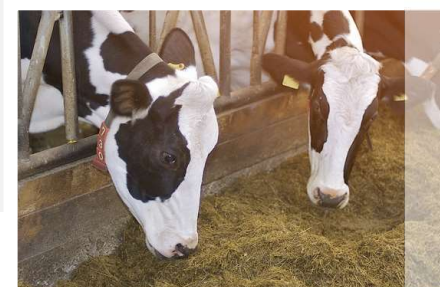
Responsible, affordable dairy means enhancing productivity & efficiencies



Wholesale



- Trident is the **wholesale division** of AB Dairy and provide a wide range of animal feeds to over 300 blenders, merchants and compounders across the UK.
- Established in 1984, Trident are the **largest supplier of co-products** in the country, marketing around **2 million tonnes** of high profile animal feed products that range from sugar beet and distillers feeds to liquids and protected fats.
- Trident has close connections with **ruminant** markets, including cows, sheep & goats, as well as **equine** and **pet**.
- Trident continues to add value to around **half a million tonnes** of sugar co-products produced from the UK's 4 sugar beet processing facilities.



Direct to farm - ruminant



- KW Feeds is the **direct to farm division** of AB Dairy and is one of the UK's largest feed retailers selling over 1 million tonnes of products to over 2,000 of the UK's dairy, beef and pig farmers across the whole of the UK.
- KW Feeds is the **leading retailer for** co-products utilising home-produced feeds from the brewing, distilling and food processing industries, alongside more traditional straights and additives.
- KW Feeds also offer **expert advice** through 6 nutritionists as well as 14 FAR trained on-farm advisors, offering unrivalled choice of feed to help farmers achieve sustainable performance.
- KW offer **product specific management** with 26 specific product sellers and back-office customer service staff tailored to the customers and product needs.



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Direct to farm – Anaerobic Digestion (AD)



- Amur is the **AD division** of AB Dairy and works with over 100 AD Operators annually to look at alternative feed stocks from the food and drink industry.
- Amur have **over 30 years'** experience in managing non-core product streams, turning waste into differentiated, in-demand products for the agricultural feed market.
- Amur help customers improve the performance of their AD, by optimising gas yields. Amur own a **dedicated laboratory** – providing rapid feedstock analysis to customers, ensuring Amur understand the biology and gas yield potential for every feedstock they sell.
- Amur own a **'gas to grid' AD plant** generating the equivalent of 3MWe, per year from 60,000T of blended food waste.
- As an **AD plant operator**, Amur know how to manage an AD plant and can utilise the plant as a 'testing' ground, working alongside our laboratory team based in York to quality assure our existing product range and rigorously test new products in development.



What are these Co-products?



Largely Brown!!



Energy Feeds



> Crackerfeed Pellets

Protein Feeds



> British Wheat Distillers

Moist Feeds



> C☆Traffordgold®

Liquid Feed



> Spey Syrup



> Supaflow



> Rapeseed Extract

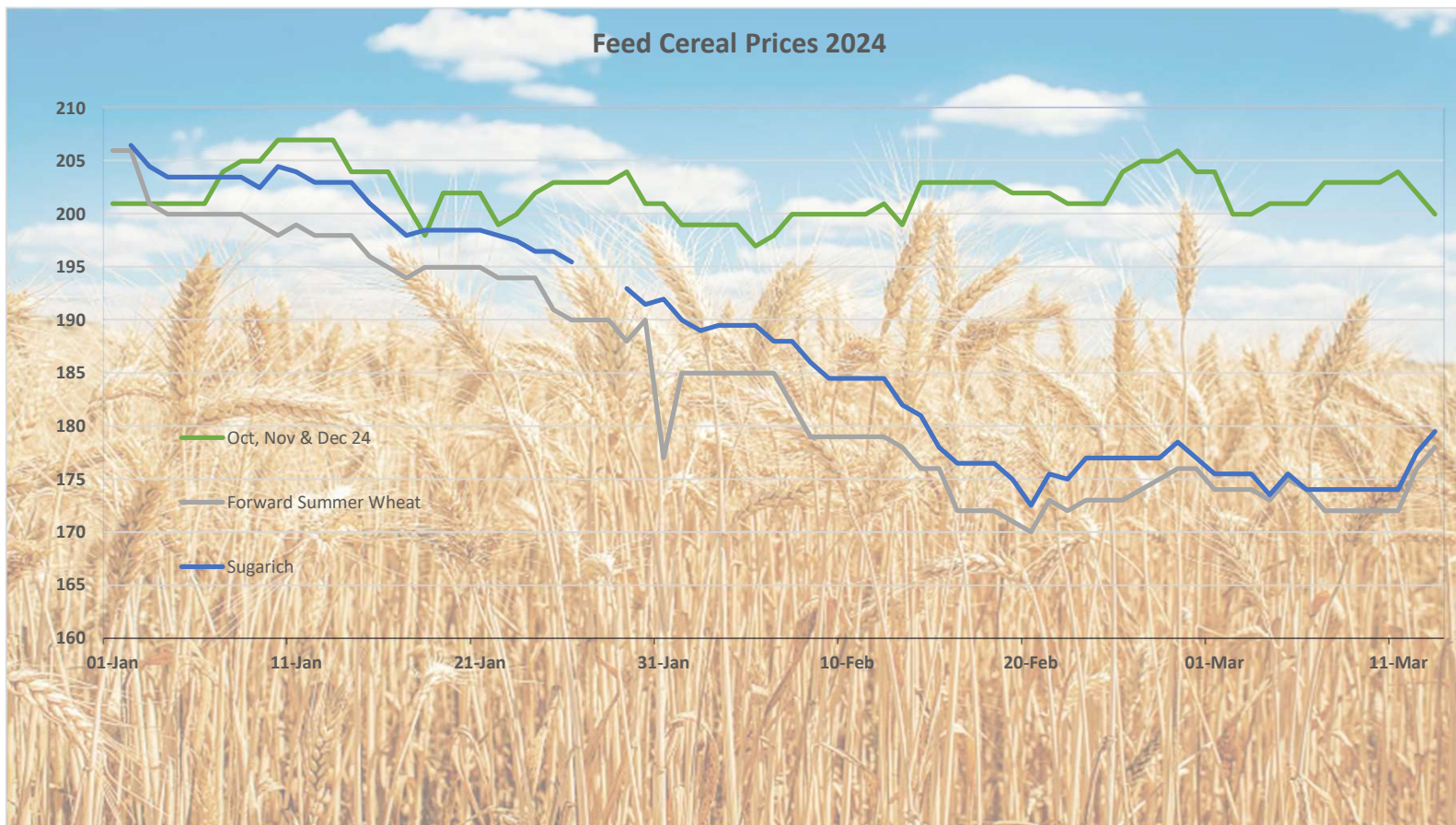


> Brewers Grains



> Wheat Syrup

The Markets - Energies.



- Energy related products track Feed wheat markets.
- Movements depend on:
 - Weather
 - Geo-political influence.
 - Demand

The Markets - Proteins.



Forward Hi pro Soya & Rapemeal May - Oct 24 Pricing.



- All proteins take direction from Soya meal pricing.
- Movements depend on:
 - Weather
 - Geo-political influence.
 - Demand



Protein Evaluation May - Oct 24

Product	Dry Matter	ME	CP	Oil	Delivered	£/DM	£/Kg/CP
Hi-Pro Soya	89	14.0	53	3	£ 373	£ 419	£ 0.79
Rapeseed Meal - Erith	86	11.8	38	2	£ 270	£ 314	£ 0.84
Vivergo WDDGS	89	13.4	35	4	£ 269	£ 302	£ 0.86
Rapeseed Expeller - Yelo	88	13.2	35	10.8	£ 269	£ 306	£ 0.87
Corn Distillers	90	13.6	28	1	£ 242	£ 269	£ 0.96
Hi-Pro Soya DF	89	14.0	53	3	£ 453	£ 509	£ 0.96
Novapro	89	12.9	32	10.5	£ 334	£ 375	£ 1.17



How we maximise the value of our Co-products.

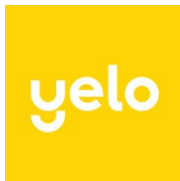


13.06.14traffordMaize Silage			FORMULATION SUMMARY		Cost per day £1.73
Feedstuff	Fresh weight	(%)	Nutrient		Amount
G. Silage HD-high acid	5.00	23.64	Fresh Weight	(kg)	21.15
Maize silage High-D	5.00	23.64	Dry matter	(%)	53.15
Barley	4.00	18.91	Dry Matter	(kg)	11.24
Traffordgold	4.00	18.91	Forage DM	(kg)	3.77
Breakfast cereal No.1	2.00	9.46	Forage Fill	(0-1)	10.90
Straw-wheat	1.00	4.73	ME Ruminants	(MJ)	135.85
KW Comp. Int. Beef	0.10	0.47	ME Ruminants	(MJ/kg DM)	12.09
Limestone Flour	0.05	0.24	FME	(MJ)	116.62
Total	21.15 kg	100.00	NDF:DM	(%)	28.64
			Starch:DM	(%)	34.39
			Sugar:DM	(%)	5.58
			Starch+Sugar:DM	(%)	39.97
			Oil B:DM	(%)	3.77
			Crude Protein:DM	(%)	11.50
			Crude Protein	(87% DM)	10.00
			ERDP:FME		7.95
			DUP	(g)	234.67
			Met.Prof.Supply	(g)	956.42
			Calcium	(g)	70.89
			Phosphorus	(g)	42.40
			Magnesium	(g)	16.35
			Salt	(g)	98.04
			Sodium	(g)	37.08
			Copper	(mg/kg DM)	15.11
			Selenium	(mg/kg DM)	0.18

Case study – Sustainability



Yelo (Novapro)



Problem

UK has been reliant on imported Soya Bean Meal for ruminants. Soya Bean Meal is seen as increasingly unsustainable and unnecessary for efficient milk production.

Solution

Worked with influencers and processors to develop demand for a protected Rapeseed meal expeller based Soya Bean Meal alternative marketed as Novapro.

Impact

Retailers now encouraging farm suppliers to ration without use of Soya. The market for Protected proteins has significantly increased.



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Case study – Feed protein



Frontier Agriculture – new UK produced feed protein product



Problem

AB Agri has a strong 'pellet' blend customer base. A reduction in the Distillers DDGS pellets left us with a supply gap.

Solution

Working with our sister company Frontier who invested £3m in a new production facility we developed a new product using a combination of low value Faba Bean fibre and UK protein to recreate the Distillers pellets.

Impact

AB Agri continues to supply UK protein pellets to a key customer base as well as adding an additional £300k value to the Faba bean fibre product stream.



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Thank you

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Realising the true value of 'wastes' - Linking resource recovery to food, energy, and the environment

Dr Becky Wheeler



Contents



Introduction

A little bit about
me and the sectors
I work in



Economy

Transitioning from
a linear to a
circular economy



Regulation

Innovation within a
strict regulatory
framework



Market

Understanding the
market for
feedstocks



Scalability

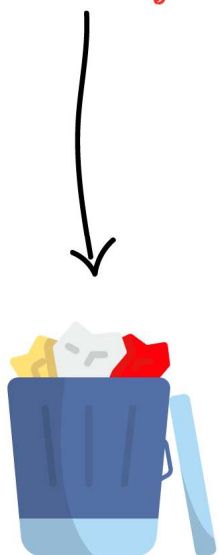
Take home
messages for
pilot-to-
commercial

About me

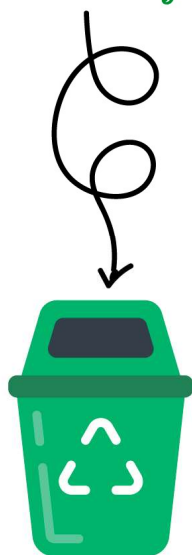


Economy

Linear economy



Recycling economy



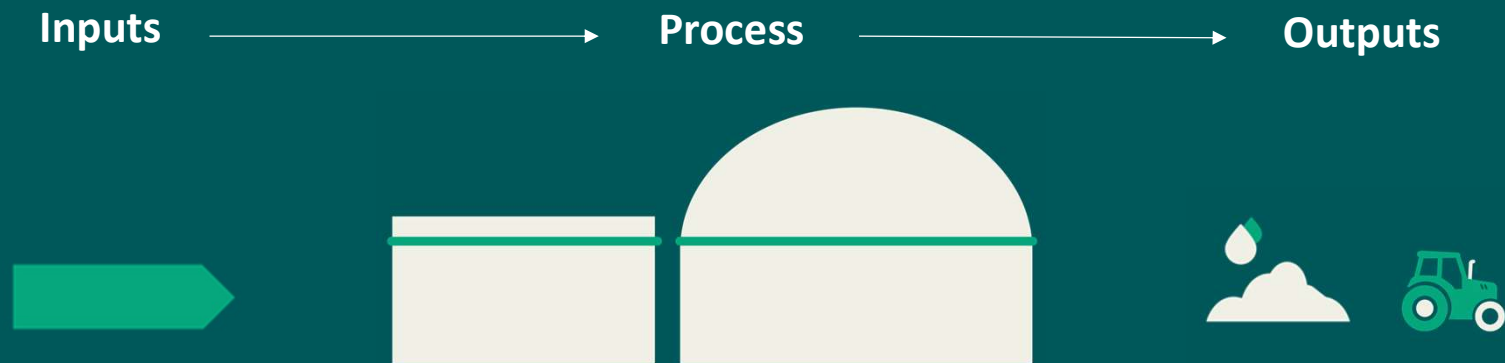
Circular economy



- ***‘By as soon as 2030, if your business model isn’t circular, you won’t be competitive.’*** WEF, 2023
- *‘With a circularity rate of 11.5% in 2022, Europe consumes a higher proportion of recycled materials than other world regions. However, progress in the EU has been slow and we are **still far from the ambition to double the Union’s circularity rate by 2030.**’* EEA, 2024

Source: Issues Online

Regulating wastes



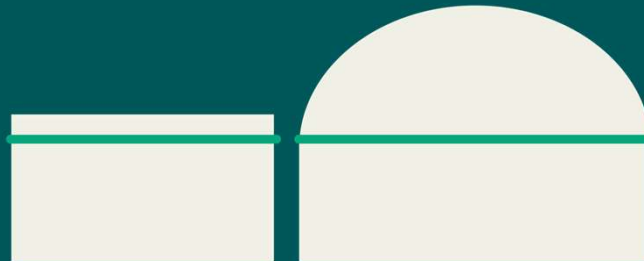
Regulating wastes

Waste Framework Directive 2008/98/EC
European Waste Catalogue
Environmental Permitting Regulations
WM3 Waste Classification
Duty of Care

Inputs

Process

Outputs



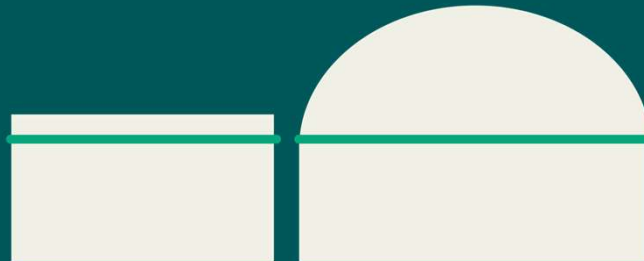
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Waste Carriers License

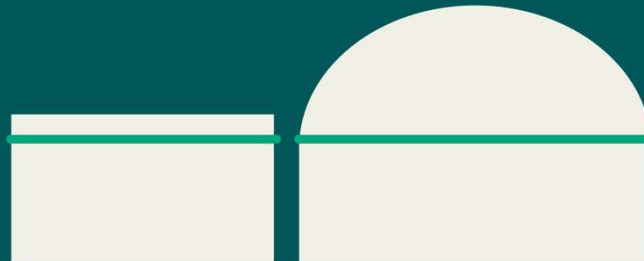
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Waste Carriers License

Local Enforcement Position (LEP) - Trials, R&D
Use, Treat, Store, Dispose Exemptions
Environmental Permit(s)
Technical Competency

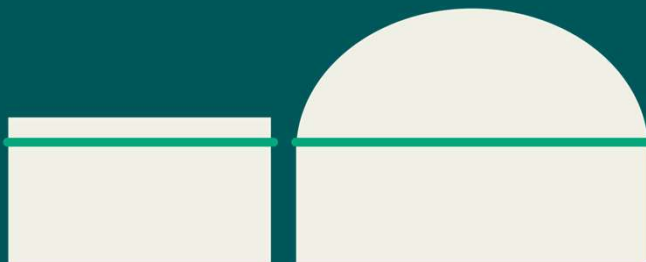
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Technical Competency

BSI Specifications e.g. PAS100/110
Quality Protocols / Resource Frameworks
Mobile Plant Permit
Sludge Regs

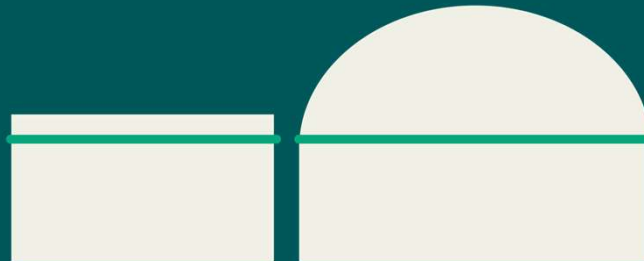
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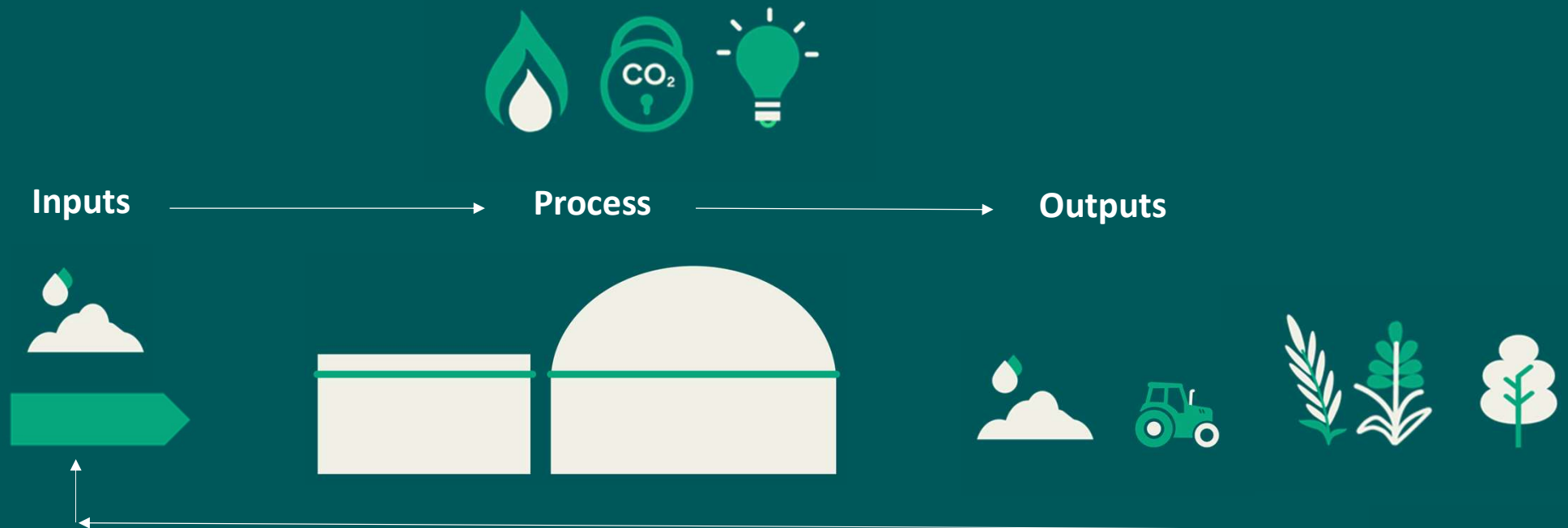
Waste Carriers License

Local Enforcement Position (LEP) - Trials, R&D
Use, Treat, Store, Dispose Exemptions
Environmental Permit(s)
Technical Competency

BSI Specifications e.g. PAS100/110
Quality Protocols / Resource Frameworks
Mobile Plant Permit
Sludge Regs

Reduction & Prevention of Ag Diff
Pollution Regs
Farming Rules for Water
CoGAP - Ammonia Emissions
CoGAP
NVZs
SSAFO / CIRIA

Food, energy & environment



AD feedstock market

- Regional market, highly variable
- Value based on biogas yield, volume and quality (i.e., contamination with packaging)
- Gate fees tracked value of gas upwards in 2022: As margins were made on gas/electricity, AD operators could pay more for feedstock
- Waste became a commodity, the polluter no longer pays

Table 3: Summary of UK AD gate fees reported by local authorities, 2022 (£/tonne)

Gate fee type	Median (£/t)	Mean (£/t)	Mode (£/t)	Range (£/t)	Response count
Food waste	13	16	10.01 to 15	-26 to 71	78

Food waste

- Food 'soup' – waste is prepared, de-contaminated and made into a more homogenous material
- *"Current market ~£50/t-£80/t"*
- *"~£40/t ex works in Yorkshire/Northeast"*
- Value dependent on potential gas yield – (typically 140-250m³ of biogas/t)



Liquid waste

- Manufacturing wastes, processing by-products, treatment outputs, wash waters *etc*
- Variable market
- Calorific value tends to be lower, but this is very waste/site-specific
- Ranges from traditional gate fee (producer pays e.g., ~£10/m³ to recycle), free drop, and AD operators may pay for higher value liquids (e.g., £5-£10/t)



Agricultural waste

- Regional, and market can be heavily impacted by weather, and location/proximity of producers and end users
- Straw - “£80-£110/t”
- Chicken Litter – “£30-£40/t”
- Cow manure – “£10/t”



Scalability

- Waste regulatory requirements for:
 - Lab-scale
 - Pilot-scale
 - Commercial implementation
 - Feedstock market research:
 - Longevity / consistency
 - Quality
 - Competing facilities / end uses
- LCA
 - Economics





Thank you

Dr Becky Wheeler
Business Development Director

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futurebiogas.com



Waste Valorisation at Pilot Scale

BBNet Annual Meeting 11th April 2024

Connecting industry & research

We **connect industry & research** to develop, scale-up and commercialise bio-based products and processes.

