Energy from biomass

Daniela Thrän
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2. Energy generation from biomass
3. Bioenergy provision today
4. Integration into renewable energy systems: smart bioenergy
5. Expectation
Estimated Renewable Energy Share of Total Final Energy Consumption, 2015

- Fossil fuels: 78.4%
- All renewables: 19.3%
  - Modern renewables: 10.2%
  - Traditional biomass: 9.1%
  - Nuclear power: 2.3%
- Biomass/geothermal/solar heat: 4.2%
- Hydropower: 3.6%
- Wind/solar/biomass/geothermal power: 1.6%
- Biofuels for transport: 0.8%
Biomass is raw material of biological origin excluding material embedded in geological formations or transformed to fossilized material. Biomass can be processed into solid, liquid or gaseous fuels or stored energy in biomass can be directly converted into other forms of energy (e.g. heat, light) (ISO 13065:2015).
Biomass
The energy content of biomass

Energy provision from biomass is based on a chemical reaction:

Binding energy: C-C: 350 kJ/mol   C=C: 615 kJ/mol   C-H: 415 kJ/mol

Oxidation of organic bindings (examples):

\[
\begin{align*}
\text{C + O}_2 & \rightarrow 2 \text{CO}_2 \quad \Delta H = -394 \text{ kJ/mol} \\
\text{CH}_4 + 2 \text{O}_2 & \rightarrow 2 \text{CO}_2 + 2 \text{H}_2\text{O} \quad \Delta H = -889 \text{ kJ/mol}
\end{align*}
\]

Carbon is sequested from CO2 by Photosynthesis (example) 6 CO2 + 6 H2O \(\text{-(light)}\) \(\rightarrow\) C6H12O6 + 6O2

The Hydrocarbons can be used directly (biomass) or after their fossilisation (coal, oil, gas)

Numbers from (Kaltschmitt et al 2001)
Biomass Resources

- Agricultural Crops & Residues
- Forestry Crops & Residues
- Sewage
- Municipal Solid Waste
- Industrial Residues
- Animal Residues

Agricultural Crops & Residues

Biomass Resources

Forestry Crops & Residues

Sewage

Municipal Solid Waste

Industrial Residues

Animal Residues
Energy generation from biomass
Pathways

Source: Thrän et al (2017); DOI: 10.1002/cite.201700083
Energy generation from biomass

Pathways

Source: Thrän et al (2017); DOI: 10.1002/cite.201700083
Energy generation from biomass
Combustion (of wood)

Combustion stages:

1. at a temperature of 150 °C the fuel is dried
2. a temperature of 150 - 600 °C pyrolytic decomposition of the fuels to product gas, pyrolysis oil and charcoal
3. at a temperature of 500 - 1000 °C further gasification (i.e. of charcoal in the firebed)
4. at a temperature of 400 - 1300 °C the gas is burned

At high temperatures, 80 - 85 % of the wood is converted to gas and burns afterwards (complete combustion)

Intermediates can be used for further product processing (synthetic natural gas, methanol, Fischer-Tropsch-Fuels etc.)

The design and optimisation of this system is a huge area
Energy generation from biomass
Pathways

Source: Thrän et al (2017); DOI: 10.1002/cite.201700083
Energy generation from biomass
Biochemical conversion – Biogas

RAW MATERIAL/BIOMASS
- Energy Crops (e.g. Corn), Grass, Overgrown silphia
- Liquid manure
- Organic waste
- Straw

Mixing → Fermentation

FINAL PRODUCTS
- Gas
- Digestate (Fertiliser)

Hydrolysis
Energy generation from biomass
Biochemical conversion – Bioethanol

RAW MATERIAL / BIOMASS
- Starch containing feedstock (e.g. corn, wheat, rice)
- Sugar containing feedstock (e.g. root beet, sugar cane)
- Lignocellulosic containing feedstock (e.g. wood, straw)

Milling / fractionation → Hydrolysis → Saccharification → Fermentation → Separation → Destillation → byproducts → Ethanol

