Green Chemistry
Centre of Excellence

THE UNIVERSITY of York

Green Chemistry
And
Sustainability

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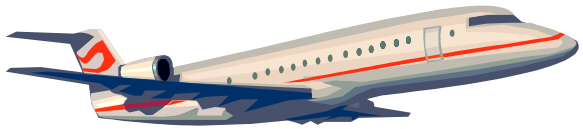
Green Chemistry Centre of Excellence
Chemistry Department
University of York, UK

www.greenchemistry.net

Research
Industry
Networking
Education

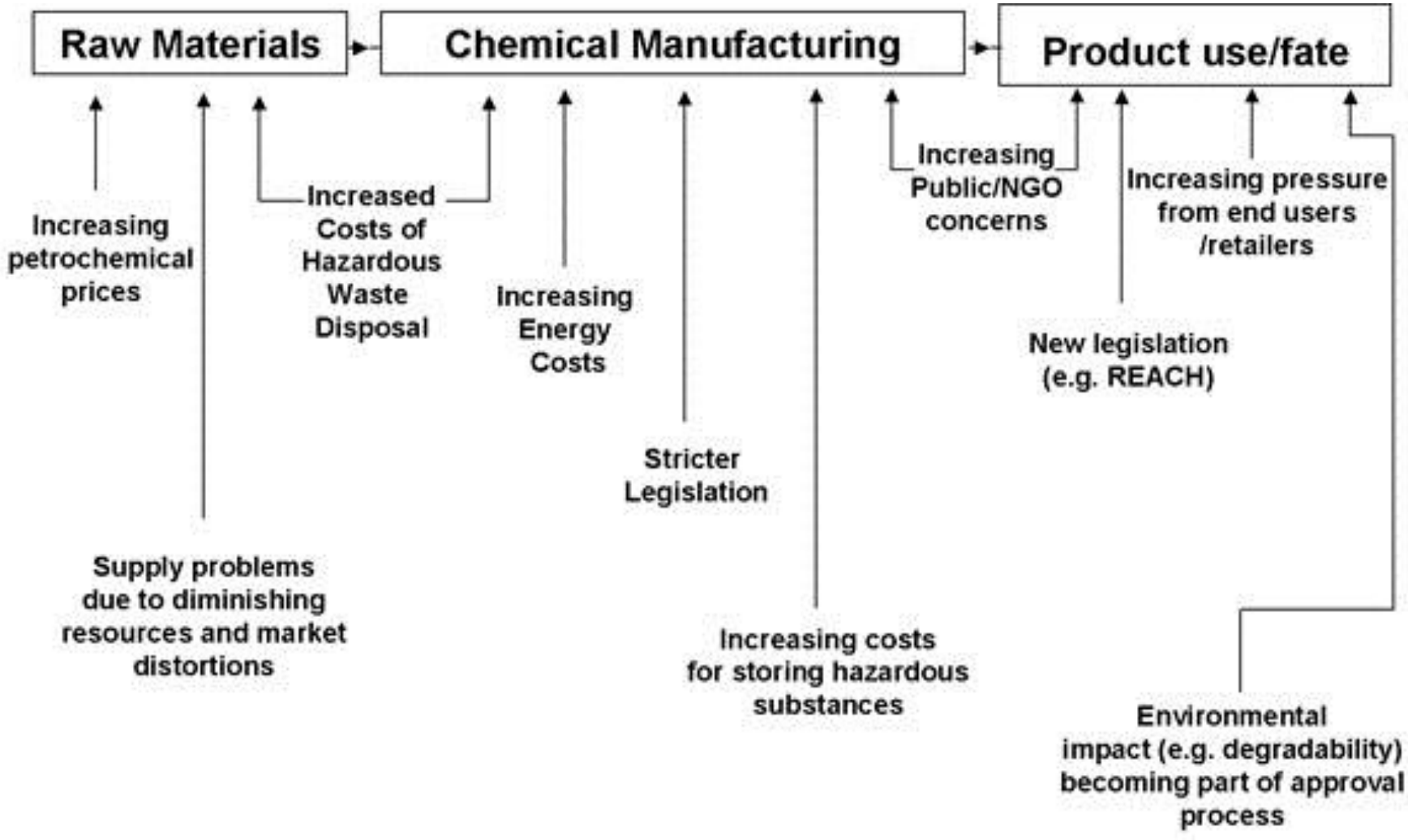
Chemicals are everywhere and vital for a growing population seeking higher living standards

Benefits of the Chemical Industry

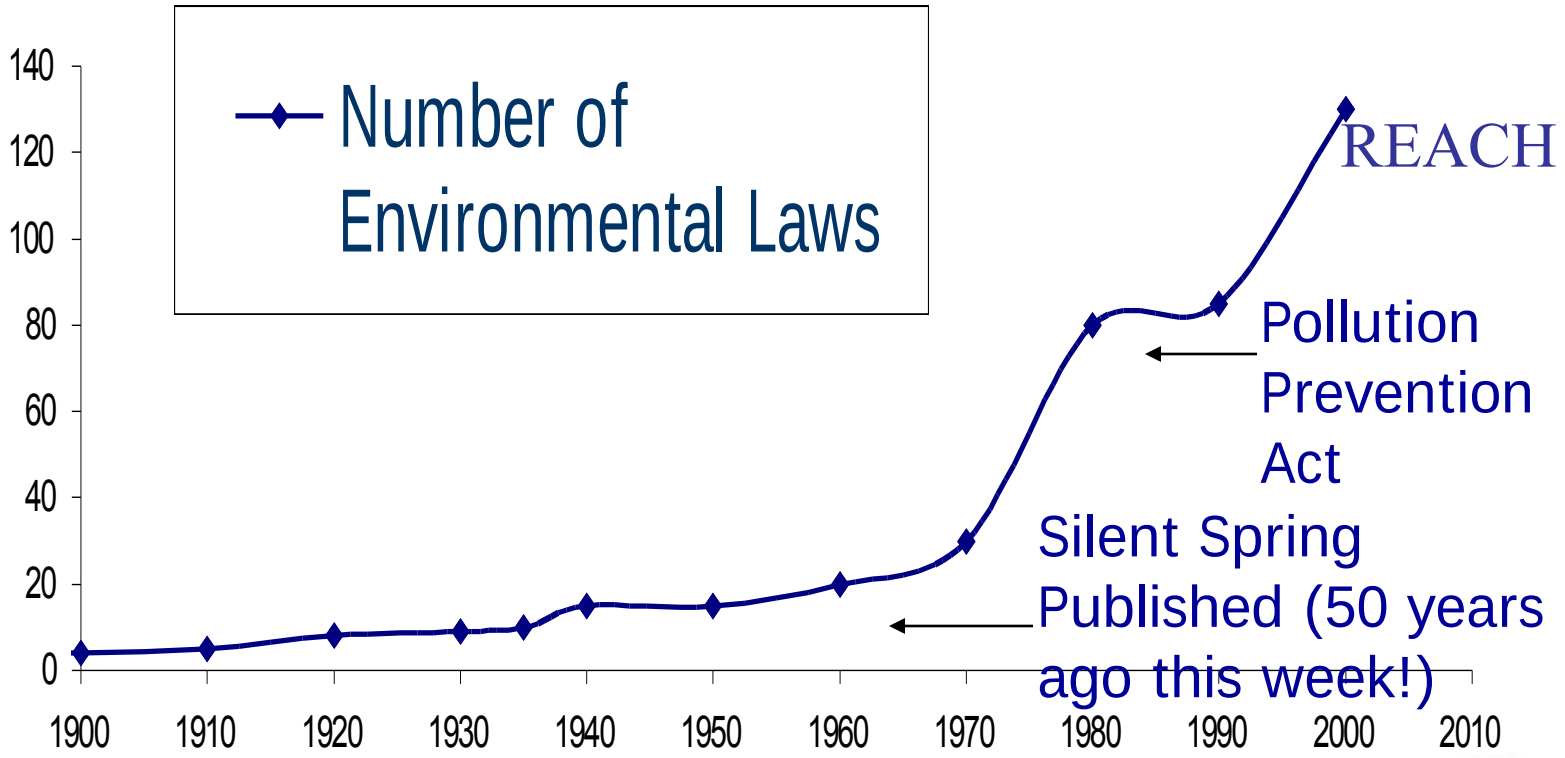


But chemicals are unpopular with the public and government pressure through legislation is growing - especially in the EU……

Pressures on Chemicals across the Lifecycle



Background to Green Chemistry



We need Green Chemistry to make safe products using cleaner manufacturing based on *renewable resources*

Making your raw material *more sustainable*

The chemical industry is too dependent on traditional virgin sources of raw materials - sources that are becoming scarce, expensive and unreliable, and often from regions with uncertain social and political conditions

Resource demands of chemical manufacturing

10% of oil for chemical manufacturing

Long global supply chains add to chemical environmental footprints

10% of oil used as raw material for making chemicals

Chemical Manufacturing produces 4% of global CO2

Disposal of chemicals can use resources and cause environmental harm

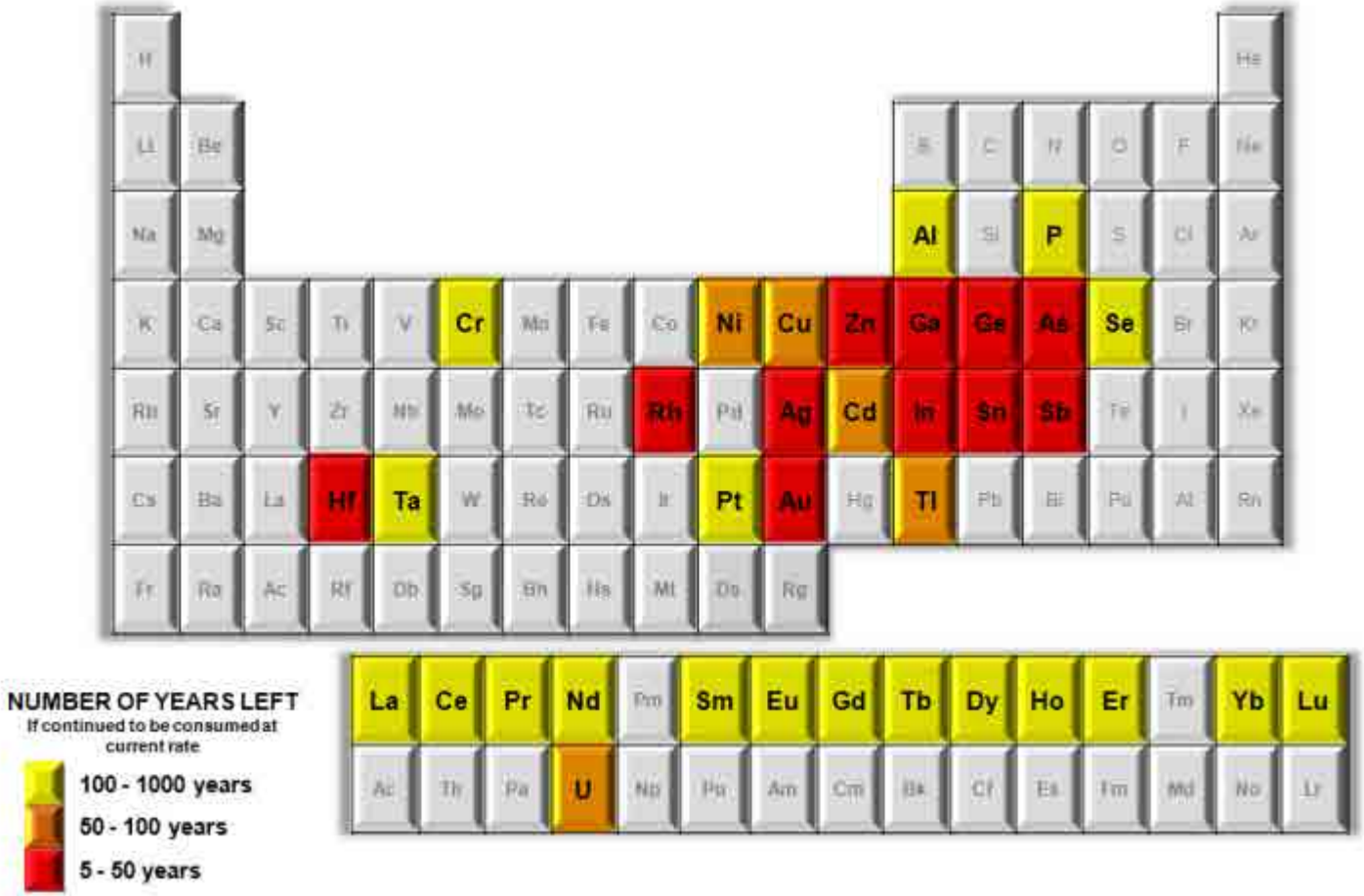
Pre-manufacturing | **Manufacturing** | **Product Delivery** | **Product Use** | **End of Life**

Chemical industry needs numerous raw materials (P, Zn, Sb,In, As..) which are becoming rare

