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Lignocellulosic biomass for the production of platform chemicals – economic and ecological assessment of a biorefinery concept

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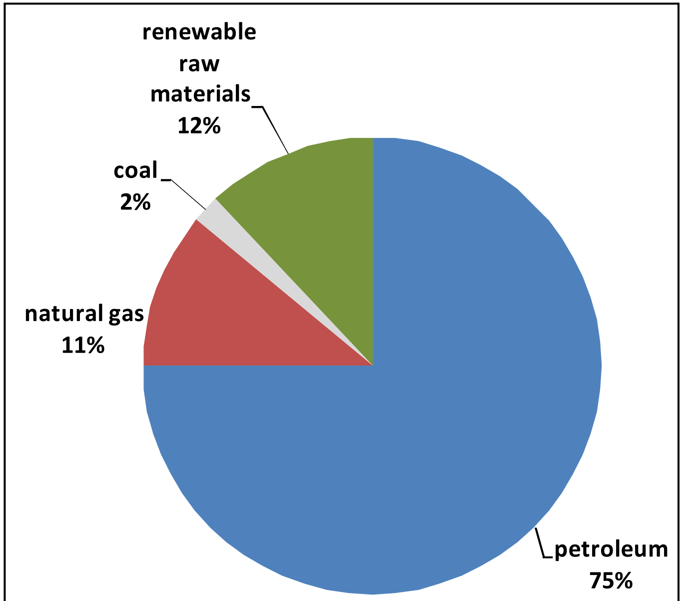
Renewable raw materials in the German chemical industry

- Ca. 2 million t of renewable raw materials are currently used in the chemical industry in Germany per year
- Currently especially vegetable oils, starch and animal fats are used for the production of e.g. tensides, polymers, lubricants
- Prospective use of lignocellulosic biomass for the production of platform chemicals and new materials
- Reduction of dependency on crude oil imports and securing of raw material supply



Raw material proportions of the German chemical industry (VCI 2008, FNR 2007)

⇒ Enhancement of research and development regarding new biomass conversion technologies

Platform chemicals from lignocellulosic biomass (examples)

Feedstock → **Precursors** → **Platform chemicals**

Lignocellulosic Biomass ❯ **Pulping, Separation** ❯ Cellulose, Hemicellulose, Lignin ❯ **Enzymatic conversion** / **Chemical conversion** ❯ Glucose, Xylose, Furfural, Phenol-derivatives

Feedstock	Pulping, Separation	Precursors	Conversion	Platform chemicals
Wood chips Bark	Possible solvents: - Ethanol/Water - Ionic Liquids - H_2SO_4	Potential material utilisation, e.g. - Binding agents - Fillers - Polymer compounds - Pulp - Cellulose derivatives	e.g. chemical or enzymatic hydrolysis	Subsequent processing to various products, e.g. - Fuel additive - Polyethylene - PLA - Acrylic acid

Objectives of the techno-economic and ecological assessment

- Estimation of costs and environmental effects for the production of glucose, xylose and lignin from wood along the whole value chain
- Determination of economic and ecological key parameters
- Identification of cost-effective and environmentally sound process configurations at an early stage of process development

Methodology for the evaluation of process chains

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Determination of a reference configuration

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Modelling of material and energy flows along the whole value chain
(e.g.: Material flow analysis, process simulation)

↓

Estimation of raw and auxiliary material flows, energy demand, waste streams, amount of products and emissions for different scenarios

↓

Economic assessment

Estimation of investments and production costs

Ecological assessment

E.g. acidification, eutrophication, global warming potential

Location and logistics planning

Availability of raw materials, infrastructure, consideration of different plant sizes

