Prospective life cycle assessment of adipic acid production from forest residue

Matty Janssen, Rio Aryapratama & Anne-Marie Tillman

Division of Environmental Systems Analysis
Department of Energy & Environment
Chalmers University of Technology
Göteborg, Sweden

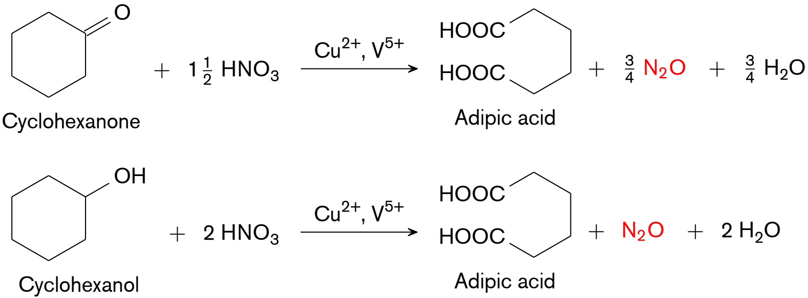
September 22, 2016

Outline

1. Traditional and alternative production of adipic acid
2. Previous LCAs of adipic acid production
3. Goal and scope of the assessment
4. Results
5. Conclusions

Fossil-based production of adipic acid

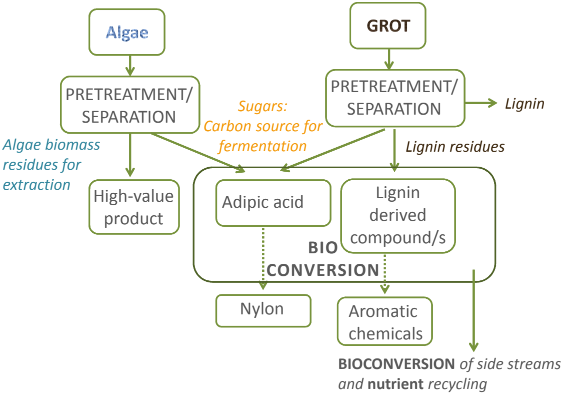
- Main application → Production of nylon-6,6
- Traditional production from fossil resources → KA oil[1]



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

Bio-based production of adipic acid

- Biorefinery concept for the production of bulk and fine chemicals



- Bulk chemical → Adipic acid, lignin derivative, e.g. terephthalic acid
- Fine chemical → Lutein

Previous LCAs of adipic acid production

- ecoinvent process for adipic acid production[2,3]
  - Global warming $\approx$ 25 kg CO_2-eq/kg adipic acid produced
  - Elimination of N_2O emissions $\rightarrow$ 75% reduction of global warming
  - Switch to renewable resource $\rightarrow$ 10% reduction of global warming

[2] H.-J. Althaus et al. Tech. rep. ecoinvent report No. 8. EMPA Dübendorf, 2007.

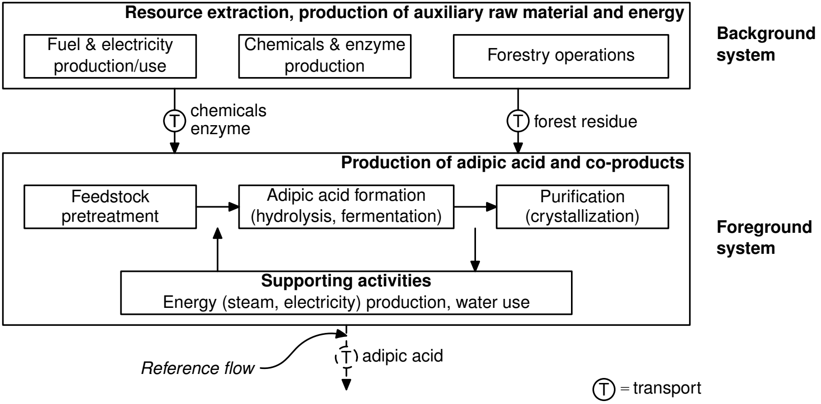
[3] E. Svensson et al. *10th Conference on Sustainable Development of Energy, Water and Environment Systems*. 2015.

