Green Chemistry:
Obnovitelné suroviny pro chemický průmysl

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"…design of chemical products and processes to reduce or eliminate the use and generation of hazardous substances."

"Sustainability requires objectives at the molecular, product, process, and system levels."

Chem. Soc. Rev., ***2010***, *39, 301–312,*
Env. Sci. Tech. ***2003***, *37(5), 94A-101A*

THE HISTORY OF GREEN CHEMISTRY

- 1962: Rachel Carson, "Silent Spring", a book outlining the devastation that certain chemicals had on local ecosystems ➔ inspired modern environmental movement.
- 1969: US National Environmental Policy Act
- 1970: U.S. Environmental Protection Agency (EPA)
  - banned the use of DDT and other chemical pesticides.
- 1980s: the chemical industry and the EPA were focused **mainly on pollution clean-up** and obvious toxins
- 1990: The Pollution Prevention Act - regulatory policy change **from pollution control to pollution prevention** as the most effective strategy for these environmental issues.
- 1993: EC Chemistry Council, ***Chemistry for a Clean World***.
- 1998: Paul Anastas and John C. Warner, ***Green Chemistry: Theory and Practice***

https://www.acs.org/content/acs/en/greenchemistry/what-is-green-chemistry/history-of-green-chemistry.html

THE 12 PRINCIPLES OF GREEN CHEMISTRY

1. **Prevention**	It is better to prevent waste than to treat or clean up waste after it has been created
2. **Atom Economy**	Synthetic methods should be designed to maximize incorporation of all materials used in the process into the final product.
3. **Less Hazardous Chemical Synthesis**	Wherever practicable, synthetic methods should be designed to use and generate substances that possess little or no toxicity to human health and the environment
4. **Designing Safer Chemicals**	Chemical products should be designed to preserve efficacy of function while reducing toxicity.
5. **Safer Solvents and Auxiliaries**	The use of auxiliary substances (e.g., solvents, separation agents, etc.) should be made unnecessary wherever possible and, innocuous when used.
6. **Design for Energy Efficiency**	Energy requirements should be recognized for their environmental and economic impacts and should be minimized. Synthetic methods should be conducted at ambient temperature and pressure.

Green Chemistry: Theory and Practice, Oxford University Press: New York, 1998, p.30.

THE 12 PRINCIPLES OF GREEN CHEMISTRY

7. **Use of Renewable Feedstocks**	A raw material or feedstock should be renewable rather than depleting whenever technically and economically practicable.
8. **Reduce Derivatives**	Unnecessary derivatization (use of blocking groups, protection/deprotection, temporary modification of physical/chemical processes) should be minimized or avoided if possible, because such steps require additional reagents and can generate waste.
9. **Catalysis**	Catalytic reagents (as selective as possible) are superior to stoichiometric reagents.
10. **Design for Degradation**	Chemical products should be designed so that at the end of their function they break down into innocuous degradation products and do not persist in the environment.
11. **Real-time Analysis for Pollution Prevention**	Analytical methodologies need to be further developed to allow for real-time, in-process monitoring and control prior to the formation of hazardous substances.
12. **Inherently Safer Chemicals for Accident Prevention**	Substances and the form of a substance used in a chemical process should be chosen to minimize the potential for chemical accidents, including releases, explosions, and fire.

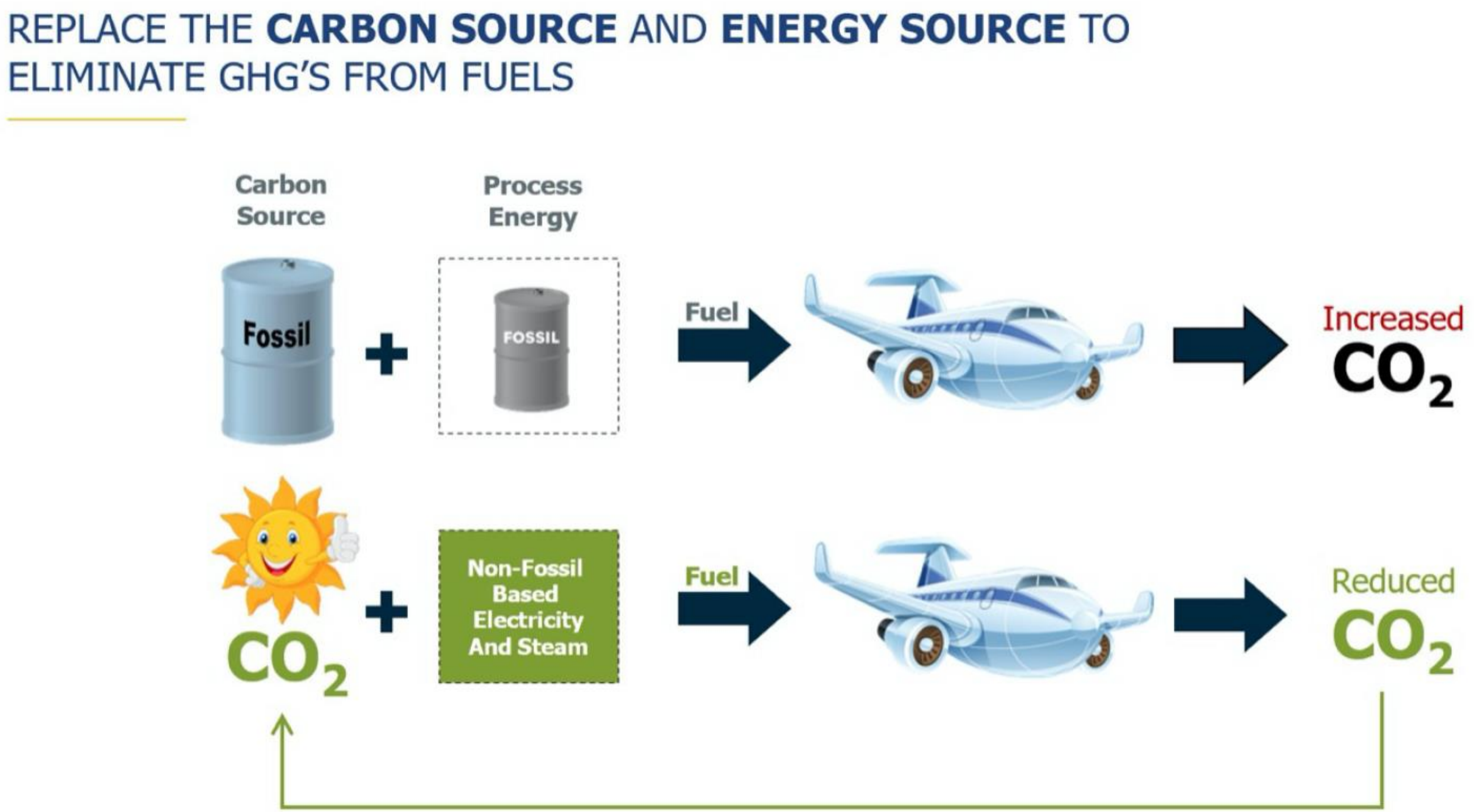
Green Chemistry: Theory and Practice, Oxford University Press: New York, 1998, p.30.

