



**INSTITUTO
DOM LUIZ**



Syngas Biorefinery

Marta Sofia Lopes Pacheco

Sustainable Energy Systems Doctoral Program



**Ciências
ULisboa**

Converting Biomass to Energy

Biomass sources for energy include:



Wood and wood processing wastes

Firewood, wood pellets, wood chips, lumber/furniture mill sawdust and waste and black liquor from pulp and paper mills



Biogenic materials in municipal solid waste

Paper, cotton, wool products, food, yard and wood wastes



Agricultural crops and waste materials


Corn, soybeans, sugar cane, switchgrass, woody plants, algae and crop/food processing residues



Animal manure and human sewage

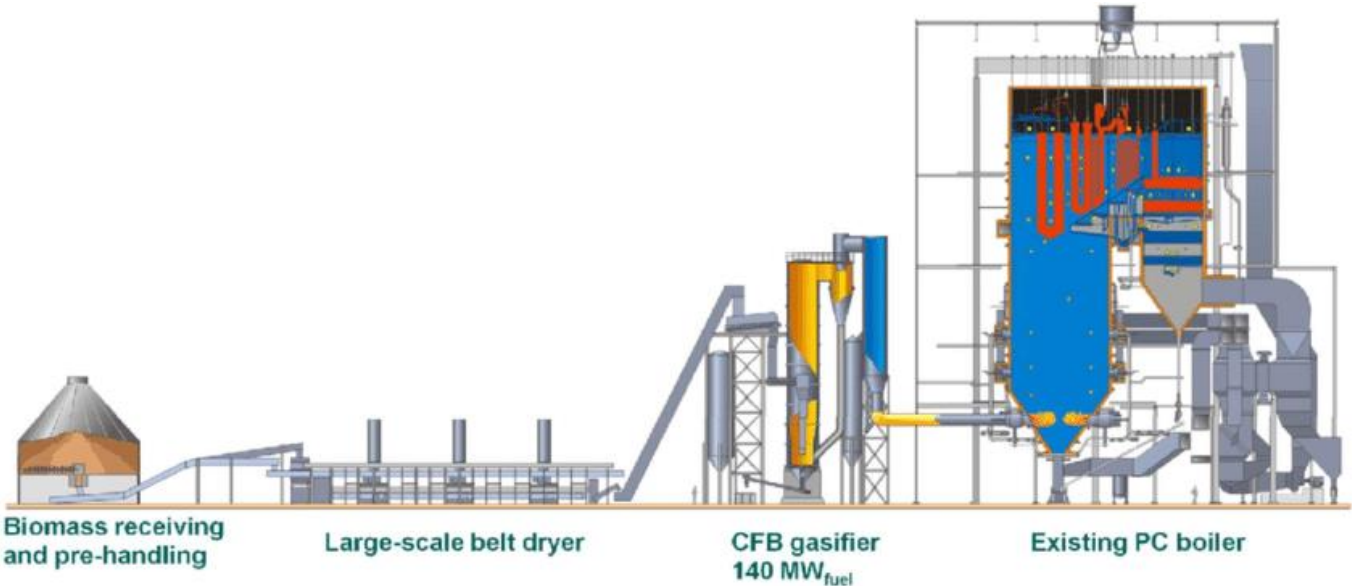
Thermochemical Biomass Valorization

Gasification

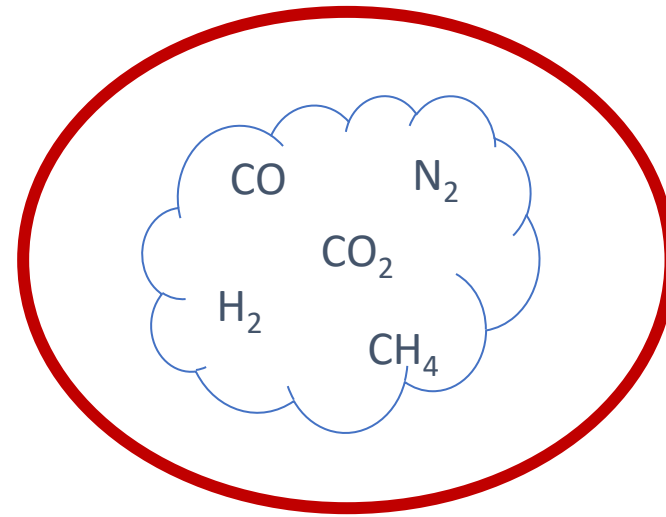
 Organic residues



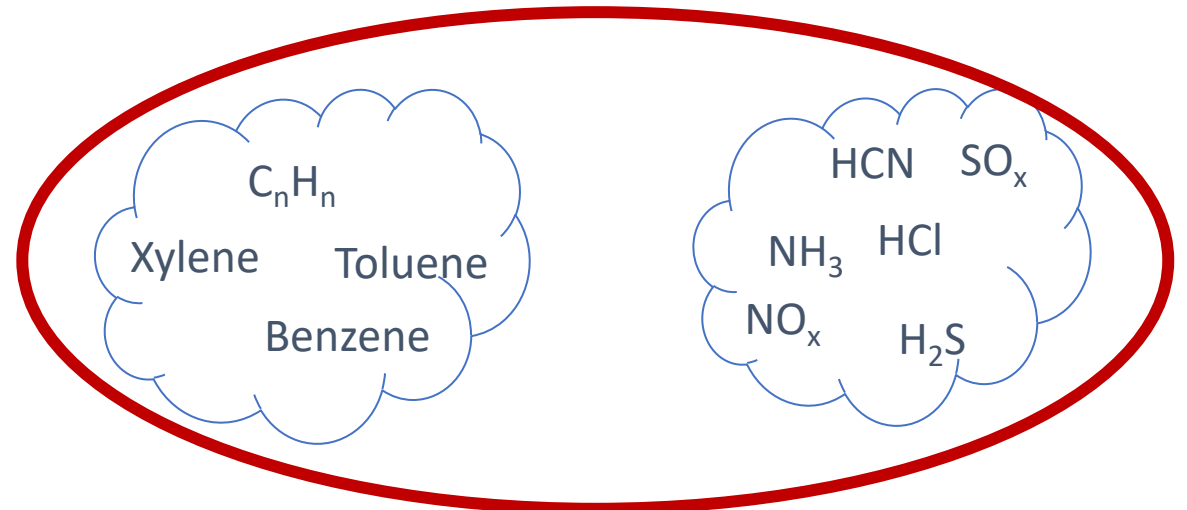
 Electricity



Syngas



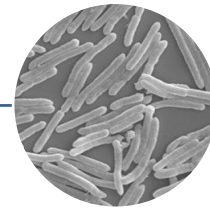
**Main
components**



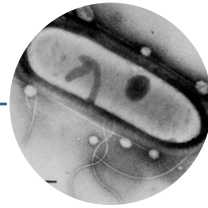
**Hydrocarbons and
inorganic compounds**

Syngas Fermenting Microorganisms

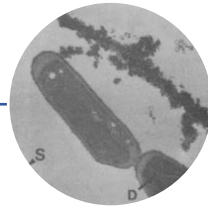
Most used
microorganisms
for syngas
fermentation