FINAL PRODUCTS
- Fodder
Energy generation from biomass
Pathways

Source: Thrän et al (2017); DOI: 10.1002/cite.201700083
Energy generation from biomass
Physical-chemical conversion – Biodiesel
Energy generation from biomass
Fuels for aviation

Aviation:
Strong increase in transport loads and fuel demand is expected for the future (>2% per year)
Long lifetime of aeroplanes (more than 30 years)
Global fuel supply system

Biojet fuels:
A wide range of biojet fuels have been tested successfully
Technical standards/Certification for five biojet fuels have been established:
- HVO
- FT-diesel
- SIP fuels (Renewable Synthesized Iso-Paraffinic fuel; renewable farnesane hydrocarbon)
- ATJ fuels (Alcohol to Jet Fuel)

They can be applied as drop-in fuels without major changes in infrastructure or aircraft engines.
Bioenergy provision today
World

Source: Thrän et al (2017); DOI: 10.1002/cite.201700083
Bioenergy provision today
Example Germany

Agricultural residues & forest residues

Residual and waste materials (waste wood, organic waste, production waste)

Biomass CHP, biogas plant, Bioethanol (electricity and mobility energy)

Heating systems (from pellet stoves to high temperature use)
Bioenergy provision in the future
Sustainable and smart
Bioenergy provision in the future
Comprehensive integration for an efficient energy transition

Focus: System effect with hydrogen
Focus: Hybrid concepts
Focus: Flexible concepts
Focus: Residual and waste materials
Focus: Negative emissions from 2030
Focus on residual and waste materials
Potential and use in Germany

Material use 29.7 Mio MgDM
Energetic use 26.9 Mio MgDM
Material or energetic use 7.3 Mio MgDM
Use unclear ≥ 3.5 Mio MgDM
Unused technical biomass potential 30.9 Mio MgDM

Used technical biomass potential 67.4 Mio MgDM

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Energetic use 26.9 Mio MgDM
Material or energetic use 7.3 Mio MgDM
Use unclear ≥ 3.5 Mio MgDM
Unused technical biomass potential 30.9 Mio MgDM

Theoretical biomass potential 151.1 Mio MgDM*

Used technical biomass potential 67.4 Mio MgDM

541 PJ + X by increase in efficiency
448 PJ

Source: Brosowski et al (2016)

*MgDM: Megagram (metric ton) dry mass

→ Residues and waste arise at the end of different value chains
→ Constant availability can be expected

23.07.2021
Joint EPS-SIF International School on Energy
Focus on residual and waste materials
Requirements for clean conversion

Background: In addition to local air pollution control, absolute particulate matter emissions in Germany must also be reduced (EU requirement).

For larger boilers from 300 kW(th), the following applies roughly:
• 10% more costs reduce particulate matter by a factor of 10;
• Non-wood fuels always need a secondary separator for limit value compliance (+10% costs), as higher emissions are produced during combustion.

Reduction of particulate matter is primarily a question of cost
Focus on flexible concepts
Towards virtual power plants

Flexibilisation offers:
- System services
- Electricity market revenues
- Hybrid heat supply

Flexibilisation requires:
- Maintaining capacities
- Controllability and concepts
- Intersections

Tagesbilanz EE (01. Mai 2018)

Source: UFZ modelliert mit Daten der Bundesnetzagentur - www.smard.de, abgefragt am 08.10.2018
Focus on hybrid concepts
Combined heat and power for different scales

Components for a renewable energy supply in a building area or housing quarter – not all used at the same single house.

Example for hybrid systems in 100 RE solutions:
- Heat has peak demand in winter, when PV has minimum electricity supply.
- Heat pumps have to make the biggest contribution (in Germany: Peak power demand up to 400 GW; peak power demand today 70-80 GW; RE capacity: 132 GW)
Options or areas of application, as well as challenges and research needs in the context of RE and bioenergy in particular.

