Using life cycle assessment to guide technology development for bio-based production: An overview

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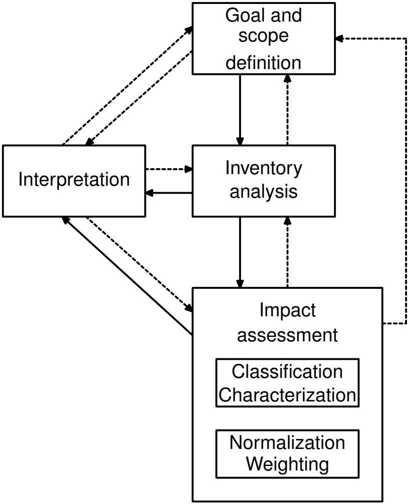
Outline

1. Life cycle assessment for technology development
2. High-gravity ethanol production from wood and wheat straw
3. Adipic acid production from forest residue
4. Sodium polyacrylate production from pulp mill side streams
5. Conclusion

Life cycle assessment (LCA) procedure



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

LCA for technology development

- Incorporating scale-up in LCA for technology under development
  - From raw lab-scale data to industrial scale processes
  - Scale-up frameworks have been proposed[1]

[1] F. Piccinno et al. *J Clean Prod* 135 (2016), pp. 1085–1097.

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- Simulation and LCA
  - Calculation and/or verification of process streams[2]
  - Methodological frameworks combining simulation and LCA[3]

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[2] C. Liptow and A.-M. Tillman. *J Ind Ecol* 16.3 (2012), pp. 420–435.
[3] R. Brunet, G. Guillén-Gosálbez, and L. Jiménez. *Ind Eng Chem Res* 51.1 (2012), pp. 410–424.

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- Prospective life cycle assessment (pLCA)[4]
  - Definition $\rightarrow$ studies of emerging technologies in early development stages, when there are still opportunities to use environmental guidance for major alterations
  - Appropriate methodological choices need to be made

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[3] R. Brunet, G. Guillén-Gosálbez, and L. Jiménez. *Ind Eng Chem Res* 51.1 (2012), pp. 410–424.
[4] R. Arvidsson et al. Under review at Journal of Industrial Ecology. 2016.

Ethanol production under high gravity conditions

- LCA along the development path[5,6,7]
  - To improve and/or optimize the HG fermentation processes in development from an environmental life cycle point-of-view
  - To help guide the technology development by providing stakeholders the environmental hotspots during all stages

[5] M. Janssen et al. *Bioresource Technol* 173 (2014), pp. 148–158.
[6] M. Janssen, C. Xiros, and A.-M. Tillman. *Biotechnol Biofuels* 9 (2016), p. 53.
[7] C. Xiros et al. *Biofuels Bioprod Biorefining* 11.1 (2017), pp. 15–27.

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  - To help guide the technology development by providing stakeholders the environmental hotspots during all stages
- Industrial-scale evaluation using raw lab data
  - Process calculations done in spreadsheet
  - Experimental set-up → 36 process options for wheat straw, 30 for spruce wood chips
  - Base case experiments for both feedstocks

[5] M. Janssen et al. *Bioresource Technol* 173 (2014), pp. 148–158.
[6] M. Janssen, C. Xiros, and A.-M. Tillman. *Biotechnol Biofuels* 9 (2016), p. 53.
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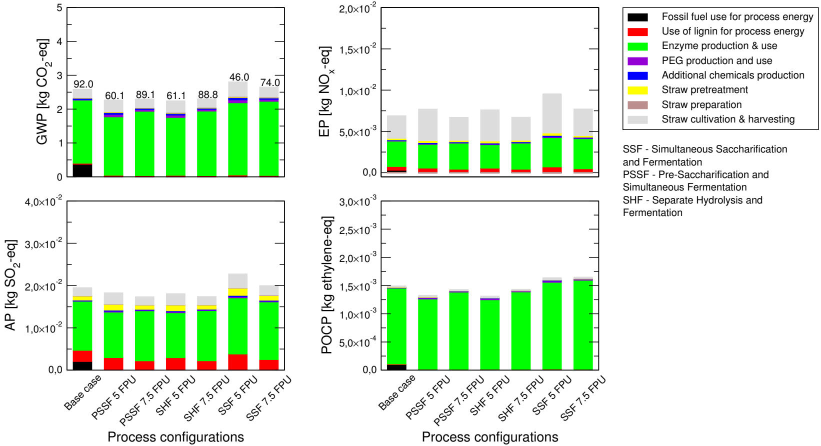
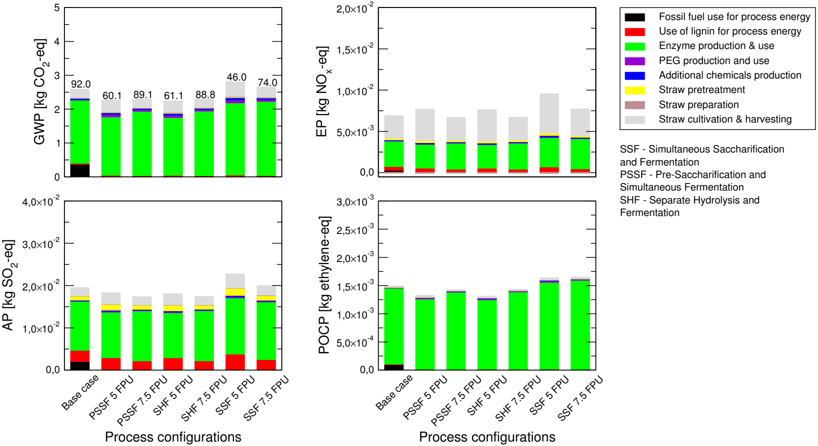
Environmental hotspots in ethanol production from straw