Multidisciplinary team of biologists, chemists, and innovation advisers with pilot-scale processing in a single coordinated centre.



Biorenewables R,D & D

BDC helps to bridge the gap between academia and industry in the research, development and demonstration of bio-based innovations:



Research

Inventors

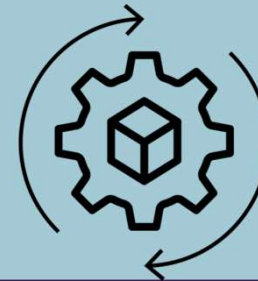
Feedstock, process
and product research
and discovery

BDC

Development

Pilot facilities

Scale-up and
demonstration



Demonstration

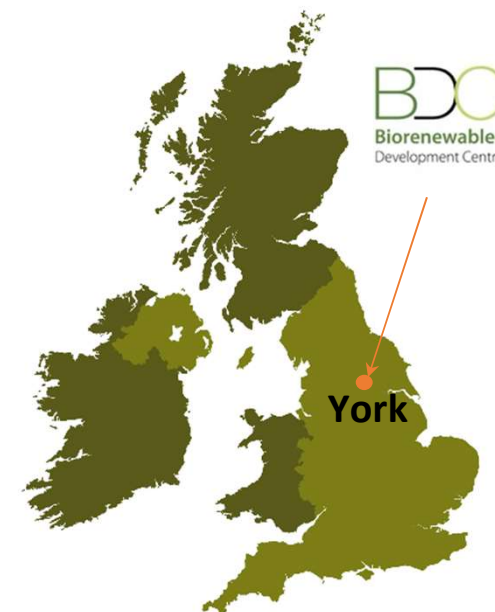
SMEs &

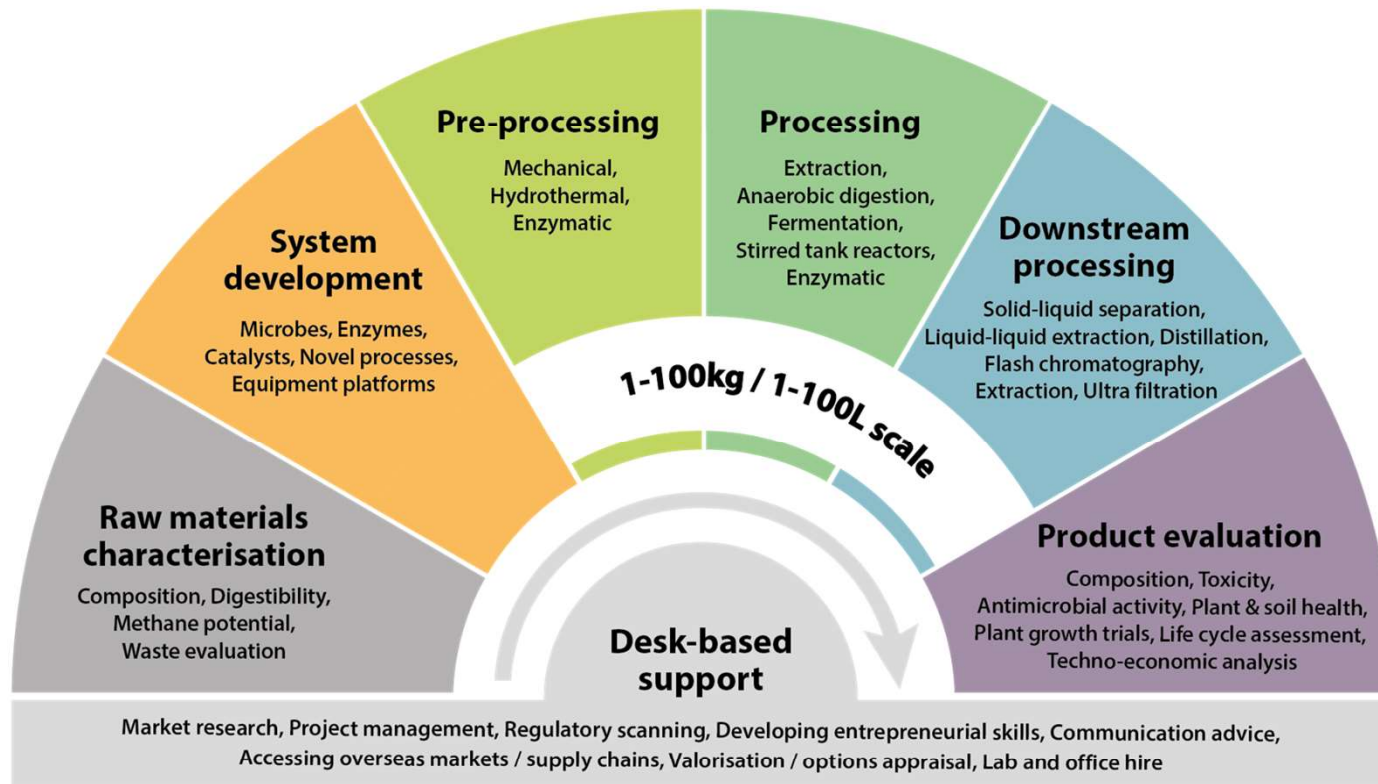
Multinationals

Process and product
development

BDC Biorenewables Development Centre

Plants • Processes • Products





Biorefining Research, Development & Demonstration at the BDC



Waste Mapping



Waste valorisation



Project partners:

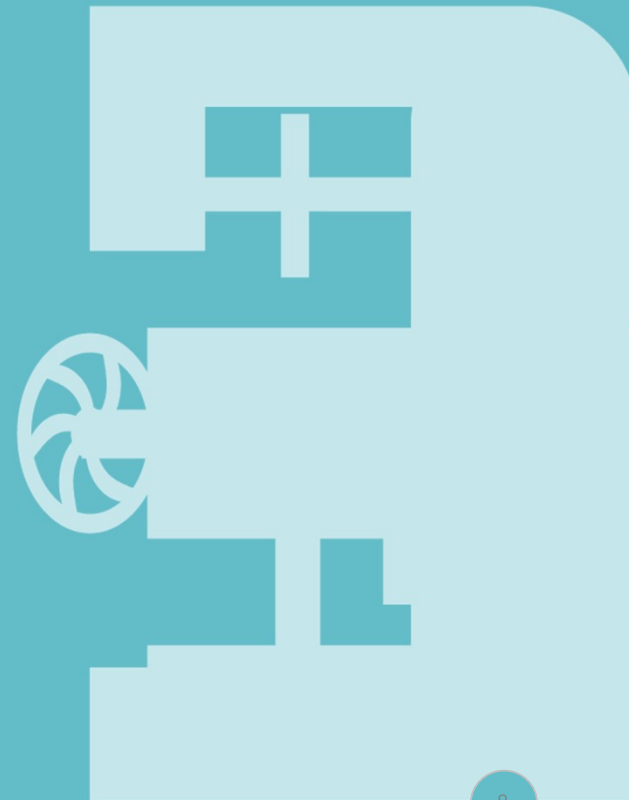


Problems!

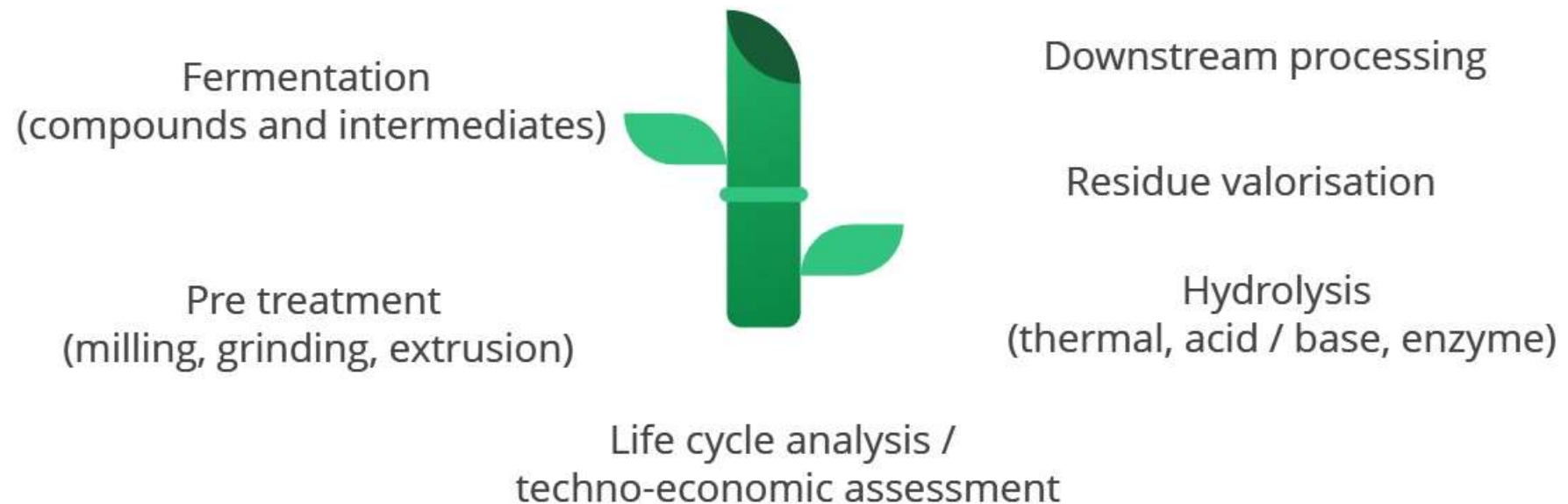
- Waste – Co-Product – Feedstock – Value
- Data
- Preconceived ideas
- Waste is not always a waste
- Knock on effects
- Transport, shelf life, risk etc



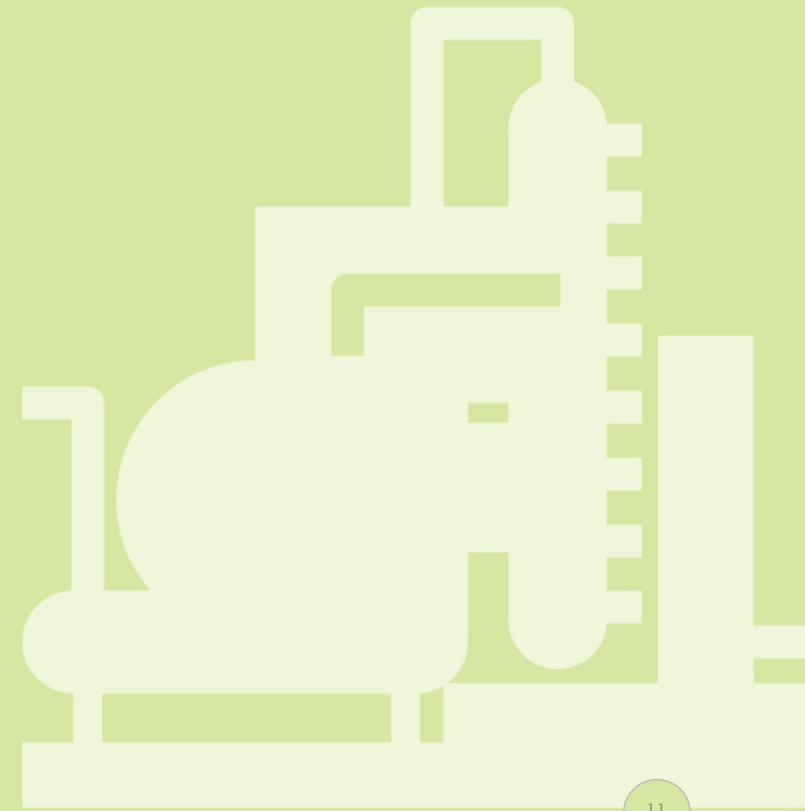
Crude Sugar



Activities around Crude Sugar



Upstream Processing



Pre-Treatment Options

- Physical
 - Drying, chipping, chopping, grading, pelletising etc
- Sugar release
 - Acid / Base
 - Hot water / steam explosion
 - Enzymatic
 - Microwave/Ultrasound/Ionic Liquid/Organosolv etc
- Thermochemical
 - Torrefaction and pyrolysis



Saccharificati



With thanks to the funders:

High-value chemicals from food by-products



Production of antibiotics using alternative sugar sources

Novel processes for existing products, reduce waste
Sector: pharmaceuticals



Pre-processing

milling
enzyme hydrolysis

Downstream processing

S/L separation
ion exchange

Processing

fermentation

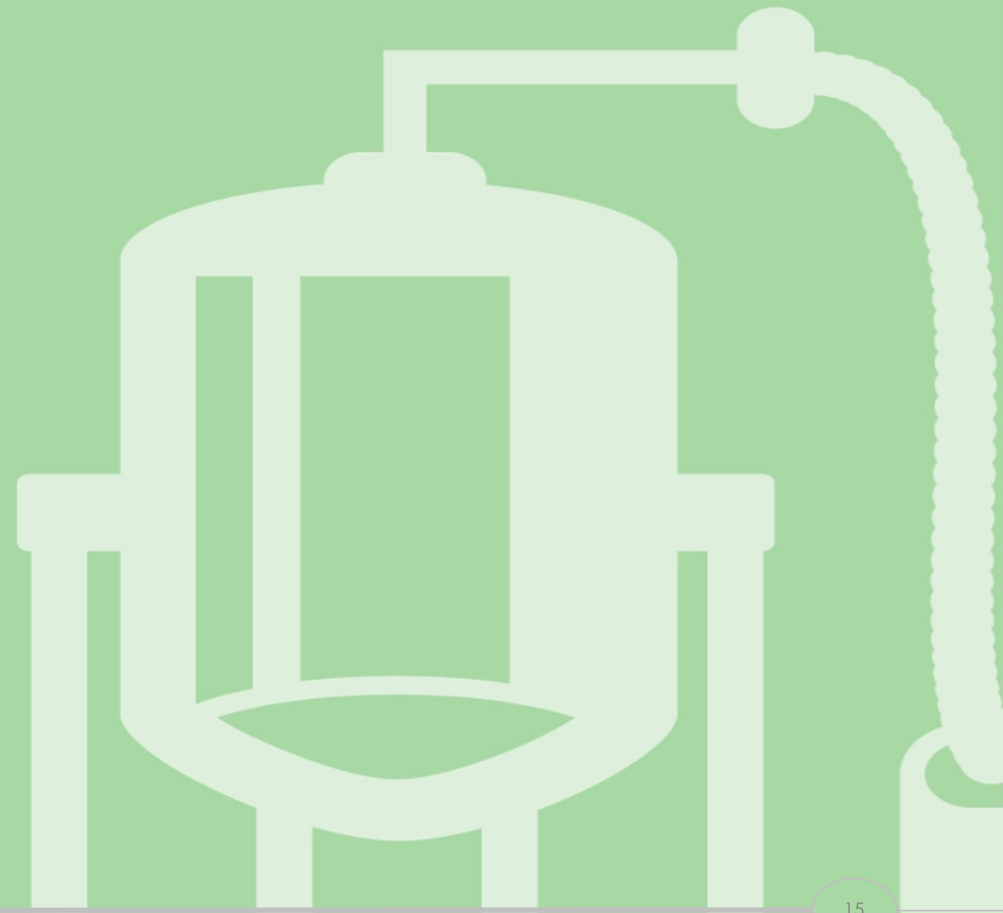
Downstream processing

Analysis

THYME Project
Teesside, Hull and York - Mobilising Bioeconomy Knowledge Exchange



Fermentation



Food processing wastes – Production of high value compounds by fermentation

CRODA
Home Care



Identify
glucose
alternatives



Food and Drink sector

Cosmetics, personal care, pharmaceuticals

Fermentation

Replacing glucose sugar streams in fermentation with food processing wastes in the production of anti-fungal compounds

- Pasta cook water, sushi rice wash water – starchy, high volume
- Salty whey, whey permeates – cheese production
- Wheat straw – glucose from lignocellulose
- Molasses – sucrose, glucose
- Waste bread – sandwich preparation

Case study: Newton Bhabha - Sugar cane bagasse to citric acid

- University of York
- ICGEB, India
- BDC
- Natems Sugar
- Jesmond Engineering
- Wilson Bio-Chemical
- Prozomix

