10th International Conference on Sustainable Solid Waste Management, Chania

What is the concept of modern biorefineries? How we will move fast towards 4th generation biofuels, supporting EU policies?

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National Technical University of Athens

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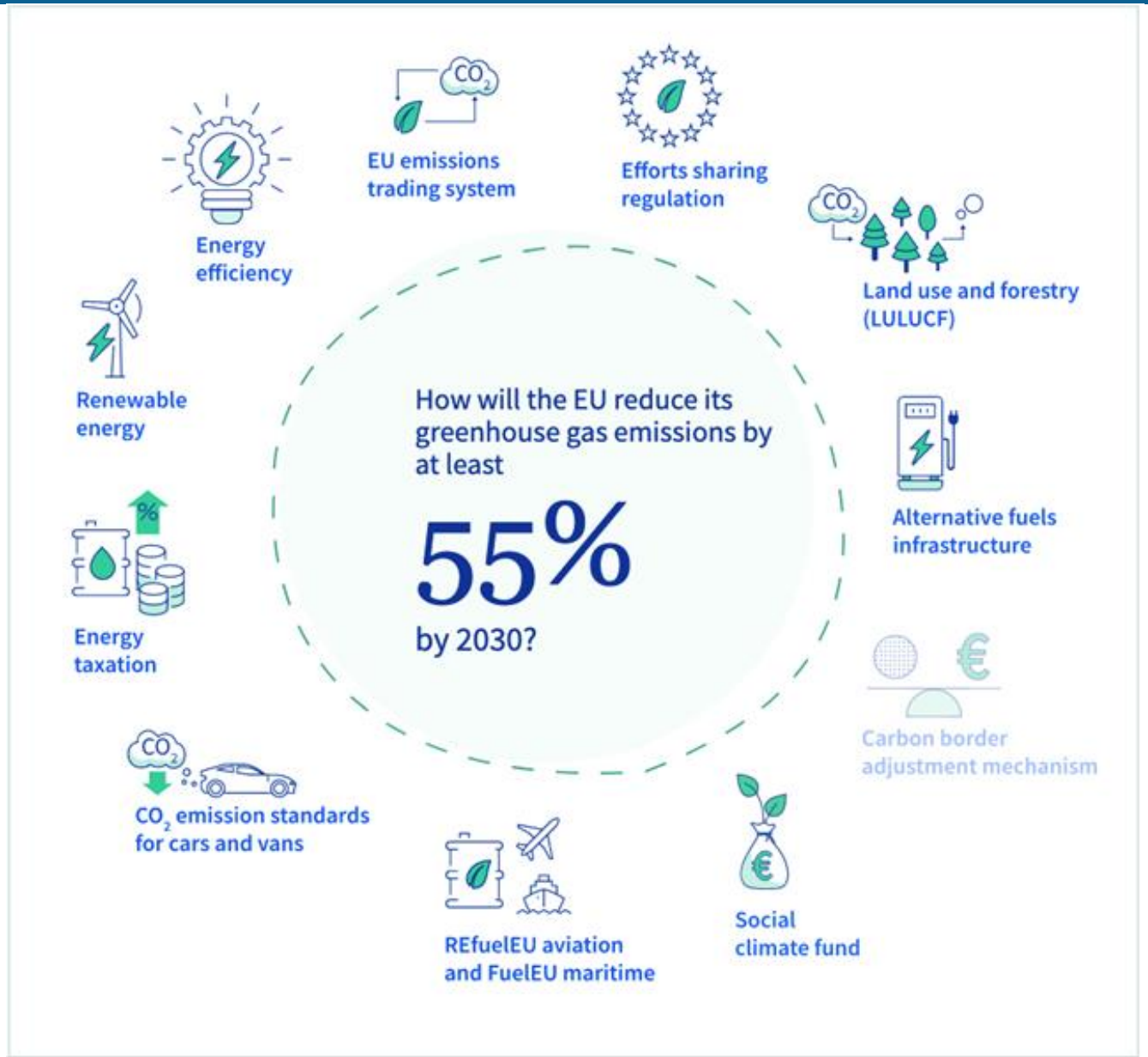
EU Legislation



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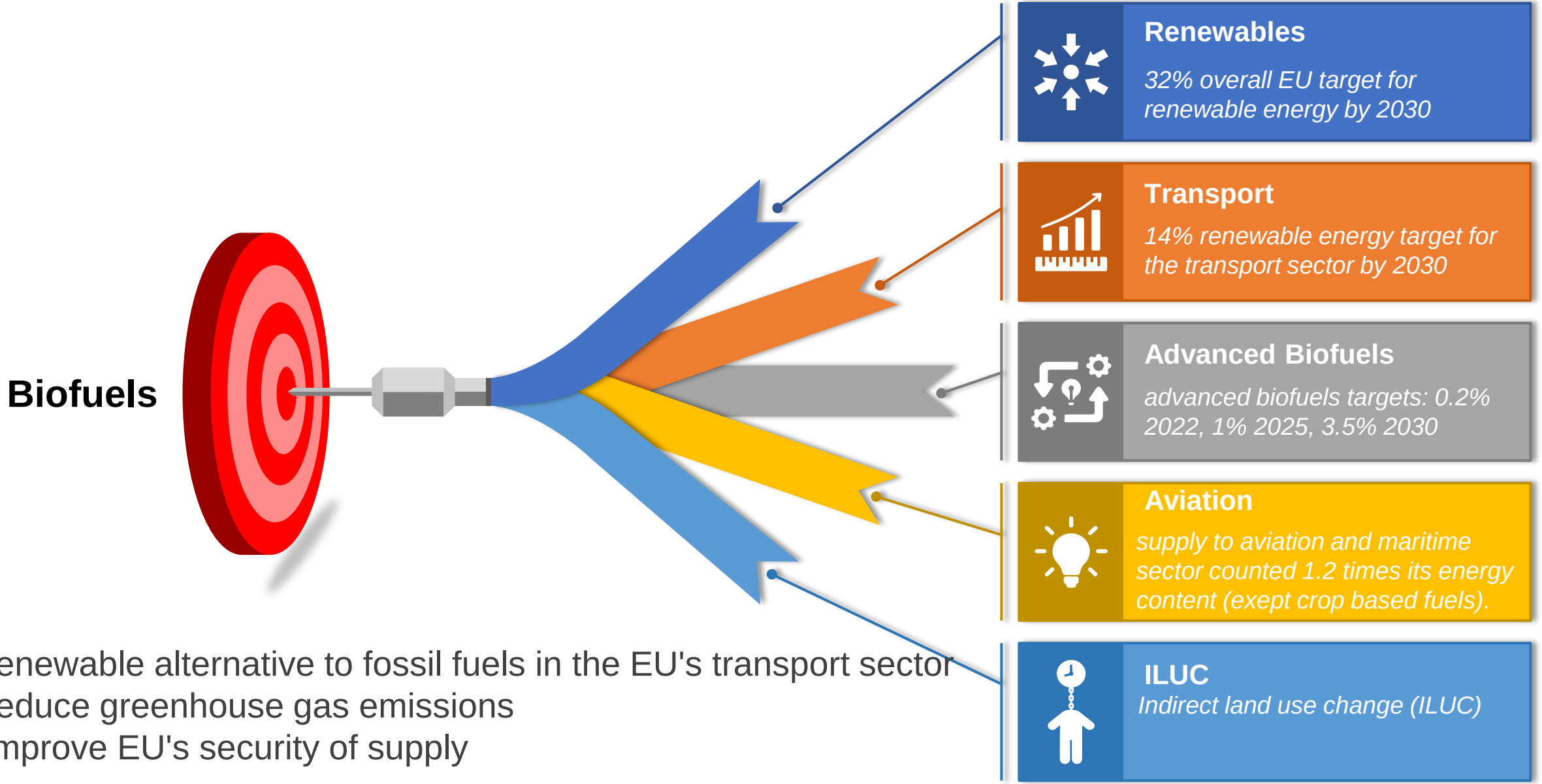
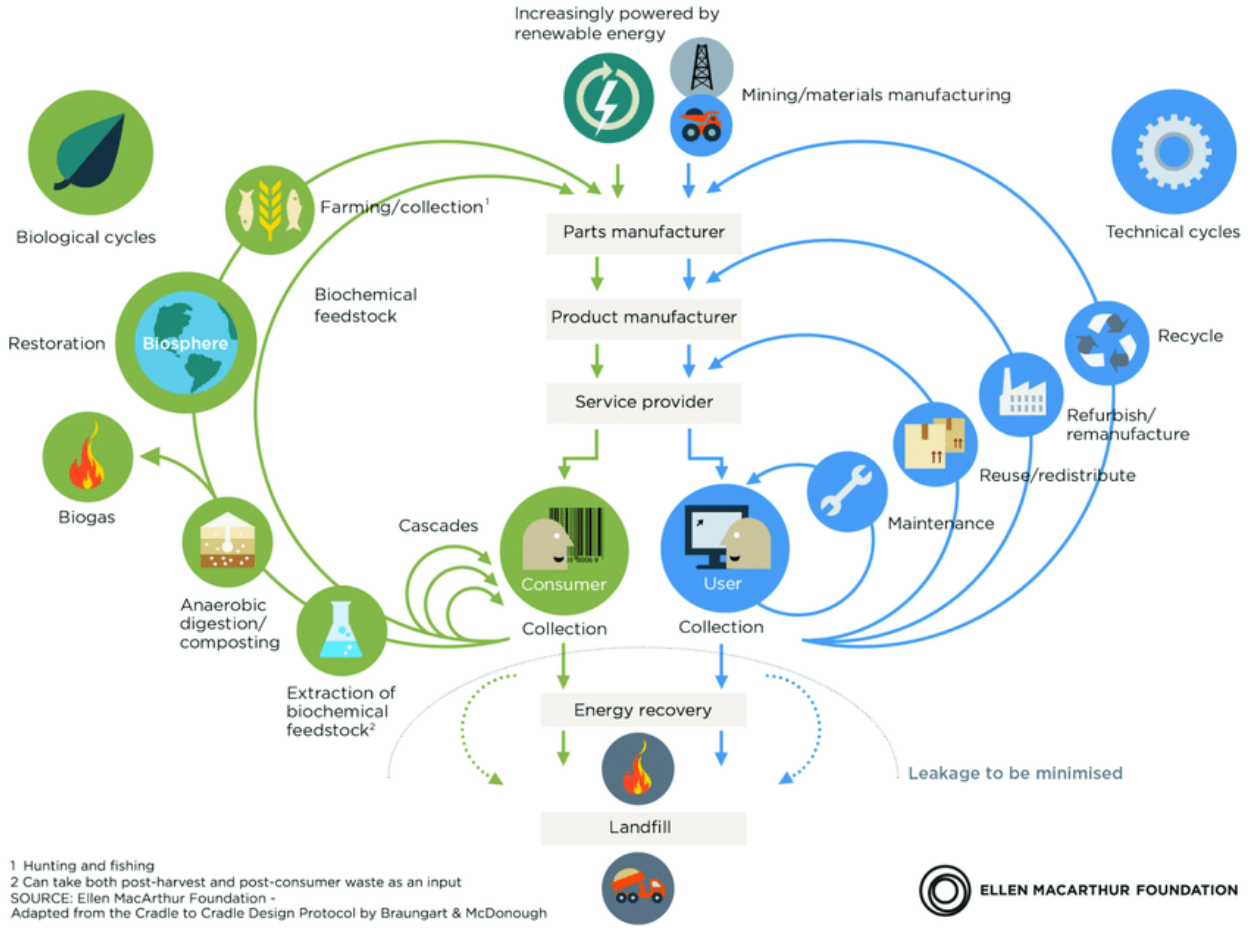
Biofuels