12 PRINCIPLES OF GREEN ENGINEERING

GREENCATS CatalystsAnalysisTestingSynthesis

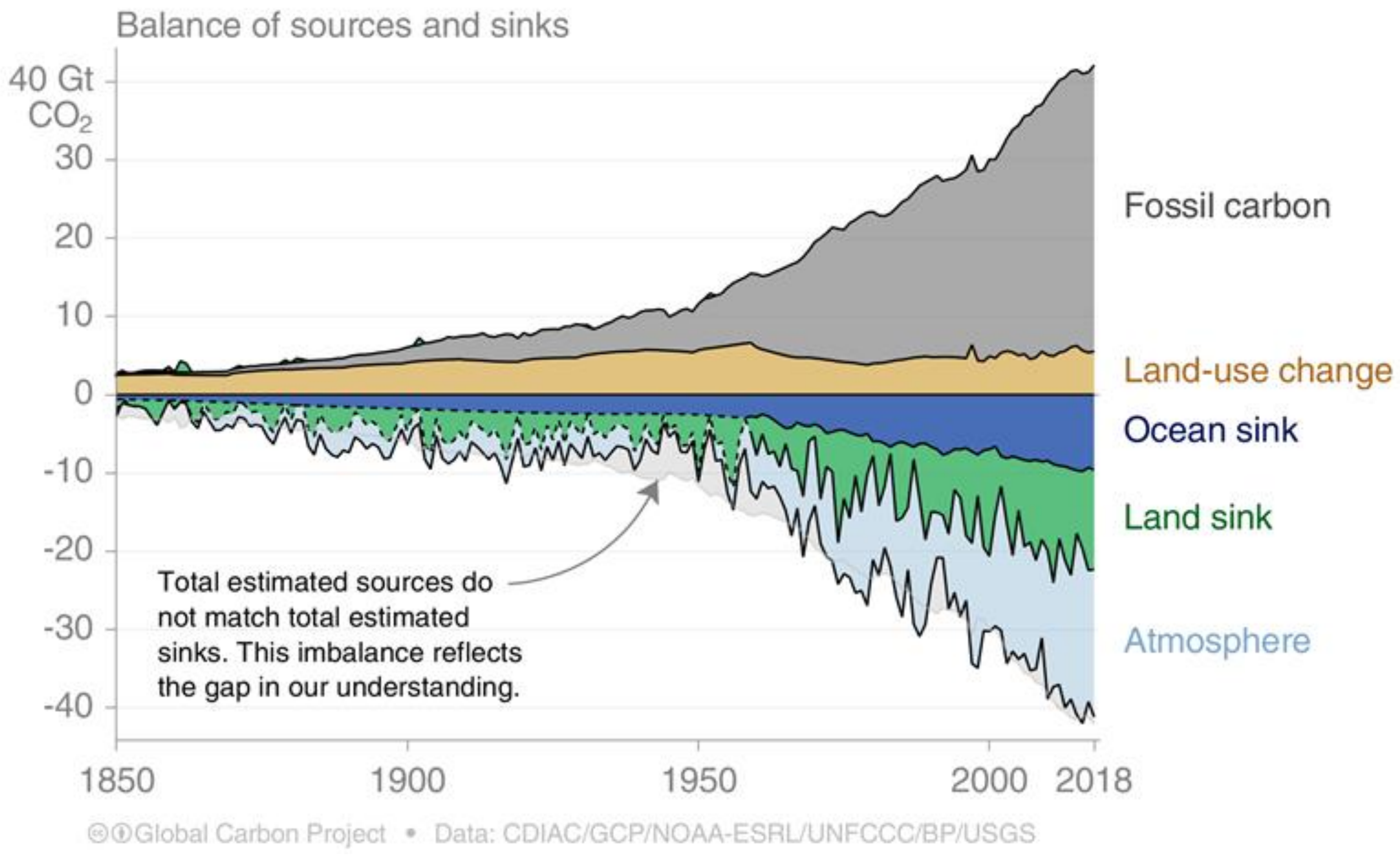
1. **Inherent Rather Than Circumstantial**	Designers need to strive to ensure that all materials and energy inputs and outputs are as inherently nonhazardous as possible.
2. **Prevention Instead of Treatment**	It is better to prevent waste than to treat or clean up waste after it is formed.
3. **Design for Separation**	Separation and purification operations should be designed to minimize energy consumption and materials use.
4. **Maximize Efficiency**	Products, processes, and systems should be designed to maximize mass, energy, space, and time efficiency.
5. **Output-Pulled Versus Input-Pushed**	Products, processes, and systems should be “output-pulled” rather than “input-pushed” through the use of energy and materials.
6. **Conserve Complexity**	Embedded entropy and complexity must be viewed as an investment when making design choices on recycle, reuse, or beneficial disposition.
7. **Durability Rather Than Immortality**	Targeted durability, not immortality, should be a design goal.
8. **Meet Need, Minimize Excess**	Design for unnecessary capacity or capability (e.g., “one size fits all”) solutions should be considered a design flaw.
9. **Minimize Material Diversity**	Material diversity in multicomponent products should be minimized to promote disassembly and value retention.
10. **Integrate Material and Energy Flows**	Design of products, processes, and systems must include integration and interconnectivity with available energy and materials flows.
11. **Design for Commercial “Afterlife”**	Products, processes, and systems should be designed for performance in a commercial “afterlife.”
12. **Renewable Rather Than Depleting**	Material and energy inputs should be renewable rather than depleting.

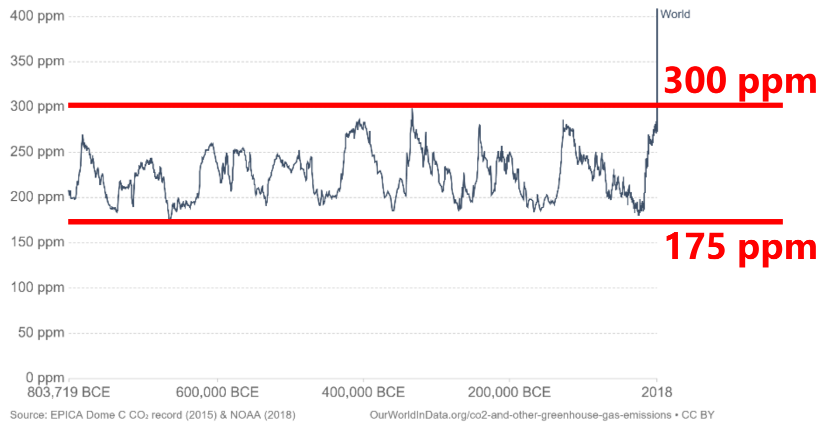
Env. Sci. Tech. ***2003***, *37(5), 94A-101A.*