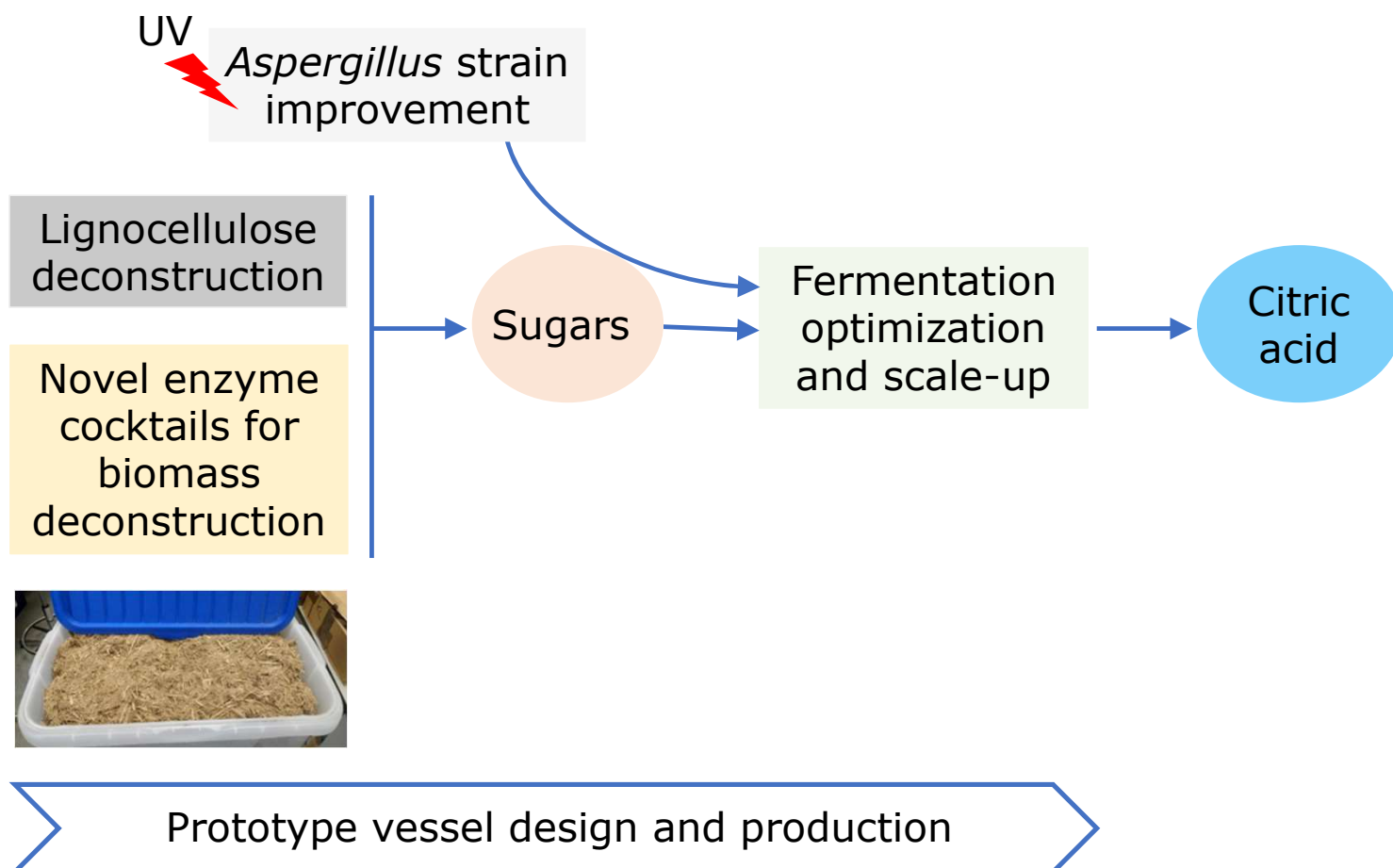


Department
of Biotechnology
Govt. of India

 Newton-Bhabha
Fund

 UKRI
Innovate
UK

 UKRI
Biotechnology and
Biological Sciences
Research Council



Case study: Newton Bhabha - Sugar cane bagasse to citric acid

- Fermentation scale-up
- Enzyme cocktail production



Shake
flask



0.5 L
fermenter



5 L
fermenter



30 L fermenter

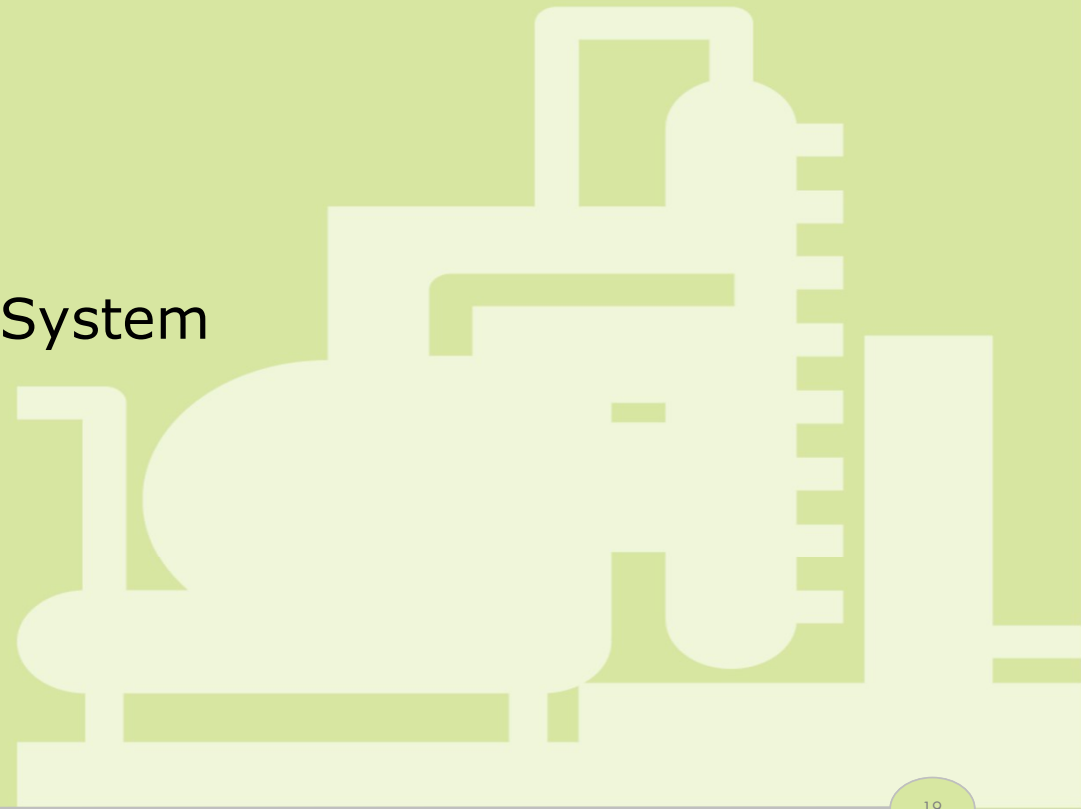
Citric acid yields:

- 60 – 140 g/L

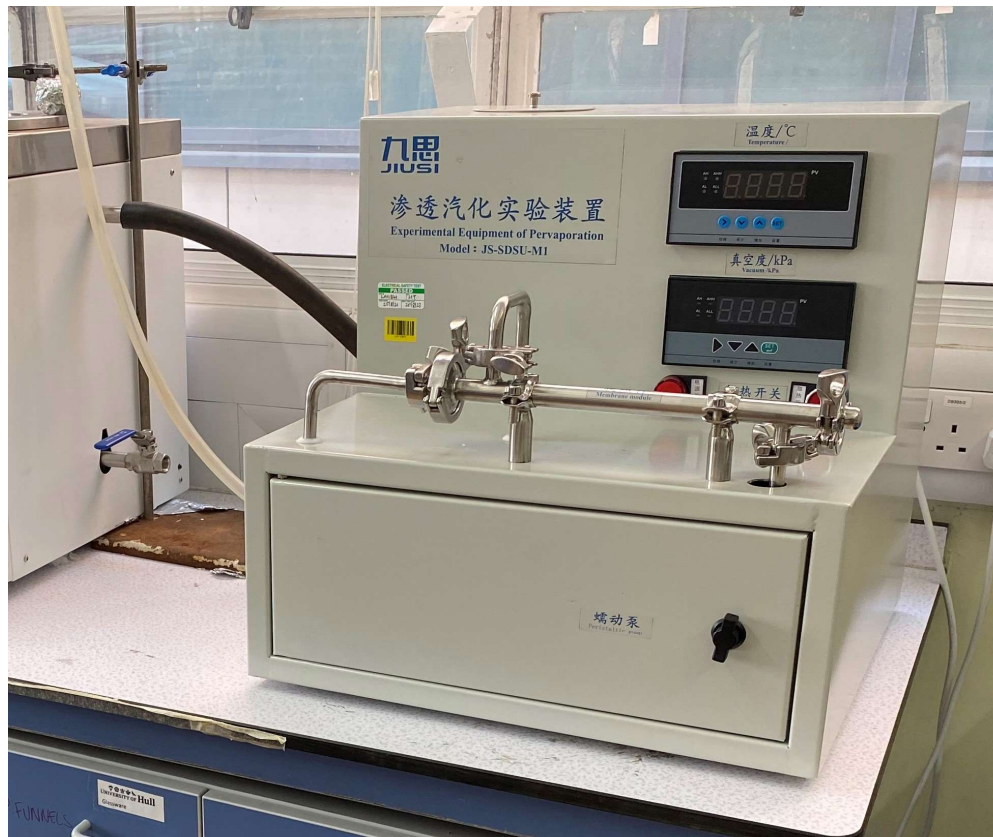


Downstream Processing

Development of a Pervaporation System

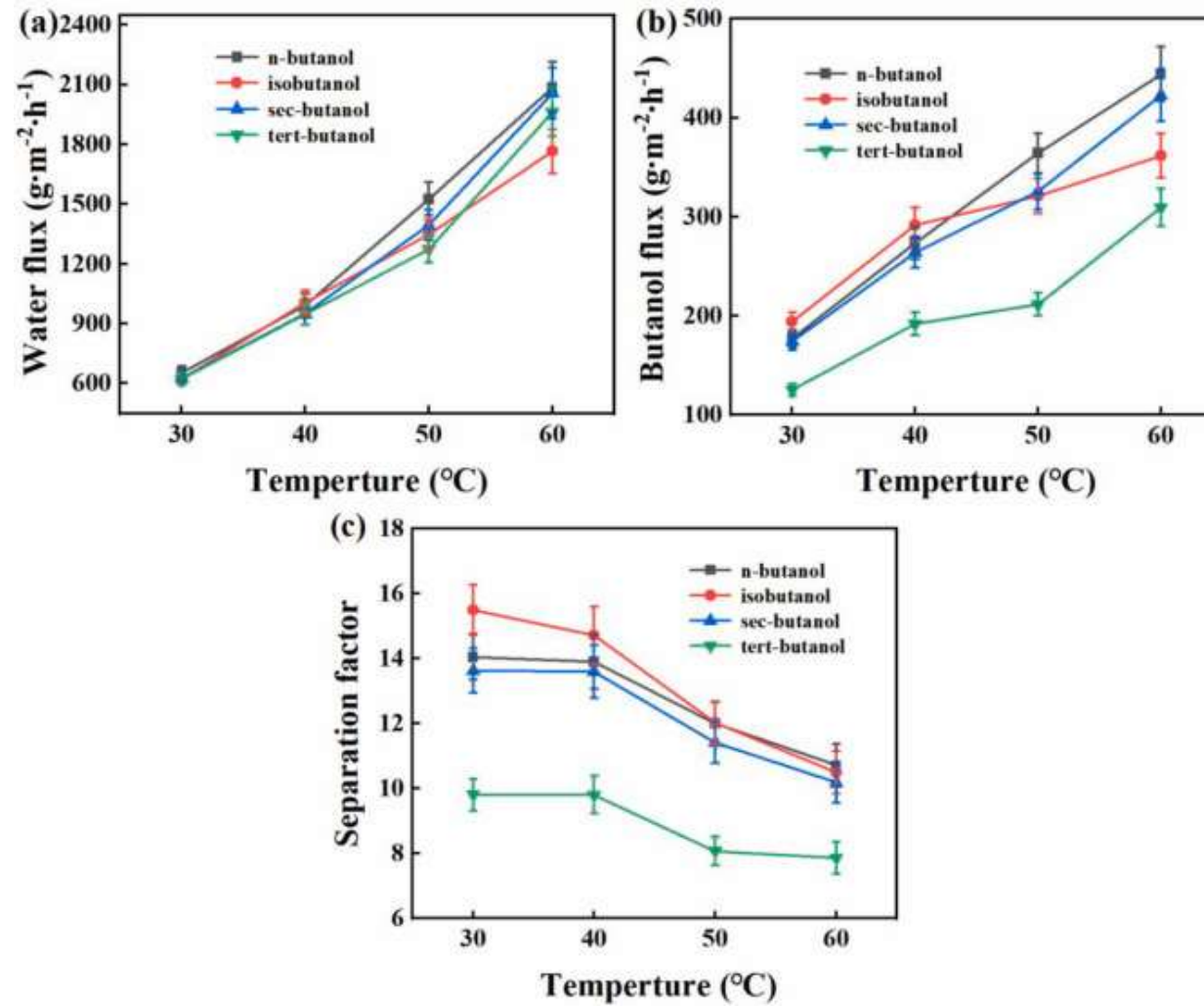


System Number 1



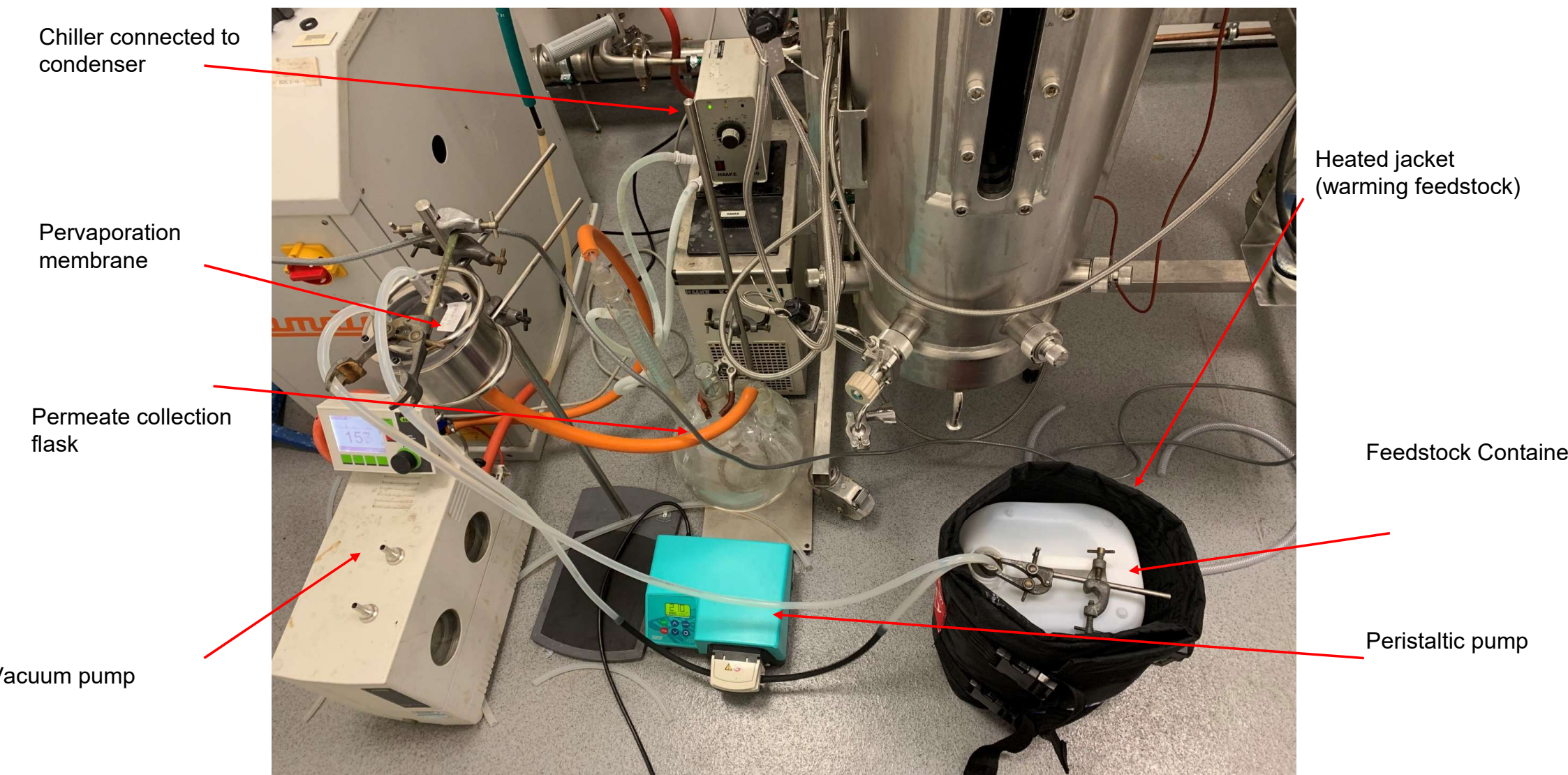
Membrane -polydimethylsiloxane (PDMS) top layer, polyvinylidene fluoride (PVDF) intermediate layer and non-woven fabrics substrate layer.

Flux and Temperature Data



Getting “Real”

- Expanding the range
 - Ethanol
 - ABE
 - Lactic acid
- Real fermentation broths
- Integration with fermenter
- Potential end user feedback



Energy efficient method for recovering high purity organic solvents from low concentration solutions (usually below 1 %)

Membrane separations typically require only 10% to 30% of the energy consumption compared to thermal processes

Enrichment up to **75-fold per pass** (0.57 wt% to 42.7 wt%)

Flux up to 200 g/m²/hr

THYME Project

Teesside, Hull and York - Mobilising Bioeconomy Knowledge Exchange

Thank you

Xuebin Ke, John Angus, Rosie Nolan, Chengye Zuo,, Jake Hindley, Xiaobin Ding, Weihong Xing, Aaliah Akhtar & Raymond Sloan

Industrial Collaborators - Nanjing Jiushi High-Tech Co., Ltd.



Down Stream Processing

Protein Extraction





Protein from stock feed potatoes and peel

Project Lead - Darren Phillips

Innovate UK

A novel ultrafiltration process to extract valuable proteins from potato peelings and waste

(<https://gtr.ukri.org/projects?ref=103919>)

Lead Participant: B-Hive Innovations Limited

◀ Go back

Overview

Organisations

People

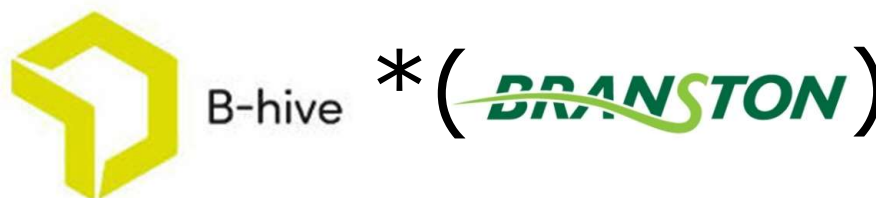
Abstract

This project aims to develop a new process to extract valuable complete undenatured proteins from potato waste (whole stockfeed grade potatoes and peel), for use as high quality food grade vegan/vegetarian protein supplements, sport protein sources and as

Funded Value:

£956,027

Funded Period:



Background information

- Protein content of potatoes around ~2% (wet weight)
- The global Potato Protein market is valued at 88 million US\$ in 2018 and will reach 110 million US\$ by the end of 2025
- Production of potato protein is distributed in Europe such as Netherlands, France, Denmark and Finland.