- ✓ renewable alternative to fossil fuels in the EU's transport sector
- ✓ reduce greenhouse gas emissions
- ✓ improve EU's security of supply

Circular Economy

A Circular Economy is an industrial system that is restorative or regenerative by design. It replaces the 'end-of-life' concept with restoration, shifts towards the use of renewable energy, eliminates use of toxic chemicals, which impair reuse, and aims for the elimination of waste through the superior design of materials, products, systems, and, within this, business models.



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Bioeconomy

The bioeconomy encompasses the production of renewable biological resources and their conversion into food, feed, bio-based products and bioenergy via innovative and efficient technologies

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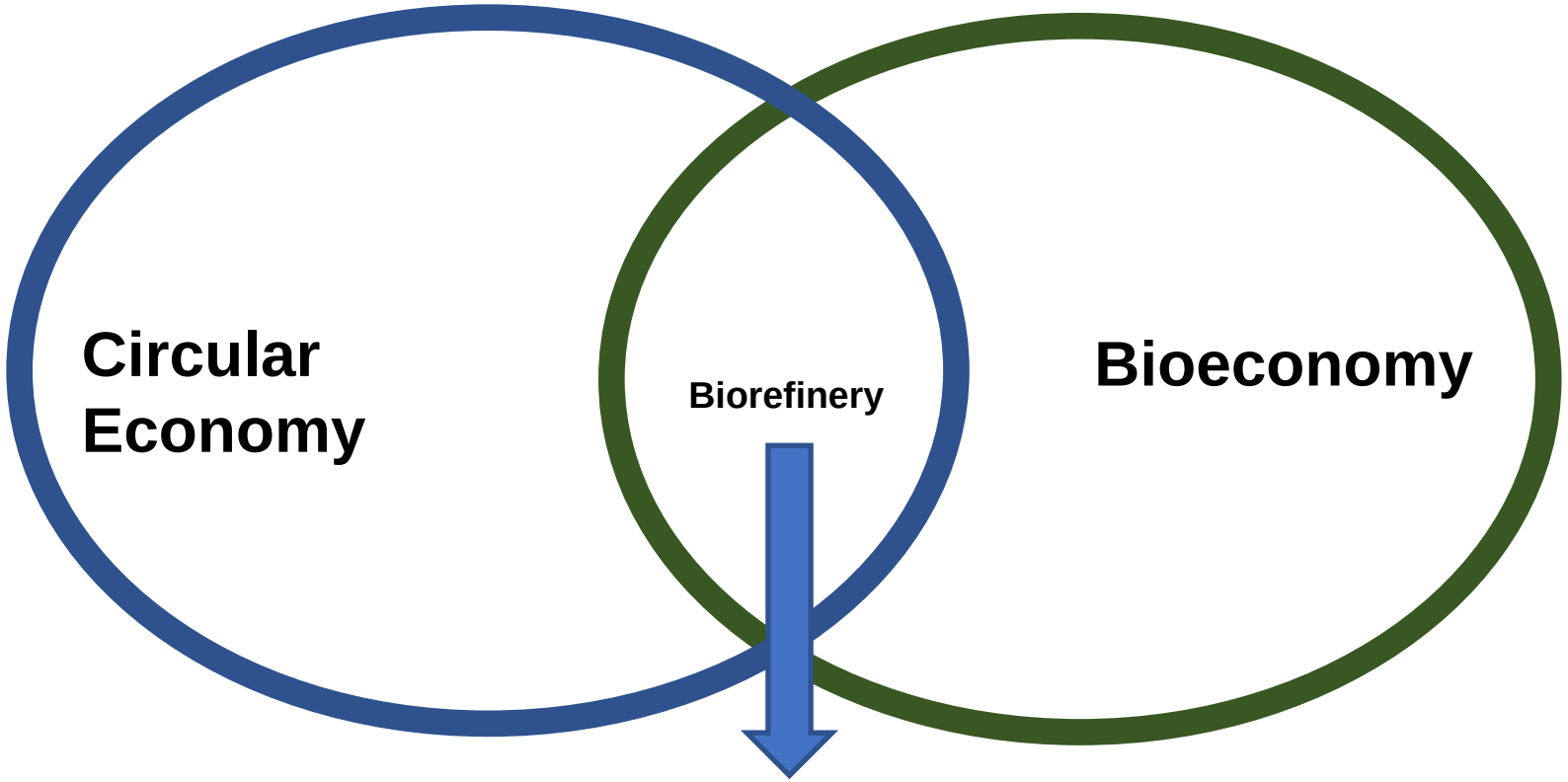
Biorefinery



Sustainable processing of biomass into a portfolio of marketable biobased products (food and feed ingredients, chemicals, materials, fuels, energy, minerals, CO_2) and bioenergy (fuels, power, heat)

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Biorefinery classification

Features:

1. **Platforms**
   - biogas
   - C5 -C6 sugar
   - syngas
   - plant-based & algae-oil
   - lignin
   - organic solutions
   - pyrolytic liquid

