Sustainable materials from food wastes

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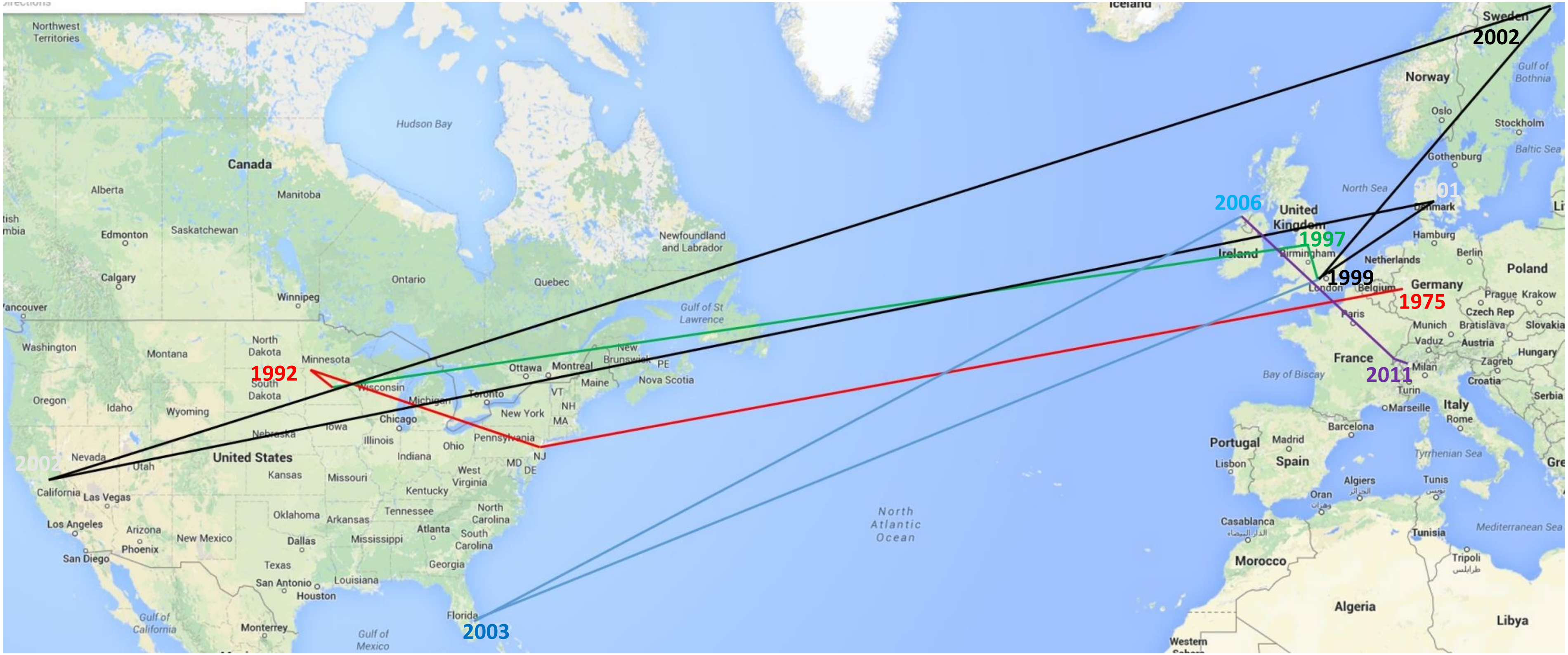

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Employment history

- 1995 – 1997 B.S. Microbiology, St. Cloud State University, MN, US
- 1997 – 1998 M.Sc. Medical and Molecular Microbiology, Univ. Manchester Medical School, UK
- 1999 – 2003 Ph.D. Food Microbiology (infant gut health) University of Reading, UK (supervisor Prof. Dr. Glenn Gibson)
- 2003 – 2005 Postdoc at Harbor Branch Oceanographic Inst. (Florida) Marine Microbial Ecology
- 2006 – 2011 Director of the Center of Applied Marine Microbiology, Marine Microbial Ecology (Co. Donegal, Ireland)
- 2011 – 2014 R&D Specialist at Nestlé Research Center (follow-on milk, probiotics & postbiotics), BSO
- 2014 – current Professor for microbiology and foodomics at the HES-SO Valais - Head of Food Safety Laboratory (ISO17025 and GMP), BSO

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A circular food bioeconomy

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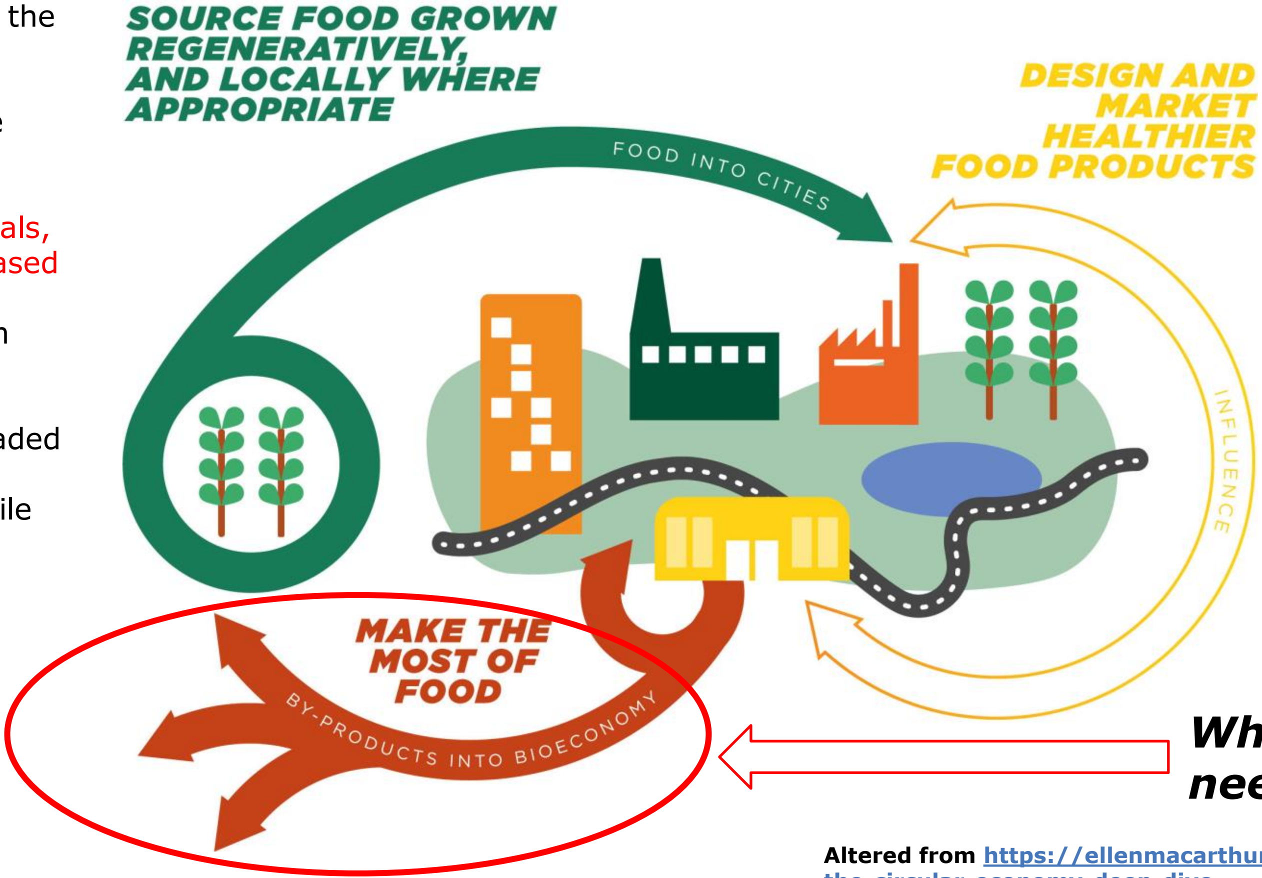
«The concept of the **circular bioeconomy** is described as the production of energy, food, platform chemicals, and other bio-based materials and compounds from biomass in a sustainable and integrated/cascaded manner (biorefinery) while generating **zero waste**»[4]



Where we need to act!

Altered from https://ellenmacarthurfoundation.org/food-and-the-circular-economy-deep-dive

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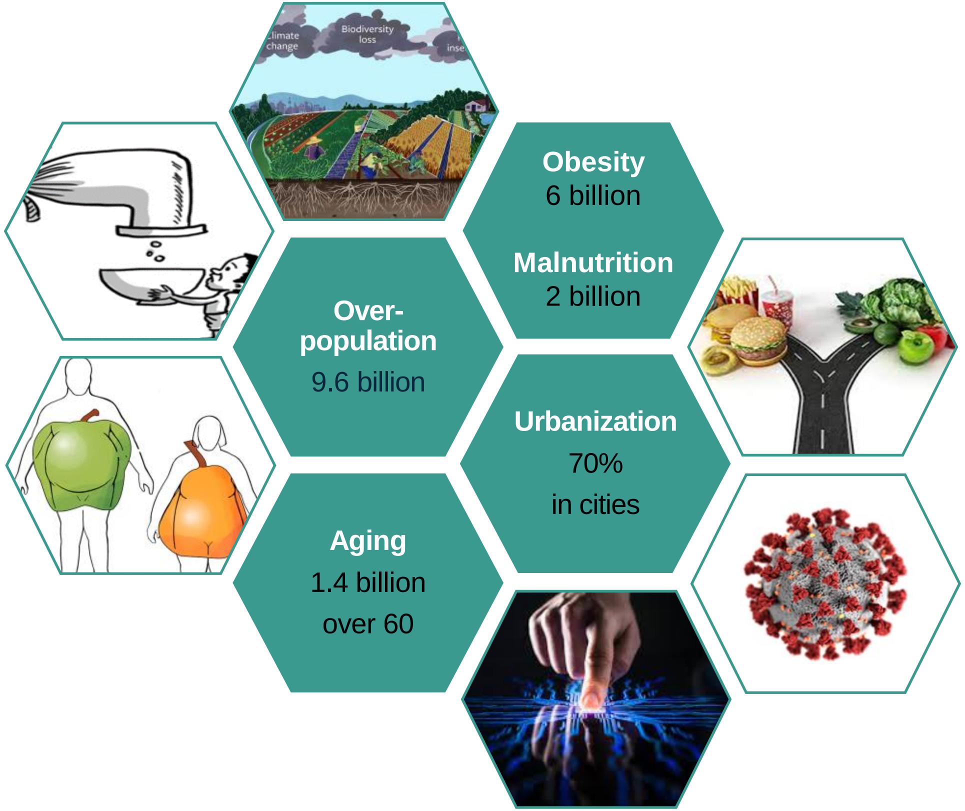
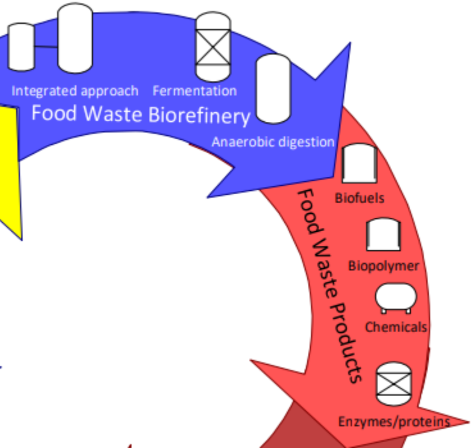
Relevant global drivers – a vision to 2050