↓

Sensitivity analysis

Reference configuration of the modelled biorefinery

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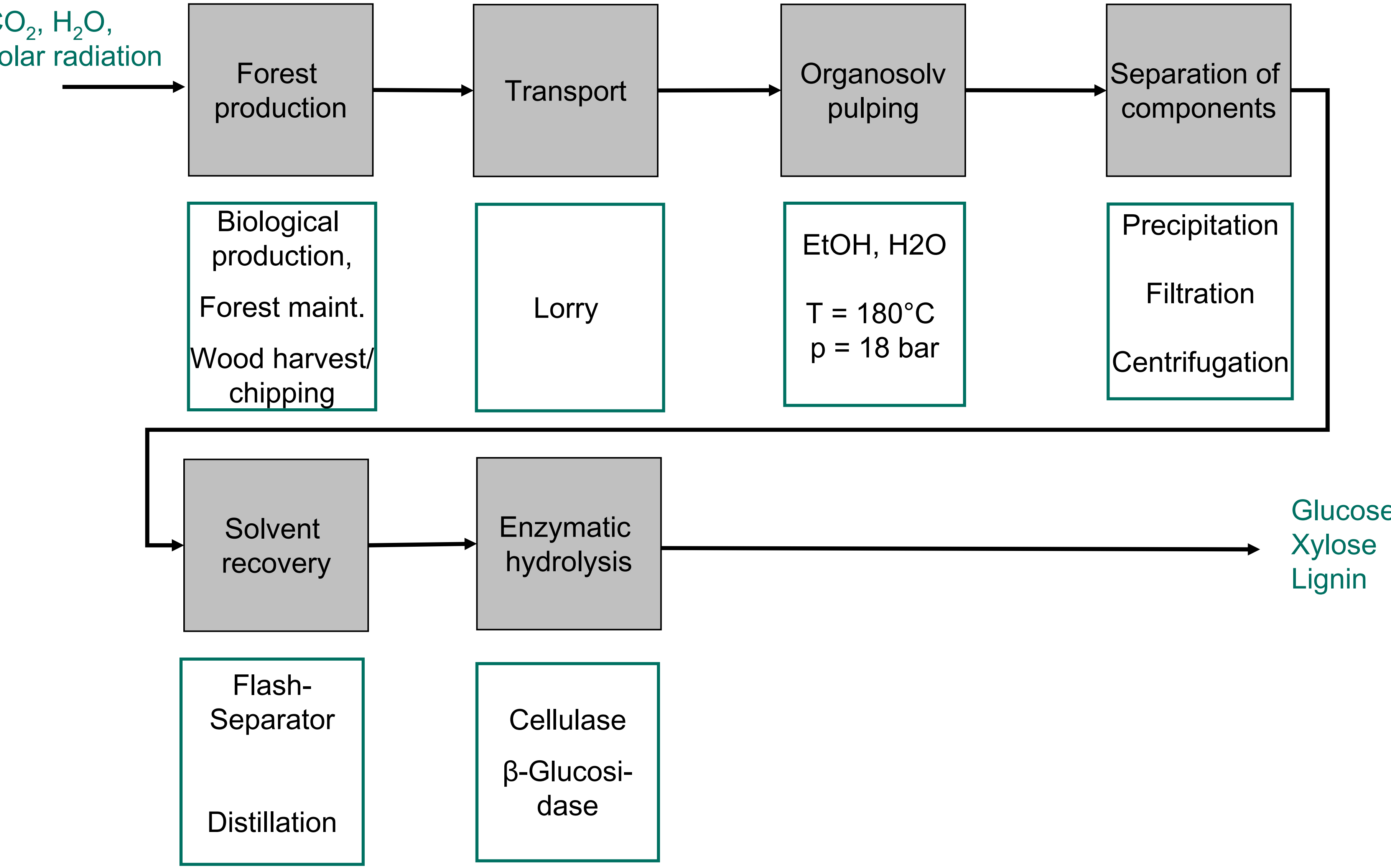
- Framework: Research project „Pilotprojekt Lignocellulose Bioraffienerie“

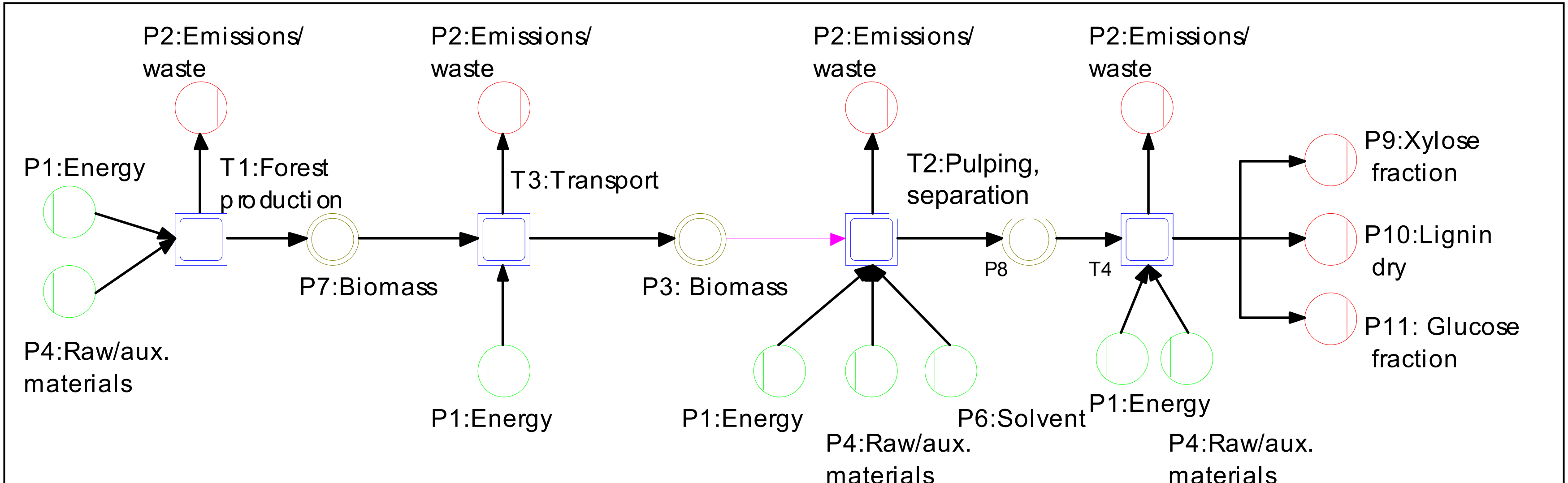
Plant capacity:	400.000 t dry wood/year
Load:	50 t dry wood/h (8000 h/year)
Feedstock properties :	Wood chips of residual wood (50% water content)
Organosolv pulping:	Ethanol/water solvent (50/50) Ratio wood : solvent = 1 : 6
Enzymatic conversion of cellulose:	Conversion rate to glucose: 82%
Hemicellulose fraction:	Solute hemicellulose fragments after organosolv pulping are subsumed to xylose
Final products:	Main product: Glucose (solution ~16 mass-%), Byproducts: Xylose (solution ~5 mass-%), lignin (dry)