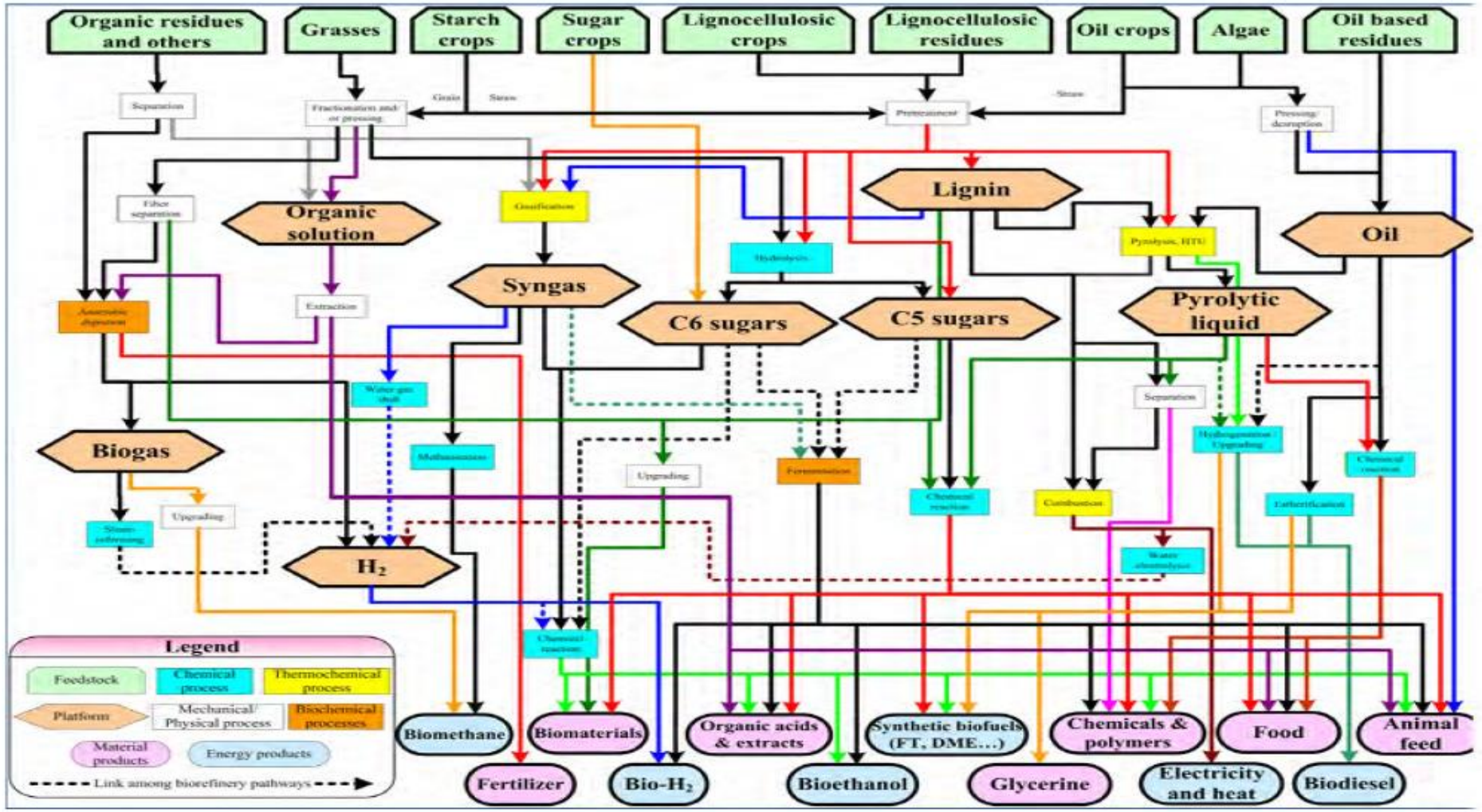
2. Products
energy carriers, chemicals and material products

Products

3. Feedstock

4. Processes
thermochemical, chemical, bi… mechanical processes

Feedstock



IEA Bioenergy Task 42 Biorefinery Clasification System

Sustainable bio-feedstock

The bio-based industries in Europe are committed to a supply of feedstock that comes primarily from European sources and is produced and delivered sustainably.

Sources:

1. **Agri-based feedstock:** agriculture, agro-food sector and their residuals and side streams

2. **Forest-based feedstock:** forestry, forest-based sector and their residuals and side streams

3. **Aquatic feedstock:** aquatic organisms, fisheries and aquaculture sectors and their residues

4. **Bio-waste and CO_2**

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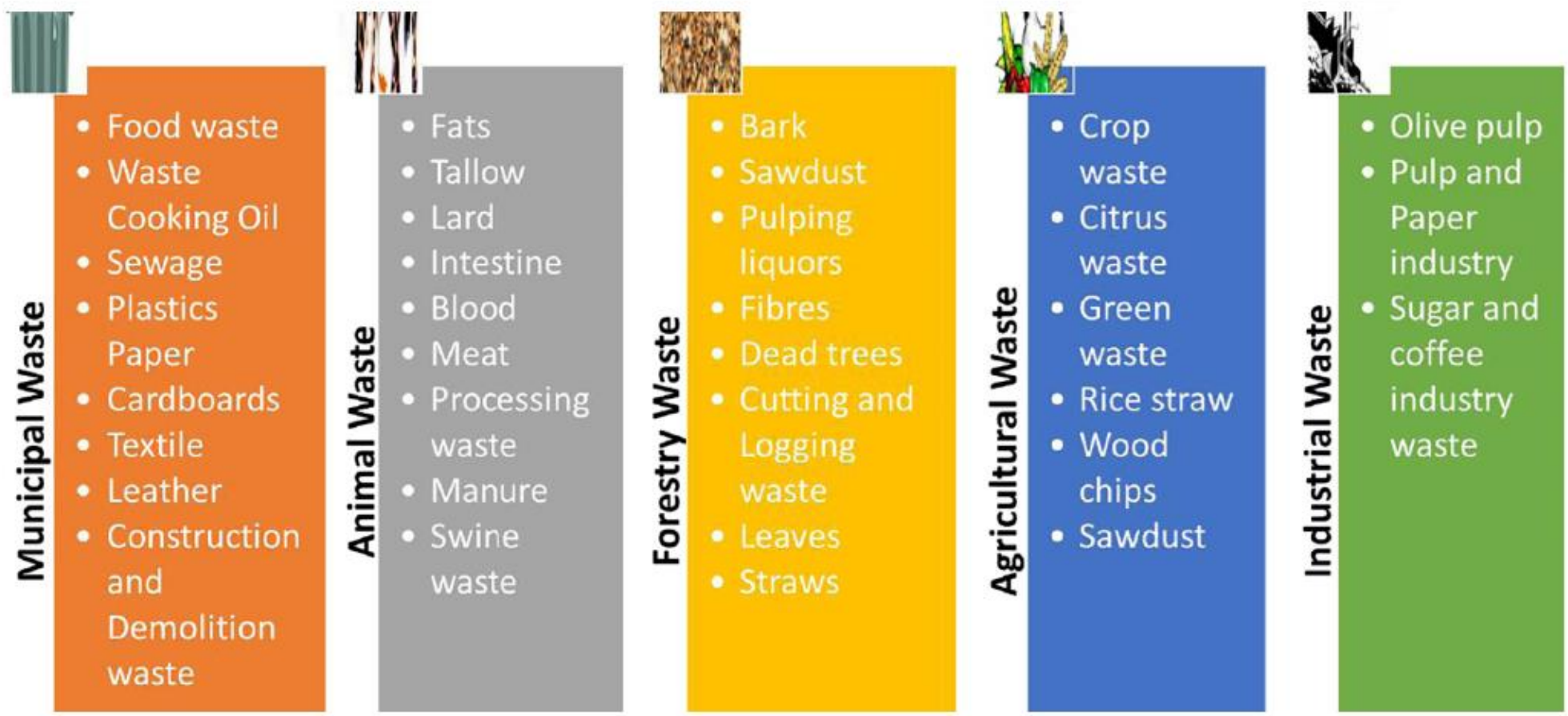
Waste sources suitable for biorefineries



Nizami, A. S., Rehan, M., Waqas, M., Naqvi, M., Ouda, O. K. M., Shahzad, K, Pant, D. (2017). Waste biorefineries: Enabling circular economies in developing countries. Bioresource Technology, 241, 1101-1117.