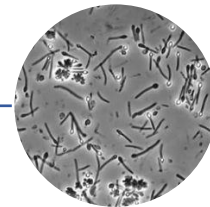
*Clostridium
carboxydivorans*



*Clostridium
ljungdahlii*



*Butyribacterium
methylotrophicum*



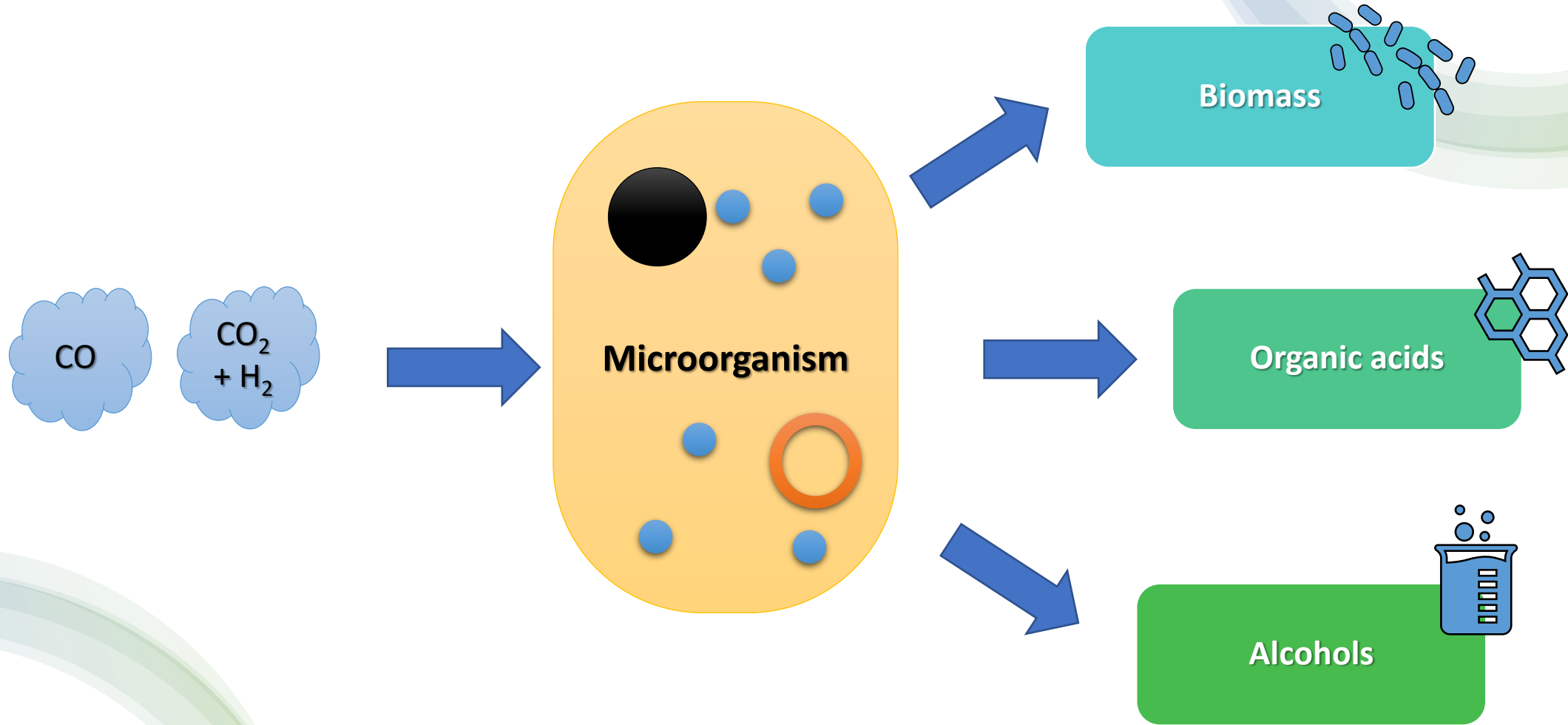
*Morella
thermoacetica*

Ethanol

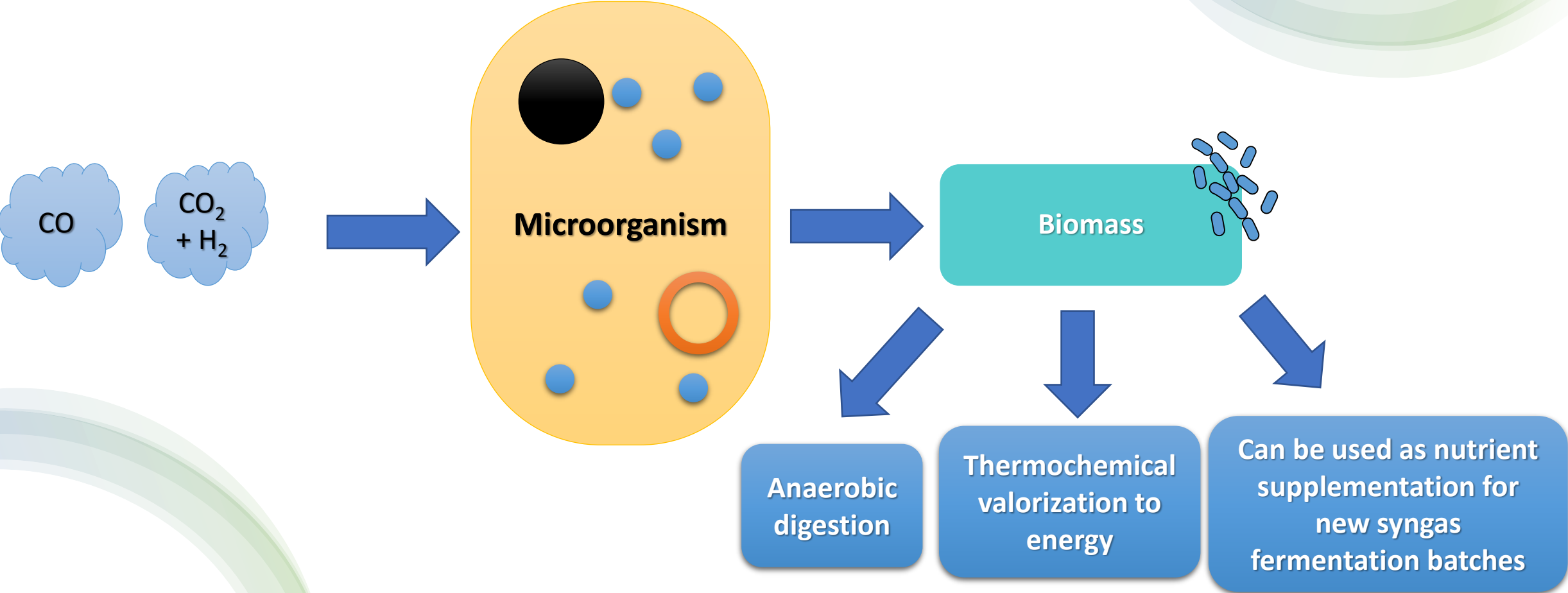
Organic acids:

