S2Biom Summer School

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Overview on biomass conversion technologies for bio-based products

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Current use of lignocellulosic biomass from forests

Total amount of **forest based lignocellulosic biomass** used for energy and material uses in 2013 (E28 + Western Balcans, Ukraine, FYR of Macedonia): **530 million tonnes** (485 in EU28)

An estimated **261 million tonnes** (245 in EU28) of wood used as a "classical" bio-based material primarily used in the woodworking and pulp and paper industry

269 million tonnes (with 240 in EU28) of wood are used for production of energy (mainly heat and power).

Sources: EuropaBio, Nova Institut, DG ENER, EnC

Current use of lignocellulosic biomass from agriculture

Total amount of **agricultural (non lignocellulosic) biomass** in 2013: almost 10% (8 million tonnes out of 79) of the raw materials base for the chemical industries in the EU was based on renewables:

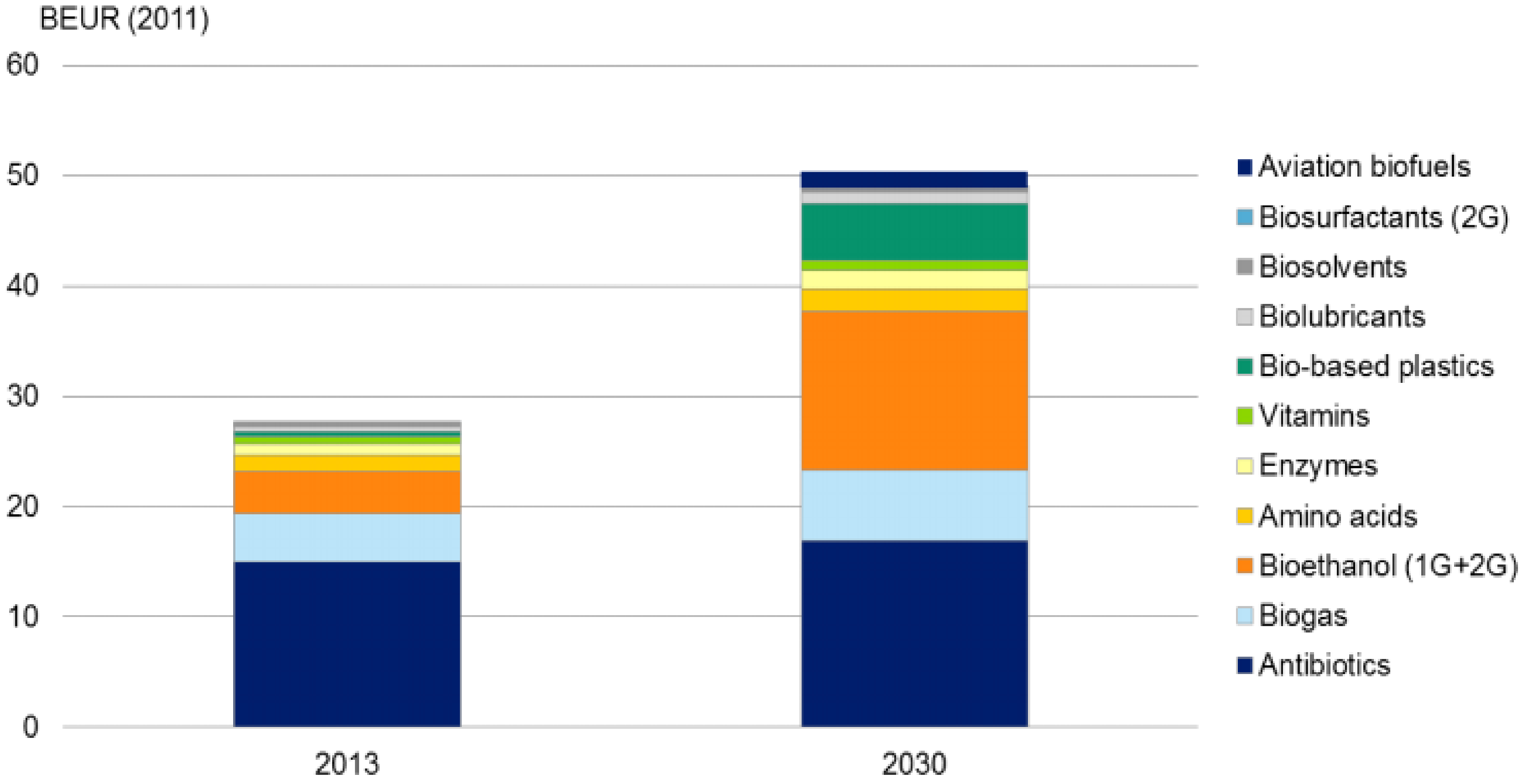
- sugar and starch: 1.56 mTonnes)
- plant oils (1.26 mTonnes)
- bioethanol ETBE (1 mTonnes)
- natural rubber (1.06 mTonnes)
- pure bioethanol (0.46 mTonnes)
- animal fats (0.43 mTonnes)
- glycerine (0.41 mTonnes)
- …

