Life cycle assessment during early development stage of a new bio-ethanol production process

Matty Janssen & Anne-Marie Tillman

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

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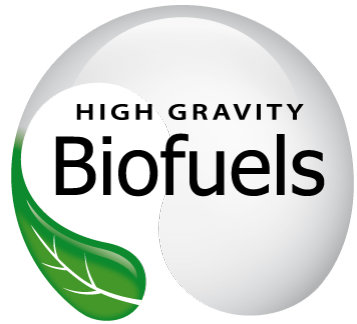

Outline

High-gravity production of biofuels

- Second generation biofuels using wood and wheat straw
- Economically feasible process $\rightarrow$ High gravity fermentation
  - Lower water use
  - Difficulties with mixing
  - High concentrations of end products and inhibitors

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  - Lower water use
  - Difficulties with mixing
  - High concentrations of end products and inhibitors
- Use LCA along the process development path
  - To improve and/or optimize the process from an environmental life cycle point-of-view
  - To help guide the technology development by providing stakeholders the environmental hotspots during all stages

Technology development and scale

- Development "stages" with respect to system boundaries[1]
  - Process step → Scale-up of equipment
  - Process complex → Optimization of the complete process
  - Value chain → Inclusion of the upstream and downstream processes

[1] M. Shibasaki and S. Albrecht. *Proceedings of European Congress of Chemical Engineering (ECCE-6)*. 2007, p. 5.

Technology development and scale

- Development "stages" with respect to system boundaries[1]
  - Process step → Scale-up of equipment
  - Process complex → Optimization of the complete process
  - Value chain → Inclusion of the upstream and downstream processes
- Time and scale in technology LCA[2]
  - Shifting time frame → Room for technical development, affects performance data, perhaps functional unit
  - Change in background system related to time and scale of penetration

[1] M. Shibasaki and S. Albrecht. *Proceedings of European Congress of Chemical Engineering (ECCE-6)*. 2007, p. 5.

[2] K. M. Hillman and B. A. Sandén. *International Journal of Alternative Propulsion* 2.1 (2008), pp. 1–12.

Process alternatives and base case

- Inbicon's IBUS process[3] in Kalundborg, Denmark
  - Feedstock is wheat straw
  - Hydrothermal pretreatment

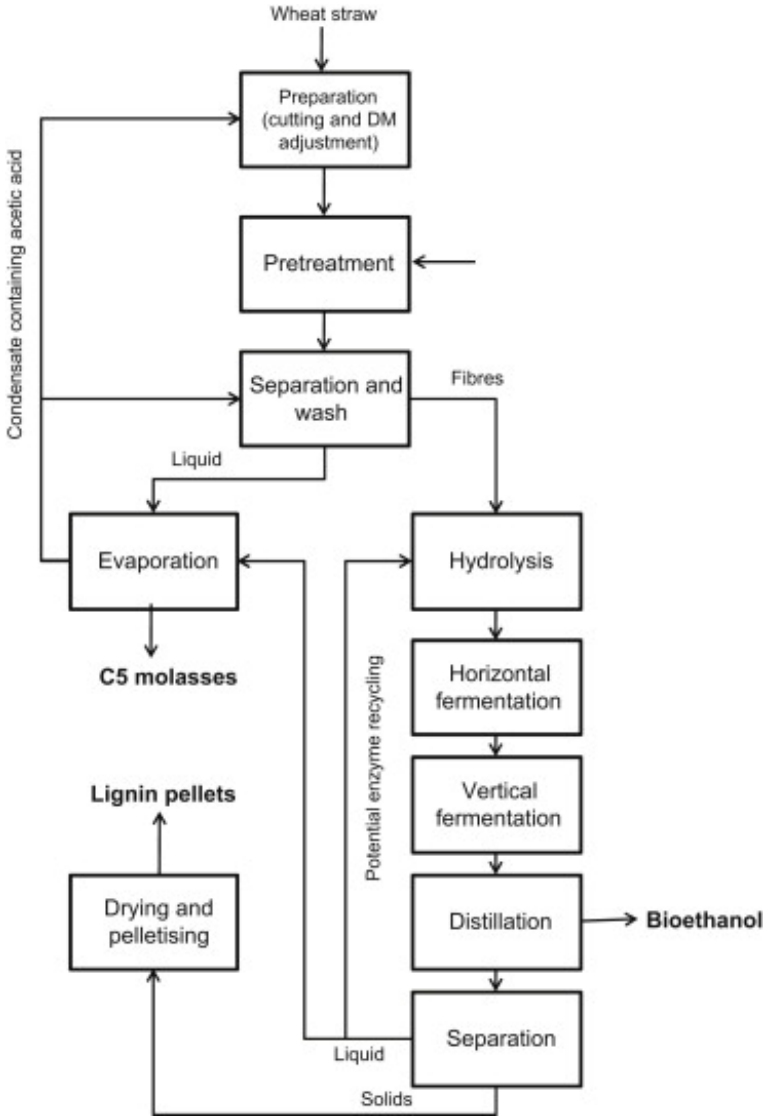
[3] J. Larsen, M. Østergaard Haven, and L. Thirup. *Biomass and Bioenergy* 46 (2012), pp. 36–45.