Major process steps for the production of glucose from wood



Modeling of material and energy flows with Umberto

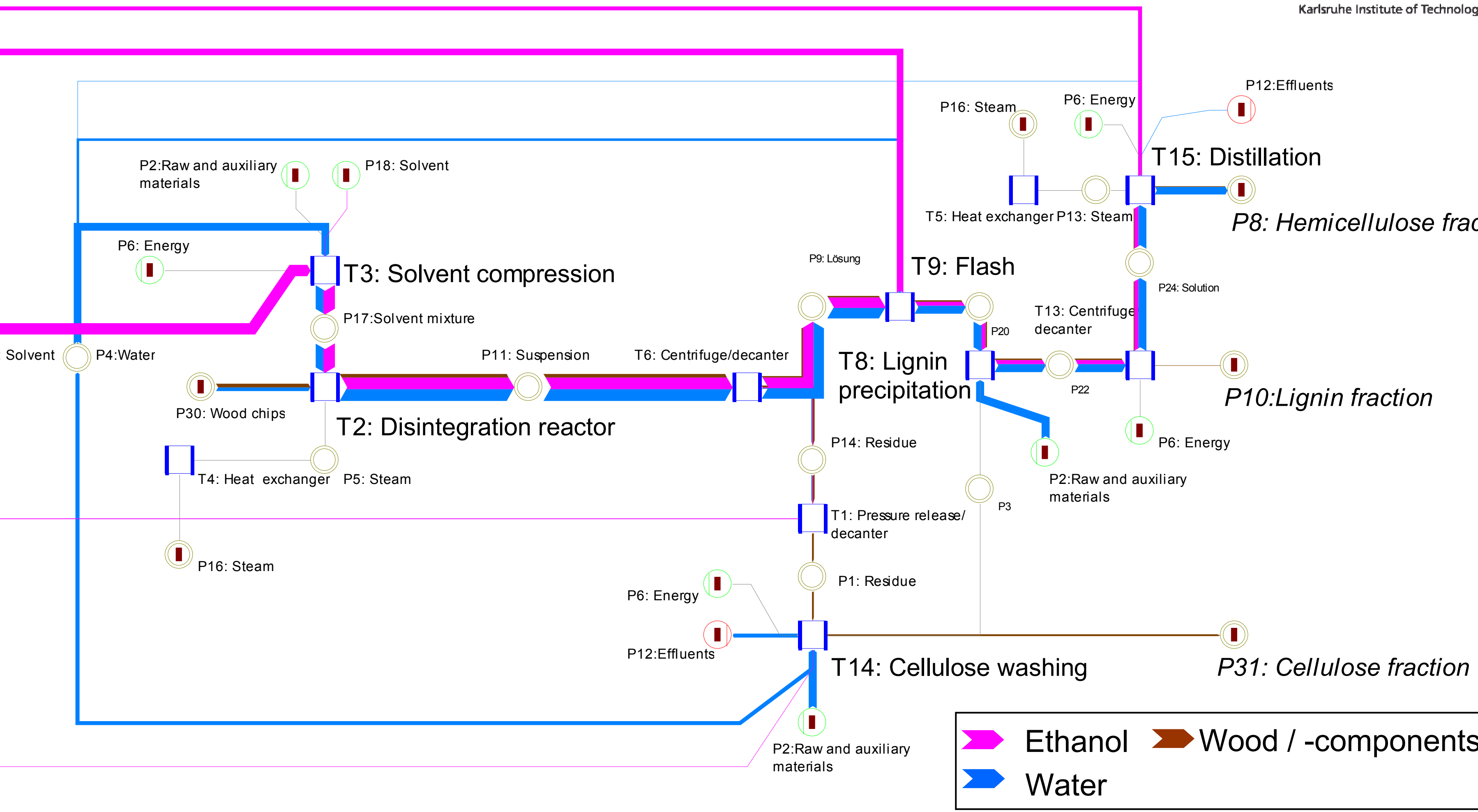
- Petri-net based software tool
- Specification of process steps along the whole value chain in different subnets



Superior Umberto material and energy flow network

- Model calculations are carried out for different scenarios via parameter selection (e.g. different wood : solvent ratios)
- Input data for the model derived from literature, laboratory experiments, thermodynamic modelling with ASPEN Plus.

