Biomass Biorefinery Network

## 4th BBNet Conference

### The future prospects for biorefining: Feedstocks, technologies and products

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# Defossilising the Chemical Industry

# – the Scale of the Challenge

**Dr Alastair Sanderson** CChem, FRSC

Alastair Sanderson Consulting Limited

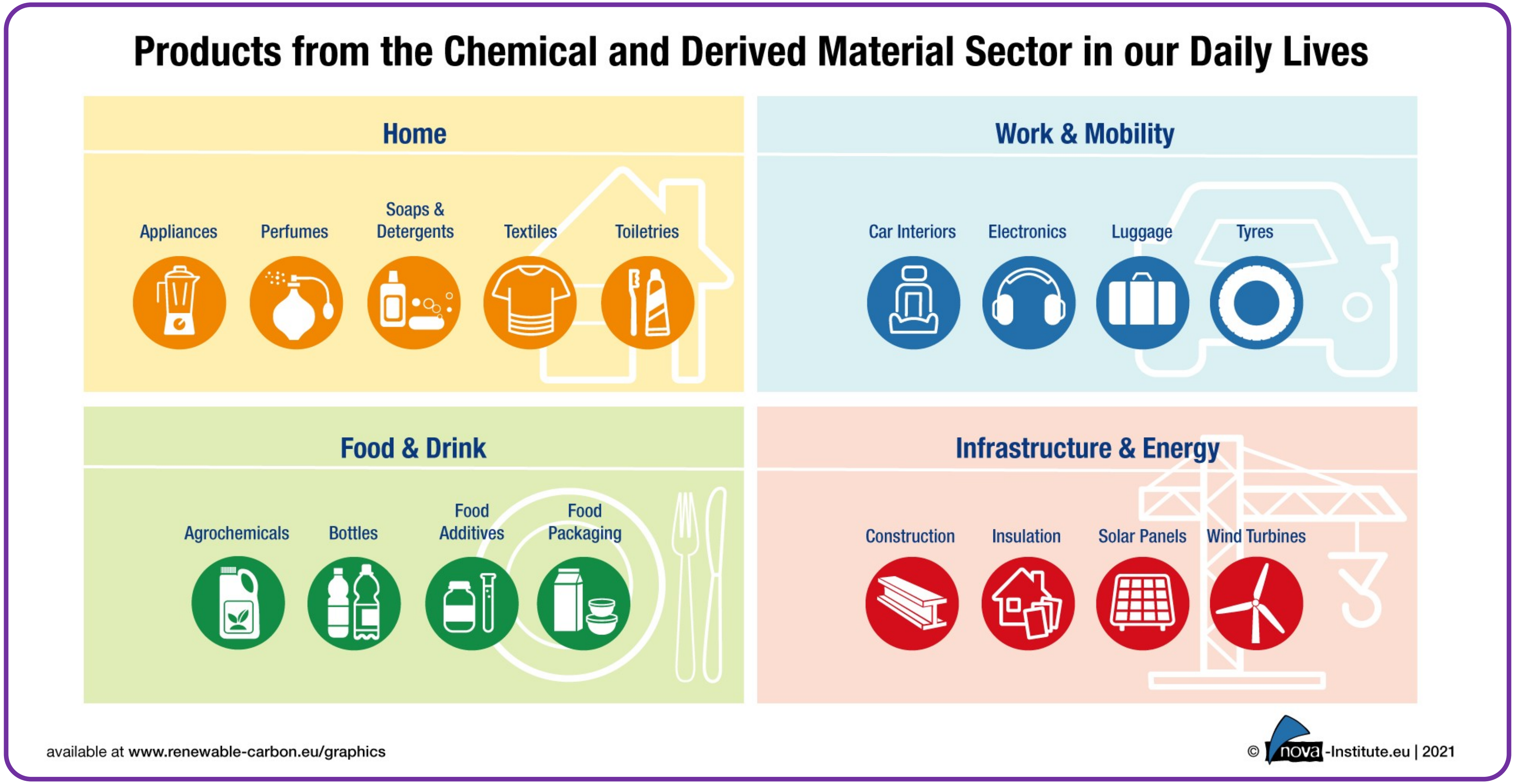
BBNET, Sheffield, 16th October 2025

# What am I going to share ?

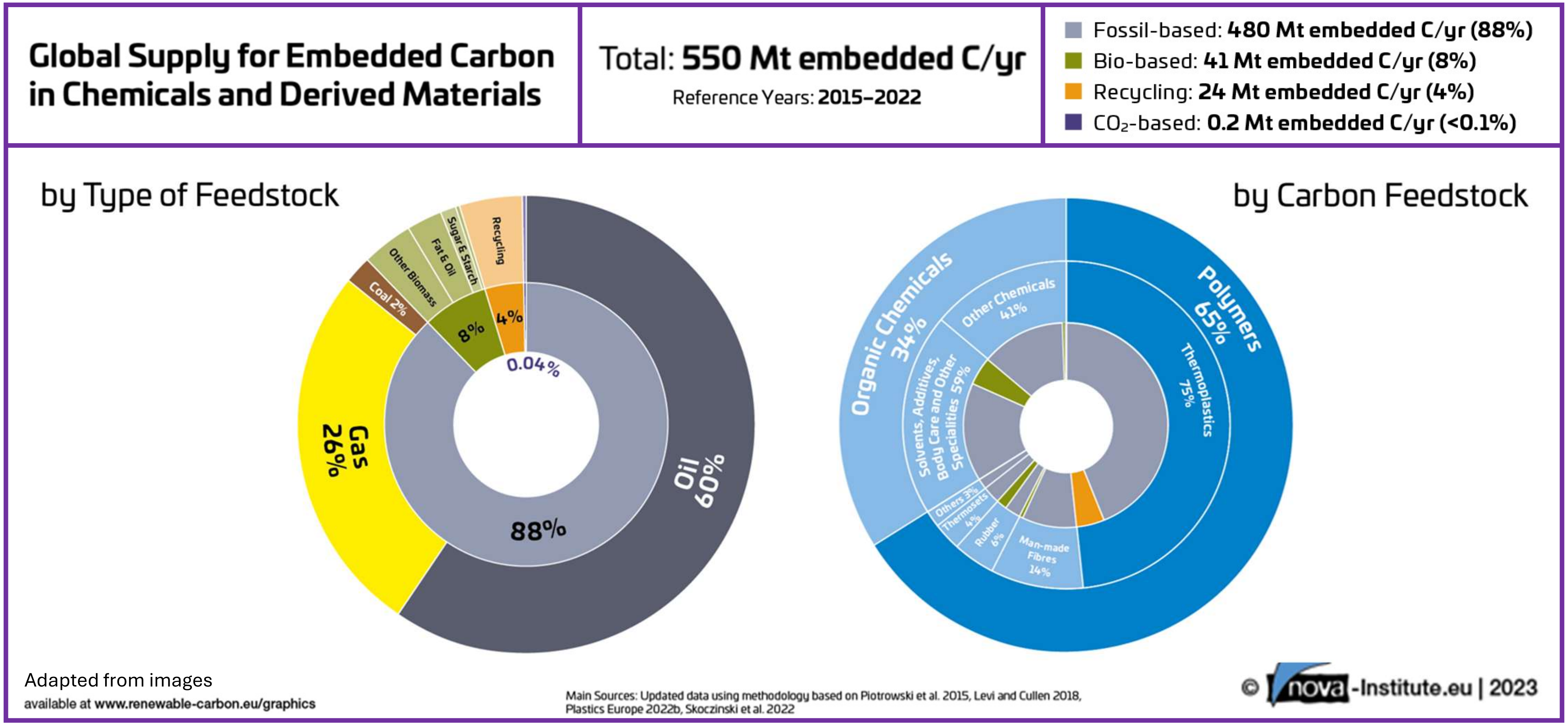
1. Role of Chemicals in meeting the needs of society.
2. Scale & Provenance of Chemicals today and looking forward to 2050.
3. Decarbonisation and Defossilisation – Chemicals need both.

4. Application Deep Dive: Chemical demand for Home and Personal Care.
5. Examples of Organic Chemical Value Chains.
6. New or Drop-in fossil carbon free Chemicals ?

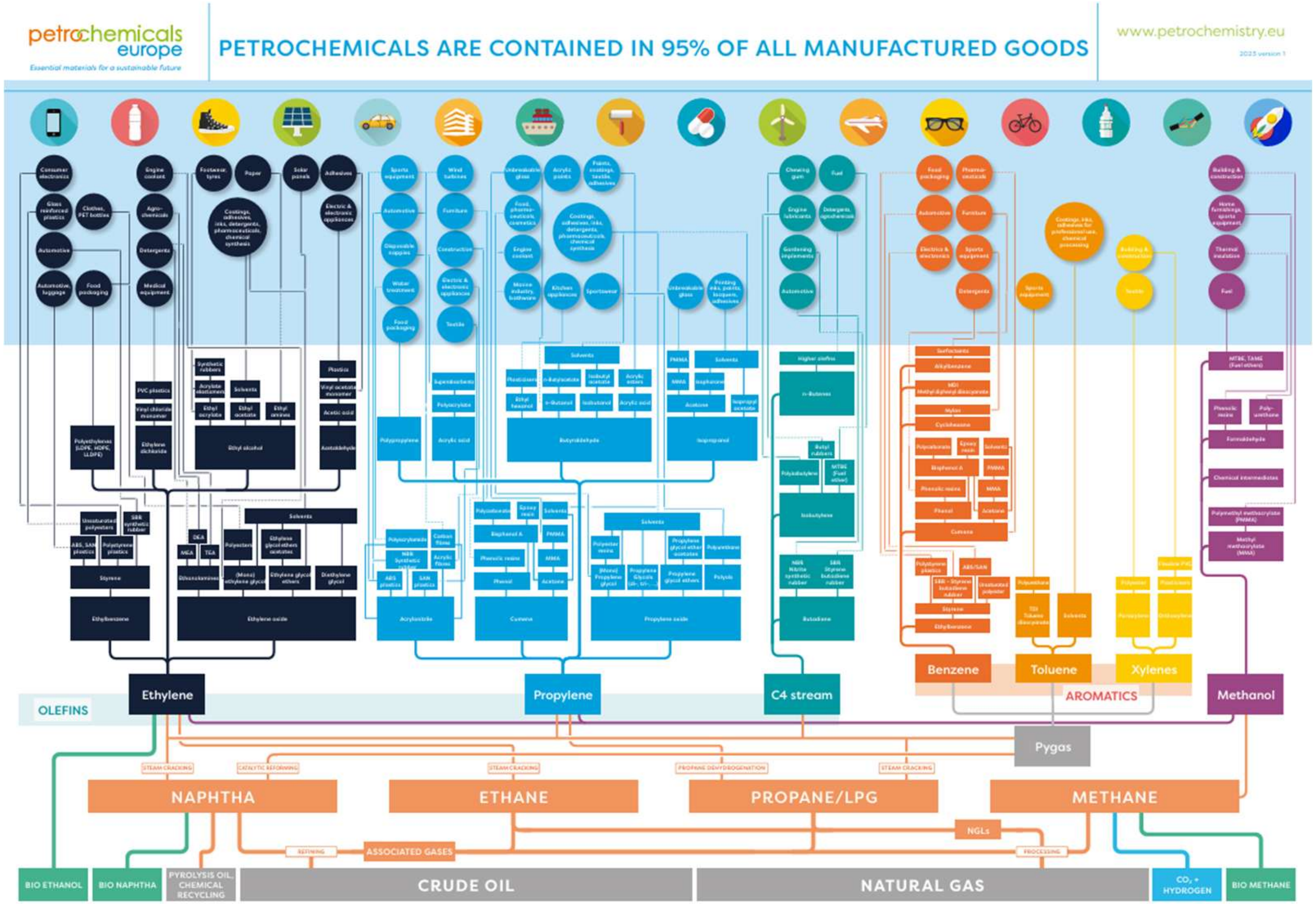
# We can’t live without Chemicals



# Carbon in Chemical Materials



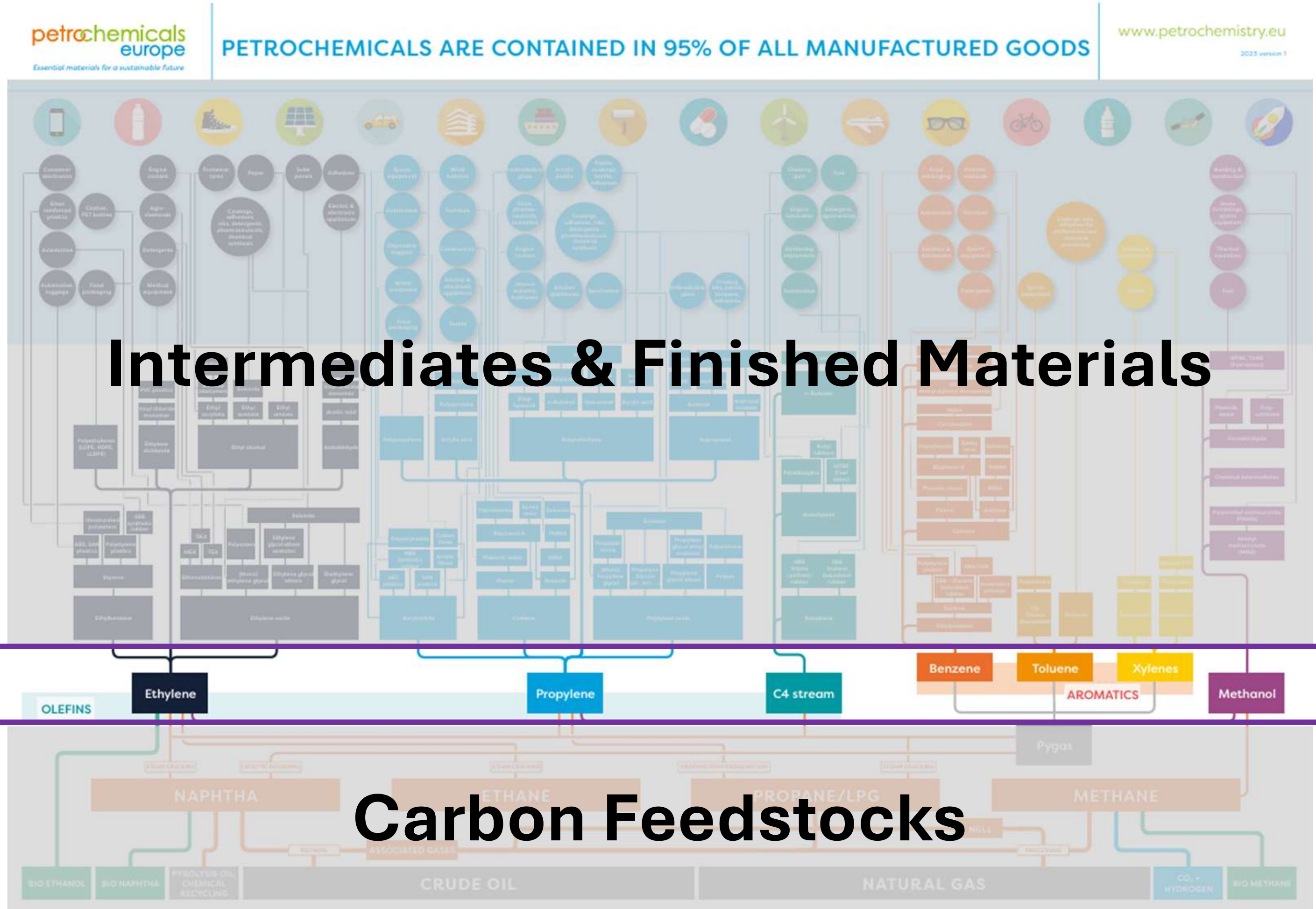
# Petrochemical Value Chain




- Integrated
- Highly Optimised
- Very Complex

https://cefic.org/news/the-journey-of-petrochemicals-explained-from-raw-materials-to-95-of-all-manufactured-goods/