High resource demands for disposal of waste

Chemical use may have high energy costs and CO2 production

Elemental unsustainability

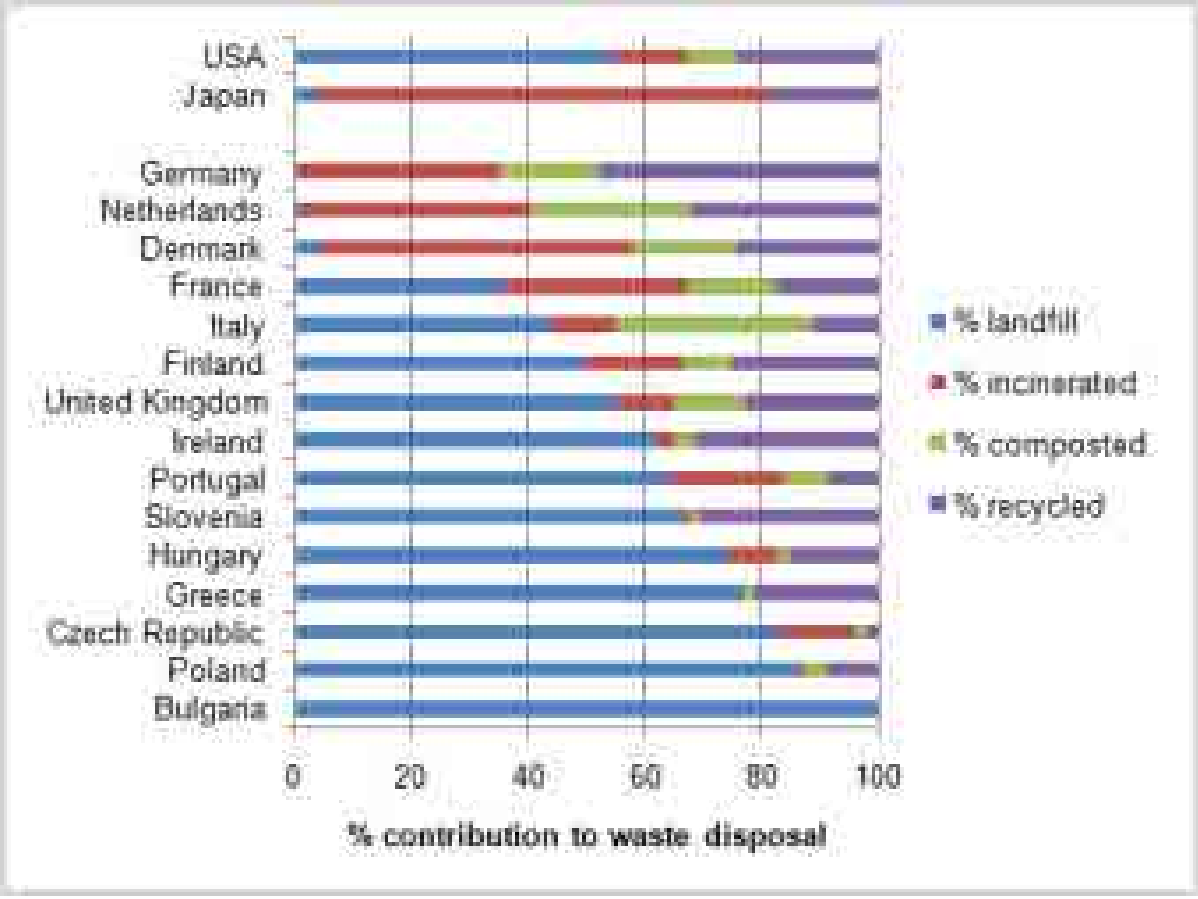


…and this is not up-to-date……

We turn carbon and other elements from a resource to a product and then to a waste….

We have to remove waste from our elemental cycles…… and move towards closed-loop manufacturing

What do we do with our waste?



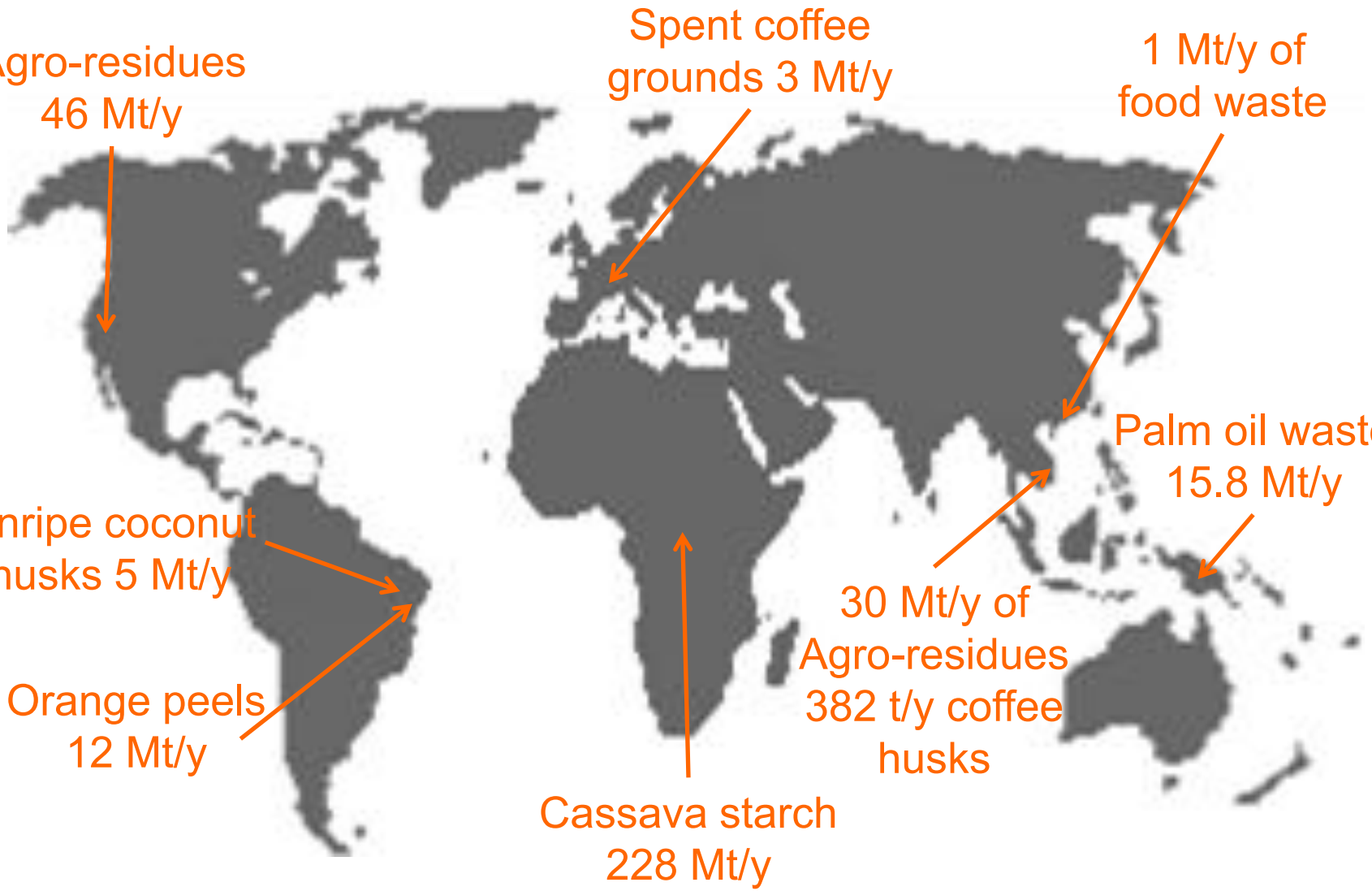
We treat our waste….like a waste….what a waste!!!

Waste is tomorrows resource

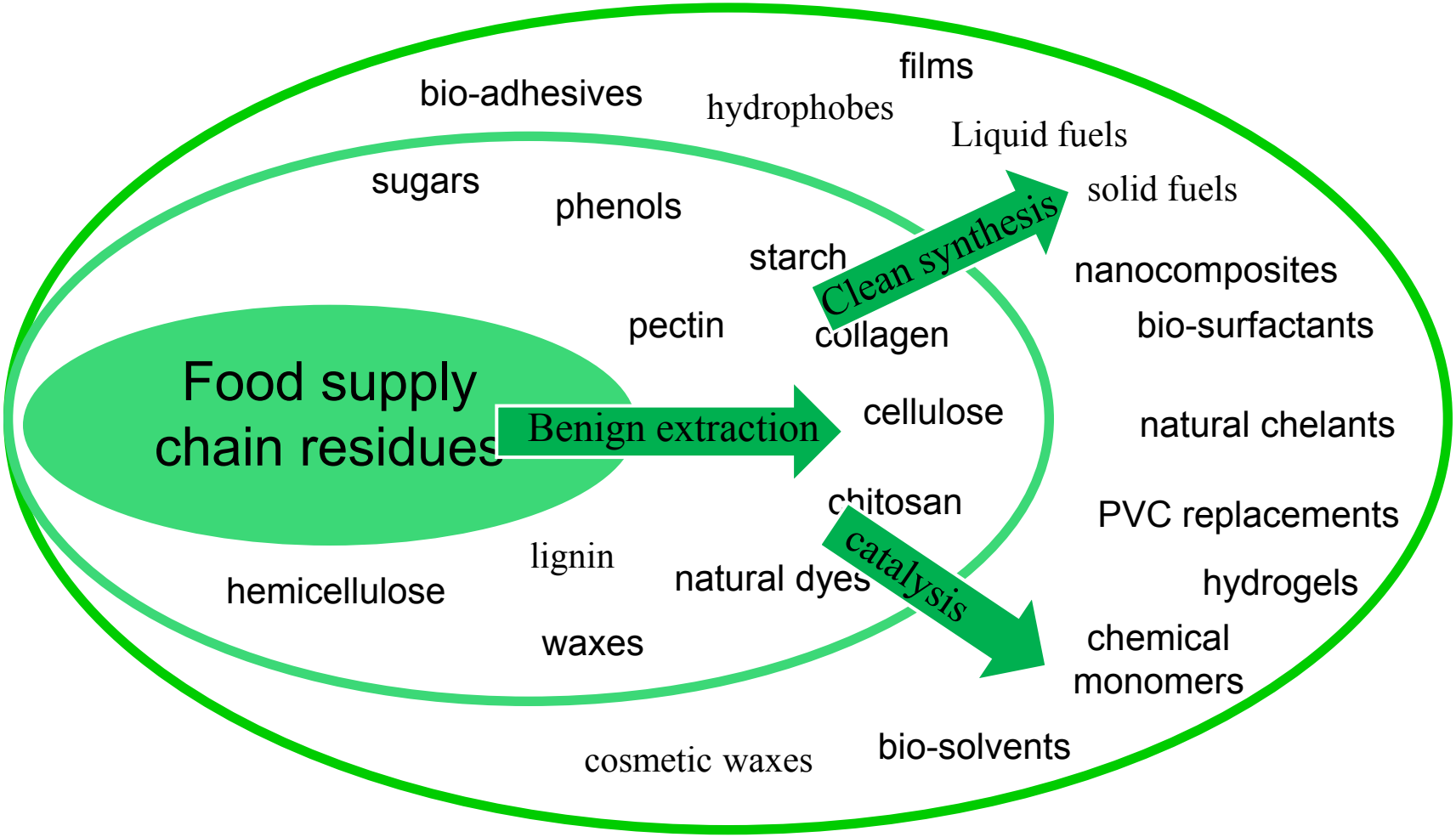
We need to encourage the greater use of chemically rich waste as a resource

Food supply chain waste:

A world of possibilities…



Chemicals from food waste

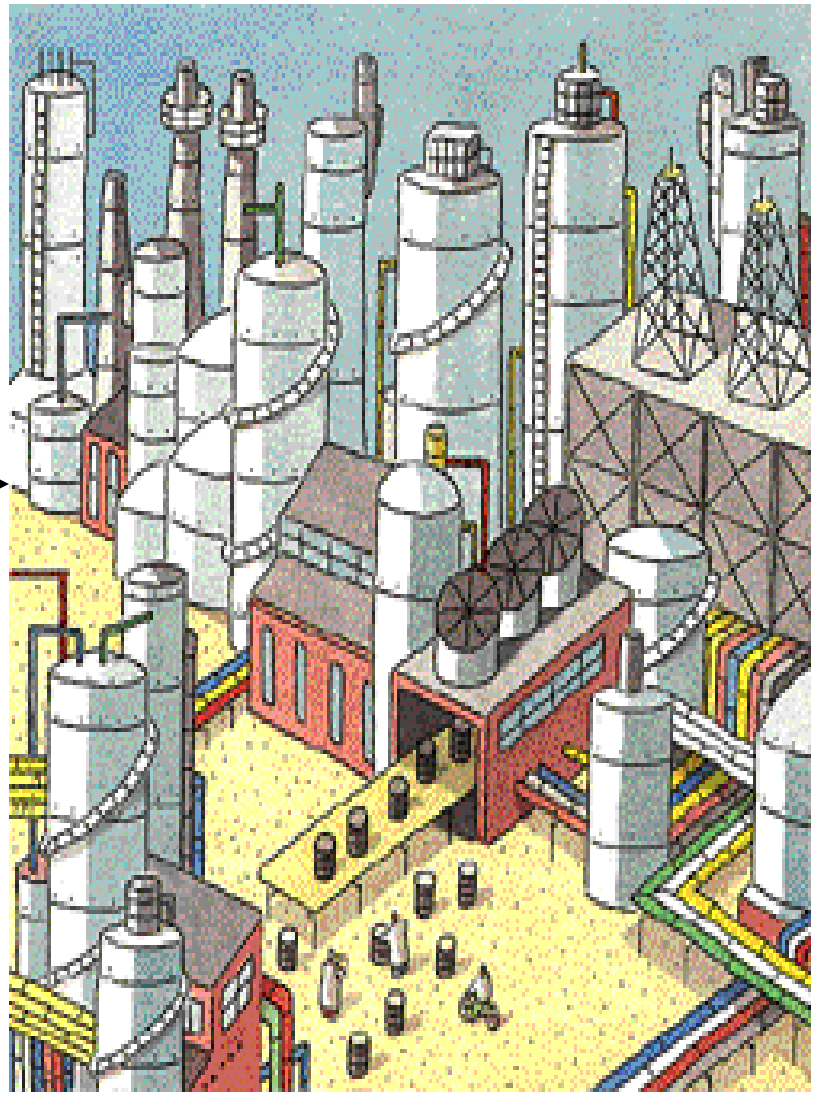


Sustainable sources of Carbon

Over 90% of organic chemicals are based on petroleum feedstocks - this is not sustainable