Integrated Biorefinery

A biorefinery should produce a spectrum of marketable products in order to maximise its ***economic sustainability*** and to aim for "***zero waste***". A variety of different biorefinery configurations are being developed. Biorefineries may be configured around a large volume product to maximise economies of scale and to allow the successful utilisation of all inputs with the integration of process operations.

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What does process integration mean?

- Process Integration is a systematic, holistic approach to process design and optimization, which exploits the interactions between different units in order to employ resources effectively and minimize costs.
- Process integration usually is applied to the design of new plants, but it also covers retrofit design.
- Among many others, pinch analyses are important tools, a methodology for minimising certain target properties
- Many issues are closely related to process integration such as process systems design, optimization, value engineering etc.

An Example of a Flow-Chart for Products from **Petroleum-based** Feedstocks

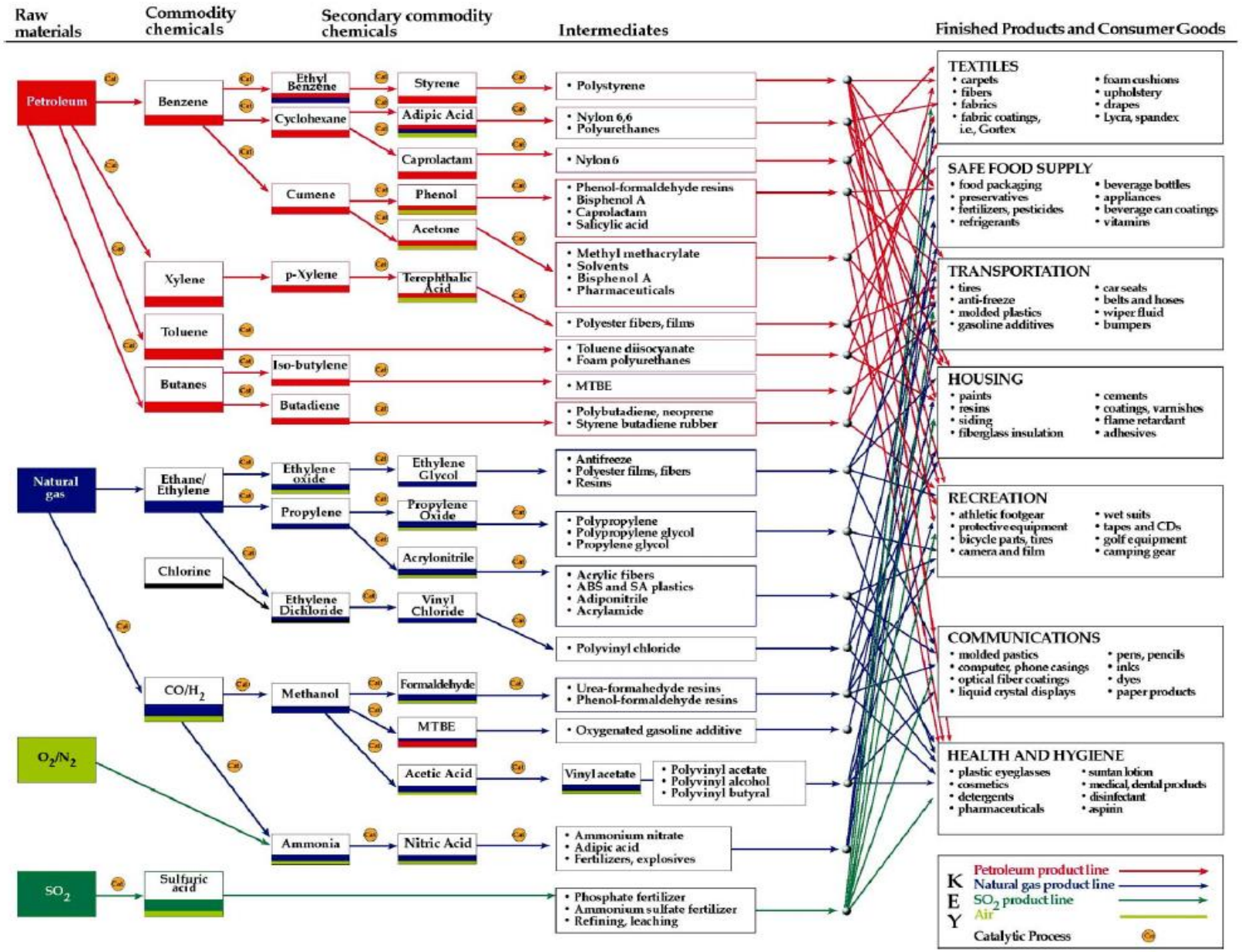
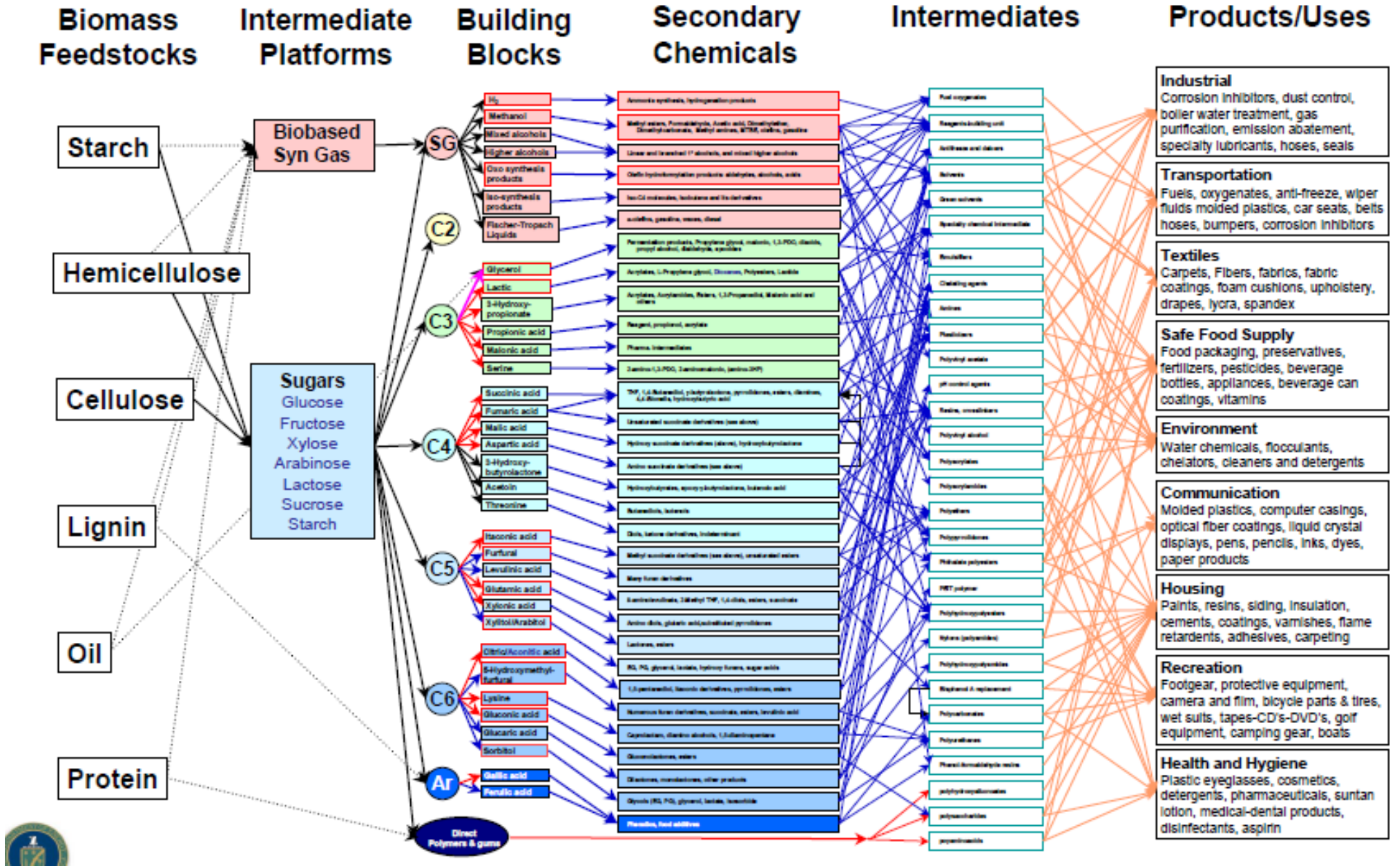
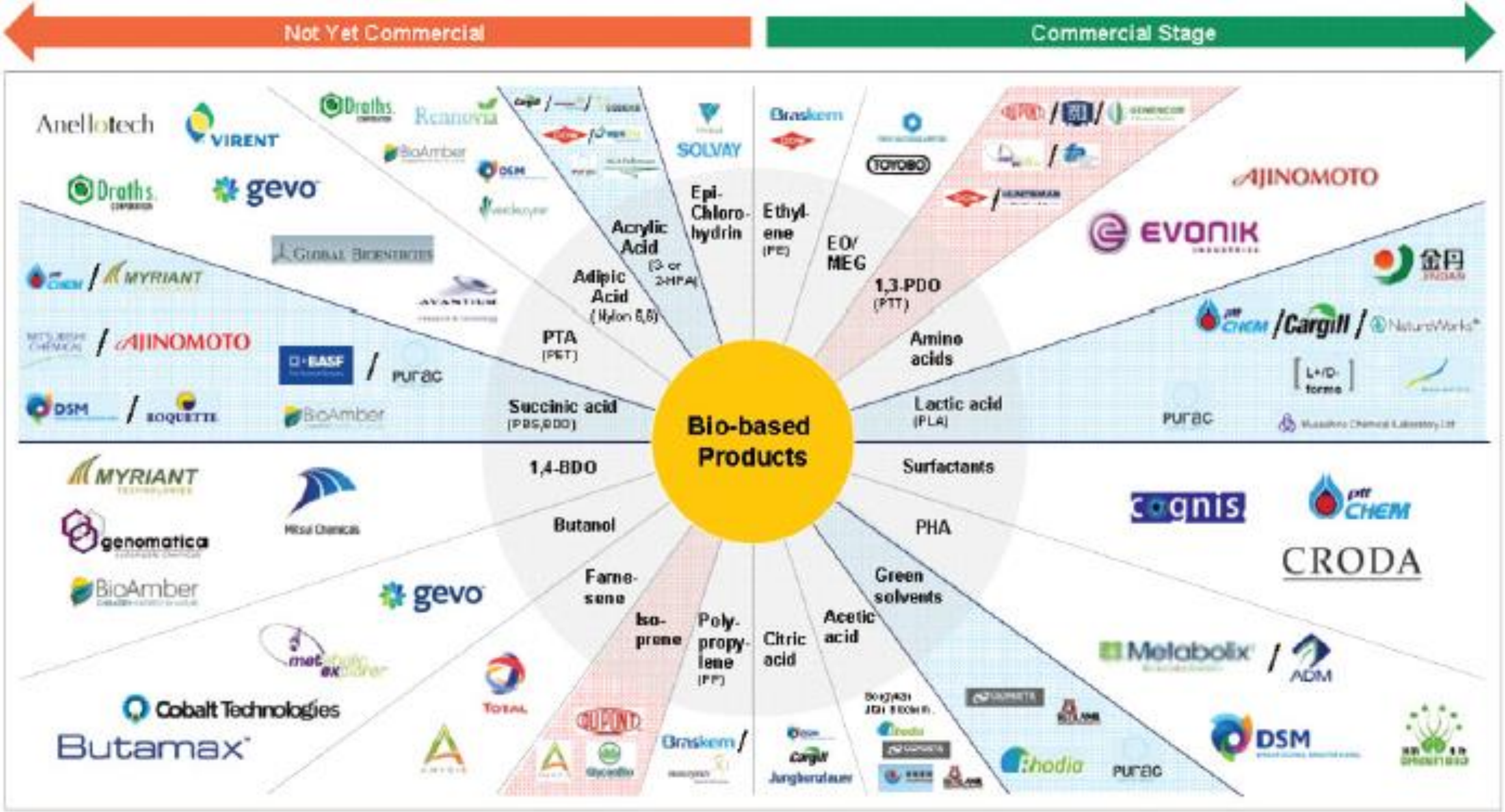


