VTT TECHNICAL RESEARCH CENTRE OF FINLAND LTD

BEST Programme
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best

Sustainable Bioenergy
Solutions for Tomorrow

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The Objective

- Objective was to compare output of three different cases with the same forest raw material to products by:
  - energy content,
  - economic value (national value) + investment needed
  - and circular use potential
- The following biomass species:
  - pulpwood,
  - logwood,
  - logging residues,
  - stumps,
  - small sized stem wood,
  - sawmill chips, bark and stumps

Research case studies

Case 1: Bioproduct mill

- Annual wood use of pulpwood and sawmill chips 6.5 million m^3 or ~14,500 GWh/a)
- CHP plant (annual use of forest energy wood 0.9 million m^3 or ~ 1,990 GWh/a)

Case 2: 5 CHP plants

- Each plant use annually 1.5 million m^3 or ~3,460 GWh/a of feedstock consisting of forest energywood, pulp wood and sawmill chips)

Case 3: 5 Fischer Tropsch diesel plants

- Each use annually 1.5 million m^3 or ~3,460 GWh/a of feedstock consisting of forest energywood, pulp wood and sawmill chips

- All cases include a sawmill

Methods

- The material/energy flows of energy from forest biomass to products were calculated, illustrated by Sankey diagrams and compared with each other.
  - The basis in energy calculations was net calorific value on 0% moisture content.
  - The efficiencies to product were calculated from the forest to products for the whole forest biomass chain (including harvesting, sawmill and the other biomass utilization plants).
- The economic value of products were calculated to illustrate the national product value in each case and compared with needed investment.
  - Costs such as transportation of biomass and chemicals were not included.
- Cascade factor was calculated for the cases for determine how many time in average the raw material is used.
- The value chain in the three cases is illustrated by a separate drawing.

Prices and technical parameters

Parameters	Value	Unit	Source
Annual operation hours of FT plant	8 000	h/a	VTT's estimate
Annual use of district heat from FT-diesel plant (influences the economic income of the plant)	5 500	h/a	VTT's estimate
Annual operation CHP plant (influences only the needed capacity and investment cost)	6 000	h/a	VTT's estimate
Pulp price	500	€/t	Expert opinion (2016)
Sawn wood price	200	€/m^3	http://www.metla.fi/julkaisut/isbn/978-951-40-2491-7/suhdannekatsaus-2014-2015.pdf
Tall oil price	400	€/t	Expert opinion (2016)
Turpentine price	600	€/t	Expert opinion (2016)
Electricity price	40	€/MWh	http://www.stat.fi/til/ehi/2015/01/ehi_2015_01_2015-06-16_kuv_006_fi.html (Statistic centre of Finland Nordspot
District heat price	20	€/MWh	VTT's estimate
FT diesel price	1 000	€/t	VTT's estimate (margin+ Fame 800 €/t)
CHP efficiency to power	29.3	%	VTT's own estimate (on dry basis for biomass)
CHP efficiency to heat	50.4	%	VTT's (on dry basis for biomass)