Subnet „pulping and separation of components“ (sankey diagram)



- High amounts of ethanol and water have to be recycled.
- Ethanol recovery via distillation: Key parameter regarding the energy demand

Methodology for economic analysis

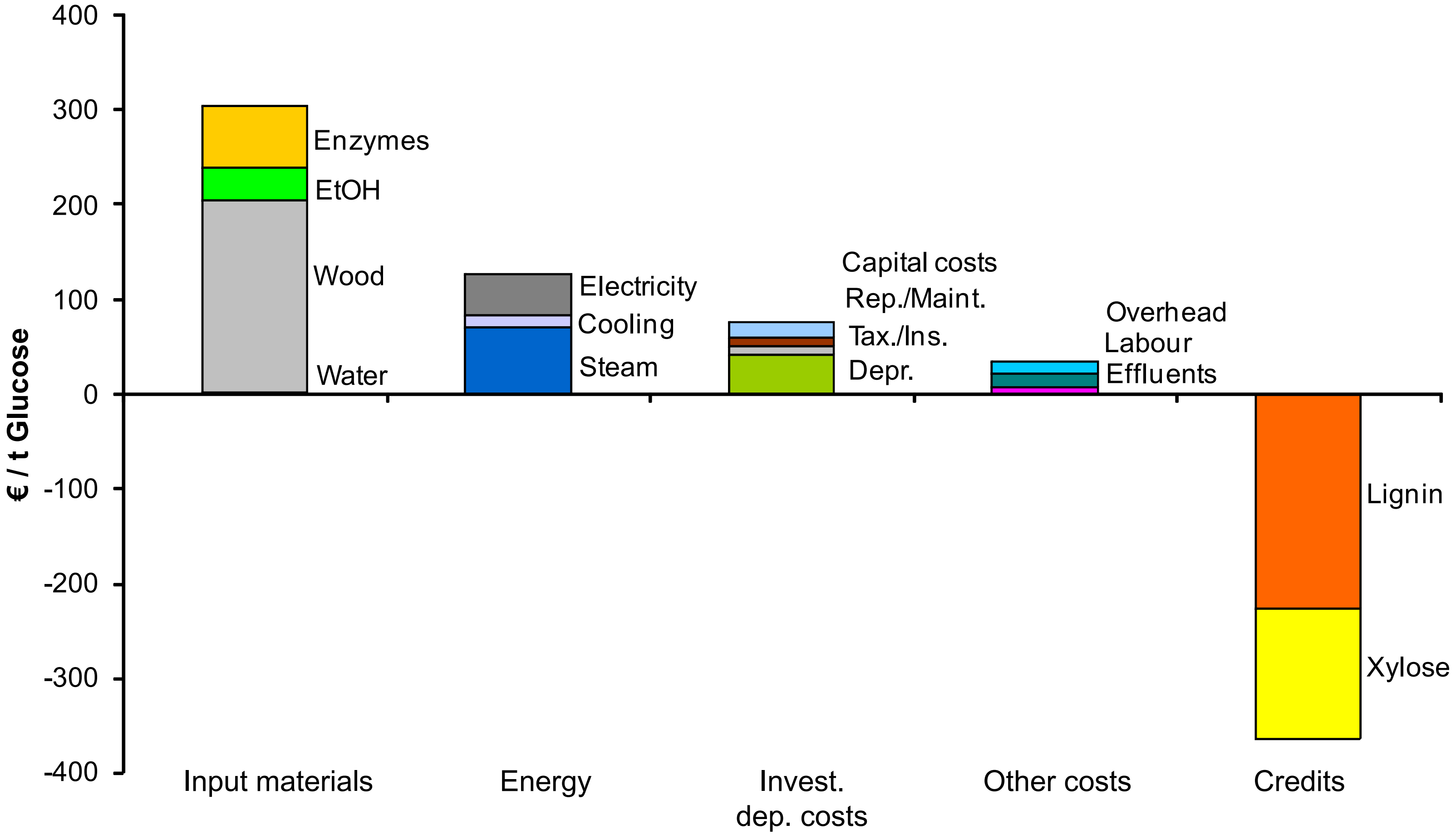
- Estimation of investments:
  - +/- 30% accuracy
  - Site infrastructure completely available and useable (outside battery limits neglected)

- Estimation of glucose production costs:
  - Variable costs and credits
    - Costs for raw and operating materials (wood chips, ethanol, water, enzymes)
    - Energy costs (electricity, steam, cooling)
    - Costs for sewage disposal
    - Credits for by-products (lignin as high grade product, xylose)
  - Investment related costs (depreciations, taxes and insurance, maintenance, costs of capital)
  - Costs for labour