The integrated biowaste biorefinery approach at HES-SO Valais/Wallis (Microbiology laboratories)

Oligosacharides	Proteins	Polyphenols	Base chemicals
Products:	*Products:*	*Products:*	*Products:*
Prebiotics	Meat analogs	Functional food additives	Food packaging
Thickeners	Dairy analogs		Edible films
Laxatives	Enzymes		Antimicrobial barriers
Stabilizers	Peptide prebiotics		

Available key technology and knowledge base: Microbial fermentation, anaerobic digestion, algae production systems, ex vivo models, foodomics



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Novel food ingredients for sustainable materials

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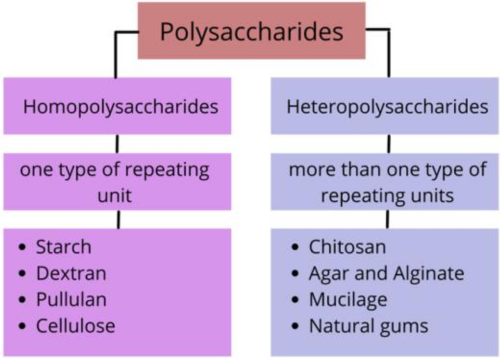
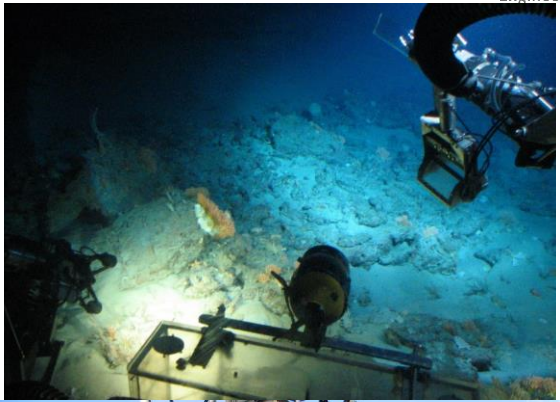


Sources of bacteria and enzymes (1)



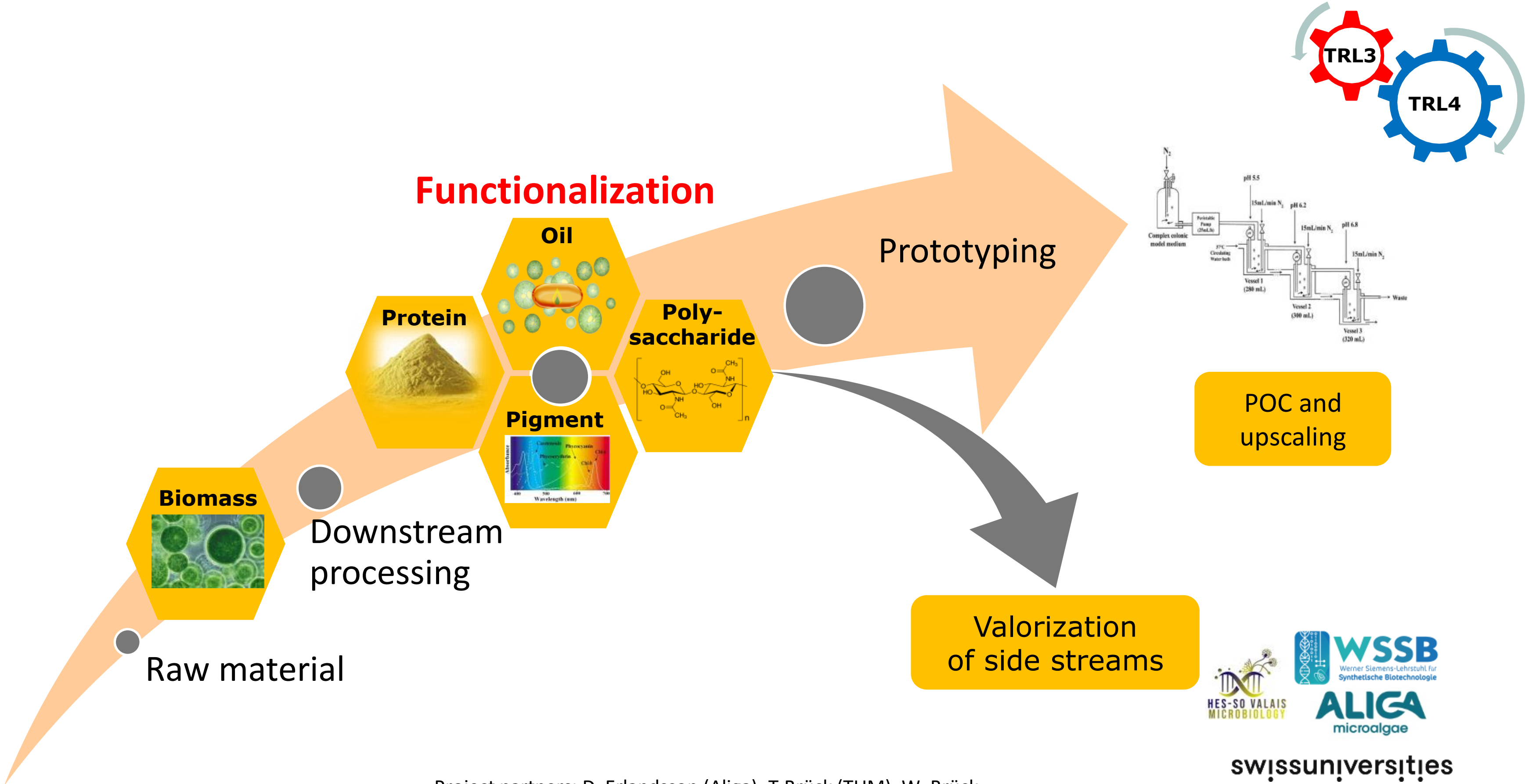
- R/V Seward Johnson
- JSL Research Submersibles
  - 1000 msw depth limit

Sources of bacteria and enzymes (2)