Total amount of **agriculture based lignocellulosic biomass:**
Estimates from 5-10 million tonnes (dry) but information relies on individual studies without recent harmonisation across EU

Sources: EuropaBio, Nova Institut, Cefic, VDI, EnC

Opportunities for bio-based industries

Estimated biobased products market demand in the EU up to 2030*



** BIO-TIC project*

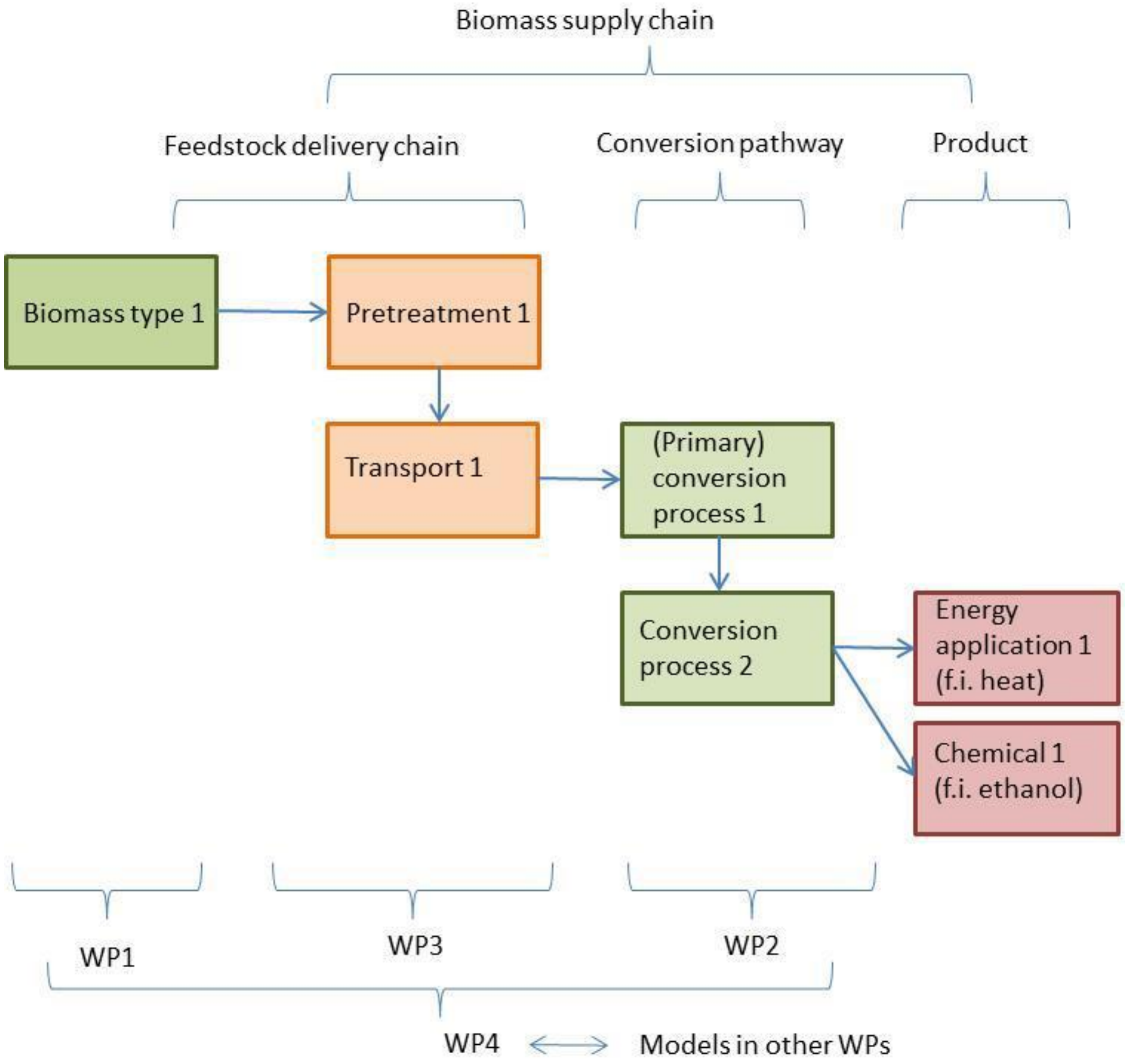
Chemicals and materials: existing studies