The Bioproduct Mill –Process Scheme

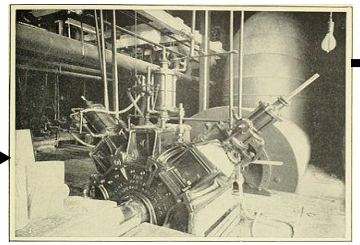
Pulp wood

Debarking and chipping

Wood chips storage

Wood chip screening

Cooking



Pulp

Drying

Baling

Pulp to customer

Black liquor

Washing and bleaching

Tall oil and turpentine

Black liquor evaporation

Recovery boiler

Green liquor treatment

Recaustising

Steam turbine

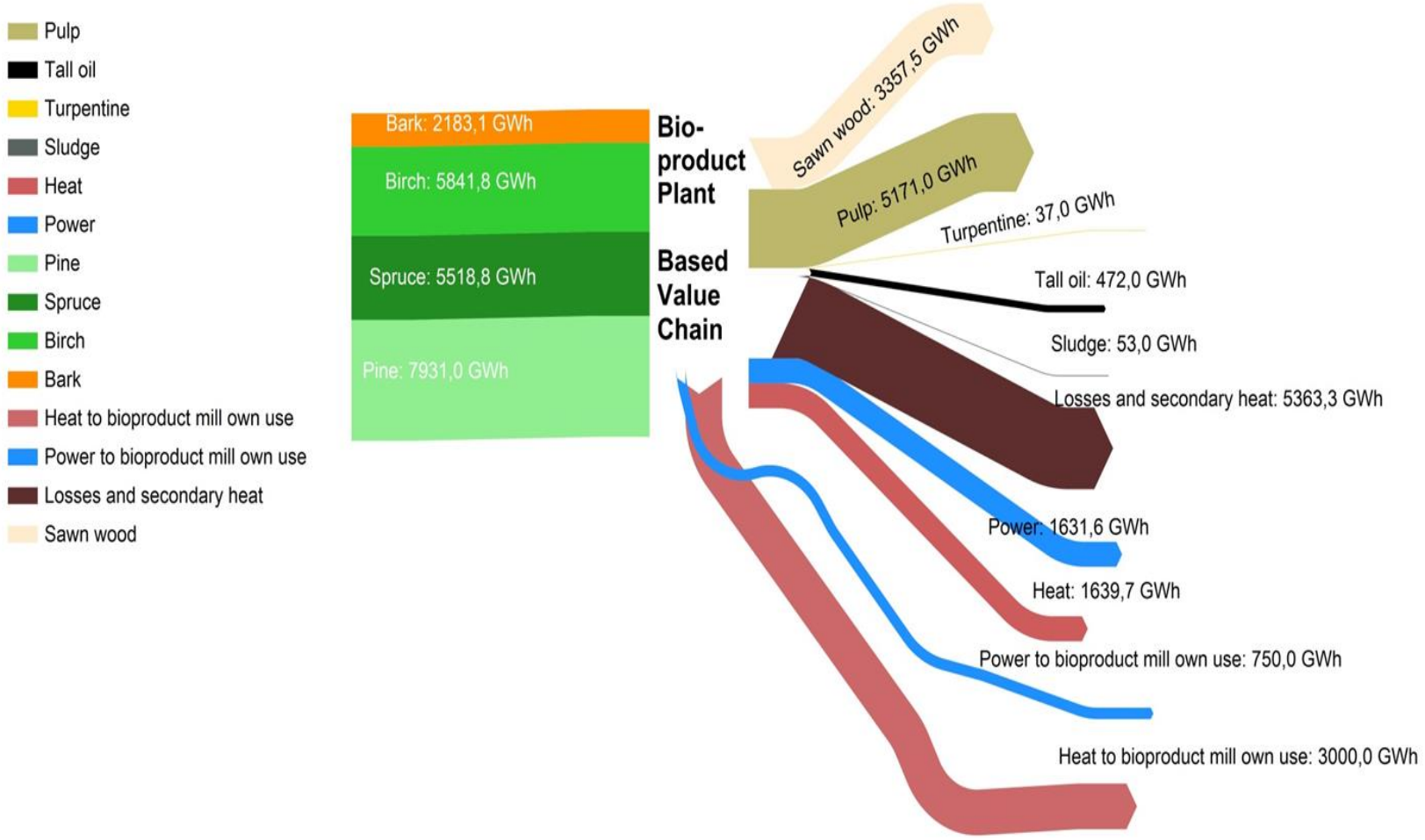
Heat and power

Bark gasifier

Lime kiln

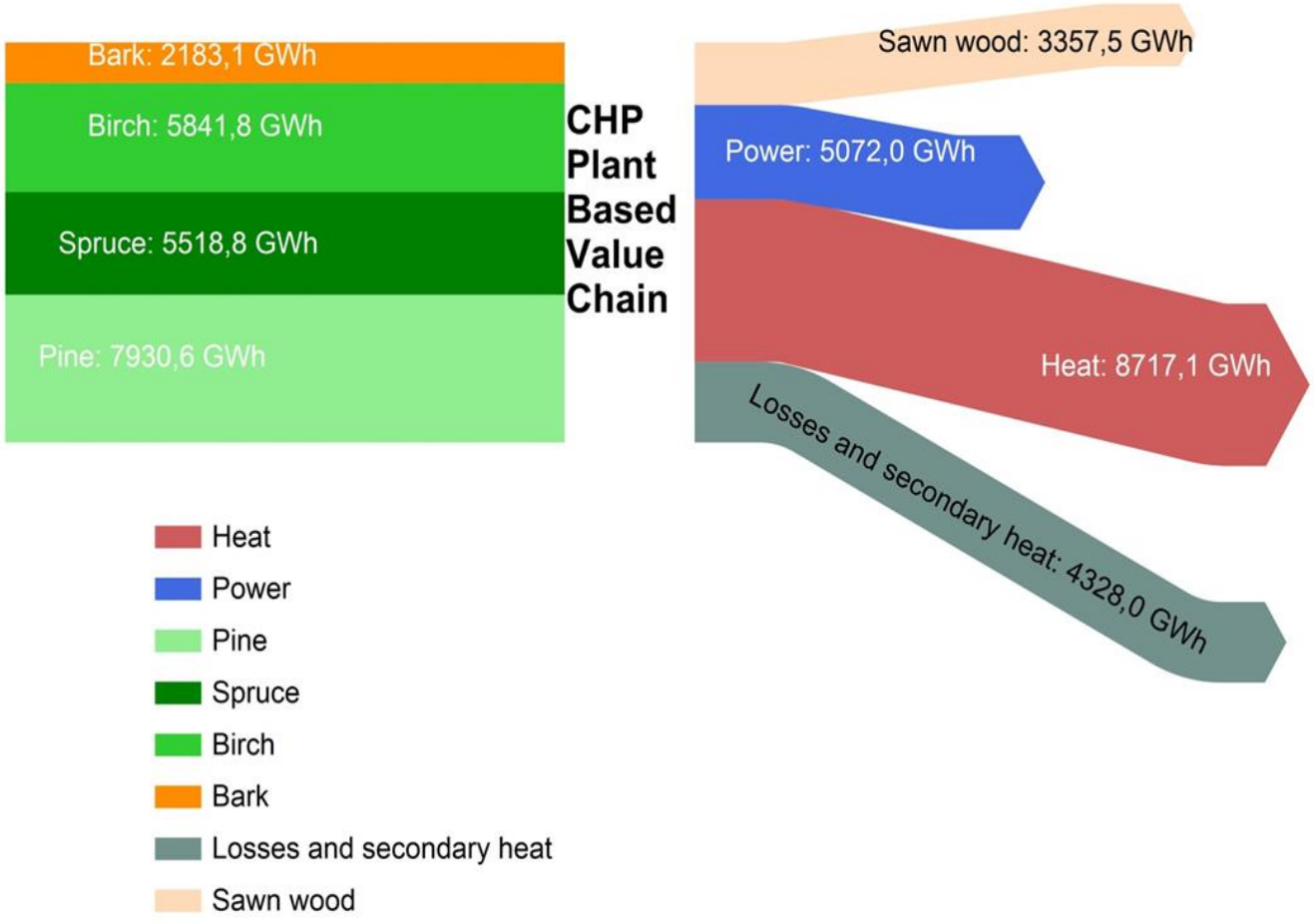
The Bioproduct Mill - Sankey Diagram

- The Bioproduct mill products amount are based on reported value by MetsäGroup



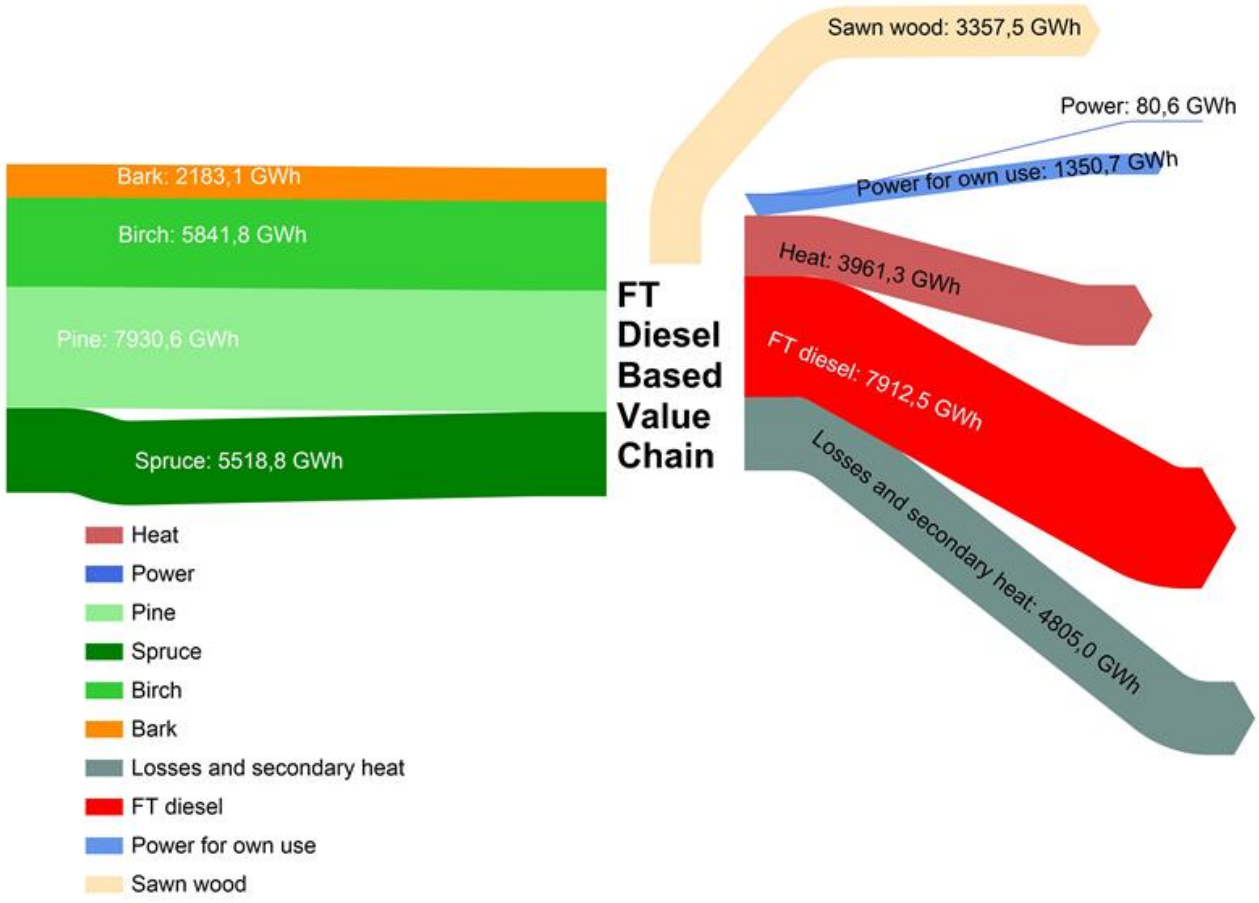
The CHP Case - Sankey Diagram

- The product values are based on estimated energy efficiencies to heat and power.



