Actions for Chemicals Production from non-fossil raw materials. Is CO_2 hydrogenation the only pathway ?

10.6.2025

TRANSFORMATIVE NON-FOSSIL FUEL AND CHEMICAL SOLUTIONS

Pre-Midsummer Party: Fueling Energy Security with Renewables

Location: Rue Jacques de Lalaing 33, 1040 Brussels, Belgium

Tuomas Koiranen, professor of chemical process systems engineering

Kristian Melin, professor of process and plant design for biorefineries

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CONTENTS

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PROFESSOR OF CHEMICAL PROCESS SYSTEMS ENGINEERING

TUOMAS KOIRANEN

- Process design in chemical and process industries
- Power-to-X processes and organic syntheses in P2X
- Fluid flows modeling and new efficient solutions in process equipment

Also: Process Intensification Working Group Member of European Federation of Chemical Engineers (EFCE)

Connect: tuomas.koiranen@lut.fi, LinkedIn

ASSOCIATE PROFESSOR OF PROCESS AND PLANT DESIGN FOR BIOREFINERIES

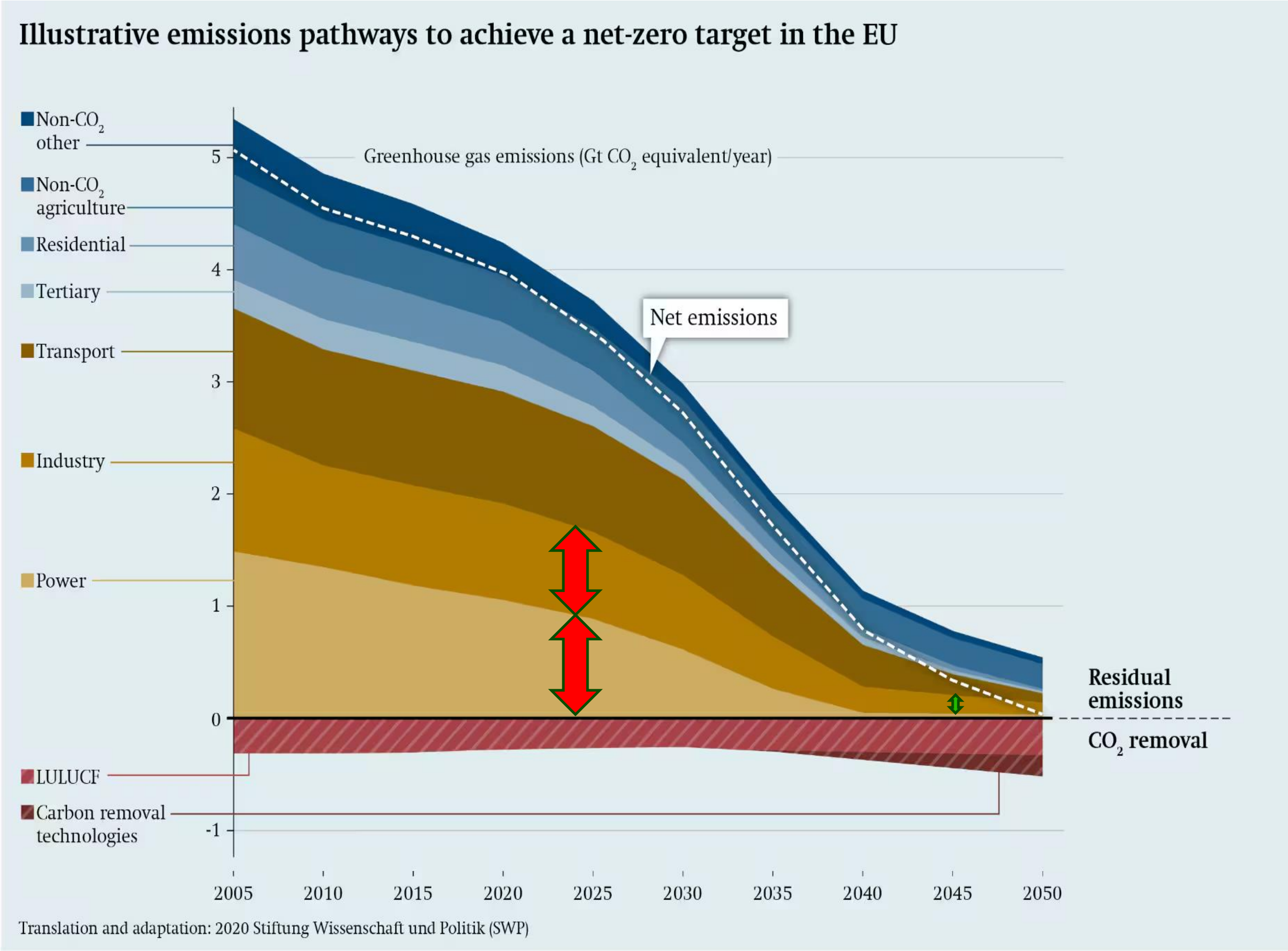
KRISTIAN MELIN

- Process design in biorefineries
- Conversion of lignocellulosic biomass into fuels and chemicals
- Merging of hydrogen economy and bioeconomy
- Power-to-X products, such as fossil-free, biodegradable plastic

Also: Collaboration with ANDRITZ Oy in fibre technology research

Connect: kristian.melin@lut.fi, LinkedIn

GREENHOUSE GAS EMISSIONS REDUCTIONS IN EU



- HOW TO REDUCE CO_2 emissions by 2045:
  - Roughly 1 Gt CO_2 –eqv from Power sector?
  - About 0.5 Gt CO_2 –eqv from Industry sector?
  - Transport sector 0.7 Gt CO_2-eqv. reduction
- CO_2 capture from Point sources (10-20 mol-%) is