- Costs for sales, administration and research are not yet determined

Structure of costs and credits

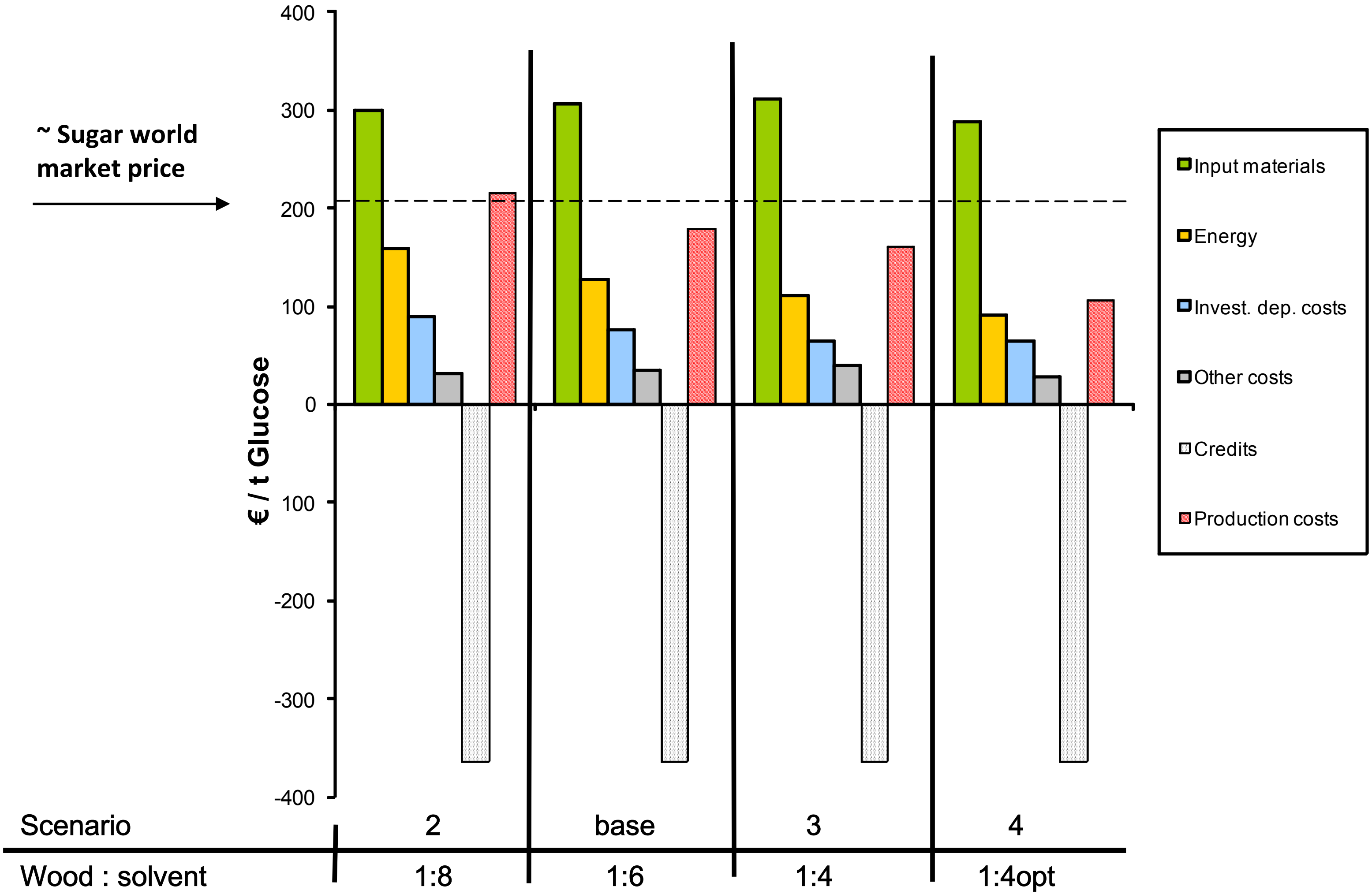
- Base scenario (ratio wood : solvent = 1 : 6)



Highest influence on the amount of glucose production costs: Costs for wood chips and the credits for lignin as by-product