- Acetic acid
- Butyric acid

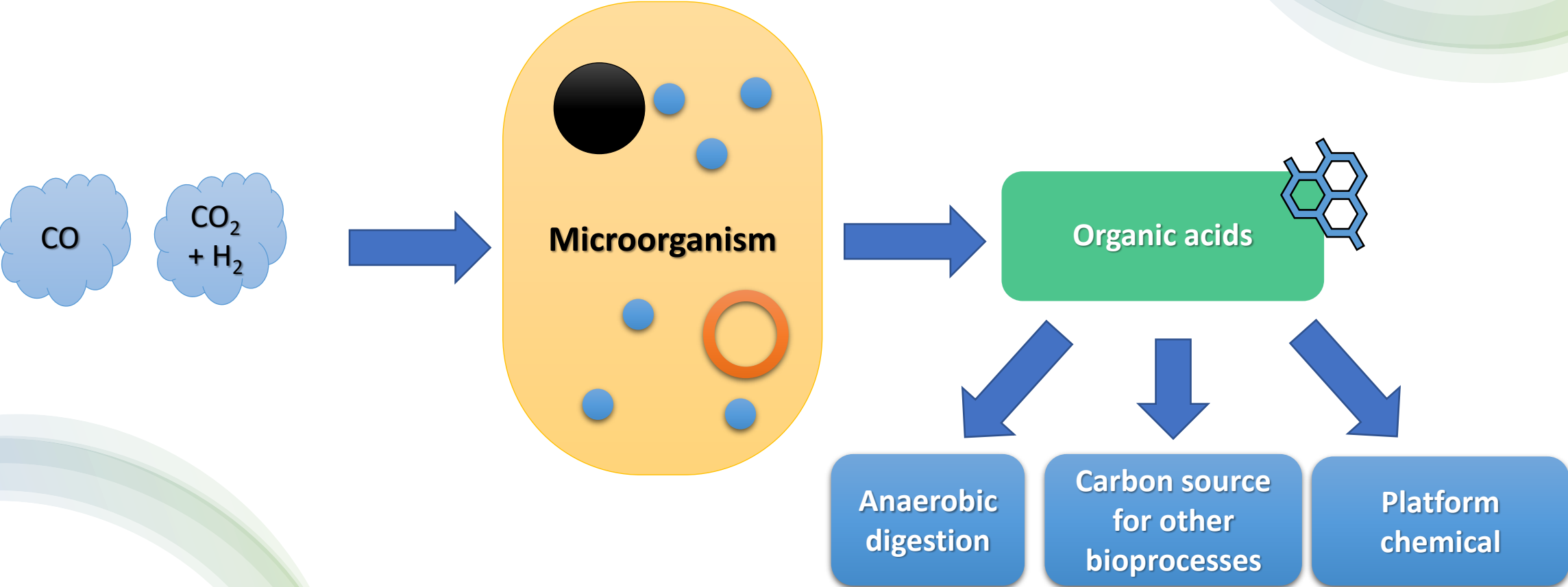
Syngas Fermentation



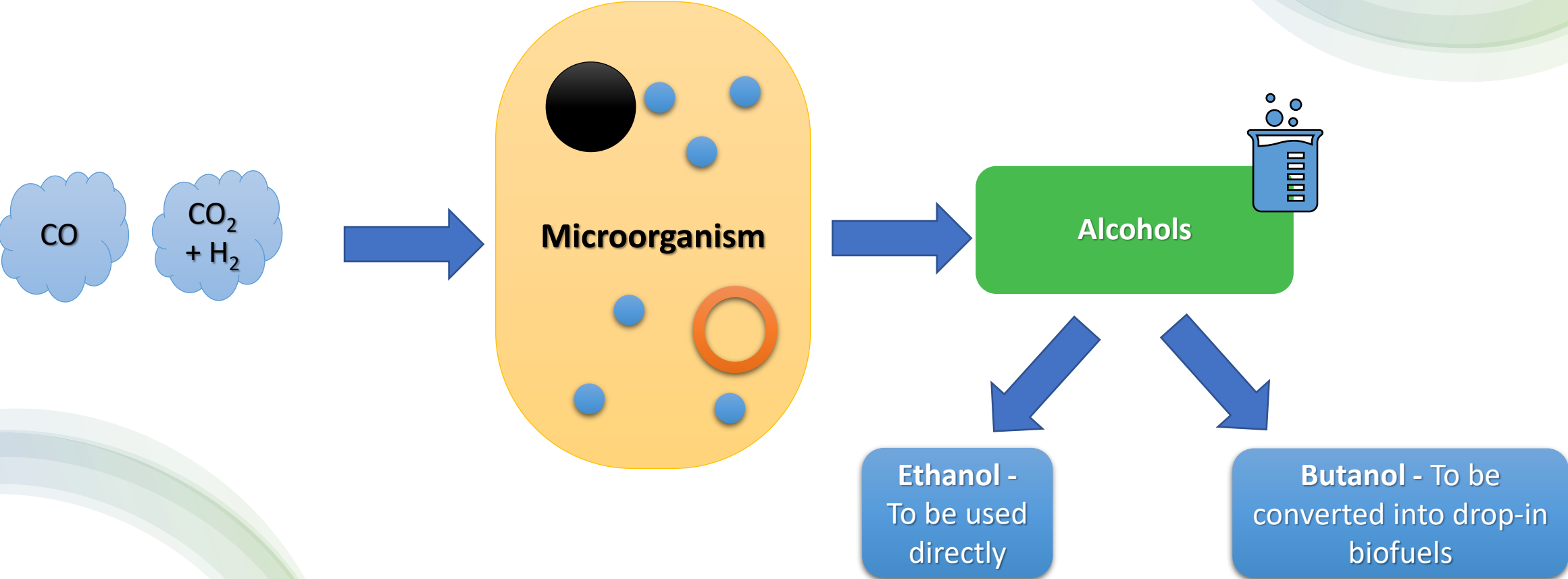
Syngas Fermentation: Product Valorization