# “Magnificent 7”

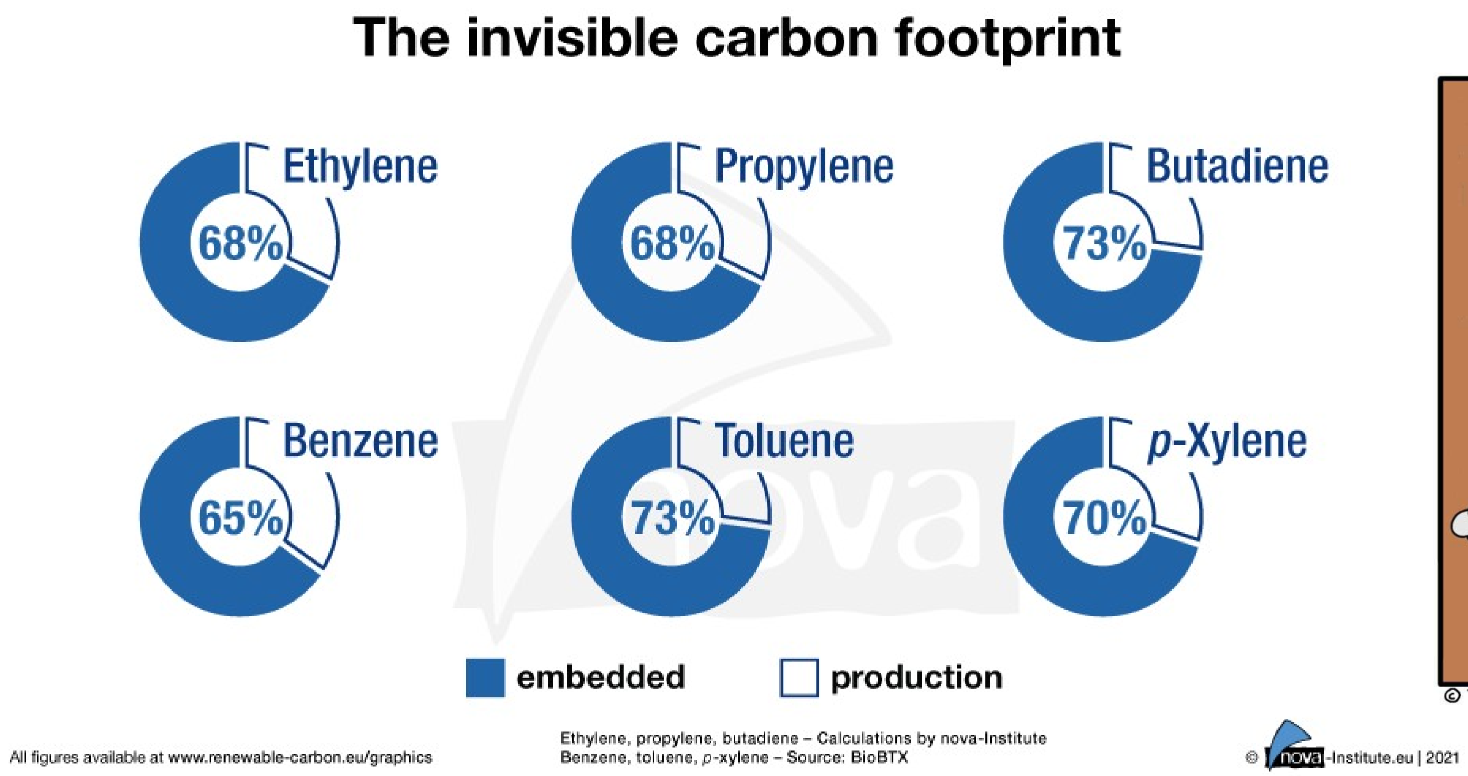


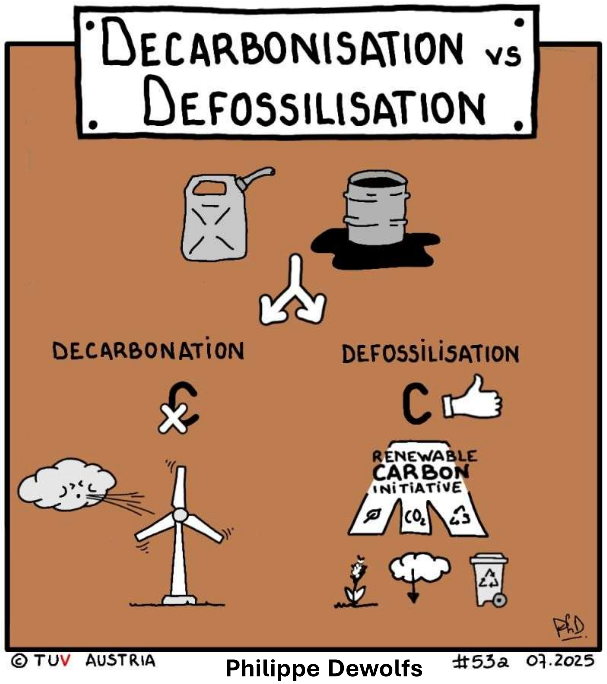

| Material | Produced Mt / year |
|---|---|
| Ethylene | 180 |
| Propylene | 160 |
| Butadiene | 20 |
| Benzene | 60 |
| Toluene | 35 |
| Xylene | 70 |
| Methanol | 50 |
| ***Total*** | ***575*** |

**7 Key Building Blocks**

https://cefic.org/news/the-journey-of-petrochemicals-explained-from-raw-materials-to-95-of-all-manufactured-goods/

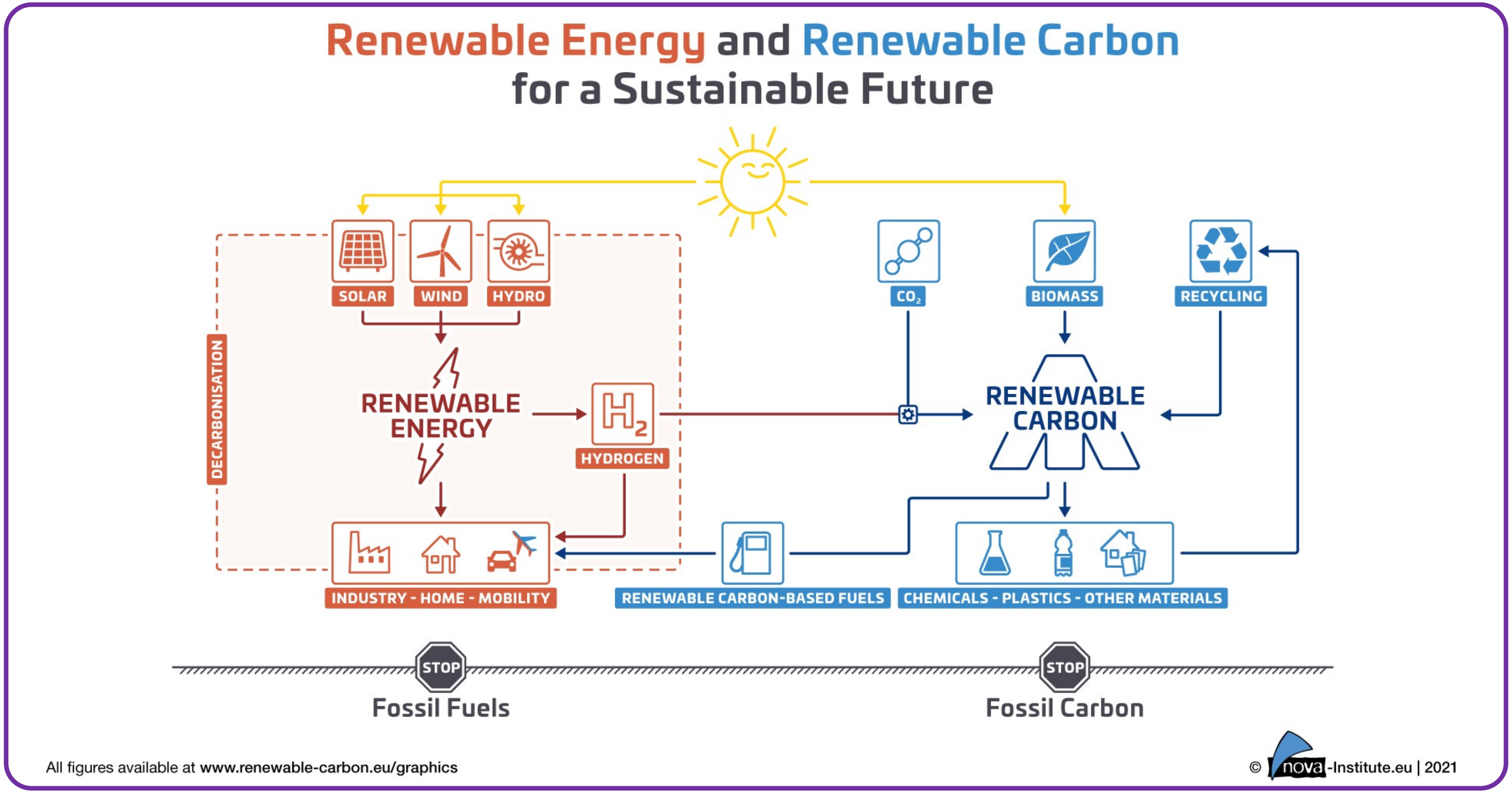
# Embedded Carbon: the Hidden PCF



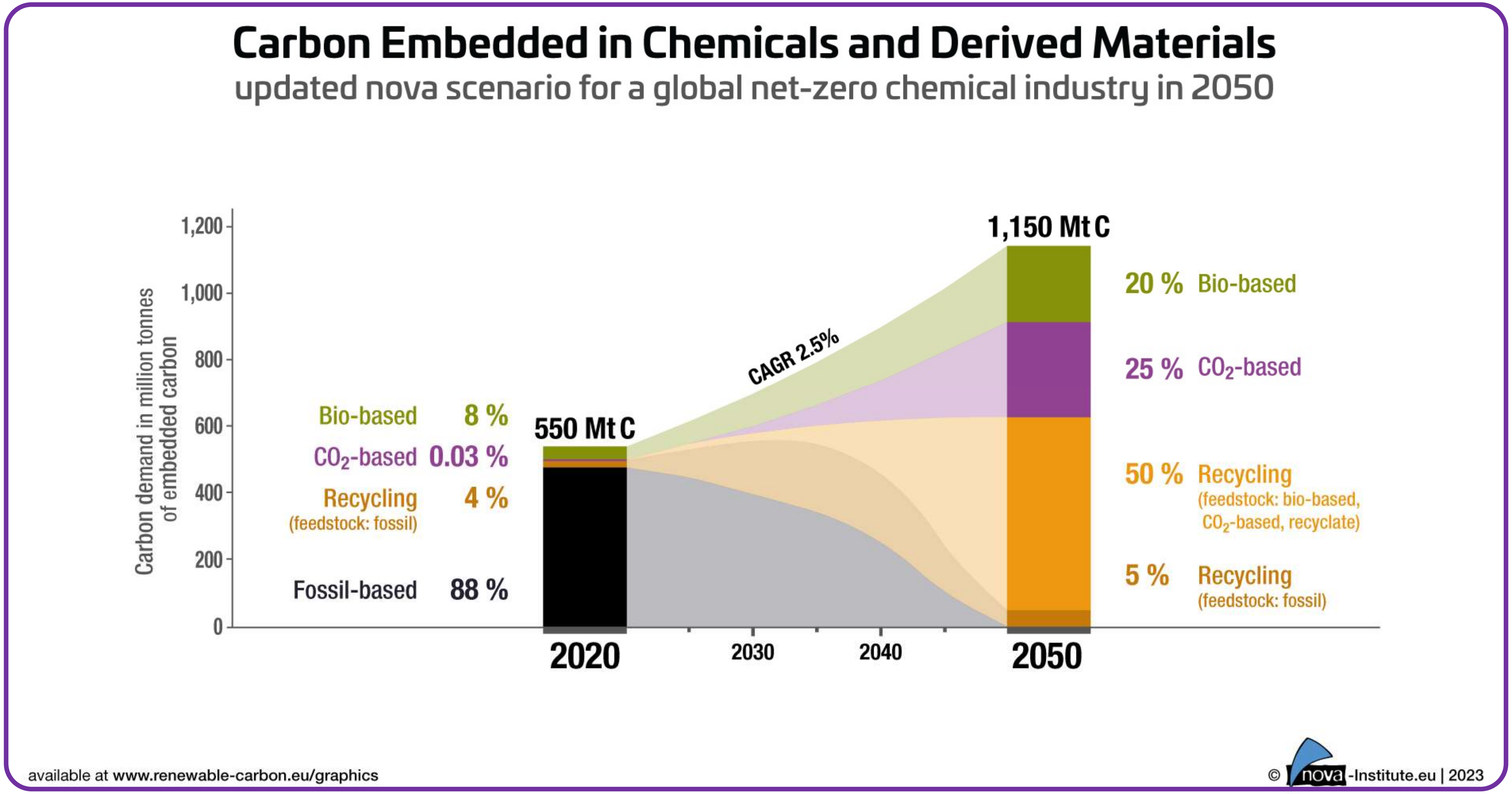




Philippe Dewolfs

# Surviving without Fossil Carbon



# Demand for Chemicals to Double



# Application Deep Dive

## Home and Personal Care Material Needs

# HPC Products – What's in the Pack ?

**Water**
**Inorganics**
**Surfactants**
**Polymers**
**Enzymes**
**Bleaches**
**Actives**
**Fragrances**
**Colourants**
**etc**

**20+ ingredients typically**

**Surfactants dominate organics**

**Formulations are HOLISTIC**

Ingredients:

- designed and formulated to work in synergy with each other
- "impurities"
  - can enhance performance
  - can adversely impact quality
  - often need "work arounds"

**In liquids especially – everything affects everything else.**

- "Same Chemical" from different suppliers not always interchangeable.
- Generally "One-in One out" does not apply.
- One small change normally triggers a full reformulation

# Home and Personal Care Ingredients 1

| | |
|---|---|
| Tons of product sold | HPC = 77 - 81 Mt/yr |
| Tons of Organic Ingredients | HPC = **18 - 25 Mt/yr** |

Atomic composition (wt%)

**35 - 40** **Carbon**

8 - 10 Hydrogen

20 - 25 Oxygen

+ N, S, P

| Material | Typical Inclusion wt% | Mt used globally in HPC |
|---|---|---|
| Linear Alkylbenzene Sulfonate (LAS) | 5.0 - 25.0 | **4.5 - 5.0** |
| Sodium Lauryl Ether Sulfate (SLES) | 5.0 – 15.0 | **2.5 - 3.0** |
| Alcohol Ethoxylates (AEO) | 1.0 – 10.0 | **3.1 - 3.5** |
| Alkyl Polyglucosides | 1.0 - 15.0 | **0.07 - 0.11** |
| Cocamidopropyl Betain (CAPB) | 1.0 – 7.0 | **0.15 - 0.20** |
| Disodium Laureth Sulfosuccinate | 5.0 - 8.0 | **0.08 - 0.10** |
| PEG-7 Glycerol Cocoate | 1.0 - 2.0 | **0.01 - 0.02** |
| Quaternary (eg TEAQ, Deedmac, 2HT) | 4.0 - 10.0 | **0.16 - 0.22** |
| Cyclopentasiloxane (D5) | 5.0 - 10.0 | **0.13 - 0.20** |
| Sodium Palmate | 2.0 - 60.0 | **1.95 - 2.9** |

