Overview of Biorefinery Concepts and Basics for Their Greenhouse Gas Balance

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IEA Bioenergy Task 38: Greenhouse Gas Balances of Biomass and Bioenergy Systems

International Workshop in Cooperation with the Salzburg State Government

“Transportation Biofuels: For greenhouse gas mitigation, energy security or other reasons?”

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Human Influence on Atmosphere

Source: IPCC 2007
Greenhouse Gas Emissions in Austrian Transportsector

- 24 Mio. t GHG/a from transportation sector
- 26% Share of total Austrian GHG-emissions
- 83% Increase between 1990/2006
- Most rapid increasing sector
European Roadmap for Biofuels

Vision 2030: 25% Biofuels

What is a “Biorefinery”?

IEA Bioenergy Task 42 on Biorefineries
Existing “Lignozellulosic Biorefiniery”

- Wood
- Black liquor
- Pulp factory
  - Pulp: 39%
  - Energy: 50%
  - Furfural: 11%
  - Acetic acid
  - Xylose

Source: Lenzing, 2007
WOOD: First Process it - then Burn it

The final products are

- technology-intensive!
- capital-intensive!
- labour-intensive!
- export-intensive!

Lignin:
- calorific value 25 – 26 MJ/kg (aromates)

Cellulose, hemicelluloses:
- calorific value 16 – 18 MJ/kg (hydrocarbons)
Austrian Concept „Green Biorefinery Austria“

- Green Biomass (e.g. Grass, Clover, Lucern,...)

  - Ensilage Process
  - Mechanical Fractionation

    - Amino Acids Separation
      - Amino Acids, Protein Products
    - Lactic Acid Separation
      - Lactic Acid, Ethyl-Lactate,...
    - Fibre Processing
      - Biogas
        - Electricity, Heat
        - Fiberboards, Biocomposites, Insulation Materials,...
      - Fine Chemicals Separation
        - Flavours, Chlorophyll, Pigments,...
      - Press Cake (Fibres)
        - Press Juice
Demonstration-Plant „Green Biorefinery“

- Location: Uztenaich in Upper-Austria
- Attached to existing biogas plant 500 kWₑ
- Capacity: processing silage from 100 ha with 10 tₑ/(ha*a)
- Investment: 1.7 Mio. €
- Operating costs for 3 years: 1.5 Mio. €
- Start up: 2008
What is a „Biorefinery“?

Biomass Resources
- oil
- starch
- sugar
- lignocellulose
- ....

Biorefinery

Energy

Transportation biofuel orientation

- liquid/gaseous transportation fuels
  - electricity
  - heat
  - solid fuels

Chemicals

- bulk chemicals
- fine chemicals
- animal feed
- materials
- fertilizer
- ....

Based on different conversion processes
- Bio-chemical
- Thermo-chemical
- Physical-chemical
- Others
“Multi-Platform” Transportation Biofuel Oriented Integrated Biorefinery Concepts

Oil crops
- Pressing
- Fermentation
- CO2 separation
- Hydrogenation
- Esterification

Residues (organic waste, manure)
- Pyrolysis
- Gasification
- Methanisation

Lingo-cellulosic crops
- Hydrolysis

Sugar crops
- Syngas
- Fermentation
- Sugarification

Starch crops
- Starch
- Sugar
- Syngas
- Hydrogen

Platforms
- Syngas
- Hydrogen
- Bioethanol
- Animal feed
- Chemicals

Oil
- Oil

SNG
- SNG
- FT-fuels
- Synthetic natural gas (SNG)

Sugar
- Sugar
- Bioethanol

Starch
- Starch

Wood
- Wood
1. “Lignocellulosic biorefinery”, based on wood and straw

2. “Whole crop biorefinery”, based on raw materials like grains and maize (whole crop)

3. “Green biorefinery”, based on Grass

4. “Two-platform-biorefinery”, with sugar and syngas platforms
According to

- ISO 14 040 „Life Cycle assessment“
- Standard Methodology of IEA Bioenergy Task 38 „Greenhouse Gas Balances of Bioenergy systems“
- Recommendations of COST Action E9 „Life Cycle Assessment of Forestry and Forest Products“
Criteria for Environmental Evaluation

- **Greenhouse gas emissions** [t CO₂-eq.] including:
  - Carbon dioxide (1 kg CO₂ = 1 kg CO₂-eq)
  - Methane (1 kg CH₄ = 23 kg CO₂-eq)
  - Nitrous oxide (1 kg N₂O = 296 kg CO₂-eq)

- **Cumulated primary energy demand** [PJ primary energy] shared in:
  - Biomass (e.g. wood, straw)
  - Fossil energy (e.g. oil, coal, natural gas)
  - Others (e.g. hydro power, waste, nuclear)

- **Indicators for environmental evaluation**
  - Specific GHG reduction [t CO₂-eq/t biomass] or [t CO₂-eq/ha]
  - Specific fossil energy reduction [TJ fossil energy/t wood]
Process System: Wood Bioethanol Biorefinery

Wood chips → Pretreatment → Hydrolysis → Fermentation → Lignin → Drying → Pyrolysis → Biooil

Lignin → Separation

Residues → Combustion

Bioethanol → Electricity → Heat → Phenols
LCA of Wood Bioethanol Biorefinery

Wood forest residues

Transportation

Bioethanol-Biorefinery

Wood chips 530 kt/a

Bioethanol 100 kt/a

Distribution

Heat grid

Heat

Electricity

Electricity grid

Distribution

Phenols

110 GWh/a

175 GWh/a

5.6 kt/a

1,000 Mio. km/a

Transportation service, electricity, heat and chemicals
## System Description for Example Environmental Evaluation