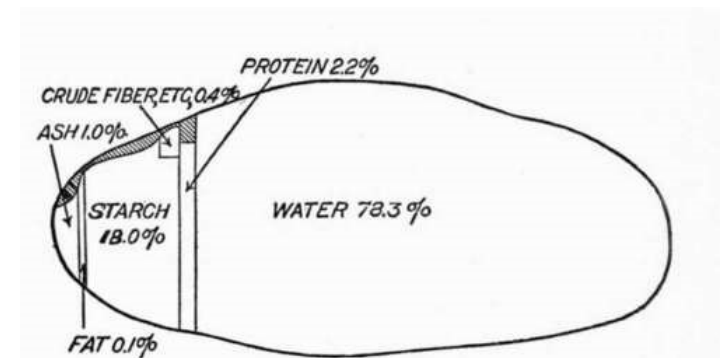
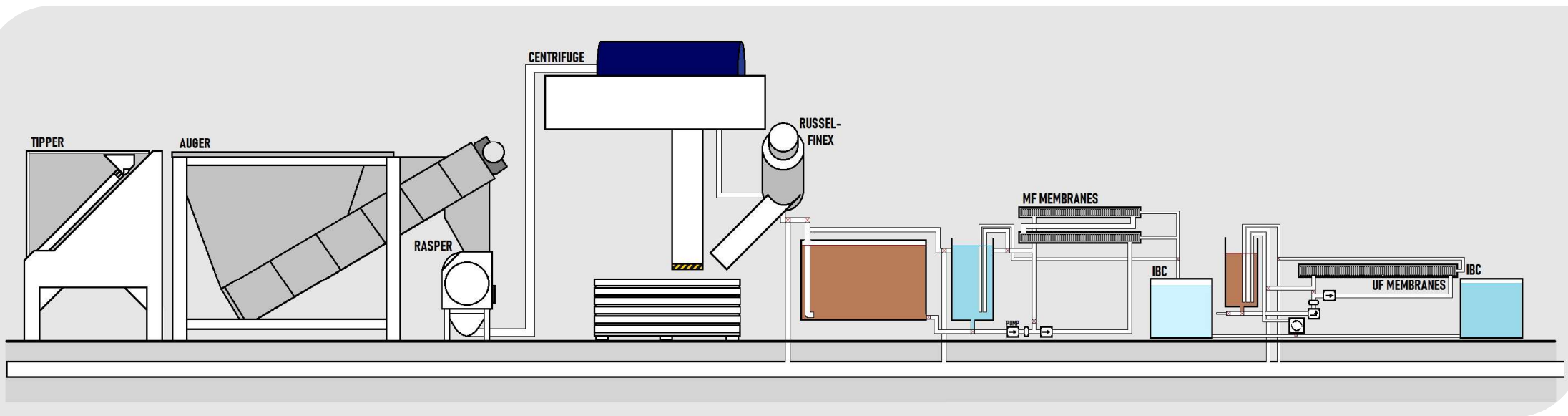


Figure 1: Composition of a potato

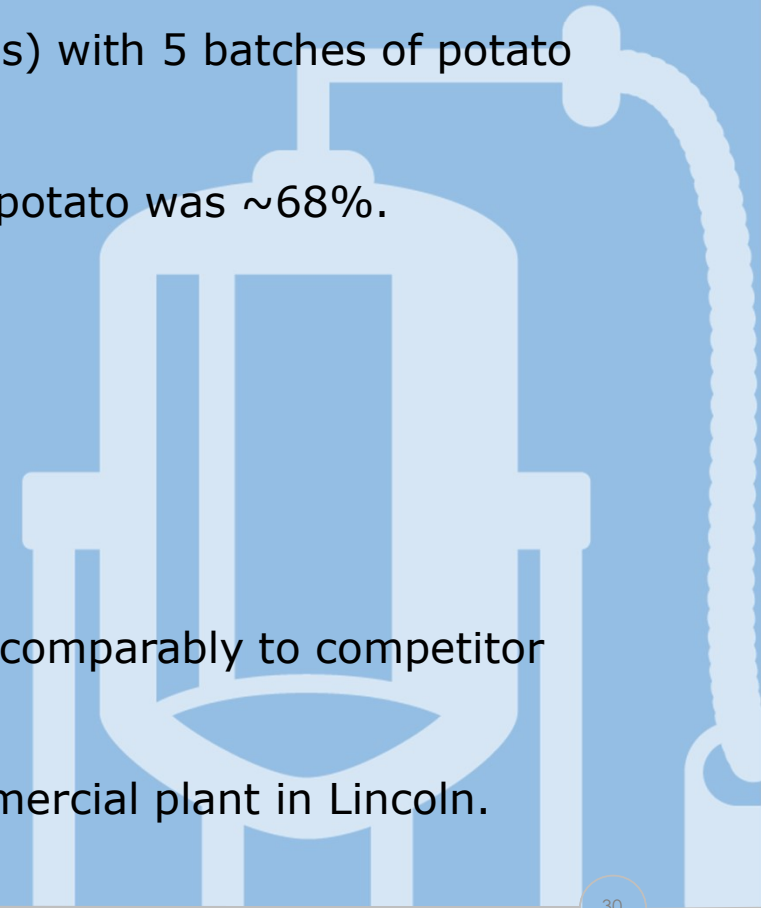


Pilot plant (1 tonne per batch).



Challenges

- In total, over 40 tonnes of potatoes processed (42 batches) with 5 batches of potato peel.
- Protein purity average achieved on plant from stock feed potato was ~68%.
- Factors affecting protein purity include:
 - Condition of potatoes (fresh/stored?)
 - Potato variety
 - Spoilage
 - Seasonality
- Protein produced from plant has been tested and scored comparably to competitor product when comparing texturizing, gelling and taste.
- Results from pilot plant used to build 6 tonne batch commercial plant in Lincoln.



Thank you

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Mark.Gronnow@york.ac.uk





**Sheffield
Hallam
University**

Bioremediation of Heavy Metals

Using Yeast

Walid Omara
Sheffield Hallam University

Heavy metal and Bioremediation

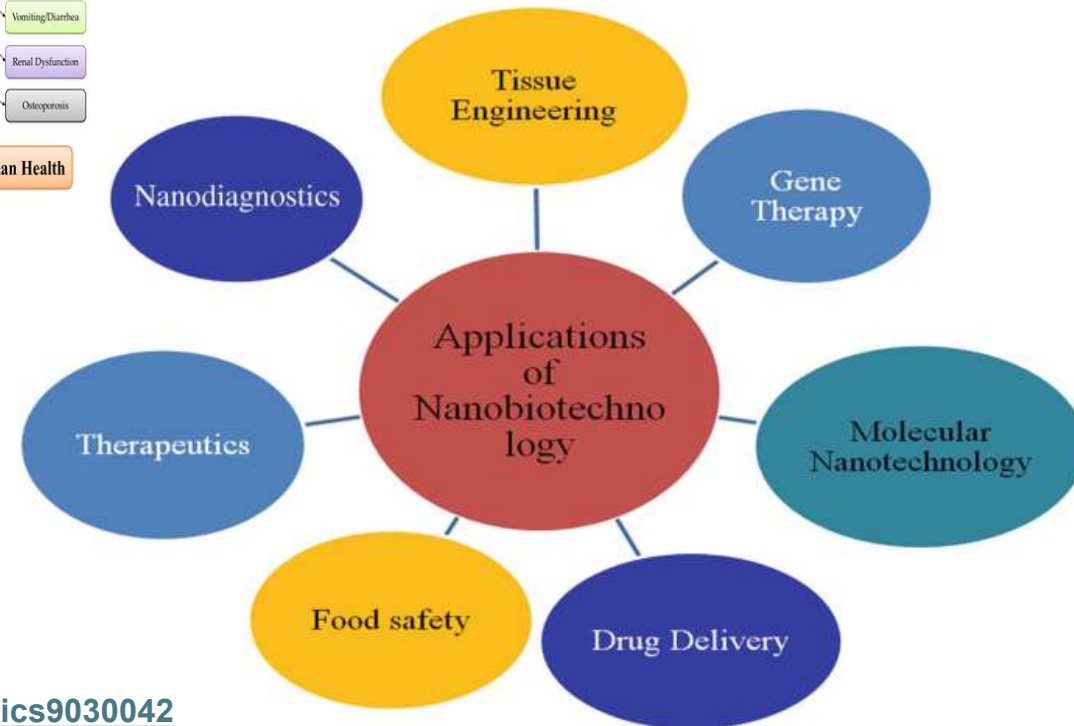
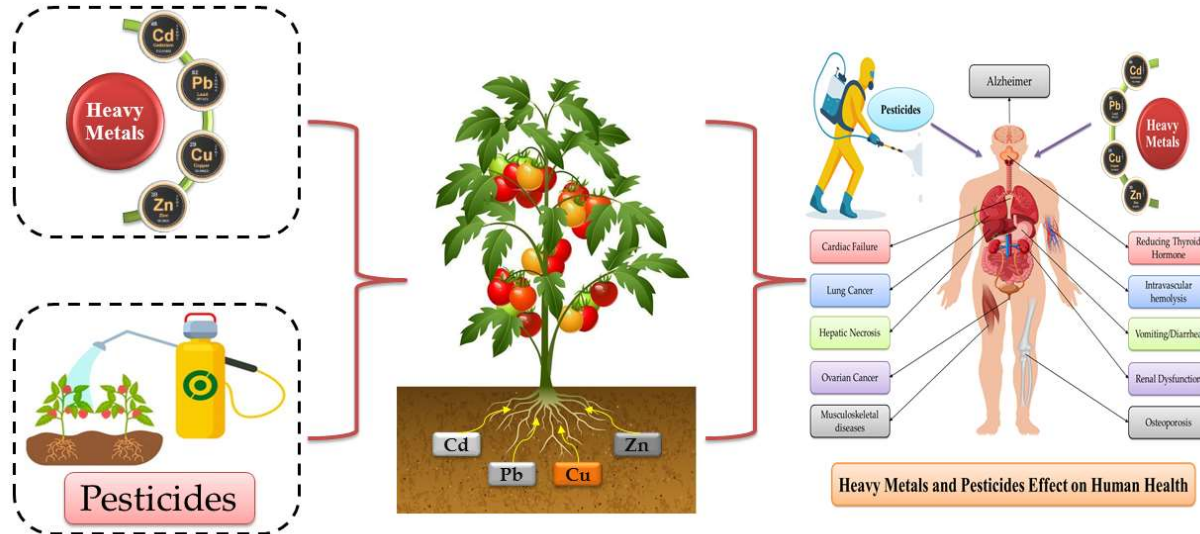
- Heavy metal contamination poses significant risks to both environmental and human health, leading to detrimental effects such as soil degradation, water pollution, and severe health complications including neurological disorders and organ damage.
- Bioremediation, an innovative environmental cleanup technique utilizing living organisms to degrade pollutants, holds significant promise for mitigating contamination while promoting ecological restoration.
- Yeast shows promise as a potential bioremediation agent due to its ability to metabolize various pollutants, offering a sustainable solution for environmental cleanup efforts



1 H Hydrogen																	2 He Helium														
3 Li Lithium	4 Be Beryllium															5 B Boron	6 C Carbon	7 N Nitrogen	8 O Oxygen	9 F Fluorine	10 Ne Neon										
11 Na Sodium	12 Mg Magnesi...															13 Al Aluminium	14 Si Silicon	15 P Phosph...	16 S Sulfur	17 Cl Chlorine	18 Ar Argon										
19 K Potassium	20 Ca Calcium	21 Sc Scandium	22 Ti Titanium	23 V Vanadium	24 Cr Chromium	25 Mn Manganese	26 Fe Iron	27 Co Cobalt	28 Ni Nickel	29 Cu Copper	30 Zn Zinc	31 Ga Gallium	32 Ge Germani...	33 As Arsenic	34 Se Selenium	35 Br Bromine	36 Kr Krypton														
37 Rb Rubidium	38 Sr Strontium	39 Y Yttrium	40 Zr Zirconium	41 Nb Niobium	42 Mo Molybde...	43 Tc Techneti...	44 Ru Ruthenium	45 Rh Rhodium	46 Pd Palladium	47 Ag Silver	48 Cd Cadmium	49 In Indium	50 Sn Tin	51 Sb Antimony	52 Te Tellurium	53 I Iodine	54 Xe Xenon														
55 Cs Caesium	56 Ba Barium	57 La Lanthan...	72 Hf Hafnium	73 Ta Tantalum	74 W Tungsten	75 Re Rhenium	76 Os Osmium	77 Ir Iridium	78 Pt Platinum	79 Au Gold	80 Hg Mercury	81 Tl Thallium	82 Pb Lead	83 Bi Bismuth	84 Po Polonium	85 At Astatine	86 Rn Radon														
87 Fr Francium	88 Ra Radium	89 Ac Actinium	104 Rf Rutherford...	105 Db Dubnium	106 Sg Seaborg...	107 Bh Bohrium	108 Hs Hassium	109 Mt Meitneri...	110 Ds Darmsta...	111 Rg Roentge...	112 Cn Coperni...	113 Nh Nihonium	114 Fl Flerovium	115 Mc Moscovi...	116 Lv Livermor...	117 Ts Tenness...	118 Og Oganes...														
																		58 Ce Cerium	59 Pr Praseod...	60 Nd Neodym...	61 Pm Prometh...	62 Sm Samarium	63 Eu Europium	64 Gd Gadolini...	65 Tb Terbium	66 Dy Dysprosi...	67 Ho Holmium	68 Er Erbium	69 Tm Thulium	70 Yb Ytterbium	71 Lu Lutetium
																		90 Th Thorium	91 Pa Protacti...	92 U Uranium	93 Np Neptunium	94 Pu Plutonium	95 Am Americium	96 Cm Curium	97 Bk Berkelium	98 Cf Californi...	99 Es Einsteini...	100 Fm Fermium	101 Md Mendelev...	102 No Nobelium	103 Lr Lawrenc...

Heavy metals are a group of metals and metalloids that have relatively high density and are toxic even at ppb levels. Examples include Pb, As, Hg, Cd, Zn, Ag, Cu, Fe, Cr, Ni, Pd, and Pt.

Risks and Benefits of Heavy Metal



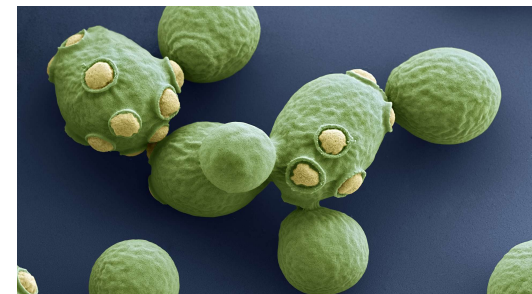
Environment Clean up vs Bioremediation

- Traditional chemical methods often involve harsh interventions that can be costly and environmentally damaging, whereas bioremediation harnesses the natural processes of living organisms to degrade pollutants, offering a more sustainable and eco-friendly approach to environmental cleanup.
- Bioremediation offers distinct advantages over traditional methods, being both cost-effective and eco-friendly, as it harnesses natural processes to restore contaminated environments without the need for expensive and disruptive interventions
- Microorganisms such as yeast play a crucial role in bioremediation by utilizing their metabolic abilities to degrade pollutants, offering a sustainable and efficient approach to environmental cleanup



Why Yeast

- *Saccharomyces cerevisiae* has been used in many studies involving metal nanoparticles
- robust metabolic capabilities and adaptability to diverse environmental conditions
- Ability to accumulate heavy metals, making it a promising candidate for bioremediation applications
- It has been hailed as a 'model organism' in the field of nanobiotechnology
- It is readily available and because of its ability to produce stable nanoparticles
- yeast is often preferred over the other types of micro-organisms since yeast can be grown quickly via nutrient culture media, and the mass production of yeast can be controlled easily
- Sustainable and efficient platform for the eco-friendly production of diverse metal nanoparticles