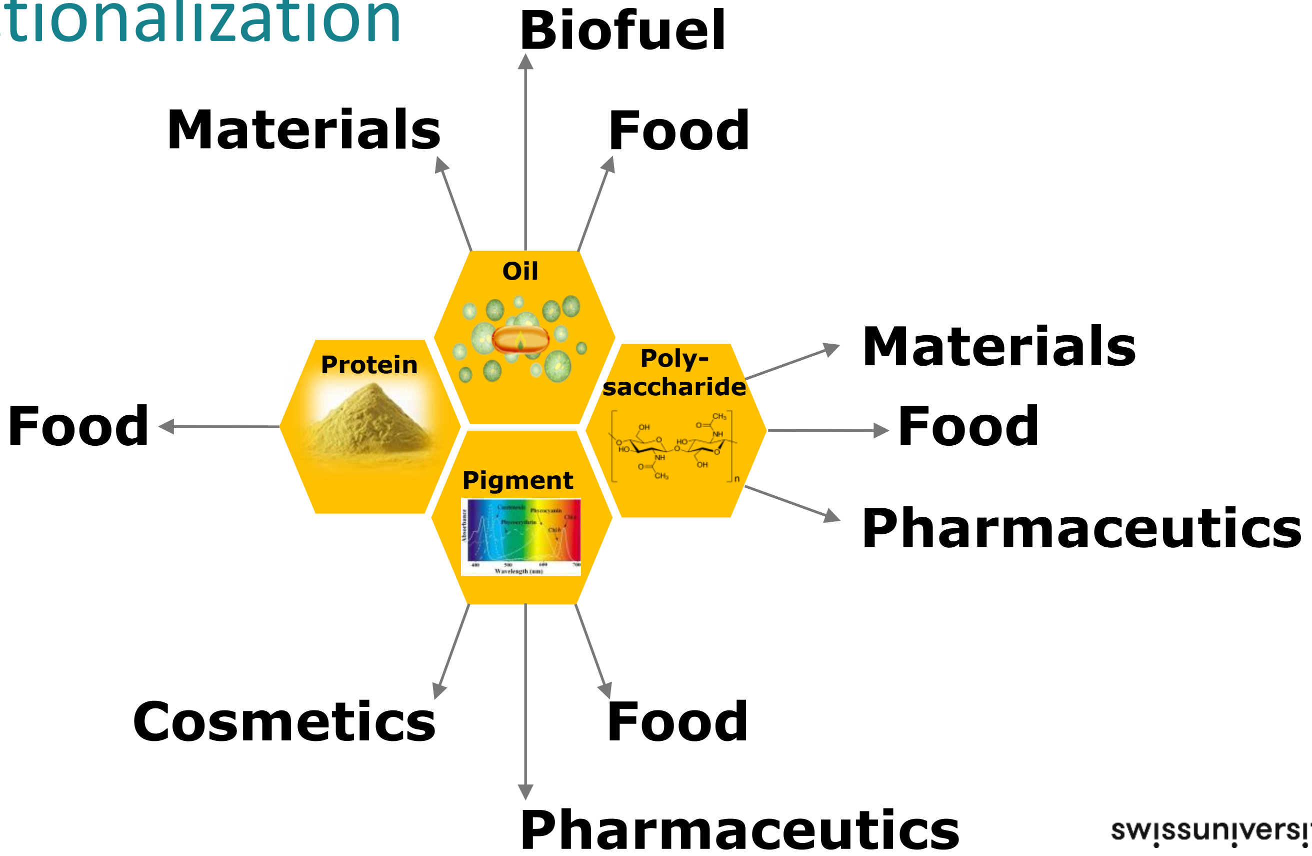


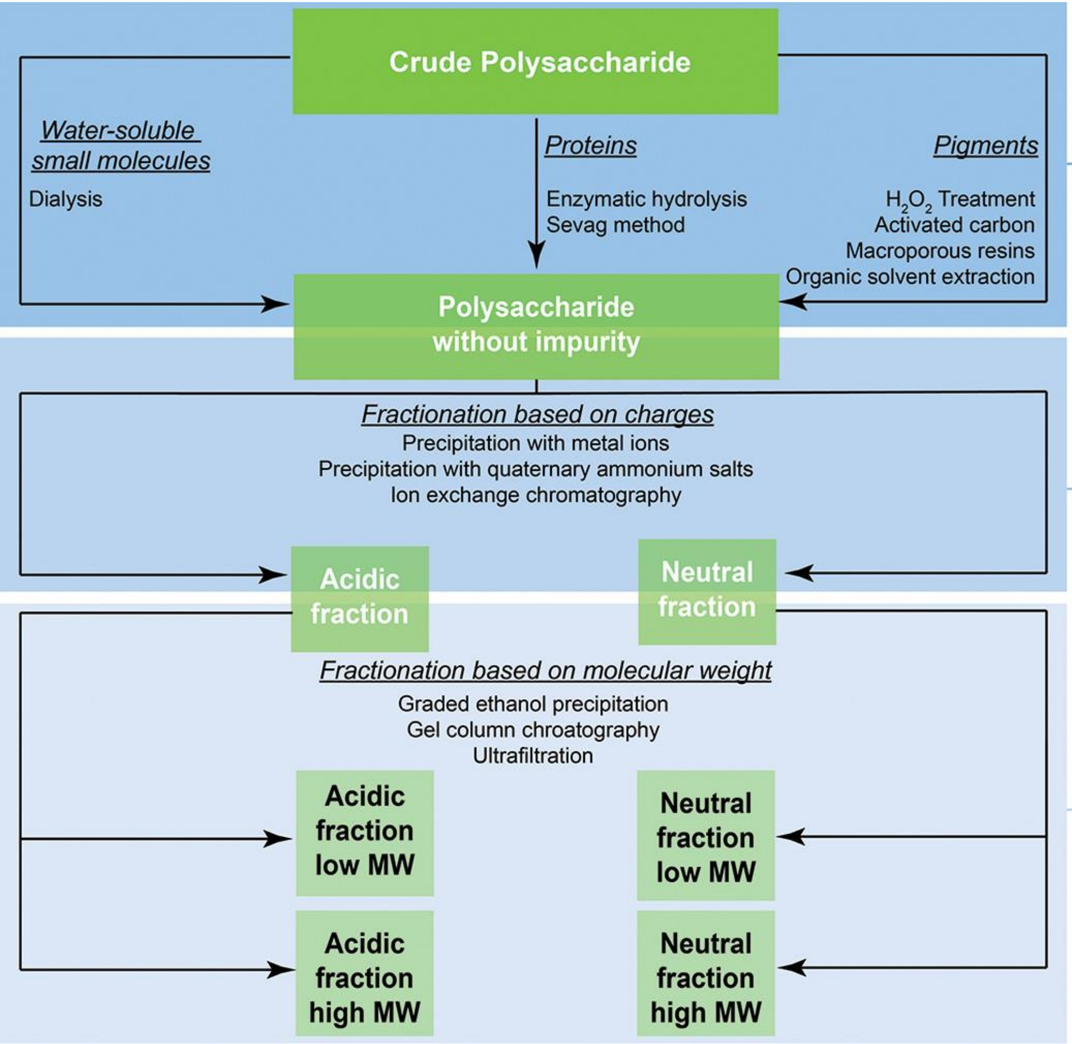

Production of algae-based materials



Project partners: D. Erlandsson (Aliga), T.Brück (TUM), W. Brück

Functionalization





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General purification methods

Isolation of charged and neutral polysaccharides

Isolation of polysaccharides with different molecular weight (MW)

Source: Biomacromolecules 2021, 22, 3, 1027–1052
https://doi.org/10.1021/acs.biomac.0c01406

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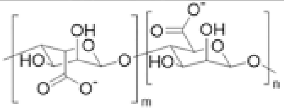
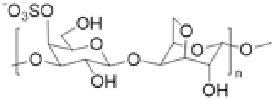
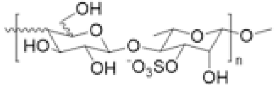
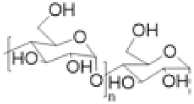
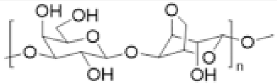
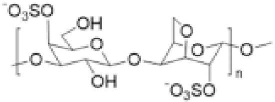
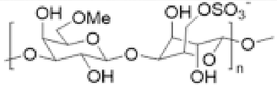
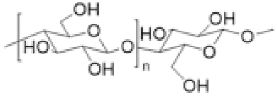
	Name	Chemical composition	General structure	Phylum
Complexation	*Alginate*	β-D-mannuronate α-L-guluronate		*Ochrophyta*
Complexation	*λ-Carrageenan*	β-D-galactose α-D-galactose		*Rhodophyta*
Complexation	*Ulvan*	β-D-glucuronic / α-L-iduronic acid α-L-rhamnose		*Chlorophyta*
Crystallization	*Starch (Amylose)*	α-D-glucose		*Chlorophyta* *Rhodophyta*
Formation of secondary structure	*Agarose*	β-D-galactose 3,6 anhydro-α-L-galactose		*Rhodophyta*
Formation of secondary structure	*ι/κ -Carrageenan*	β-D-galactose 3,6-anhydro-α-D-galactose		*Rhodophyta*
Formation of secondary structure	*Porphyran*	β-D-galactose 3,6-anhydro-α-L-galactose		*Prophyra*
Colloidal assembly	*Cellulose*	β-D-glucose		*Chlorophyta,* *ochrophyta*

Algal polysaccharides

Source: Biomacromolecules 2021, 22, 3, 1027–1052
https://doi.org/10.1021/acs.biomac.0c01406

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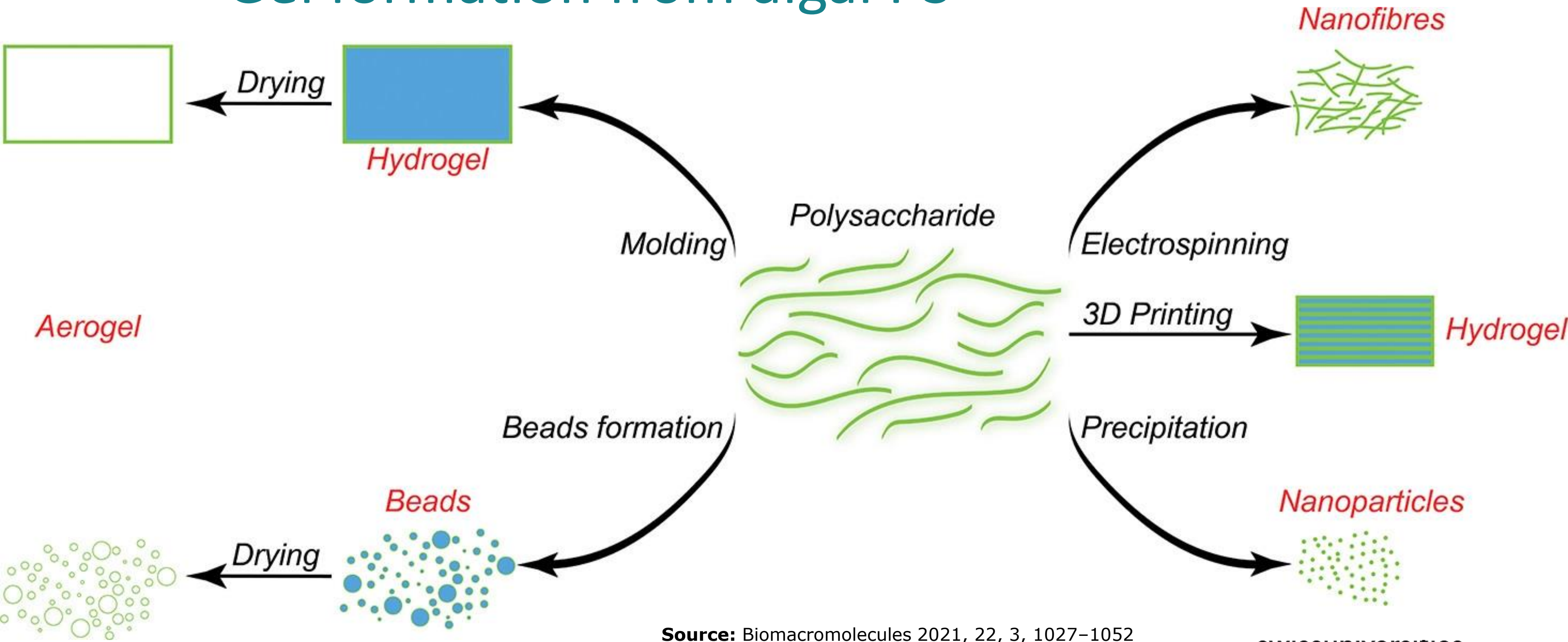
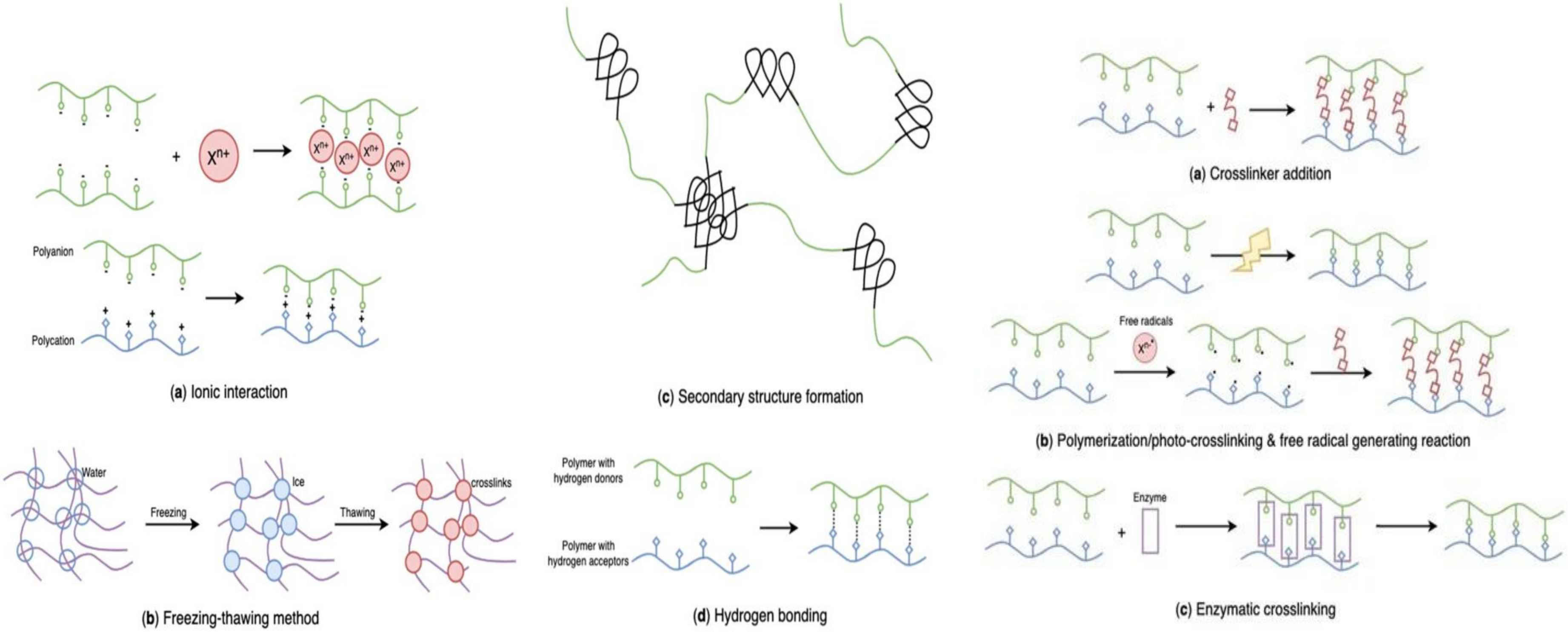
Gel formation from algal PS