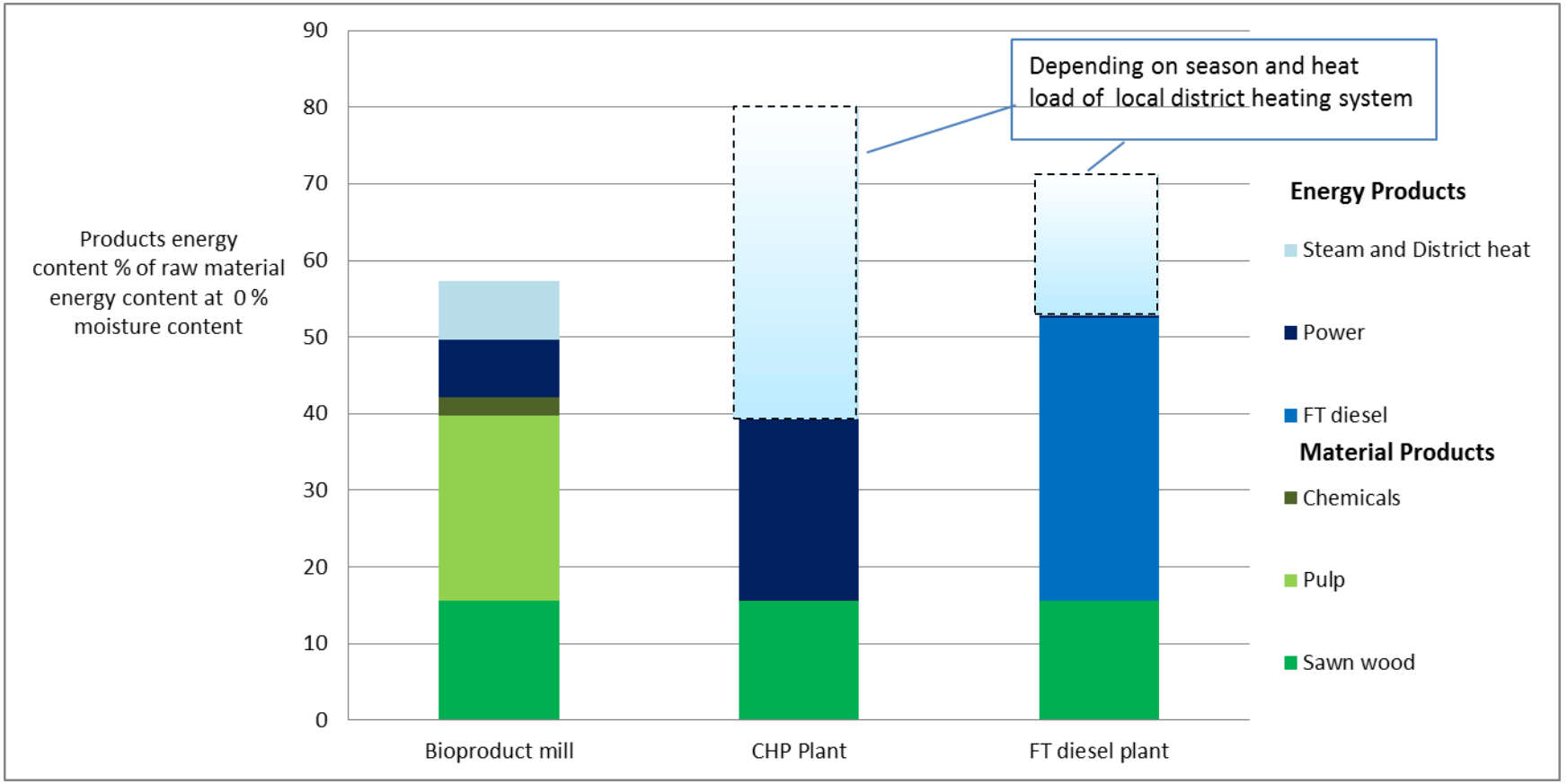
The FT diesel - Sankey Diagram

- The efficiency to products is based on VTT Technology 91 report.