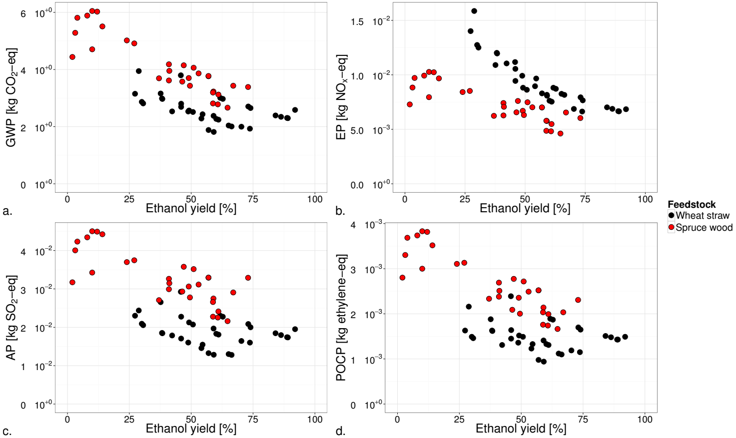
SSF - Simultaneous Saccharification and Fermentation
PSSF - Pre-Saccharification and Simultaneous Fermentation
SHF - Separate Hydrolysis and Fermentation

Environmental hotspots in ethanol production from straw



- Enzyme production and use is the main hotspot
- Yield is the main determinant of the environmental impact

Comparison of ethanol from wheat straw and spruce wood chips



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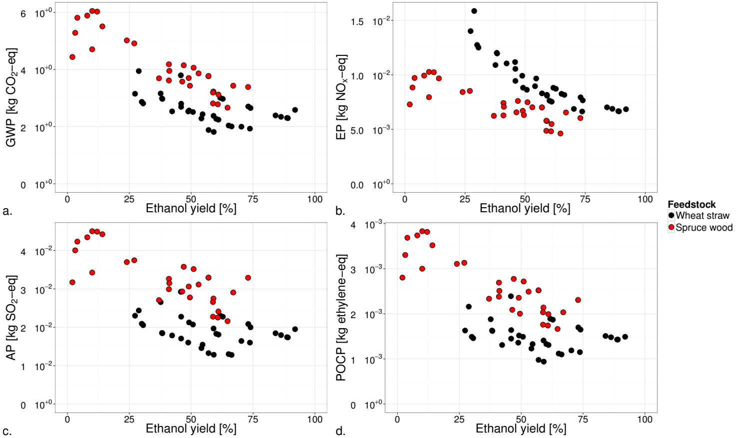

- Environmental impact is similar for the two feedstocks

Lowering the impact of enzyme production and use?

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- Enzyme recycling during straw-based ethanol production

Process configuration	Reduction of environmental impacts GWP [%]	EP [%]	AP [%]	POCP [%]
Base case	19	20	13	20
Highest yield at 20 % DM	18	18	14	21
Highest yield at 30 % DM	20	17	14	22

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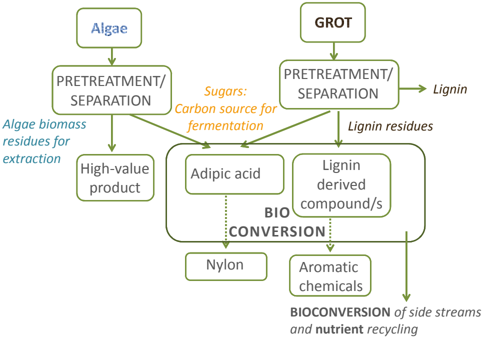
- On-site enzyme production during wood-based ethanol production

Process configuration	Reduction of environmental impacts GWP [%]	EP [%]	AP [%]	POCP [%]
Base case	59	53	32	67
Highest yield at 20 % DM	62	68	44	77
Highest yield at 30 % DM	65	69	51	85