Process alternatives and base case

- Inbicon's IBUS process[3] in Kalundborg, Denmark
  - Feedstock is wheat straw
  - Hydrothermal pretreatment
- Industrial-scale evaluation using raw lab data
  - Process calculations done in spreadsheet
  - Experimental set-up $\rightarrow$ 33 process options
    - Type of enzyme
    - Process configurations
    - Enzyme load
    - Solids content in the reactor
    - Additive to increase enzyme activity
  - Base case experiment

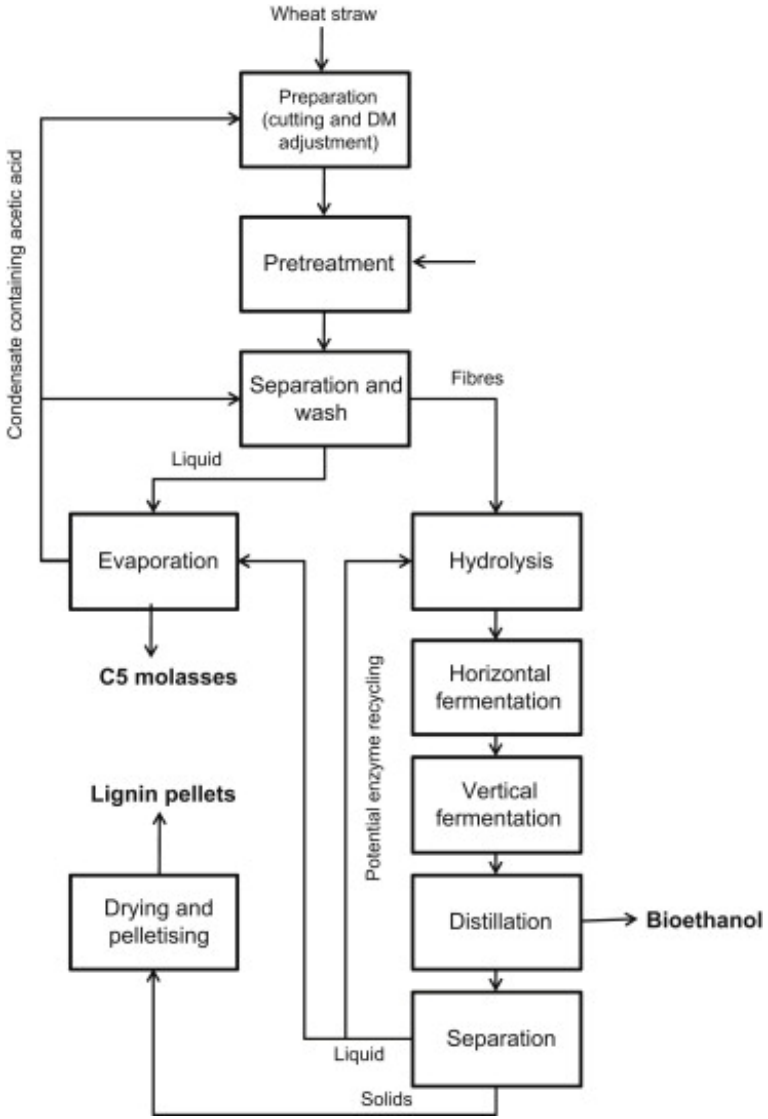
[3] J. Larsen, M. Østergaard Haven, and L. Thirup. *Biomass and Bioenergy* 46 (2012), pp. 36–45.