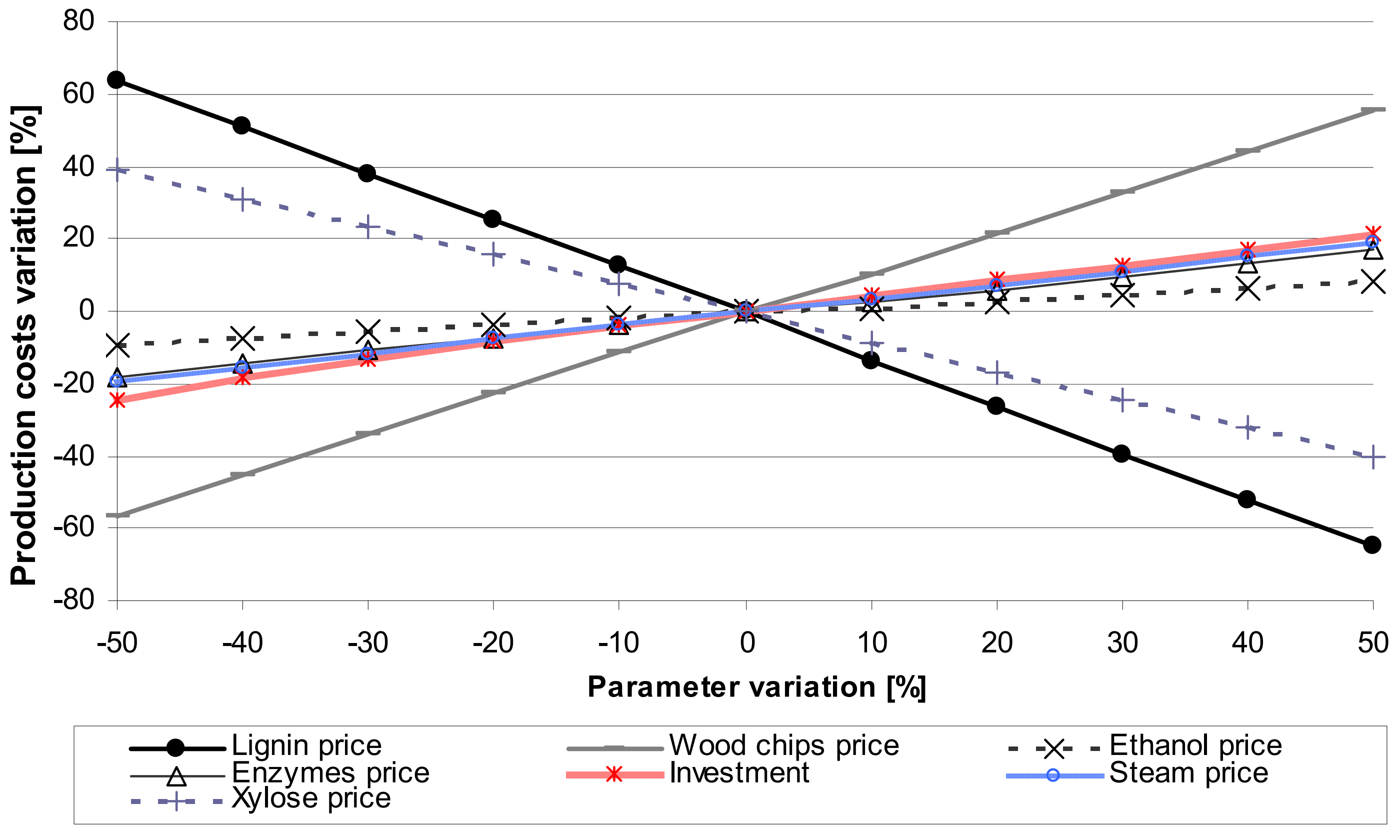
Estimation of glucose production costs

- Comparison of different wood : solvent ratios
- Requirement for economic efficiency: production costs << sugar market price



Sensitivity analysis

- Base scenario (ratio wood : solvent = 1 : 6)
- Influence of different prices on the glucose production costs



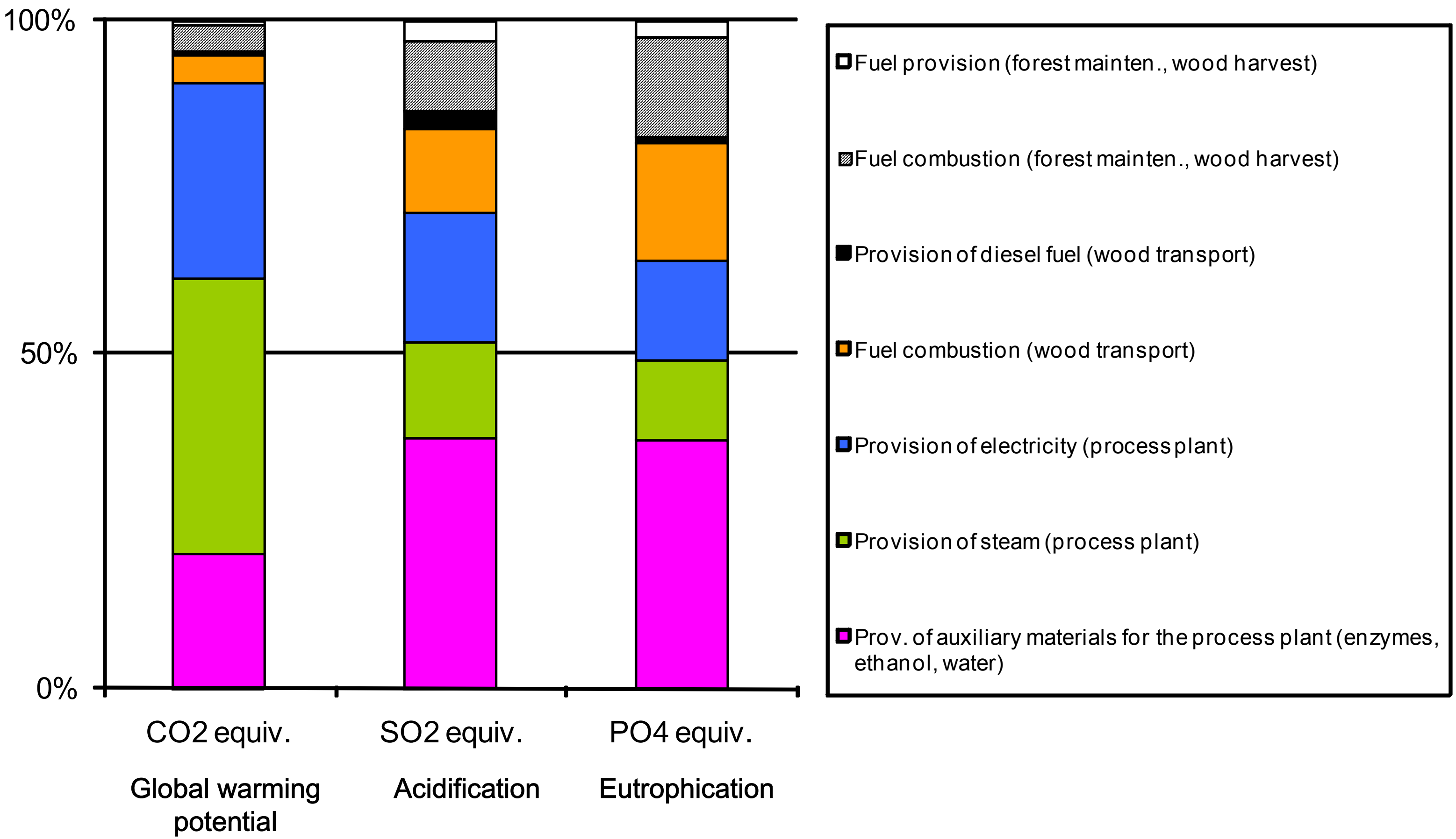
- Prices for wood chips and lignin mainly influence glucose production costs