	Current state	2020	2030
Bioplastics	• European Bioplastics: 280 kT (2013) • BioTic: around 1 B€	• European Bioplastics: 512 kT (2018) • BioTic: around 2 B€	• - • BioTic: around 5,2 B€
Biolubricants	• ERRMA: 137 kT (2008) • BioChem: 150 kT (2008)	• ERRMA: 420 kT (2020) • BioChem: 230 kT (2020)	• -
Biocomposites	• ERRMA: 362 kT (2010) • Nova institute: 315 kT (2010)	• ERRMA: 920 kT (2020) • Nova institute: 830 kT (2020)	• - • -
Biochemicals	• Chemical industry is estimated to use 8-10% renewable raw materials • BioTic: around 1 B€ (Chemical building blocs - 2013)	• The share of biobased chemicals is expected to be 20% • BioTic: around 1,5 B€ (Chemical building blocks)	• The share of biobased chemicals is expected to be 30% (BIC Vision) • BioTic: around 3 B€ (Chemical building blocks)
Bioenergy & biofuels	• BioTic: bioethanol around 4 B€ • Nova institute: biofuels (all) around 6 B€ (2011) • DG Agri: bioethanol 3,3 Mtoe (2013)	• BioTic: bioethanol around 11 B€ and 0,5 B€ aviation fuels • DG Agri: bioethanol 6,1 Mtoe (2023)	• BioTic: bioethanol around 14,2 B€ and 1 B€ aviation fuels

Work Package 2 - Objectives

- The overall objectives of WP 2 are the following:
  - To identify and extensively characterise existing and future non-food biomass conversion technologies for energy and bio-based products.
  - To develop a standardized methodology according to which the different biomass categories identified and quantified in WP1 need to be characterised.
  - To assess the optimal match of biomass categories of different quality with the existing and future non-food biomass conversion technologies.

Work Package 2 connections



Structure of WP2 in WP1-4 of the S2Biom project

Database structure for WP2

In order to be able to match the technology requirements with biomass characteristics, the different technologies were categorized into three main categories:

- Thermal conversion technologies
- (Bio-)chemical conversion technologies
- Anaerobic digestion technologies

Database structure

Category	Subcategory	Process name
Thermal conversion technologies		
Direct combustion of solid biomass	*Fluidised bed combustion for CHP (steam cycle)*	*BFB direct combustion*
		CFB direct combustion
	Fixed bed combustion for heat	*Grate boiler for heat*
	Fixed bed combustion for CHP (steam cycle)	*Grate boiler with wood chips for CHP*
		Grate boiler with agrobiomass for CHP
	Direct co-combustion in coal fired power plants	*Co-firing in PC*
	Waste incinerators with energy recovery	*Grate fired waste incinerator*
	Domestic pellet burners for heat	*Pellet boiler for heat*
	Domestic residential batch fired stoves for heat	*Batch stove for heat*

Product-market combinations (PMC) considered in WP7

	Product	Market
1	Heat	District heating
2	Electricity	Power market
3	Advanced Biofuels	Transport fuel
4	C6 sugars	C6 chemistry: polymers & plastics, others
5	C5 sugars	C5 chemistry: polymers & plastics, others
6	Bio-methane	Grid, transport
7	BTX	Petrochemical industry
8	Methanol	Transport, chemical industry
9	Hydrogen	Transport, (petro)chemical industry
10	Ethylene	(petro)chemical industry