Primary Surfactant

**2 - 5 Mt**

Co-active

**10 - 250 kt**

# Home and Personal Care Ingredients 2

| Material | Typical Inclusion wt% | Mt used globally in HPC |
|---|---|---|
| Enzymes (various: as delivered with c. 5-10% protein) | 0.10 - 1.0 | **0.6 - 0.9** |
| Glycerin | 2.0 - 5.0 | **1.3 - 1.5** |
| Cetearyl Alcohol | 3.0 - 6.0 | **0.20 - 0.26** |
| Caprylic / Capric Triglyceride | 5.0 - 10.0 | **0.10 - 0.11** |
| Sodium Carboxy Methyl Cellulose (SCMC) | 0.5 - 2.0 | **0.08 - 0.10** |
| Soil Release Polymer (eg PET-POET) | 0.20 - 2.0 | **0.05 - 0.07** |
| Preservative | 0.5 - 1.0 | **0.1 0 - 0.11** |
| Acrylate Polymers (eg CP5) | 0.5 - 3.0 | **0.21 - 0.26** |
| Ethoxylated Polyethyleneimine (EPEI) | 0.1 - 3.0 | **0.06 - 0.08** |
| Tetraacetylethylenediamine (TAED) | 1.0 - 5.0 | **0.12 - 0.15** |
| Optical Brightener (eg CBS-X) | 0.1 - 0.5 | **0.08 - 0.10** |
| Fragrance (10's-100's of components) | 0.5 - 2.0 | **1.2 - 1.5** |

Plus c. 2Mt
Specialist Polymers
Solvents,
Hydrotropes,
Organic acids,
Colourants

Commodities

**c. 1.0 MT**

Specialist Materials

**10 – 300kt**

# Insights on Material Scale in HPC

- **To reach Net Zero or Defossilise HPC products, 18 to 25 Mt organic materials are in scope**
  - Many common materials also used in other industries: volume to convert is higher (c. >350 Mt)
  - Surfactants Dominate in HPC; product differentiation driven by specialist functional ingredients

| Material | T / year |
|---|---|
| Primary Surfactants & Bulk Commodities | 1,000,000 – 5,000,000 |
| “Co-Surfactants” & Speciality Chemicals | 10,000 – 300,000 |

# What does this look like operationally ?

| Scale T/yr | Units a day produced and distributed |
| --- | --- |
| 10,000 |  |
| 100,000 |  |
| 1,000,000 |  |
| 5,000,000 |  |

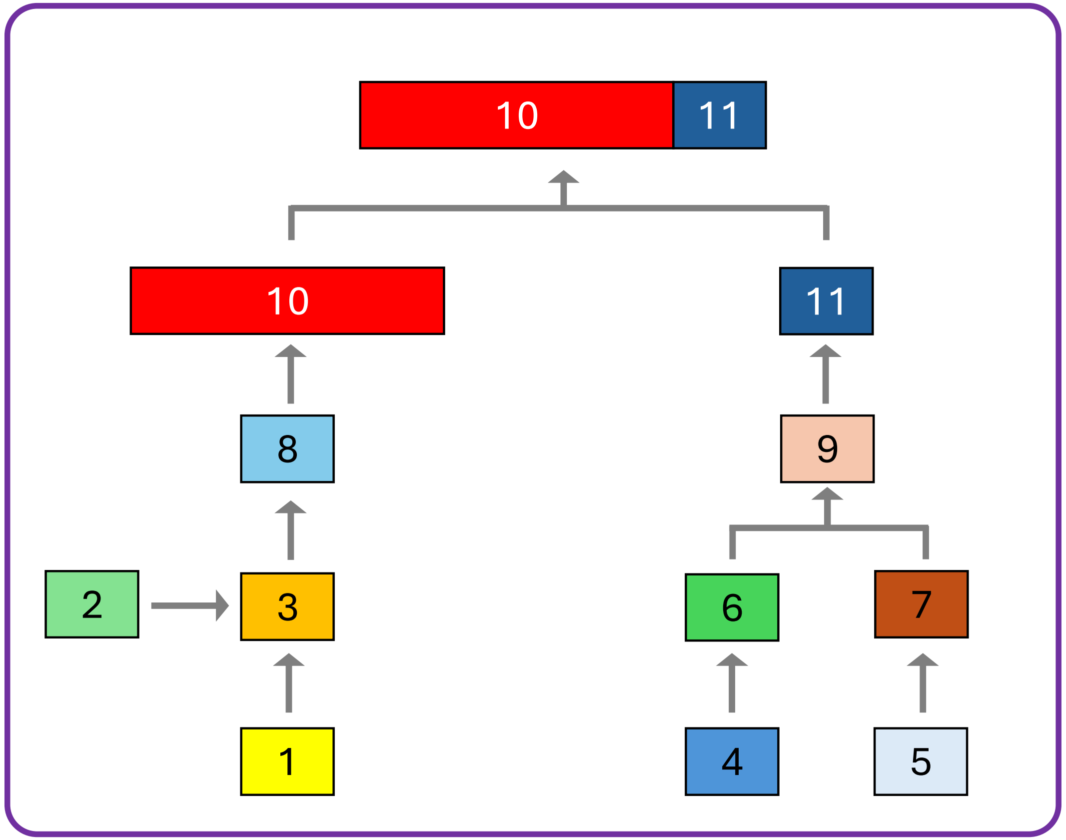

40T

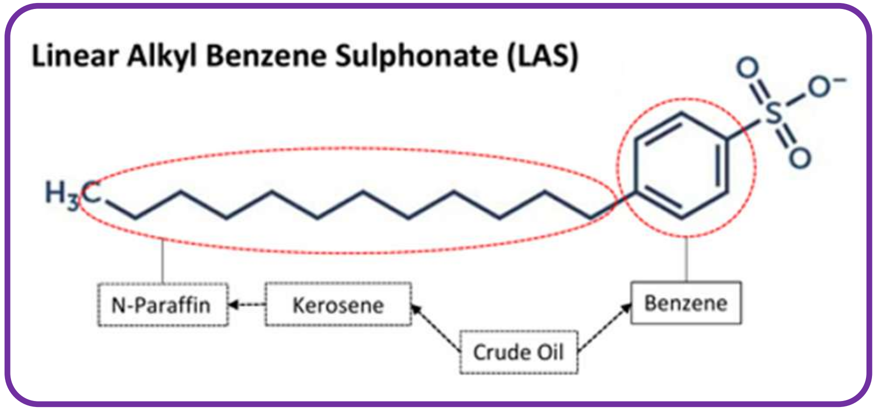

1 kT

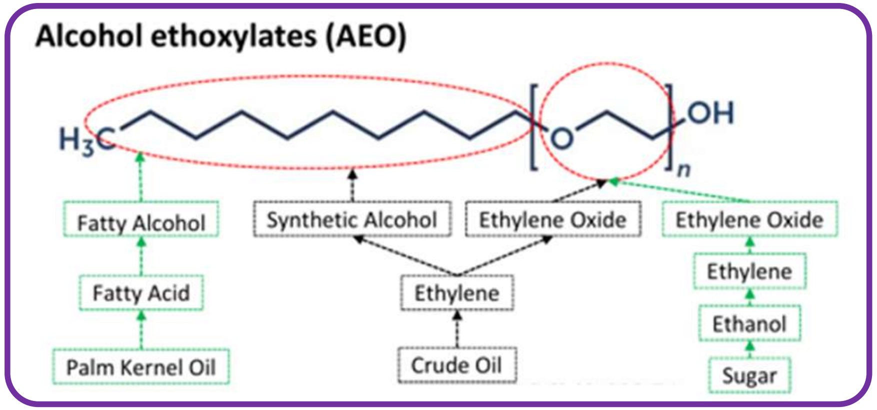

15 kt

# What to make ?

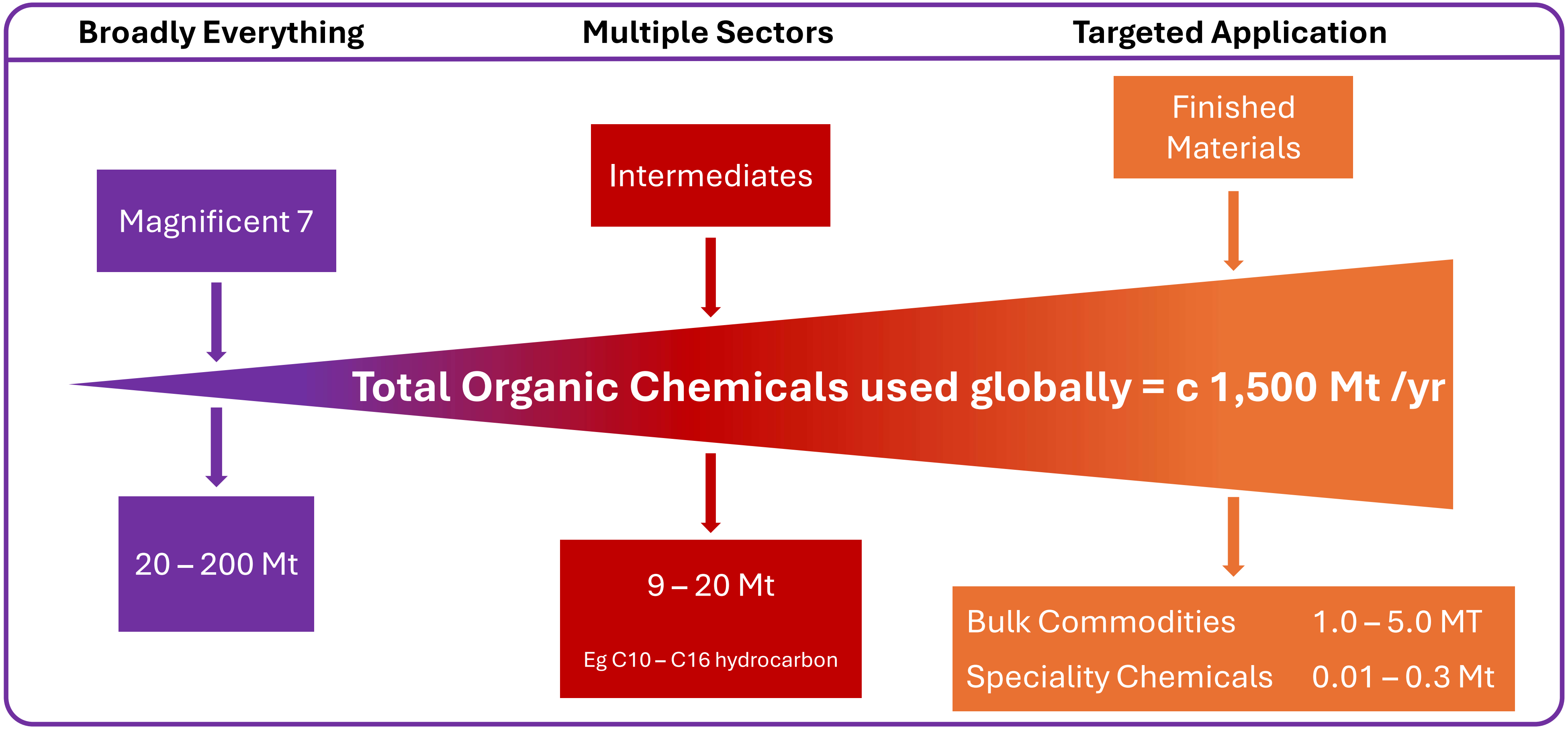
# Simplified Material Value Chain



# Value Chain Entry Point Informs Scale



# New or Drop-in Replacement Chemicals ?

1. Petrochemical Industry optimised and scaled over c. 100 years

2. "Magnificent 7" from renewable refinery feedstocks could utilise many current assets.

3. New BioTechnology processes can be discrete and incompatible with Petrochemical infrastructure.

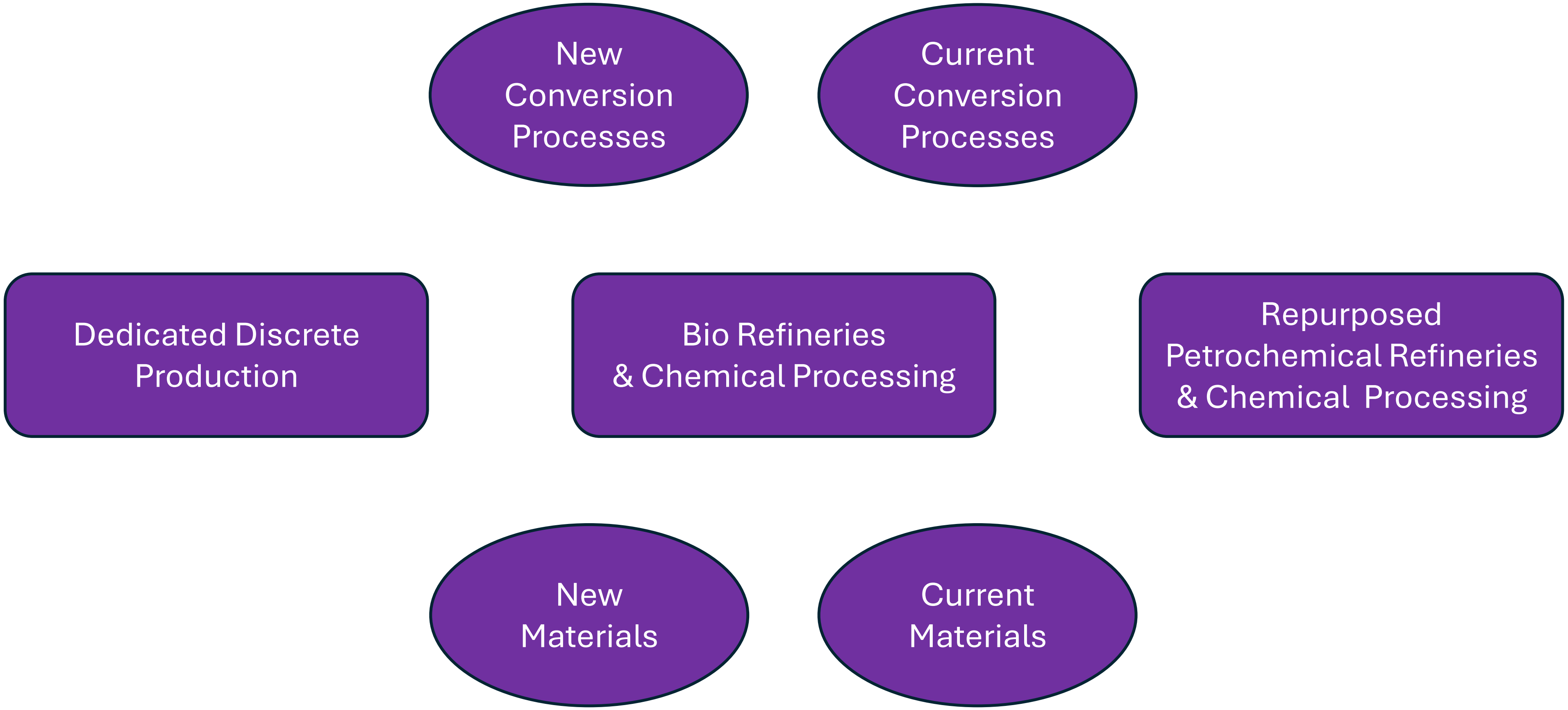
4. New materials always needed (enhance holistic performance, increase weight efficacy).