Petroleum Refinery

Petroleum feedstock



- Fuels
- Solvent
- Bulk chemicals
- Plastics
- Fibres
- Fine chemicals
- Oils

Bio-refinery

Biomass →

→ Fuels

→ Solvent

→ Plastics

→ Bulk chemicals

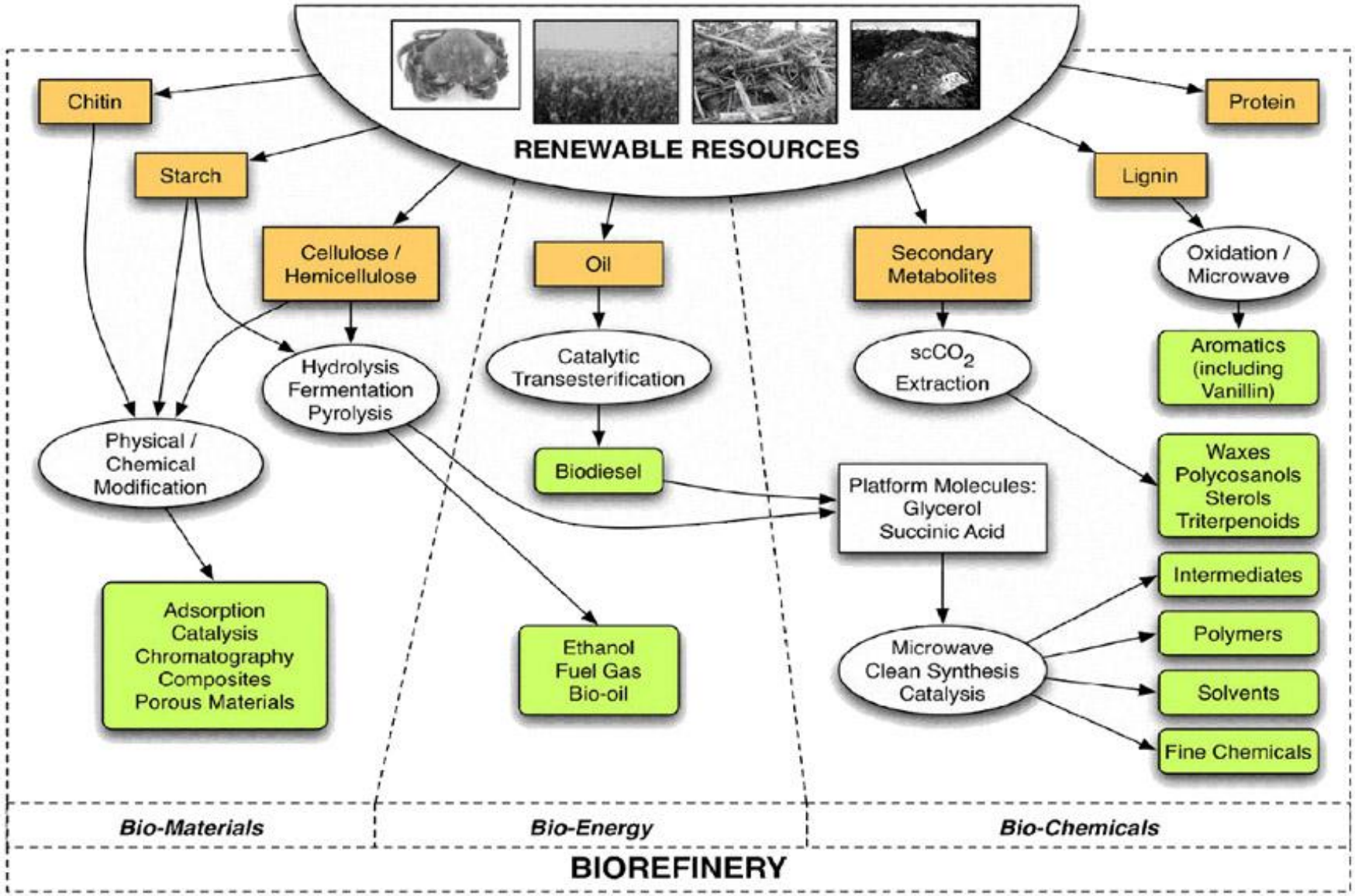
→ Fine chemicals

→ Fibres

→ Oils

Don’t use food quality feedstocks!!

Renewable Resources & Biorefineries



Green Chemistry at York

Activity Areas

The Centre's Activities can be groups into 4 areas:

- **Research**
- **Industry collaboration**
- **Education, including development of teaching and promotional materials**
- **Networking with all chemical stakeholders**

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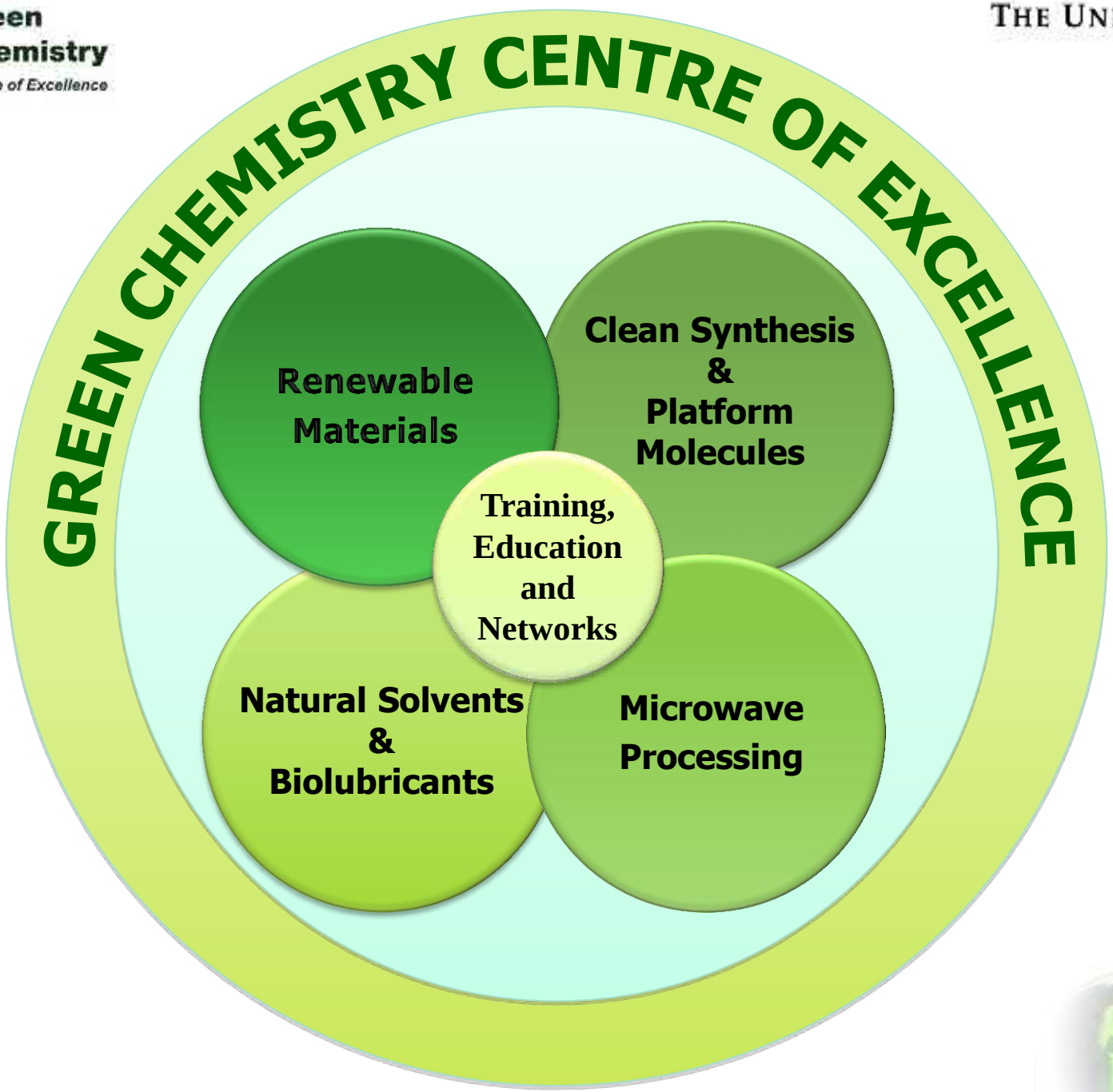
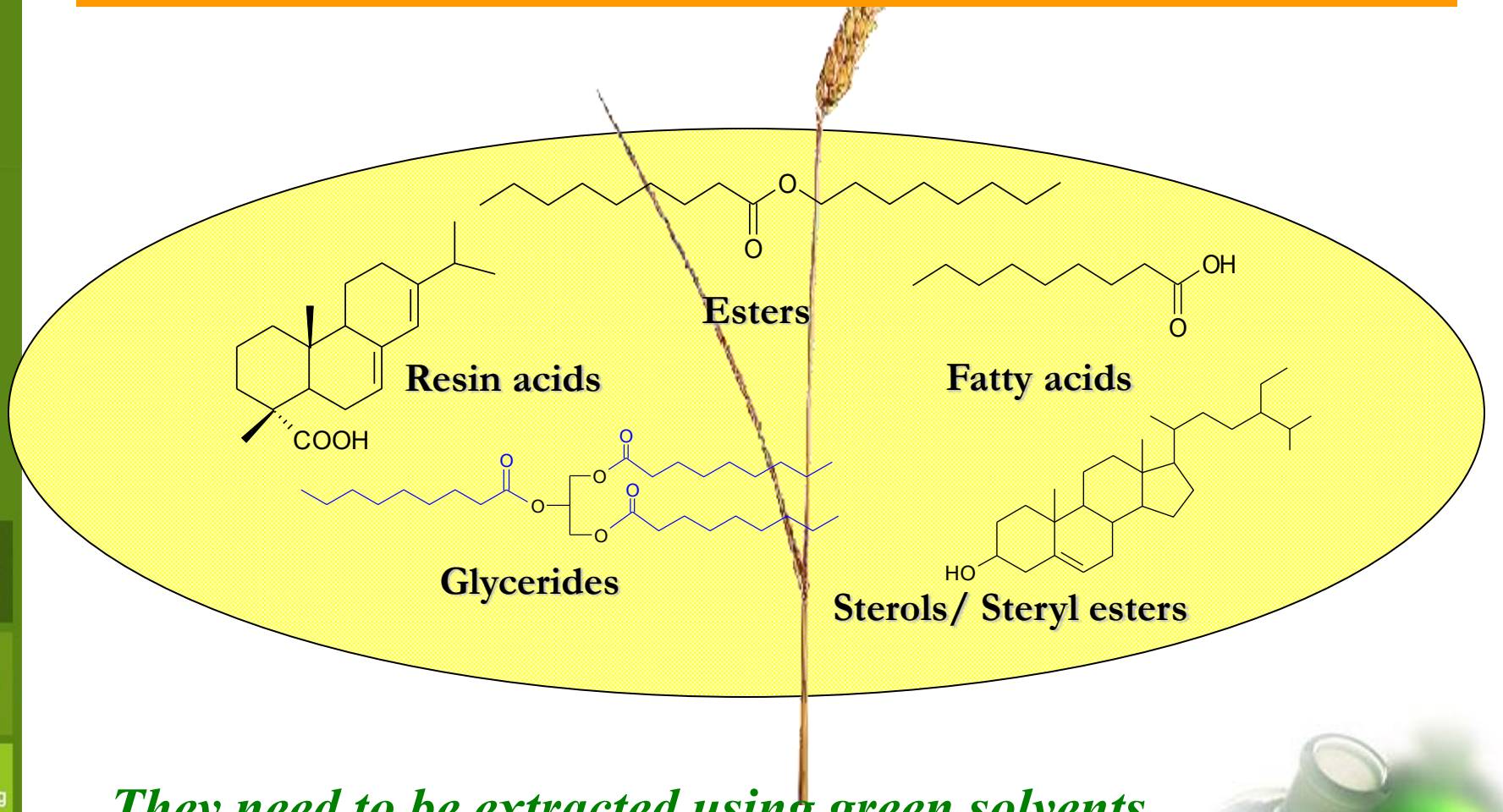


Research
Industry
Networking
Education

www.greenchemistry.net

Agro residues/wastes…….

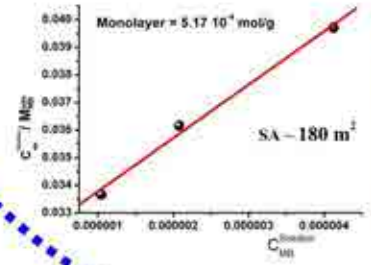
Plant waxes (surface chemicals)



They need to be extracted using green solvents…

Food waste….