Source: Biomacromolecules 2021, 22, 3, 1027–1052
https://doi.org/10.1021/acs.biomac.0c01406

Schematic representation of physically and chemically crosslinked, algal polysaccharides-based hydrogels



Source: *Mar. Drugs* **2022**, *20*(5), 306
https://doi.org/10.3390/md20050306

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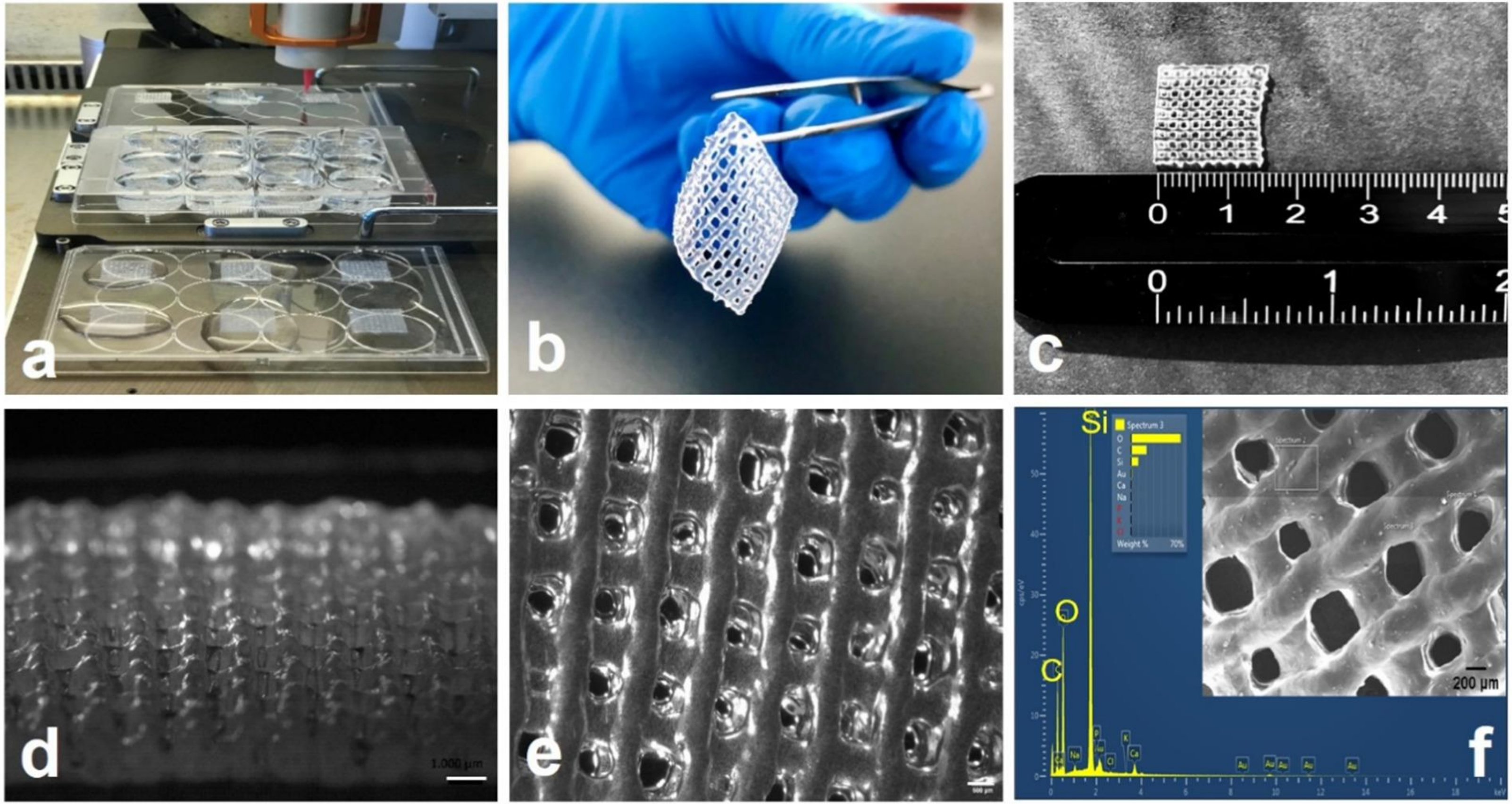
3D printed algal hydrogel constructs



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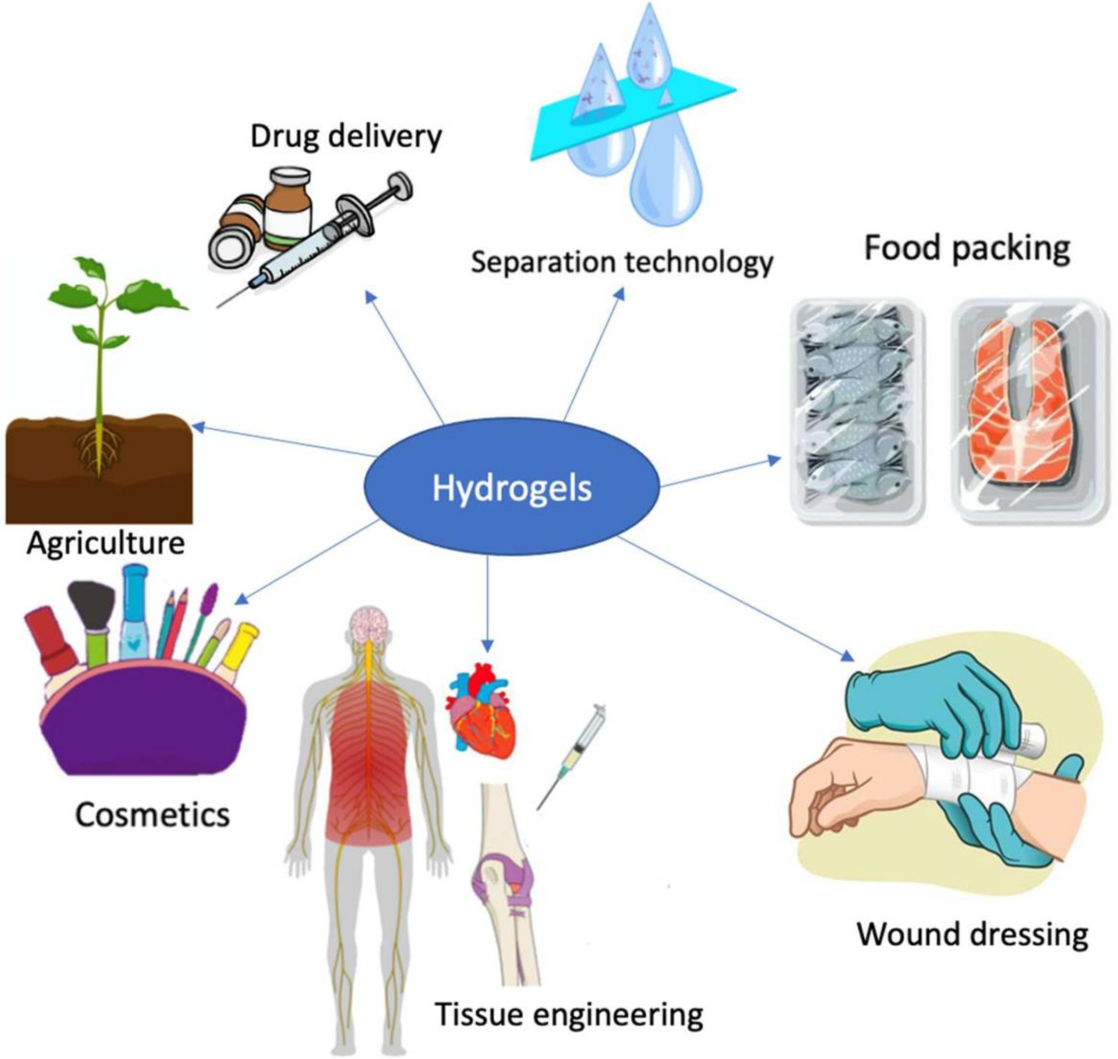