Inventory analysis for straw-based ethanol production



Cultivation and harvest

Inventory analysis for straw-based ethanol production

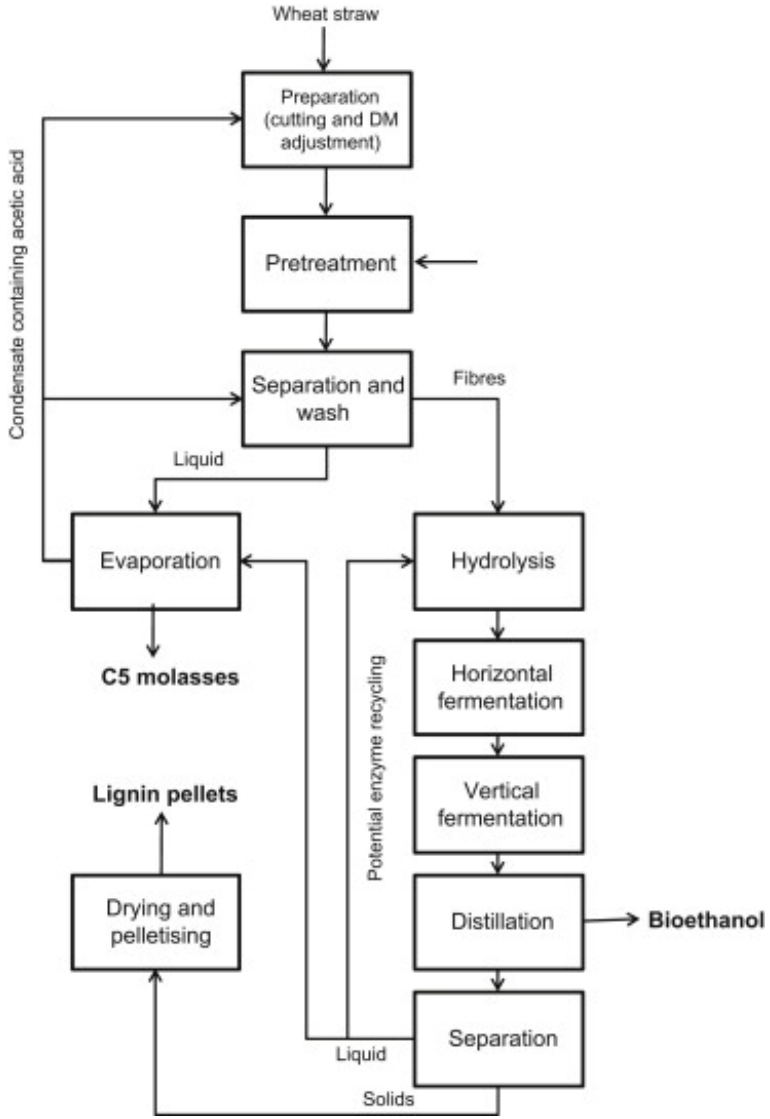


Cultivation and harvest

Preparation and pretreatment

- Conditions: p=15 bar, T=195 °C
- Lignin used as energy source

Inventory analysis for straw-based ethanol production



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Hydrolysis & fermentation

- Differences in conversion efficiency
- Yield as basis for mass balance

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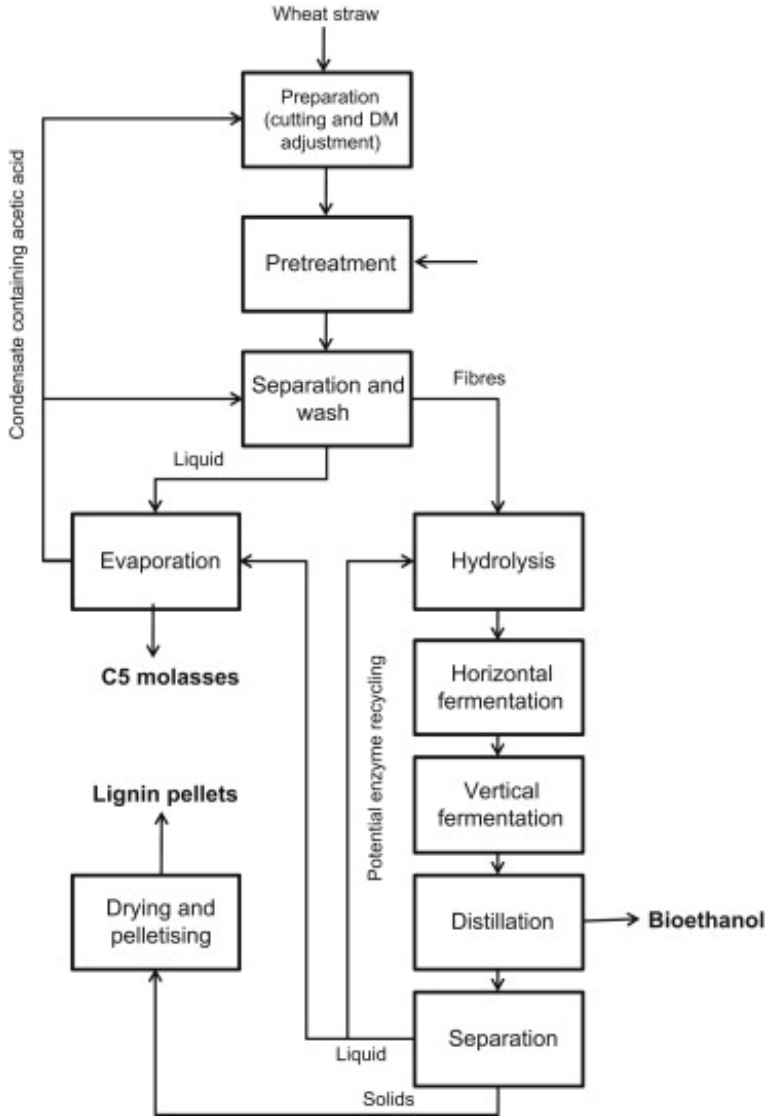