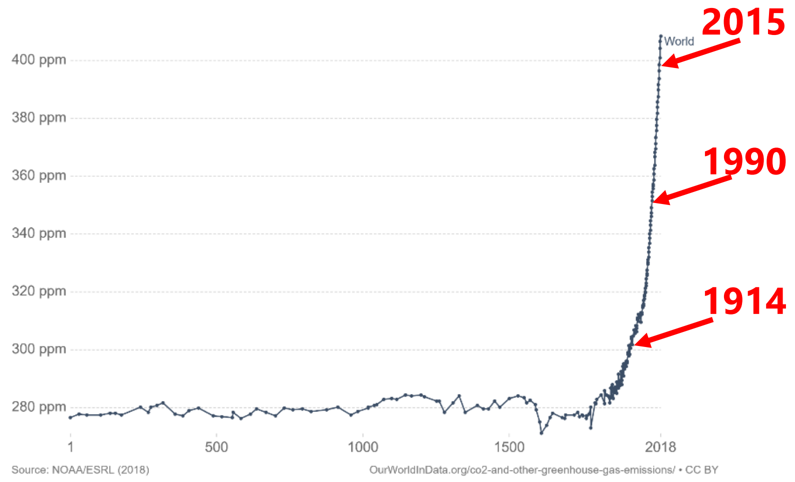


biofuelsdigest.com/bdigest/2020/05/25/3-things-that-need-to-happen-for-sustainable-aviation-fuel-totake-off/

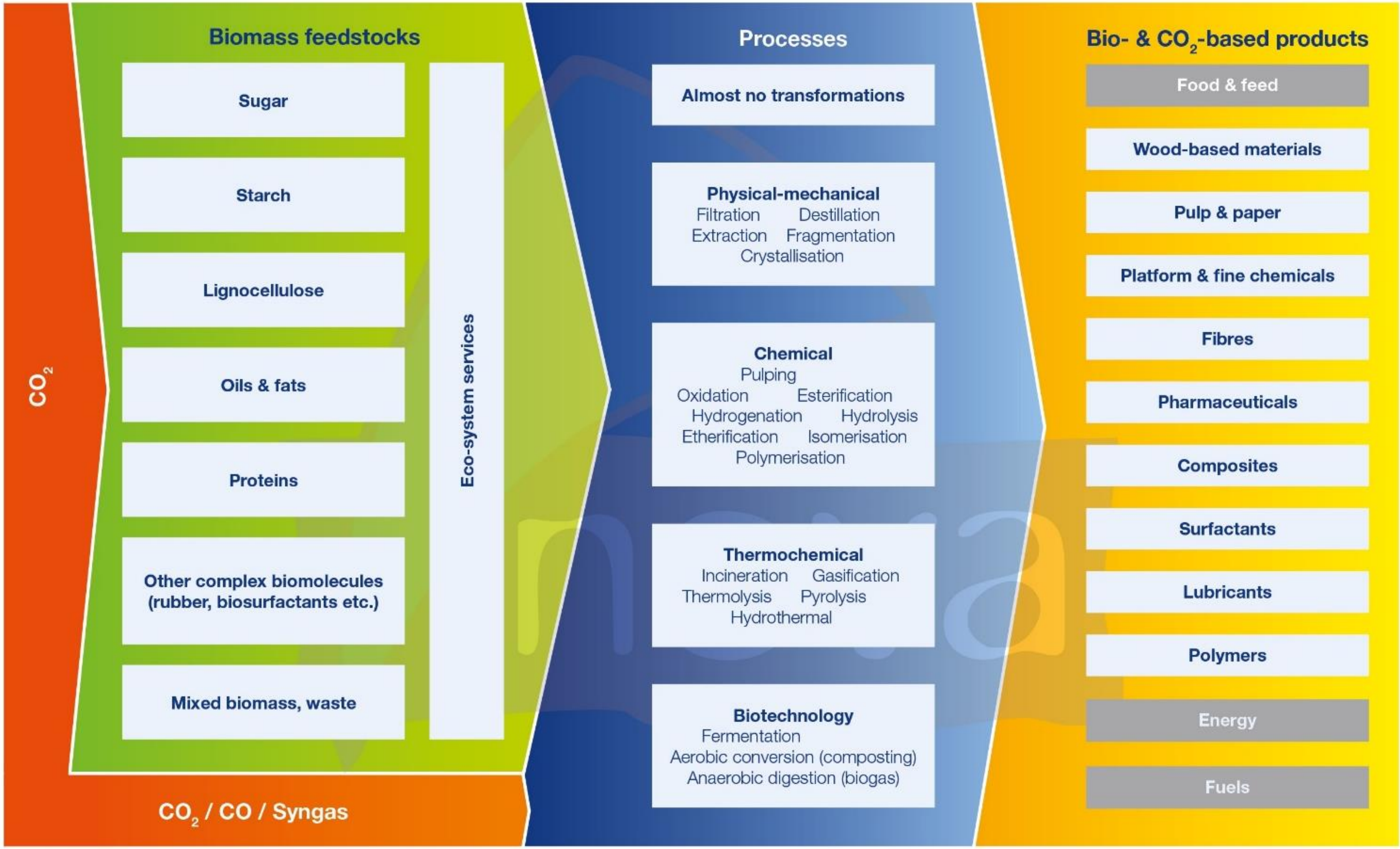
WHY TO REDUCE GHG EMISSIONS?