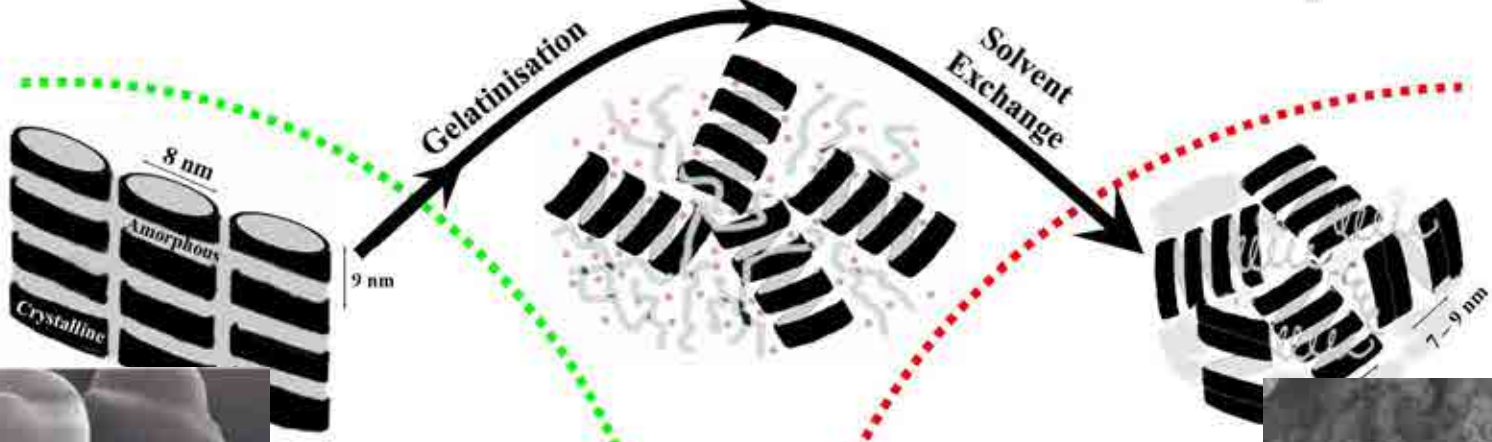
Porous polysaccharide-derived materials

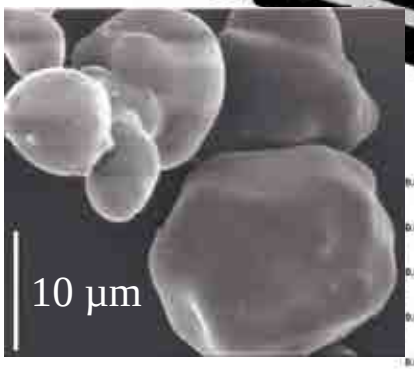


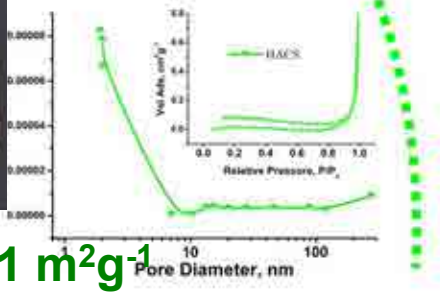
Native Starch

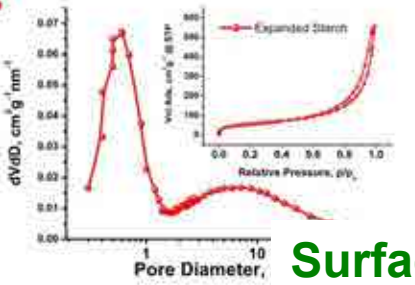
Retrogradation

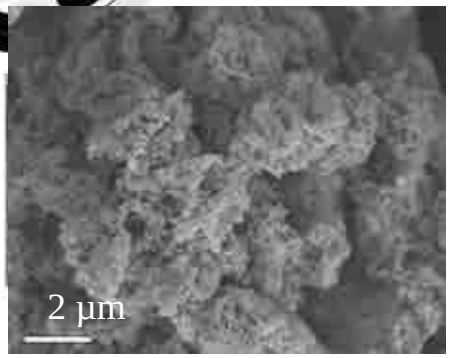
Expanded Starch











Surface Area < 1 m^2g^{-1}

Pore Volume < 0.002 cm^3g^{-1}

Surface Area > 180 m^2g^{-1}

Pore Volume > 0.5 cm^3g^{-1}

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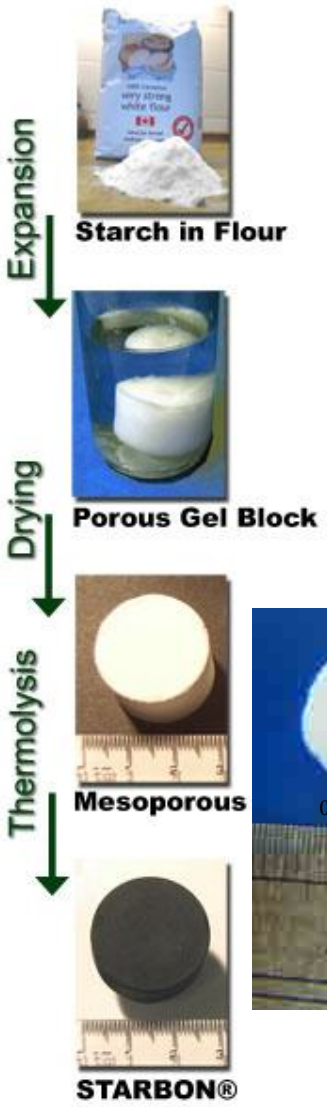
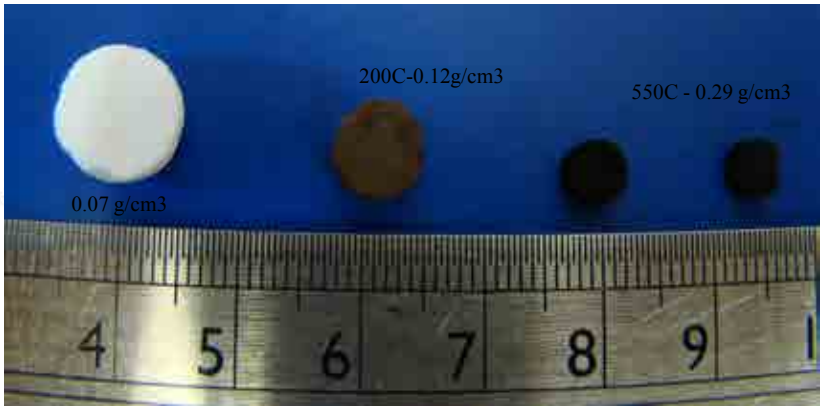
STARBONS®

An exciting new class of carbonaceous materials



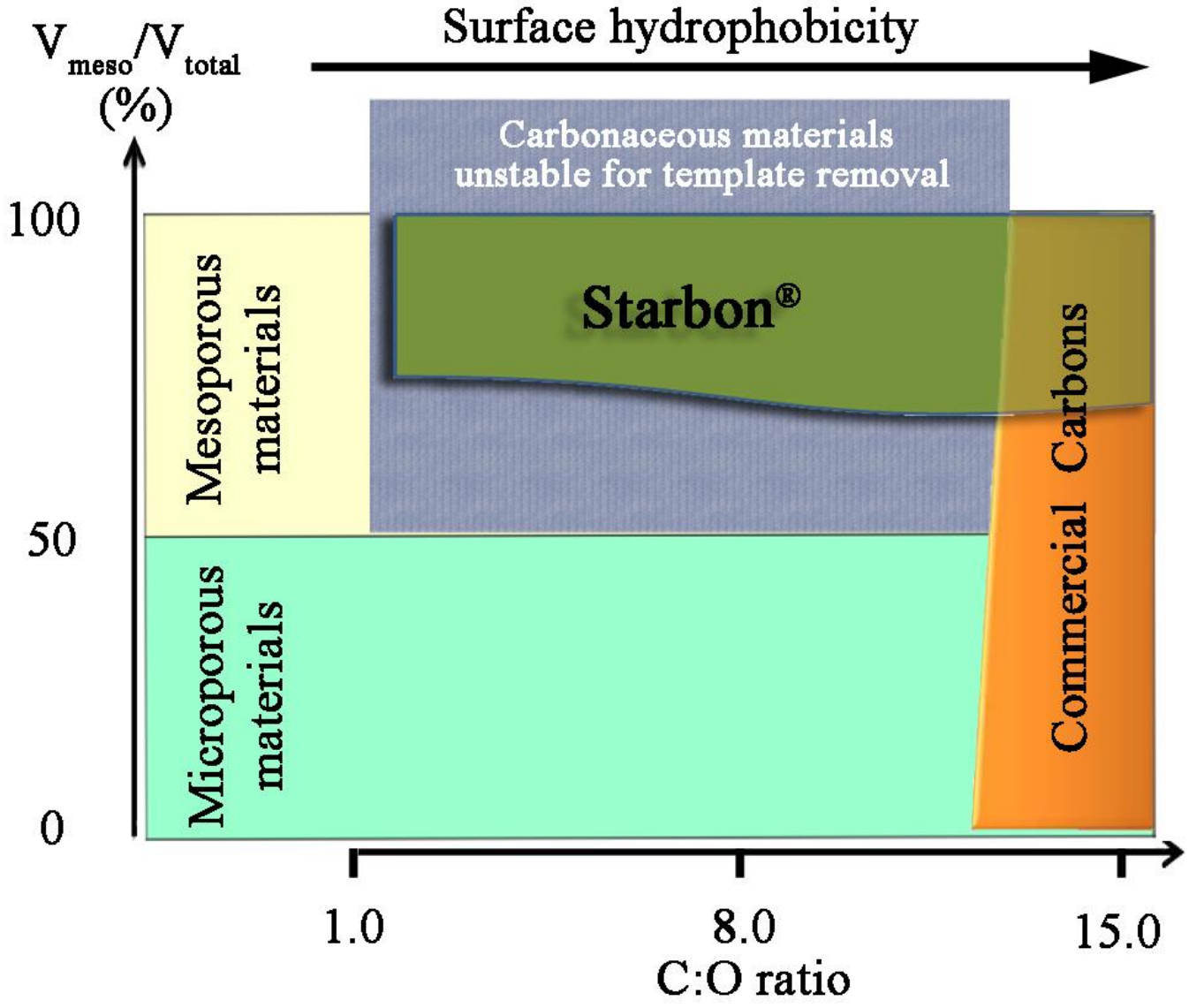
Applications

- Separation media
- Catalysis
- Absorbency
- Water purification
- Fuel cells



Properties

- Adjustable surface energies and polarities
- High mesoporocity and surface areas
- Readily functionalisable with acid/base/metal functionality
- Excellent solvent stability
- Good chemical and heat resistance
- Controllable electrical conductivity
- Formation of composites and blends
- Particulate/ monolithic forms


Surface hydrophobicity
V_{meso}/V_{total} (%)
100
50
0
Carbonaceous materials unstable for template removal
Starbon®
Mesoporous materials
Microporous materials
Commercial Carbons
1.0
8.0
15.0
C:O ratio

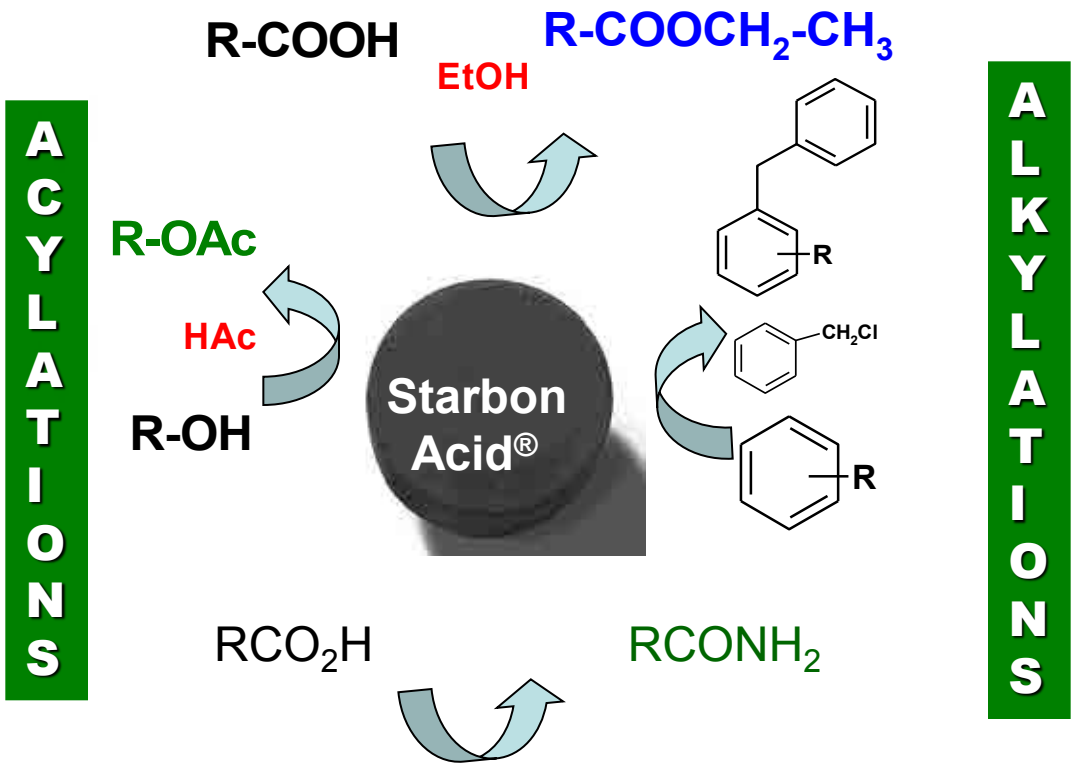
Making your process *greener*

Chemical manufacturing is largely based on chemistry that is complex, energy- , solvent-, and water-intensive and produces a lot of CO_2 and considerably more (often hazardous) waste than product

STARBON® ACIDS as catalysts

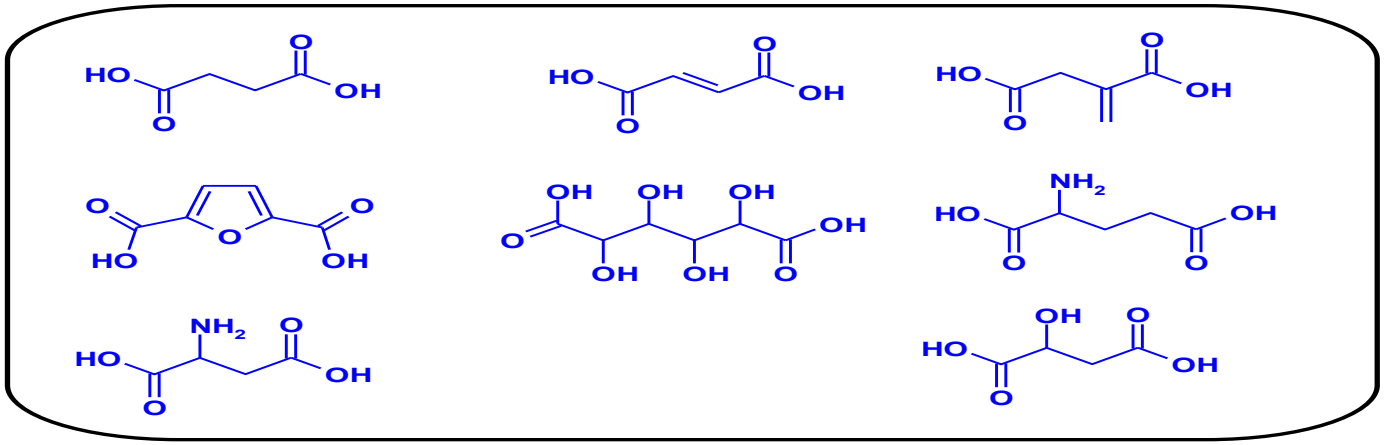
direct downstream chemistry on fermentation broths