Cultivation and harvest

Preparation and pretreatment

- Conditions: p=15 bar, T=195 °C
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Hydrolysis & fermentation

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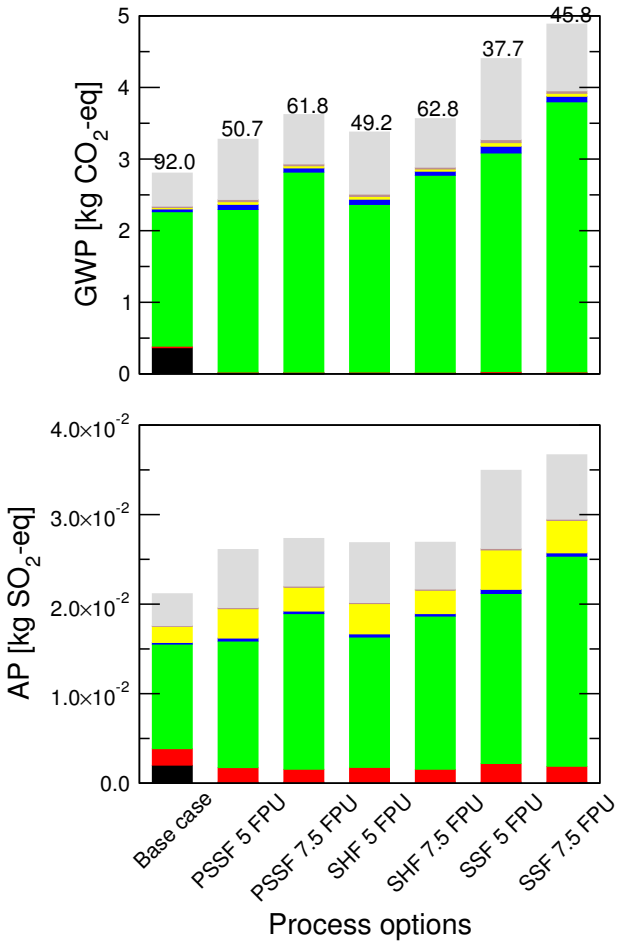
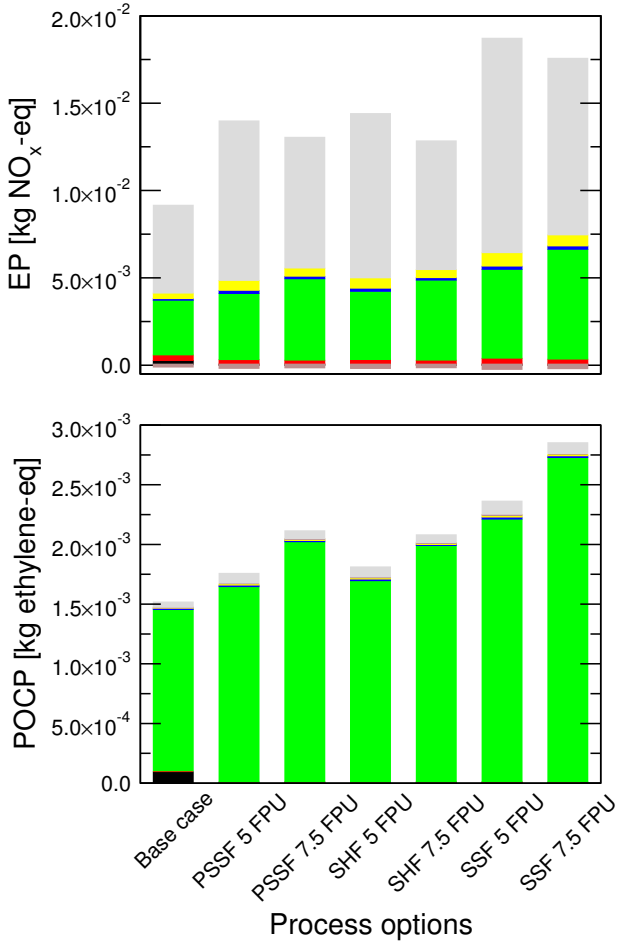
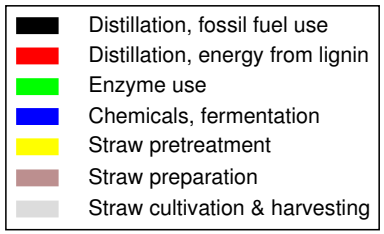
Downstream processing