Figure 2 – An Example of a Flow-Chart for Products from Petroleum-based Feedstocks

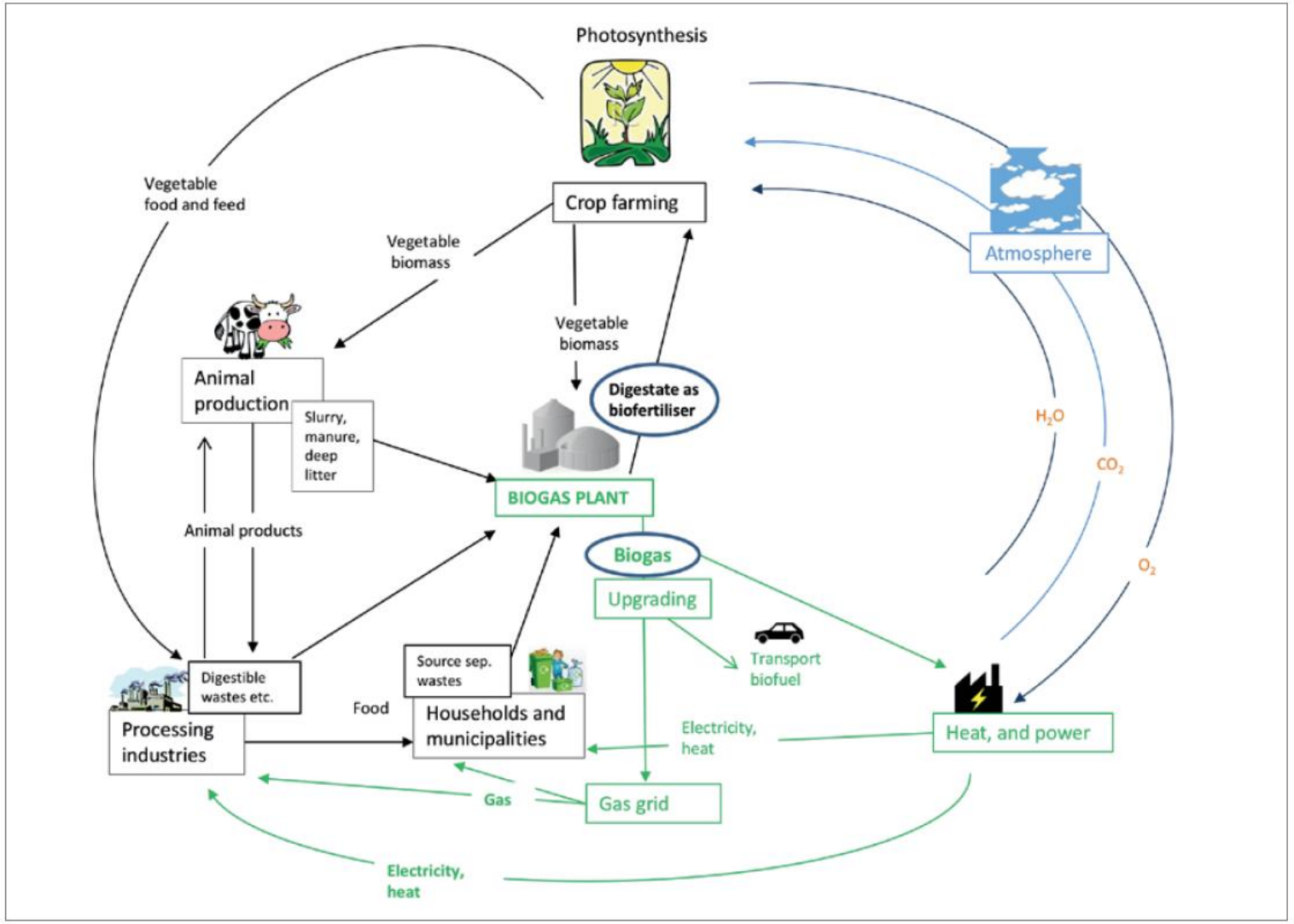
Analogous Model of a Bio-based Product Flow-chart for Biomass Feedstocks





Not Yet Commercial
Commercial Stage
Bio-based Products
Acrylic Acid (3- or 2-HPA)
Epi-Chloro-hydrin
Ethyl-ene (PE)
EO/ MEG
1,3-PDO (PTT)
Adipic Acid (Nylon 6,6)
PTA (PET)
Amino acids
Succinic acid (PBS,PDO)
Lactic acid (PLA)
L+/D-forms
1,4-BDO
Surfactants
Butanol
PHA
Farne-sene
Green solvents
Iso-prene
Poly-propy-lene (PP)
Citric acid
Acetic acid

Anaerobic Digestion - Biorefinery



An example of how a modern co-digestion biogas plant fits into the circular economy (Source: Al Seadi et al, 2018)

The biogas plant has a special place in a biorefinery as one of the major facilities for converting biomass to high-value or bulk products in the circular economy. Solutions involving biogas can be part of a dynamic innovation culture where novel materials may be produced, which have a substantially higher value per mass or energy content than biogas and digestate.