Syngas Fermentation: Product Valorization



Syngas Fermentation: Product Valorization



Other Applications

This technology can be applied on any carbon rich gas streams from:

- Cement and concrete factories
- Metallurgy
- Power plants
- Furnaces

Syngas Fermentation

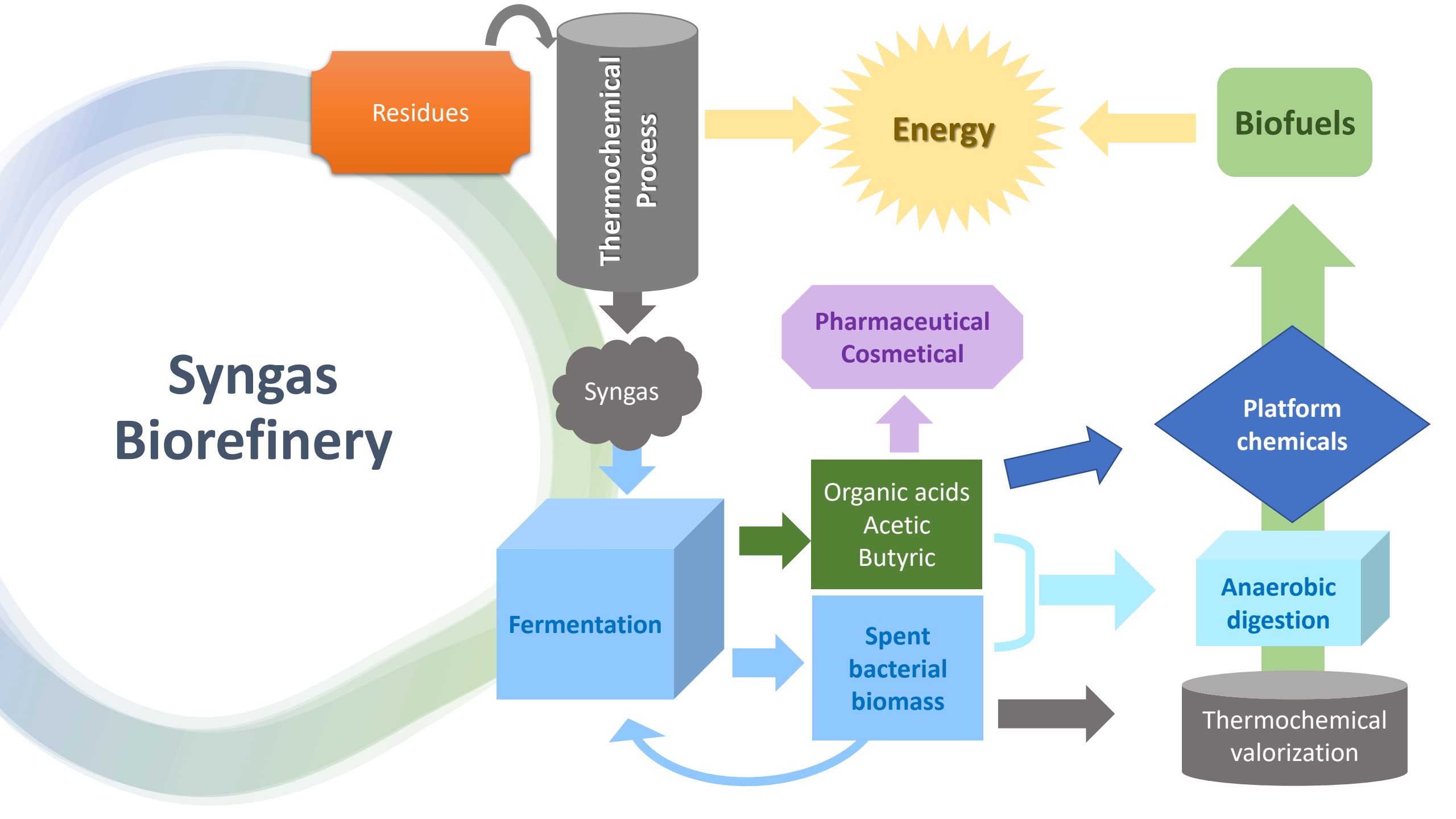
Advantages

- Reduce carbon emissions
 - Conversion of pollutant gases into biofuels
- Not dependent of high temperatures or expensive metal catalysts
- Brings further value to the overall process due to high added value byproducts
- Great potential for adaptation to other gas producing technologies