Metal Nanobiotechnology

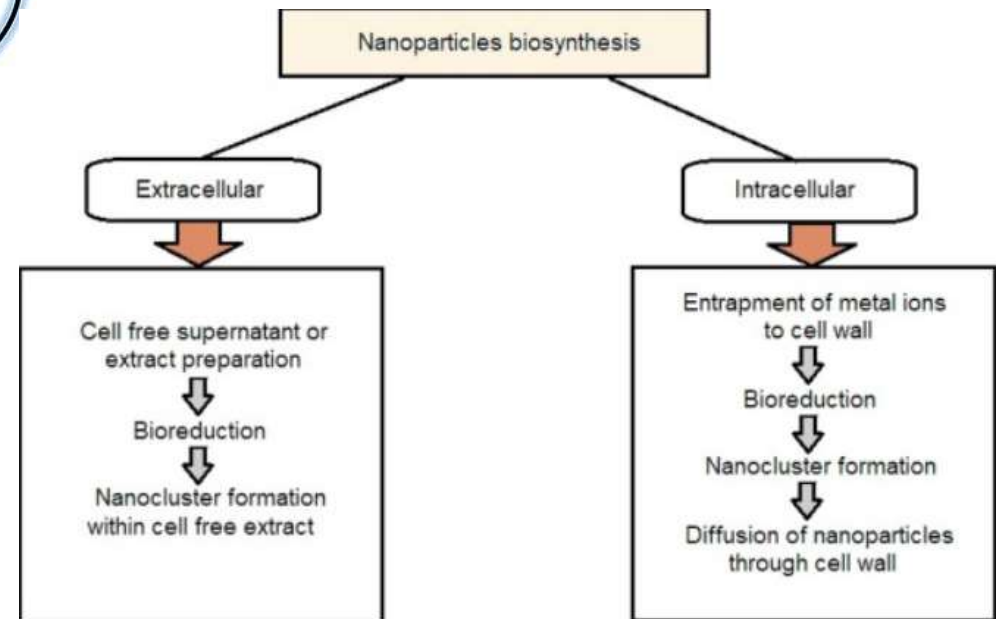
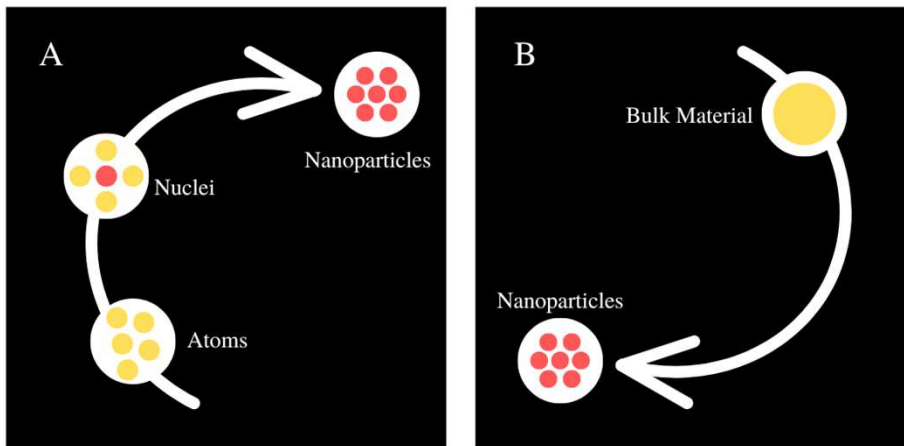
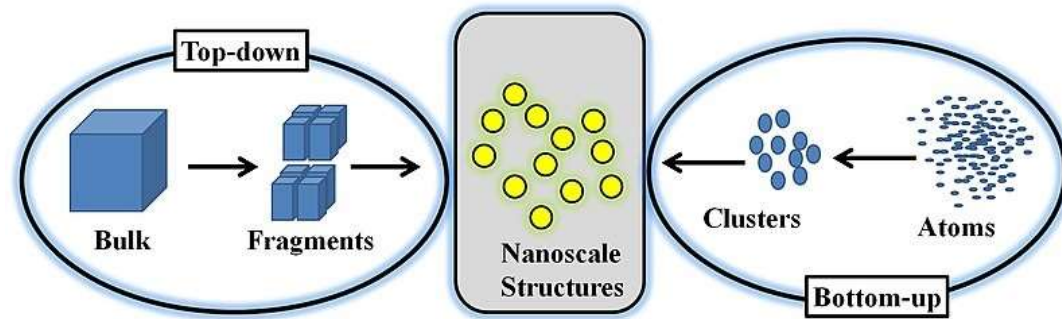
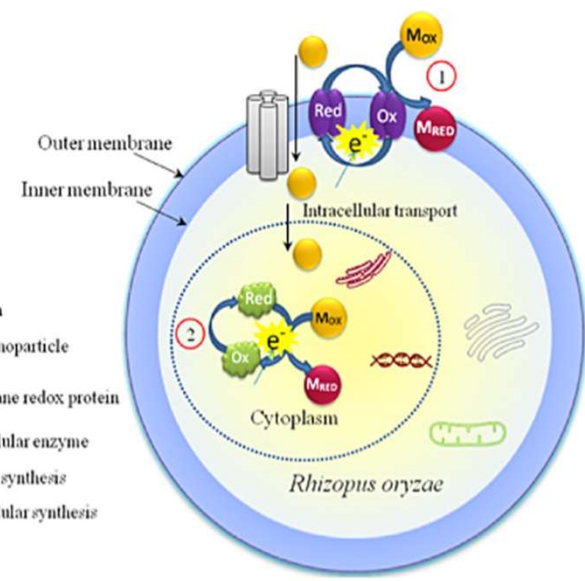
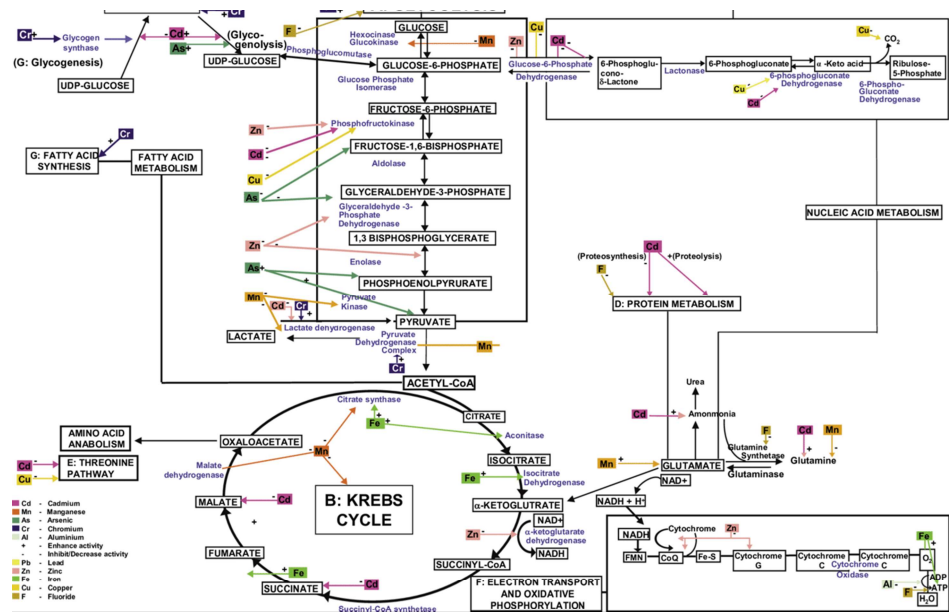
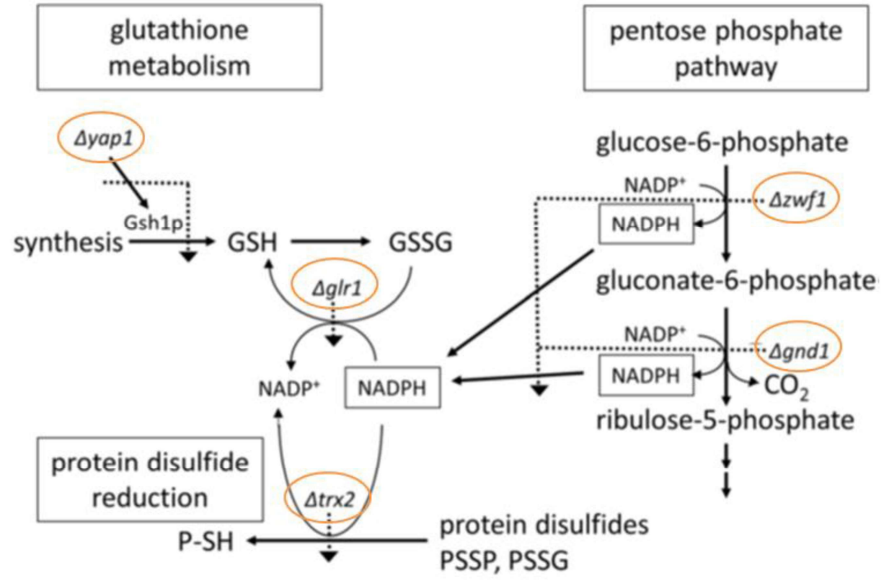
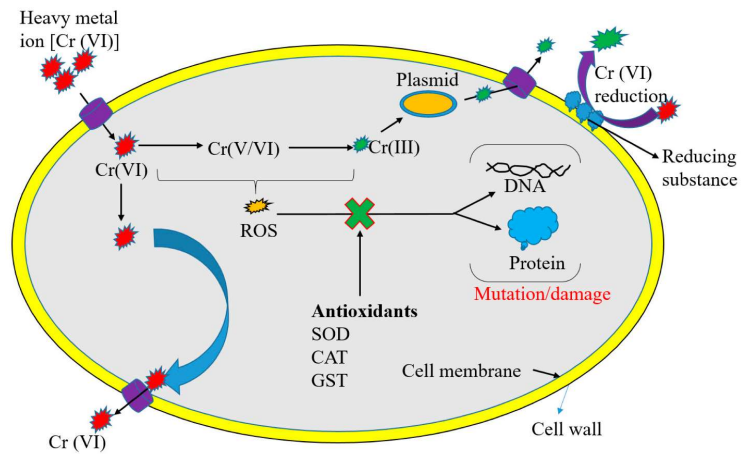


Figure 1: Top-down and bottom-up approach of the synthesis of nanoparticles (nanoScience, 2023).

Mechanisms of Biosynthesis



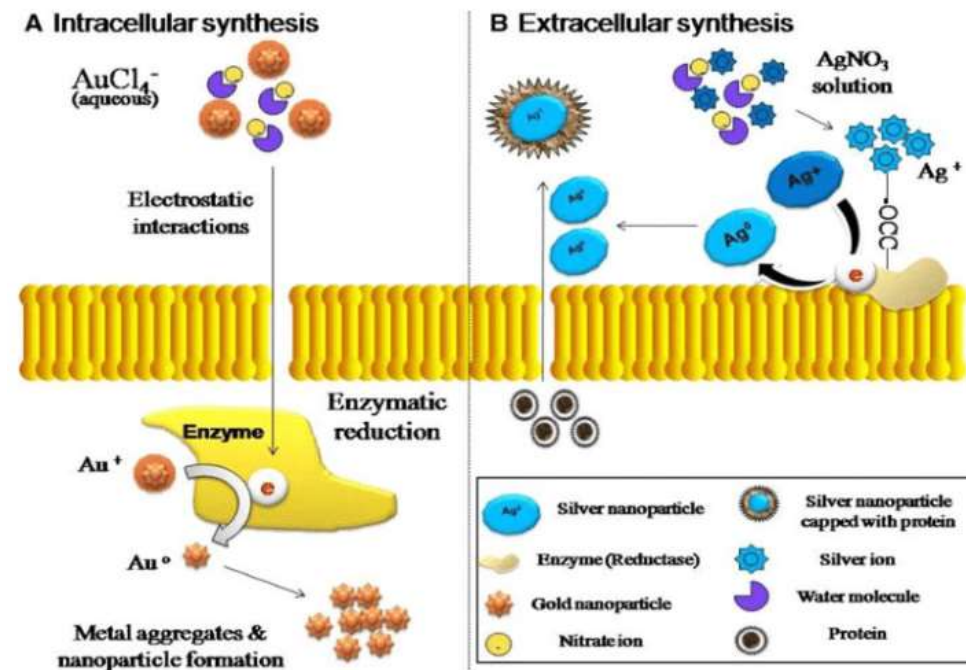
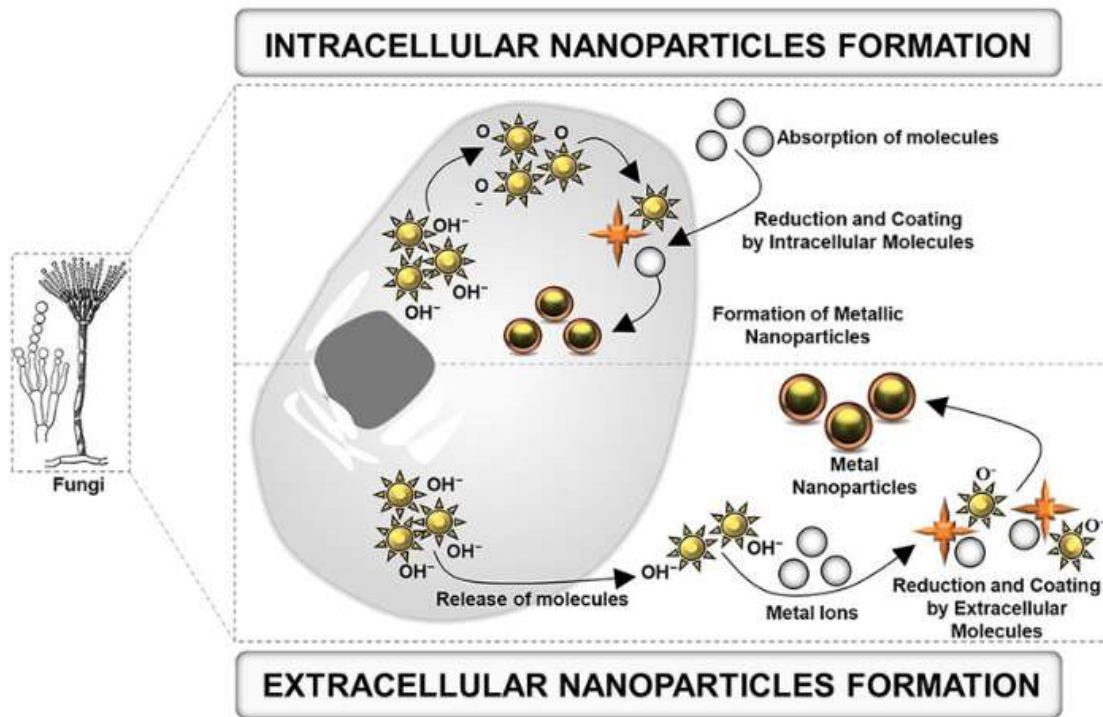
- Gold ion
- Gold nanoparticle
- Membrane redox protein
- Intracellular enzyme
- 1 Surface synthesis
- 2 Intracellular synthesis



metabolic pathways affected by metal ions (C Strydom et al, 2006)

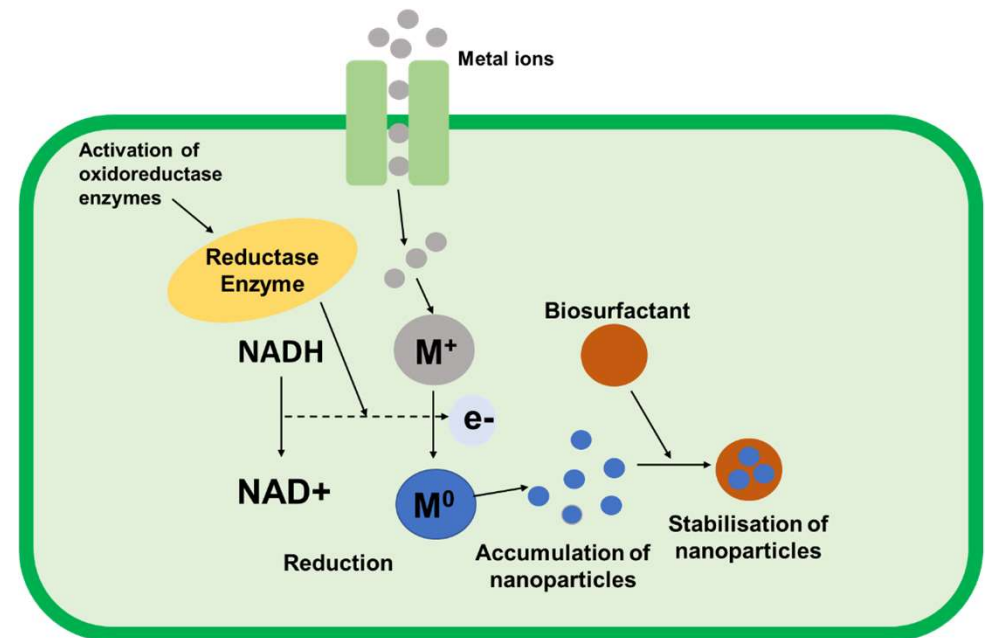
Biosynthesis by Yeast

- Yeast produces metal nanoparticles from the oxidoreductase and quinones which is membrane bound. Reductases also activated from the increase in pH levels.
- *Saccharomyces cerevisiae* (Baker's yeast) is widely studied in genetics and physiology thus genes related to glutathione metabolism (e.g., GSH1, GLR1) and ion homeostasis (e.g., CCC1, PMR1)



Hypothesis

- *Saccharomyces cerevisiae* is able to produce large number of metal nanoparticles in large amounts
- Each metal nanoparticle will need some optimisation for optimum production
- There is a universal pathway for biosynthesis in addition to specific metabolic pathway for some metal nanoparticles



Universal/Specific Pathway for Metal nanoparticle biosynthesis in Yeast

Comparative Study Design

Variables/ Parameters

- Substrate or precursors
- Concentration
- Time of addition
- Time of harvesting
- Growth media
- pH
- Temperature
- Shaking speed
- Yeast strain
- Separation techniques

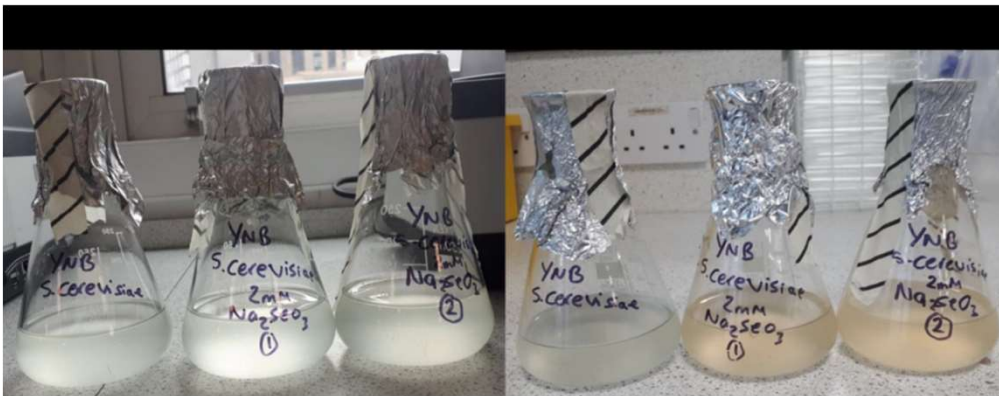
Sampling

- Head space
- Cell Palettes
- Nanoparticles
- Supernatants

Characterisation

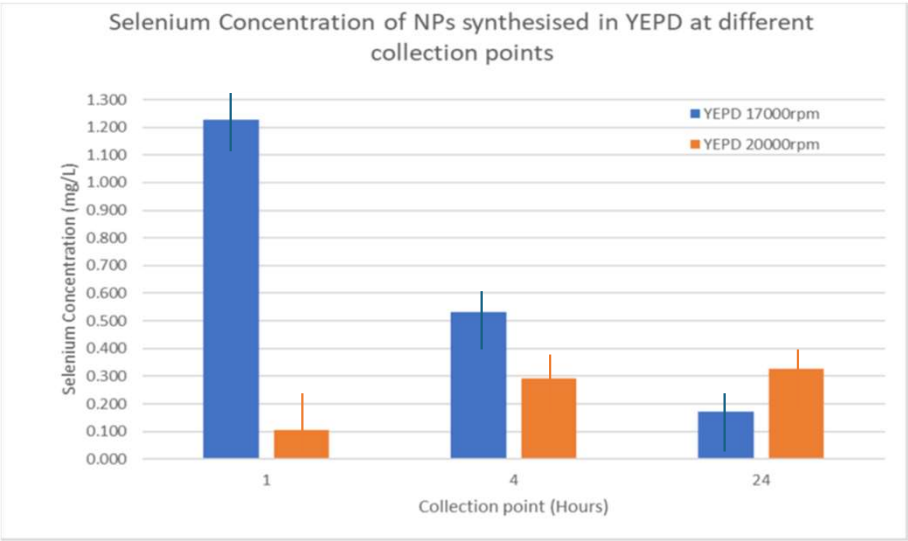
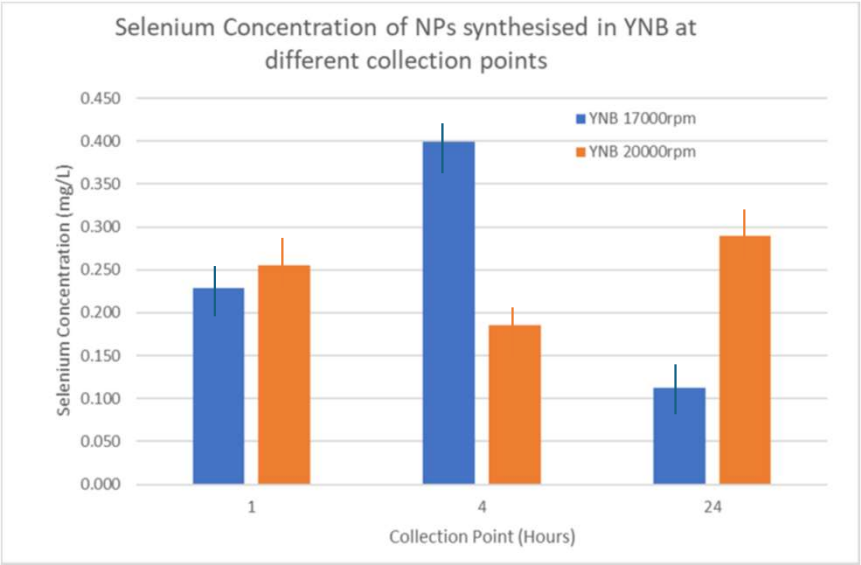
- UV/Vis Spectrophotometry
- FTIR
- ICP/MS
- LC/MS
- Fluorescence Microscopy
- Metabolomics
- Transcriptomics
- Proteomics
- TEM & SEM