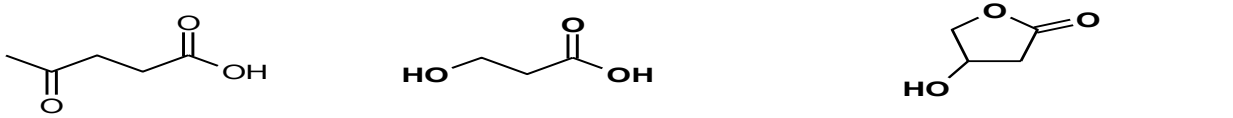
ESTERIFICATIONS

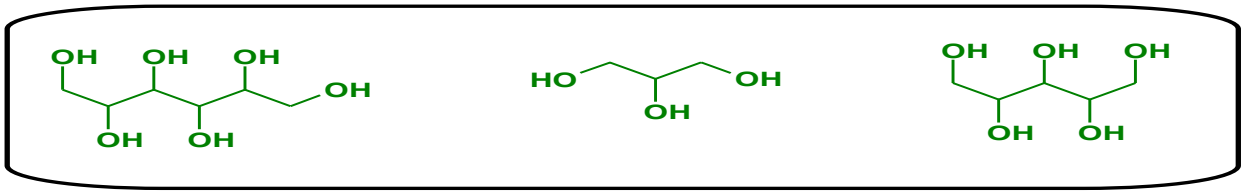


AMIDATIONS

Major platform molecules via fermentation



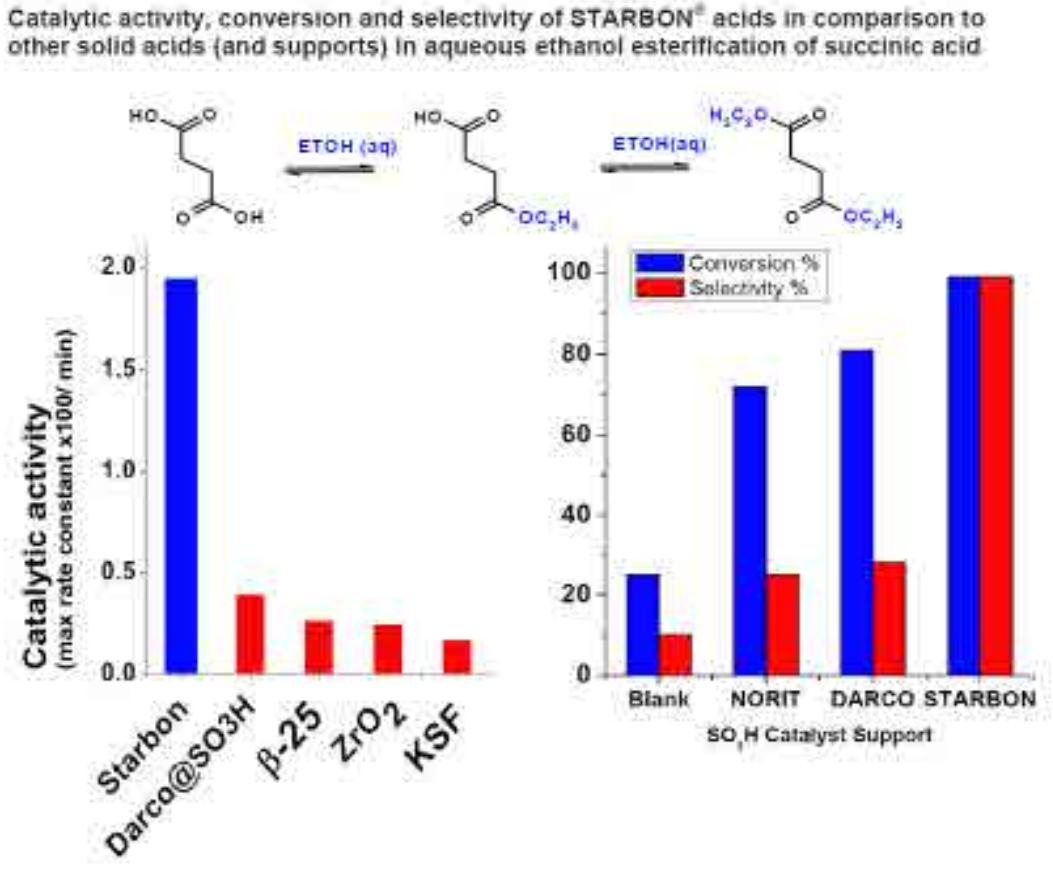




Clean Synthesis methods

A very wide range of useful products

Starbons- a new generation of water-tolerant catalysts
-Acid catalysis directly on fermentation broths



Esterification of succinic acid.

Starbon® Technologies Ltd

Starbon® TECHNOLOGIES

The bio-based mesoporous material company

Starbon® is sustainable, reusable and environmentally benign.

Visit us at the CIA Stand at ChemSpec

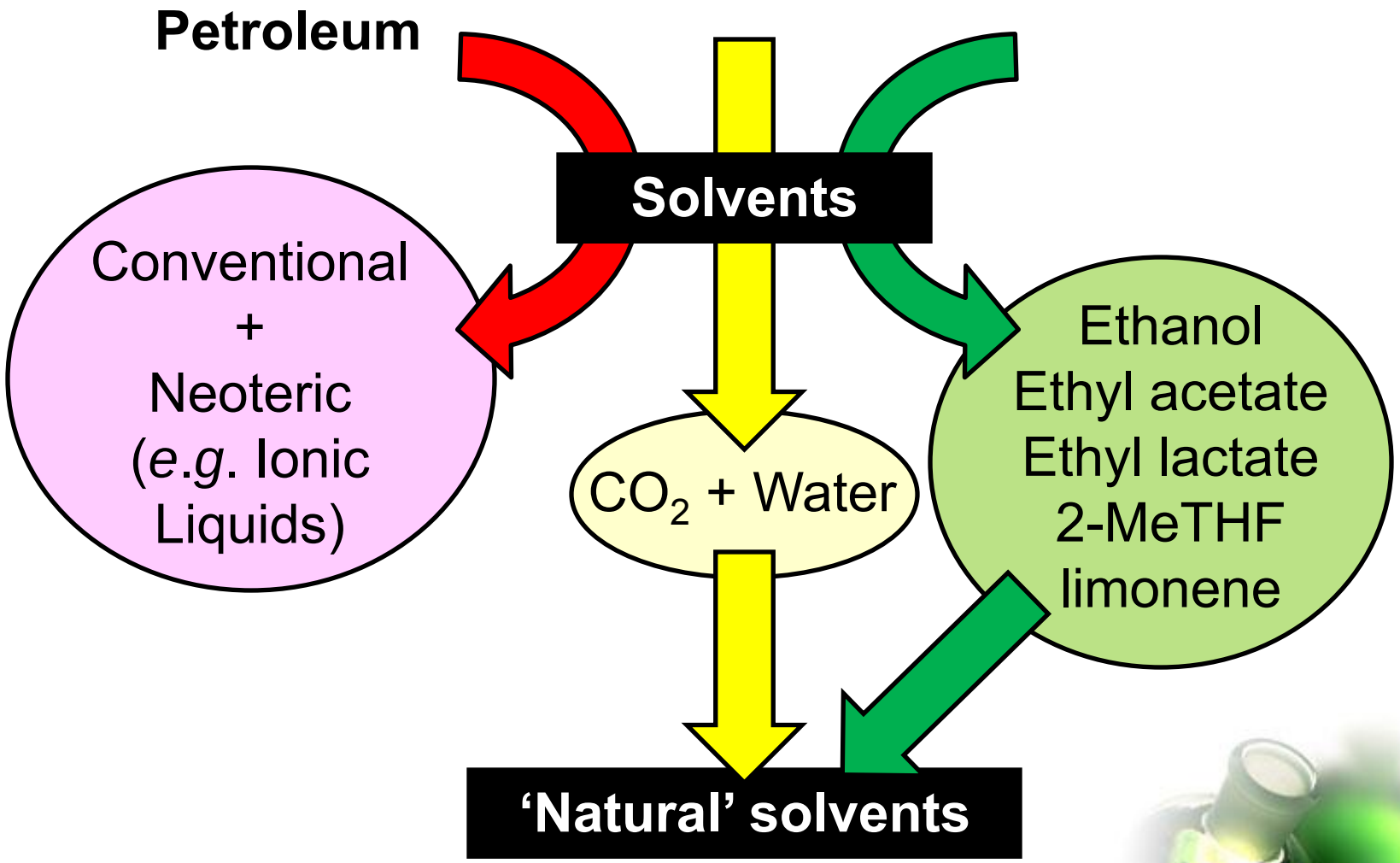
Starbon® Technologies Ltd

Starbon® TECHNOLOGIES

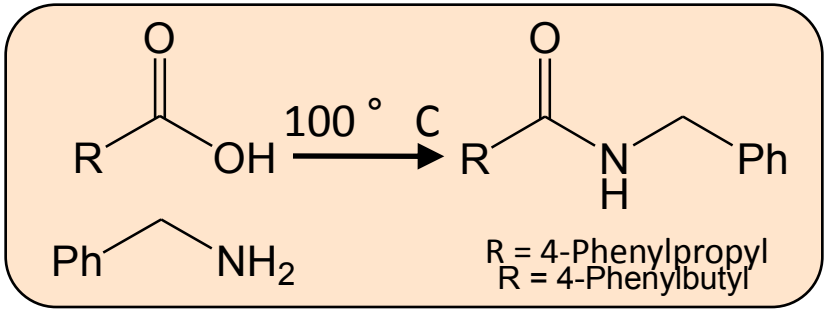
Starbon® product Series

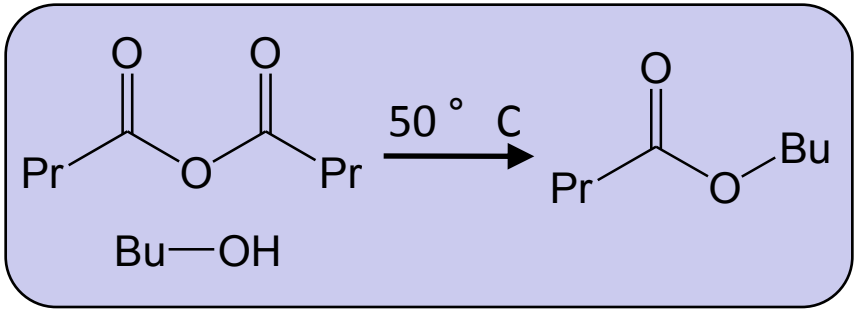
	Application areas	Key advantages	Benefits
Starbon® C SERIES	Catalysis particularly esterification in aqueous media	Aqueous systems Recoverable and reusable Improved selectivity (v. Acid Resins)	Active in aqueous systems Ease of product isolation Reduced catalyst use
Starbon® S SERIES	Separation by chromatography of complex mixtures with Starbon® as the stationary phase	Better separation Greener technology (v. PGC)	Higher productivity Separations effected that are difficult or impossible by other methods
Starbon® P SERIES	Purification of water and clean up of waste streams	Captures larger molecules Faster adsorption rate Recoverable and reusable (v. Activated Carbons)	Removal of harmful organics Transferable Global availability of starch
Starbon® R SERIES	Recovery of precious metals	Reductive adsorption of noble metals (v. Activated Carbons)	More efficient and effective recovery of precious metals

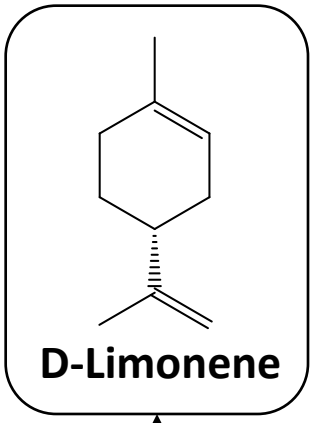
Greener Solvents



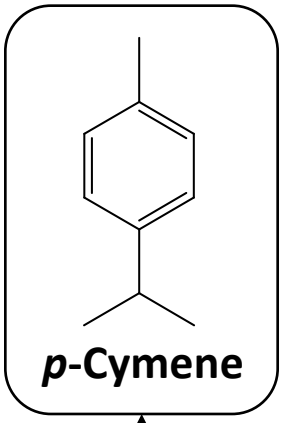
Amidation and Esterification in Bio-Solvents