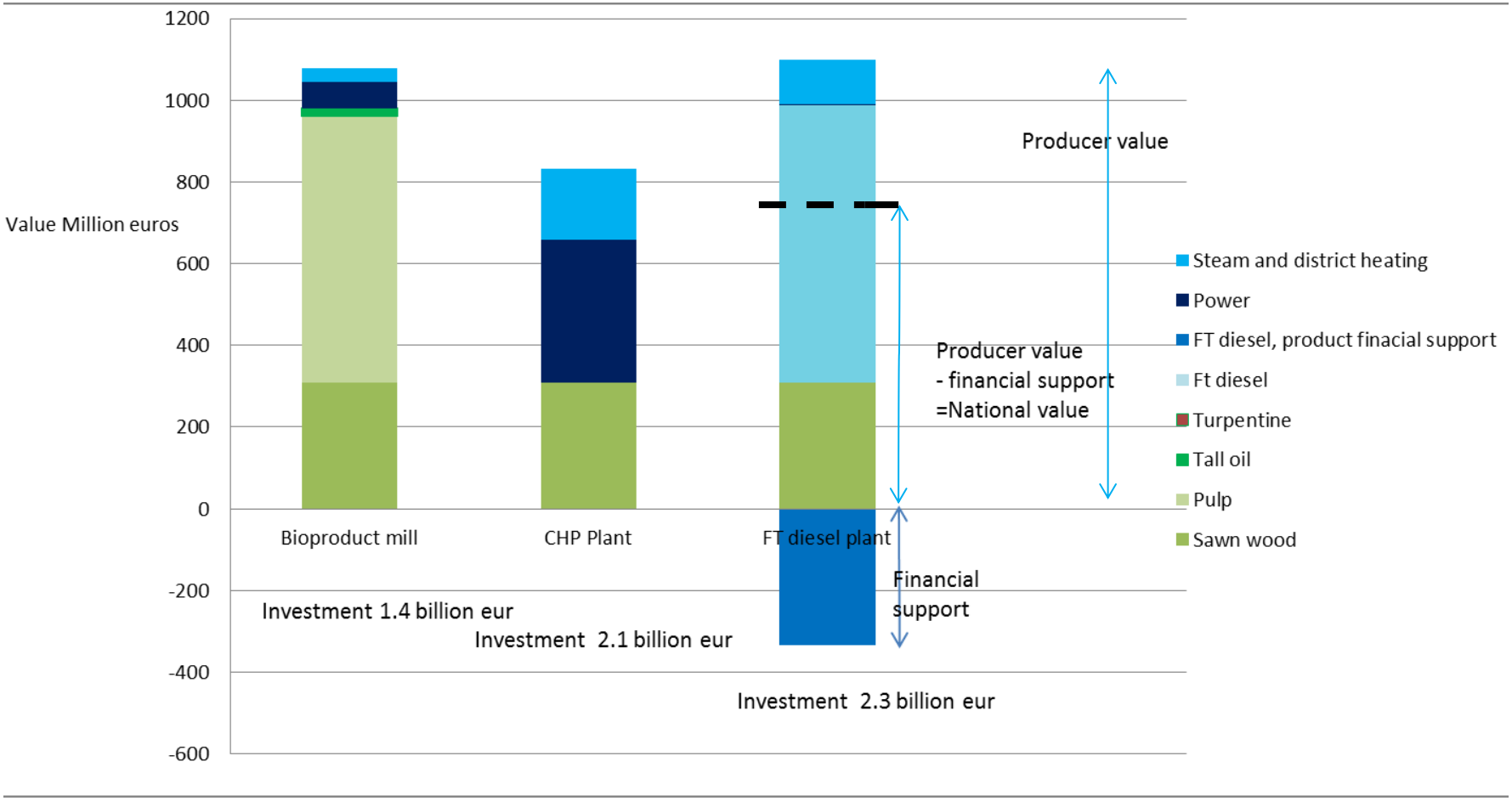
Kurkela, E. & Hannula, I. 2013. Liquid transportation fuels via large-scale fluidised bed gasification of lignocellulosic biomass, VTT Technology 91. http://www.vtt.fi/inf/pdf/technology/2013/t91.pdf

