Forest Biorefineries: Current Status & Outlook

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Outline

1. What is forest biorefinery?
2. Example
3. Why it is interesting?
4. What is the current state?
5. The long-term outlook
6. Implications to socio-economic research
What is forest biorefinery? Definitions:

1. A biorefinery is a facility that integrates biomass conversion processes and equipment to produce fuels, power, and value-added chemicals from biomass
   (National Renewable Energy Laboratory, USA / www.nrel.gov/biomass/biorefinery + Wikipedia)

2. Efficient use of the entire potential of raw materials and by streams of the forest-based sector towards a broad range of high added value products (by co-operation in and between chains)
   (EU Forest-Based Sector Technology Platform / Biorefinery Taskforce, April 17, 2007)

3. Full utilization of the incoming wood biomass for production of fibres, chemicals and energy
   (STFI-Packforsk, Sweden)
→ Better use and processing of raw-materials and waste streams to produce current and new products

Roundwood, residues, stumps, branches, bark, etc.

Pulp
Paper

Biofuels
Chemicals
Heat
Power

chips, bark, sawdust

black liquor
According to the definition, many forest industry plants are already today "biorefineries".

However, the term forest biorefinery, which came to more wider use only about 2005-2006, is specially linked to the introduction of following factors:

1. New technology and production processes
2. New products and business strategies

Thus, using the biorefinery concept, instead of pulp and paper mill or sawmill, helps to make the distinction with the current operations and seems to be justified.

Biorefineries using forest biomass are not restricted to forest industry (power- and chemicals industries).
Integrated Forest Industry Biorefinery

- Pulp, paper, lumber, etc.
- Forest Biomas
  - agri. biomass
  - recycled biomass
  - urban waste
- Process heat and power
- Power unit
- Pulp and paper mill / sawmill
- Biomass handling
- Pretreatment
- Bark
- Wood residues, etc.
- Biomass conversion (biochemical / thermochemical / combination)
- Power + chemicals stream
- District Heat
- Electricity to grid
- Chemicals
- Crude biofuels
- diesel, ethanol, mixed alcohols

Pretreatment
Biomass handling
Pulp and paper mill / sawmill
Process heat and power
Power unit
Pulp, paper lumber, etc.
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Biorefinery biofuels and chemicals options include:

<table>
<thead>
<tr>
<th>Biorefinery Product*</th>
<th>Target Market</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>FT Naphtha</td>
<td>Motor Gasoline</td>
<td>Upgradeable to gasoline blendstock or can be used as chemical feedstock, e.g., naphtha to olefins. Co-produced with FT distillate.</td>
</tr>
<tr>
<td>FT Distillate</td>
<td>Distillate (diesel) Fuel</td>
<td>High cetane, sulfur-free diesel blendstock. Main product of FT synthesis.</td>
</tr>
<tr>
<td>Ethanol</td>
<td>Motor Gasoline</td>
<td>Currently ~3.5% of U.S. gasoline market</td>
</tr>
<tr>
<td>Higher Alcohols</td>
<td>Ethanol or MTBE, existing alcohol markets</td>
<td>Mixed OHs can be sold as gasoline blendstock or components can be separated &amp; sold into existing alcohol markets</td>
</tr>
<tr>
<td>Methanol</td>
<td>Methanol</td>
<td>Methanol as chemical intermediate (e.g., for olefins) is most promising market. Fuel use (MTBE) is in decline.</td>
</tr>
<tr>
<td>Dimethyl Ether (DME)</td>
<td>Diesel or LPG</td>
<td>Blendable with LPG to 20-25% with no infrastructure change. Diesel engine use requires fueling infrastructure changes (fleet potential first).</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>Hydrogen</td>
<td>Market is growing, mainly for use in refineries (captive market)</td>
</tr>
<tr>
<td>Ammonia</td>
<td>Ammonia</td>
<td>Among the largest commodity chemicals (e.g., fertilizer)</td>
</tr>
</tbody>
</table>

* Not an exhaustive list. A wide range of chemicals can be produced from syngas, but their volumes are typically smaller than the fuels and chemicals listed here.