Bottlenecks

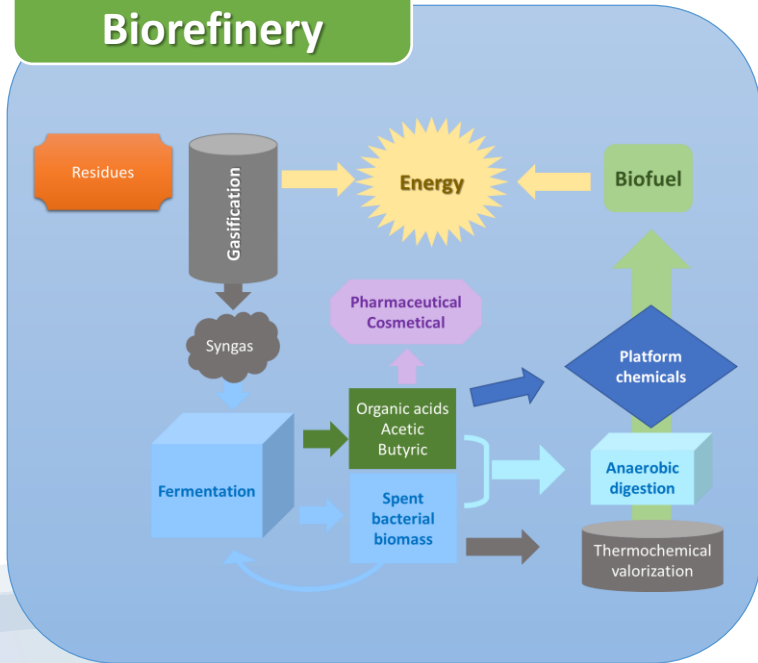
- Mass transference issues
 - Low solubility of the main syngas components on the liquid fraction
 - Optimization of bioreactor design
- Tests with “real” syngas
 - Influence of impurities on the cells
 - Optimization of fermentation parameters
- Low Technological Readiness Level (TRL)
 - Gasification and pyrolysis are already implemented at an industrial level