5. Creating new materials to replace every Petrochemical and formulating them is a herculean task

| | |
|---|---|
| 5 - 10 years+ | commercialise and register a new material |
| 3 - 5 years+ | learn how to build a formulation around new materials |
| 1 - 2 years | validate a Drop-in is suitable for end application |

**Both New & Drop-in fossil free replacements needed to Defossilise the Petrochemical Industry.**

# A Renewable Carbon Chemical Industry



# Key Takeaways

1. Society can’t live without Chemicals: most are fossil based.
2. Organic Chemicals use 550Mt embedded Carbon per year, doubling by 2050.
3. Decarbonise Energy & Defossilise Carbon: $CO_2$, Biomass, Recycling.
4. Scale daunting: Only HPC; Mt Commodities and 100’s kt Specialities.
5. Chemical Value Chains are Complex – need clarity on our purpose.
6. New or Drop-in fossil carbon free Chemicals ? We need both “at scale”.

# Contact Details

Tel: +44 (0)777 368 3940

Email: alastair@ascltd.org

www.linkedin.com/in/alastair-sanderson-ab539b11

# Microbial conversion of lignin to monomers for bioplastic production: a case study

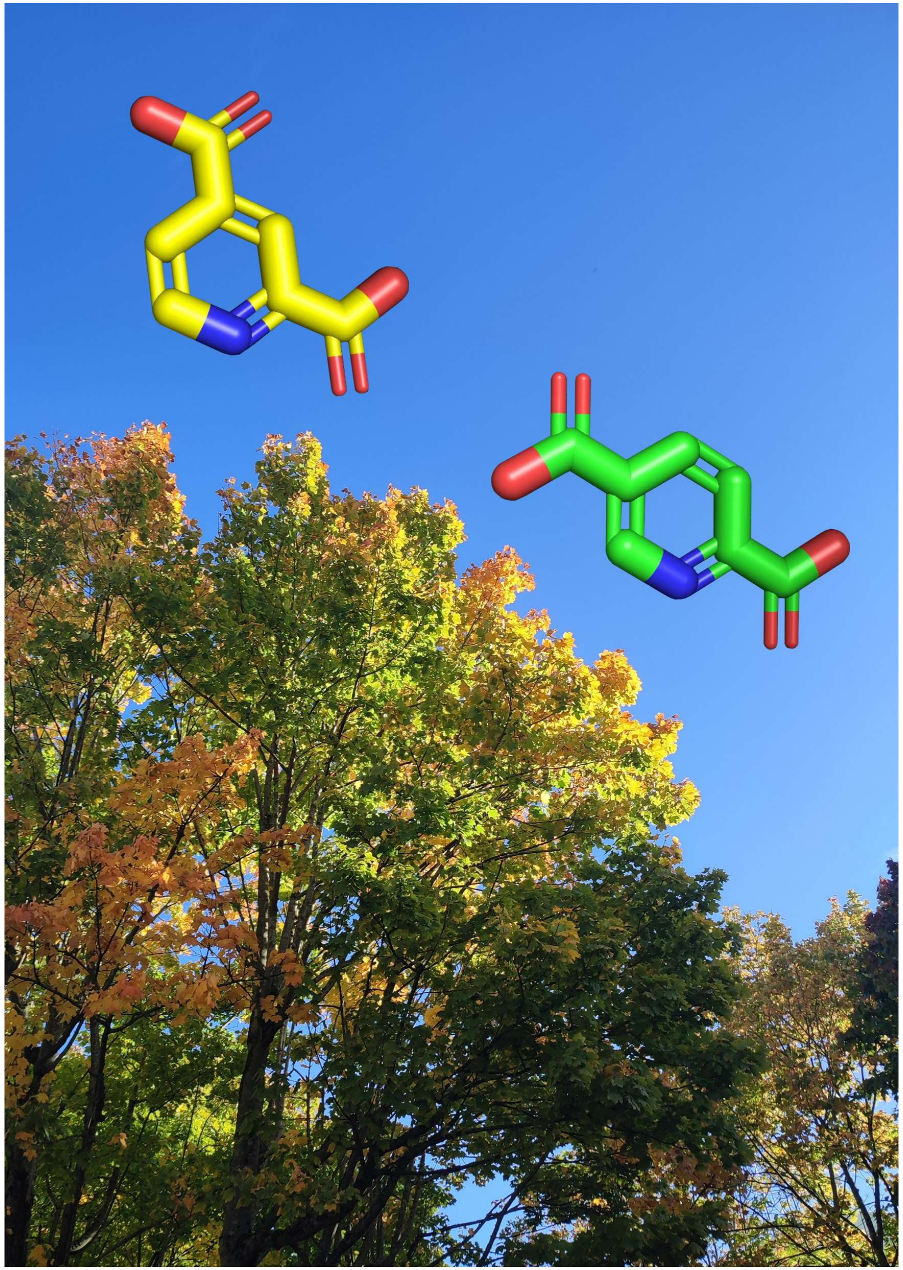
Dr. Victoria Sodré

Research Fellow in Biotechnology/Enzymology

Bugg group

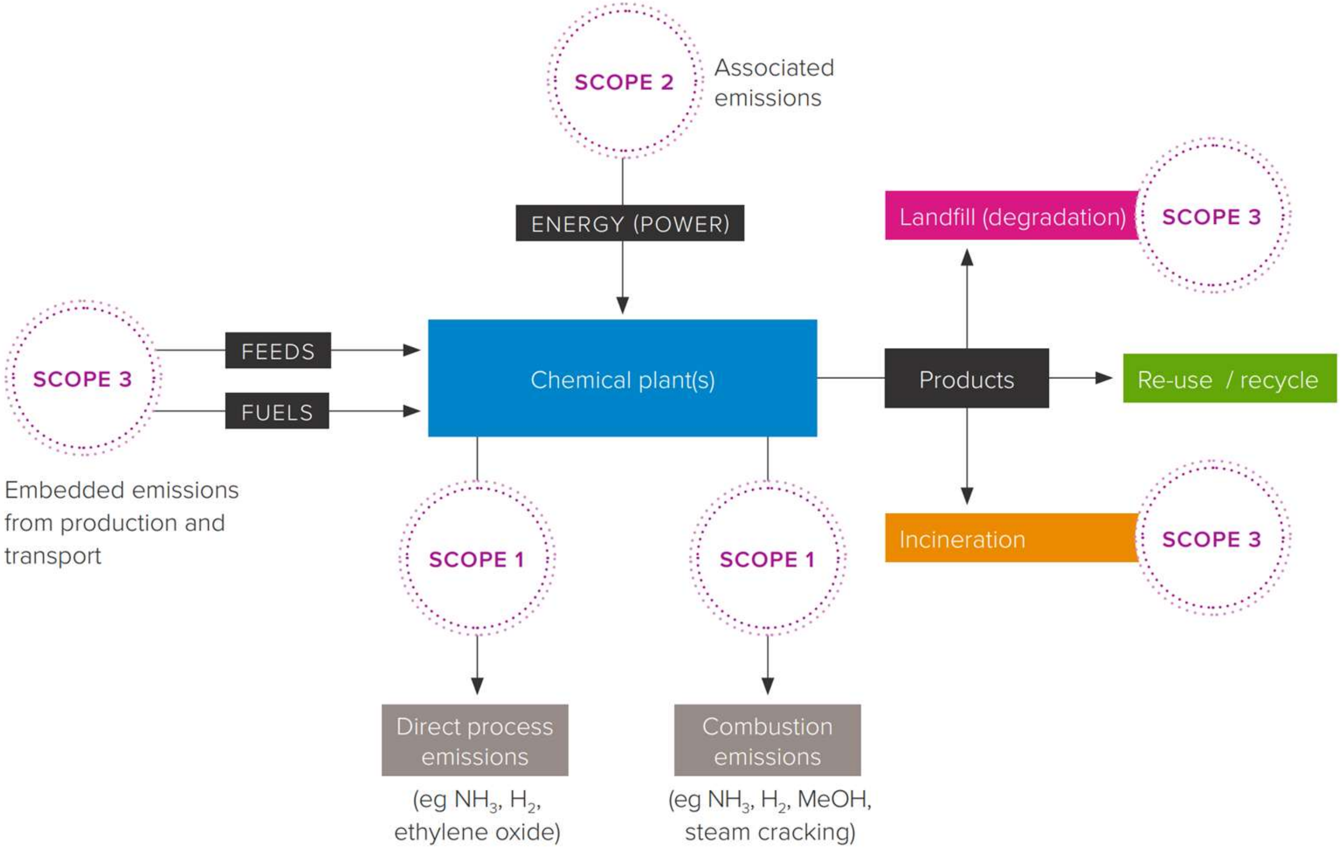
Chemistry Department

UNIVERSITY OF WARWICK



# Defossilising the chemicals sector

- The chemicals sector is responsible for 6% of global $CO_2$eq emissions




"Catalysing change: Defossilising the chemical industry – policy briefing", 2024, The Royal Society

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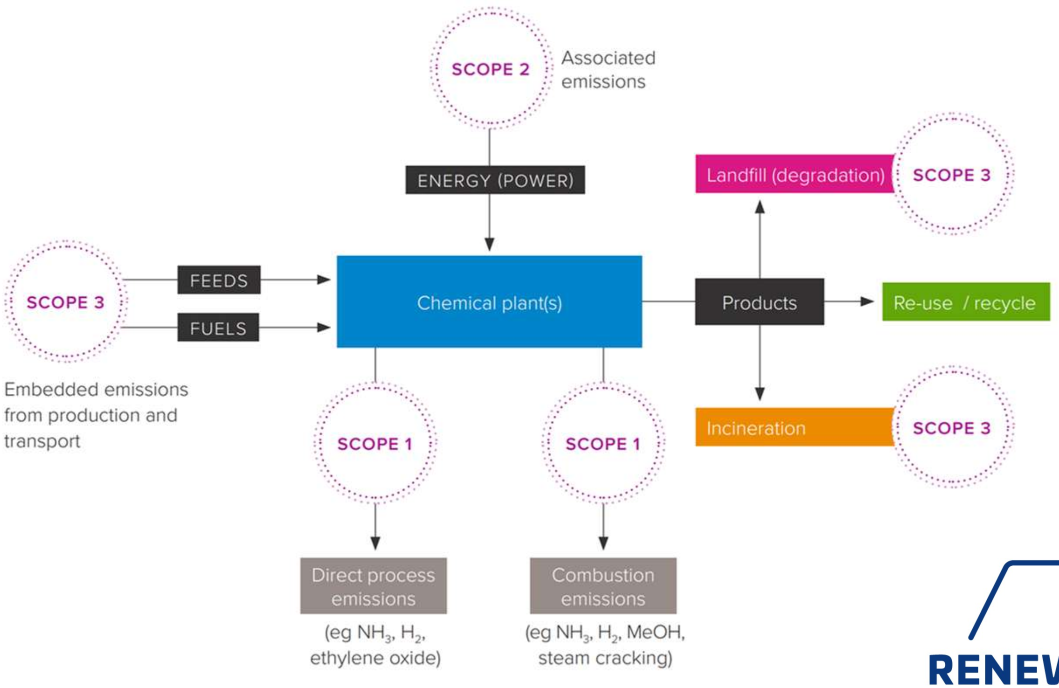
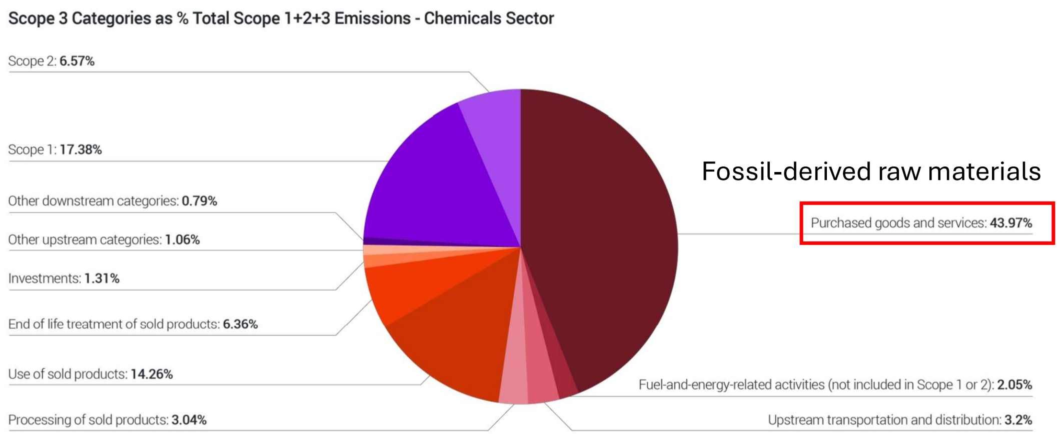



"Catalysing change: Defossilising the chemical industry – policy briefing", The Royal Society, 2024

"CDP Technical Note: Relevance of Scope 3 Categories by Sector", CDP, 2025

# The issue of plastics

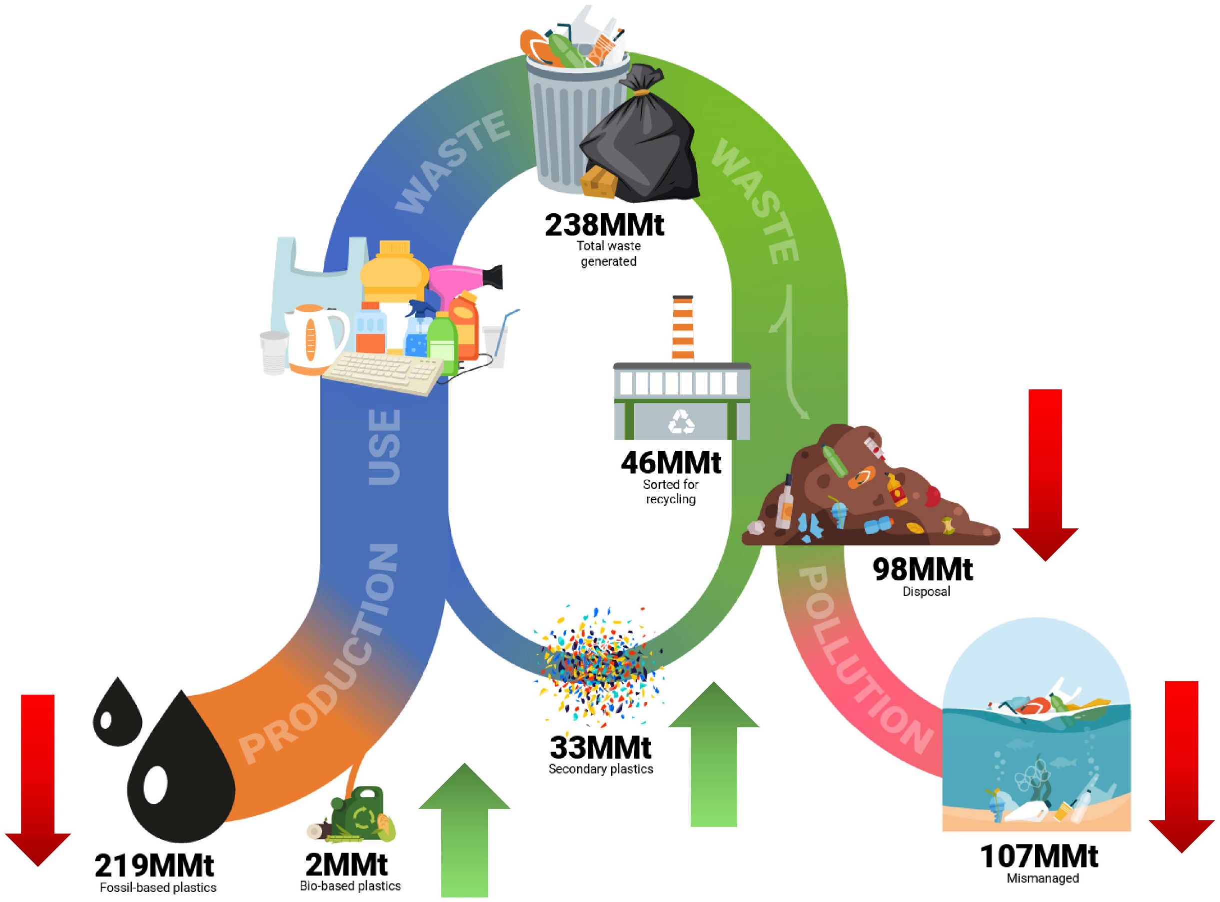
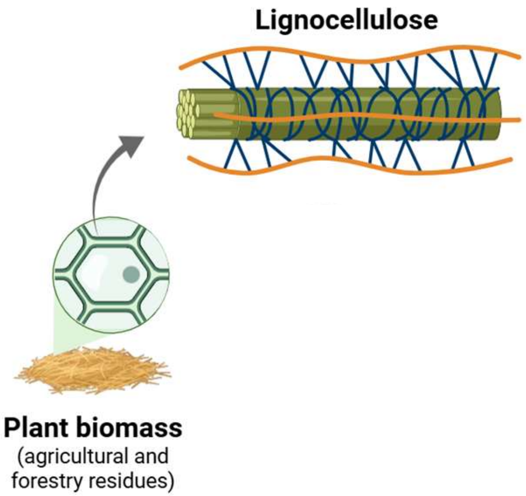