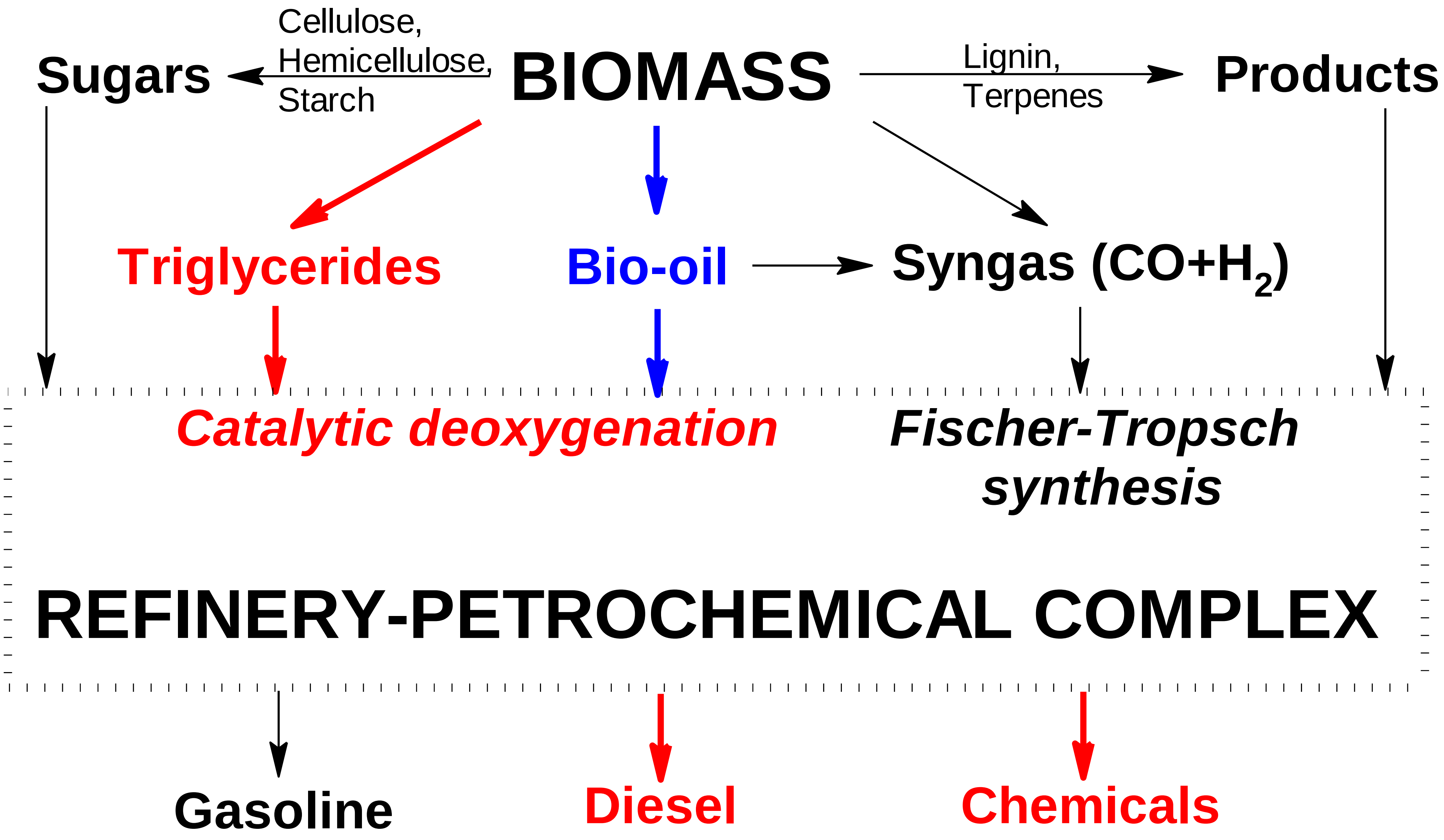


https://ourworldindata.org/

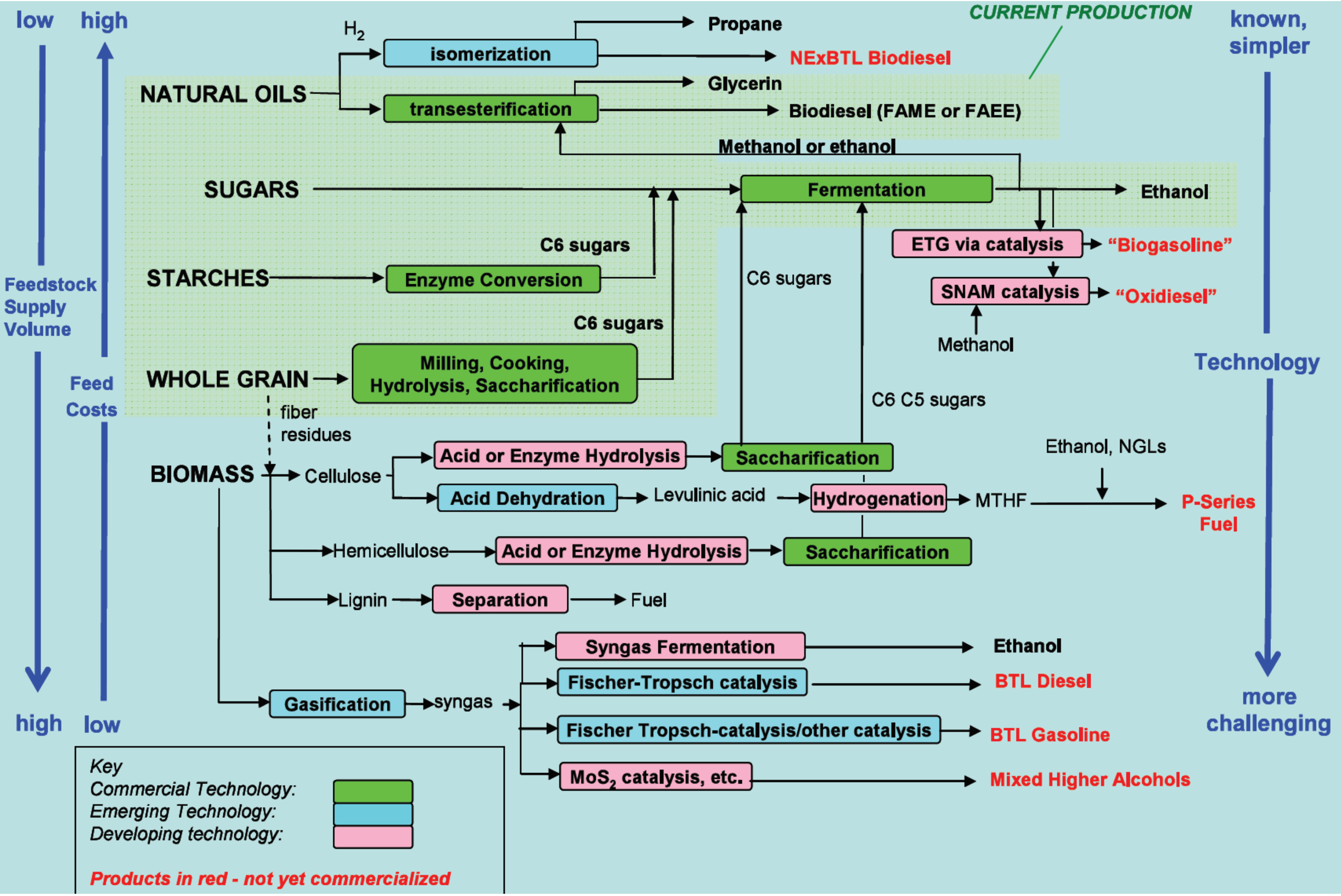


CO_2
Biomass feedstocks
Sugar
Starch
Lignocellulose
Oils & fats
Proteins
Other complex biomolecules (rubber, biosurfactants etc.)
Mixed biomass, waste
Eco-system services
CO_2 / CO / Syngas
Processes
Almost no transformations
Physical-mechanical
Filtration Destillation
Extraction Fragmentation
Crystallisation
Chemical
Pulping
Oxidation Esterification
Hydrogenation Hydrolysis
Etherification Isomerisation
Polymerisation
Thermochemical
Incineration Gasification
Thermolysis Pyrolysis
Hydrothermal
Biotechnology
Fermentation
Aerobic conversion (composting)
Anaerobic digestion (biogas)
Bio- & CO_2-based products
Food & feed
Wood-based materials
Pulp & paper
Platform & fine chemicals
Fibres
Pharmaceuticals
Composites
Surfactants
Lubricants
Polymers
Energy
Fuels