Syngas Biorefinery



Integrated Biorefinery

Bench Scale Biorefinery



Reduce emissions

Reduce waste production

Increase process efficiency

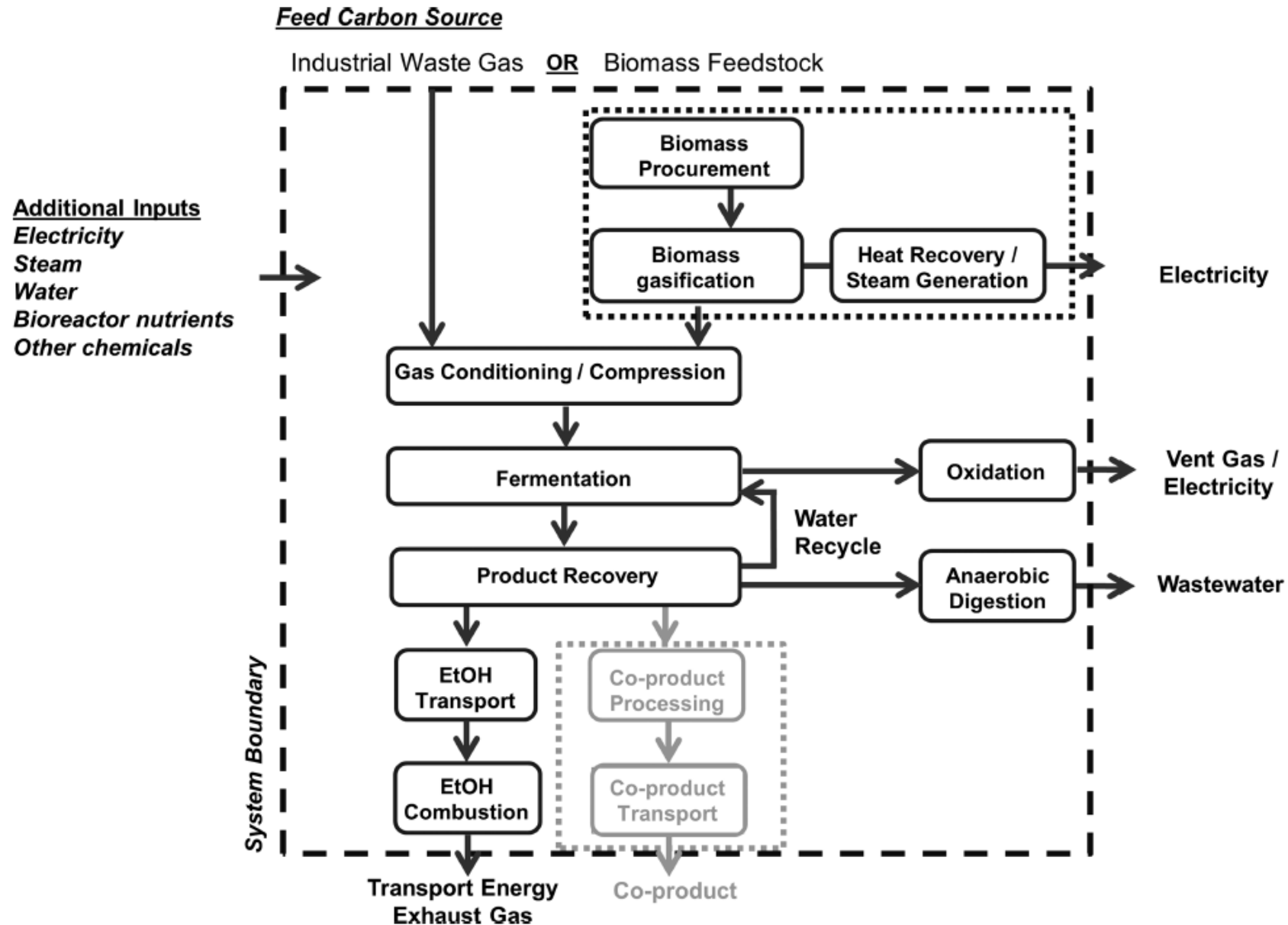
Increase energy production

Diversify value chains

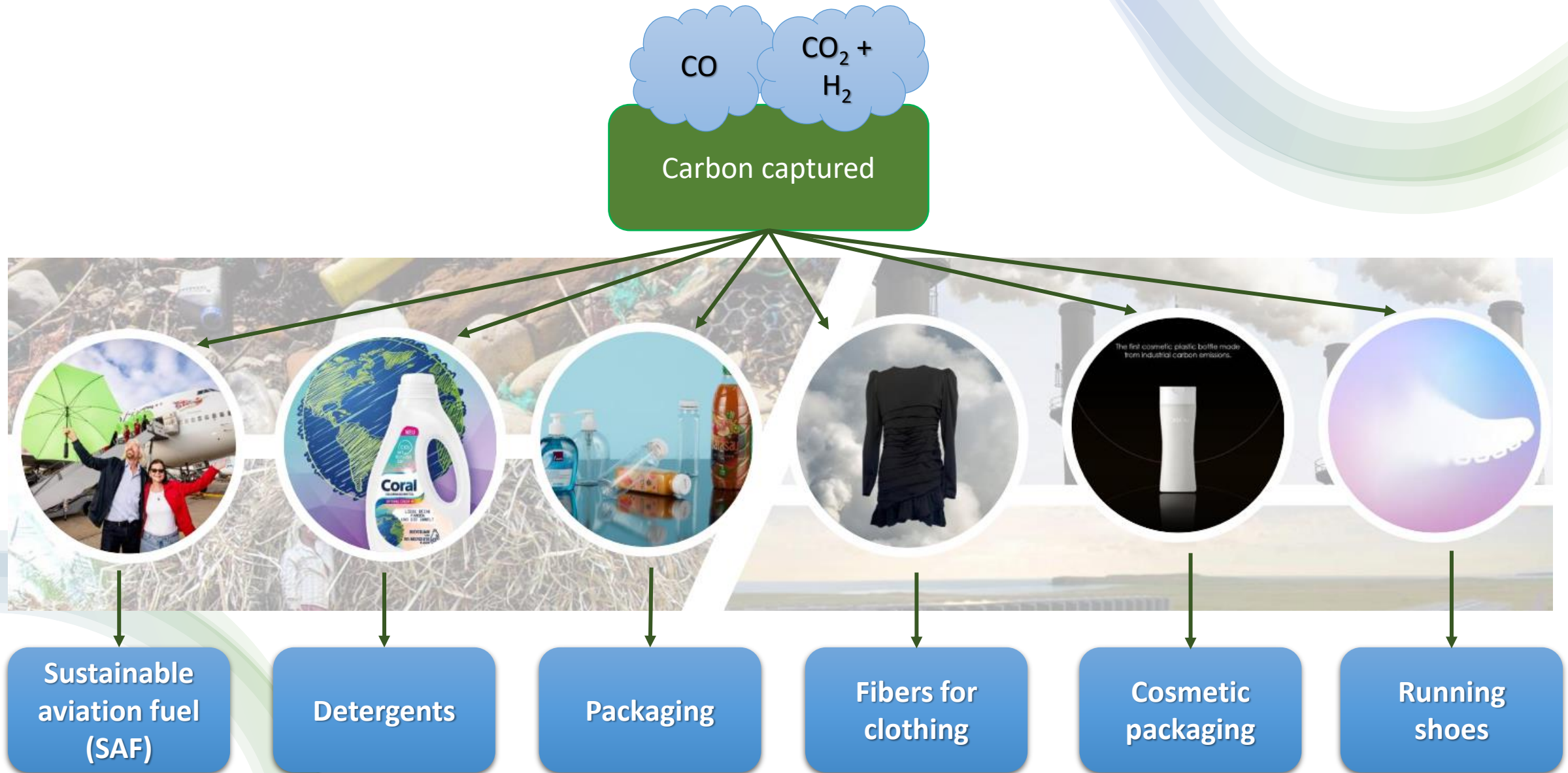
Integrated Biorefinery – An example



Integrated Biorefinery - Lanzatech



Integrated Biorefinery - Lanzatech



Bibliography

- International Energy Agency Global Energy Review 2021: Assessing the effects of economic recoveries on global energy demand and CO₂ emissions in 2021. IEA Publications 2021.
- <https://bioenergyinternational.com/opinion-commentary/portugal-celebrates-national-bioenergy-day-2018>
- <https://www.apren.pt/en/renewable-energies/production/>
- Liakakou, E.T.; Vreugdenhil, B.J.; Cerone, N.; Zimbardi, F.; Pinto, F.; André, R.; Marques, P.; Mata, R.; Gírio, F. Gasification of Lignin-Rich Residues for the Production of Biofuels via Syngas Fermentation: Comparison of Gasification Technologies. *Fuel* 2019, 251, 580–592, doi:10.1016/j.fuel.2019.04.081.
- Whitty, K.J.; Zhang, H.R.; Eddings, E.G. Emissions from Syngas Combustion. *Combust. Sci. Technol.* 2008, 180, 1117–1136, doi:10.1080/00102200801963326.
- Henstra, A.M.; Sipma, J.; Rinzema, A.; Stams, A.J. Microbiology of Synthesis Gas Fermentation for Biofuel Production. *Curr. Opin. Biotech.* 2007, 18, 200–206, doi:10.1016/j.copbio.2007.03.008.
- Pinto, F.; André, R.; Marques, P.; Mata, R.; Pacheco, M.; Moura, P.; Gírio, F. Production of Syngas Suitable to Be Used in Fermentation to Obtain Biochemical Added-Value Compounds. *Chem. Engineer. Trans.* 2019, 76, 1399–1404, doi:10.3303/CET1976234.
- Infantes, A.; Kugel, M.; Raffelt, K.; Neumann, A. Side-by-side Comparison of Clean and Biomass-Derived, Impurity-containing Syngas as Substrate for Acetogenic Fermentation with *Clostridium ljungdahlii*. *Fermentation* 2020, 6, 1–27, doi:10.3390/FERMENTATION6030084.
- Zeikus, J.G.; Lynd, L.H.; Thompson, T.E.; Krzycki, J.A.; Weimer, P.J.; Hegge, P.W. Isolation and Characterization of a New, Methylotrophic, Acidogenic Anaerobe, the Marburg Strain. *Curr. Microbiol.* 1980, 3, 381–386, doi: 10.1007/BF02601907.
- Bertsch, J.; Müller, V. Bioenergetic Constraints for Conversion of Syngas to Biofuels in Acetogenic Bacteria. *Biotechnol. Biofuels* 2015, 8, 1–12, doi:10.1186/s13068-015-0393-x.
- Deshmukh, G.; Manyar, H. Production Pathways of Acetic Acid and Its Versatile Applications in the Food Industry. In *Acetic Acid-Production and Applications in the Food Industry [Working Title]*; IntechOpen, 2020 ISBN 978-1-83881-182-2.
- Xu, Z.; Jiang, L. Butyric Acid. In *Comprehensive Biotechnology*; Moo-Young, M., Ed.; Pergamon, 2011; Vol. 3, pp. 235–243 ISBN 9780444640475.
- Fernández-Naveira, Á.; Veiga, M.C.; Kennes, C. H-B-E (Hexanol-Butanol-Ethanol) Fermentation for the Production of Higher Alcohols from Syngas/Waste Gas. *J. Chem. Technol. Biot.* 2017, 92, 712–731, doi:10.1002/jctb.5194.
- Kato, J., Takemura, K., Kato, S. et al. Metabolic engineering of *Moorella thermoacetica* for thermophilic bioconversion of gaseous substrates to a volatile chemical. *AMB Expr.* 2021, 11, 59, doi: 10.1186/s13568-021-01220-w.