The results of the market analysis indicate that:

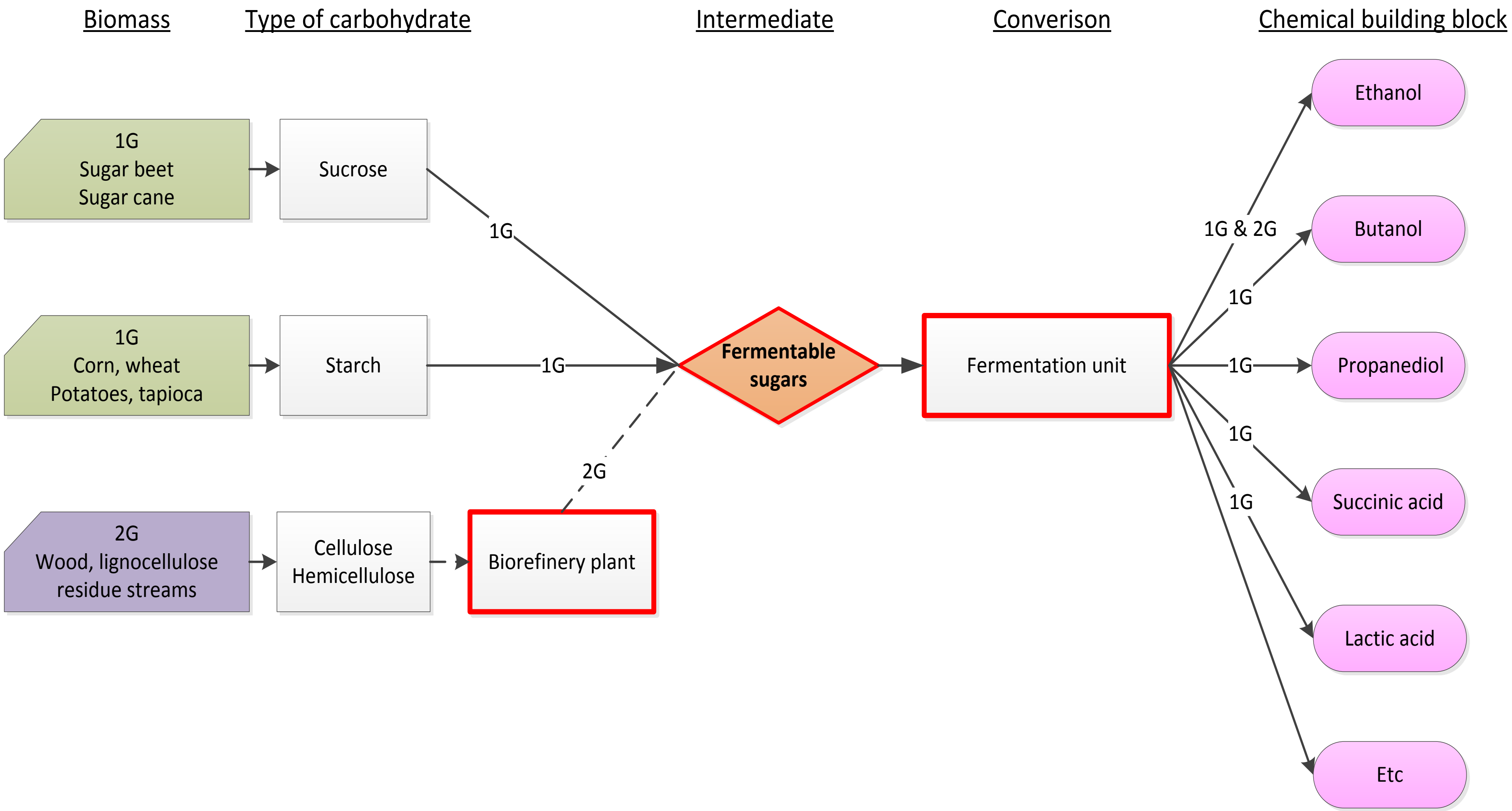
- Demand for lignocellulosic biomass for chemicals and materials at pan European level in 2020 would be around one million tonne, increasing to less than 10 million tonnes in 2030
- Based on the energy content, the demand would be around 0.4% of the corresponding demand for bioenergy and biofuels (PMCs 1-3), increasing to 1.4% in 2030