CONCEPTUAL BIOMASS VALORIZATION



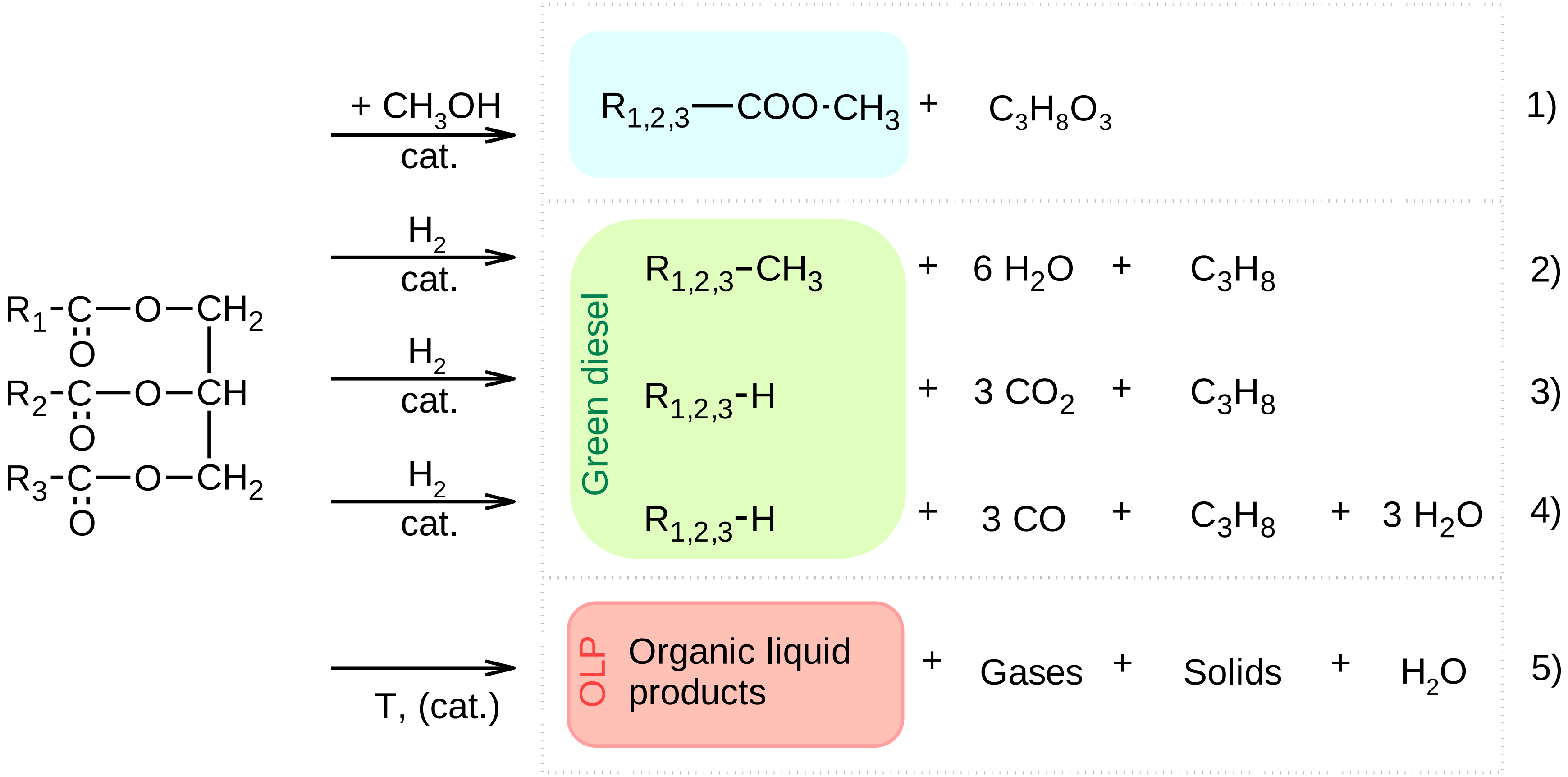
BIOMASS UPGRADING ALTERNATIVES



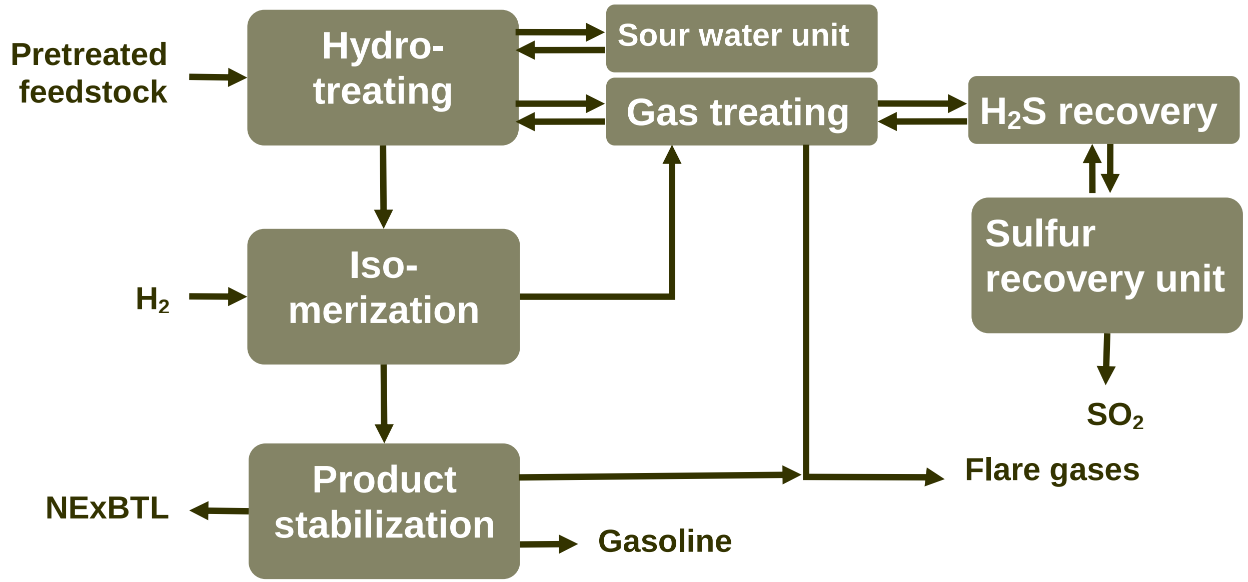
Nexant Chemsystems

RENEWABLES TO FUELS AND CHEMICALS: SOME EXAMPLES

TRIGLYCERIDES TO HYDROCARBONS: HVO & SAF



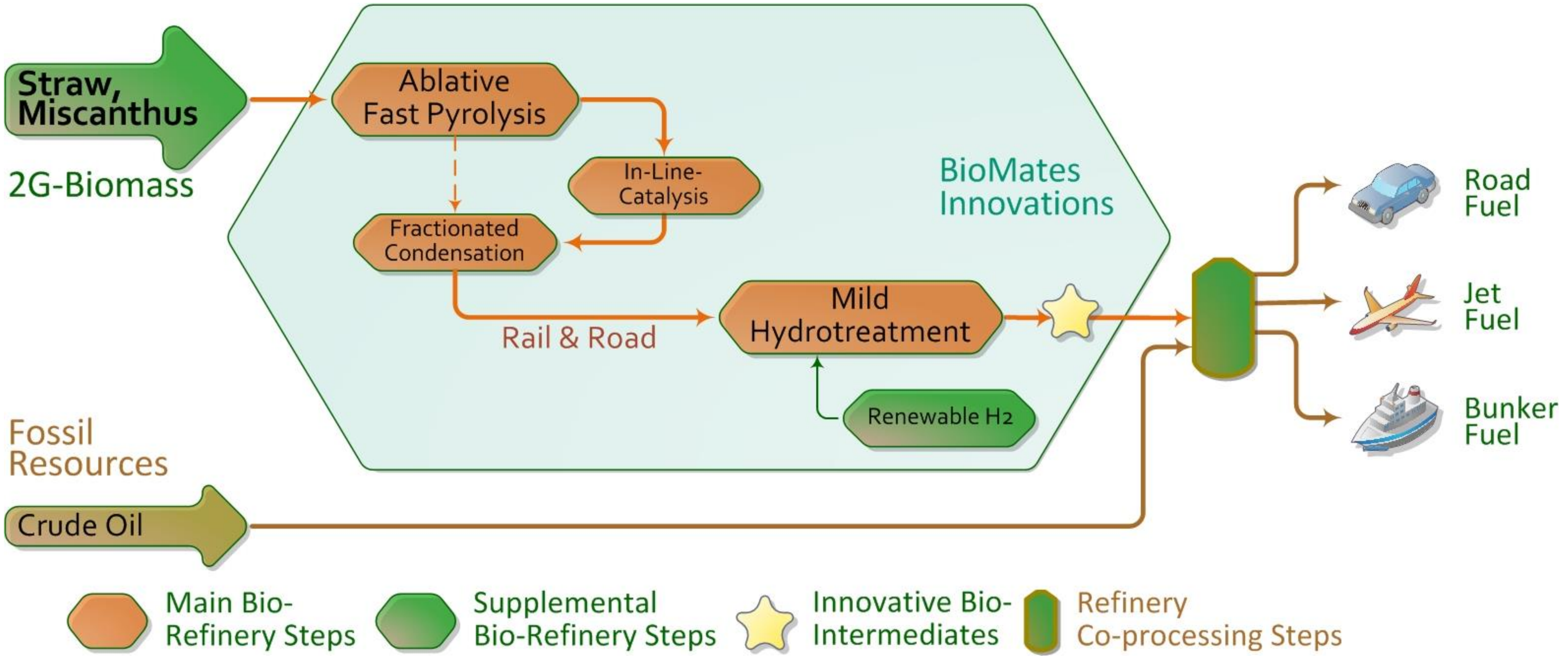
Kubičková, I.; Kubička, D. Waste Biomass. Valor. 2010, 1, 293-308.

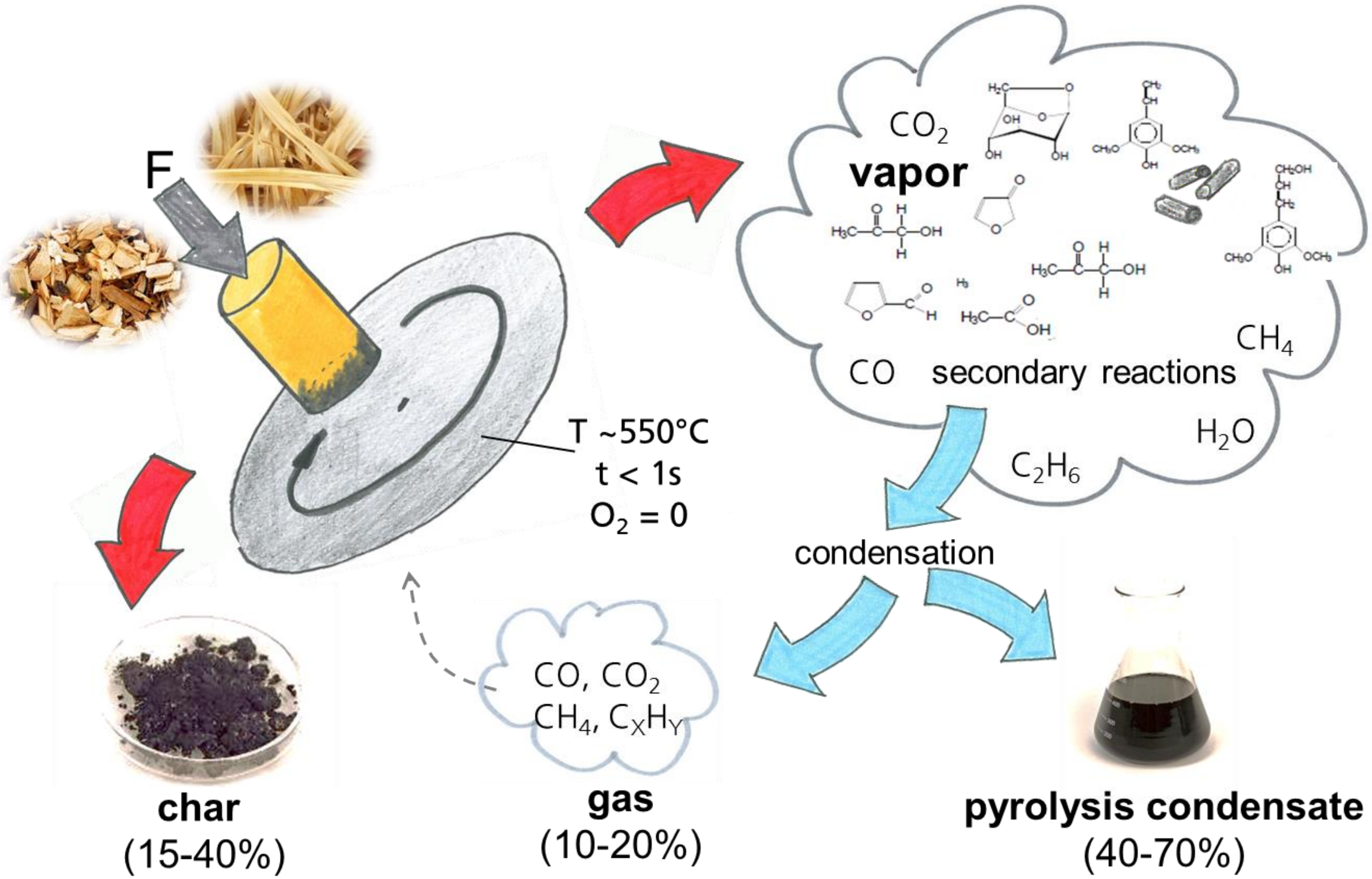


Technology	Place	Capacity, kt/a	Start-up
NexBTL (NesteOil)	Finland Finland Singapore Netherlands	210 210 1000 1000	2007 2009 2010 2011
Ecofining (UOP/ENI)	USA USA Italy, Venice Italy, Gela	500 (900) 125 360 (560) 750	2013 (in progress) operated 2014 (2021) 2018
Vegan (Axens/IFP)	La Mede, France	500	2018
BioVerno (UPM)	Lapeenranta, Finland	100	2015

NexBTL process (Hodge, 2006)

BIOMASS TO BIOOIL TO BIOFUELS: BIOMATES





("bio-oil")