Se NPs

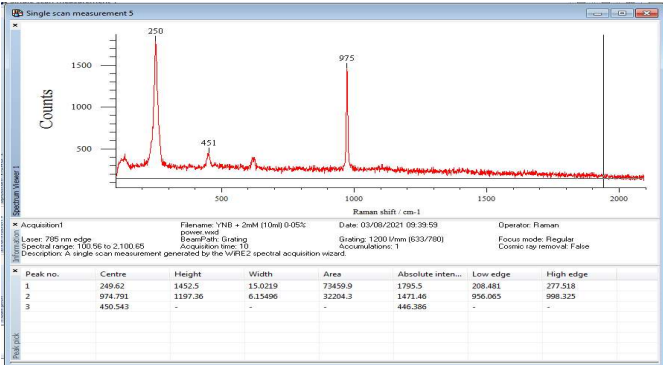
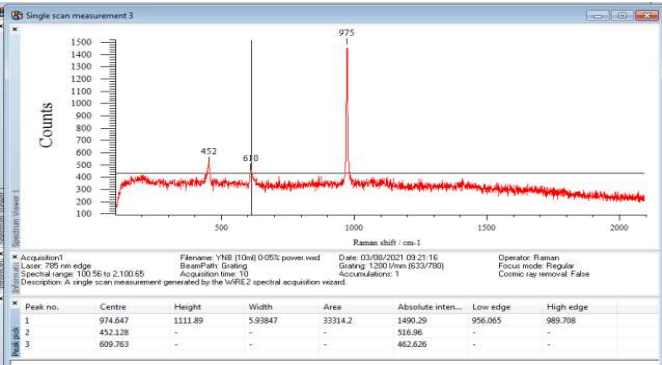
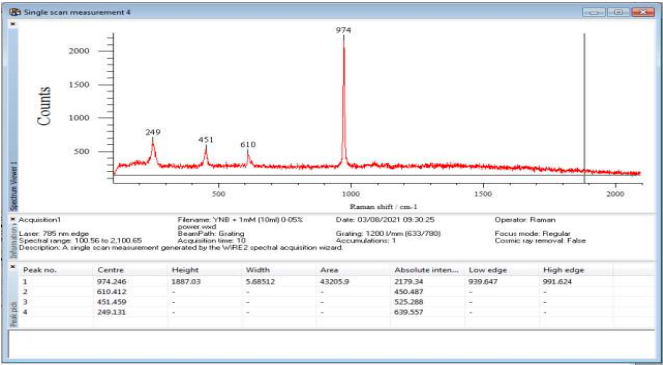


Se NPs

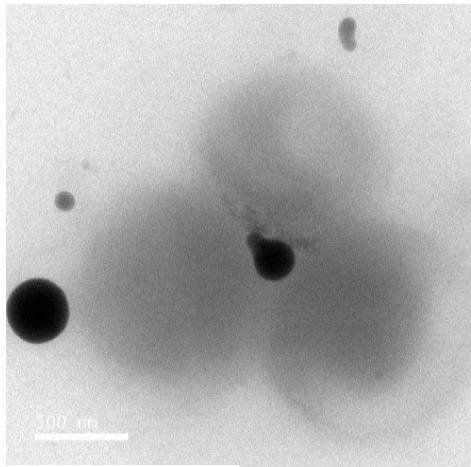
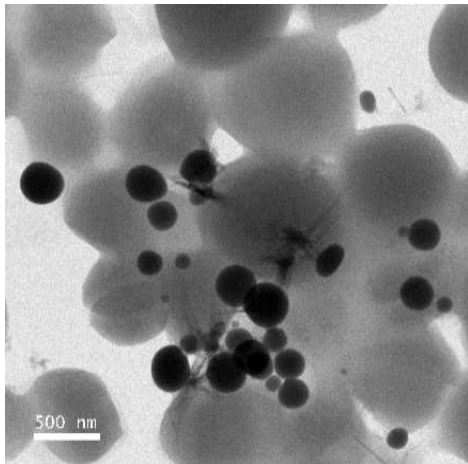
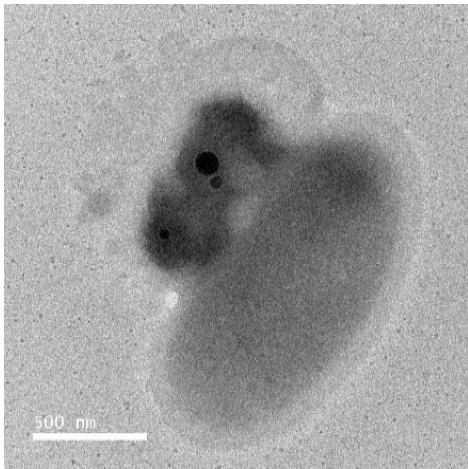
Media, Time of Harvesting & NP size



RAMAN Analysis

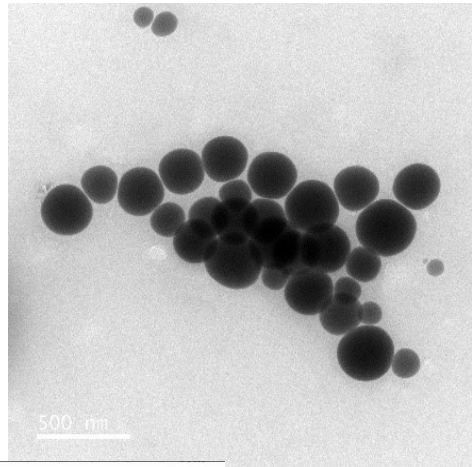
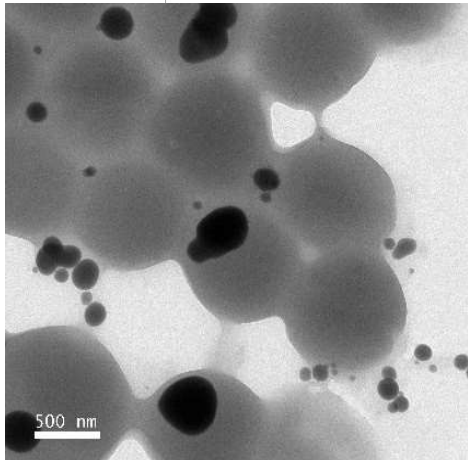
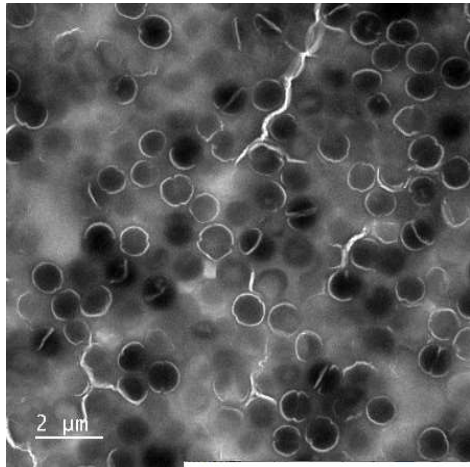


Se NPs



Summary

Slice	Count	Total Area	Average Size	%Area	Mean	Circ.	Solidity
Picture2.jpg	257	44835.006	174.455	0.369	254.960	0.957	0.957



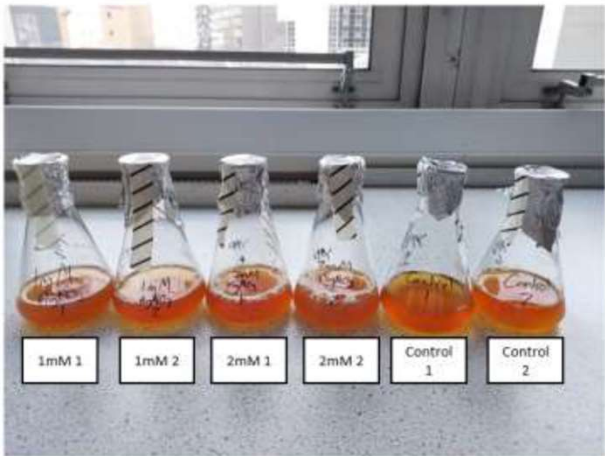
Summary

Slice	Count	Total Area	Average Size	%Area	Mean	Circ.	Solidity
Picture4.jpg	34	439971.305	12940.332	3.399	251.581	0.894	0.950

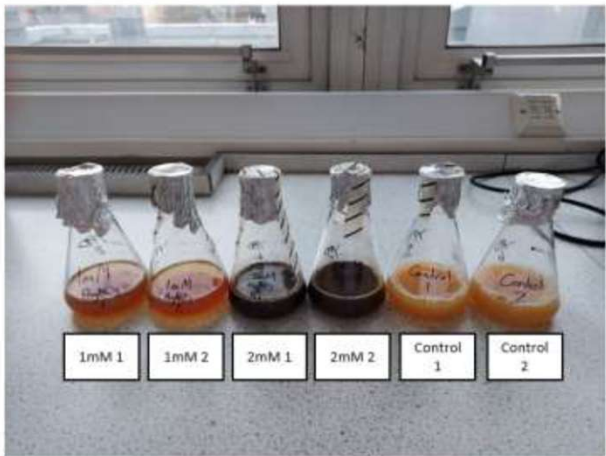
TEM Analysis

Ag NPs

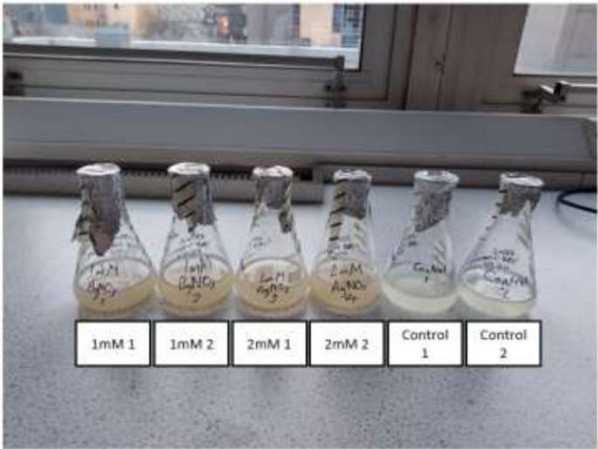
a) Silver Nitrate at 0 Hours



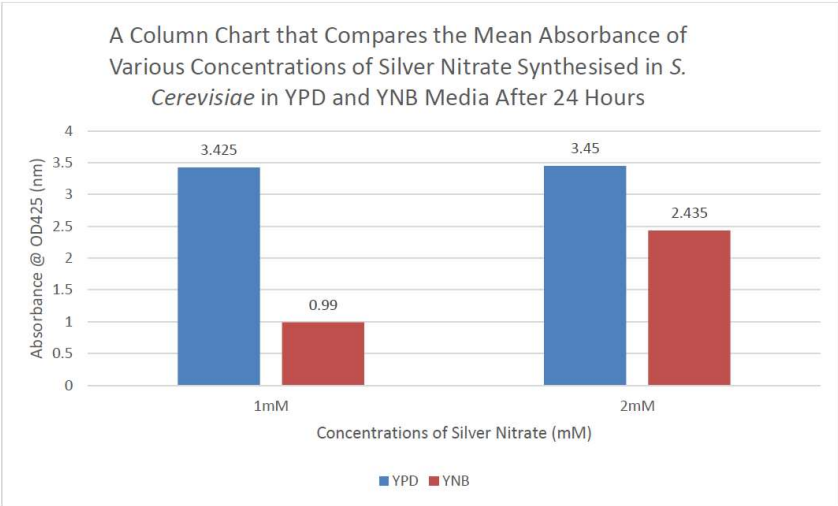
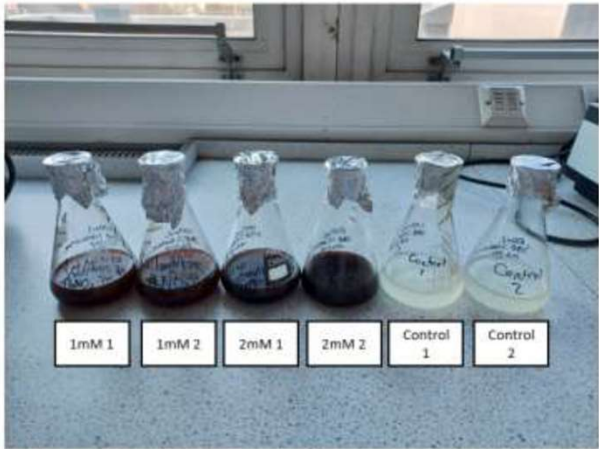
b) Silver Nitrate at 24 Hours



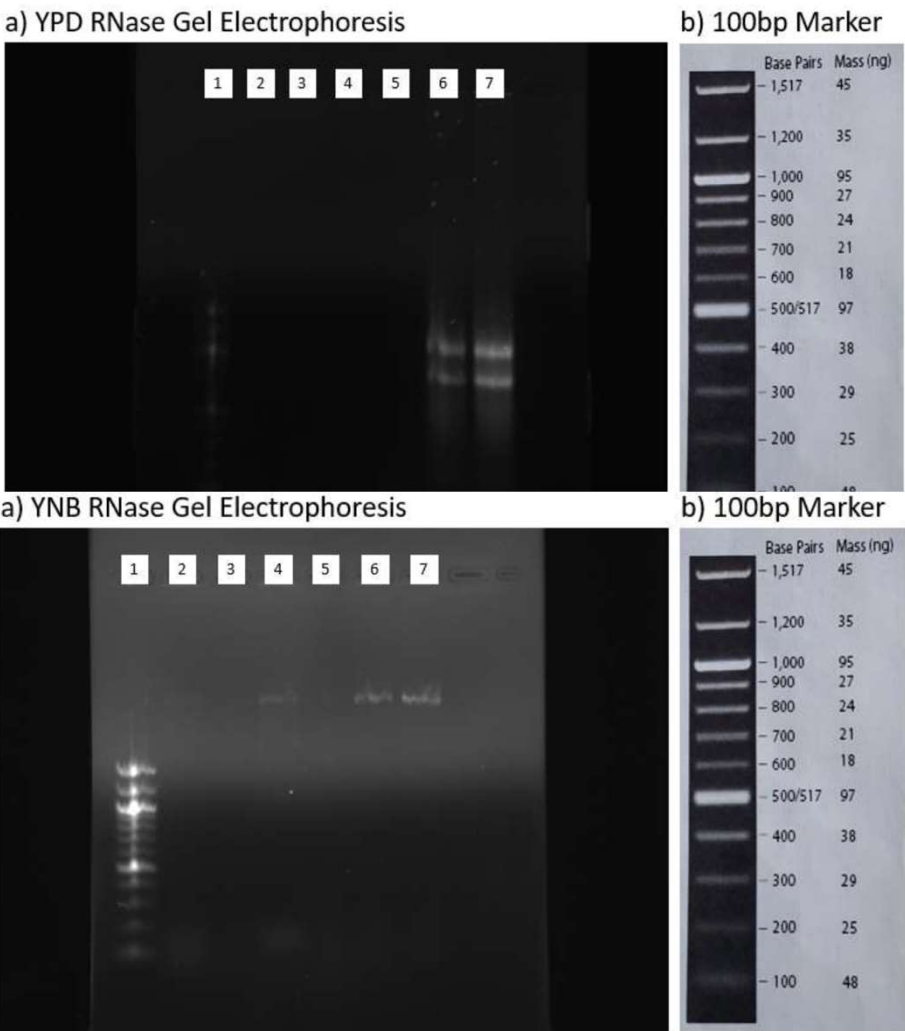
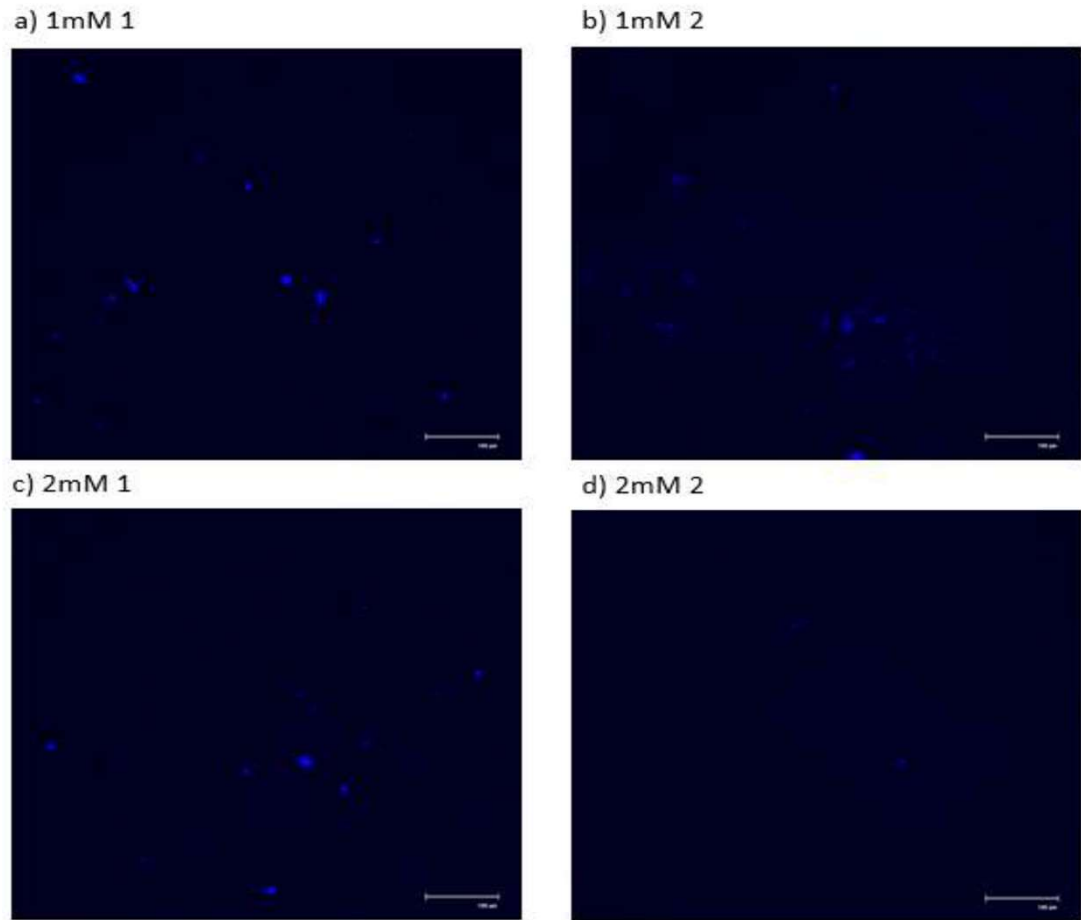
a) Silver Nitrate at 0 Hours