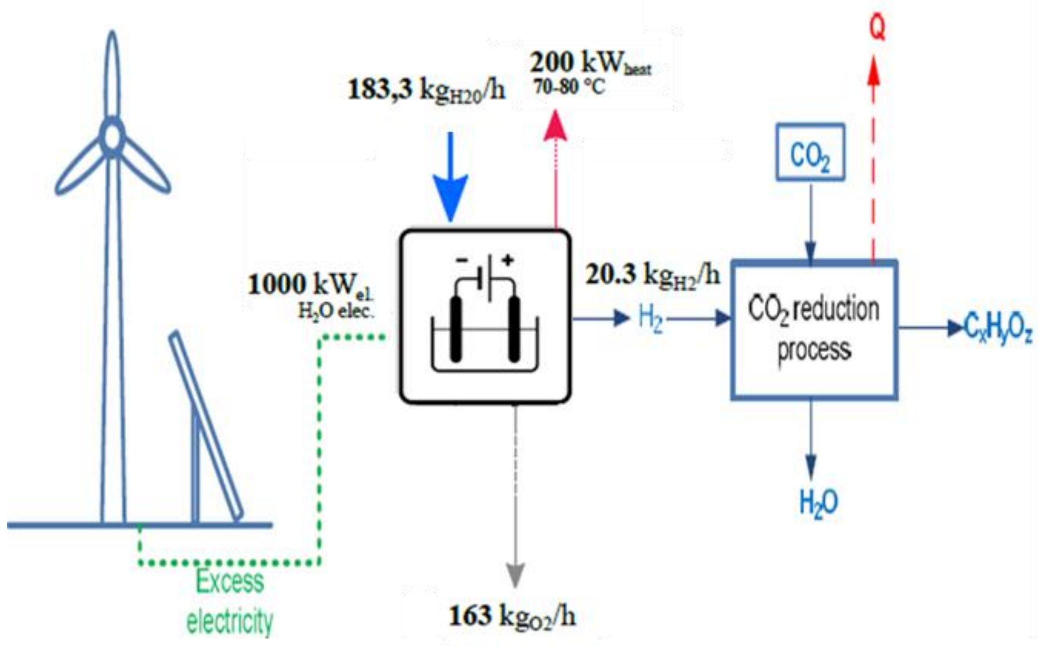
  - 70-90 EUR/tCO_2 capture

  - 50-60 EUR/tCO_2 liquefaction, shipping, storage
- CO_2 reduction by capture equals 200 billion EUR (110% EU Budget)
- CO_2 Storage effects to nature: underneath sea, rock caves etc?

World economic Forum, 2020. https://www.weforum.org/stories/2020/11/heres-why-the-eu-needs-a-carbon-sink-strategy-for-climate-neutrality
Yun S, Jang M and Kim J (2021) Techno-economic assessment and comparison of absorption and membrane CO2 capture processes for iron and steel industry. Energy (Oxford) 229: 120778
.Suviranta, Roosa, Carbon capture integration to steam cracker furnaces – techno-economic evaluation, MSc. Thesis, 2021, LUTPub.

HOW TO SUBSTITUTE FOSSIL BASED FUELS&CHEMICALS?

CO2 HYDROGENATION SCALE-UP ?



- **AVERAGE 1500 Mt CO_2 HYDROGENATED TO METHANOL OR TO SYNFUELS/KEROSENE BY 2045 ?**
  - Need for 10 Mt/a Green hydrogen (3000-9000 EUR/t) to Methanol via Syngas (H_2/CO mixture)
  - **Costs 40-90 billion EUR/a**
  - Necessary RWGS (Reverse water gas shift) reaction consumes Green Hydrogen to side-product Water
- **Severe technology challenges in Syngas conversion using high temperature RWGS process**: Water production from expensive Green hydrogen, lack of inexpensive industrial catalysts, potential catalyst poisoning, energy losses due to cooling before Methanol production…
- Optional Fischer-Tropsch synthesis to Synfuels production same challenges than with RWGS
- Fischer-Tropsch synthesis results in even 30% lower yields of synfuel fractions than methanol production route
- **Estimated fuel costs for consumers 3-4 times more than fossil-based products**

National Academies Press, Carbon Utilization Infrastructure, Markets, Research and Development; Final Report, 2024, Washington DC, USA

OPTION FOR USING WASTE TO PRODUCE X ?

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CARBON BASED BIOMASS WASTE

MUNICIPAL WASTE

IS THERE ENOUGH WASTE ?