Example: Processing lignin to electricity and heat in Sweden

*LingoBoost, a subsidiary company of STFI-Packfrosk*

(jointly financed by STFI-Packforsk, Södra, Stora Enso, Fortum, Värme and the Swedish Energy Agency)

High quality lignin extracted from black liquor (kraft pulp mill)

Electricity + heat

Pellets directly from the pieces of a kraft lignin cake

Could also produce chemicals
Lingoboost demonstration plant in operation since late 2006

Wermland Paper, Bäckhammar mill

LignoBoost Demonstration plant

- market value appx. 150 €/ton

4000 t/a lignin by rail to Stockholm

Fortum power company

"Green" electricity and heating to 1 300 family houses in Stockholm

Lauri Hetemäki / August 14, 2007
World Lignin Potential

Lignin in Different Black Liquors

<table>
<thead>
<tr>
<th>kg/t pulp</th>
<th>Spruce</th>
<th>Birch</th>
<th>Eucalypt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lignin</td>
<td>510</td>
<td>340</td>
<td>340</td>
</tr>
</tbody>
</table>

- World production of kraft pulp approx 100 million tonnes
- Assume 25 % lignin will be removed per ton of pulp; and an average of 400 kg lignin per ton of pulp → world total lignin potential would be 10 million tons
- Assume a lignin price of 150 €/t → world total would be 1.5 € billion
- ”A full-scale plant is expected to recover more than ten times the amount of lignin produced by the demonstration plant. A market study shows that there is a potential for full-scale operations in more than 100 pulp mills all over the world” (LignoBoost, press release, 12 February 2007)
What makes forest biorefinery interesting?

- It has the potential to marry the interests of the society, environment and the industry (forest sector)

Society + environment:
- Jobs, taxes, rural communities, etc.
- Energy security
- Help to mitigate climate change

Industry + forest sector:
- New products and profitability boost for the industry
- Help to re-structure and re-innovate the struggling forest sector in countries such as Canada, Finland, Sweden, USA
- Image-factor. Something different from the "sun-set industry" and "smokestack" label often linked to the forest sector
  → bioeconomy, innovative technology, carbon neutral, etc.
What is the current state?

- Many serious forest biorefinery projects are in progress, e.g.:
  1. LignoBoost (Sweden); 2. Stora-Enso & Neste Oil (Finland); 3. UPM & Cargil (USA); 4. Weyerhauser & Chevron (USA); 5. Flambeau River Papers (USA); 6. Potlatch Corporation (USA)

- Intensive R&D, specially in North America and Scandinavia

- R&D so far very much technologically and company driven. Very little or no socio-economic research

- **Biochemical platform**: R&D breakthroughs needed to improve conversion and reduce costs

- **Thermochemical platform**: conversion technologies available today e.g. for FTL & DME – no major R&D breakthroughs needed

- Development is very much pulp and paper industry centered. Almost no discussion or R&D in sawmill sector. Serious shortcoming!
Biorefinery may provide good return on capital already today

Internal Rate of Return Analysis: FTc

- $330 million incremental capital investment
- $50/bbl Crude Oil Scenario (AEO '06 Reference Projection)
- Electricity sale price: 5.3 c/kWh (without incentives)
- Incentives examined:
  - Excise Tax Credit (ETC): Equivalent to existing $0.51/gal for ethanol on energy basis.
  - Investment Tax Credit (ITC): 20% gasification tax credit (under EPA at 2005).
  - Production Tax Credit (PTC): $9/MWh for 10 years (on incremental electricity relative to Tomlinson).
  - Renewable Energy Credit (REC): $20/MWh (e.g., under RPS or green credits). Applies only to incremental electricity.
  - CO₂ Credits: $25/tCO₂ applied to net reductions (including grid offsets and petroleum displaced)
  - FT Crude Premium: $4.2/bbl for superior performance

Some cautionary observations

- Forest biorefinery interest and enthusiasm is of a very recent origin.
- Expectations are great and sometimes probably not very realistic. Typical feature, which may even be necessary to get the new ideas and projects moving on the agenda.
- However, critical assessment of biorefinery are required at least for the following reasons:
  1. Investments in biorefinery (e.g. pilot plants) that do not meet the expectations, may frighten away investors, and hence hinder the general development.
  2. Potential negative side impacts of biorefineries (e.g. biodiversity, crowding-out other activities) should be addressed, and taken care at the early stage – before they come serious problems.
  3. If the potentially problematic societal (genetotechnology) and environmental impacts (forest biodiversity) are clearly addressed and pointed out, the credibility of biorefineries will be enhanced.
The Outlook

The outlook for forest biorefineries depends largely on the following factors:

1. Policy (bioenergy-, climate change- & rural policies)

2. Fossil fuel prices (oil)

3. Technology development (less costly biorefinery production processes)

4. Social-environmental (general attitudes to green energy and how the potential negative side impacts of biorefineries are overcome)
No new markets need be created for biorefinery products. They have been created by political decisions even before production has been started up:

1. **Energy security.** Oil and gas production will be increasingly concentrated in a small number of countries, and government controlled companies (e.g. OPEC, Russia)

2. **Climate change mitigation policies.** Policies getting stricter → costs of fossil energy consumption increases

3. **Rural area policies** (EU, USA). Strong lobby groups for agricultural sector

4. **R&D policies** (EU Technology Platform; Agenda 2020)
   - However, there may be conflicts between polices 1.-3.
Example: EU

Agreed actions

- **Energy Policy:**
  - Energy efficiency: 20% improvement by 2020
  - Renewable energy: 20% mandatory objective by 2020
    - Differentiation of targets between countries
    - Flexibility in target setting within a country between sectors
  - Biofuels target of 10% by 2020
  - Strategic Energy Technology Plan
    - Internal market-options unbundling & regulatory powers:
      - Important for functioning EU ETS
      - Overcome hurdles for renewables
    - Sustainable power generation from fossil fuels: 12 large scale CCS demonstration plants by 2015; aiming at near-zero emissions by 2020
  - Nuclear: member states’ choice

- **Climate Strategy:**
  - EU ETS (Review, aviation)
  - Other policies (e.g. fuel quality)
  - Global carbon market (incl. CDM)

At least -20% CO₂

Up to - 5% of GHG emissions
Example: USA

President’s Biofuels Initiative Timeline

2006: President Announces Biofuels Initiative (January 31, 2006)

2012: Make Cellulosic Ethanol Cost Competitive

2025: Replace More Than 75% of Current Oil Imports From the Middle East

2012 Cost Targets:
- Ethanol Production Cost of $1.07/gallon
- Enzyme Cost of $0.16/gallon of Ethanol
- Delivered Feedstock Cost of $55/dry ton

2030: Replace 30% of Current Gasoline Consumption with Biofuels

Tools/R&D Focus

- Feedstock development to move from starch-based to cellulosic-based ethanol
- Help industry build first-of-a-kind plants
- Cost-share industrial-scale validation of technology & economics
- Establish Regional Feedstock Partnerships
- Accelerate Thermochemical Platform

Feedstock development focus on pulp & paper mill residues, forest residues, & perennial energy crops
IEA Biofuels Markets Scenarios

Share of Biofuels in Road-Transport Fuel Consumption

Biofuels are set to play a much larger role in meeting world road-transport fuel demand
Example: The *high price* scenario would make forest biorefinery prospects very good, but *low price* scenario bleak

"One of the most challenging aspects of the biorefinery economic analysis is deciding what future energy prices to use" (Eric Larson et al. 2006)
The long-term outlook (enlightened guestimation)

- There will be a number of different forest biorefinery concepts, which vary according to local conditions and markets.

- 2007-2010: forest biorefineries (based on "2nd generation technology") are at demonstration/pilot stage.

- 2010-2013: first commercial scale forest biorefineries are built.

- 2013-2020: forest biorefineries investment boom.

- 2020 - :major impact on the forest sector and local bioenergy markets, but relatively small impact on global energy markets.

- To what extent forest biorefineries will be located in South-America, Asia, Russia vs. Scandinavia and North America?

- When will the biorefineries boom take place in the sawmill and plywood industries?
Biorefinery Uncertainties & Risks

1. Energy prices (nobody knows)
2. Policy (regulations may change, a complex set of policies)
3. Advancement in biofuels production & technologies (when do new technologies become applicable on commercial scale?)
4. Rawmaterial availability & prices (forest biomass demand-supply changes)
5. Where to invest (Scandinavia and North America vs. South America and Russia)?
Implications to socio-economic research

1. Understanding the new concepts and their implications (energy and chemicals markets, forest sector multiple output technology, etc.)

2. Need to link the biofuels (energy) and chemicals markets to forest sector. Basically need to model demand and supply of forest biomass in a new setting

3. Model feed-back effects and links between forest products and biofuels/chemicals markets

4. Need to provide different scenarios (uncertainty & risks). For example: Oil price $40 vs. $100; tax exemption for forest biomass based diesel 0% vs. 100%, etc.