<table>
<thead>
<tr>
<th>Digitalisation</th>
<th>Flexibilisation</th>
<th>Technology combinations</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Interfaces (management)</td>
<td>• Input material flexibility (broad raw material spectrum vs. quality requirements)</td>
<td>• Network control of district heating networks in sub-networks and coupling of electricity, gas and heat</td>
</tr>
<tr>
<td>• Regional energy &amp; climate data</td>
<td>• Flexible operating strategies (bioenergy production in complementarity with volatile RE; heat: flexible temperature levels through biomass)</td>
<td>• Micro-satellite CHP for biogas plants (biogas in the gas grid)</td>
</tr>
<tr>
<td>• Forecast of energy demand</td>
<td>• Product flexibility (flexible electricity/heat/fuel production; biobased gases as intermediates)</td>
<td>• Central high-temperature heat pumps in combination with heat grids</td>
</tr>
<tr>
<td>• Automated systematic data collection</td>
<td></td>
<td>• Seasonal storage and solar thermal</td>
</tr>
<tr>
<td>• Merging simulation tools</td>
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<td></td>
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<tr>
<td>• Communication of added value to users</td>
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Focus: System effect with hydrogen
On the way to a climate-neutral circular economy

Climate-friendly hydrogen can be produced from biomass
(Hydrogen from biomass)

Hydrogen can be used in bioenergy processes to increase efficiency
(Hydrogen with biomass)

Hydrogen can produce climate-friendly PtX products with biogenic CO2
(Hydrogen with bioenergy)

Hybrid concepts for hydrogen and Bioenergy are particularly useful
(Hydrogen and bioenergy)

More information coming soon:
https://task44.ieabioenergy.com/publications
All climate scenarios expect negative emissions and give bioenergy a high priority because:

- technically available in a wide range
- Potential for real CO2 removal
- Energy as a by-product
- Combination with industrial processes (e.g. cement)
Focus on bioenergy options for negative emissions from 2030 onwards

Example: CO2 removal from bioenergy plants in Germany

How can 1 million tonnes of bio-CO2 be provided?

- 8–20 Bioethanol plants
- or 130 biomethane plants
- or 60 biomass cogeneration plants

<table>
<thead>
<tr>
<th>Plant category</th>
<th>Number of plants (status 2019)</th>
<th>Typical CO2 availability per plant</th>
<th>Theoretical CO2 potential of operating plants</th>
</tr>
</thead>
<tbody>
<tr>
<td>BtL- plant (Biodiesel)</td>
<td>0</td>
<td>up to 900 kt/a (?)</td>
<td>none</td>
</tr>
<tr>
<td>Bioethanol</td>
<td>7</td>
<td>48–271 kt/a</td>
<td>665 kt/a</td>
</tr>
<tr>
<td>Biomethane</td>
<td>216</td>
<td>7,5–8,5 kt/a</td>
<td>1.500 kt/a</td>
</tr>
<tr>
<td>Biomass CHP plant</td>
<td>&gt;600</td>
<td>5–30 kt/a</td>
<td>6.380 kt/a</td>
</tr>
<tr>
<td>Biogas (on-site electricity generation)</td>
<td>8.870</td>
<td>2,5–3,5 kt/a</td>
<td>27.000 kt/a</td>
</tr>
<tr>
<td>Biomass furnace / boiler</td>
<td>11.123.000</td>
<td>0,0005–1,5 kt/a</td>
<td>40.000 kt/a</td>
</tr>
</tbody>
</table>

Costs: 100–200 US$/tCO₂
(Fuss et al. 2018)

Towards net zero
Expectations from IEA

Assuming moderate potential assumptions and distribution across all sectors
Bioenergy is the most relevant renewable energy source today. Many technologies and concepts are implemented.

Biomass is a limited resource, so bioenergy provision needs integration, not only in the energy system but also in sustainable supply systems.

The use of residual and waste materials will increase and need mobilisation strategies and utilisation technologies.

The areas of application remain diverse; however, flexible and hybrid concepts are gaining importance in all energy sectors.

The interaction with hydrogen and negative emissions is relevant in the long term and needs to be researched now.

Further technology development (especially particulate matter) and digitalisation (predictive controls, interface standardisation...) are pioneers.
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Journal: Energy, Sustainability & Society
https://energsustainsoc.biomedcentral.com/

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Thank you!

31.03.2021

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