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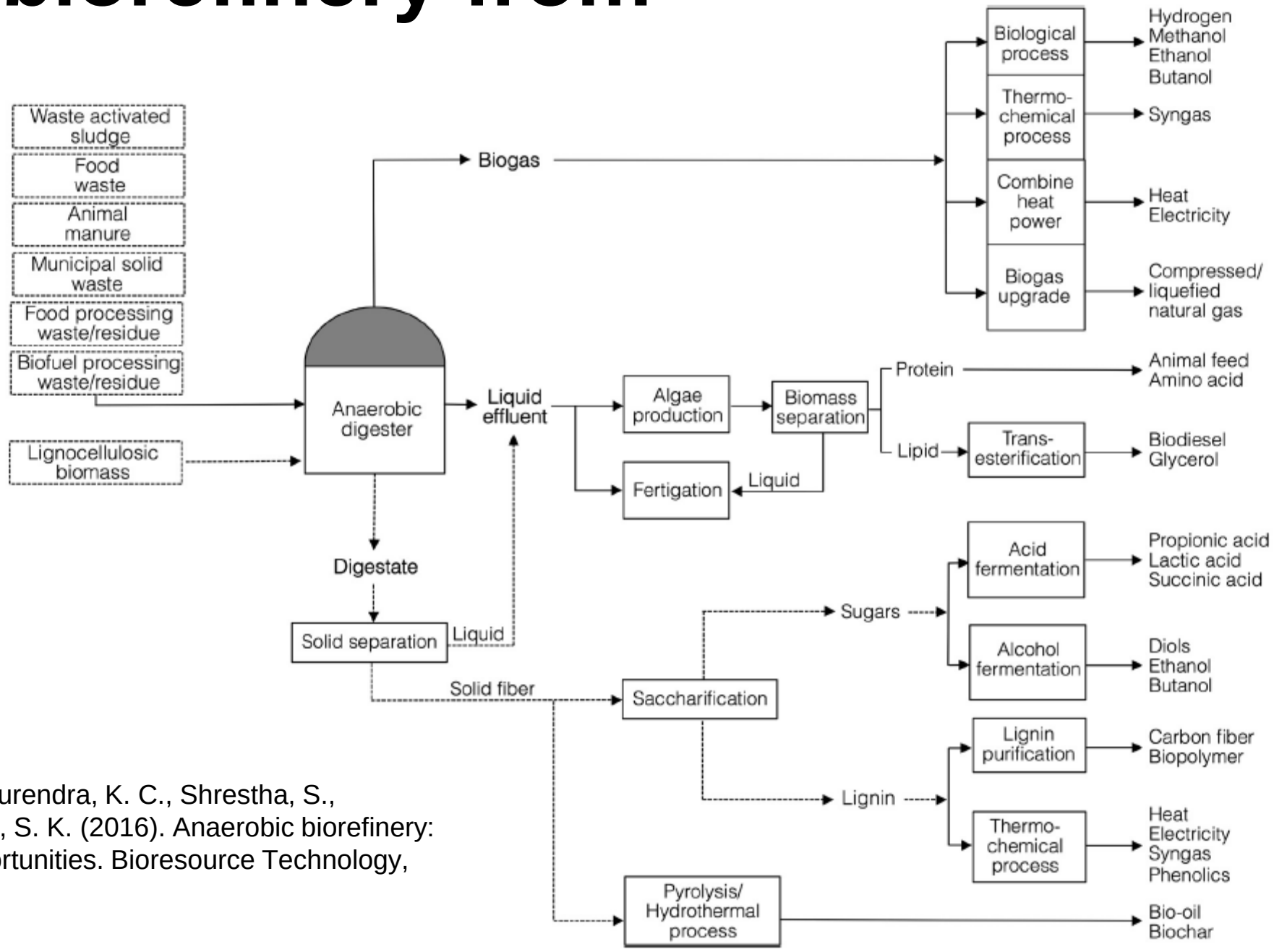
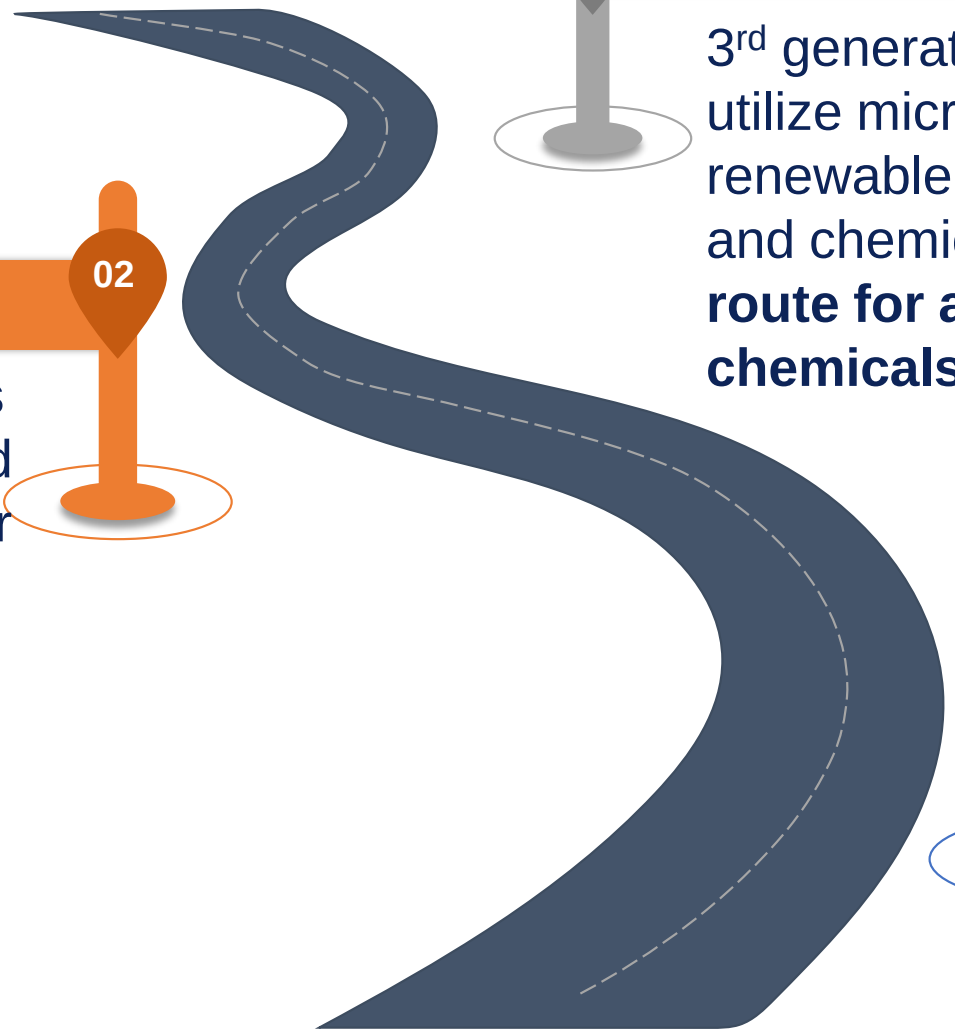
Anaerobic biorefinery from waste



Sawatdeenarunat, C., Nguyen, D., Surendra, K. C., Shrestha, S., Rajendran, K., Oechsner, H., Khanal, S. K. (2016). Anaerobic biorefinery: Current status, challenges, and opportunities. Bioresource Technology, 215, 304-313.

Evolution of biorefineries



03 **3rd generation**

3rd generation (3G) biorefineries aim to utilize microbial cell factories to convert renewable energies and CO_2 into fuels and chemicals, and hence represent a **route for assessing fuels and chemicals in a carbon-neutral manner**.

02 **2nd generation**

2nd generation biorefineries use **nonfood biomass** and conversion technologies for the production of bioenergy and biobased products.