EU

- In EU 511 kg/person municipal waste, 229 Mt/a

FINLAND

- In Finland 468 kg/person municipal waste, 2.6 Mt/a

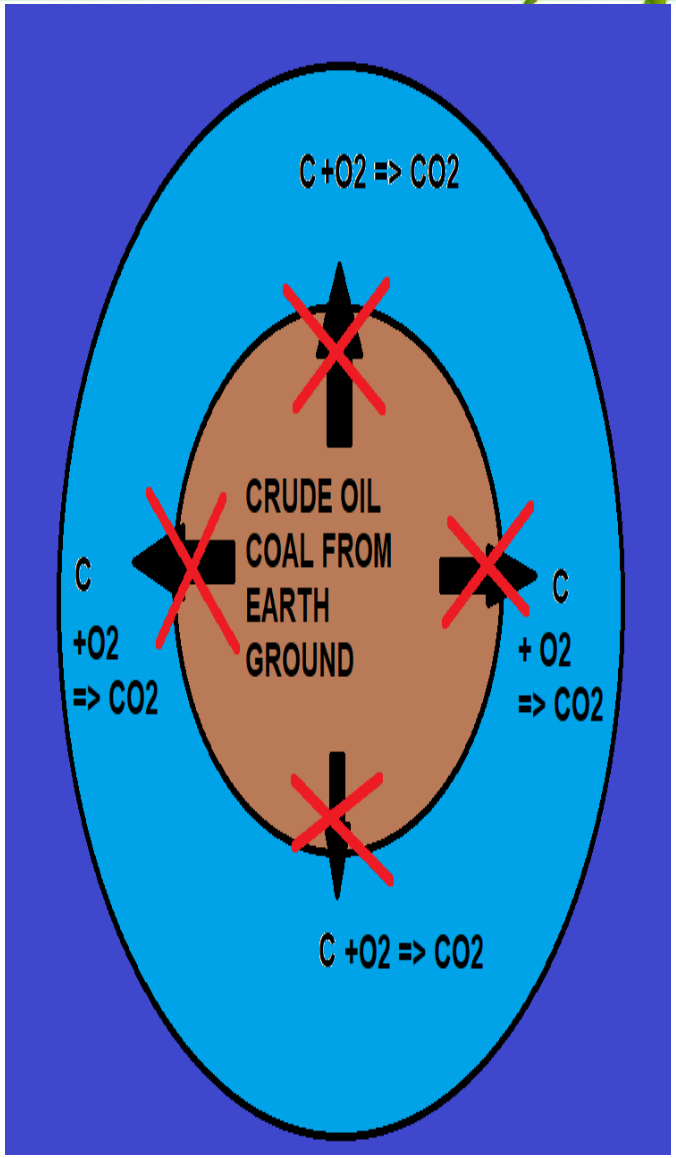
  - E.g. in Finland wood based waste is combusted 16 Mt/a, 20 Mm^3 wood/a => 12 Mt Methanol/a

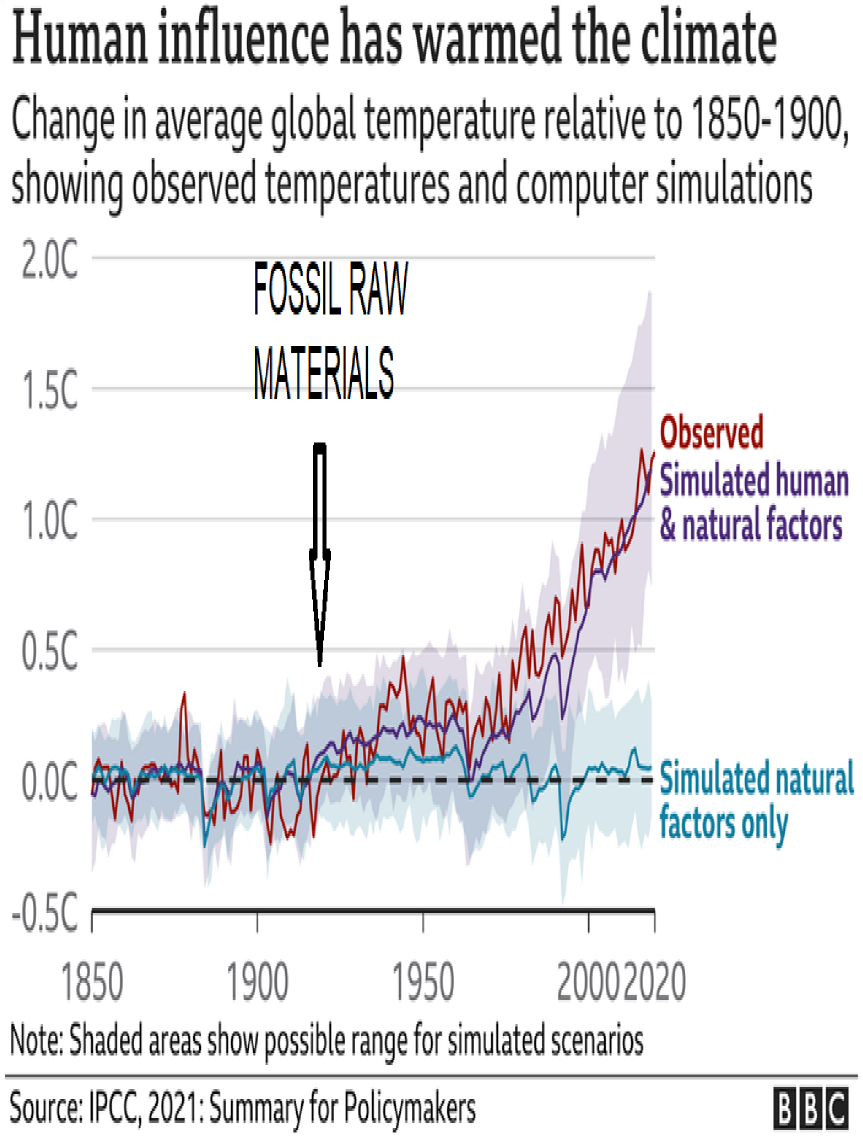
    (Methanol consumption in EU 11.3 Mt Methanol/a)

EUROSTAT, Statistics explained, https://ec.europa.eu/eurostat/statistics-explained
ChemAnalyst. https://www.chemanalyst.com/industry-report

WHY TO USE WASTE TO PRODUCE X ?