D-Limonene



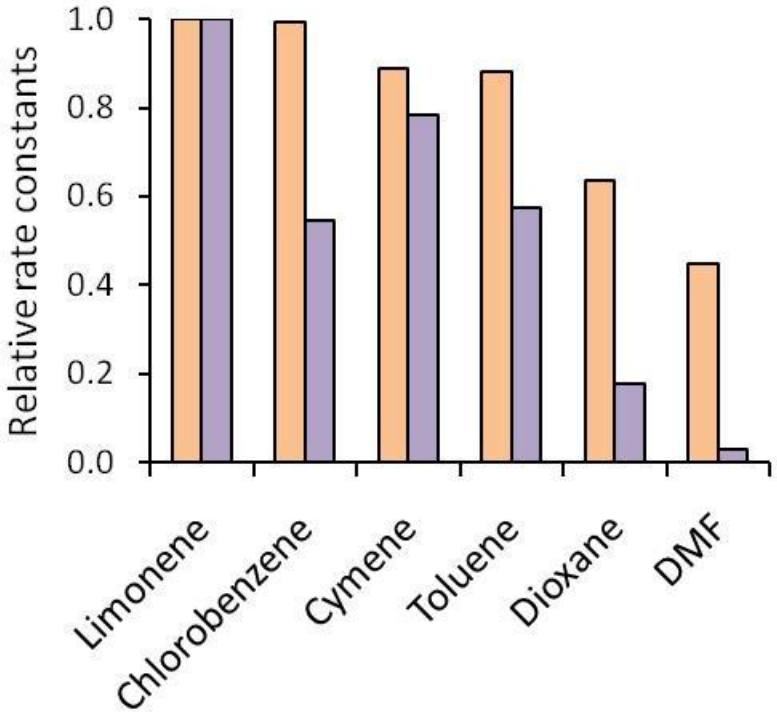
***p*-Cymene**

$scCO_2$ extraction

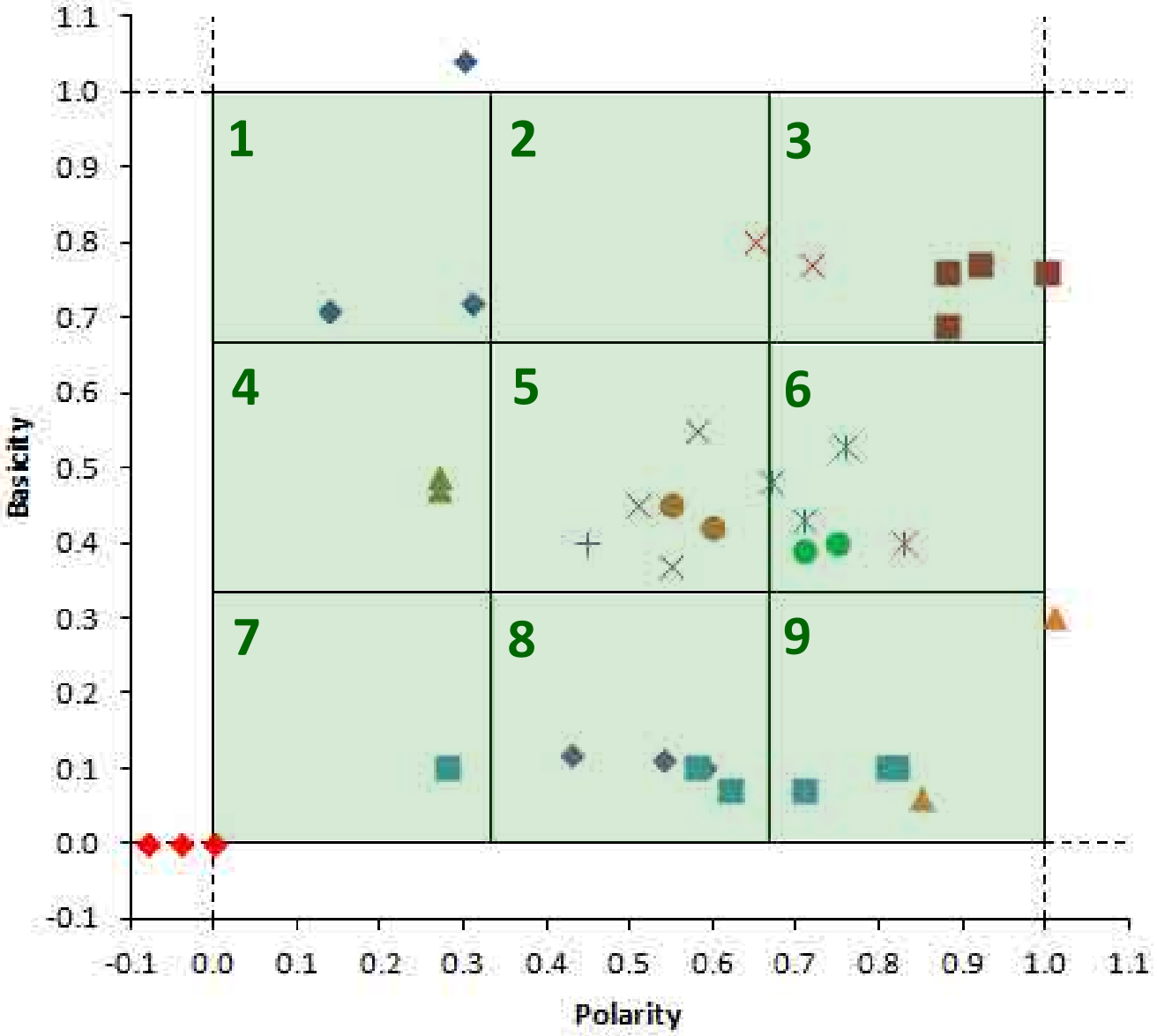
Orange peel

O_2 + Pd-γ-Al_2O_3

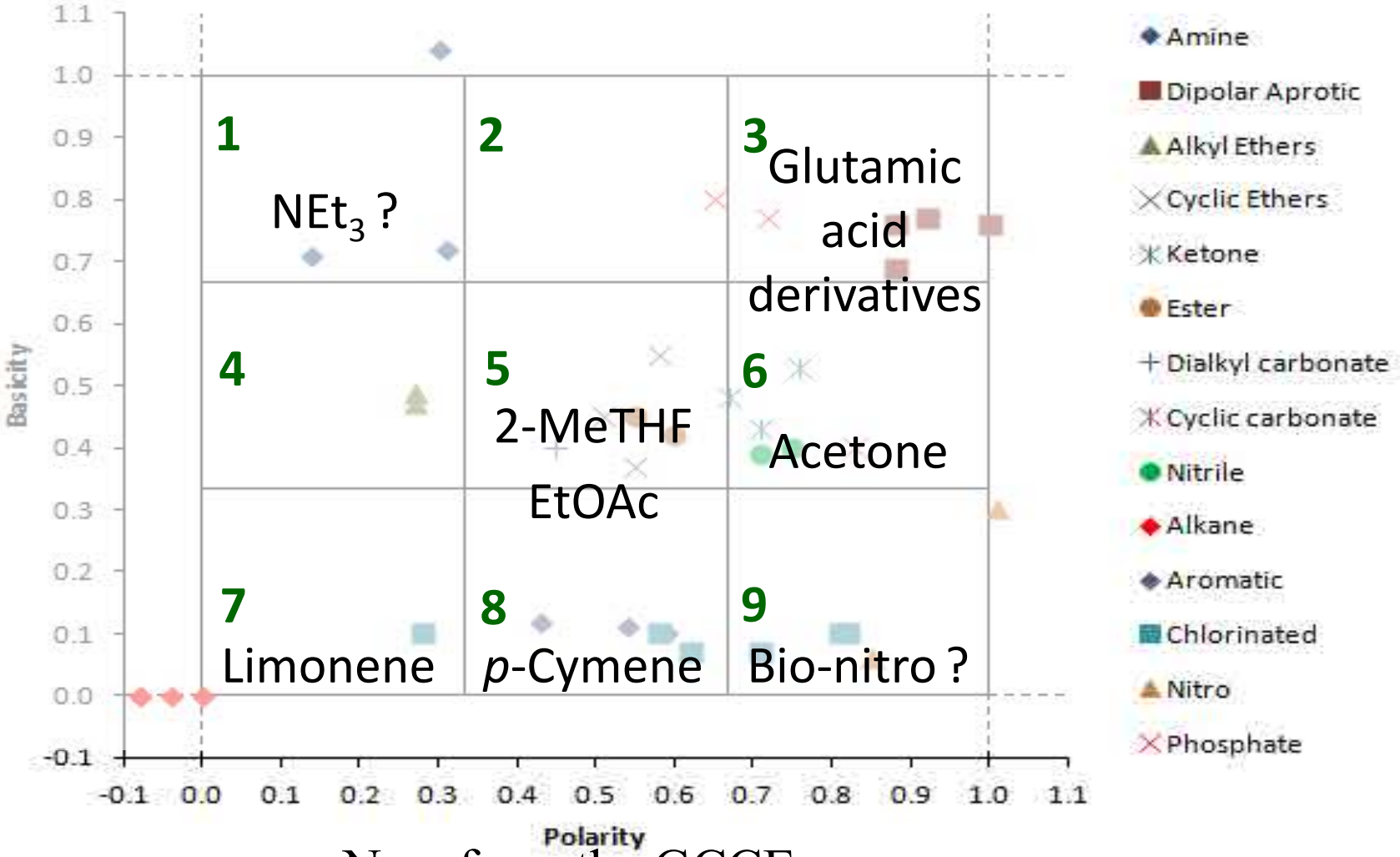
Eucalyptus oil



Solvent Polarity Map (Aprotic)



Sustainable Solvent Polarity Map (Aprotic)

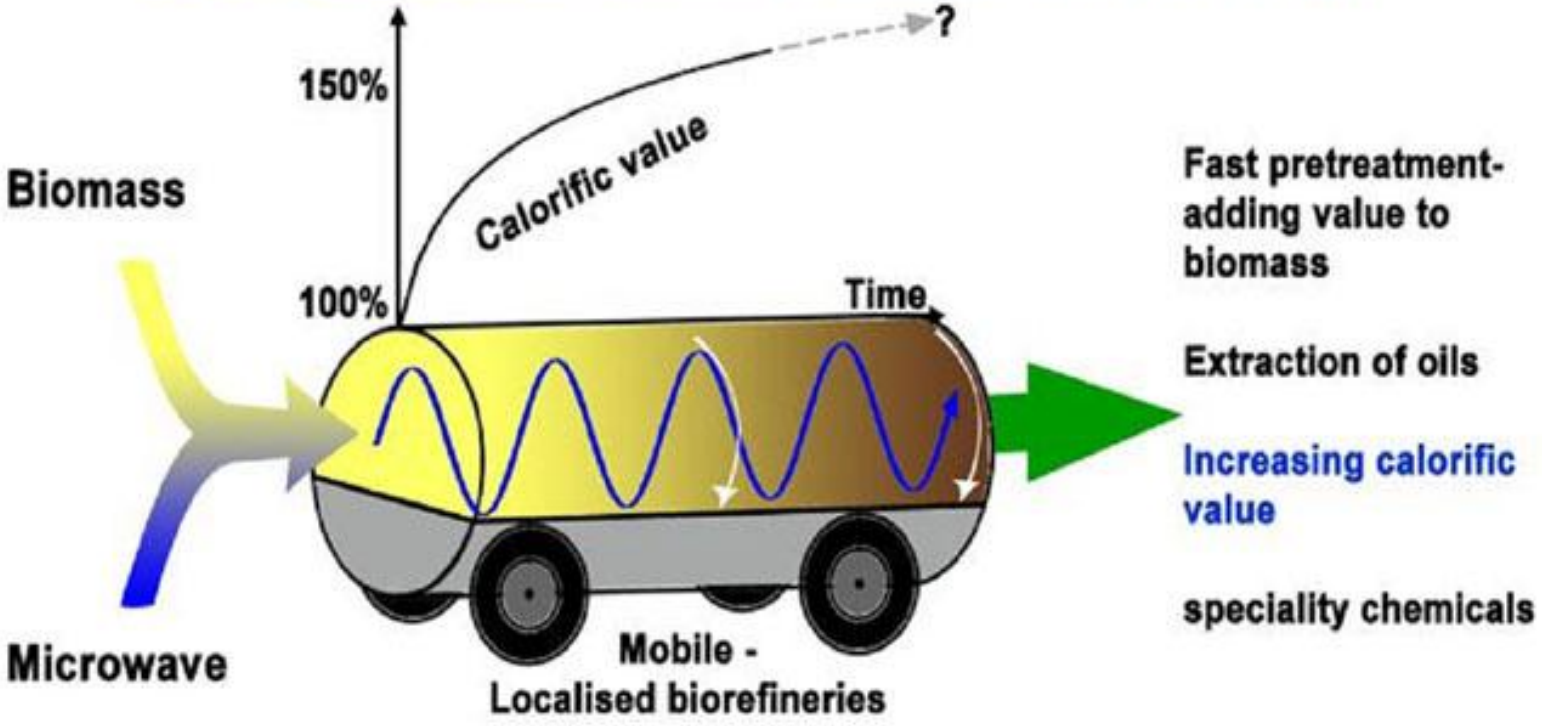


New from the GCCE:

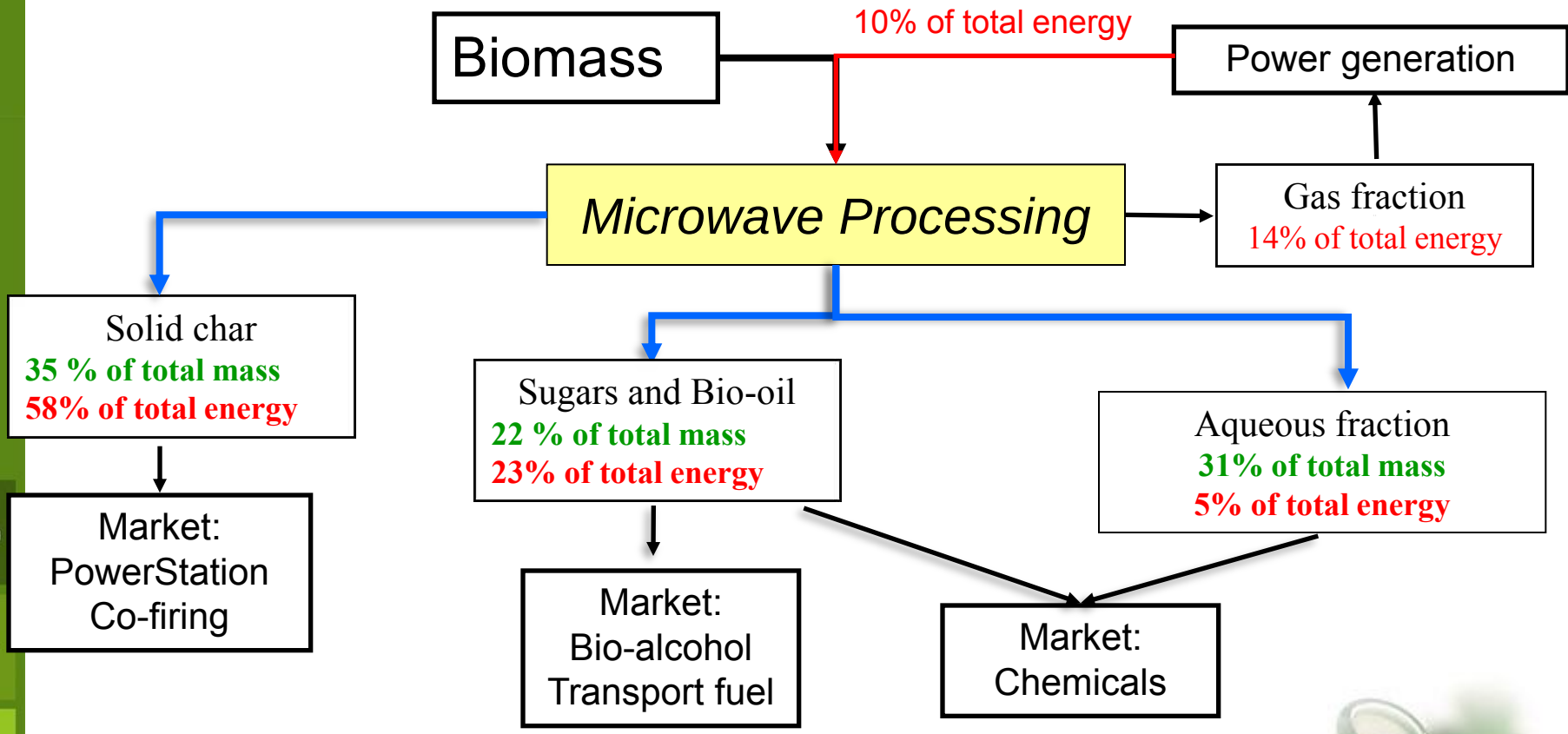
Sustainable Solvents Selection Service- S4

Microwave activation of biomass

development of an alternative method of decomposing biomass



Microwave Biorefinery Flow Chart



Making your product *greener*

Social, environmental, legislative, supply chain and worldwide political pressures make the introduction of greener products imperative

Using plant extracts….