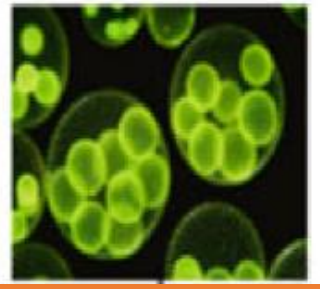
01 **1st generation**

1st generation biorefineries use **feedstocks** such as corn starch or sugar cane that are renewable, but **that also have feed/food uses.**

Biofuels evolution

Fermentation
Hydrolysis
↓
Biofuel
↓
Responsible for food v/s fuel debate

Biochemical
Thermochemical
↓
Biofuel
↓
Biomass to liquid fuel
Method employed



Biochemical
Thermochemical
↓
Biofuel
↓
Extensive downstream Processing required

Genetic Engineering
↓
Biofuel
↓
Higher lipid content
CO_2 capture
Economical in long run

1st Generation

2nd Generation

3rd Generation

4th Generation

Jaiswal, R., & Saxena, R. (2022). *Novel methods for biofuel production* doi:10.1007/978-981-19-2572-6_25

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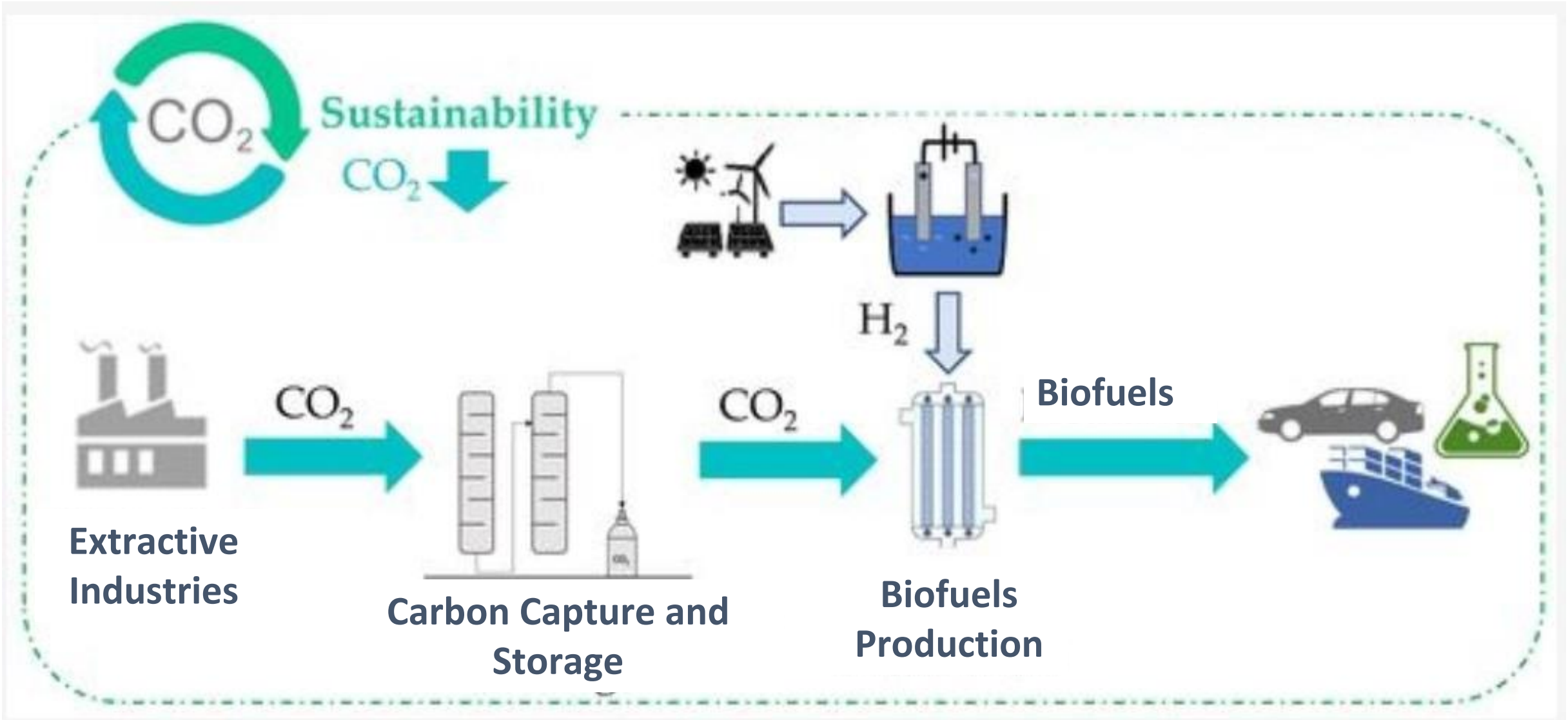
Carbon capture in novel biofuels production



Peppas, A.; Kottaridis, S.; Politi, C.; Angelopoulos, P.M. Carbon Capture Utilisation and Storage in Extractive Industries for Methanol Production. *Eng* **2023**, *4*, 480-506. https://doi.org/10.3390/

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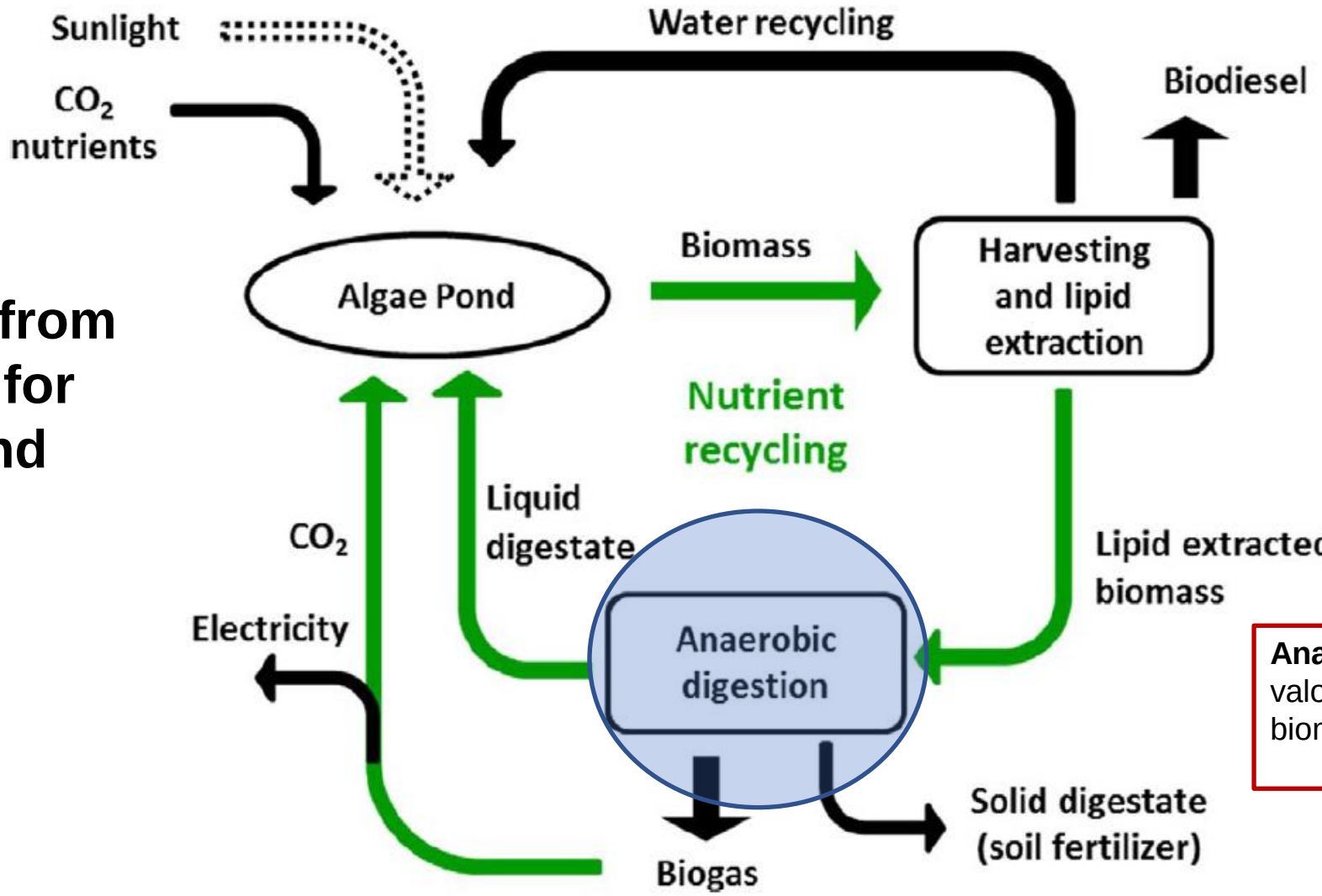
Carbon capture in novel biofuels production