Figure 1: **Short-lived plastic flows in 2020.**

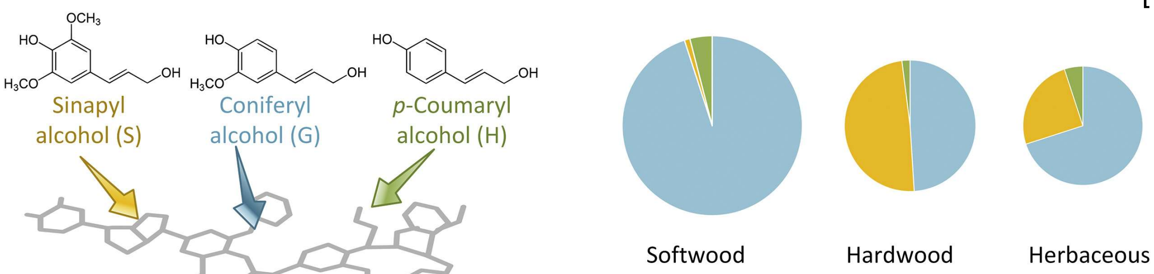
*Source: UNEP modelling building on The Pew Charitable Trusts and Systemiq (2020) and OECD (2022).*

# Lignocellulose-based biorefinery concept

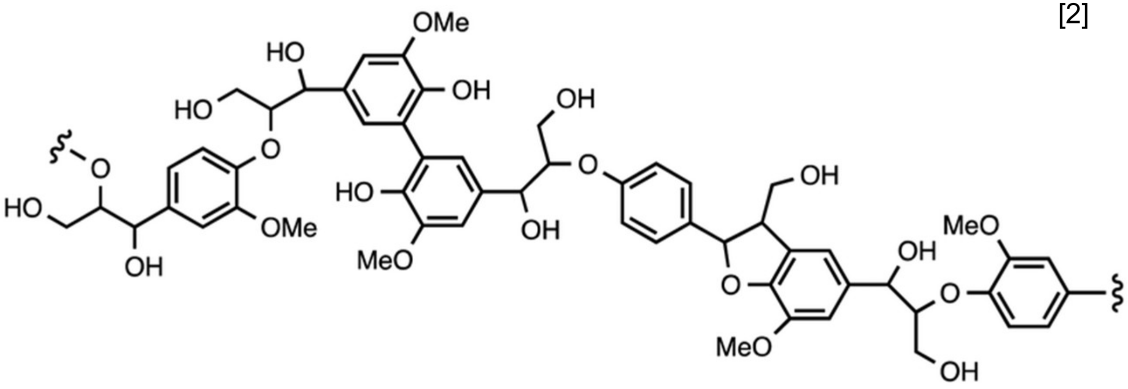


# Molecular structure of lignin

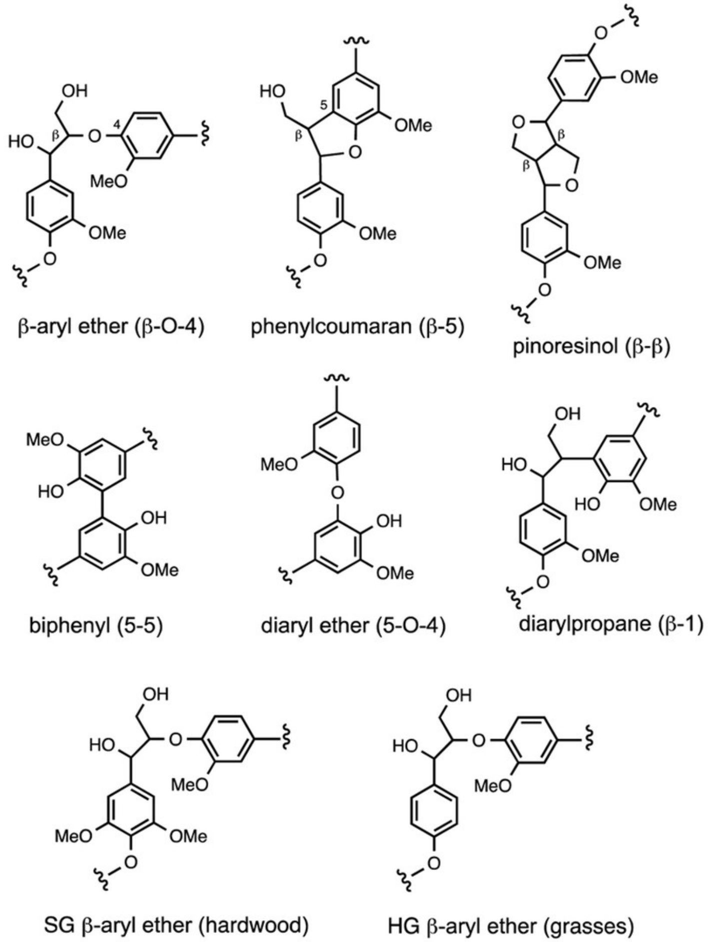
[1]




[2]



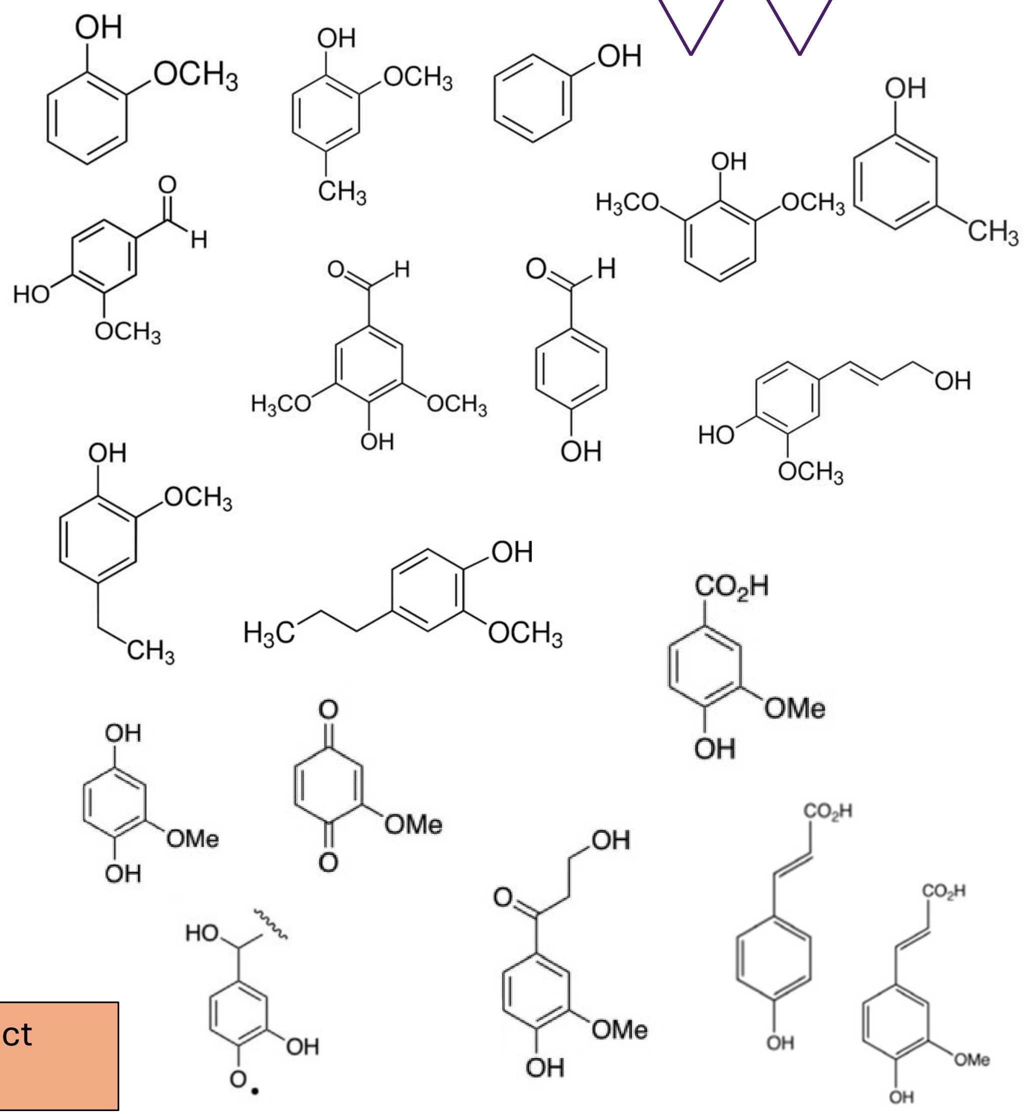
[2]




Adapted from: [1] Becker and Wittmann, *Biotechnol Adv*, 37(6), 2019; [2] Sodré and Bugg, *Chem Commun*, 60, 2024

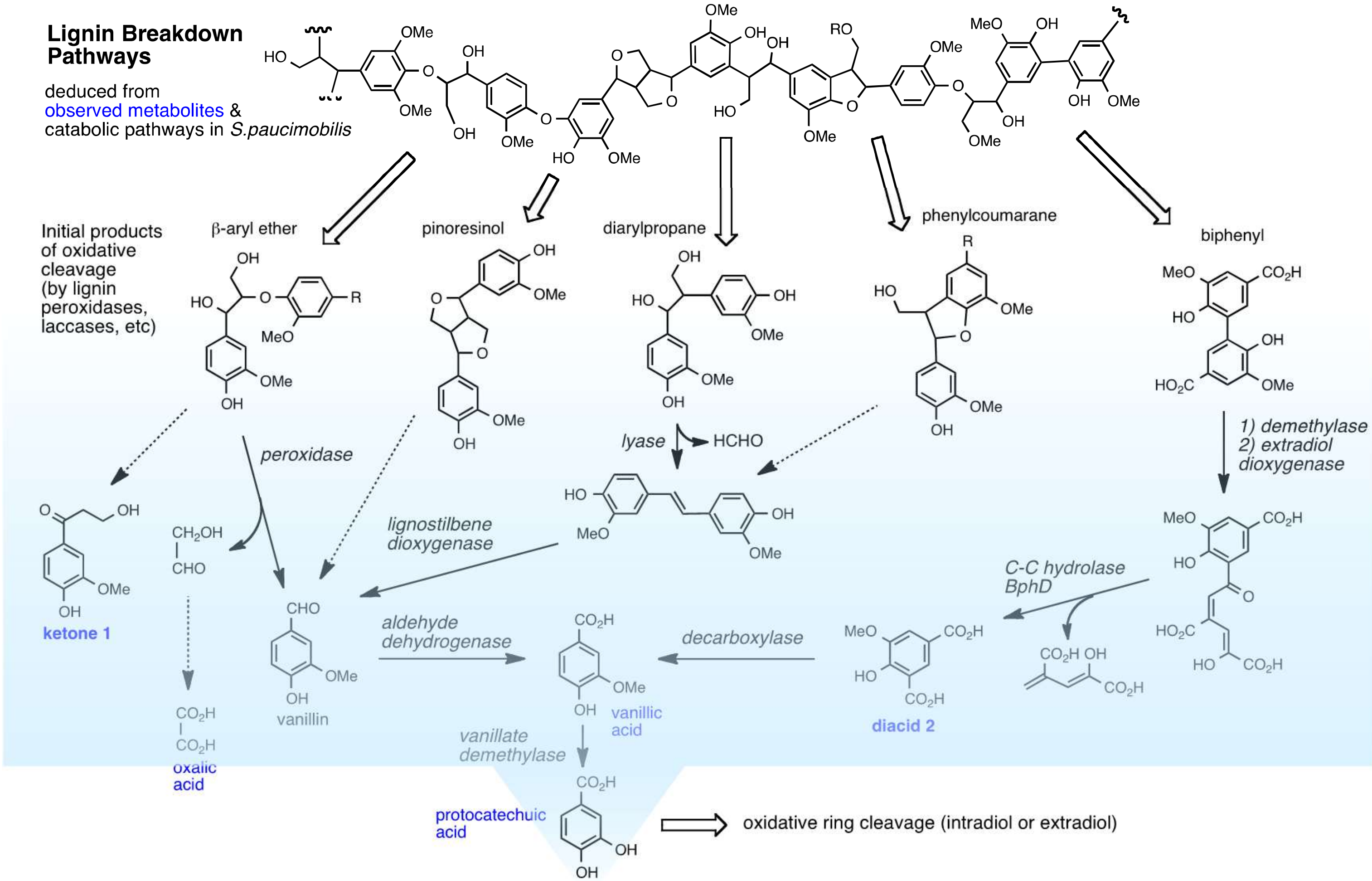
# Methods for lignin depolymerisation

- **Thermochemical**
  - Pyrolysis
  - Hydrothermal liquefaction
  - Organosolv/Solvolysis
  - Oxidative depolymerization
  - Reductive Catalytic Fractionation
  - Acid/Base Catalysis
- **Biological**
  - Enzymatic oxidation
  - Microbial degradation
  - Chemoenzymatic



Complex product mixtures!

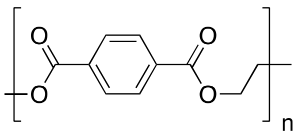
# Biological funnelling of lignin degradation products



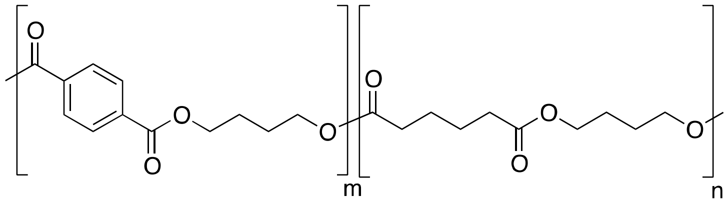

Can these pathways be manipulated to produce target molecules?