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

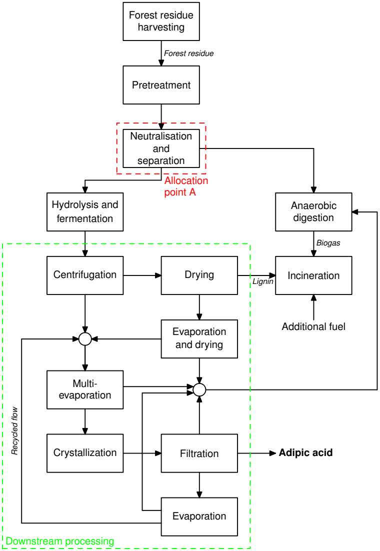
[2] H.-J. Althaus et al. Tech. rep. ecoinvent report No. 8. EMPA Dübendorf, 2007.
[3] E. Svensson et al. *10th Conference on Sustainable Development of Energy, Water and Environment Systems*. 2015.
[4] Q. Wang et al. *Chemical Engineering Journal* 234 (2013), pp. 300–311.
[5] J. van Duuren et al. *Biotechnology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

System description I



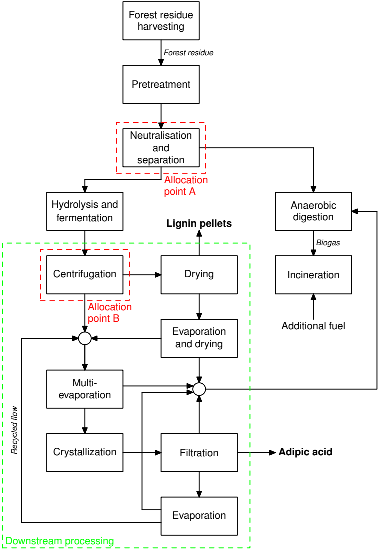
- Goal → Guide technology development
- Functional unit → 1 kg of adipic acid produced

System description II



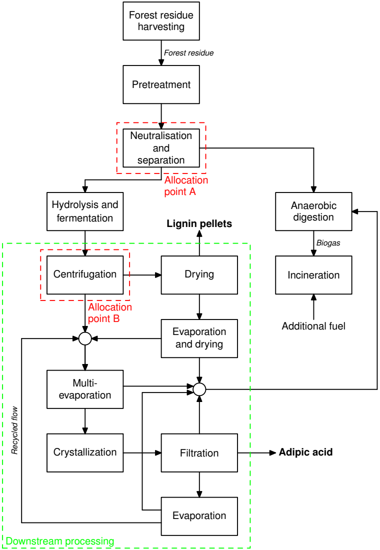
- Pretreatment
  - Acid-catalyzed → SO_2
  - Alkaline → $NaBH_4$
- Additional fuel use → Fossil, biomass
  - Fermentation yield
  - Concentration of product

System description II



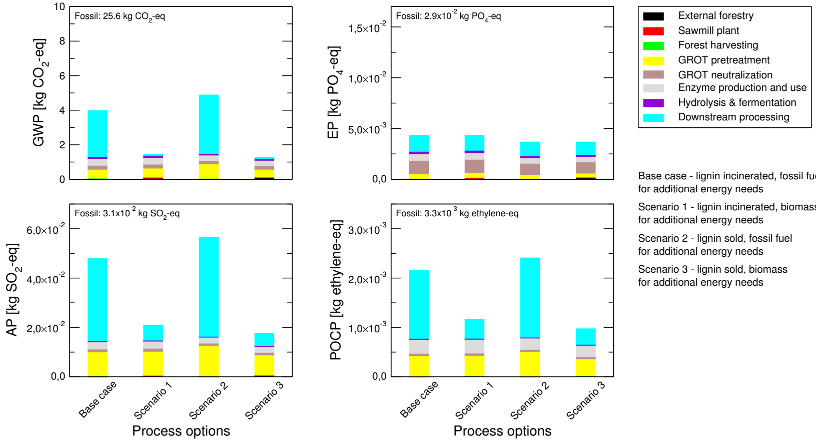
- Pretreatment
  - Acid-catalyzed → SO_2
  - Alkaline → $NaBH_4$
- Additional fuel use → Fossil, biomass
  - Fermentation yield
  - Concentration of product
- Lignin use → As fuel, as product

System description II



- Soil organic carbon change
- 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