Integrated biorefinery from microalgae for biodiesel and biogas production



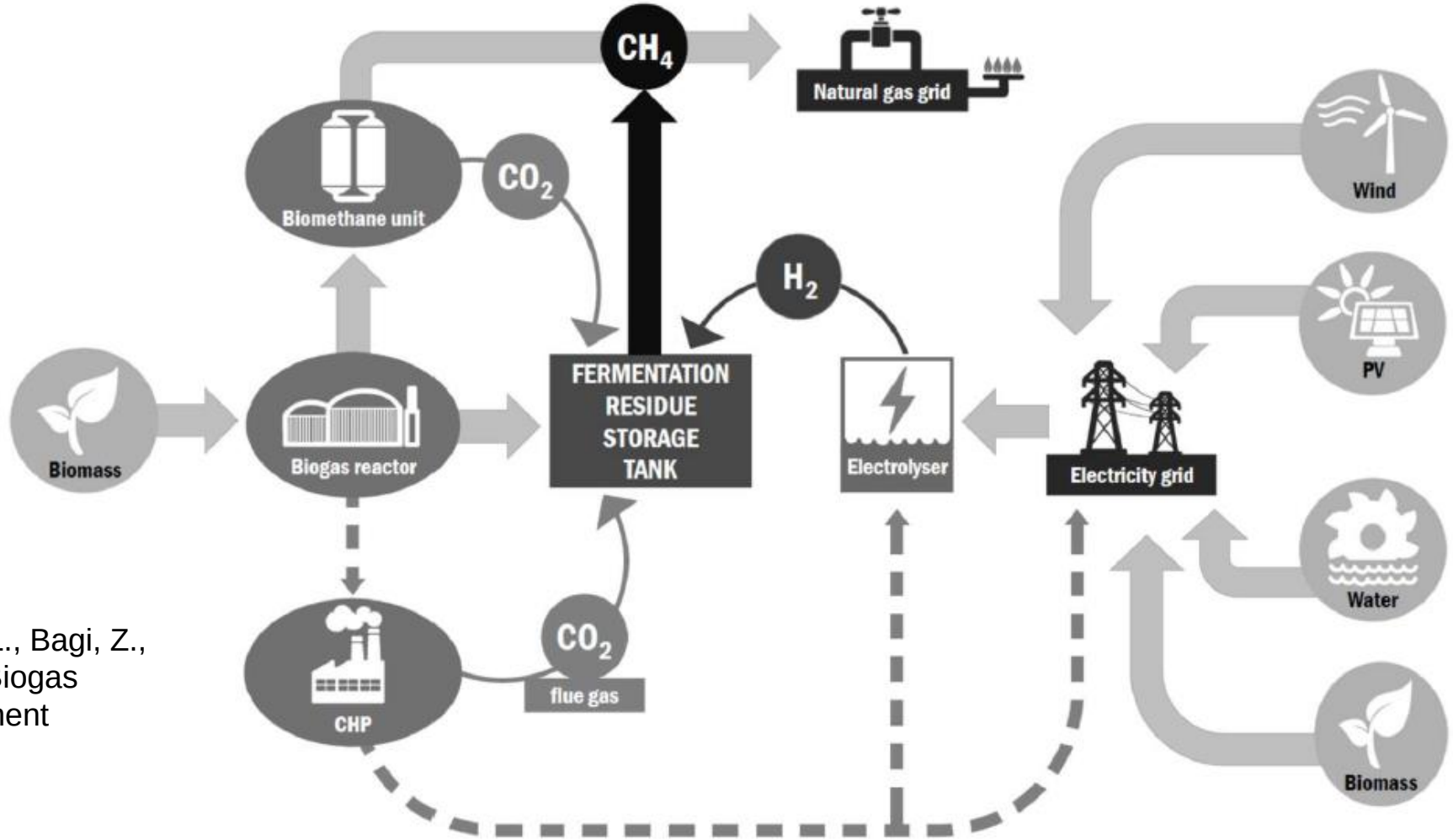
Anaerobic digestion for the valorization of lipid extracted biomass

González-González, L. M., Correa, D. F., Ryan, S., Jensen, P. D., Pratt, S., & Schenk, P. M. (2018). Integrated biodiesel and biogas production from microalgae: Towards a sustainable closed loop through nutrient recycling. Renewable and Sustainable Energy Reviews, 82, 1137-1148.

Carbon capture in novel biofuels production

Scheme involving the AD fermentation residue storage tank as bio-CH_4 reactor, which converts CO_2 from biogas or flue gas and H_2 from electrolysis by renewable electricity

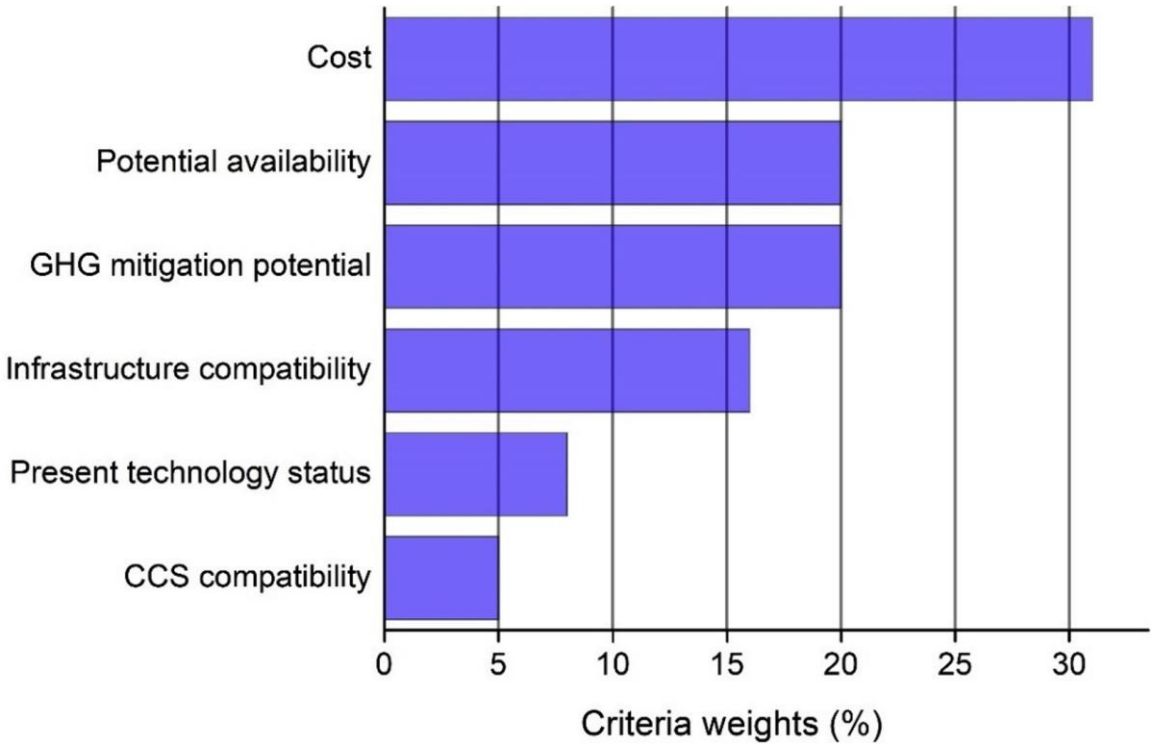
Digestate valorization: production of bio-CH_4



Szuhaj, M., Ács, N., Rákhely, G., Kovács, K.L., Bagi, Z., Power-to-Gas in Fed-Batch Reactors Using Biogas Digestate Catalyst, Comm. Appl. Biol. Sci, Ghent University, 82/4, 2017.

Challenges of biofuels production with carbon capture

- Cost
- Potential availability
- GHG mitigation potential
- Infrastructure compatibility
- Present technology status
- CCS compatibility



Mukherjee, A., Bruijnincx, P., & Junginger, M. (2020). A perspective on biofuels use and CCS for GHG mitigation in the marine sector. *IScience, 23*(11) doi:10.1016/j.isci.2020.101758

Thank you

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