b) Silver Nitrate at 24 Hours



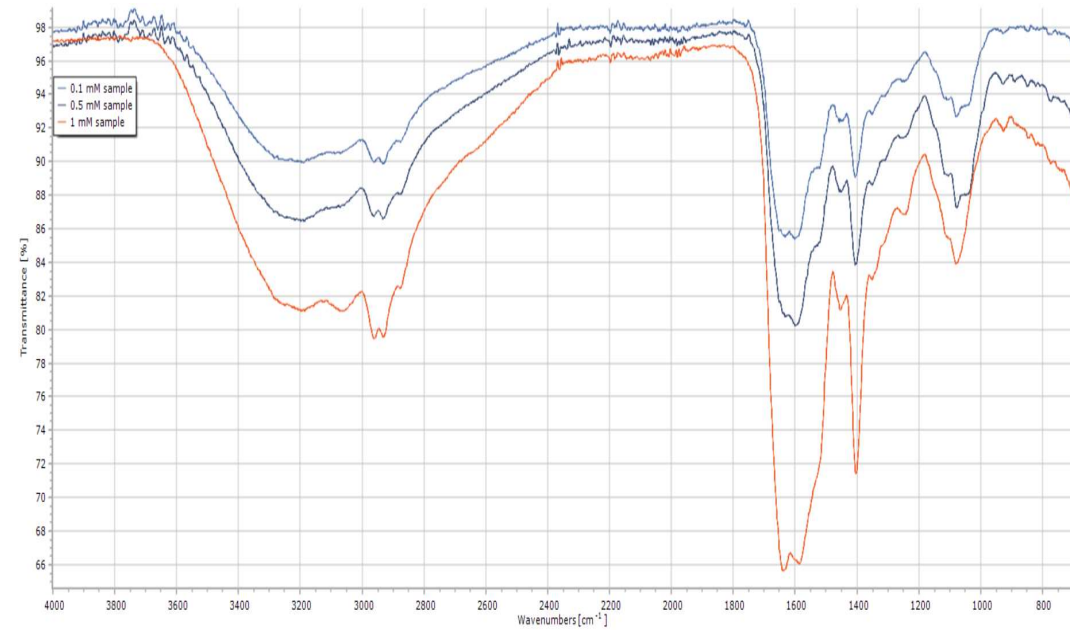
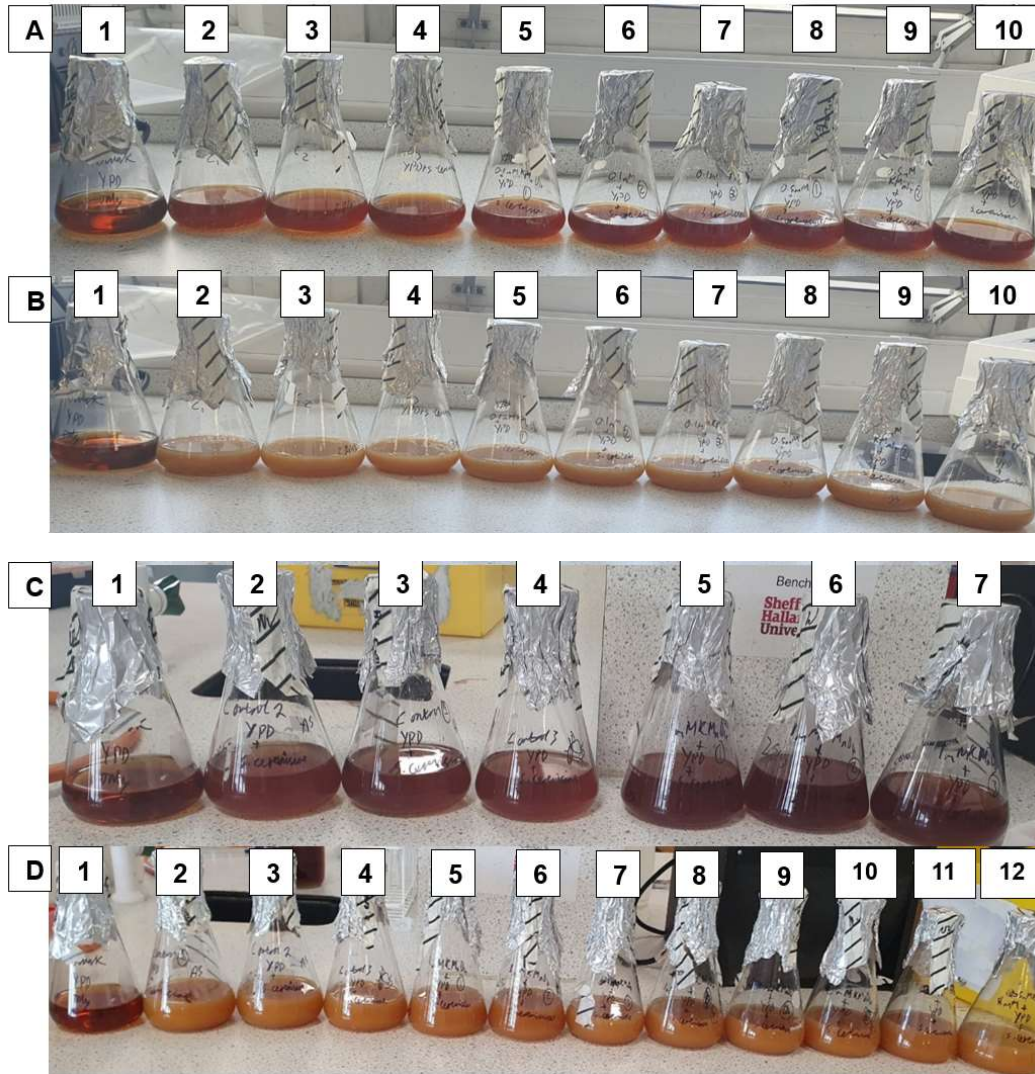
Ag NPs



EVOS fluorescent microscope

Expression of PKC1 (Ag-specific gene)

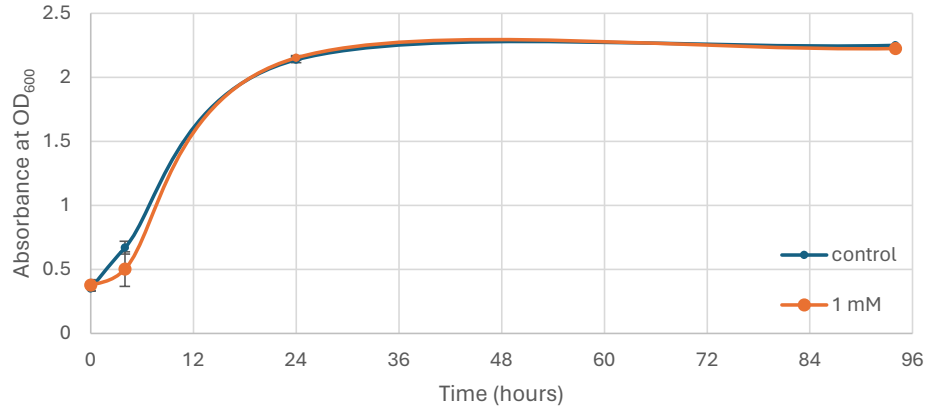
MnO₂ NPs



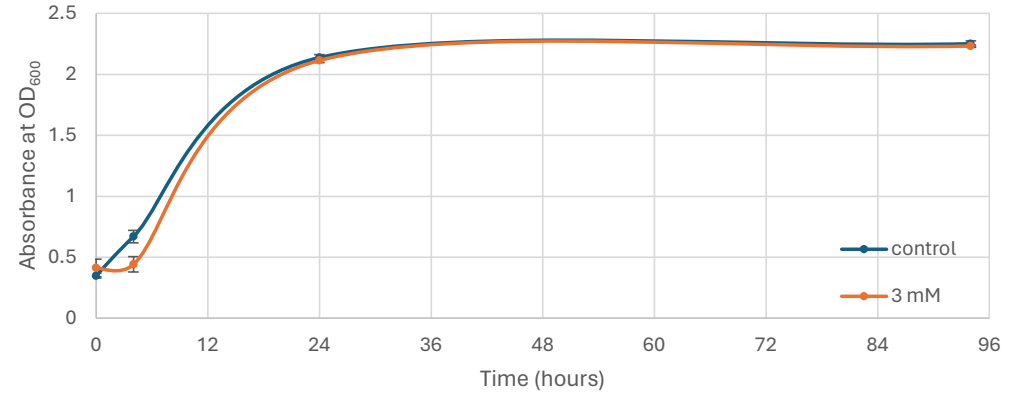
FTIR for MnO₂ NPs

MnO₂ NPs

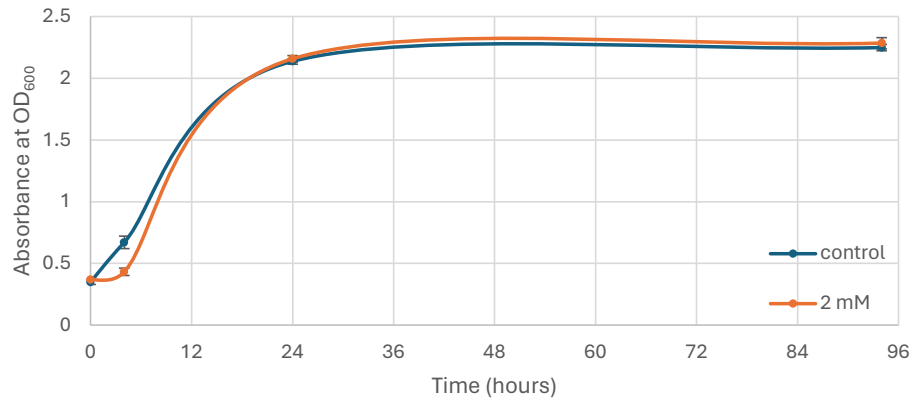
YPD + *S. cerevisiae* + 1 mM of KMnO₄ Growth Curve



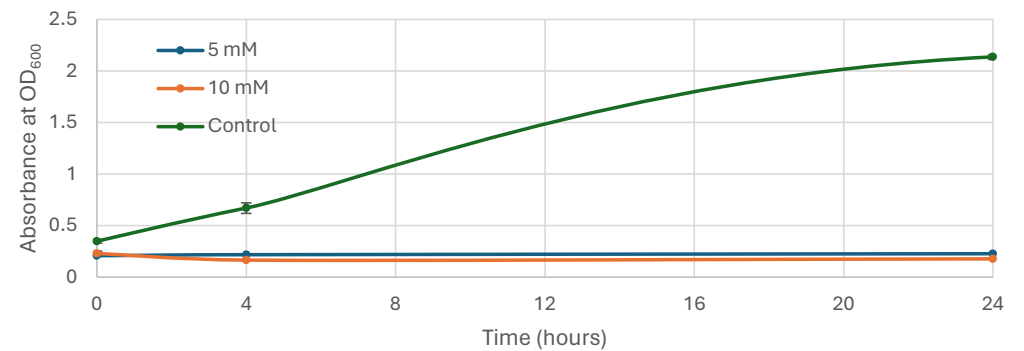
YPD + *S. cerevisiae* + 3 mM of KMnO₄ Growth Curve



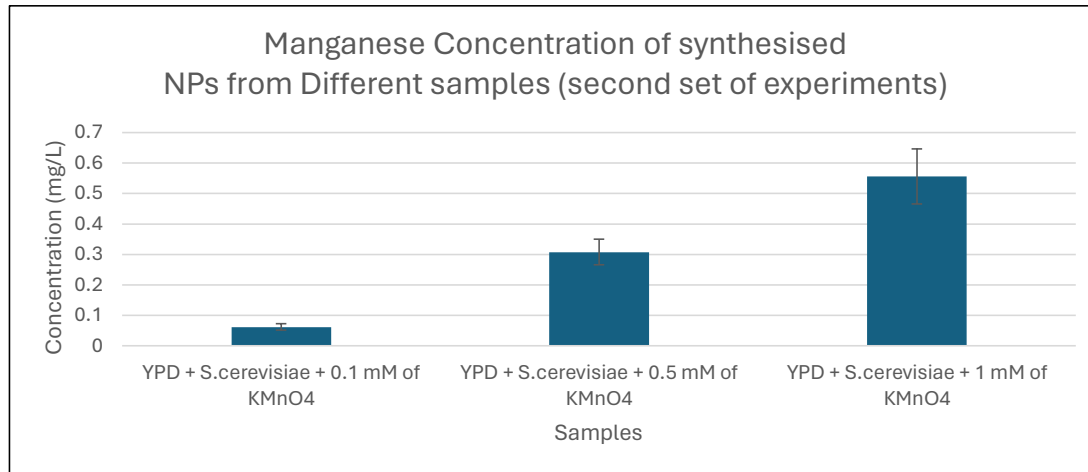
YPD + *S. cerevisiae* + 2 mM of KMnO₄ Growth Curve



YPD + *S. cerevisiae* + 5 mM and 10 mM of KMnO₄ Growth Curve

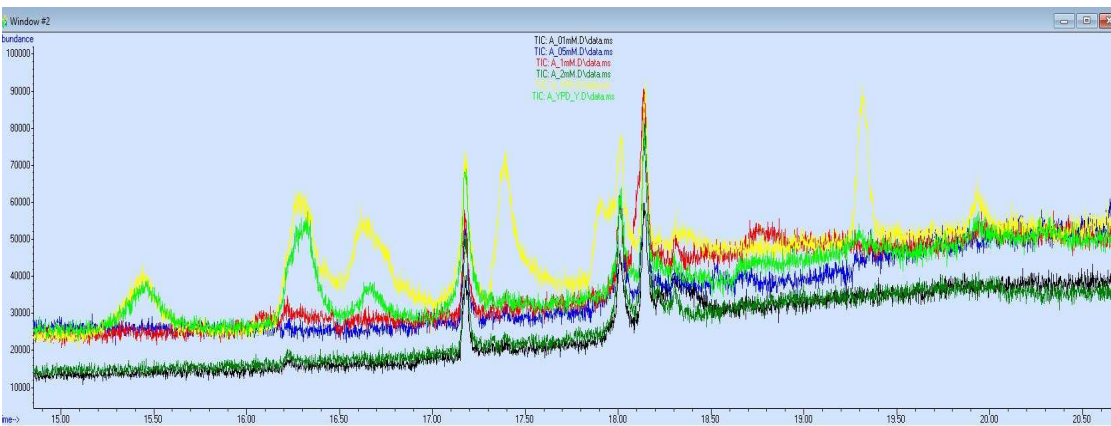


MnO₂ NPs

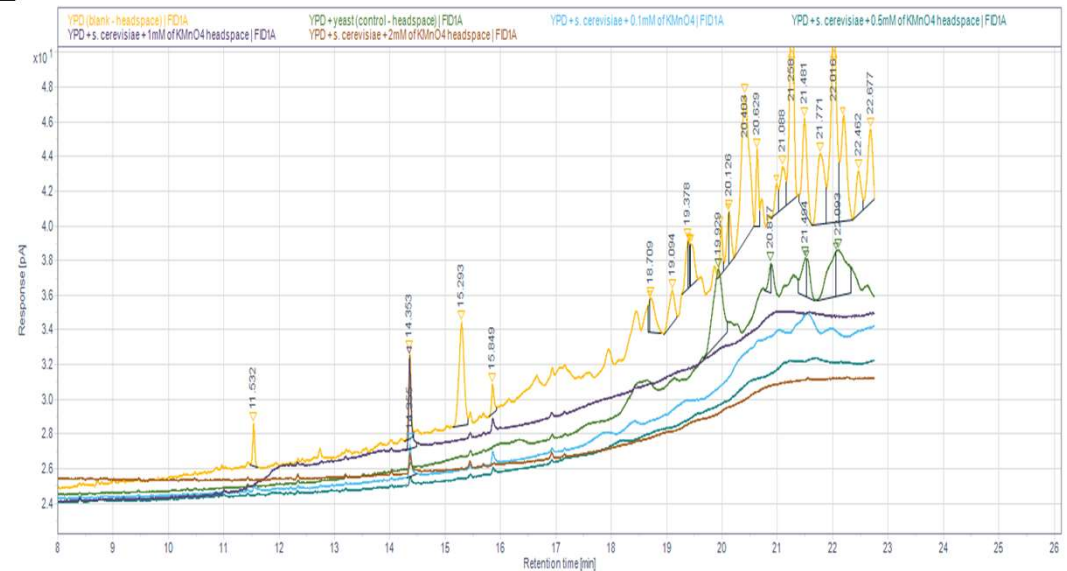


ICP-MS for MnO₂ NPs

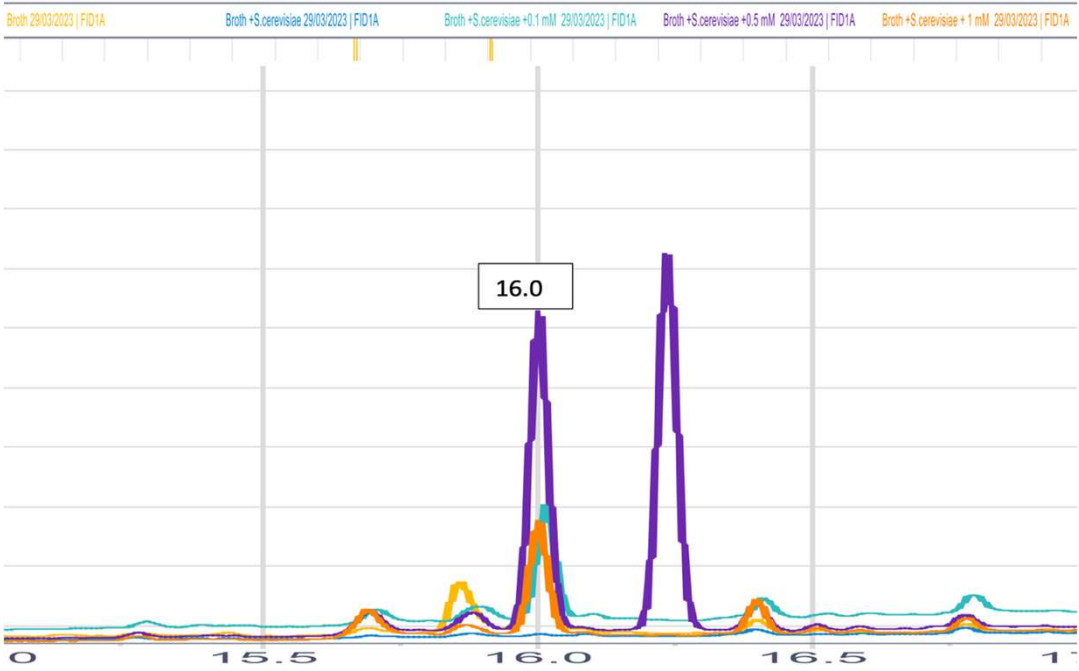
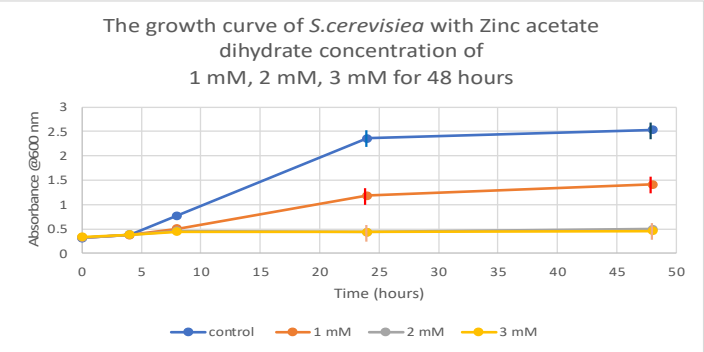
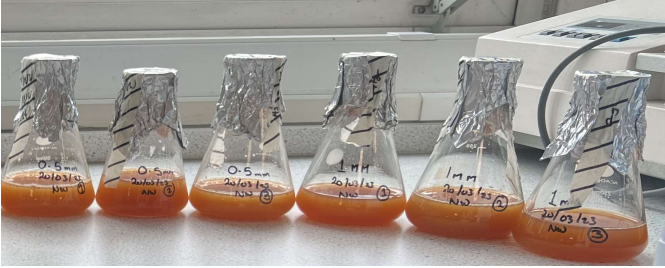
GC-MS for volatile metabolites with MnO₂ NP2