# Microbial production of pyridine dicarboxylic acids

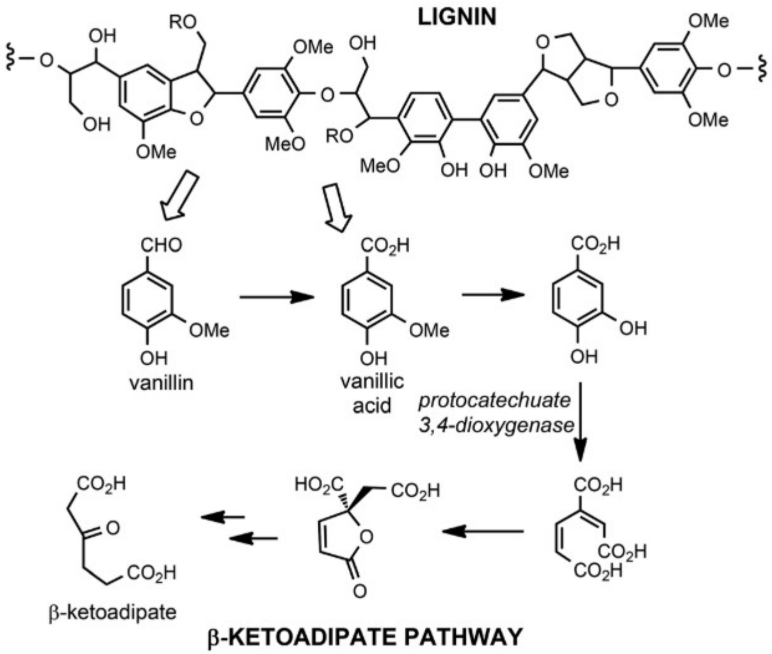
PET (polyethylene terephthalate)



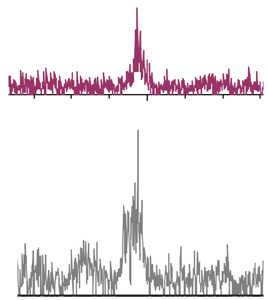
PBAT (polybutyrate adipate terephthalate)



with Biome Bioplastics Ltd

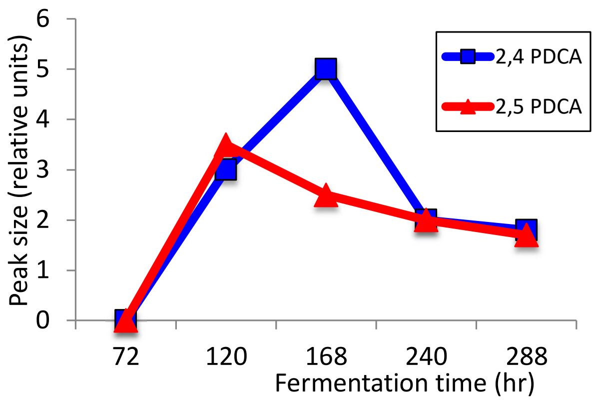


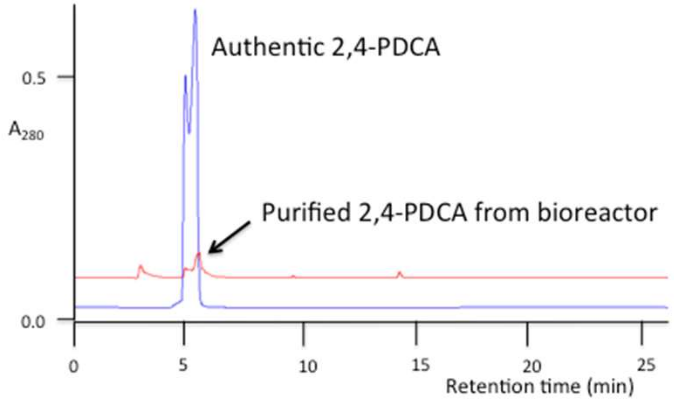

Identification by LC-MS from M9/1% wheat straw:



Z. Mycroft et al, *Green Chemistry* **2015**, *17*, 4974-4979.

# Production of PDCAs by *Rhodococcus jostii* RHA1



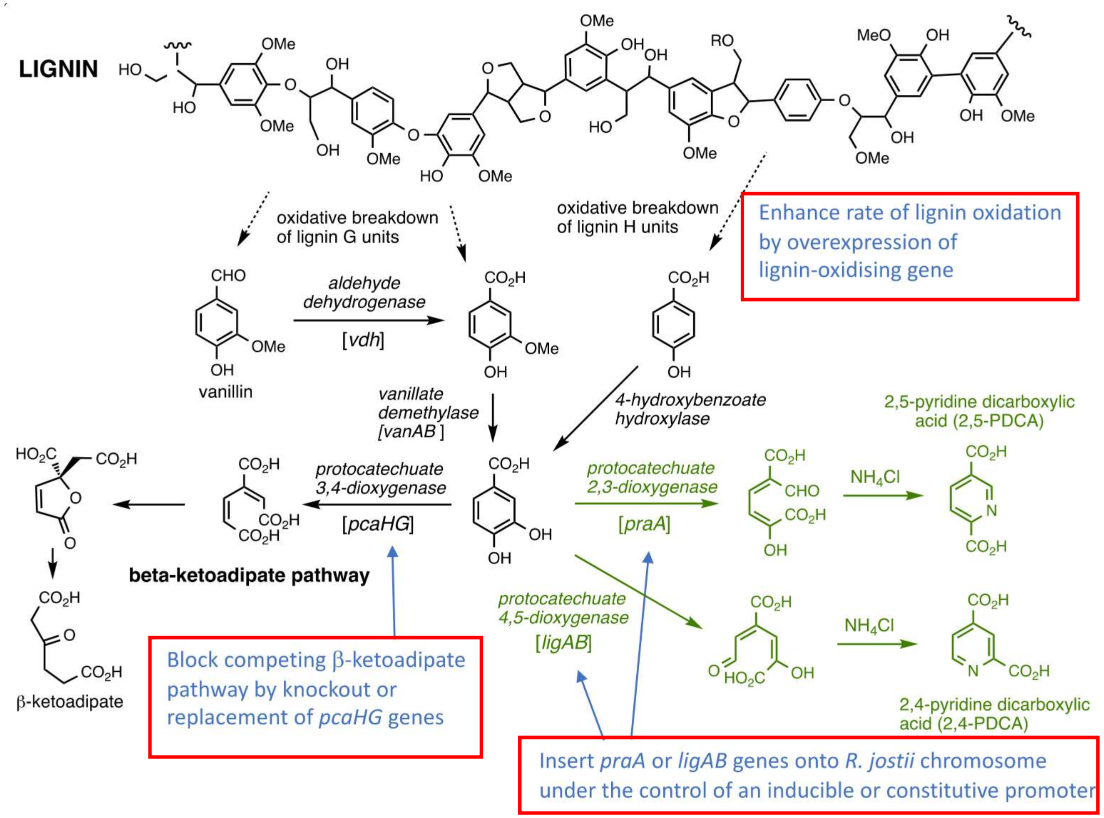




| | | | Carbon source for M9 minimal media | | |
|---|---|---|---|---|---|
| Strain | Product | Scale | 0.1% vanillic acid | 1% wheat straw | 0.5% Kraft lignin |
| *R. jostii* pTipQC2-ligAB | 2,4-PDCA | 50 mL | 112 mg $L^{-1}$ (7 days)[a] | 90 mg $L^{-1}$ (7 days)[a] | NT |
| | | 2.5 L bio-reactor | NT | 125 mg $L^{-1}$ (9 days)[a]<br>102 mg $L^{-1}$ [b] | 53 mg $L^{-1}$ (4 days)[b] |
| *R. jostii* pTipQC2-praA | 2,5-PDCA | 50 mL | 80 mg $L^{-1}$ (5 days)[a] | 79 mg $L^{-1}$ (5 days)[a] | NT |
| | | 2.5 L bio-reactor | NT | 106 mg $L^{-1}$ (9 days)[a]<br>65 mg $L^{-1}$ [b] | NT |

[a] Yield estimated from LC-MS analysis, comparison with authentic standard. [b] Yield of product after ion exchange chromatography, calculated *via* UV-vis absorption. Length of fermentation time indicated in brackets. NT, not tested.

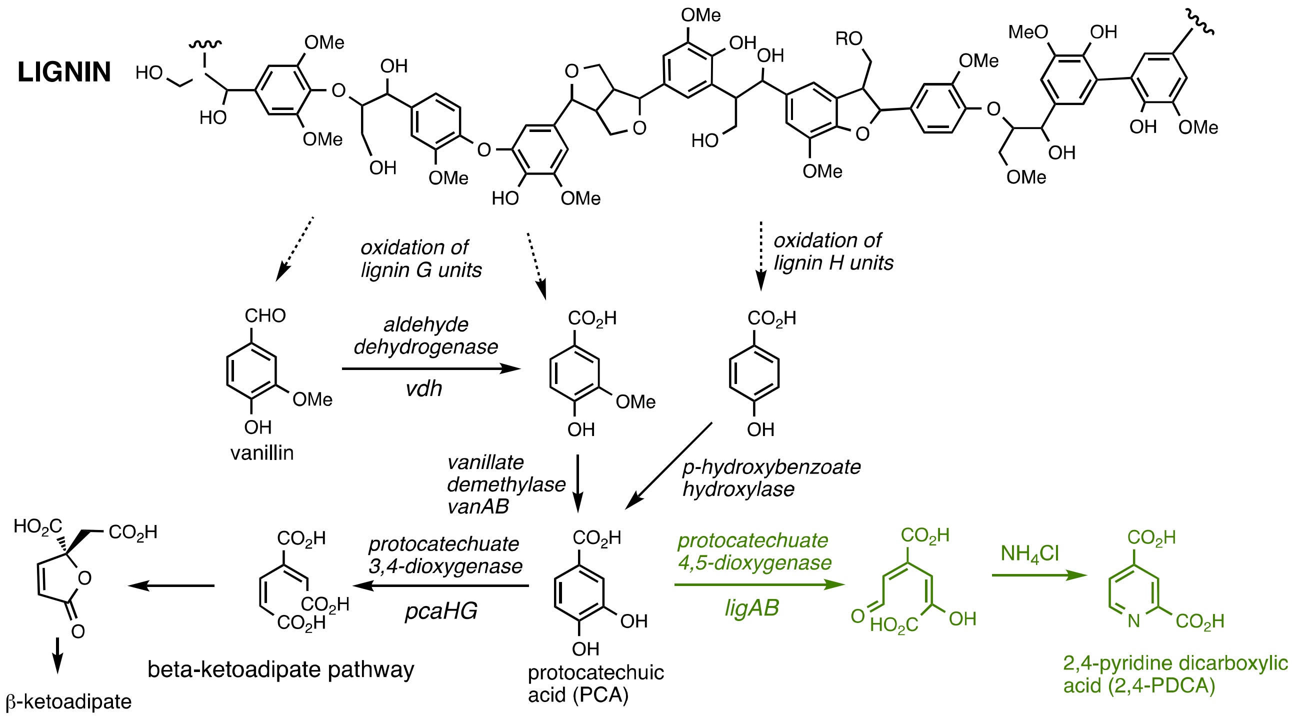
Z. Mycroft et al, *Green Chemistry* **2015**, *17*, 4974-4979.

# Genetic engineering of *R. jostii* for PDCA production




E. Spence et al, *Microbial Cell Factories,* **2021**, 20:15

# Overexpression of lignin degradation enzymes improves PDCA titre in *R. jostii*



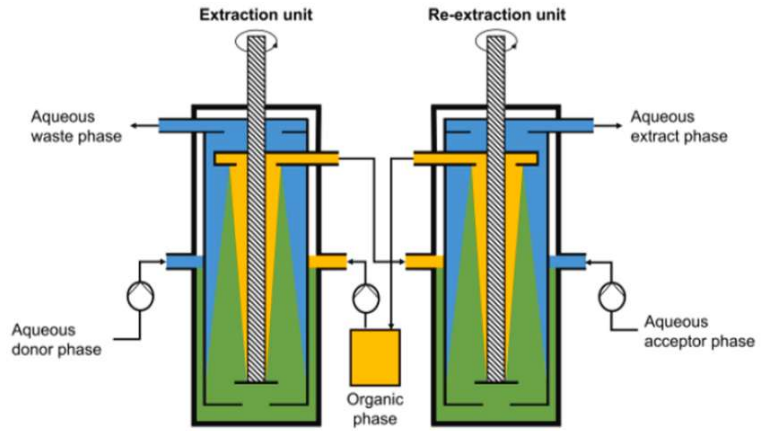

| Overexpressed gene (pTipQC2 plasmid) | 2,4-PDCA mg/L (1% Green Value lignin) |
|---|---|
| *R. jostii* ΔpcaHG::($P_{tpc5}$)ligAB | 164 |
| *Amycolatopsis* sp. 75iv2 *dyp2* | 240 |
| *Streptomyces viridosporus* SLAC | 190 |
| *R. jostii dypB* | 205 |
| ***R. jostii mcoA*** | **365** |
| *R. jostii mcoB* | 205 |
| ***R. jostii mcoC*** | **510** |

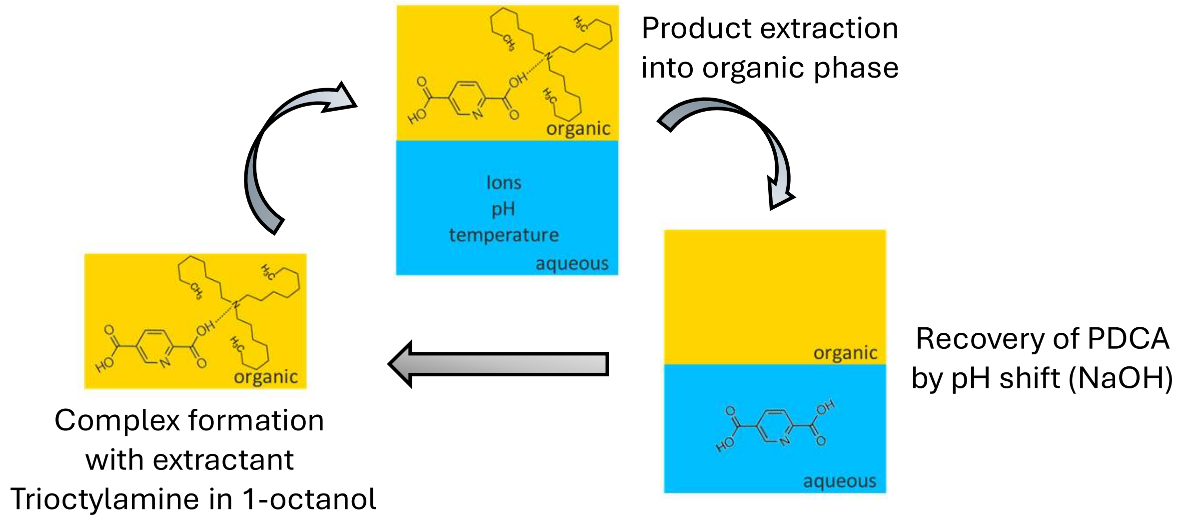
**3x improvement!**

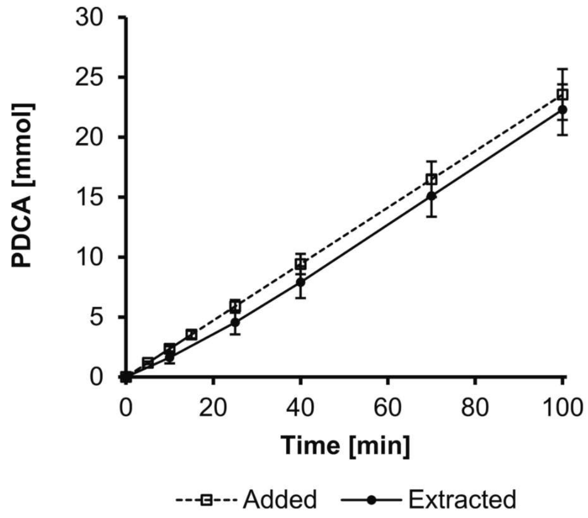
GMM Rashid, V Sodré, J Luo, TDH Bugg, *Biotechnology and Bioengineering*, 2024, 121(4):1365-69.