Eco-waxes

Charles Jackson Farms - Botanix - Croda - L'Oreal - Processum

Wheat straw

$ScCO_2$ extraction

Wax products

- Cosmetic Products
- Semiochemicals (Rothamsted)
- Health Products

"Natural" products are very desirable…they need to be:

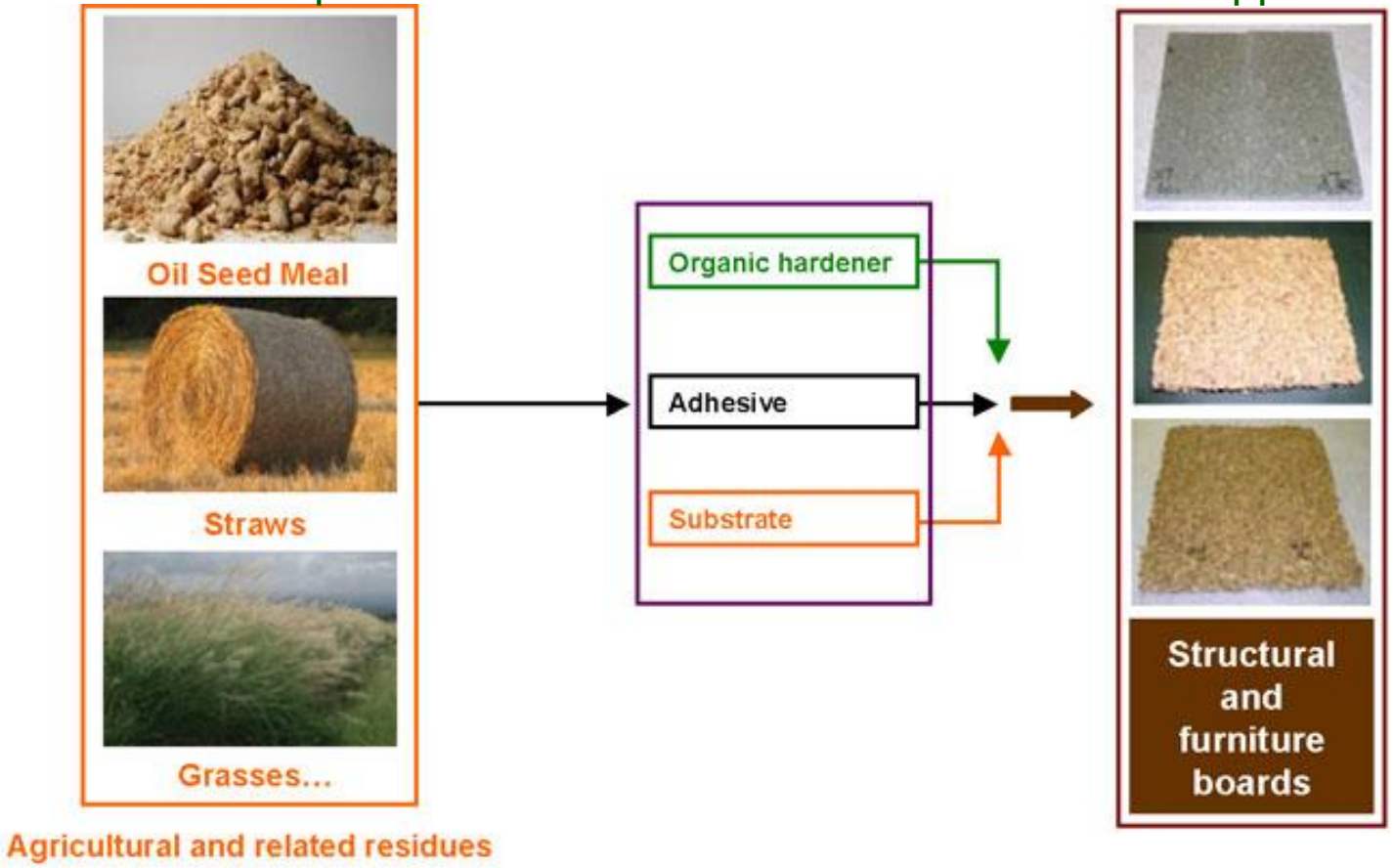
- *derived from natural resources*
- *extracted using "natural" solvents (H_2O, EtOH, CO_2)*
- *modified only be "natural" methods (biocatalysis)*

and for the residues……

Green Office

Velcourt-Bical-BCC-PQ-B&Q-Compak

Bio-based composite materials for structural and furniture applications

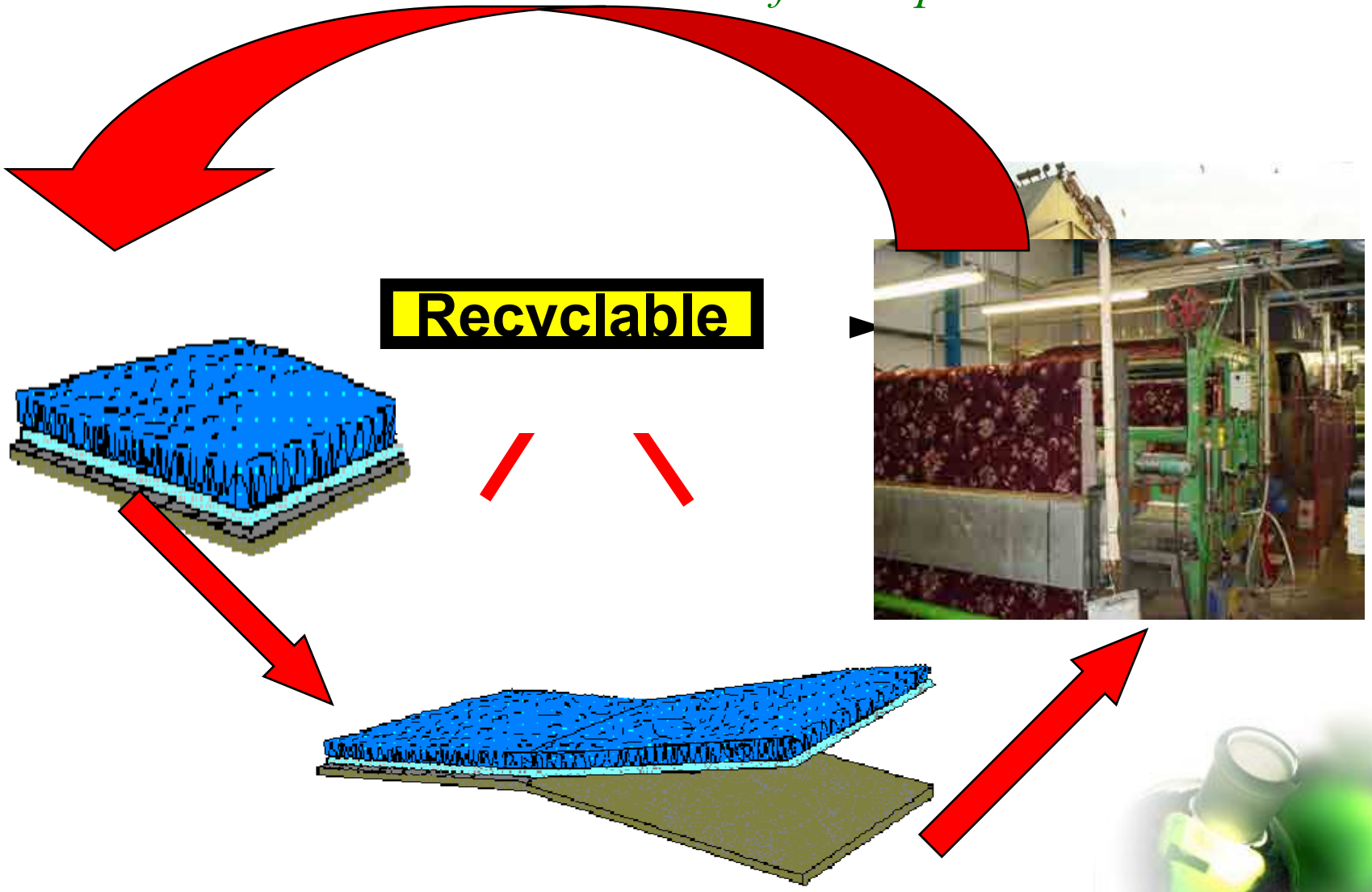


Overall good metrics for sustainability, greener products, waste avoidance and low environmental impact manufacturing

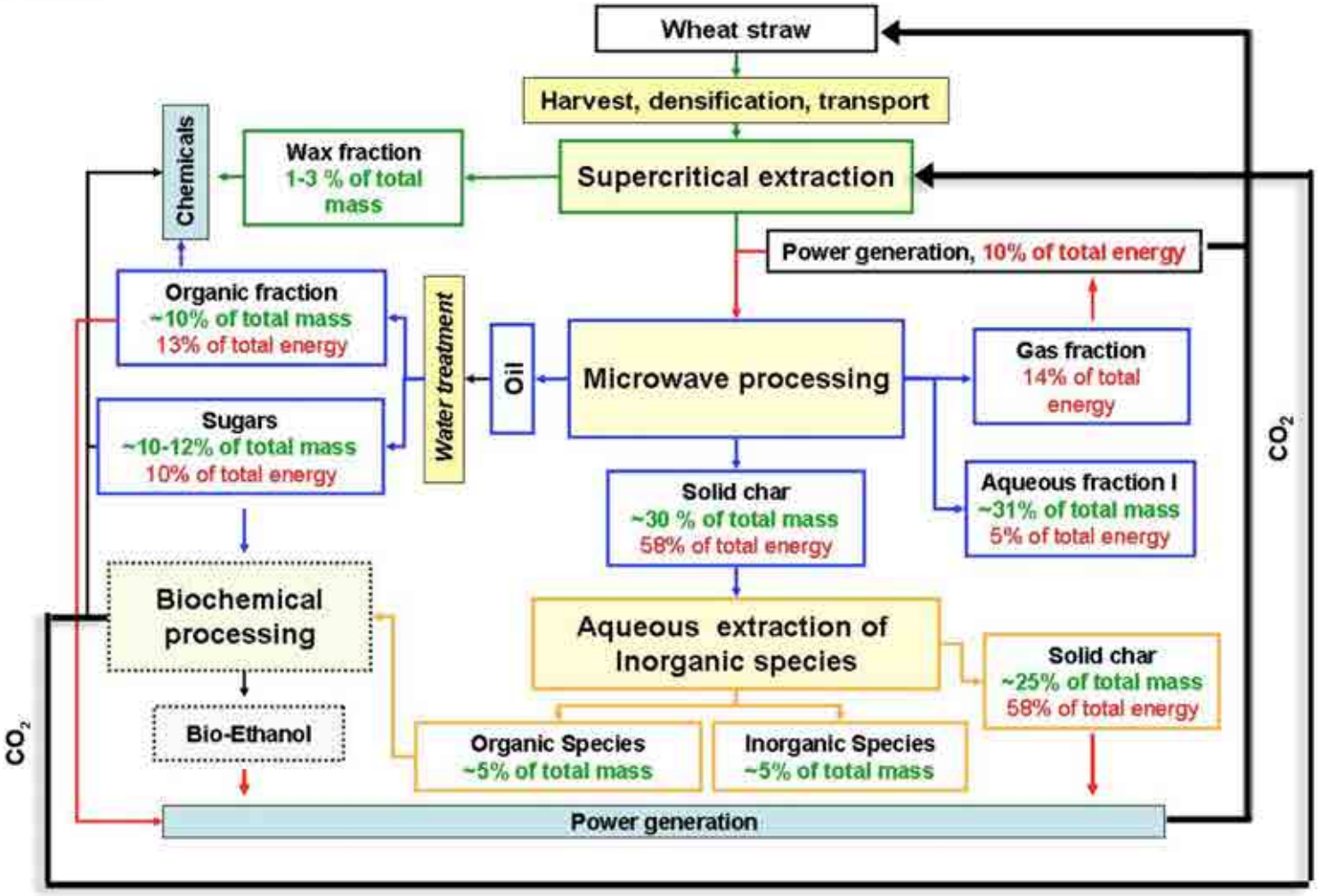
and waste starches…….