Material and energy Products - Energy Yields



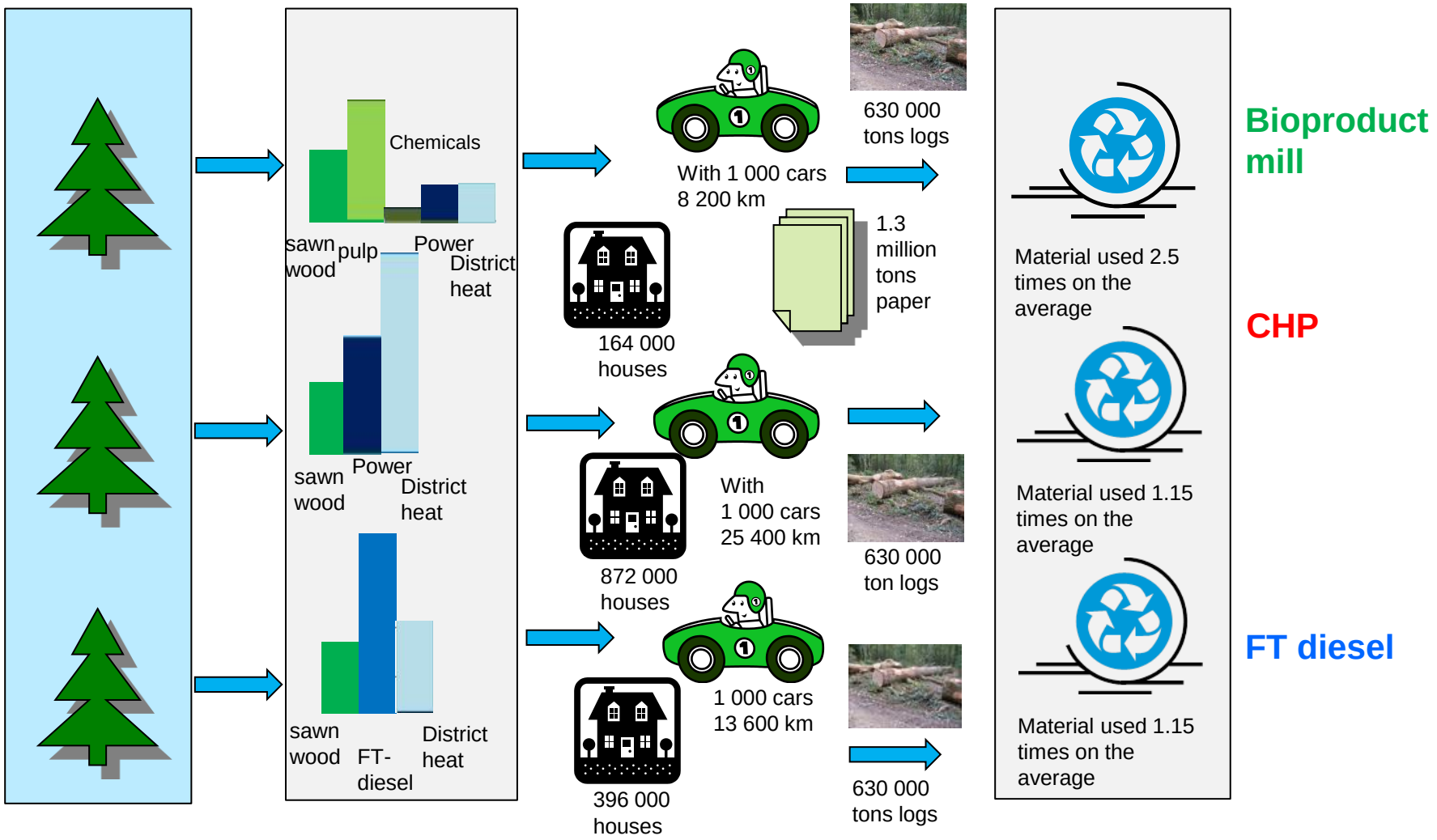
- Electricity's higher exergy value compared to heat not taken into account
- The raw material energy content refers to whole raw material forest energy content
- The biomass conversion includes saw mill in all cases and 1 additional CHP plant for the Bioproduct mill

Comparison of Economic value of products



- CHP and FT-diesel investment cost include 5 plants in both
- The investment cost estimate for CHP plant takes into account higher capacity due to lower annual demand for district heat (6,000 h/a)
- The Bioproduct mill include the investment cost of 1 CHP plant and saw mill investment in not included in any of the cases.