- Heat duty in distillation varies little at higher ethanol concentration
- Lignin used as energy source

Results for 30% dry matter content

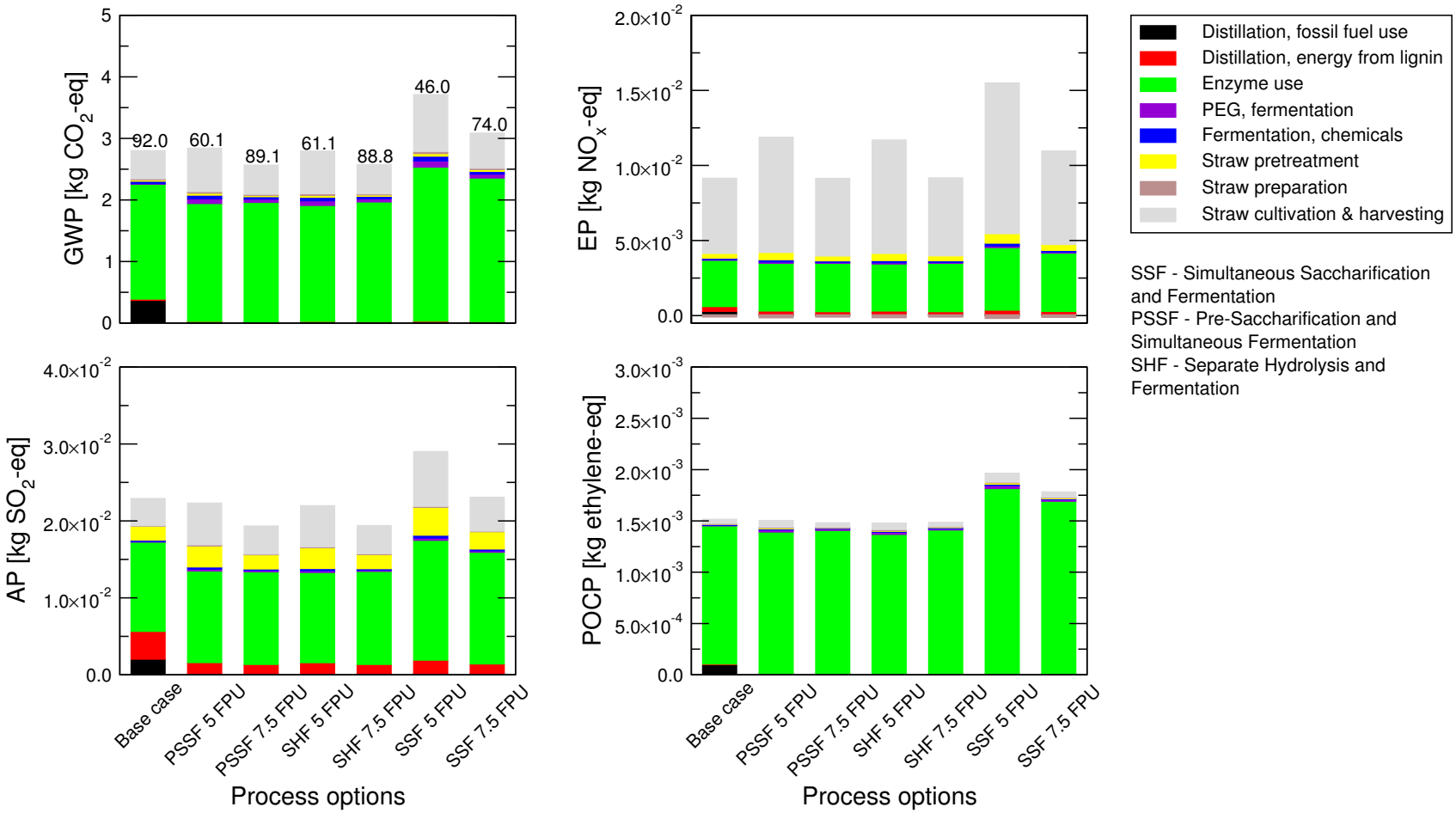






SSF - Simultaneous Saccharification and Fermentation