York-Interface-Itac-Contract Chemicals

Fire-resistant switchable adhesives for carpet tiles…and more…



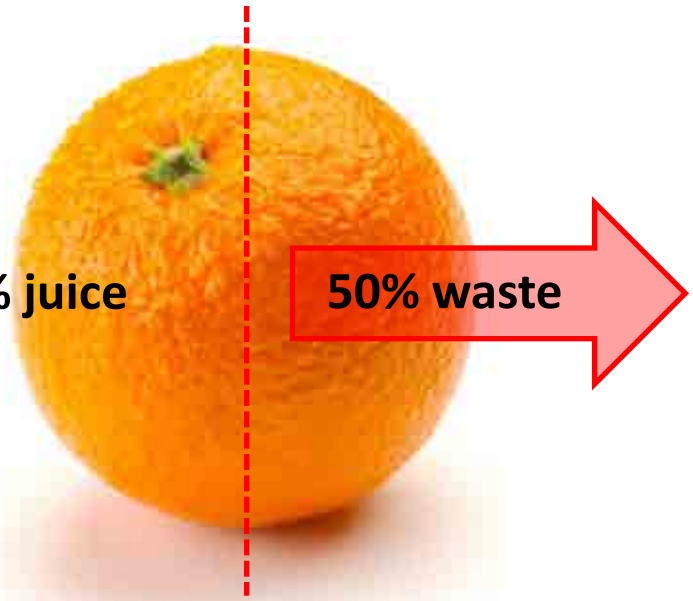
One type of future biorefinery based on single large volume feedstock and using green chemical technologies to make a range of products



Integrated wheatstraw biorefinery

A new OPEC-
Orange Peel Exploitation Company

Valorisation of a million ton scale pre-consumer waste
to bio-chemicals, bio-materials and bio-fuels.



100 million MT oranges
(Brazil, USA, China, India, Africa, Mexico, Spain….)

BIO-CHEMICALS

Bio-solvents
Natural fragrance chemicals
Chemical intermediates
acid catalysts

BIO-FUELS

bio-ethanol
chars
sugars
liquid fuels

BIO-MATERIALS

catalysis
separations
water purification

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Oranges

Orange juice

Juicing process

8,069,705 T/y of waste orange peels available in Brazil for example

Chemicals & solvents

Sugars

Pectin

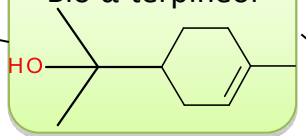
Cellulose

Waxes, alkanes, surface hydrophobes, insect repellant

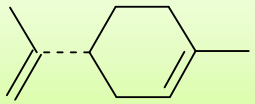
Personal care product additives

Flavours & fragrances

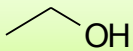
Bio α-terpineol



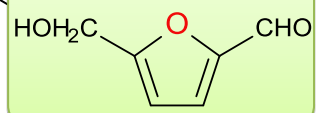
Bio d-limonene



Bio-ethanol



Other platform molecules i.e. HMF

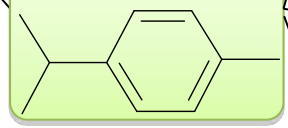


Pectin thickening agent in food products

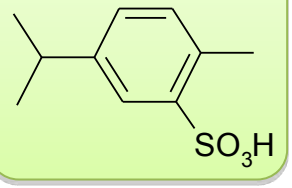
Mesoporous carbonaceous material for catalysis, metal support, water purification and separation

Bio-plastics (i.e. PET)

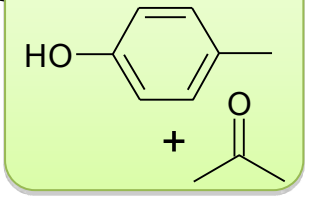
Bio p-cymene



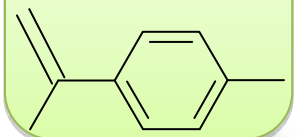
Bio p-cymene sulphonic acid: organic acid catalyst



Bio p-cresol & bio-acetone: commodity chemicals



p-α-dimethyl styrene



www.greenchemistry.net

Green Chemistry at York: from research bench to semi-scale

Ideas

Speculative Research

Discovery

Focussed Research

Industrial Collaboration

Applied Research

Green Chemistry Centre

Biorefinery R&D Centres

Commercial Products

Laboratory & Desk-top Studies

Environmental Impact Assessments

Scale-up & Application Studies

Proving routes & technologies

Training for industry partners

Green Chemistry
Centre of Excellence

THE UNIVERSITY of York

Research

Industry

Networking

Education

Biorenewables Development Centre

www.biorenewables.org

Project Part-Financed by the European Union

European Regional Development Fund

Project Sponsor

Science City York

A collaboration between the Green Chemistry Centre CNAP, FERA and Science City York

Biorenewables Development Centre



Facilities

- A range of pre-treatment equipment including a granulator, hammer mill, pelletizer and macerator all scaled to handle up to 100kg batches of biomass.
- A 30kg/h continuous flow, low temperature, microwave pyrolysis system.
- A 10 litre sub- and super-critical CO2 extraction and fractionation capability.
- A 100 litre high pressure and temperature fibre explosion system.
- A microbiological suite including fermentation capacity up to 42 litres.

BDC Biorenewables Development Centre

- **Biorenewables Feedstock Development Unit** will source, evaluate and develop plants, algae and fungi as production systems for high value chemicals and materials.

- **Biorenewables Process Development Unit** will allow pre-treatment, extraction, processing and separation of biorenewable feedstocks on an industrial scale.

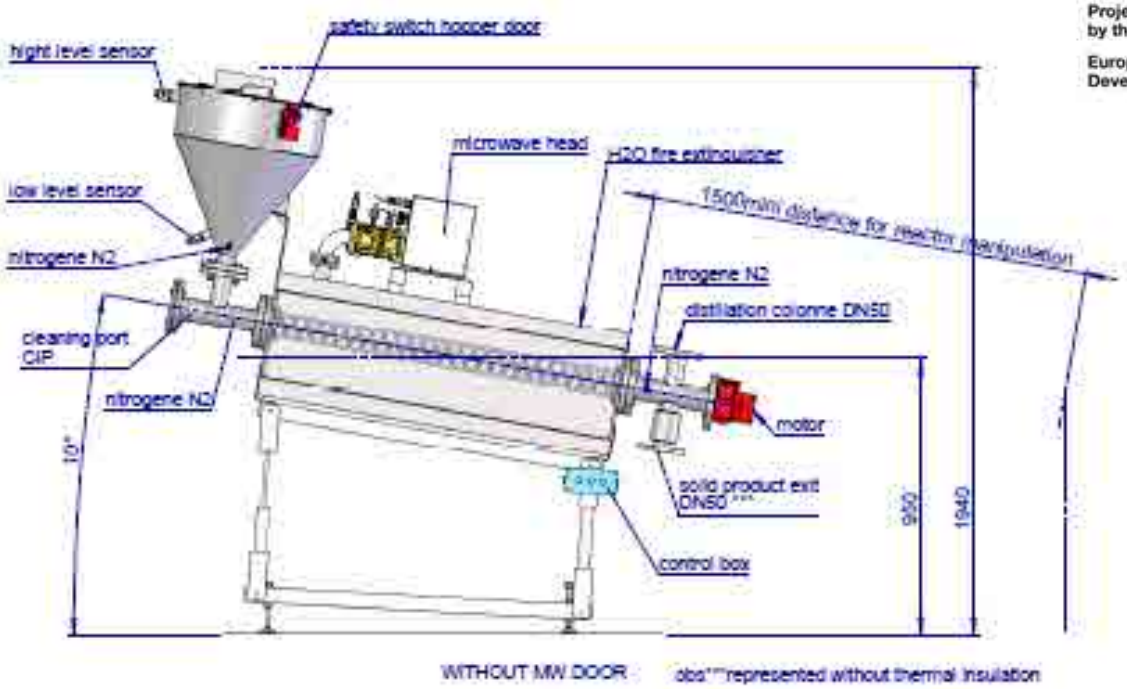
- **Biorenewables Business Development Unit** will engage with relevant industrial organisations to identify business opportunities and help companies develop new economically viable products and processes.

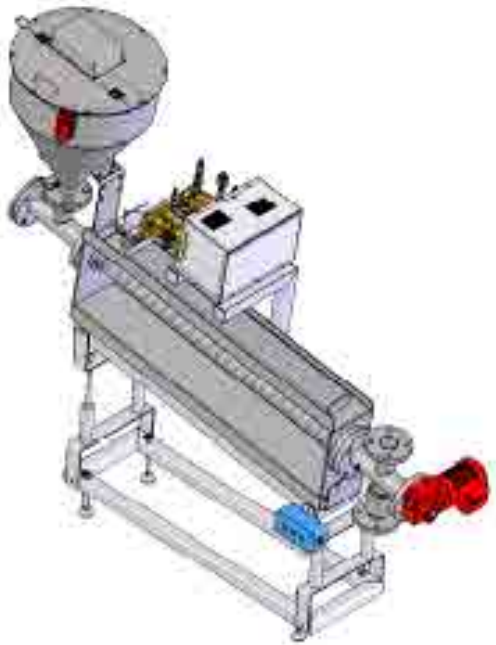
Official launch by UK Government Minister
July 5, York

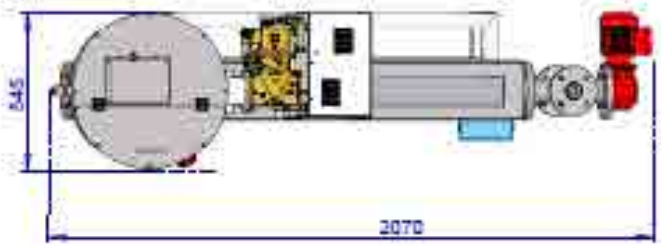
BDC Biorenewables Development Centre

Project Part-Financed by the European Union
European Regional Development Fund

Project Sponsor
Science City York







THE UNIVERSITY of York

Green Chemistry Centre Developments

2012

Biorenewables Development Centre

The Biorenewables Development Centre is a major new initiative focusing upon the identification, development and processing of biorenewable materials including bio-wastes. BDC facilities include demonstrator scale continuous microwave, supercritical and fermentation processes. The BDC has dedicated management, scientific, technical and business development staff.

Starbons

Starbons® Ltd was formed in 2012 as a spin-out originating from research conducted at the University of York. It is the GCCE's first commercialisation company focusing on the Starbons® technology, which converts waste polysaccharide into high value mesoporous materials. Starbons® Ltd is based near the BDC and the GCCE in the York Science Park.

International Networks

The latest Green Chemistry Centre network initiative, Biowaste Industrial Symbiosis (BIS), launched in 2012 and will reach across the globe to help create a multidisciplinary community with common interests in valorising food supply chain waste.

BIS

Green Chemistry
Centre of Excellence

2013

New Building

Industrial Engagement Facility

The Industrial Engagement Facility will be integrated within the new Green Chemistry Centre building. It will provide a flexible meeting space for visiting industrialists to have discussions with Centre scientific staff. The IEF will have a dedicated manager and support staff.

New Chair in Green Chemistry

In late 2012, the Green Chemistry Centre of Excellence will appoint a new Chair in Green Chemistry, expanding the senior academic staff to 5 and broadening its knowledge base and research expertise.

Email: info@greenchemistry.net

More Information: http://www.york.ac.uk/greenchemistry

NORSC

Combining the expertise of the leading Northern England Universities to provide sustainable chemistry solutions to industry

MUSC

The Chemical Industries Association and the Green Chemistry Centre working together to create new green and sustainable supply chains for chemical products

Promoting awareness and facilitating, education, training and practice of green chemistry worldwide

Anglo-French collaboration chemicals from biomass using green chemistry and white biotechnology

SUSTOIL

The international Network for alternatives to petroleum

Green Chemistry and the Consumer

Green chemistry solutions for the retailer and producer

The

BIS

Biowaste Industrial Symbiosis

www.sustoil.org/bis.html

Green Chemistry networks worldwide

Greece, Portugal, Cyprus, Japan, USA, Mexico,India Korea, Brazil……

Green Chemistry
Centre of Excellence

THE UNIVERSITY of York

BIS
Bio-waste Industrial Symbiosis

We need the BIS to help us better valorize bio-wastes into chemicals, fuels and materials

✓ *because we need to cross traditional disciplinary boundaries*
✓ *because we need to employ better technologies*
✓ *because we need to work across national boundaries*
✓ *because we need to overcome legal obstacles and other barriers*

NOW A NEW EUROPEAN COST ACTION

Join us at www.sustoil.org/bis.html

And at the launch in Santa Clara (June 21)

Research
Industry
Networking
Education

We work at all stages from young children to professional (re)training…

Early Education and Outreach

Aims

- To **excite** young people about **chemistry** and the **positive** impact it can have.
- To **enable** young people to **critically engage** with ideas and solutions

Impacts/areas of work

- lots of projects and funding at key stage 2

- Discovery Days, Countryside Days, Science Days in Primary Schools

- High awareness about environment at young age, interest and enthusiasm

- opportunities at GCSE/A level stage

Training the next generation…..

MSc in Green Chemistry & Sustainable Industrial Technology

Principles & Technologies

Principles, Environmental Impact, Chemical Engineering, Catalysis for Green Chemistry, Alternative Reaction Media, Energy, Clean Synthesis, Renewable Resources, Greener Products

Supporting Courses

IP, Business Opportunities, Green Chemistry Presentations, Legislation Presentations and Literature Research

Research Project & Oral Presentation

In collaboration with Industry

Transferable Skills

Industry

Education

Green Chemistry

Centre of Excellence

www.greenchemistry.net

Research

Networking

RSC Green Chemistry Book Series

Series Editor in chief :James Clark (UK),
Associate editors: George Kraus (USA), Andrzej Stankiewicz (EU);
Peter Seidl (Brazil); Yuan Kou (China)

Concise digest of the latest research and thinking in Green Chemistry

Accessible handbooks to both those entering and established in the field

Latest titles: