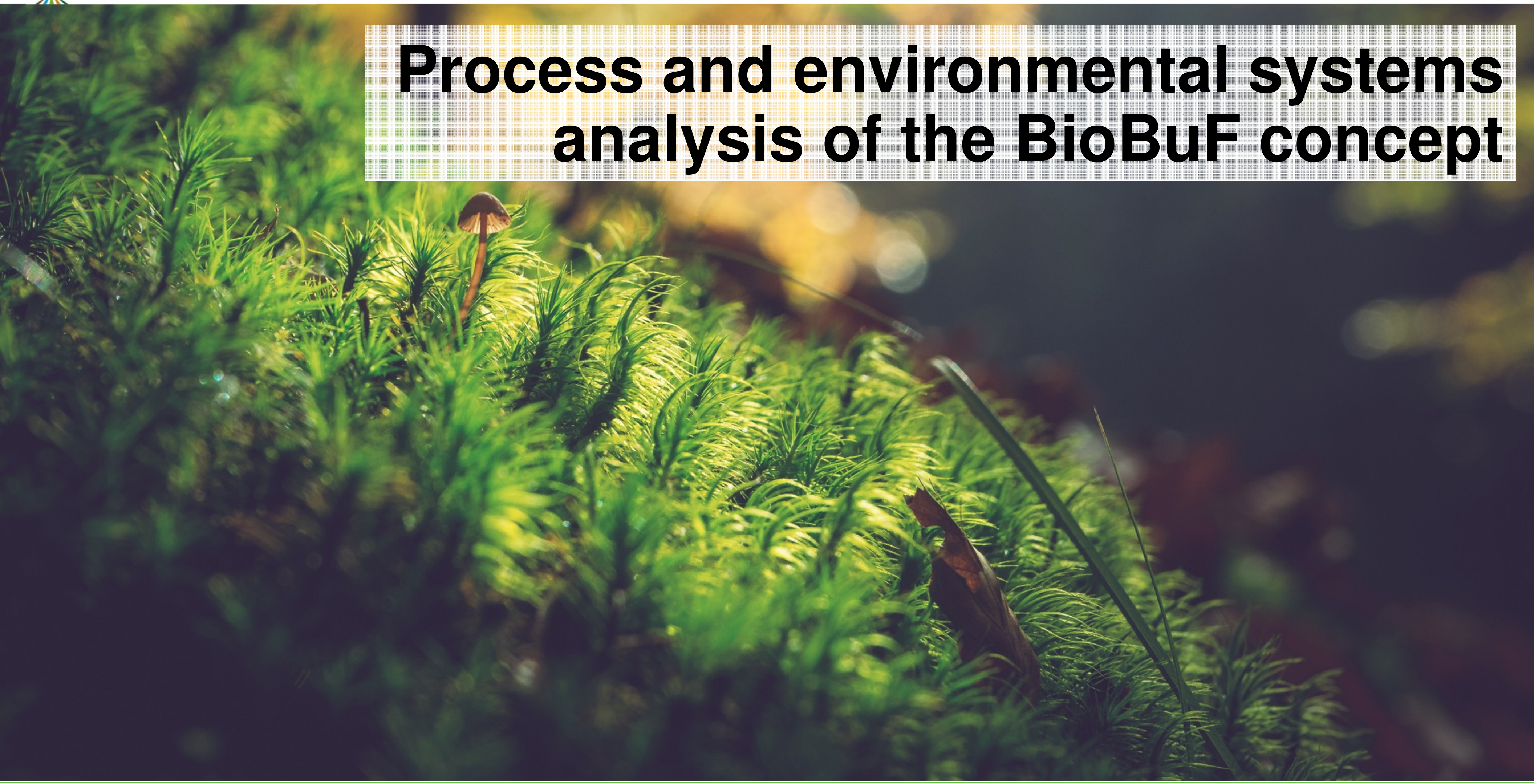
Process and environmental systems analysis of the BioBuF concept

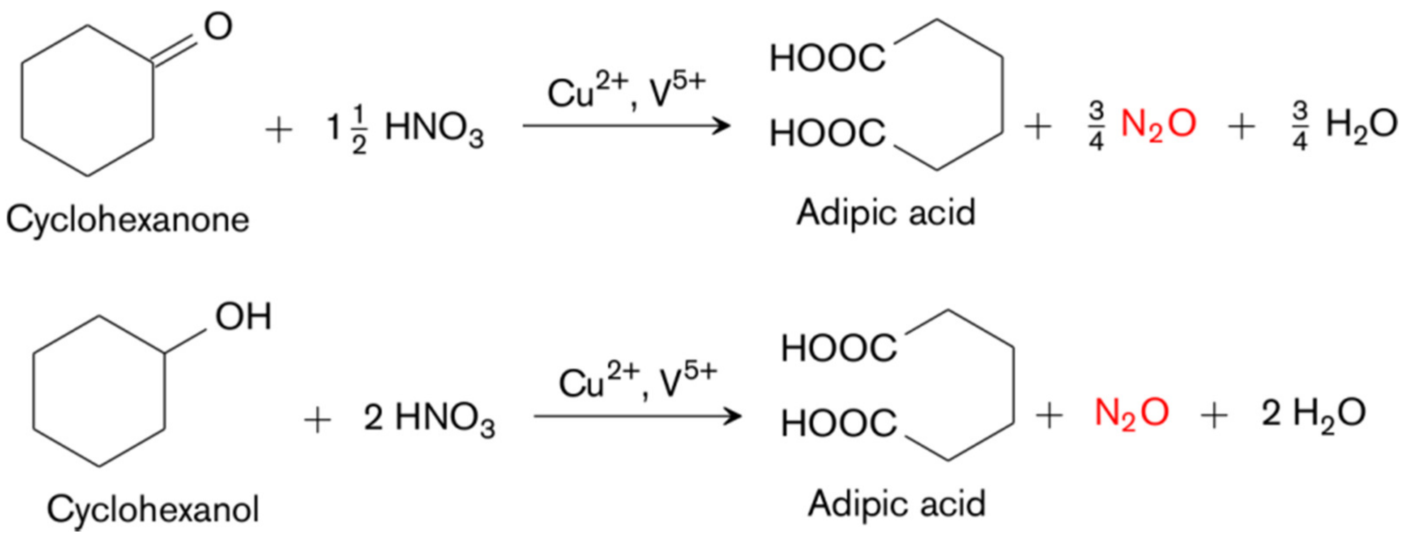


Outline

- Conventional adipic acid production
- Process and environmental systems analysis in BioBuF
- Some environmental systems analysis results
- Assessment of processes in early development stages

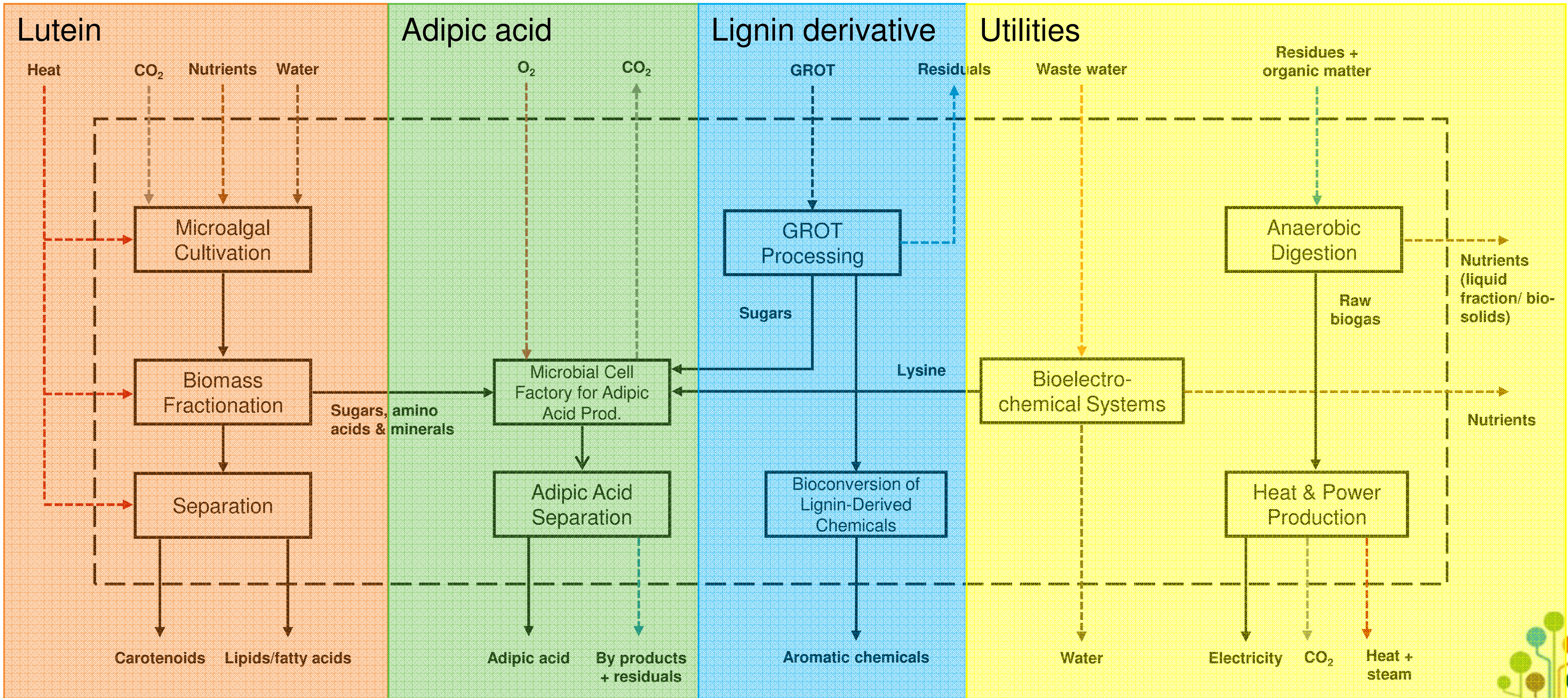
Conventional adipic acid production

- Production from fossil resources → KA oil[1]

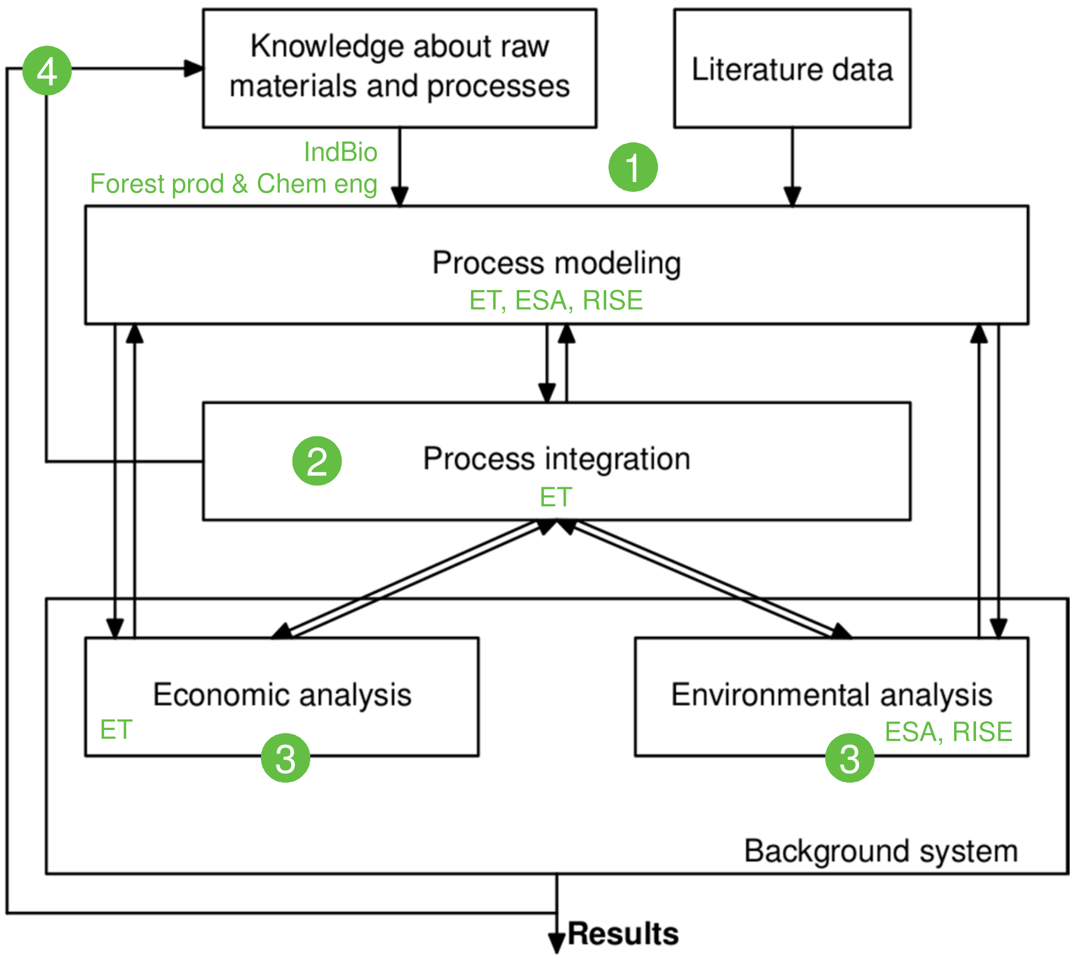


[1] A. Shimizu, K. Tanaka, and M. Fujimori. *Chemosphere - Global Change Science* 2.3-4 (2000), pp. 425–434.

Process flow diagram of the BioBuF concept



Information flow in the project - 1



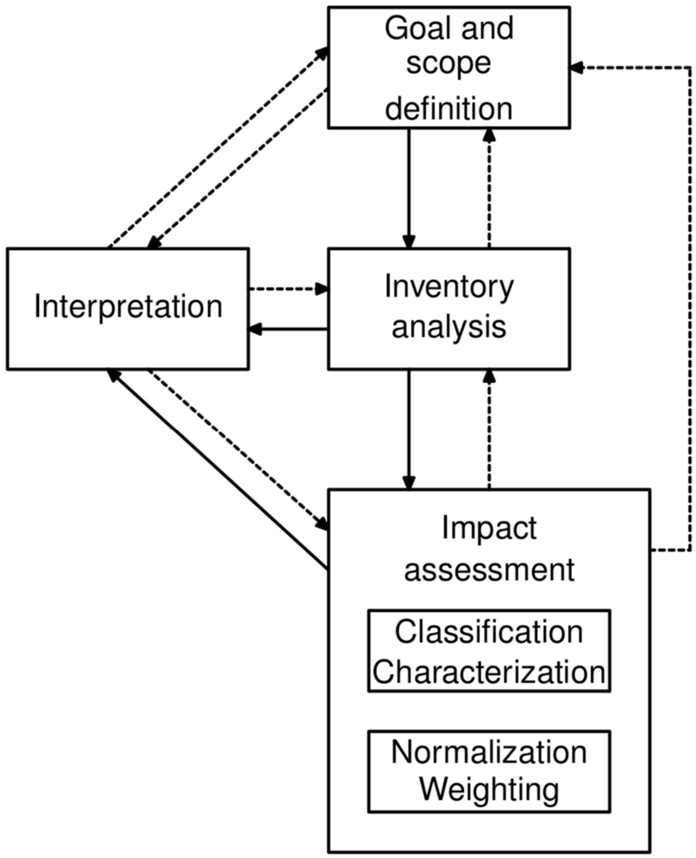
1. Modelling based on experimental, lab-scale data
2. Process integration
3. Economic and environmental analysis
4. Feedback to development

Information flow in the project – 2

- Development of systemic communication protocols → Maximize output from research of biorefineries

1. Lab scale → Experimental and in-silico data for enzyme selection, metabolic engineering and bio-reaction networks, biomass fermentation, anaerobic digestion, fractionation and lignin characterization, and bio-electrochemical systems
2. Process scale → Conceptual to rigorous process modelling and design of upstream and downstream separation technologies
3. Plant level → Process integration for material and energy recovery using scenario based and superstructure approaches
4. Economic and environmental assessment level → Operating and capital cost estimations, and environmental assessment using LCA

Life cycle assessment (LCA) framework



Environmental loads e.g.
- MJ fossil energy
- g SO_2
- g NO_x
- kg waste

Environmental potential effects, e.g.
- resource depletion
- global warming potential
- acidification potential

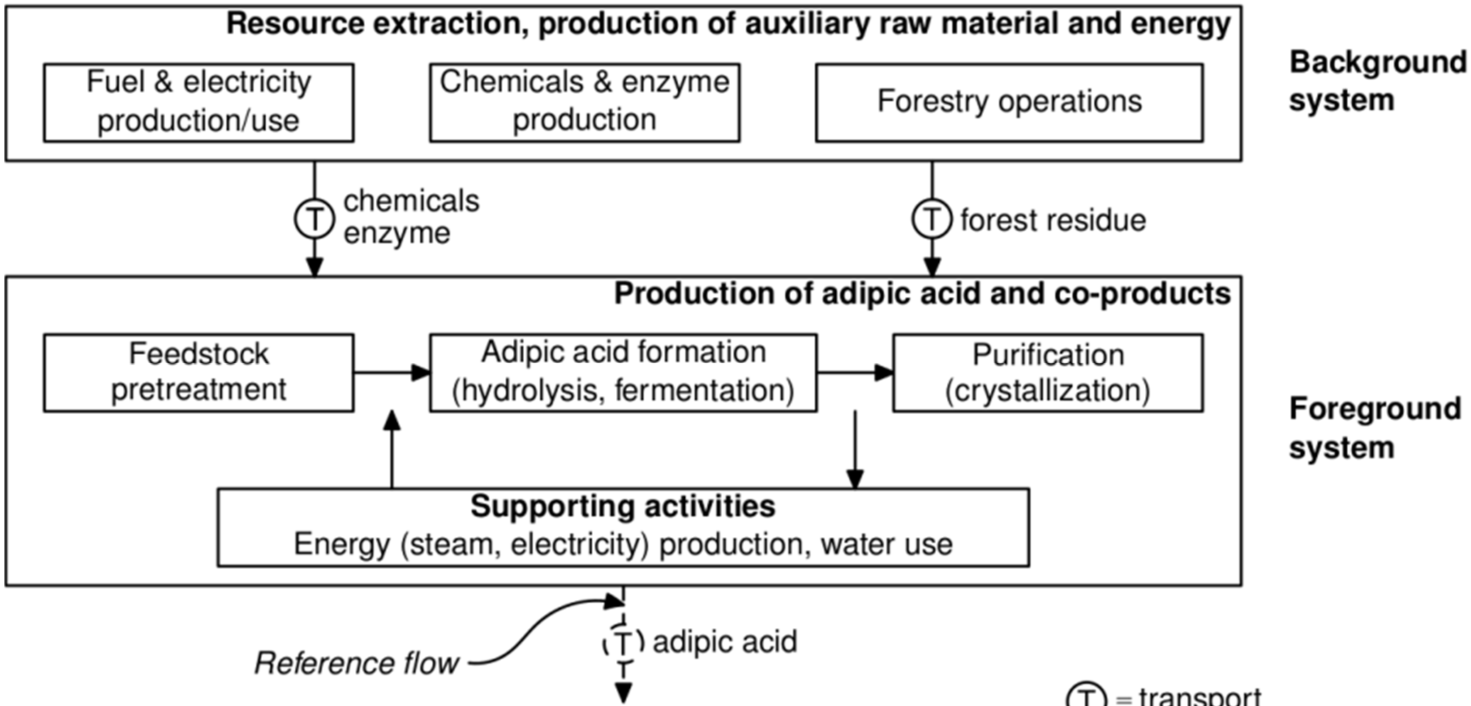
Final assessment e.g.
- one-dimensional index

Previous LCAs of adipic acid production

- ecoinvent process for adipic acid production[2,3]
  - Global warming ≈ 25 kg CO_2-eq/kg adipic acid produced
  - Elimination of N_2O emissions → 75% reduction of global warming
  - Switch to renewable resource → 10% reduction of global warming
- Production from cyclohexene using H_2O_2[4]
  - Fossil-based feedstock but no use of HNO_3
  - Global warming ≈ 6 kg CO_2-eq/kg adipic acid produced
- Production from aromatic compounds via fermentation[5]
  - Both fossil-based and bio-based feedstock, no N_2O emissions
  - Global warming reduction → 9 to 17 kg CO_2-eq/kg adipic acid produced

[2] H.-J. Althaus et al. Tech. rep. ecoinvent report No. 8. EMPA Dübendorf, 2007.
[3] E. Svensson et al. *10th Conference on Sustainable Development of Energy, Water and Environment Systems*. 2015.
[4] Q. Wang et al. *Chemical Engineering Journal* 234 (2013), pp. 300–311.
[5] J. van Duuren et al. *Biotechnology and Bioengineering* 108.6 (2011), pp. 1298–1306.

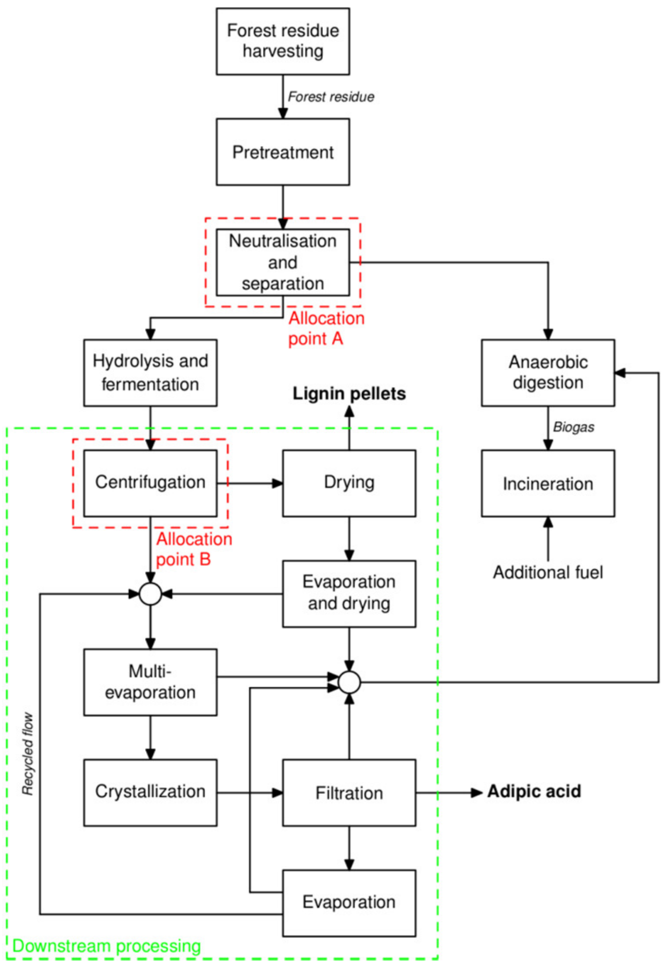
System description - 1



- Goal → Guide technology development[6]
- Functional unit → 1 kg of adipic acid produced

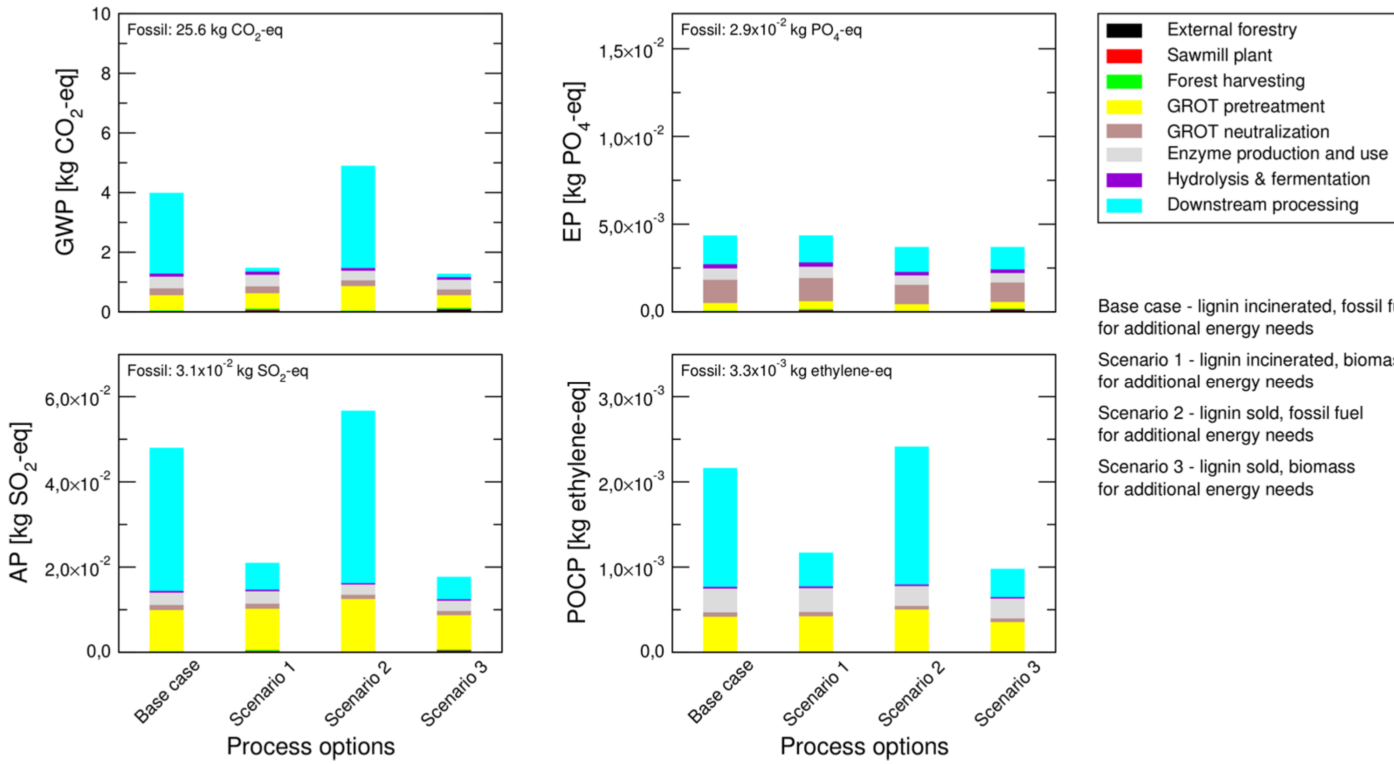
[6] R. Aryapratama and M. Janssen. Under review at Journal of Cleaner Production. 2017.