PSSF - Pre-Saccharification and Simultaneous Fermentation
SHF - Separate Hydrolysis and Fermentation

Results for 30% dry matter content, PEG added



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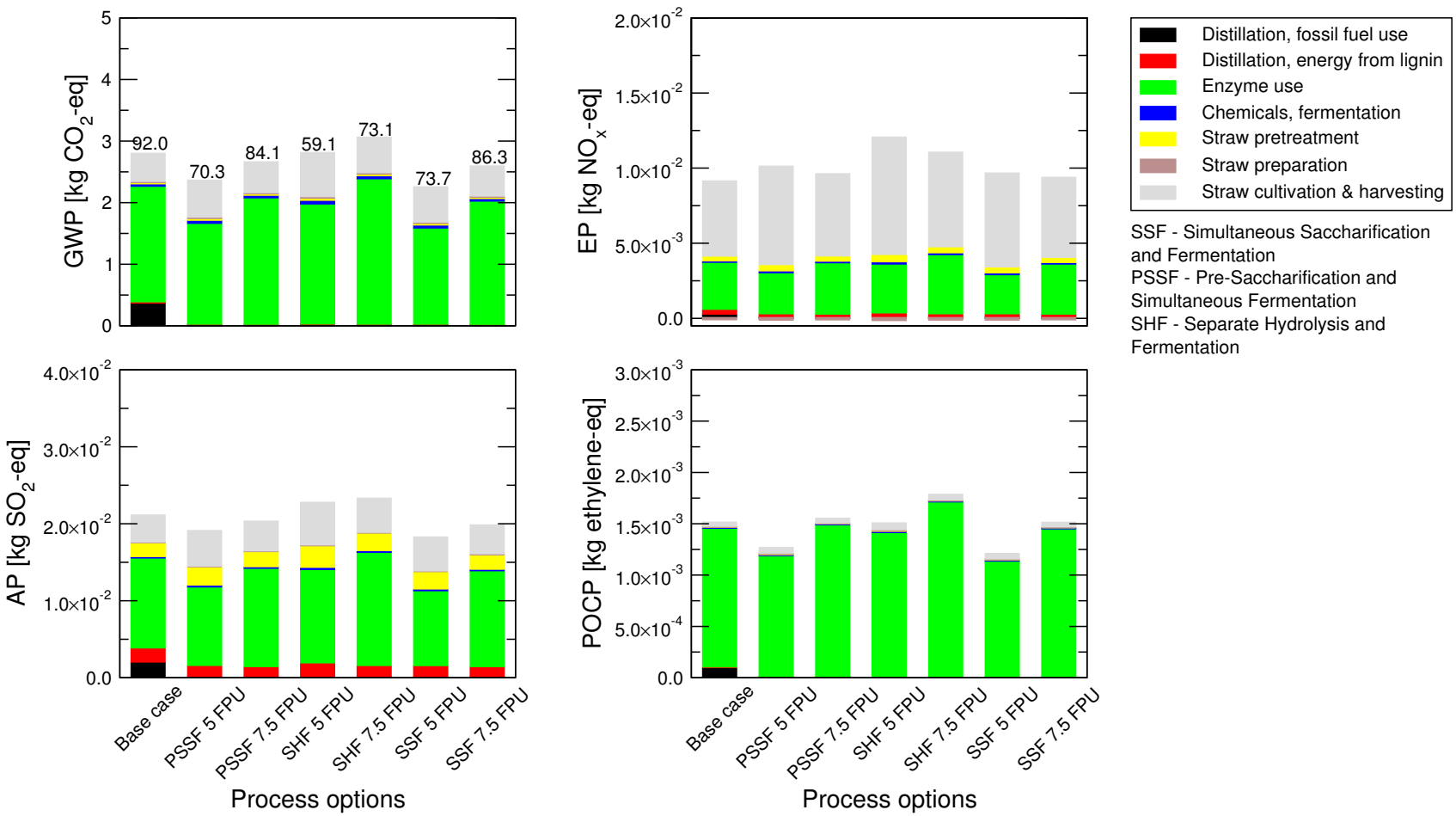
Results for 20% dry matter content