- Rückel, A.; Hannemann, J.; Maierhofer, C.; Fuchs, A. and Weuster-Botz, D. Studies on Syngas Fermentation With *Clostridium carboxidivorans* in Stirred-Tank Reactors With Defined Gas Impurities. *Front. Microbiol.* 2021, 12, 655390, doi: 10.3389/fmicb.2021.655390.
- Daniell, J.; Köpke, M. and Simpson, S. D. Commercial Biomass Syngas Fermentation. *Energies* 2012, 5, 5372–5417, doi: 10.3390/en5125372 .
- Muthudineshkumar, R. and Anand, R. Life cycle assessment on biofuel production from biomass gasification and syngas fermentation. *IOP Conf. Ser.: Earth Environ. Sci.* 2019, 312, 012016, doi: 0.1088/1755-1315/312/1/012016
- Poritosh, R. and Animesh, D. A Review of Life Cycle of Ethanol Produced from Biosyngas. *BIOETH* 2013, 9–19, doi: 10.2478/bioeth-2013-00.
- <https://www.eia.gov/energyexplained/biomass/>
- Pacheco, M.; Pinto, F.; Ortigueira, J.; Silva, C.; Gírio, F. and Moura, P. Lignin Syngas Bioconversion by *Butyribacterium methylotrophicum*: Advancing towards an integrated Biorefinery. *Energies* 2021, 14, 7124, doi:10.3390/en14217124
- Pacheco, M.; Pinto, F.; Brunsvik, A.; André, R.; Marques, P.; Mata, R.; Ortigueira, J.; Gírio, F. and Moura, P. Effects of Lignin Gasification Impurities on the Growth and Product Distribution of *Butyribacterium methylotrophicum* during Syngas Fermentation. *Energies* 2023, 16, 1722, doi: 10.3390/en16041722

Thank you for your attention!

Acknowledgements

The author would like to specially thank Dr. Patrícia Moura (LNEG) and Prof. Dr. Carla Silva (IDL) for the PhD thesis supervision, and family and friends for all the support.

The author is supported by national funds through FCT PhD grant DFA/BD/6423/2020.