System description - 2



- Pretreatment
  - Acid-catalyzed → SO_2
  - Alkaline → $NaBH_4$
- Additional fuel use → Fossil, biomass
- Fermentation yield
  - Concentration of product
  - Lignin use → As fuel, as product

Acid-catalyzed pretreatment



Base case - lignin incinerated, fossil fuel for additional energy needs

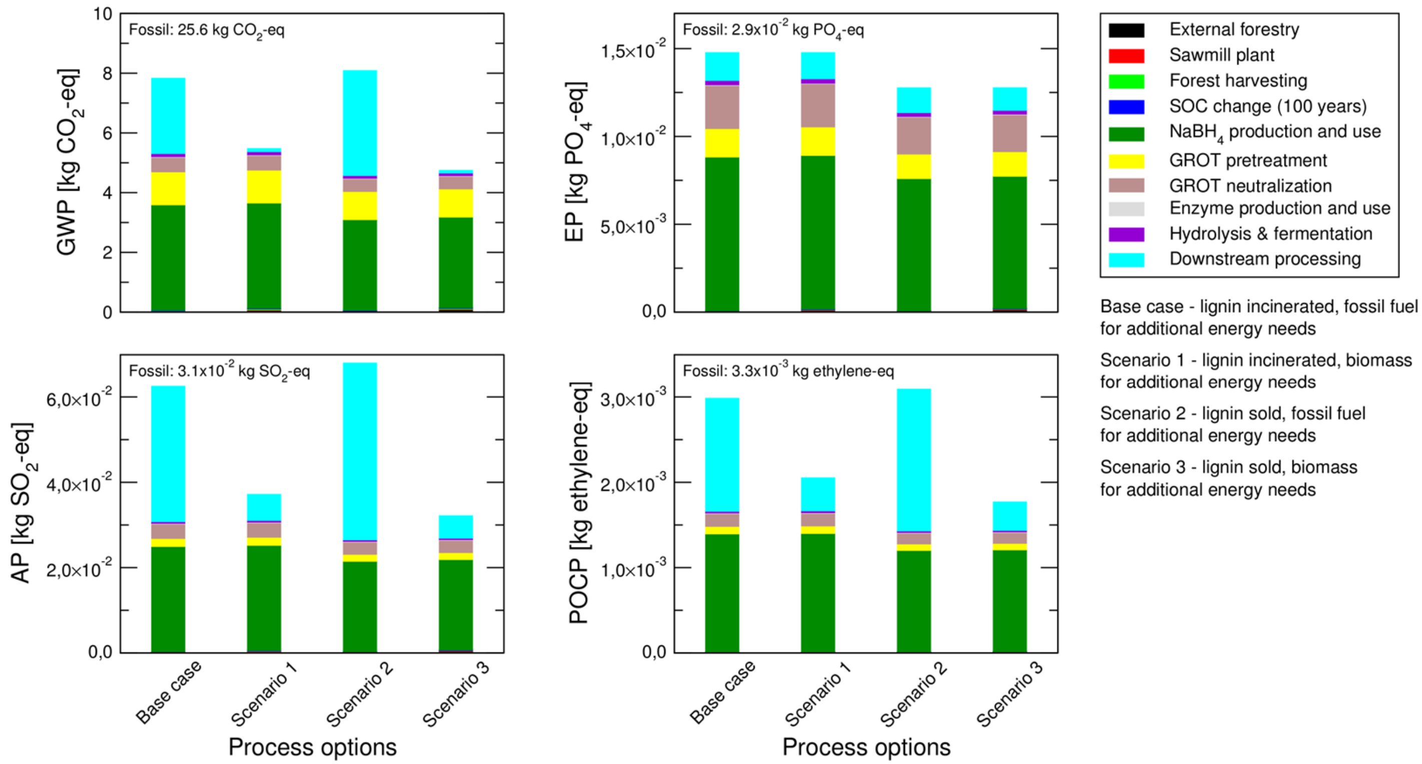
Scenario 1 - lignin incinerated, biomass for additional energy needs