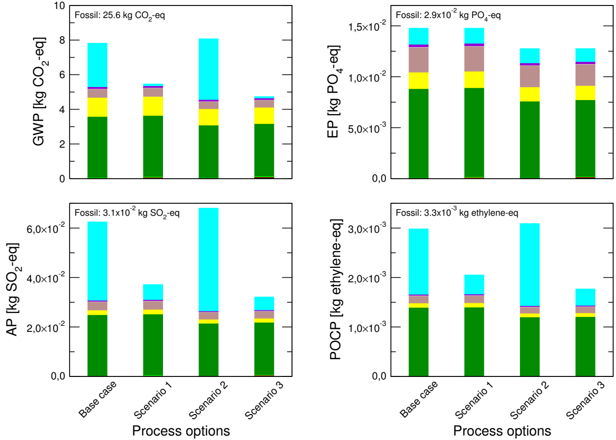
Scenario 1 - lignin incinerated, biomass for additional energy needs

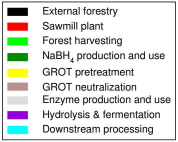
Scenario 2 - lignin sold, fossil fuel for additional energy needs

Scenario 3 - lignin sold, biomass for additional energy needs

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

Alkaline 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

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

$NaBH_4$ production and use

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

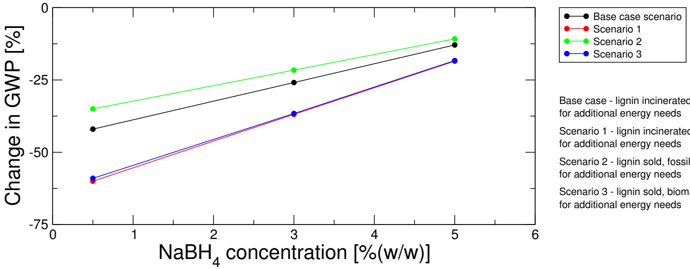
Scenario	**GWP change [%]**
Base case	-22
1	-32
2	-19
3	-32

$NaBH_4$ 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



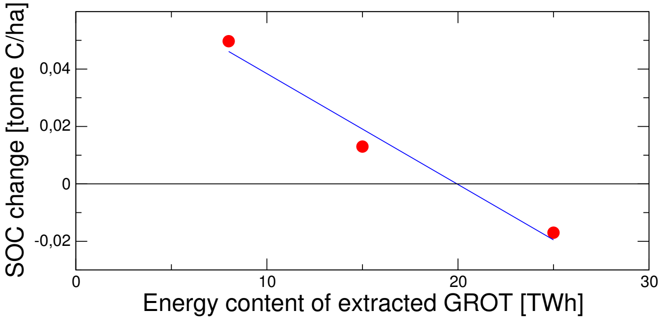
Base case - lignin incinerated, fossil fuel for additional energy needs

Scenario 1 - lignin incinerated, biomass for additional energy needs

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

Scenario 3 - lignin sold, biomass for additional energy needs

SOC change due to adipic acid production



- SOC change over 100 years[6]
- Plant capacity of 100 000 t per year → 2.9 TWh (or 6×10^5 t) of extra GROT extracted
- Loss of carbon of 3.2 g C (or 11.7 g CO_2) per kg adipic acid

[6] C. A. Ortiz et al. *Biomass and Bioenergy* 70 (2014), pp. 230–238.

Conclusions

- Significant environmental benefit when using to a forest-based feedstock
  - In some cases, worse AP
  - Further improvement by using biomass as an energy source

Conclusions

- Significant environmental benefit when using to a forest-based feedstock
  - In some cases, worse AP
  - Further improvement by using biomass as an energy source
- What are the environmental hotspots?
  - Acid-catalyzed pretreatment → Downstream processing, GROT pretreatment
  - Alkaline pretreatment → $NaBH_4$ production and use, downstream processing
- Alkaline pretreatment results in a higher environmental impact
  - Cleaner production of $NaBH_4$ can be achieved
  - Lower usage of $NaBH_4$

Conclusions

- Significant environmental benefit when using to a forest-based feedstock
  - In some cases, worse AP
  - Further improvement by using biomass as an energy source
- What are the environmental hotspots?
  - Acid-catalyzed pretreatment → Downstream processing, GROT pretreatment
  - Alkaline pretreatment → $NaBH_4$ production and use, downstream processing
- Alkaline pretreatment results in a higher environmental impact
  - Cleaner production of $NaBH_4$ can be achieved
  - Lower usage of $NaBH_4$
- Changes in organic carbon content in the soil due to adipic acid production are small
  - Insignificant climate impact
  - Other impacts?

THANK YOU
Any questions?

BIOBUF