- Replacement of fossil based products => substantial CO_2 emission reduction
- CO_2 hydrogenation is expensive and inefficient due to losing hydrogen in water production. Waste-to-X is option.
- Waste treatment currently utilises low efficiency electricity production by combustion or even land fill storage
- Current techniques in waste treatment increase CO_2 emissions
- Green electricity can subtitute heat and power obtained form waste combustion based energy production.





HOW IS IT DONE ?

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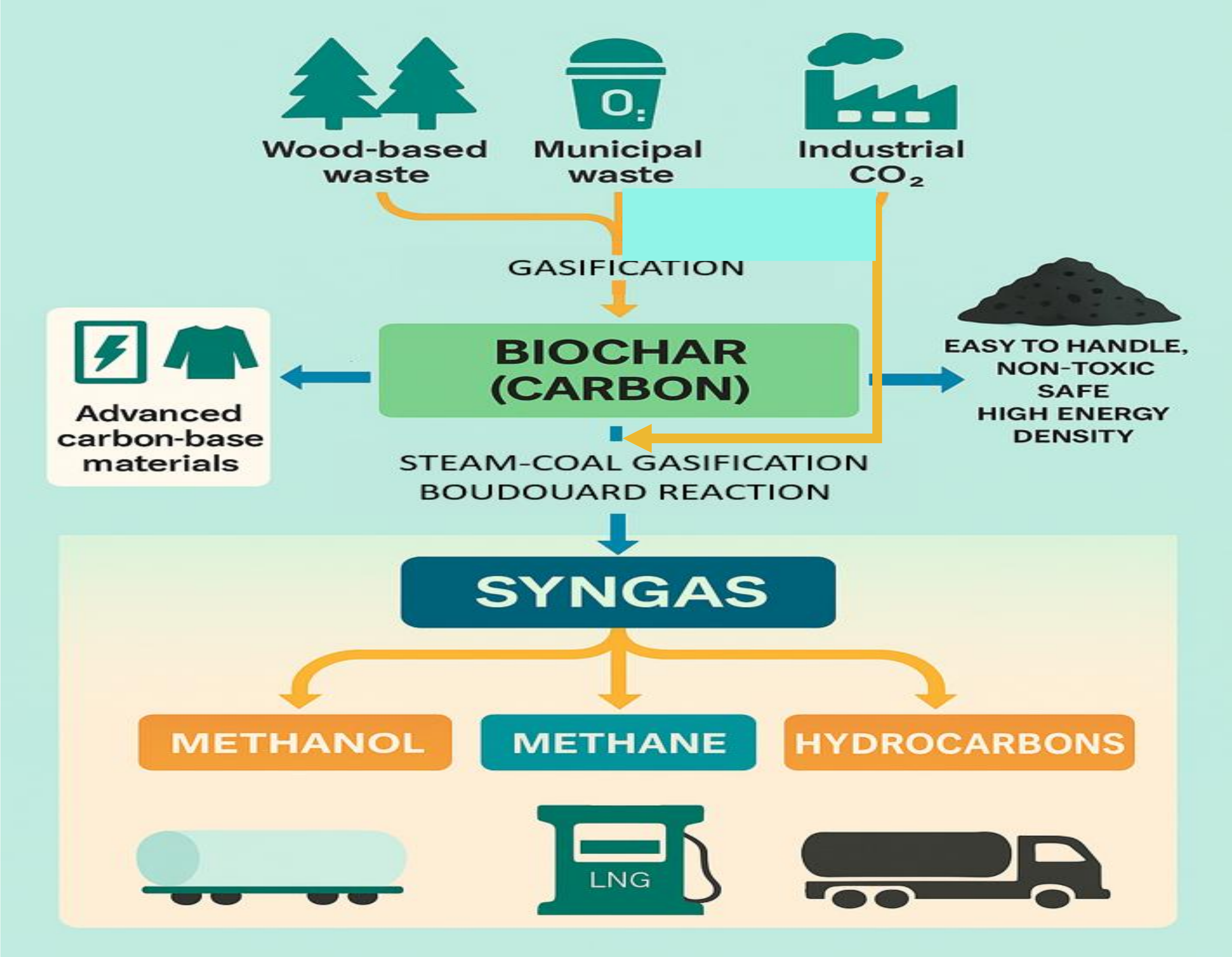
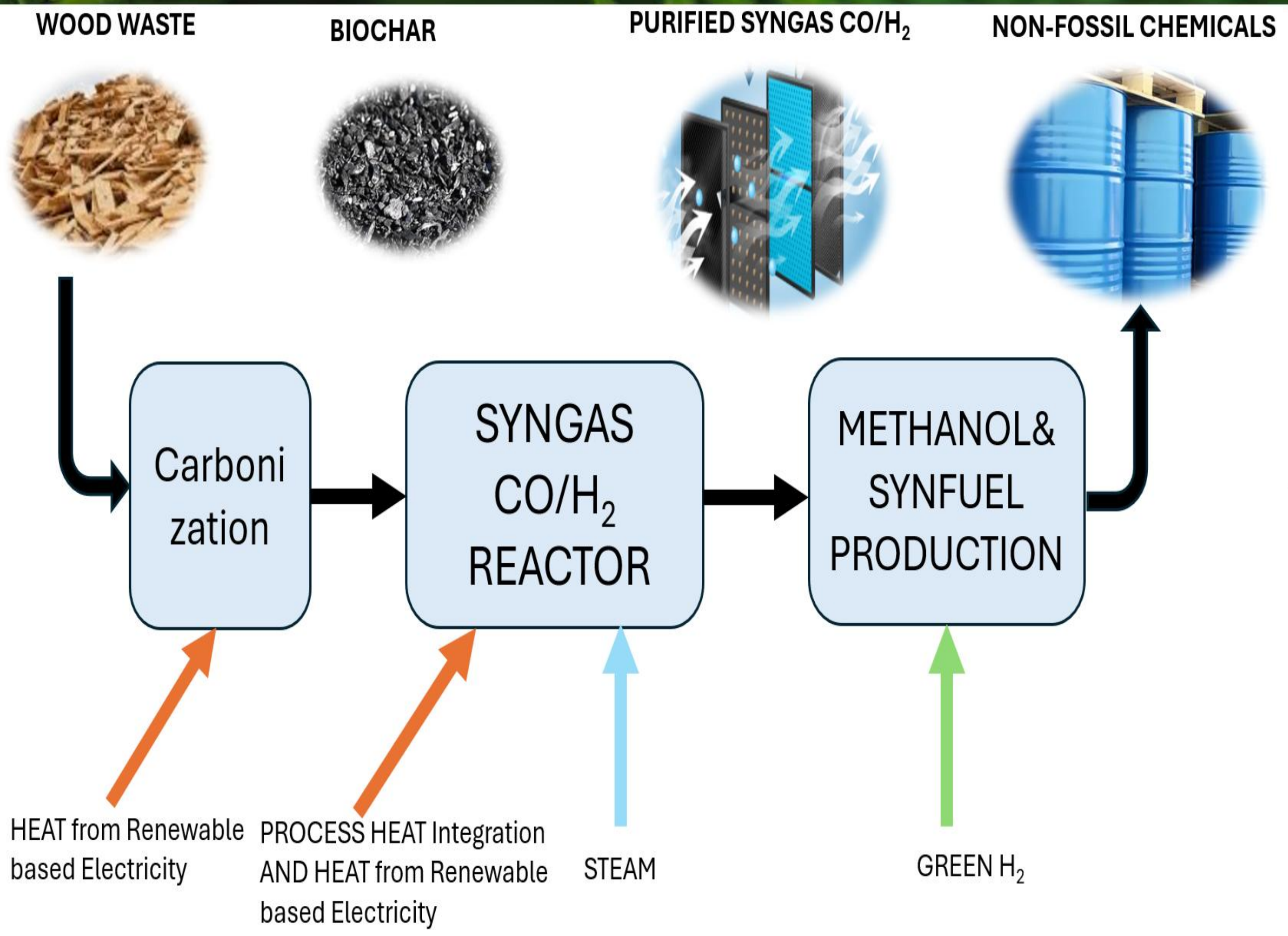
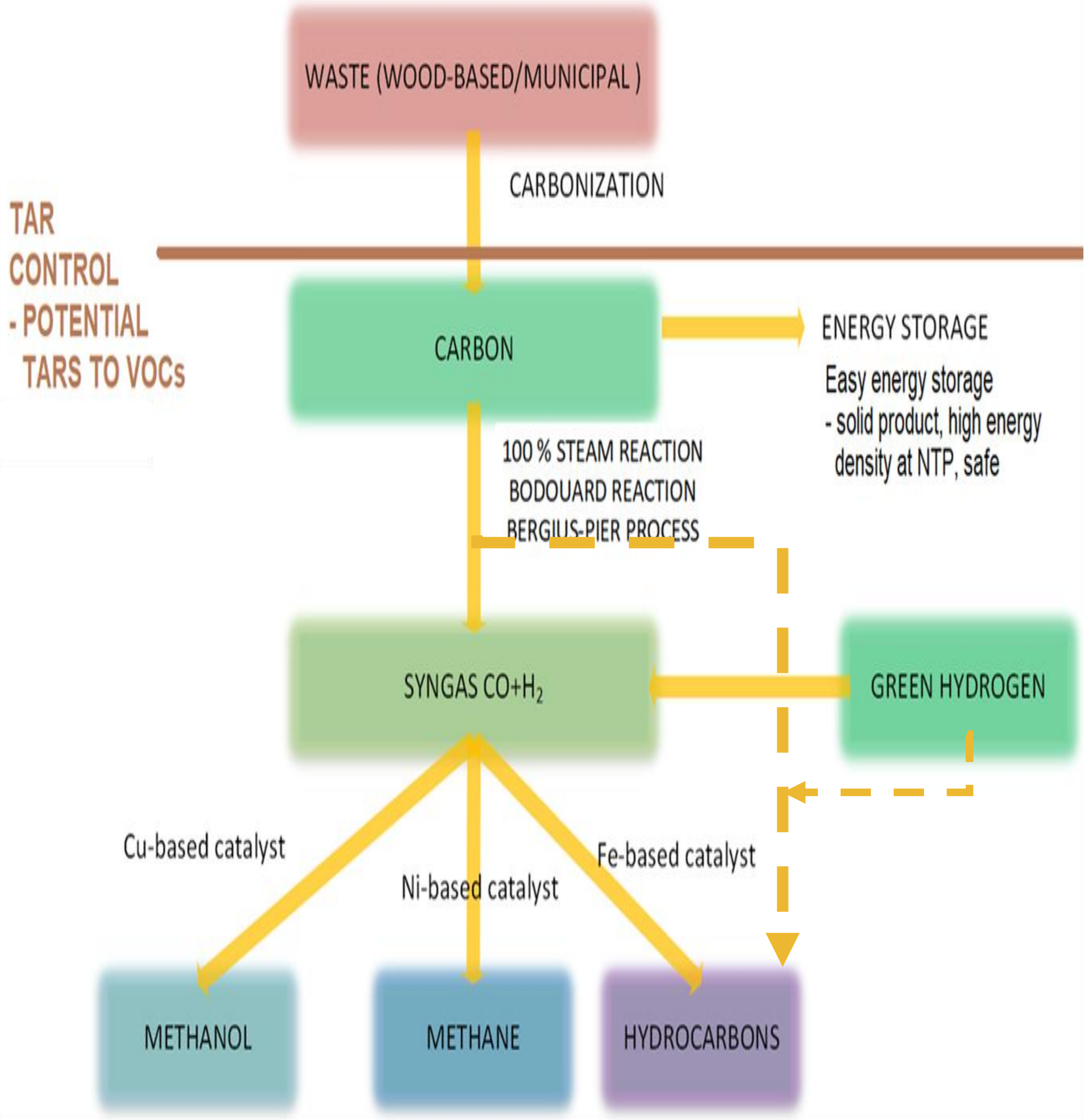