Scenario 2 - lignin sold, fossil fuel for additional energy needs

Scenario 3 - lignin sold, biomass for additional energy needs

- Bio-based pathway → Significant environmental benefits
- Hotspots → Downstream, GROT pretreatment, enzyme production

Alkaline pretreatment



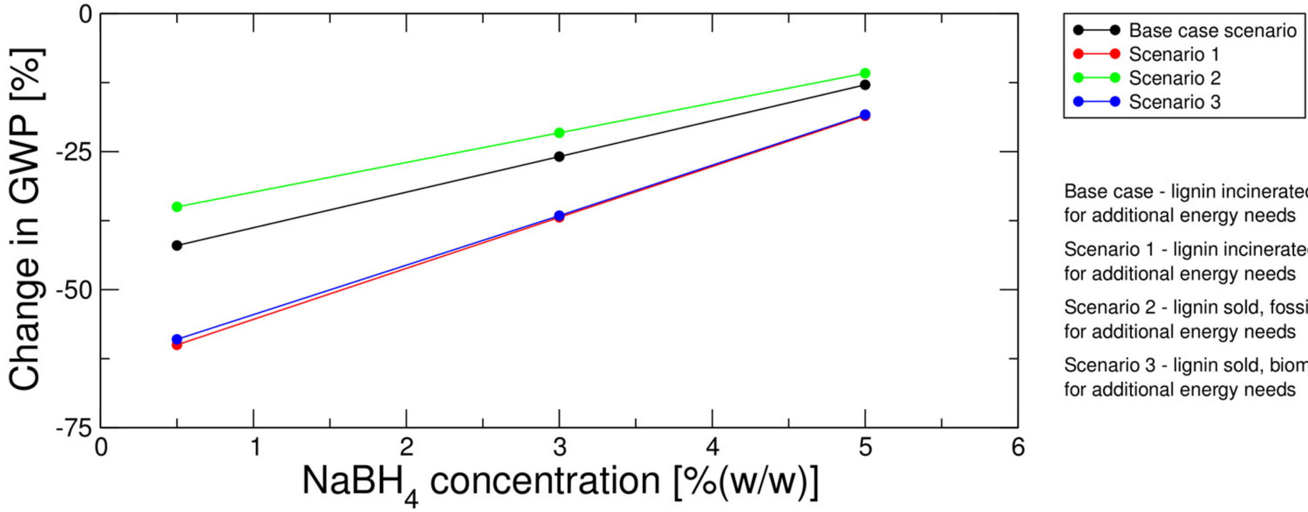
- Higher impacts when compared to the acid pretreatment
- Hotspots → $NaBH_4$, downstream processing, GROT neutralization

$NaBH_4$ production and use

- Switch to biomass use for energy purposes in $NaBH_4$ production

Scenario	GWP change [%]
Base case	-22
1	-32
2	-19
3	-32

- Change in dosage of $NaBH_4$ in pretreatment step



Base case - lignin incinerated, fossil fuel for additional energy needs

Scenario 1 - lignin incinerated, biomass for additional energy needs

Scenario 2 - lignin sold, fossil fuel for additional energy needs

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What have we learned?

- Technology
  - Moving from fossil-based to bio-based adipic acid production creates environmental benefits
  - Moving from fossil-based to bio-based adipic acid production may also lead to environmental burden shifting
  - Acid-catalyzed pretreatment performs better than alkaline pretreatment
- Methodology
  - Using data from large LCA databases can result in misleading results
  - Assessment of the complete biorefinery concept
  - Quantifying the benefits of integration of processes into an overall biorefinery concept

Prospective LCA

- Definition → "Studies of emerging technologies in early development stages, when there are still opportunities to use environmental guidance for major alterations"[7]

- Appropriate methodological choices need to be made
  - Technology alternatives
  - Foreground system
  - Background system
- Incorporating scale-up in LCA for technology under development
- Simulation and LCA

[7] R. Arvidsson et al. Under review at Journal of Industrial Ecology. 2017.

Thanks for your attention

Project partners:

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