Industrial outlets for algal-based hydrogels

Source: *Mar. Drugs* **2022**, *20*(5), 306
https://doi.org/10.3390/md20050306

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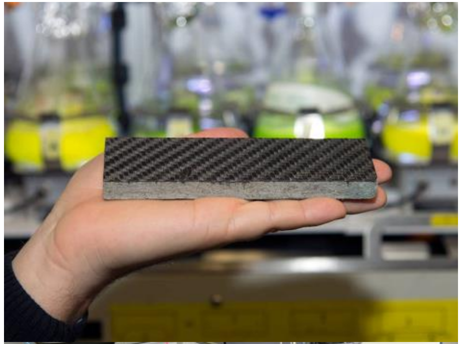

WSSB
Werner Siemens-Lehrstuhl für
Synthetische Biotechnologie

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Algae-oil based products

Land use change

Rapeseed oil

Palm oil

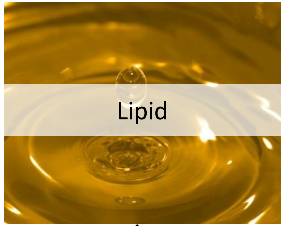
Biofuel

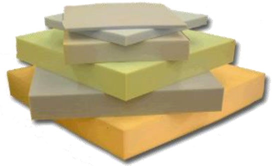
Extraction

Food application

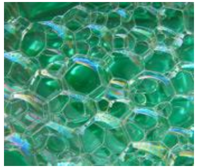
Material applications

Food application

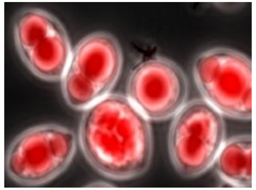




Polymer Materials



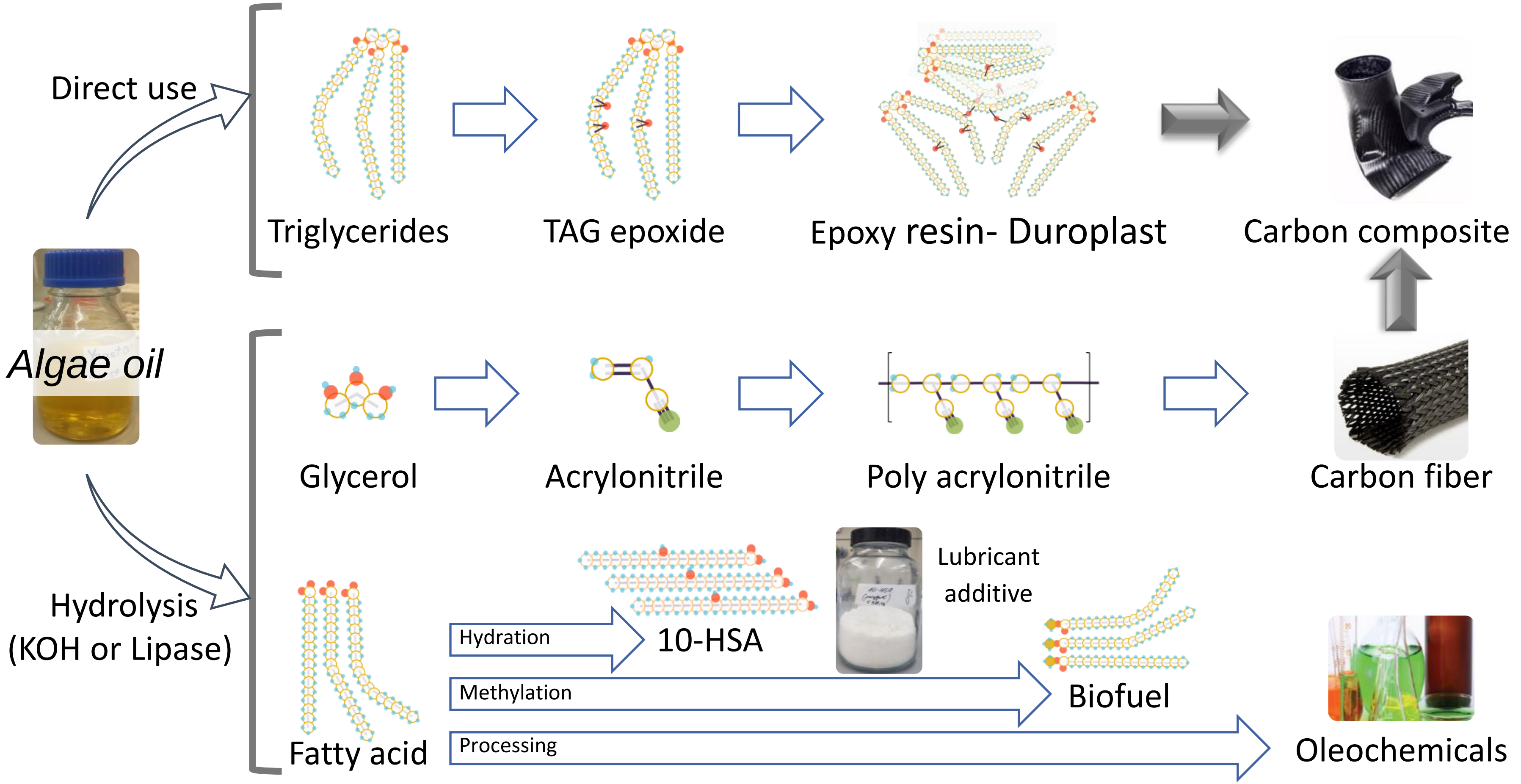
Oleochemicals



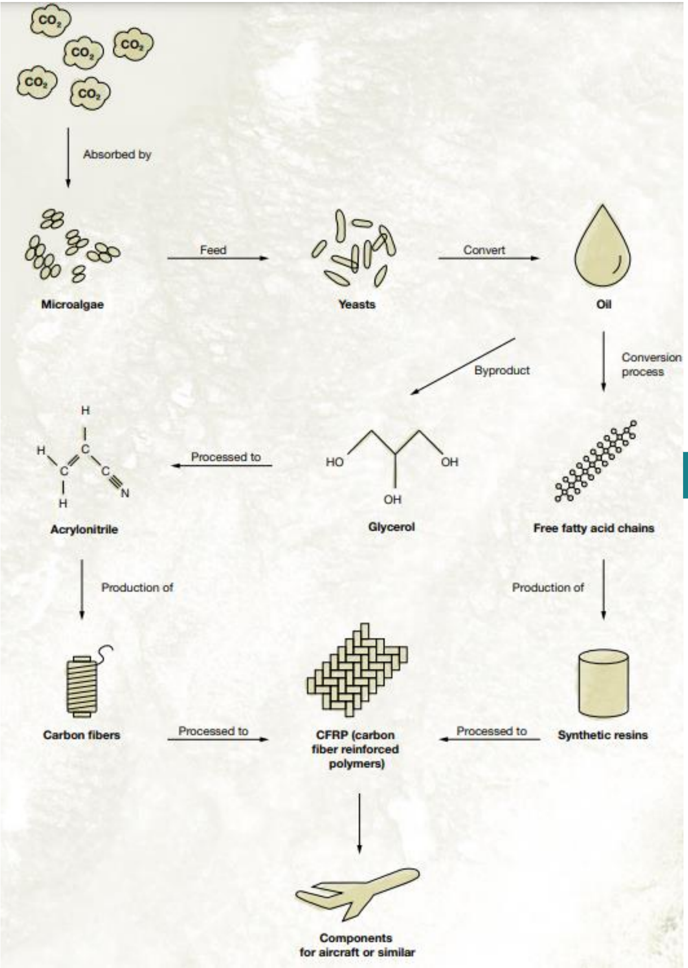
- **Waste recycling**
- **Sustainable oil producers**
- ➢ **Microbial lipid**

Hill (2000) Pure Appl. Chem. 72, 1255–1264

Algal lipid processing to produce carbon fiber

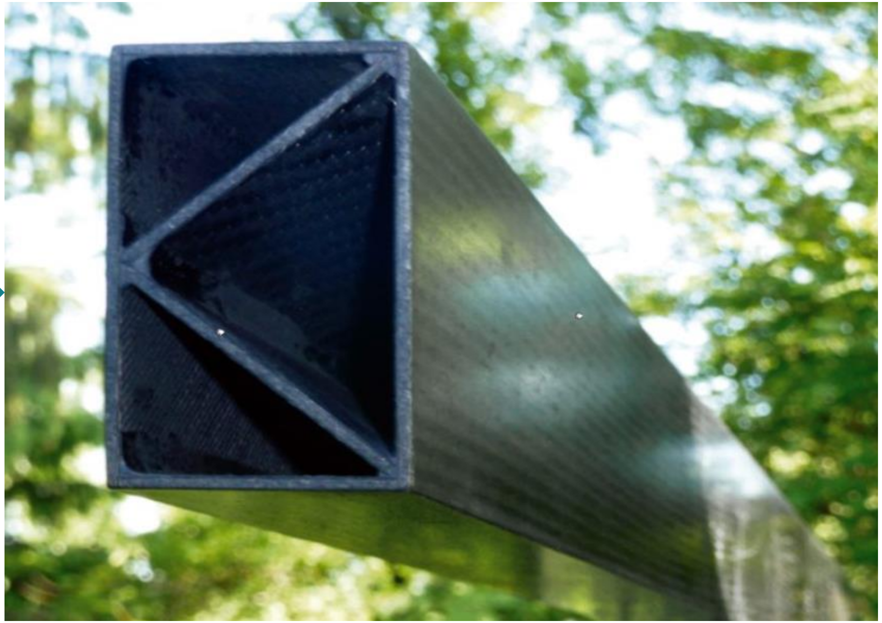


Carbon fiber – alternative processes



CLEAN CARBON TECHNOLOGY

Sources:
1. https://csengineermag.com/innovative-materials-carbon-fibers-made-from-algae/
2. https://patents.justia.com/patent/20220081806



A beam made of carbon fiber reinforced granite (Mineral Carbon Composite, MCC) is load-bearing like steel, light as aluminum and extremely durable.