# Challenges for scale-up: downstream processing

- Pyridinedicarboxylic acids form a zwitterion at pH 7
- Mycroft et al, 2015: purification by anion exchange chromatography
    - Works well, but high associated costs
- Spence et al, 2021: extraction using IPA at high ionic strength
    - Not very efficient, product contaminated with high amount of salt
- Notheisen and Takors, 2024: reactive extraction with trioctylamine (TOA)




J. Notheisen and R. Takors, *Sep. Purif. Technol.*, **2024**, *333*, 125826

# Challenges for scale-up: choice of microbial host

| Organism | Characteristics | Max. PDCA titre | Growing/resting cells | Time (h) | Feedstock | Reference |
|---|---|---|---|---|---|---|
| *Rhodococcus jostii* RHA1 | Great lignin-degrader and robust aromatic catabolism, slow growing, difficult to engineer | 510 mg/L (2,4-PDCA, shake flask) | Growing cells | 168 | 1% Green Value Lignin | Mycroft et al, 2015<br>Spence et al, 2021<br>Rashid et al, 2024 |
| *Pseudomonas putida* KT2440 | Lignin-degrader, faster growing, more genetic tools available | 40 mg/L (2,4-PDCA, shake flask) | Resting cells | 20 | 1.5% Green Value Lignin | Goméz-Álvarez et al, 2022 |
| *Corynebacterium glutamicum* | Widely used in industry, lots of genetic tools, not lignin-degrader | 15 g/L (2,6-PDCA, 1.8L fed-batch) | Growing cells | 86 | Glucose | Cho et al, 2024 |
| *Escherichia coli* | Model organism, not lignin-degrader | 10.6 g/L (2,5-PDCA, 1L fed-batch) | Growing cells | 144 | Glucose | Katano et al, 2025 |

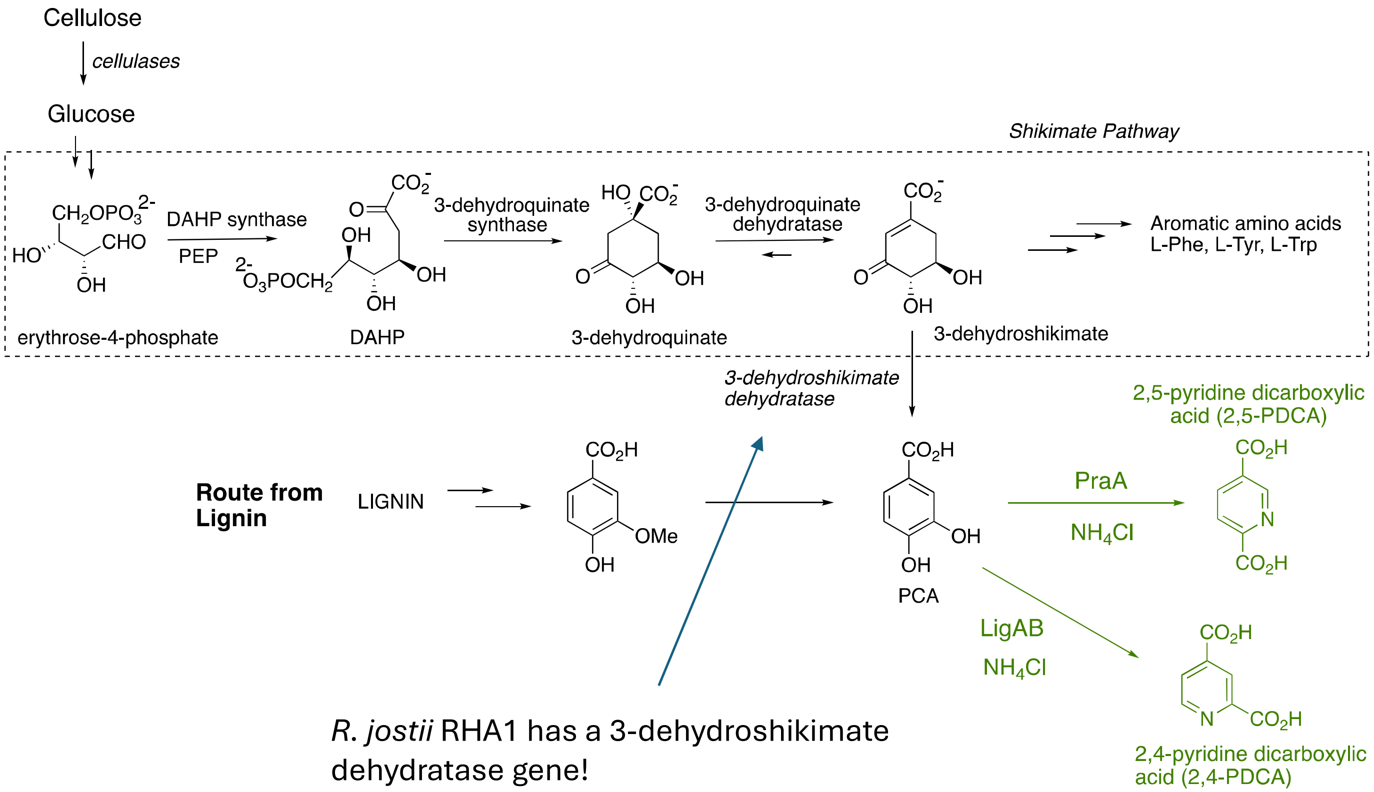
# Challenges for scale-up: choice of feedstock

| Type of lignin | Availability | Applications | Approx. price range (USD / ton, dry basis) | PDCAs yield (mg/L) |
|---|---|---|---|---|
| **Lignosulfonates** | High (sulfite pulping) | Large-volume dispersants, binders, concrete additives | **150 – 400** | NT (not tested) |
| **Kraft lignin** | High (pulp/paper) | Combustion, resins | **300 – 800** | **53** (Mycroft et al, 2015) |
| **Soda lignin** | Limited (could be produced on site) | Potential for biochemicals, resins | **600 – 1 000** | **510** (Rashid et al, 2024) |
| **Organosolv lignin** | Limited | Potential for biochemicals, resins, carbon fibres, adhesives, coatings | **800 – 1 800** | NT (not tested) |
| **Lignocellulose (wheat straw)** | High | Animal bedding, soil amendment, biorefinery | **50-110** | **330** (Spence et al, 2021) |

# Utilisation of cellulose by *R. jostii* RHA1

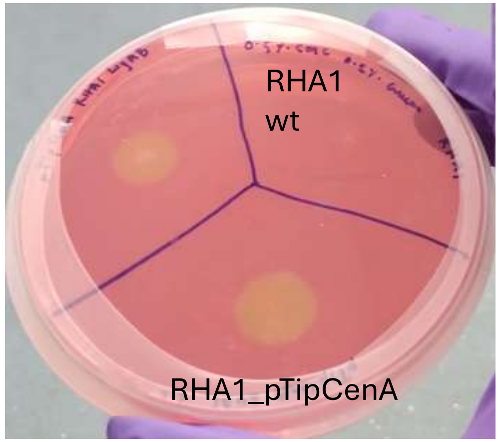
**Route from Cellulose**

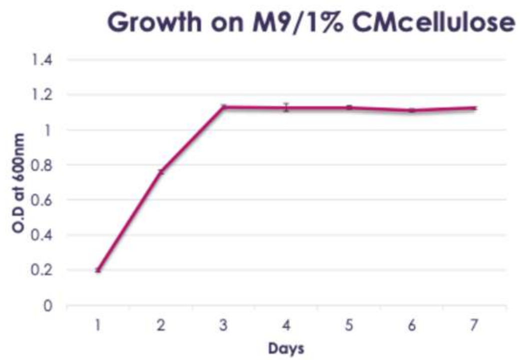
**Proposed routes to PDCA monomers**




*R. jostii* RHA1 has a 3-dehydroshikimate dehydratase gene!

Expression of *C. fimi* endocellulase *cenA* permits growth on carboxymethylcellulose

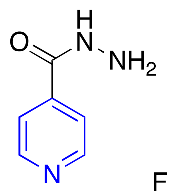


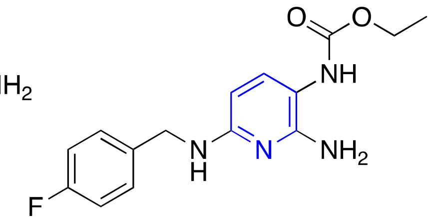

R. Yasin et al, *Heliyon*, **2023**, 9, e19511

# Beyond PDCAs

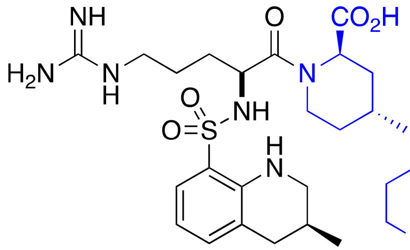
Substituted pyridines and piperidines are often found in pharmaceuticals and agrochemicals – currently derived from petrochemicals



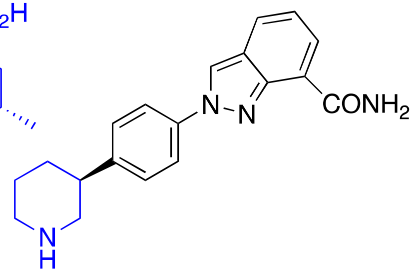

Isoniazid




Flupirtine

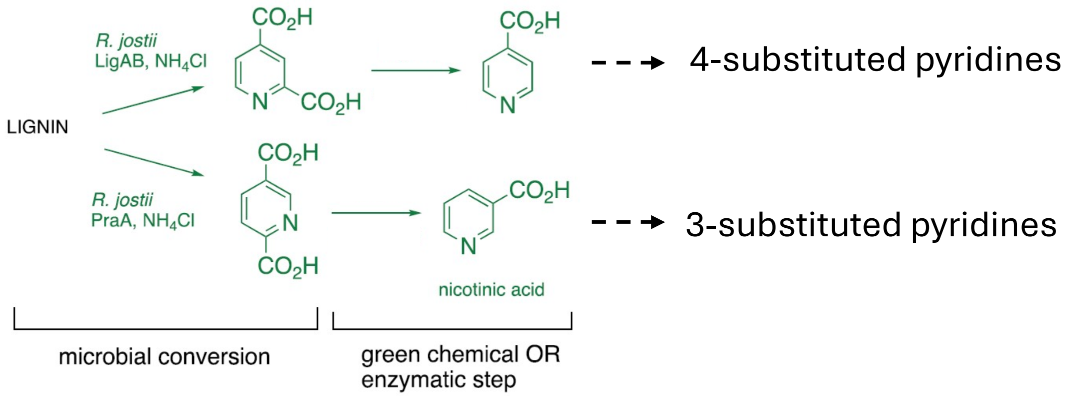



Argotroban

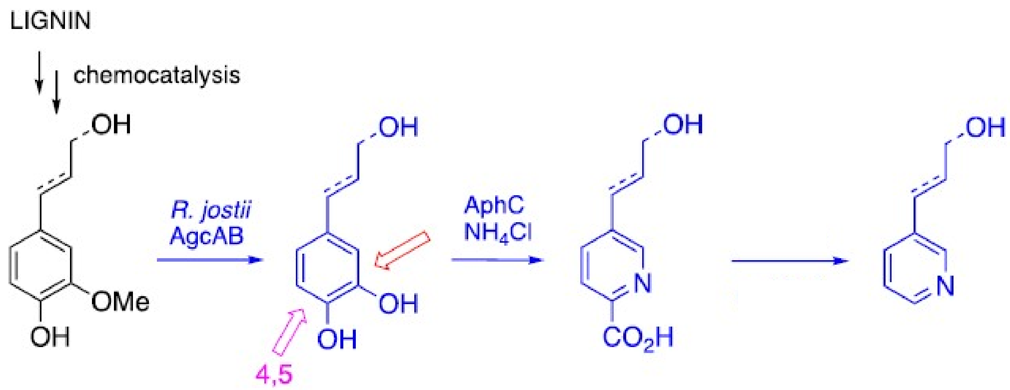



Niraparib

## From PDCA bioproducts:




## From 4-alkylguaiacols (RCF):



# Acknowledgments

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MILIMO

ERA CoBioTech

ZELCOR
Zero Waste Ligno-Cellulosic Bio-Refineries

BBSRC
20 Years of Pioneering
Great British Bioscience

biome
bioplastics

BBI JU

Bio-based Industries
Consortium

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holiferm

# Accelerating on the Commercial Path of Industrial Biotechnology

4th BBNet Conference | 16 October 2025

4th BBNet Conference

# Ways to accelerate on the commercial path

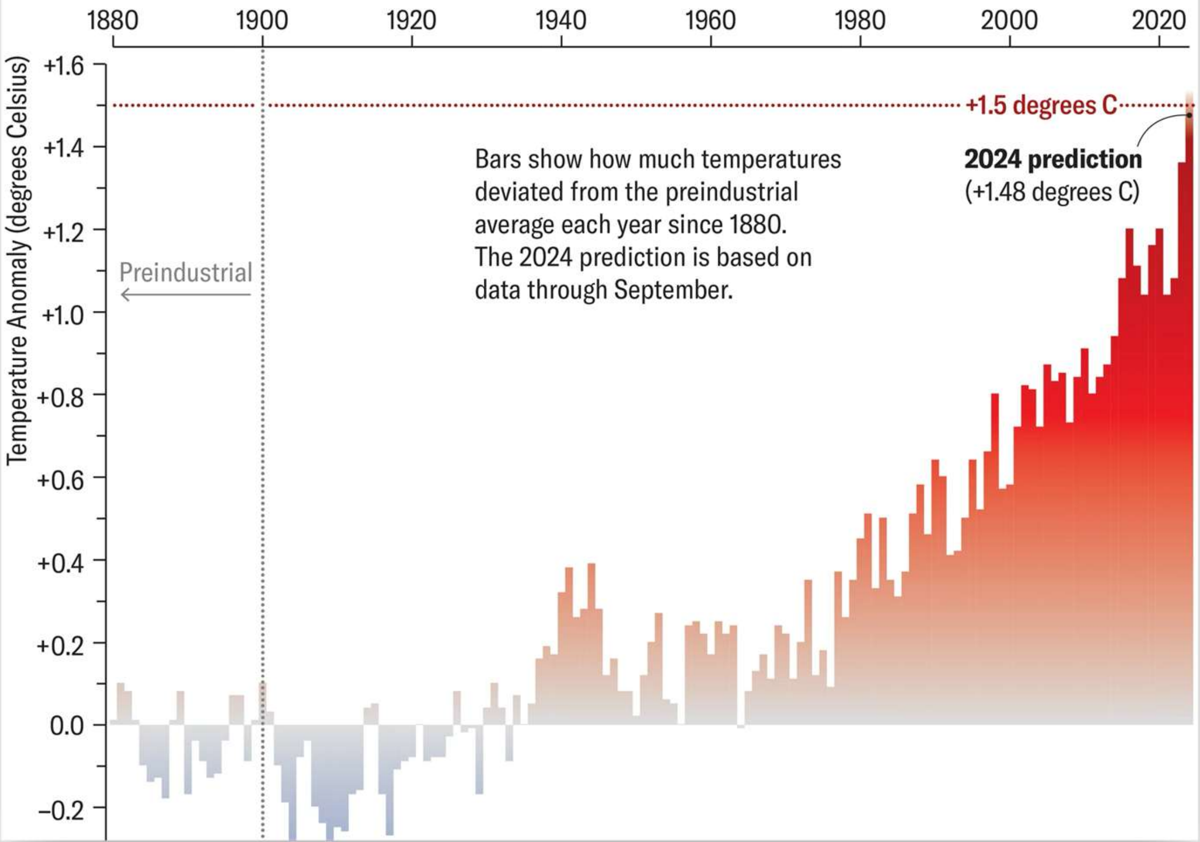
01 **Must make money for investors and partners**
A holistic view that our partners and customers and ultimately end-users will value our innovation

02 **Applications development - "Make it real"**
"Make the technology real" by showcasing performance properties and making adoption by customers frictionless

03 **Competitive cost structure is key**
The single greatest "unlock" in the bioeconomy is cost structure (and capital efficiency)

04 **Emotional connection**
Marketing that transcends the data and science and extends to feelings and experience

## Annual Global Temperature Anomalies Compared with Preindustrial Period (1850–1900)



“Science is undefeated, and if you step out of a window from the third floor talking about how gravity doesn’t exist, you’re still going to hit the ground.”