Key factors affecting this picture are:

- The rate of technology development (both for advanced chemicals/material
- and for biofuels and bioenergy)
- The exact shaping of the supporting policy framework, and
- The future of the (petro)chemical industry in Europe
- Besides, the oil price is a strong factor affecting the prospects for biobased chemicals and materials

Chemical and biochemical conversion processes

Products of the Sugar platform

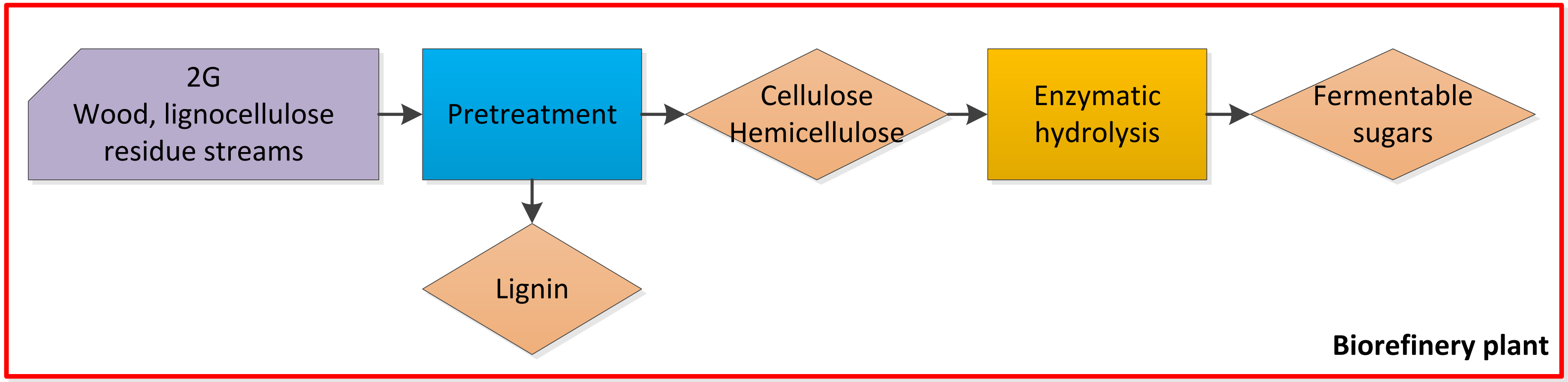


Sugar Platform

- **1G biomass is easily converted to high-purity sugars with conventional technology. On average, 1G biomass (sugar or starch rich raw materials) contains 72 wt% dry matter carbohydrates. Isolation efficiency : 95%.**
- **2G biomass also contains carbohydrates but these are more difficult to isolate On average, 60 wt% of the dry biomass are carbohydrates, Isolation efficiency: 80%.**
  - These sugar streams are less pure than sugars from 1G biomass due to the isolation and extraction processes. Further purification is a costly process.
- **Sucrose can be fed to the fermentation unit directly, and starch can be enzymatic hydrolysed by amylases to glucose prior to fermentation.**

Sugar Platform

- **For the conversion of cellulose and hemicellulose (from lignocellulosic biomass) to sugars a biorefinery plant is required.**
  - This biorefinery plant can be compared to a pulp mill for the production of paper, with the difference that the carbohydrate polymers cellulose and hemicellulose are now further degraded to monomers for fermentation.



Pretreatment

Pretreatment is the first and also crucial step in the conversion of lignocellulose to sugars

- cellulose will be made more accessible to the enzymes that convert the carbohydrate polymers to fermentable sugars
- Pretreatment has been recognised as one of the most expensive processing steps in lignocellulose conversion.