Industrial outlets of CO_2 based Carbon Fiber composites

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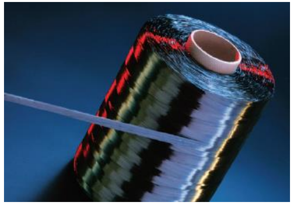
Existing industrial demands

Automotive / Mobility / Sports

Aviation

Construction

supply chain from precursor fiber via CF/CFC to construction elements



- Potential end of life CFK deposit in open cast coal mine
- Permanent CO_2 removal without toxic by products
- **Carbon capture and removal in Gt range**

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Production of chitin-based materials

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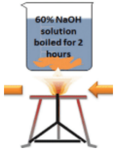
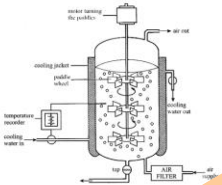
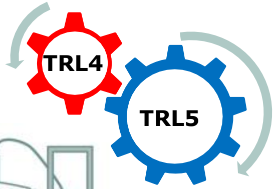
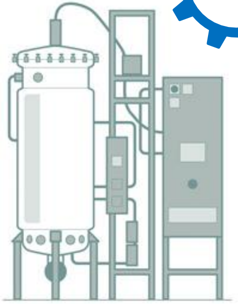
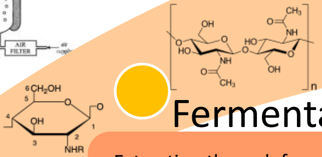
Benchmarking with existing extraction technologies











Raw material

Pretreatment and side-stream analysis

Fermentation

Extraction through fermentation and enzyme processing, downstream processing, analytical product characterization

Prototyping

LCA, product and side-stream characterization and management

Upscaling to technical level

Project partners: W. Brück, T. Abitbol (EPFL), Bridge Discovery (to be resumitted 2023)

BRIDGE

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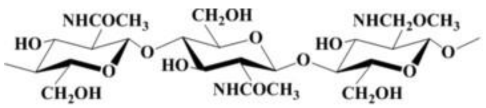
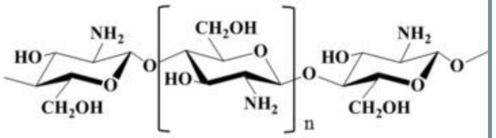
chitin can remove some pesticides

Deacetilation → Depolimerization →



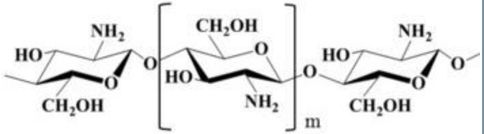
CHITIN

1. Found in insects cuticles, crustaceans shells, and fungi cell walls
2. Hard to dissolve in water, acid, and alkali solvent
3. More than 1000kDA
4. Poor Absorbability



CHITOSAN

1. Chitosan is rarely found in nature.
2. Poor water solubility, but feely dissolves in acid solvent
3. MW more than 1,000 kDa
4. Absorbability 1-3%



COS

1. Entirely dissolves in water
2. MW less than 3.9kDa
3. Absorbability almost 100%

Regardless of having various bioactivities, the water insolubilities of chitin and chitosan limit their applications in many industries

Source: (Joshi et al., 2019)

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ChiBio is funded by the European Commission within the Seventh Framework Programme

Contents of chitin and calcium carbonate in industrially important marine species

Type	Location of chitin	Chitin (%)	CaCo3 (%)
Phylum Crustacea:			
Euphausia sp. & *Meganyctiphanes* sp. (Krill)	cuticle/exosceleton	20-30	20-25
Chionoecetes sp., *Cancer* sp. & *Carcinus* sp. (Crab)	cuticle/exosceleton	15-30	40-50
Paralithodes sp. (King crab)	cuticle/exosceleton	~35	40-50
Callinectes sp. (Blue crab)	cuticle/exosceleton	~14	40-50
Crangon sp. & *Pandalus* sp. (Shrimp)	cuticle/exosceleton	17-40	20-30
Penaeus sp. (Prawn)	cuticle/exosceleton	~40	20-30
Nephrops sp. & *Homarus* sp. (Lobster)	cuticle/exosceleton	60-75	20-30
Lepas sp. (Goose Barnacle)	shell	~59	20-30
Phylum Mollusca:			
Mytilus sp. & *Pecten* sp. etc.(Mussels, clams etc.)	shell	~3	85-90
Crassostrea sp. (Oyster)	shell	~6	85-90
Loliginidae sp. & *Ommastrephidae* sp. (Squid)	pen	20-40	negligible

CHITOOLIGOSACCHARIDES

EXTRACTION METHODS

Chemical

Depolimerization with:

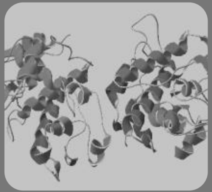
•Hydrochloric acid (Trombotto et al 2008)
•Nitrous acid (Mourya et al., 2011).
• Hydrogen peroxide (Hai et al., 2019)
•Phosphoric acid. (Jia, 2002)

Physical

Depolimerization with :

•Microwave: (Xing et al., 2005)
•Hydrothermal and Ultrasonication (Savitri et al., 2015)

Enzymatic



•Chitinases:
•Bacterial chitinases (Kielak et al., 2013)
•Fungal chitinases (Deeba et al, 2016).
•Plant chitinases (Punja and Zhang, 1993)

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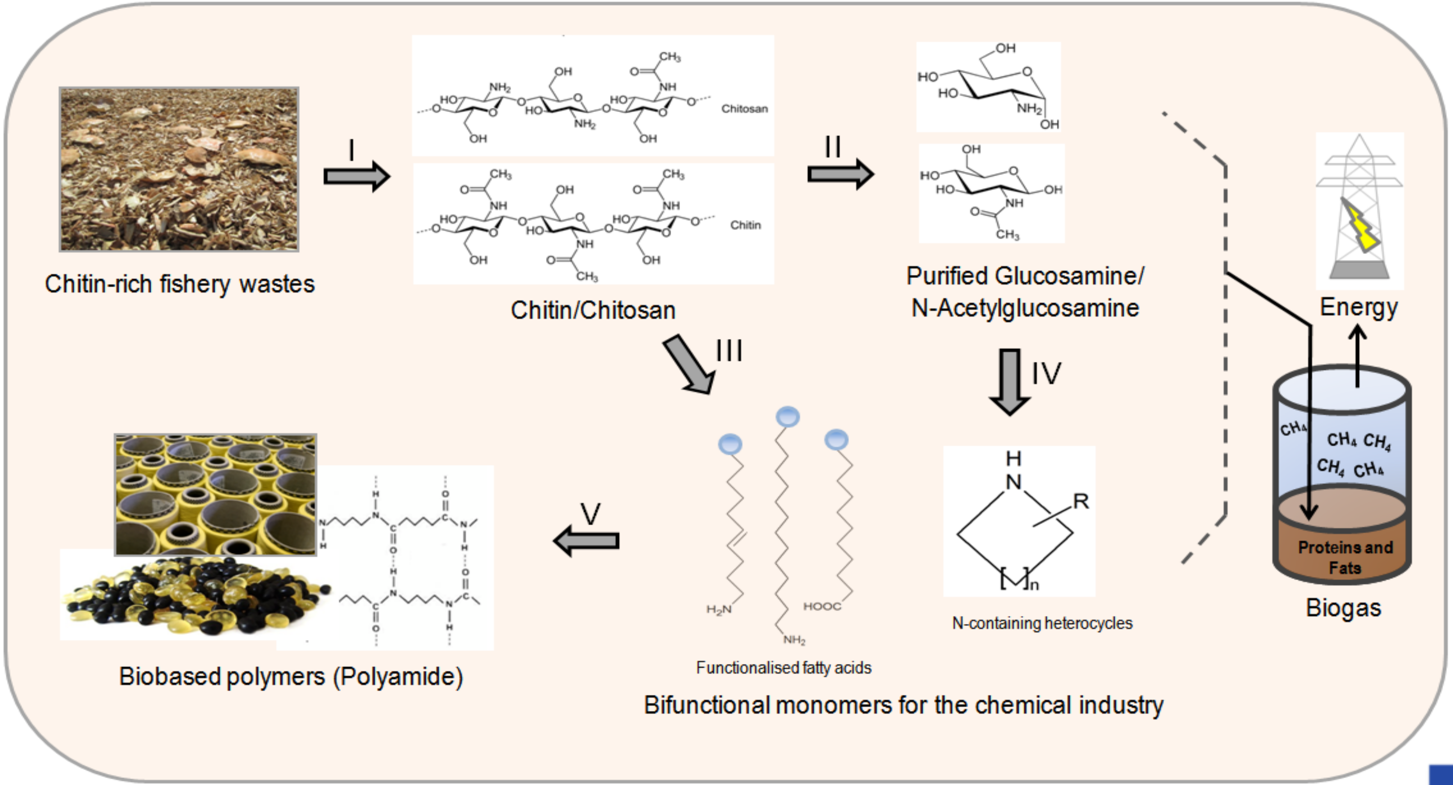
Chitin Biorefinery