<table>
<thead>
<tr>
<th>Systems</th>
<th>Supplied energy services</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood bioethanol biorefinery</td>
<td><strong>Heat</strong> 110 GWh/a</td>
</tr>
<tr>
<td>Wood polygeneration, con. phenols</td>
<td><strong>Electricity</strong> 175 GWh/a</td>
</tr>
<tr>
<td>Wood CHP **), gasoline, con. phenols</td>
<td><strong>Transportation</strong></td>
</tr>
<tr>
<td>Wood heating, natural gas, gasoline, con. phenols</td>
<td>service *) 1,000 Mio. km/a</td>
</tr>
<tr>
<td>Fossil reference system</td>
<td><strong>Phenols</strong> 5,600 t/a</td>
</tr>
</tbody>
</table>

- Wood
- oil
- gasoline
- wood
- natural gas

*) Bioethanol: 100,000 t/a
**) Combined heat and power
Comparison Wood to Bioethanol Biorefinery and Polygeneration

Wood Bioethanol Biorefinery
- Wood forest residues
  - Transportation
    - Bioethanol-Biorefinery
      - Distribution
        - Bioethanol Vehicle
        - Heat grid
        - Electricity grid
  - Natural oxidation
    - Distribution
      - Bioethanol Polygeneration
        - Refinery
          - Transportation
            - Extraction raw oil
              - Phenols
                - Distribution

Wood Bioethanol Polygeneration
- Wood forest residues
  - Transportation
  - Natural oxidation
  - Transportation
  - Heat grid
  - Bioethanol Vehicle
  - Electricity grid

Transportation service, electricity, heat and chemicals
Comparison Wood to Bioethanol Biorefinery and Polygeneration

Wood Bioethanol Biorefinery

Wood forest residues

Transportation

Bioethanol-Biorefinery

Distribution

Bioethanol Vehicle

Heat grid

Electricity grid

Fossil Reference System

Extraction raw oil

Transportation

Refinery

Natural oxidation

Distribution

Heating plant

Gasoline Vehicle

Distribution

Heat grid

Electricity grid

Extraction natural gas

Transportation

Power plant

Phenols

Transportation service, electricity, heat and chemicals
Each system provides:

- **Electricity**: 175 GWh/a
- **Transportation service**: 1,000 Million km/a (based on 100 kt/a of bioethanol for passenger car)
- **Phenols**: 5,600 t/a
- **Heat**: 110 GWh/a
Greenhouse Gas Emissions

- Fossil reference system: 408 t CO₂-eq./a, -10% reduction
- Wood heating, natural gas, gasoline, con. phenols: 367 t CO₂-eq./a, -29% reduction
- Wood CHP, gasoline, con. phenols: 288 t CO₂-eq./a, -86% reduction
- Wood polygeneration, con. phenols: 57 t CO₂-eq./a, -88% reduction
- Wood bioethanol, biorefinery: 48 t CO₂-eq./a
Cumulated Primary Energy Demand

- **Fossil reference system**: 5.91 PJ/a
  - Reduction: -9%

- **Wood heating, natural gas, gasoline, con. phenols**: 5.85 PJ/a
  - Reduction: -33%

- **Wood CHP, gasoline, con. phenols**: 6.2 PJ/a
  - Reduction: -84%

- **Wood polygeneration, con. phenols**: 7.0 PJ/a
  - Reduction: -90%

- **Wood bioethanol biorefinery**: 8.6 PJ/a
  - Reduction: -90%

**Cumulated Primary Energy Demand [PJ/a]**

- Fossil energy
- Biomass
- Others
Indicator for Environmental Evaluation: Specific GHG Reduction

Specific Greenhouse Gas Emissions Reduction [t CO$_2$-eq./t$_{wood}$]
Indicator for Environmental Evaluation: Specific Fossil Fuel Reduction

-12.6 - Wood heating, natural gas, gasoline, con. phenols
-9.8 - Wood CHP, gasoline, con. phenols
-9.1 - Wood polygeneration, con. phenols
-7.4 - Wood bioethanol biorefinery

Specific Fossil Fuel Reduction [GJ fossil energy/\text{t}_\text{wood}]
Indicator for Environmental Evaluation: Trade Off (I)

Specific GHG reduction \([ \text{t CO}_2\text{-eq/t wood} ]\)

- Wood bioethanol biorefinery
- Wood polygeneration, con. phenols
- Wood CHP, gasoline, con. phenols
- Wood heating, natural gas, gasoline, con. phenols
- Fossil reference system
Indicator for Environmental Evaluation: Trade Off (II)

GHG reduction [ t CO₂-eq/a]

-400.00 -350.00 -300.00 -250.00 -200.00 -150.00 -100.00 -50.00 0.00

-1.0

-0.8

-0.5

-0.3

-0.1

-0.0

0.0

Specific GHG reduction [t CO₂-eq/twood]

-1.0

-0.8

-0.6

-0.4

-0.2

0.0

Wood bioethanol biorefinery
Wood polygeneration, con. phenols
Wood CHP, gasoline, con. phenols
Wood heating, natural gas, gasoline, con. phenols
Fossil reference system
Conclusions

Indicators developed for environmental evaluation CO$_2$-eq and fossil fuel saving (specific/absolute terms)

Evaluation of biorefinery systems is complex

“Multi-platform biorefinery system” might be biorefinery complex of the future

Many different biorefinery systems – focus on transportation biofuels orientated systems