Bio-based production of adipic acid

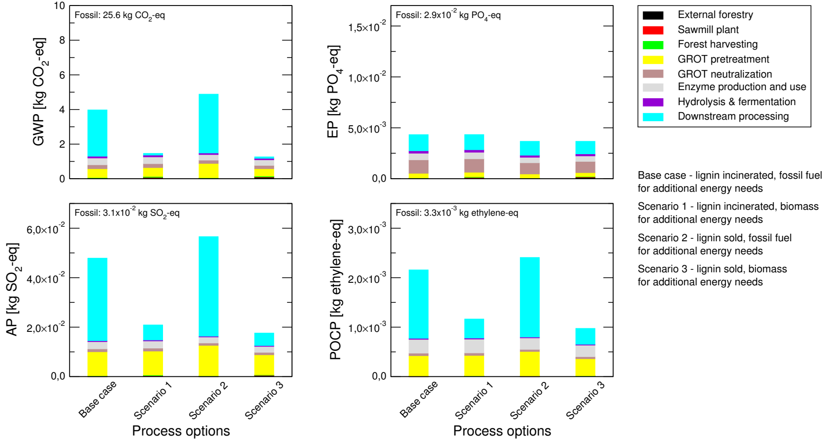
- Biorefinery concept for the production of bulk and fine chemicals



- Bulk chemical → Adipic acid[8], lignin derivative, e.g. caffeic acid
- Fine chemical → Lutein

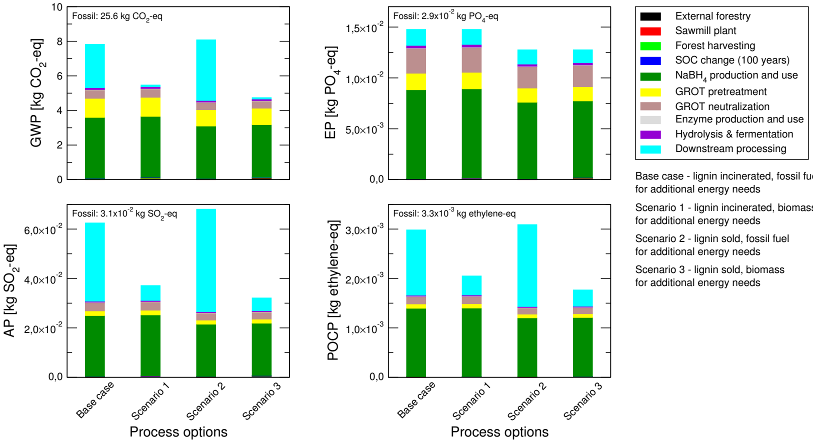
[8] R. Aryapratama and M. Janssen. Under review at Journal of Cleaner Production. 2017.

Acid-catalyzed pretreatment



- 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

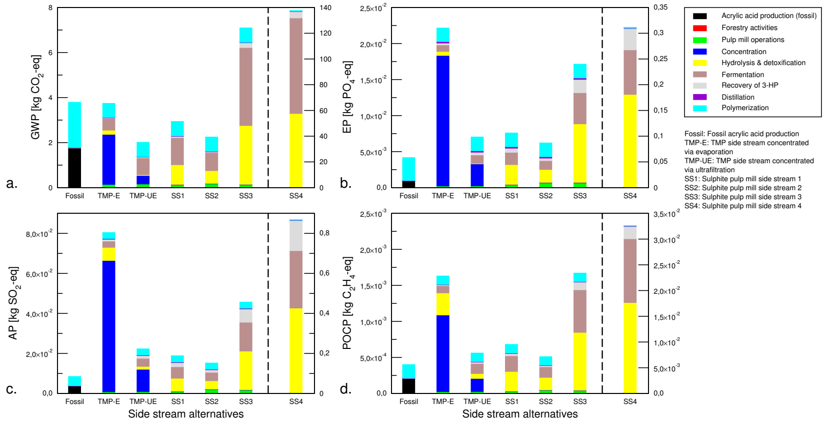
- Higher impacts when compared to the acid pretreatment
- Hotspots → $NaBH_4$, downstream, GROT neutralization

Biobased sodium polyacrylate production from pulp mill side streams

- Super-absorbent used in various hygiene products
- Purpose of the LCA[9] $\rightarrow$ Compare the production of renewable, bio-based sodium polyacrylate and its non-renewable, fossil-based counterpart
- Case study for thermo-mechanical and sulfite pulp mills
- Production in an integrated biorefinery concept from fermentable sugars present in diluted side streams

[9] P. Gontia and M. Janssen. *J Clean Prod* 131 (2016), pp. 475–484.

Environmental impacts for different side streams



- Main determinant of the environmental impact is the sugar concentration in the side streams
- Higher fermentation yield → Lower environmental impact

Environmental impacts important for bio-based production

- Other GHG, N_2O, CH_4 – Possible, not always included
- Impact of biogenic CO_2 – Methods proposed, still under discussion
- Pesticides – possible, not always included
- Eutrophication, N, P – possible, often included
- Impact on biodiversity – Some methods start to emerge
- Land use change – Sometimes done, results highly uncertain and controversial

LCA for technology development

- Scale-up from lab to industrial scale
  - Assumptions need to be carefully considered
  - There are frameworks, but these are not widely applied
  - Sensitivity analysis for important process parameters and variables
- Integration of LCA and simulation can be improved
- Prospective life cycle assessment
  - Technology alternatives
  - Foreground system data
  - Background system
- LCA gives valuable information regarding further technology development

THANK YOU

Any questions?