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Accumulation of marine chitin-degrading microbiota (on crab-shell waste)

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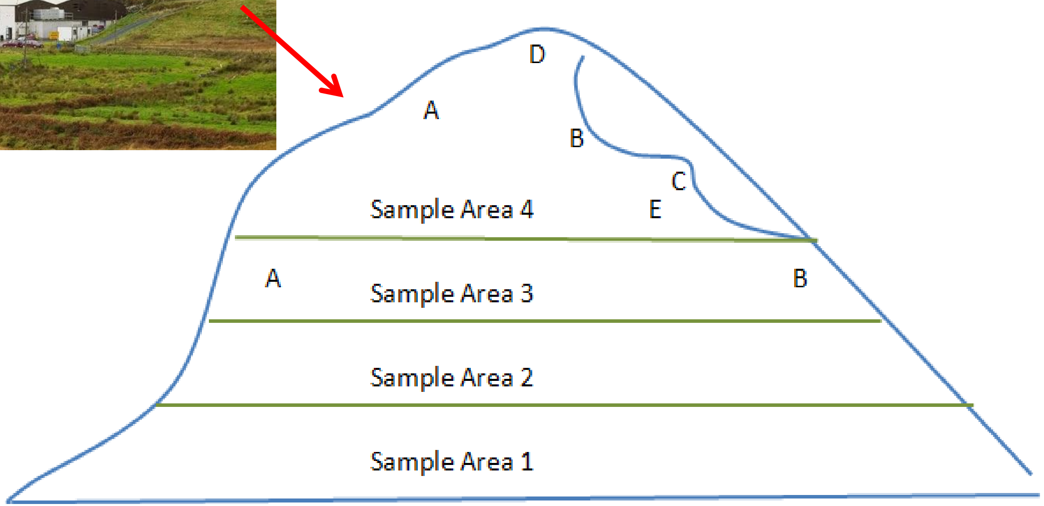
Accumulation of chitin-degrading microbiota (on crab-shell waste dumping site)



Map of Sampling Site at Earagail Eisc Teoranta Ltd

EXPERIMENTAL DESIGN

Chemical treatment | Biological treatment

Crustacean shellwaste from food processing

Chemical: Washing, drying and crushing of the shells
Biological: Washing, drying and crushing of the shells

Crushed shells

Chemical: Alkali treatment (1M NaOH for 1 – 72 h at 65 – 100 °C)
Biological: Organic acid (lactic acid) producing bacteria

Proteins ← → Minerals (calcium carbonate & calcium phosphate)

Deproteinization | Demineralization

Chemical: Acidic treatment (0.275 – 2.0 M HCl for 1 - 48 h at 0 – 100 °C)
Biological: Protease producing bacteria

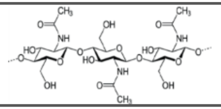
Minerals (calcium carbonate & calcium phosphate) ← → Proteins and Pigments

Demineralization | Deproteinization

Chemical: Discolouration and bleaching (organic mixture of chloroform, methanol and water 1:2:4 at 25 °C)

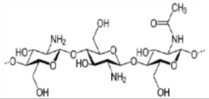
Pigments (carotenoids) ←

Chitin



Chemical: Deacetylation (NaOH/KOH -30-50 % (w/v) at 80 - 150 °C)
Biological: Deacetylation (Chitindeacetylase or lactic acid bacteria)

Chitosan



Chemical: Enzymatic/chemical hydrolysis
Biological: Hydrolysis by chitinolytic enzymes

Chito-oligosaccharides

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Preparation of cooked, minced brown crab for chitin extraction processes

Starting Material

Step 1: Hammering

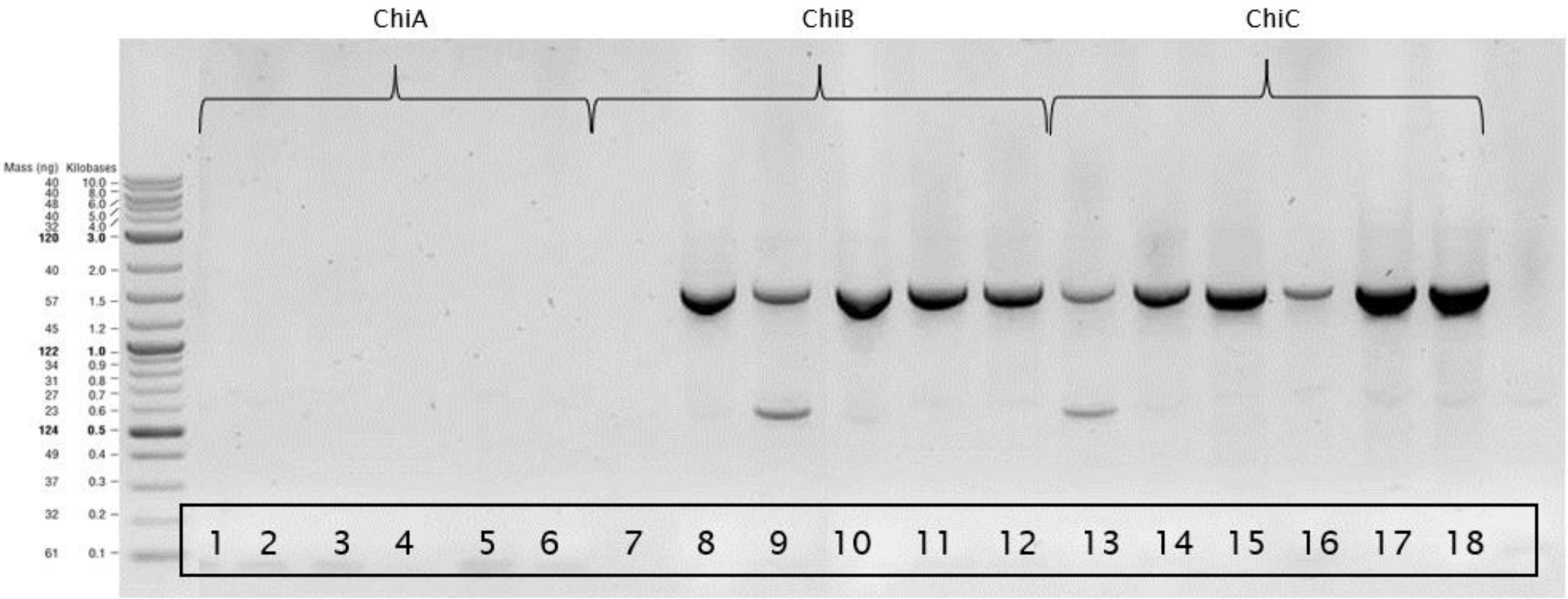
Step 2: Homogenising

Step 3: Drying @55°C

Step 4: Grinding

Workable raw Material

PCR products visualized on 1% agarose GEL ELECTRPORESIS



- Presence of ChiB and ChiC genes in the three Serratia isolates used. ChiA is not present.