In-line catalysis

IH2 TECHNOLOGY – GTI & SHELL

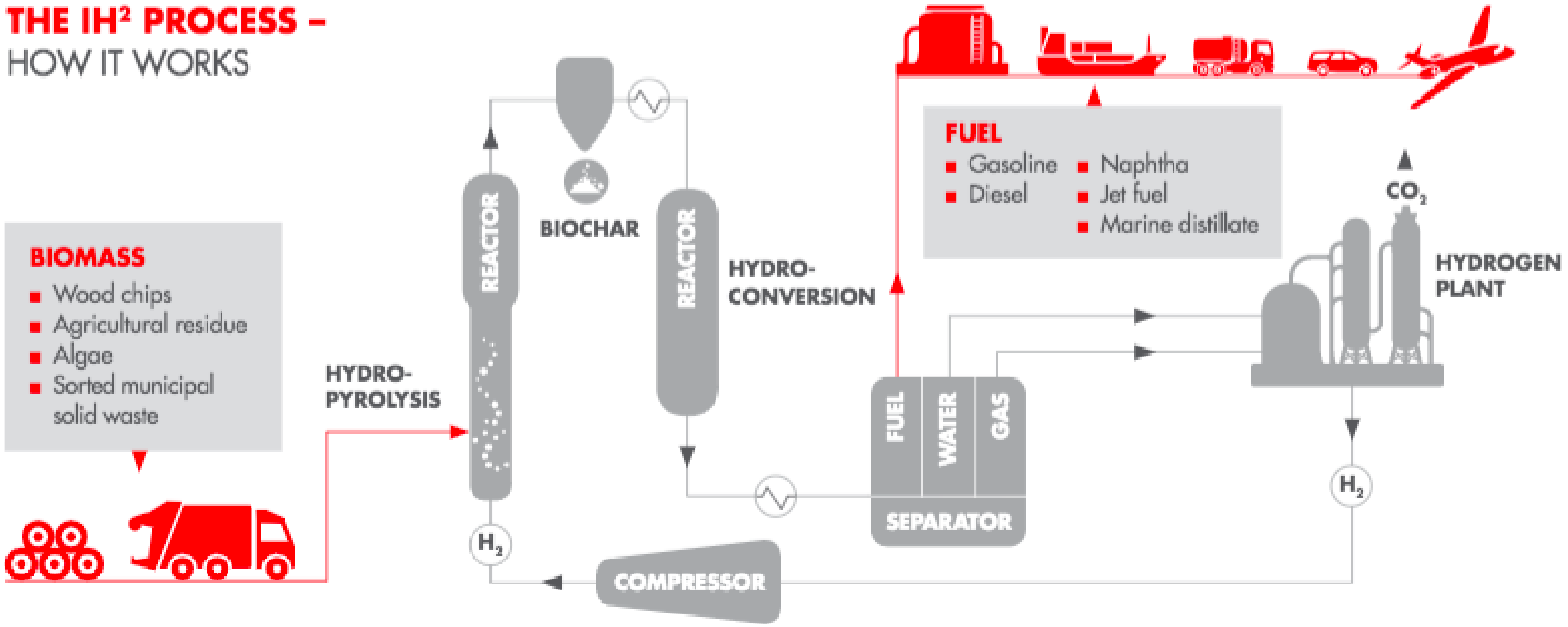
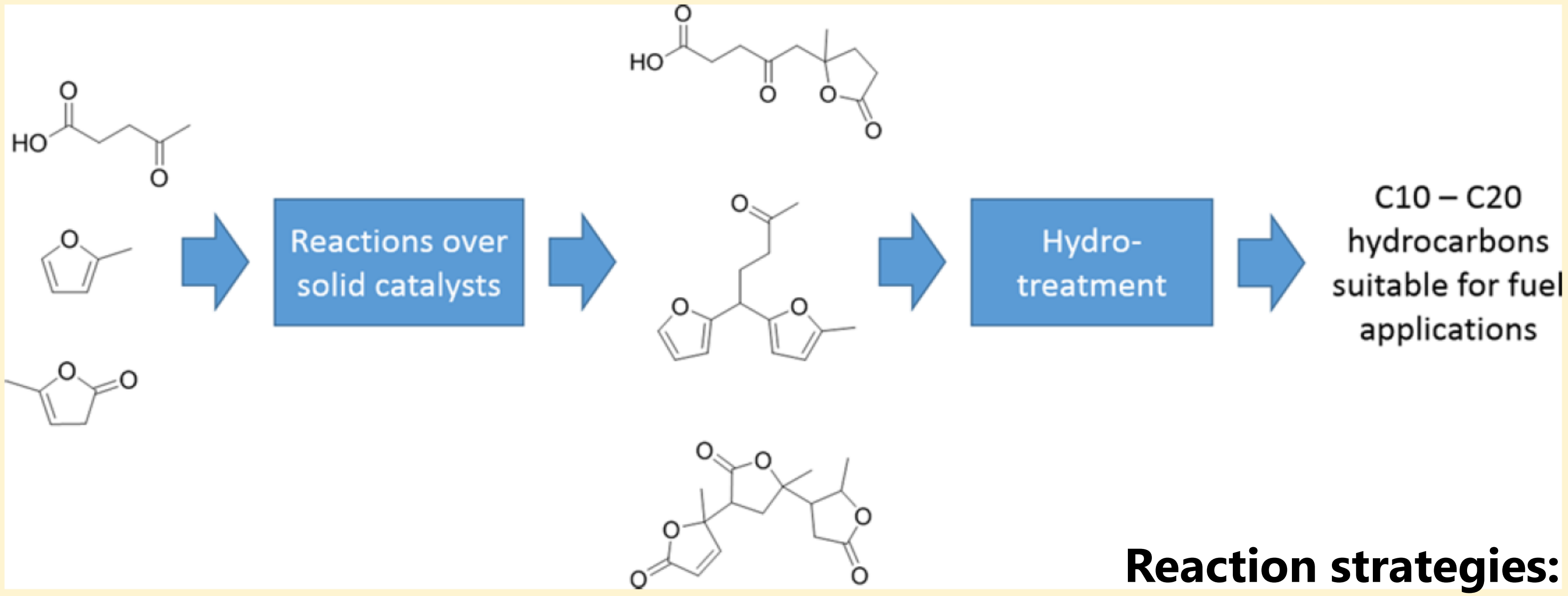


Figure 1: The IH² process.

*IH² is a registered trademark of the Gas Technology Institute.

https://catalysts.shell.com/en/ih2-technology-fact-sheet

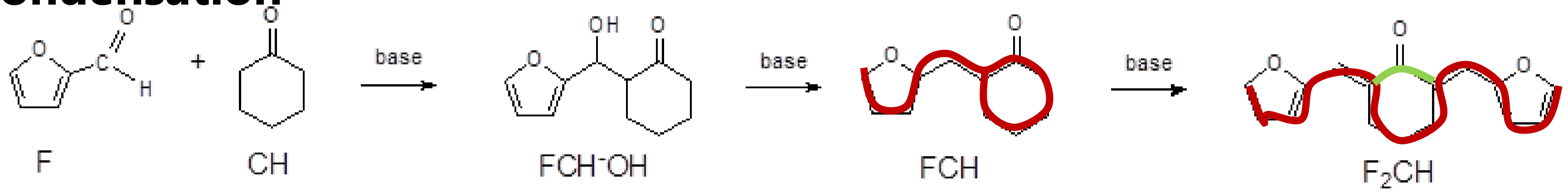


Reaction strategies:

- Aldol condensation / Condensation
- Guerbet reaction
- Ketonization
- Oligomerization
- Alkylation