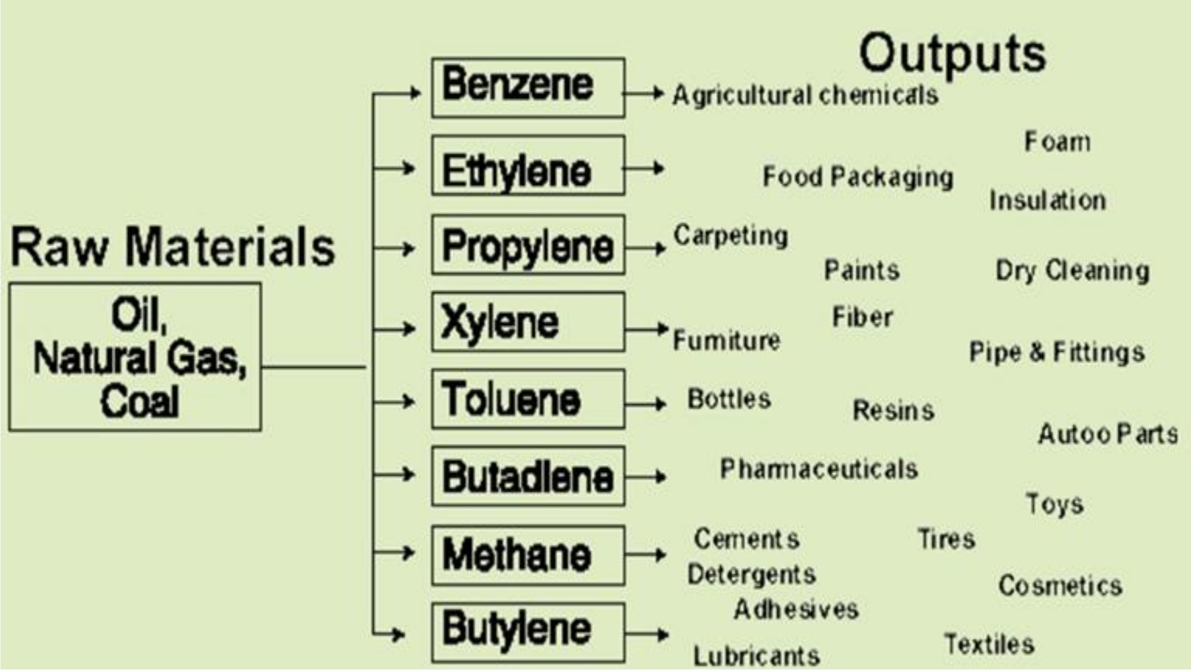
- RAW MATERIALS
- BIOCHAR PRODUCTION
  - Biochar as energy storage
  - Biochar as simple transport
- LOW TAR SYNGAS PRODUCTION FROM BIOCHAR + STEAM =>hydrogen and carbon monoxide OR biochar + CO2 => carbon monoxide
- ELECTRICAL HEATING improves syngas yield significantly compared to standard gasification employing oxygen+steam
- SYNGAS TO PRODUCTS