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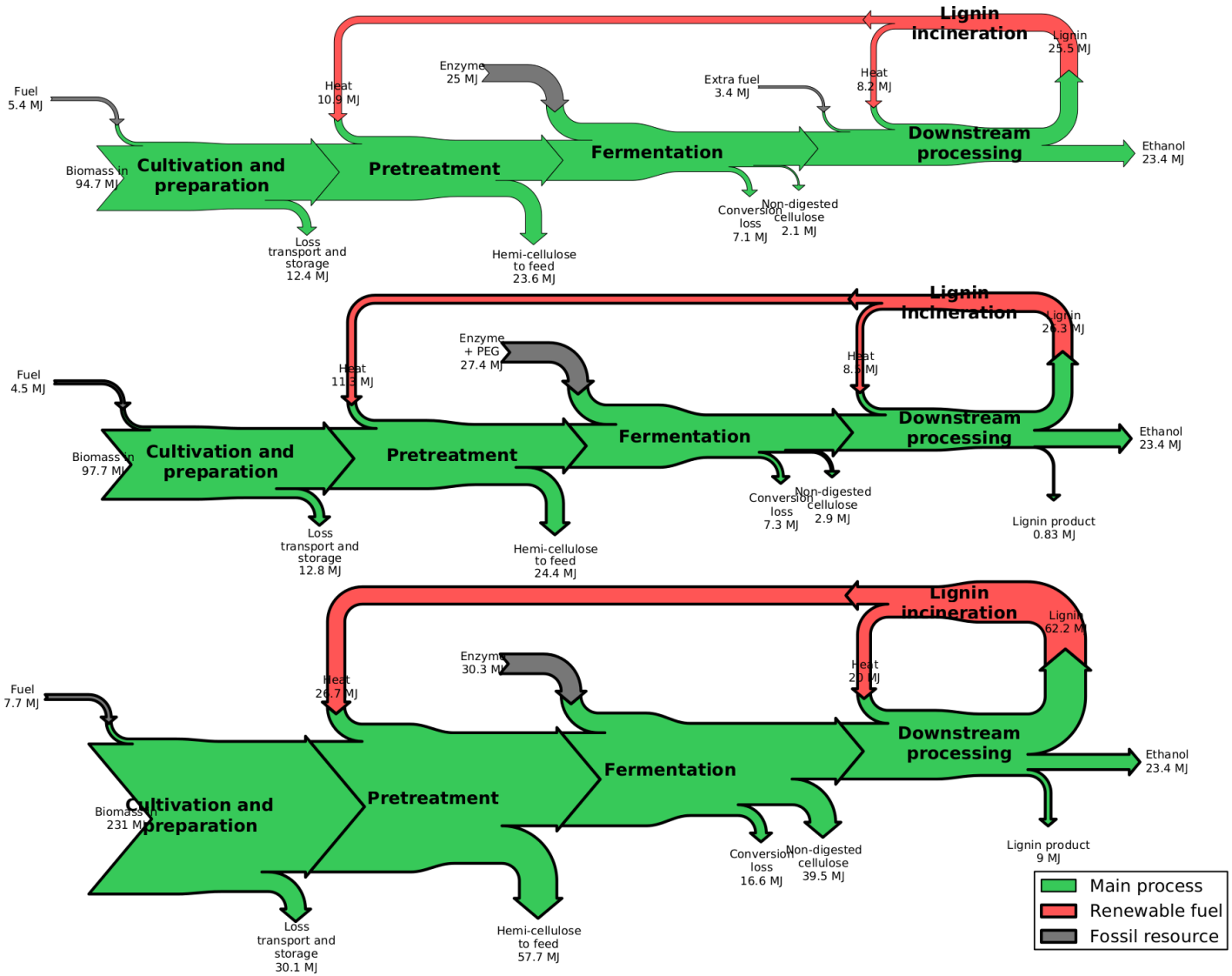
Energy flows in process options