Methodology for ecological assessment

- Methodology for life cycle assessment (LCA) according to the international standard DIN EN ISO 14040 and 14044
- Goal and scope definition and life cycle inventory (LCI) analysis
  - „Cradle to gate analysis“ including forest production (wood maintenance, wood harvest/chipping), wood transport and the biorefinery processes
  - Integration of supply chains for the provision of energy and operating materials (ecoinvent v2.0 LCI database)
- Selection of impact categories, e.g. global warming potential, acidification, eutrophication
- Life cycle impact assessment (assignment of LCI results to the corresponding impact categories and conversion to indicator values, e.g. CO_2 equivalents)

Ecological assessment – Examples (1)

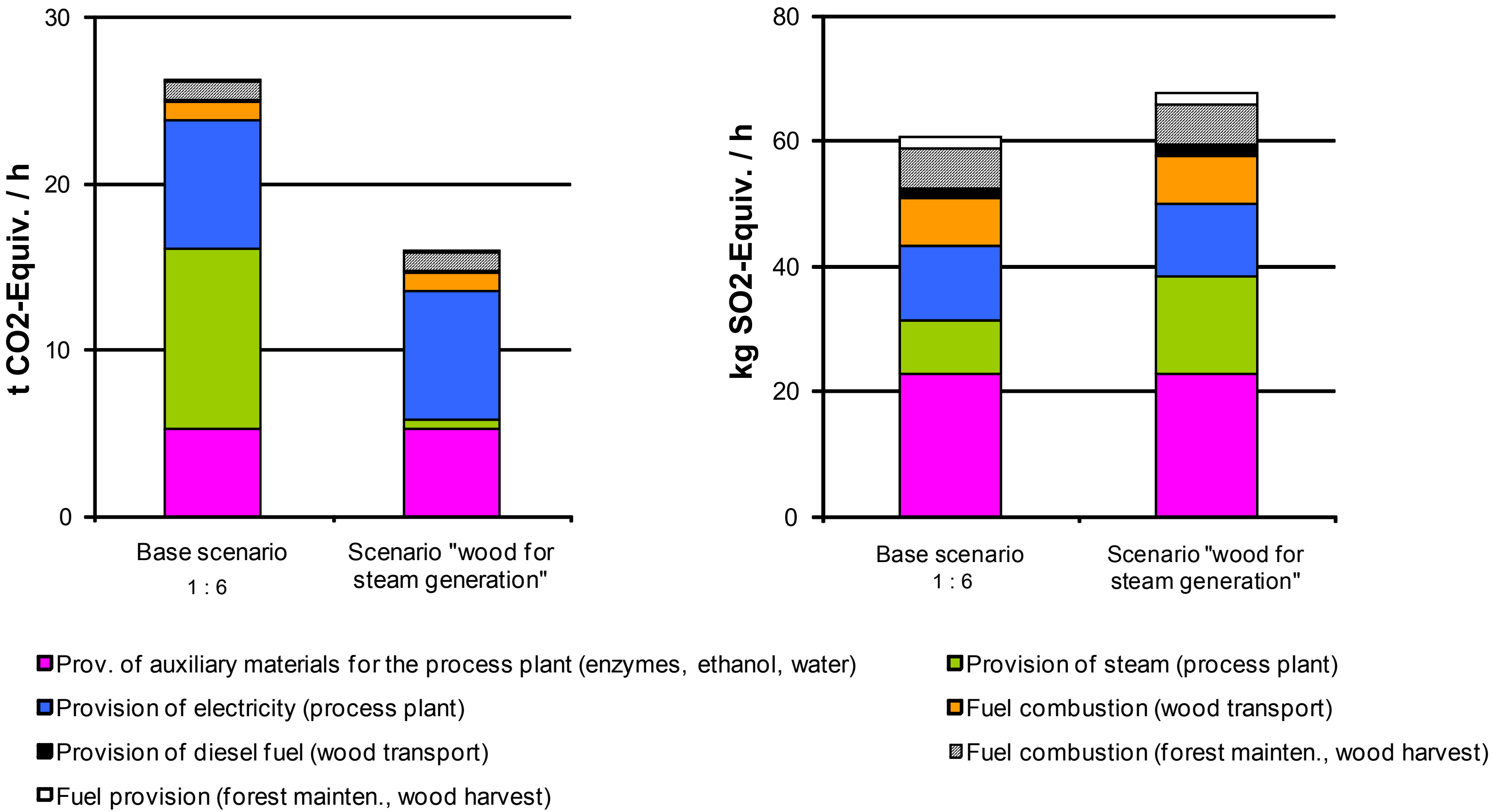
- Determination of proportions of particular process steps to the emission equivalents of selected impact categories



- Uncertainties for contributions caused by enzymes production especially for PO_4- equiv.