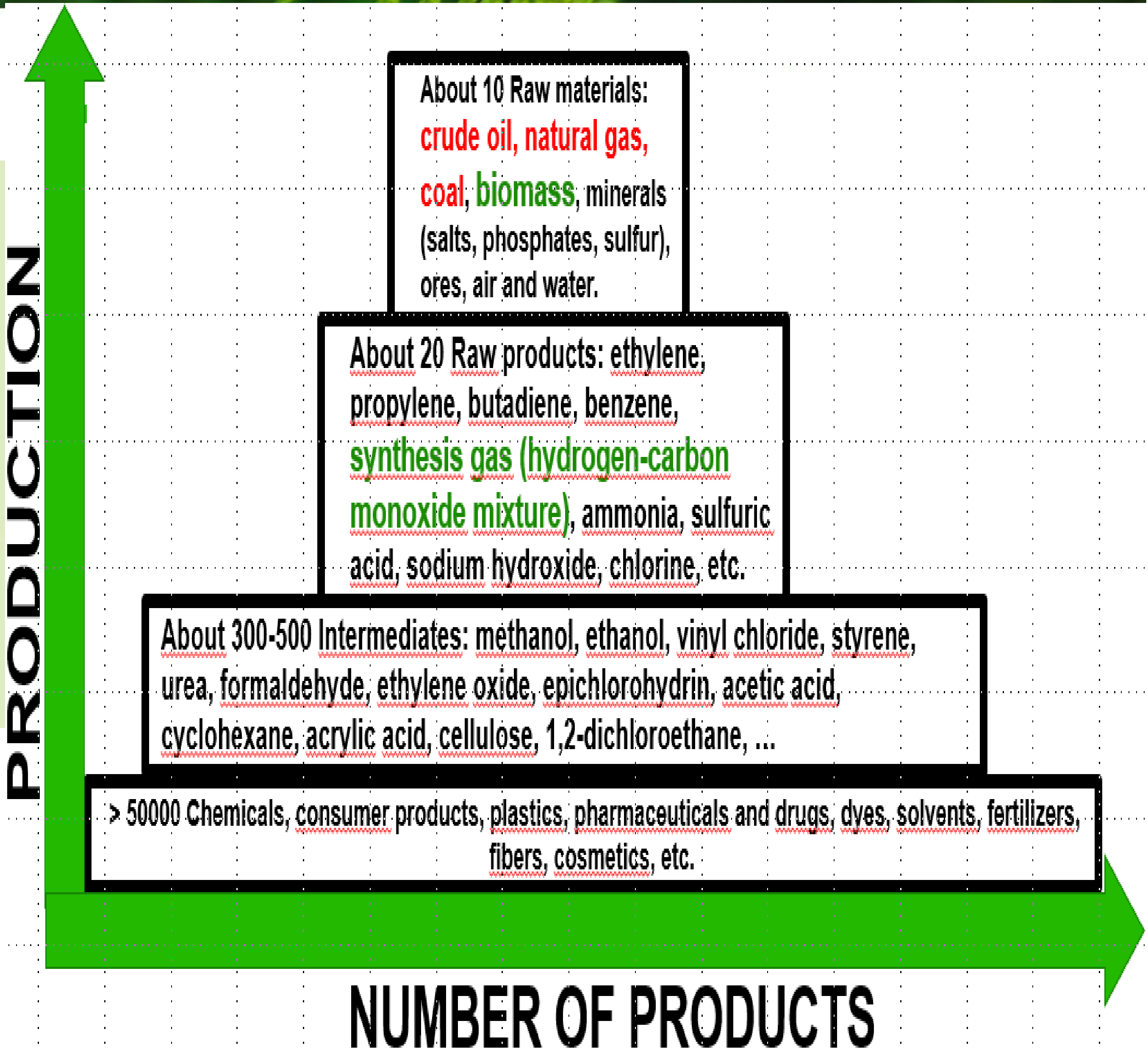
HOW IS IT DONE ?





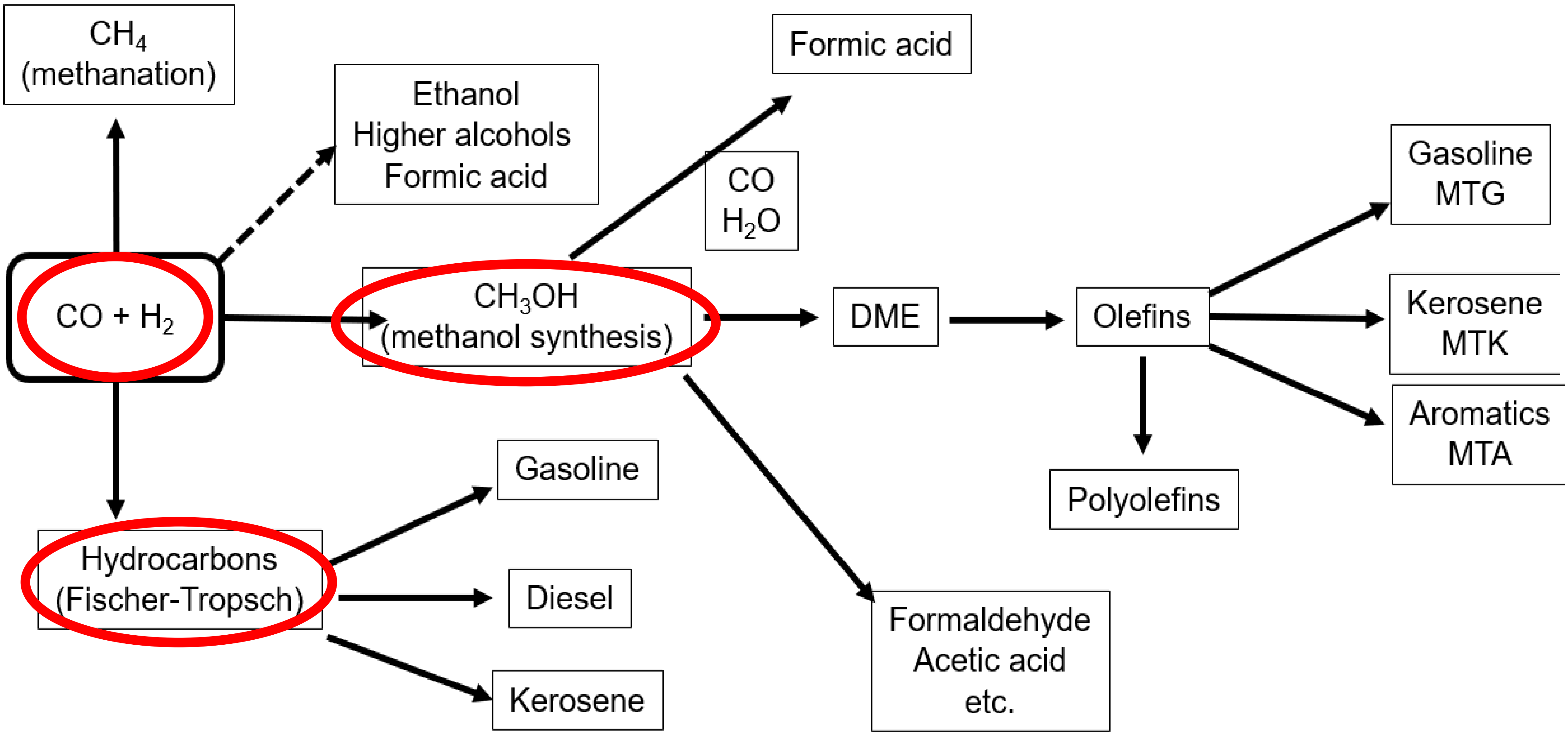
WHAT FOSSIL BASED CHEMICALS ARE SUBSTITUTED ?