Ind. Eng. Chem. Res. 2017, 56, 13356-13366

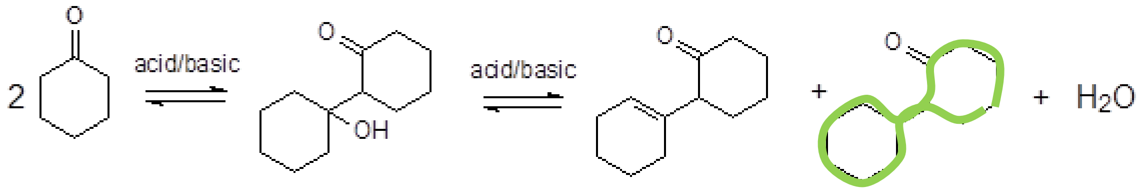
Aldol condensation



cyclic-C11

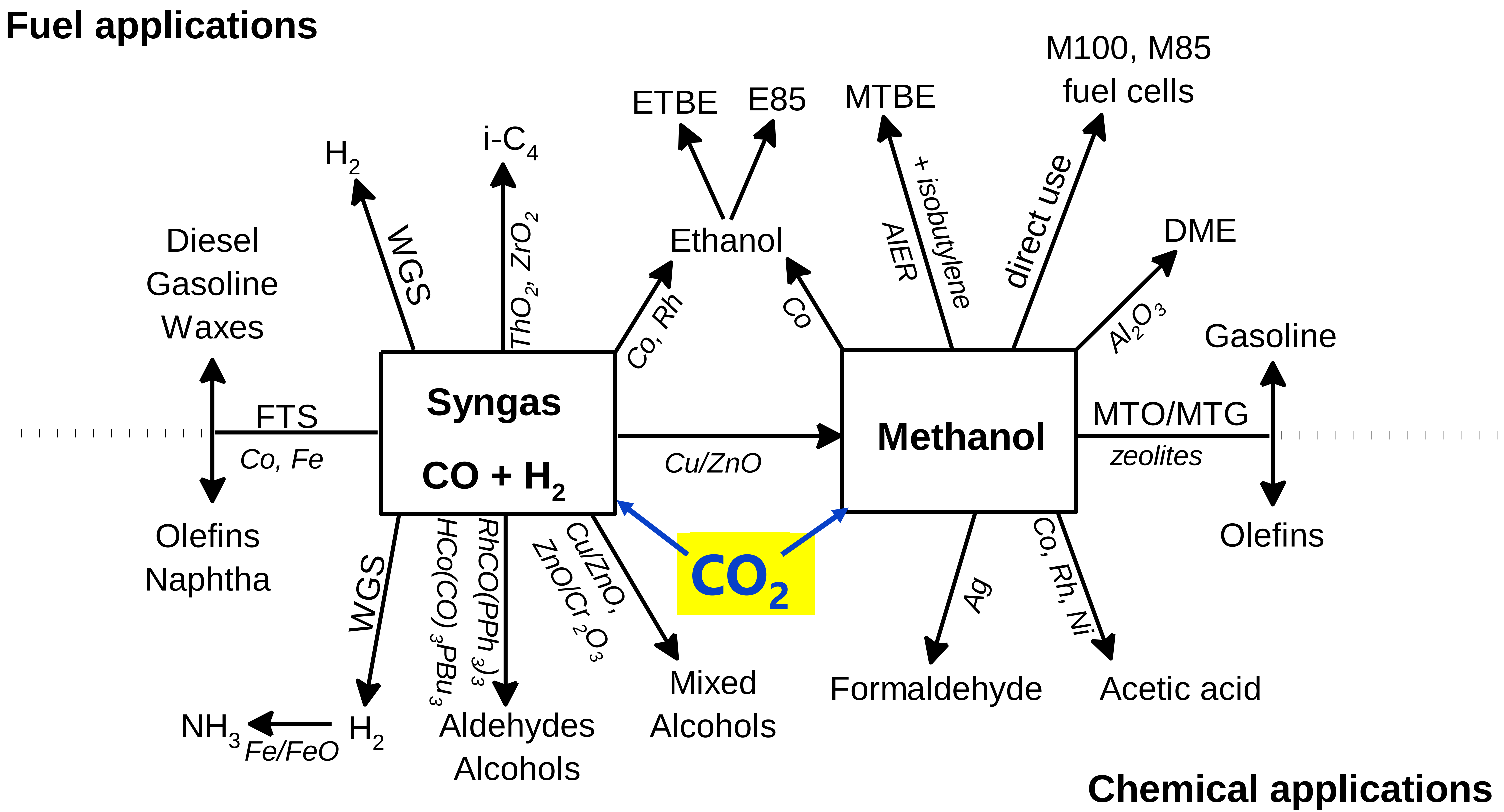
cyclic-C16

Self condensation



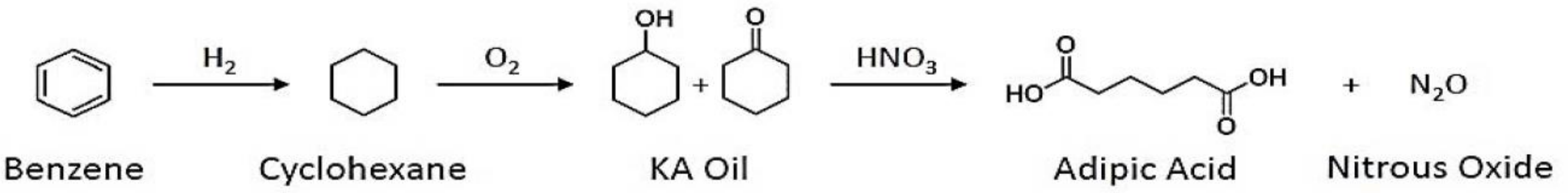
cyclic-C12

BIOMASS TO SYNGAS TO ANYTHING

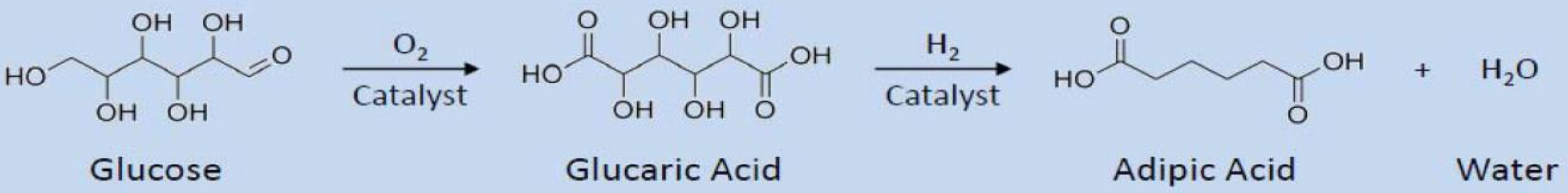


BIOMASS TO ADIPIC ACID: TOWARDS NYLON 6,6

Classical petrochemical route



Rennovia bio-based route



2 heterogeneous catalyst process steps:

1. Aerobic oxidation of glucose → glucaric acid
2. Hydrodeoxygenation of glucaric acid → adipic acid

Source: Tecnon OrbiChem

CONCLUSIONS AND OUTLOOK

- “Bright future” for advanced biofuels
- However, not everything that „looks green is green”

  - No “silver bullet” solutions
  - Catalysis to play a pivotal role

    - “Technology” & “Sustainability” to be addressed simultaneously
    - Thermochemical & biochemical approaches to be combined

- **NCK Chemie pro uhlíkově neutrální ekonomiku**
  - „Obnovitelná chemie“
  - „Cirkulární chemie“

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EUROPA CAT 2023

15th European Congress on Catalysis

August 27 – September 1, 2023
Prague, Czech Republic

SAVE THE DATE

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Catalysis: A pillar of modern society