5. Undoubtedly – many other open issues. Room for pioneering research!
Thank you!
Supplementary slides
Forest Biorefinery Conversion Routes

Conversion/ Technology

- Biochemical
  - hydrolysis, fermentation
- Thermochemical
  - synthesis gas
- Combined Bio-Thermo
- Combustion
- Pyrolysis

Intermediate / end products

- Forest products
- Power
- Heat
- Gas
- Fuels (ethanol, FT, Diesel, mixed alcohols)
- Chemicals

Biomass

- Forest Biomass
- Other Biomass
  - urban waste
  - agricultural
  - recycled
Overall Energy In and Out

US Forest Industry & Ethanol -example*

- US forest products industry harvested 278 million bone-dry tons of wood in 2003
- This contained appx. 90 million tons of hemicellulose
  → assume forest industry can extract half of this hemi = 45 m.t.
  → this can be fermented to about 20 m.t. or 22.7 billion liters (6 bil. gallons) of ethanol
  → this is equivalent to 1/7 of the US national 35 billion gallon /year target
- "This does not require harvesting one additional log" ???

U.S. Pulp/Paper Industry Technical Potential for Biofuel Production in 2034

(billion gallons per year ethanol equivalent)

- FT configurations: 5 to 14 billion gal/yr
- DME configurations: 3 to 7 billion gal/yr
- For comparison:
  - 2005 corn ethanol production: 4 billion gallons
  - Latest administration goal: 35 billion gallons in 2017

The world of secondary forest resources, when thought of as bioproducts feedstocks, is huge.

If converted to ethanol at 100 gals/ton, these feedstocks represent over 35 billion gallons/yr.

AND — it’s sustainable and renewable.

### U. S. Poplar Plantation Industry: Pulp and Paper Production

<table>
<thead>
<tr>
<th>Region</th>
<th>Biomass Growth Rate (MT ha⁻¹ yr⁻¹)</th>
<th>Rotation (yrs)</th>
<th>Area ¹ (ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pacific Northwest</td>
<td>13.5</td>
<td>6 to 8</td>
<td>14,000</td>
</tr>
<tr>
<td>North Central</td>
<td>9.4</td>
<td>12</td>
<td>10,000</td>
</tr>
<tr>
<td>Mississippi River Valley</td>
<td>10.1</td>
<td>8 to 10</td>
<td>11,000</td>
</tr>
</tbody>
</table>


*Brian Stanton (managing director, tree improvement group, Green Wood Resources) "Hybrid Poplar Feedstock Production". Presentation at the TAPPI Renewable Energy Conference, Atlanta 10-11 May 2007, p.8.*
The sustainable forest resource potential is nearly 370 million dry tons annually.

For conversion, (2000 lbs) tons x 0.907 = metric tonnes

The sustainable forest resource potential
~ 370 million dry tons per year

For conversion, (2000 lbs) tons x 0.907 = metric tonnes

## Feedstocks for Biorefining

<table>
<thead>
<tr>
<th>Starch, Sugar &amp; Oil</th>
<th>Cellulose / Hemicellulose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn</td>
<td>Hybrid Poplar</td>
</tr>
<tr>
<td>Soybean</td>
<td>Grasses</td>
</tr>
<tr>
<td>Palm</td>
<td>Forest residue</td>
</tr>
<tr>
<td>Sugar cane</td>
<td>Hemp</td>
</tr>
<tr>
<td></td>
<td>Sawdust</td>
</tr>
<tr>
<td></td>
<td>Cereal straw</td>
</tr>
<tr>
<td></td>
<td>Yard waste</td>
</tr>
</tbody>
</table>

**Livestock and Food Processing Wastes**

<table>
<thead>
<tr>
<th>Manure</th>
<th>Animal fats &amp; used frying oils</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cheese whey</td>
<td>Food processing wastes</td>
</tr>
<tr>
<td>Corn syrup</td>
<td>Fruit processing wastes</td>
</tr>
<tr>
<td>Milling byproducts</td>
<td>Biorefinery wastes</td>
</tr>
</tbody>
</table>

April 10, 2007

Slide source: Stewart Campbell (vice pr., commercial development, Canadian Bioenergy Corporation) "Biorefining: New Demand / New Landscape, Presentation at the TAPPI Renewable Energy Conference, Atlanta 10-11 May 2007"
Reducing the Cost of Cellulosic Ethanol