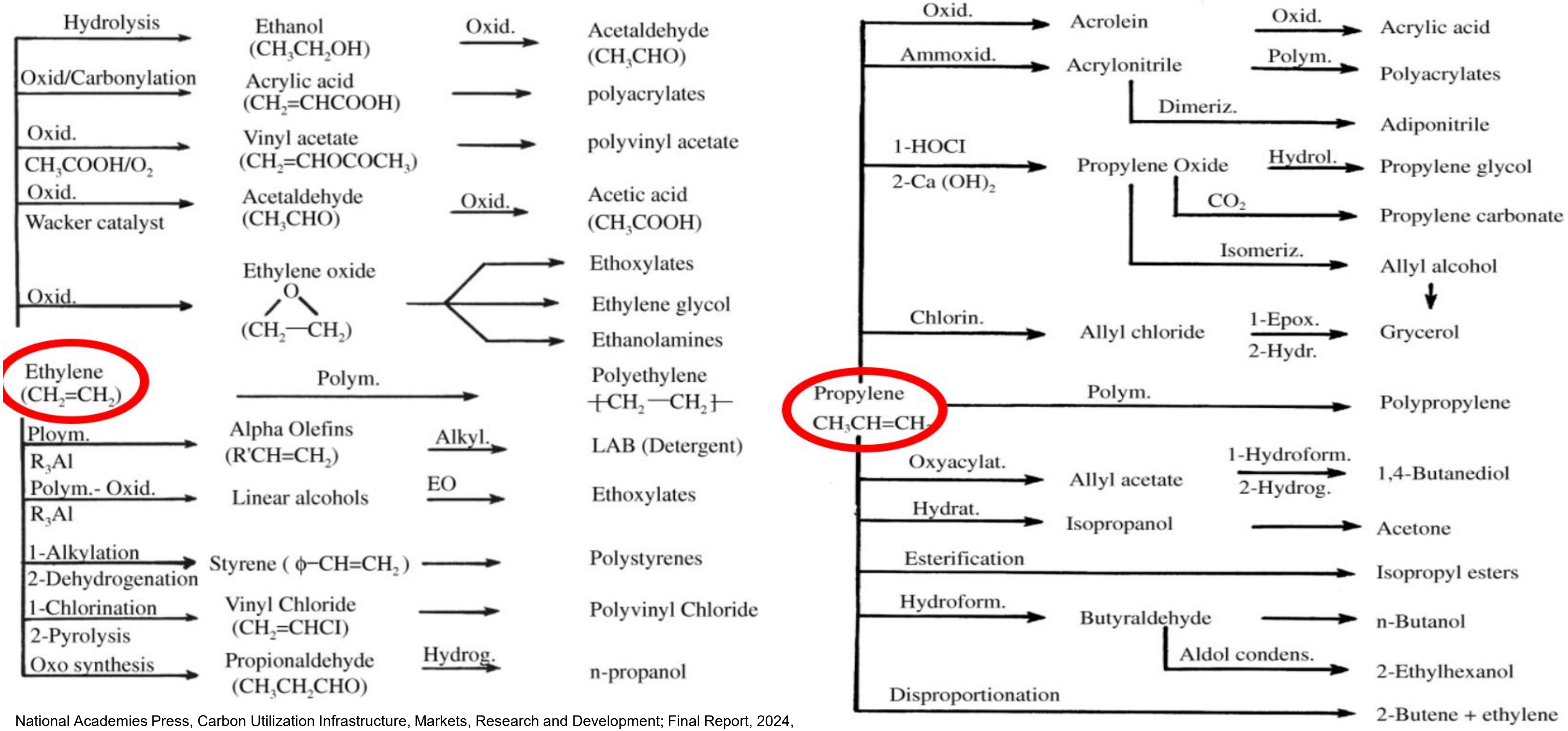


Weissermel,K., Arpe, H-J, Industrial Organic Chemistry, Wiley-VCH, Weinheim, 1997
Ullmann's Chemical Engineering&Plant design: Plant and Process design Vol.2, Wiley-VCH, Weinheim 2005

WHAT FOSSIL BASED CHEMICALS CAN BE SUBSTITUTED ?



WHAT FOSSIL BASED CHEMICALS CAN BE SUBSTITUTED ?



National Academies Press, Carbon Utilization Infrastructure, Markets, Research and Development; Final Report, 2024, Washington DC, USA

SUMMARY AND CONCLUSION

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- Very expensive to cut down co2 emissions by co2 hydrogenation
  - Especially when renewable electricity for green production is mainly available at day time and periodically during the year
  - Recycling of carbon through biochar and employing electrical heating more efficient => lower cost and higher efficiency
- Severe technical challenges in rwgs process converting co2 to syngas
- Waste-to-x instead of combustion has potential to non-fossil fuels&chemicals production
- Co2 emissions reduction due to substituting combustion & fossil raw materials use
- Estimated methanol production costs 500-650 eur/t significantly lower than > 1200-1300 eur/t for co2 hydrogenation with green h2
- Future platform chemicals: syngas, methanol, ethene, propene, and ft-products


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