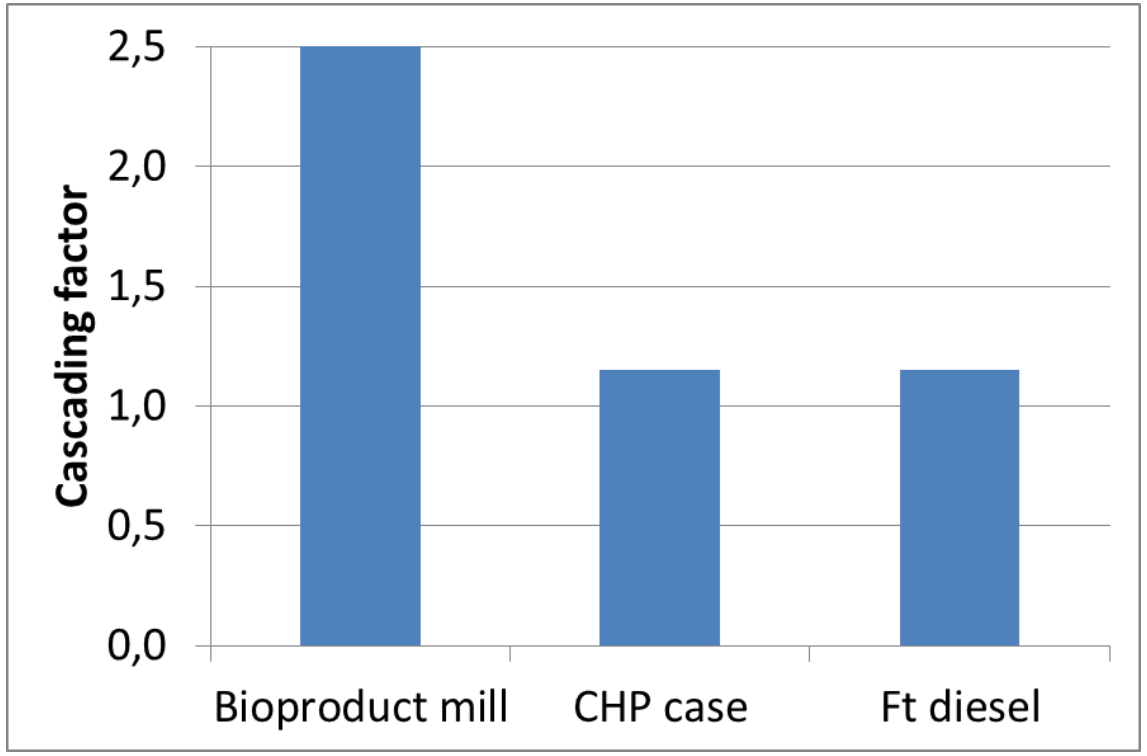
Production Chain drawing



- Electric car consumption 20 kWh / 100 km, diesel car 60 kWh / 100 km (~6 L / 100km),
- Annual heat need for a typical house in Finland: 10 MWh/a
- 1 ton air dried pulp is assumed to produce 1 ton of paper

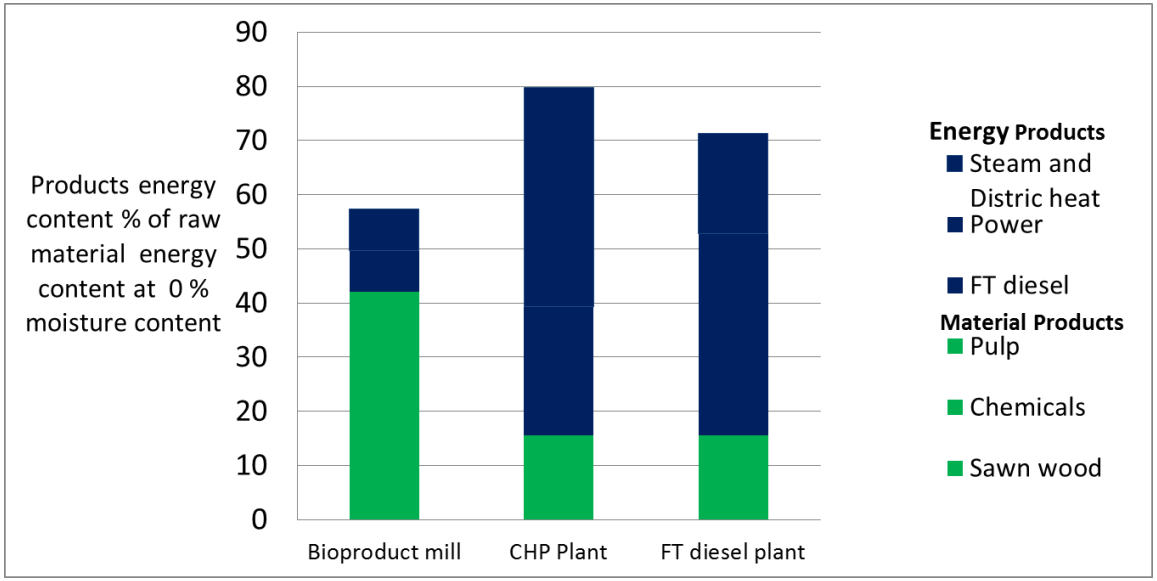
Cascading use of products

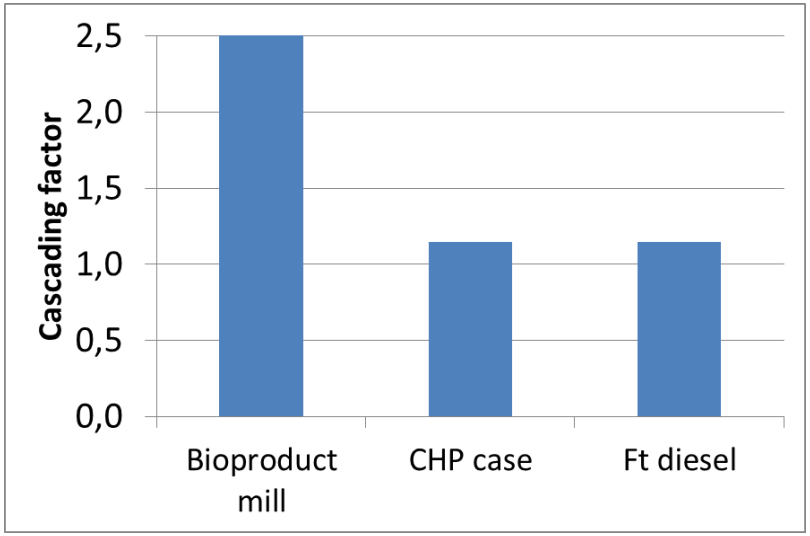
- Here the share's of wood in different product were allocated by energy content.
  - Assumptions: 85% of pulp can be recycled
  - 100% of sawn wood is used 2nd time for energy
  - Export or import was not considered