- Ryan Gellert, September 23, 2025


5 years
to 2030 to avert 1.5° C
Pacific Palisades, CA

“A mind that is anxious about future events is miserable.”

- Seneca

# Anxiety

# Fear

# Guilt

# Shame

Status Quo

Fear — Love

*Fight or Flight* — *Rest and Digest*

Creative

Scarcity — Abundance

How might we best catalyze change?

Emotional storytelling that inspires creativity, hope and courage

Clear economic opportunity
that excites innovators,
customers, investors, and policymakers;

Show how it makes money

## THE POTENTIAL OF SYNTHETIC BIOLOGY & BIOMANUFACTURING

Biological applications could unlock an estimated **$2 trillion to $4 trillion** in annual direct global economic impact in 10–20 years

MATERIALS

CONSUMER PRODUCTS

HUMAN HEALTH & PERFORMANCE

AGRICULTURE

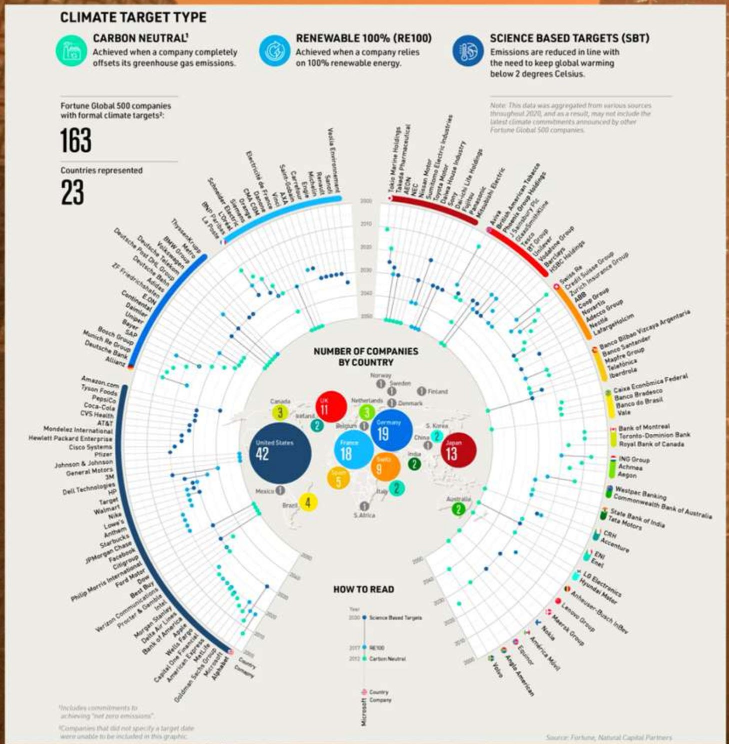
ENERGY PRODUCTION

Source: McKinsey, The Bio Revolution (2020)

NYC Skyline, June 2023

# The Fortune 500 Have Aggressive Targets

## How can Holiferm accelerate meeting this demand?




x

# The Biomanufacturing Industry's Experience to Date

Impact and investor returns for industrial biotechnology have not yet met expectations

# The Solution

The key to unlocking the potential of biomanufacturing:

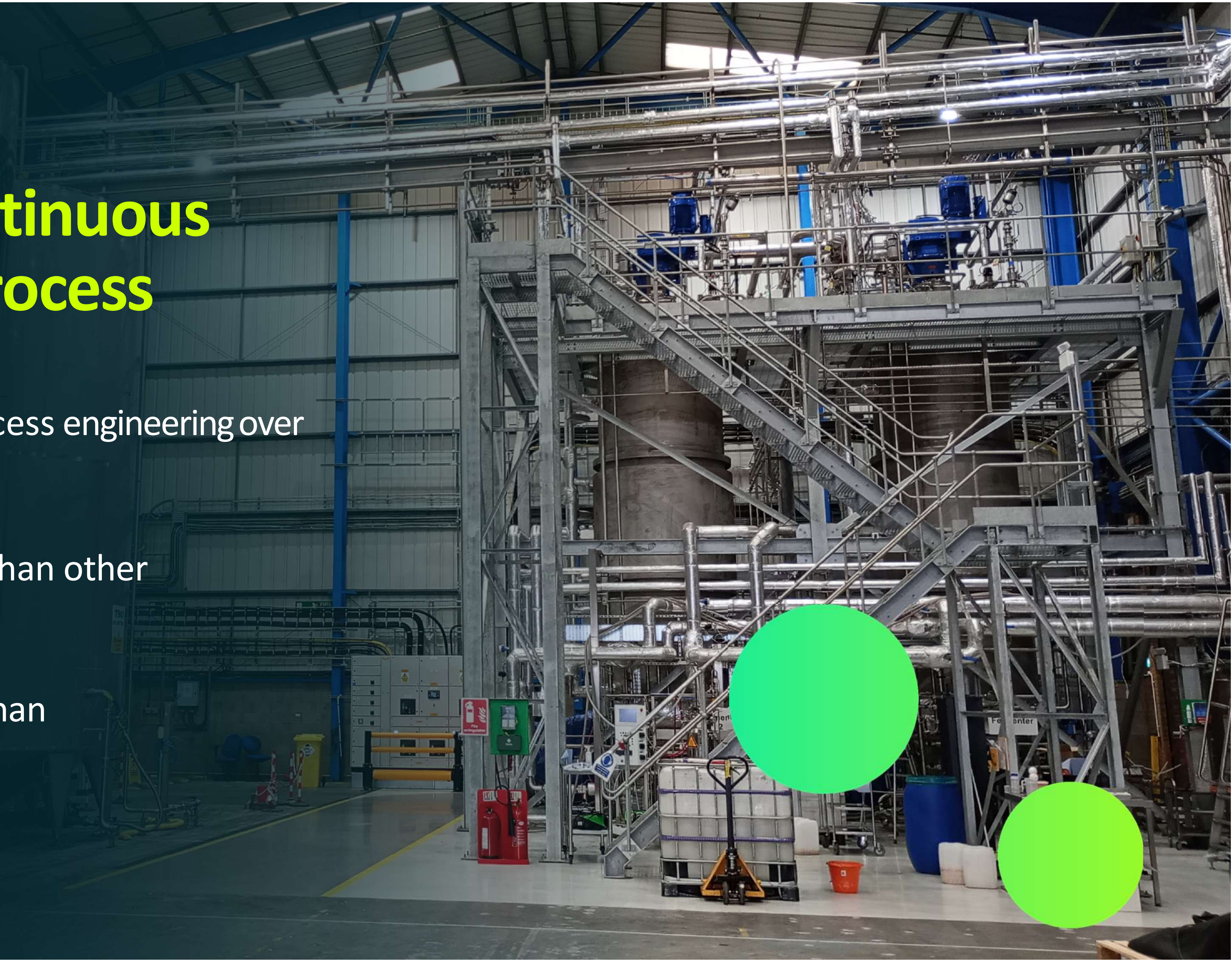
**competitive unit economics** and **capital efficiency**

# Patented Continuous Production Process

Focus on systems and process engineering over strain engineering

50% lower marginal cost than other sophorolipids

75% less capex intensity than alternatives




holiferm
HIGH FOAMING (HF)
HoliSurf
holiferm
LOW FOAMING (LF)
HoliSurf

We biomanufacture and commercialise surfactants starting in personal care, home cleaning and industrial applications

# What are Surfactants?

The word **'surfactant'** is a contraction of surface-active agent and they are used in thousands of applications across industry

**Foaming**

Shower Gels

**Wetting**

Pesticides

**Emulsification**

Mayonnaise

**Dispersancy**

Pigments & Dyes

**Detergency**

Cleaning

**Hydrotroping**

Micellar Water

# Market Opportunity

**Total Addressable Market:**

– Global biotech market: $1.74T (2025) →$5.00T (2034)

– Surfactants market alone: $45B+ annually

– Industrial biotechnology: Fastest growing segment

**Holiferm's Beachhead:**

– Starting with $15B+ biosurfactants opportunity

– Expanding to broader industrial biotechnology applications

– Platform technology applicable across multiple verticals

**187% market growth over nine years**

# Agriculture

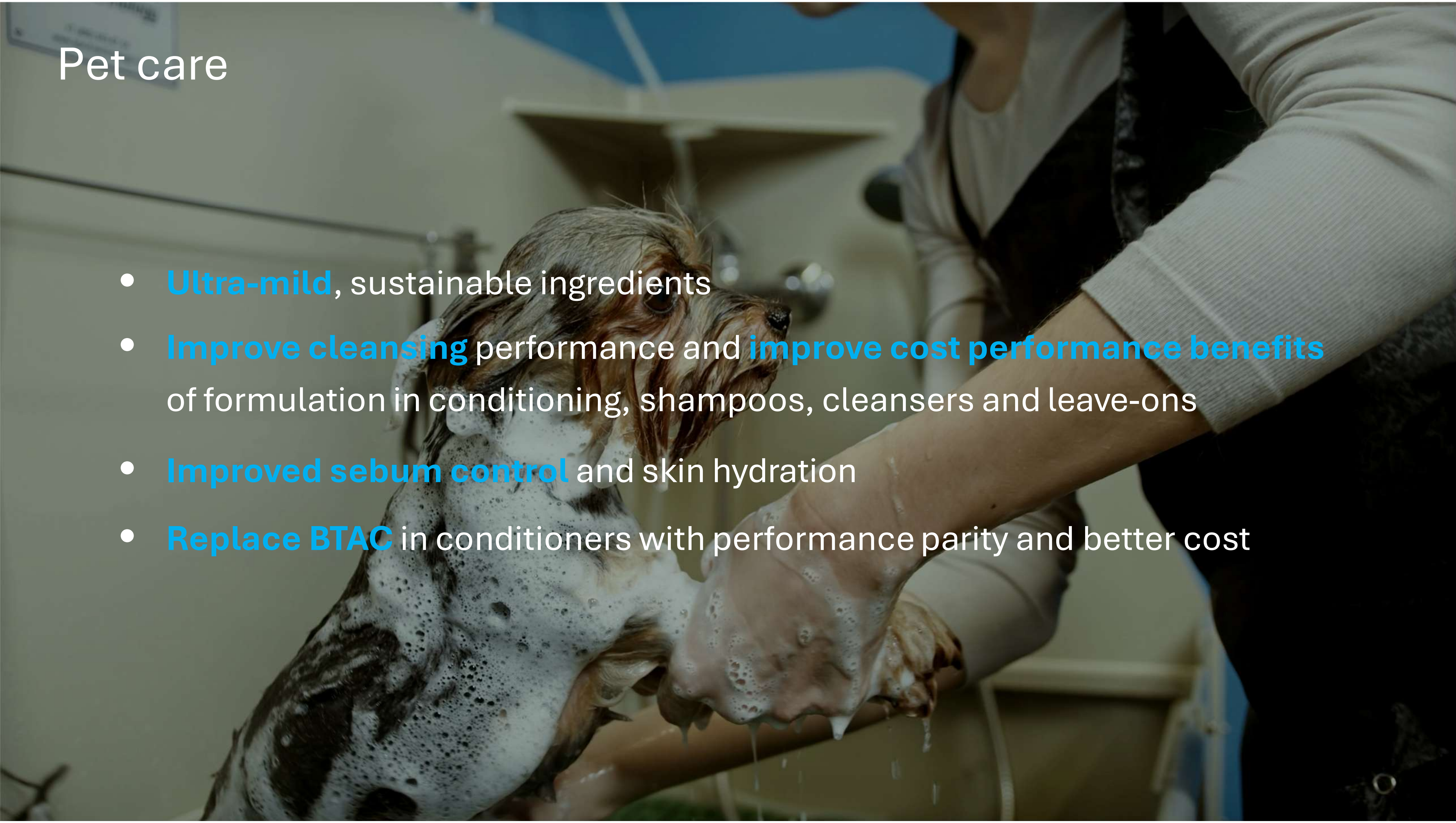
- AgriSurf HF & AgriSurf LF **outperform other organic soil wetting solutions to reduce water usage**
- **Prevents “dry spots**” in soil
- **Increases root hydration** & healthy root growth
- **Superior rain-fastness** for copper-based fungicides
- **Increases efficacy of insecticides** for whitefly control
- Benefits lead to **overall improvement in crop yields**
- **Low CMC**: Performs well at lower concentrations than other surfactants
- AgriSurf is **readily biodegradable** within 28 days

# Home care

- **Ultra-mild, sustainable** ingredients which improve cost performance benefits of formulation
- Improved/parity surface cleaning compared to all industry benchmarks
- >10% cost reduction of green hand dish formula whilst maintaining performance
- Improved soil removal in green and mild laundry formulations

# Fruit and vegetable preparation

Wash vegetable and fruit
before consumption to **remove pesticides**



# Pet care

- Ultra-mild, sustainable ingredients
- Improve cleansing performance and improve cost performance benefits of formulation in conditioning, shampoos, cleansers and leave-ons
- Improved sebum control and skin hydration
- Replace BTAC in conditioners with performance parity and better cost

# Performance, price, scale ... and sustainable

- Sophorolipids can improve overall formulation **performance**
- More **sustainable**, saving 1.5 tonnes of $CO_2$/tonne vs petrochemical
- **Four products launched** (high and low foaming for diversified applications)
- Better **appearance** (lighter in colour and clearer than market sophorolipids)
- **Growing pipeline** of multiple differentiated biosurfactant products

1.65 kts → 3.5 kta → 15 kta

# Biopowered by Holiferm

**Holiferm products are already in over 100 consumer products on shelves in the UK**

## Personal Care

**38 Customers**
**48 Products Launched**
**14 Product Types**

## Home & Industrial Cleaning

**16 Customers**
**21 Products Launched**
**6 Product Types**

## Other

**9 Customers**
**9 Products Launched**
**5 Product Types**

# How we are building

**Holiferm has achieved a breakthrough competitive advantage by delivering superior cost-performance across in our focus areas: home and personal care applications**

### Value Proposition
Products deliver better performance at lower cost than alternatives

### Competitive Differentiation
Breaks the traditional cost, performance, sustainability triangle – Holiferm delivers all three

### Market Impact
Creating value for our customers, and their customers

### Sales Enabler
Cost performance advantage is directly driving improved sales results and customer adoption

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Thank you.

**Charles Dimmler**

CEO, Board Member, Advisor | Industrial Biotechnology | Sustainability | Climate Tech...

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BB Net
Biomass Biorefinery Network

**Be sure to visit our exhibition throughout the conference**

AGRIFOODX

Anaero Technology

cpi

Supergen Bioenergy

BDC Biorenewables Development Centre
Plants • Processes • Products