GC-MS for Soluble metabolites with MnO₂ NP2

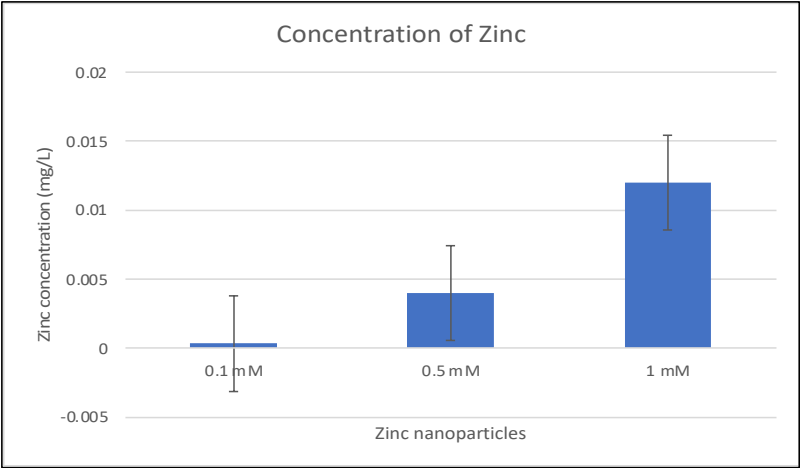
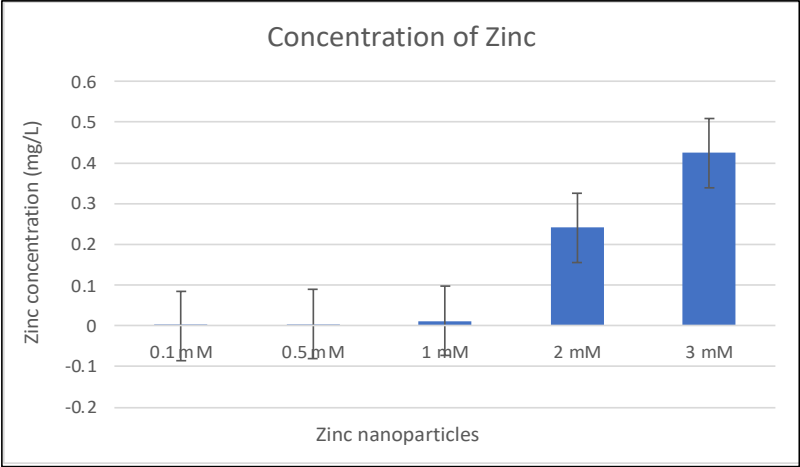


ZnO NPs

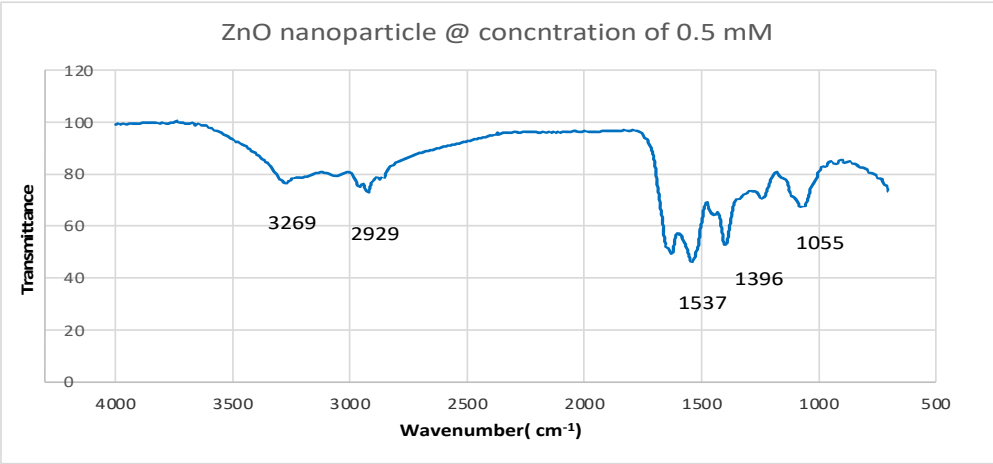
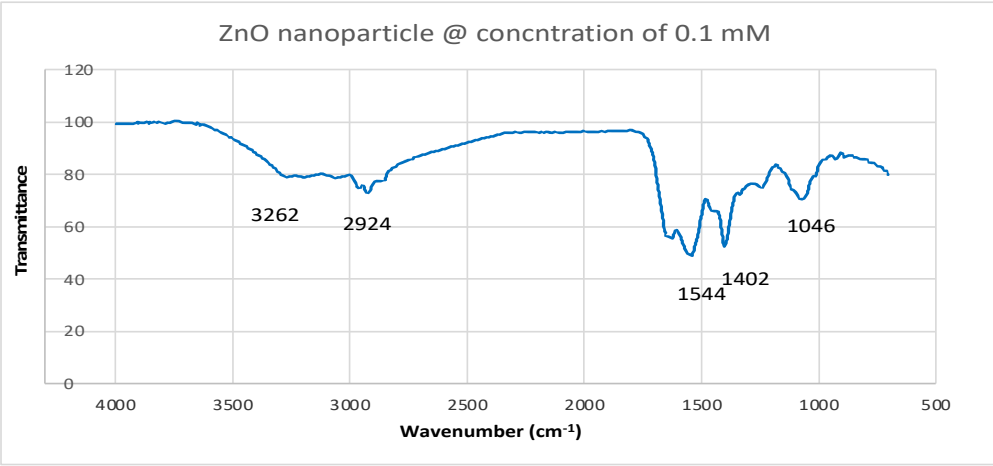


GC-MS for Soluble metabolites with ZnO NP2

ZnO NPs

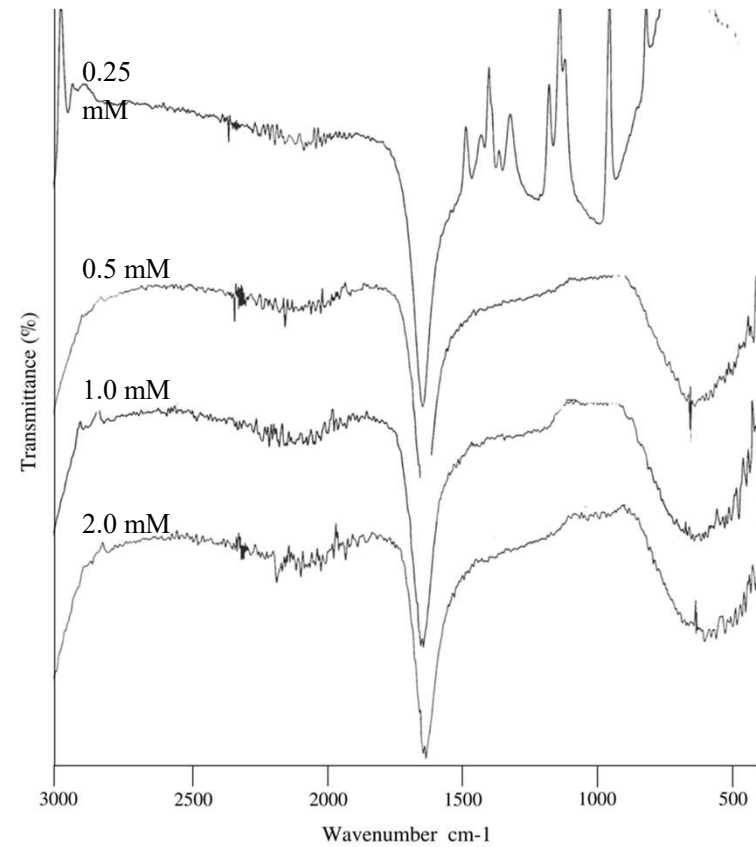
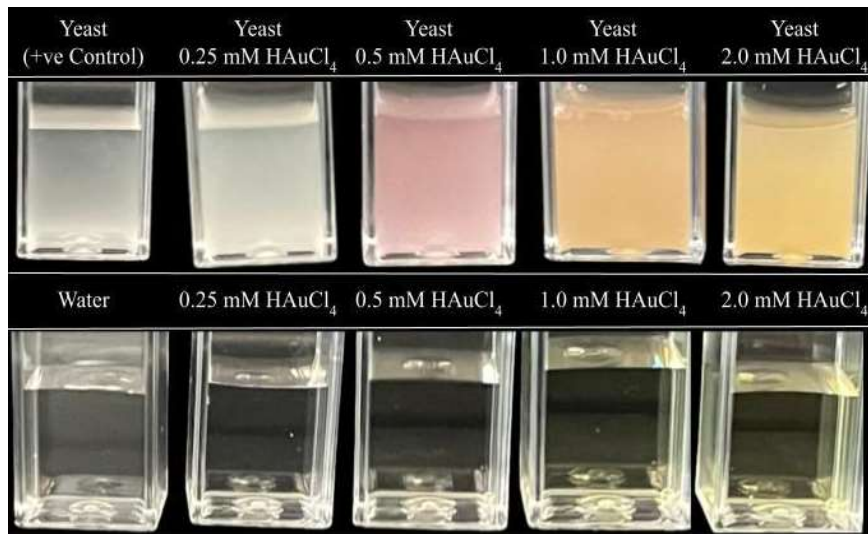
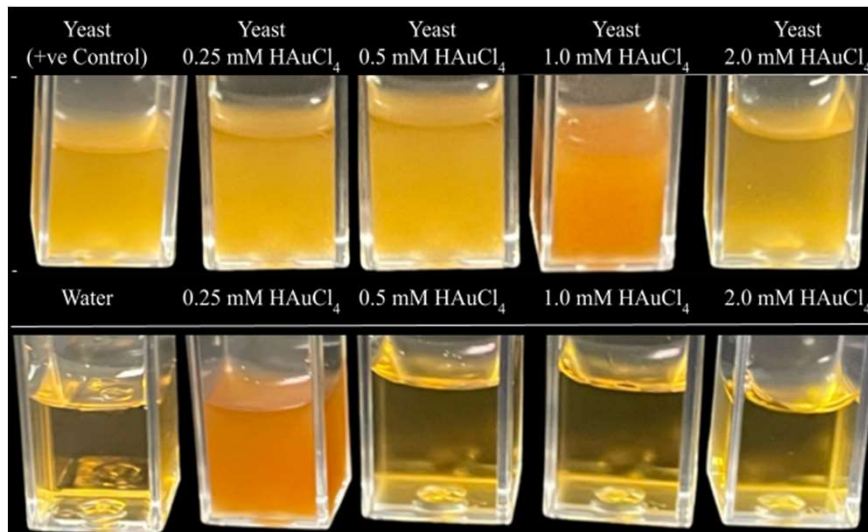


ICP-MS for ZnO NPs



FTIR for ZnO NPs

Au NPs



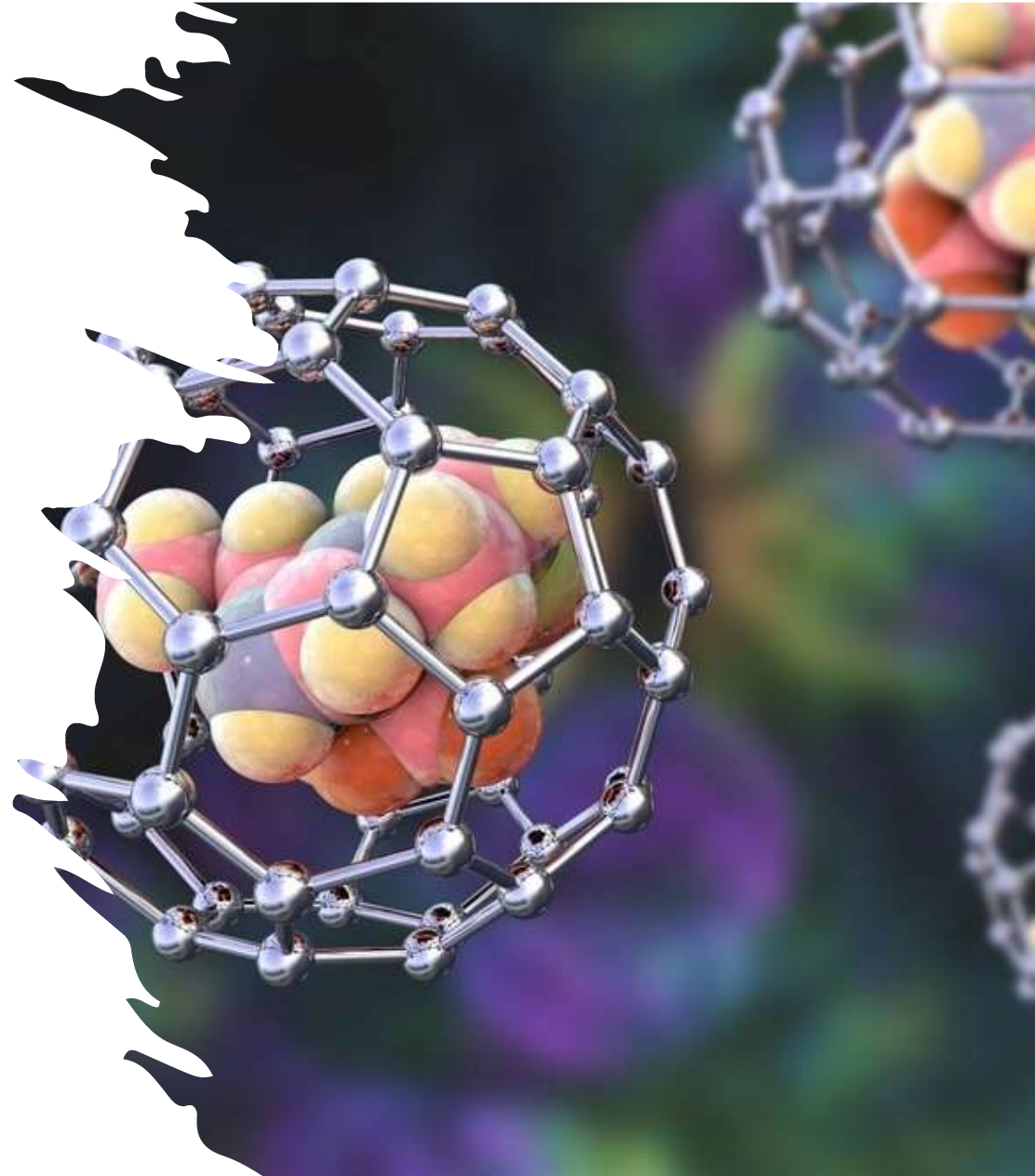
FTIR for Au NPs

Target Genes For transcriptional analysis

CCC1	Mn		GLR1	Gluthathione
MET5	Se, Cr		GSH2	Glutathione
MET10	Se, Cr		GTO1	Glutathione Transferase
CUP1	Se, Ag		GRX2	Dithiol Glutaredoxine
PKC1	Ag			
BACL2	Ag		PMR1	Mn
C-MYC	Ag		SMF2	Mn
PDA1	Housekeeping		ZRT1	Zn
ACT1	Housekeeping		ZRT3	Zn
VAN1	Vanadium		VAN2	Vanadium

Conclusion

- Yeast can be used to produce large number of metal nanoparticles
- Yeast can be modified with various conditions to improve the productivity
- More research to be done to completely reveal the full mechanism of metal nanoparticle biosynthesis





**Sheffield
Hallam
University**

Biomolecular
Sciences
Research Centre



Queen Mary
University of London



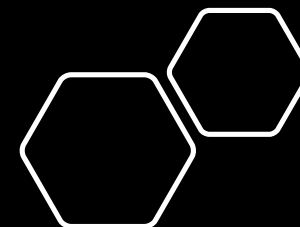
Swansea University
Prifysgol Abertawe

MANCHESTER
1824

The University of Manchester



IBMS Institute of
Biomedical Science



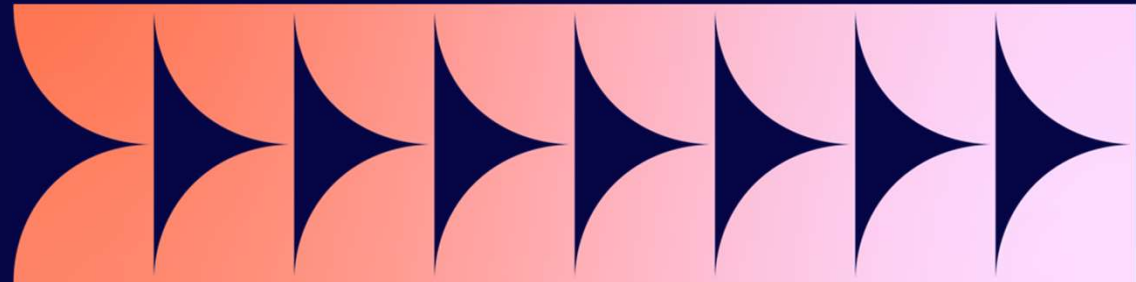
Sustainable Processes Linked for an Integrated Circular Economy (SPLICE)

Fatemeh Khodaparastan – PhD Student

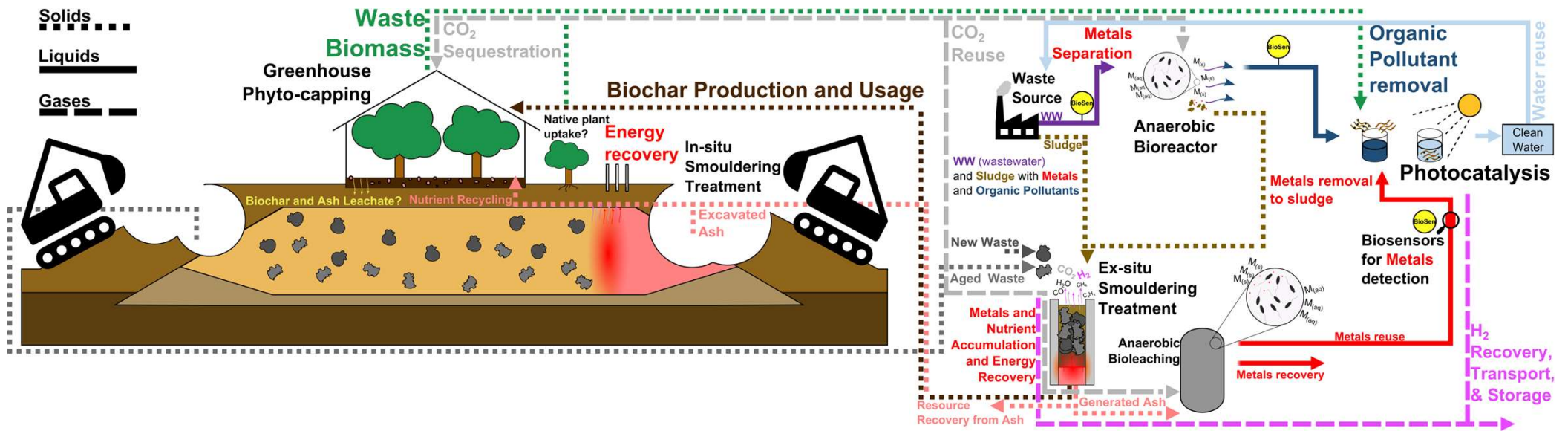
The Open University

April 11th, 2024

Tarek Rashwan, Harri Williams, Simon Collinson, Michael Macey, Nicholas Power, Daniel Payne, James Bowen



SPLICE



Thank you