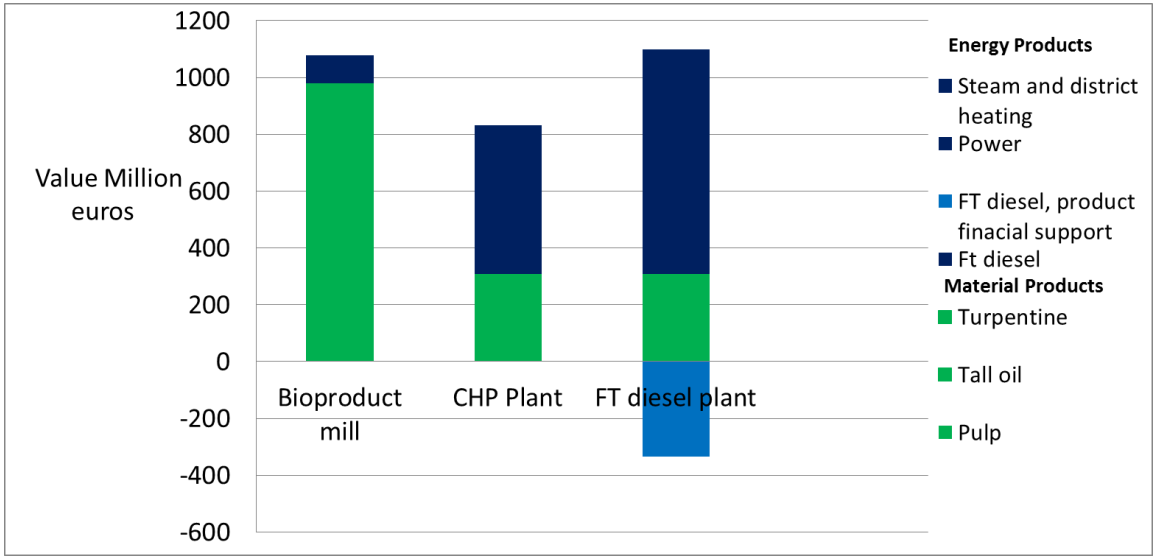


The wood cascading factor defines how many times on the average wood is used.

Multi-criteria comparison of production chains







Conclusions (1/3)

- In the study the same amount and quality of woody biomass is assumed to be used as raw material in **three** well-known **biorefinery cases**:
  - 1) pulp production (the 'Bioproduct mill'),
  - 2) direct incineration for power and heat (CHP), and
  - 3) FT -diesel production.
- All three cases and conclusions below include sawmill, which enables better comparison.
- It is not always meaningful to compare these three cases directly to each other because the end-product portfolios differ significantly.
- However, the methodology used still gives some indication regarding the nature of the cases in question.
- The **Sankey diagrams** clearly show that because cases 2 and 3 have, in terms of energy yield, one energy main product, case 1 has a more diverse product portfolio including material and energy products.

Conclusions (1/3)

- When the **energy content** of the end products is used as the measure,
  - direct incineration in a CHP plant shows the best yield (about 80%).
  - However, half of the yield value comprises surplus steam and heat. The realization of this part of the yield is strongly dependent on the local demand for such utilities. The demand also varies peaking in winter time and being even zero at summer time.
- When neglecting steam and heat, the ‘winners’ in terms of energy yield are
  - Case 1 (Bioproduct mill) and
  - Case 3 (FT-diesel) (equally good at about 50% yield).

Conclusions (3/3)

- When using **economic value** created as the measure the difference between cases 1 and 2 is as expected:
  - CHP (+sawmilling) generates little over €800 million per annum (assuming all surplus steam and heat can be sold), and
  - the Bioproduct mill (+saw milling) about €1.1 billion per annum.
- The **FT- diesel production** is more complex. If only seen from the perspective of the producer and adding the expected governmental financial support to the income, the value created is about €1.1 billion . However, from a national perspective the value created is only about €700 million.
- The role of **cascading factors** is increasing when trying to understand various raw material utilizing value chains. In this study
  - The best cascading factor was calculated for the Bioproduct mill case (**2.52**), in which the main final product is chemical pulp, is quite efficiently recycled.
  - In the direct incineration (CHP) and FT-diesel cases, the cascading factor was **1.15**.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