Ecological assessment – Examples (2)

- Comparison of CO_2- and SO_2- emission equivalents assuming different fuels for steam generation

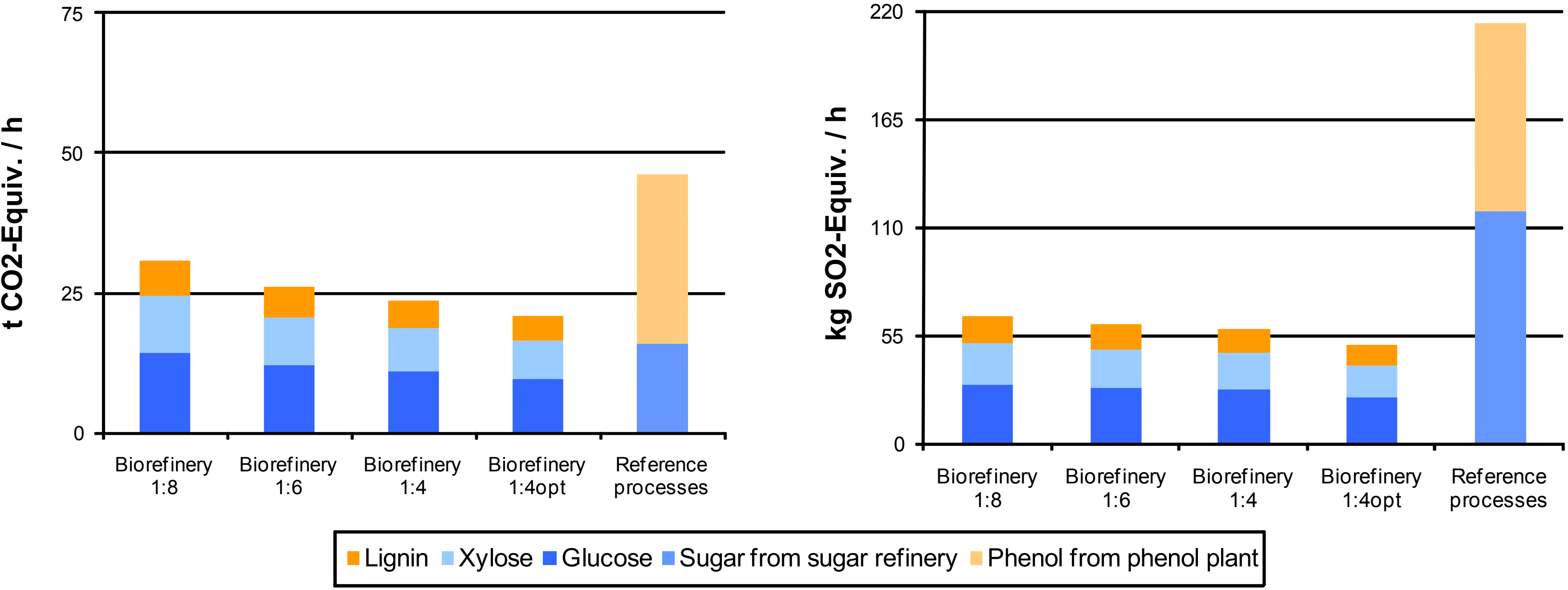


- Wood combustion for steam generation lowers CO_2- emission equivalents but elevates SO_2-emission equivalents

Ecological assessment – Examples (3)

- Comparison of CO_2- and SO_2- emission equivalents of the biorefinery with the production of potential reference products[1]

- Assumptions:
  - Sugar from a sugar refinery as reference product for solute xylose and glucose
  - Phenol from a phenol plant as reference product for lignin



- Lower CO_2- and SO_2- emission equivalents for the biorefinery compared to selected reference processes

[1] Values for reference processes derived from the ecoinvent v2.0 LCI database

Summary

- Development of new concepts for the non-energetic use of biomass
- Modelling of mass and energy flows of a wood biorefinery along the whole value chain for different scenarios
- Early-stage techno-economic and ecological assessment for the identification of sustainable production processes
- Economic efficiency highly depends on prices for wood chips and the sales price for lignin
- Further improvement of the process design is necessary to enhance economic efficiency
- Steam and electricity generation are crucial for the extent of GHG emissions
- Analysis of different environmental impact categories may lead to different conclusions
- Further research is needed especially with respect to products utilization/processing
- Consideration of more detailed analysis of product streams

Thank you for your attention

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