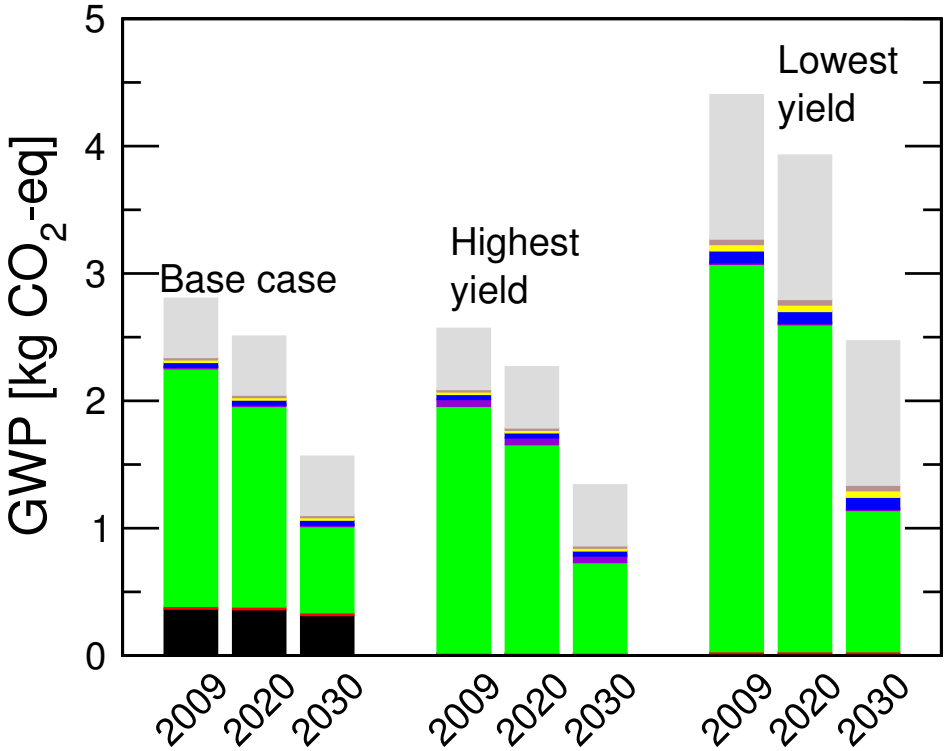


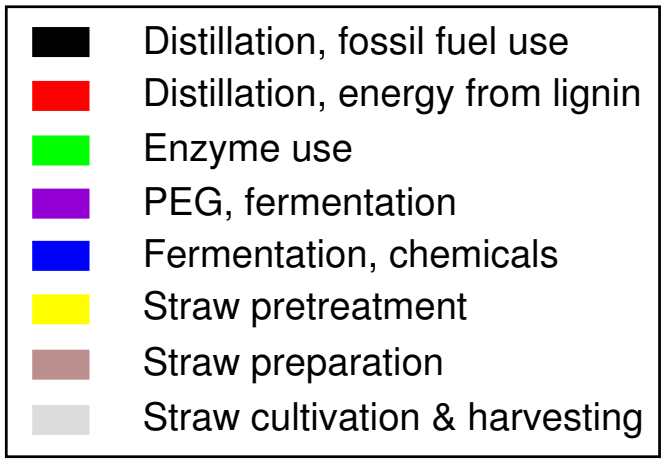
Base case

Highest yield

Lowest yield

Change in energy mix over time





Base case (yield = 92%) - 10% DM, 7.5 FPU
Highest yield (yield = 89%) - 30% DM, 7.5 FPU, PSSF, PEG addition
Lowest yield (yield = 38%) - 30% DM, 5 FPU, SSF

Fossil share in energy mix:
- 2009: 80%
- 2020: 67%
- 2030: 50%

Conclusion

- Related to the case study results
  - Enzyme use has a significant impact
  - Several trade-offs can be identified that influence environmental impact
  - Energy analysis provides additional information about the process options

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  - Enzyme use has a significant impact
  - Several trade-offs can be identified that influence environmental impact
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- Related to scale-up
  - Equipment scale-up $\rightarrow$ Use data of industrial scale processes with similar characteristics
  - Complete system scale-up $\rightarrow$ Increased use of biomass
  - Level of detail needed at a very early development stage

THANK YOU

Any questions?