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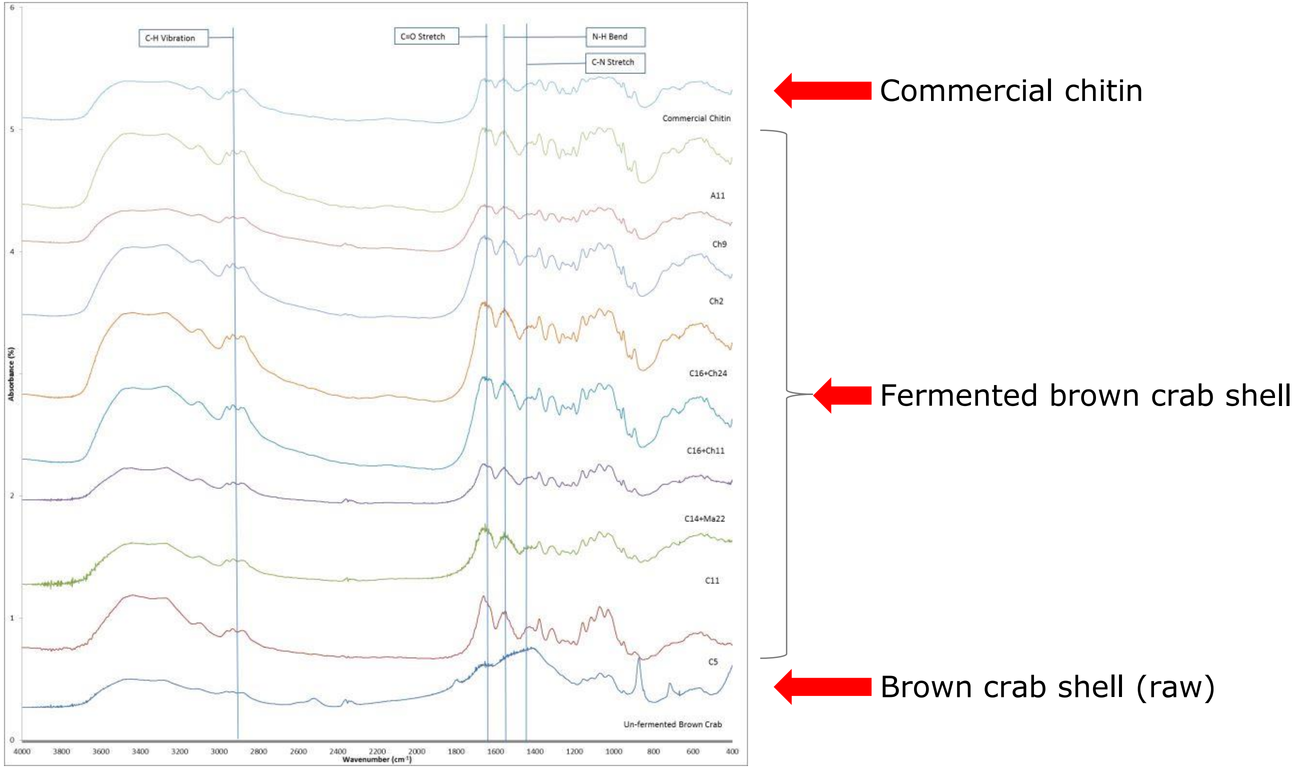
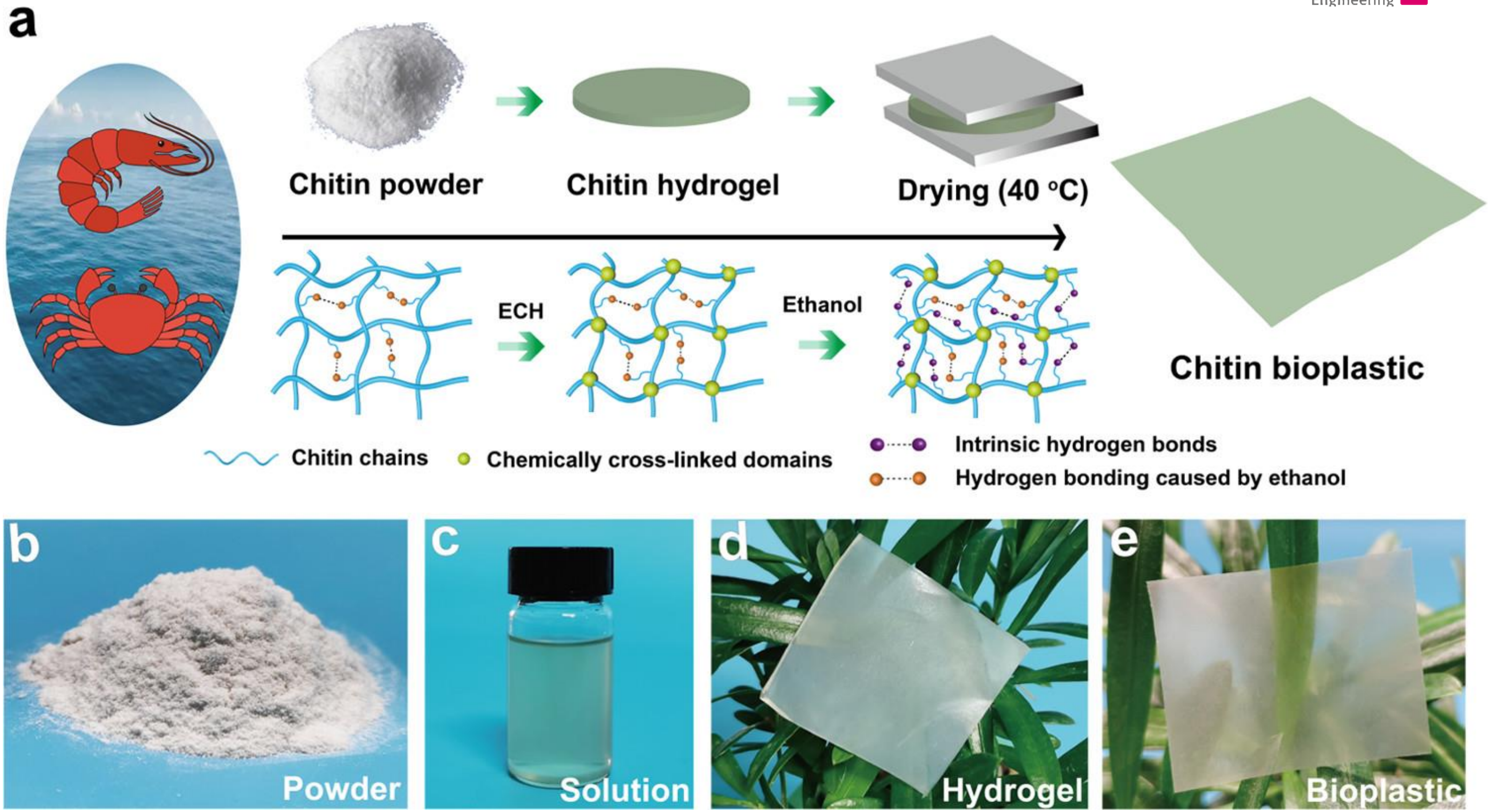
Quality assessment



FTIR spectra of all isolates are similar to the commercial chitin.

Production of chitin-based bioplastics



Source: https://doi.org/10.1021/acsami.2c12764

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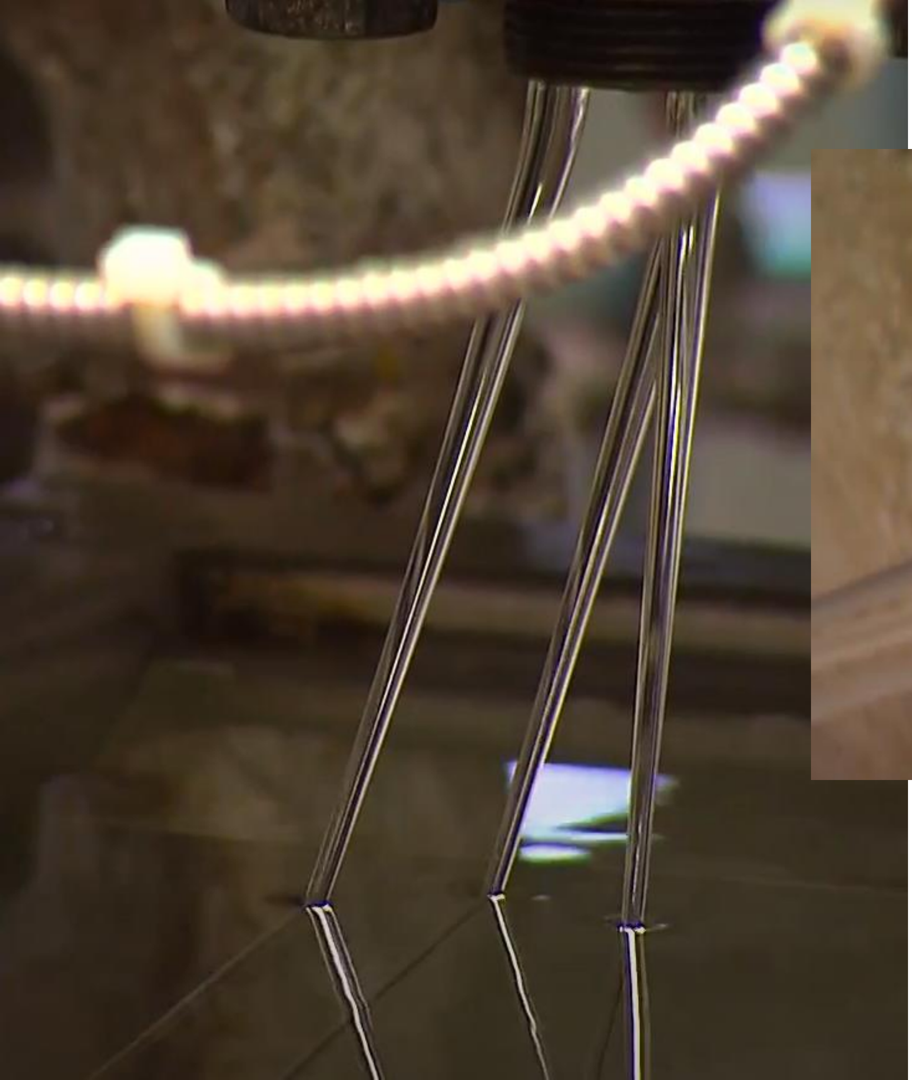

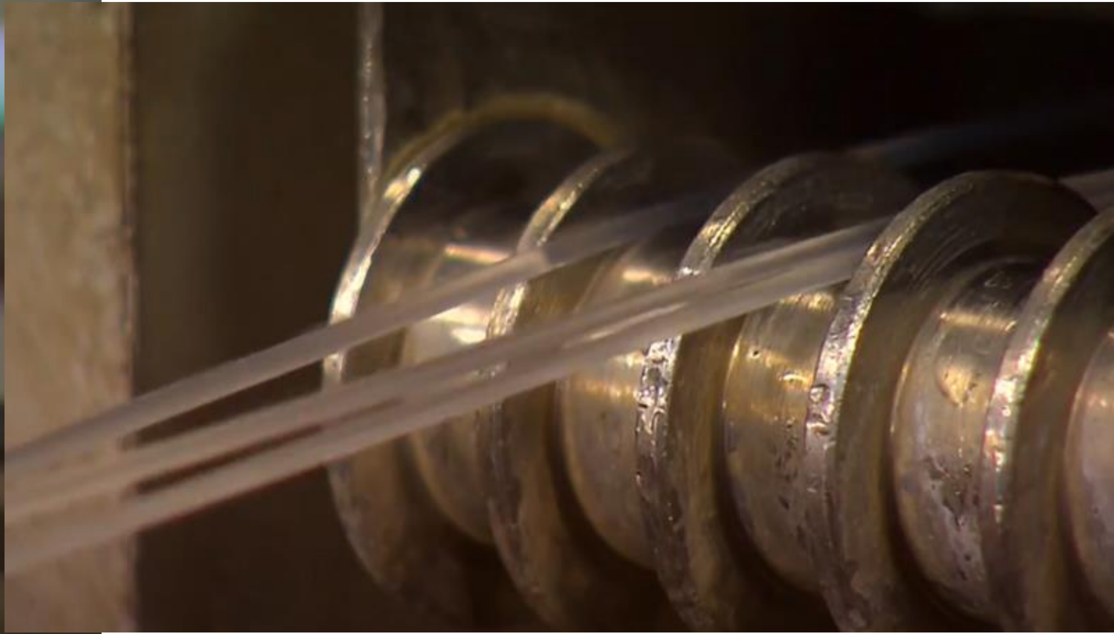

Bulk-produced polyamide (PA) 6.12, containing 3% of one of the ChiBio key monomers

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Conclusions

- A circular economy for food mimics natural systems of regeneration so that waste does not exist but is instead feedstock for another cycle.
- Food side-streams can:
  - Provide additional value by creating new products.
  - Be used to revolutionize material science for the building, manufacturing, food, pharmaceutical or cosmetic industries.
  - Combat climate change
- Food side-streams have no eco-toxicology or biodiversity impact
- A Circular Food Biorefinery is a new route to an eco- and cost- efficient bioeconomy

Thank you for your attention.

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