In general, pretreatment techniques can be divided

- in acid-related processes (aiming for hemicellulose degradation) and
- alkaline-related processes (aiming for lignin removal)

Further steps of biorefinery

In the second step the cellulose and hemicellulose polymers are being converted to fermentable sugars by enzymatic hydrolysis (expensive enzymes). Major challenge:

- full conversion of the carbohydates to monomers and to reduce the amount of enzymes used

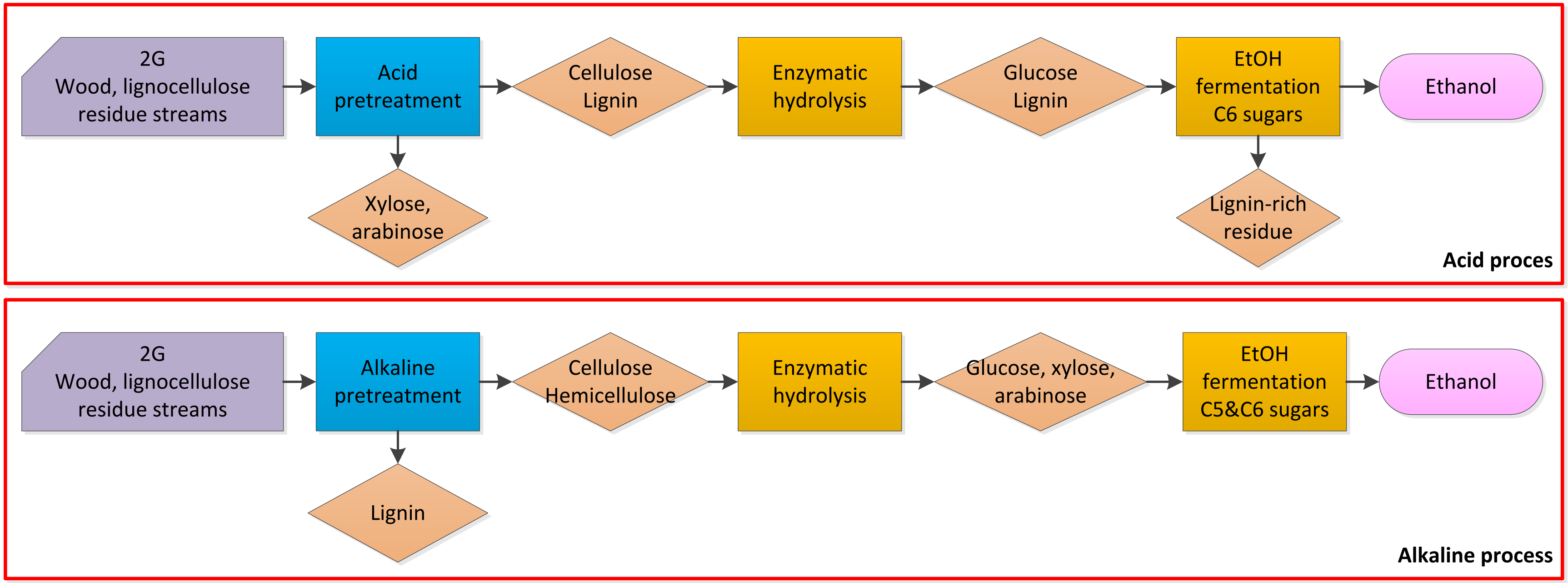
The fermentation unit converts the sugars to various chemical building blocks like ethanol, butanol, lactic acid etc. Chemically speaking there is no difference between glucose from starch (1G) and glucose from lignocellulose (2G)

- But, in order to isolate sugars from lignocellulose, elevated temperature and pressure is required to remove lignin and disrupt the crystalline structure of cellulose.

Bio-based routes in the database

pretreatment techniques

- acid-related processes (aiming for hemicellulose degradation) and
- alkaline-related processes (aiming for lignin removal)



Biochemical conversion technologies in the database

- focus on processes (conversion technologies) that convert lignocellulose biomass to fermentable sugars, rather than including various fermentation processes that currently make use of 1G carbohydrates.
- Ethanol is the only chemical building block today that is produced on a large scale from lignocellulose, others are still at R&D-level
- Nowadays the number of chemical building blocks produced from renewable resources is still limited. Most examples of industrial production of biobased chemicals are based on first generation (1G) materials, with ethanol as the only exception

Biochemical conversion technologies in the database

- In order to be able to use the data in the database for the matching tool, in matching biomass to a final product, the description of a full value chain from biomass to ethanol was required
- This value chain consists of multiple processes, which makes it a complex entry in the database

Fermentation

- **Fermentation is the conversion of an organic substrate to a product using cell cultures or microorganisms such as bacteria or fungi.**
- **The organic substrate is generally a sugar solution**
  - Fermentation can take place in the absence of oxygen (anaerobic) or in the presence of oxygen (aerobic)
- **Characteristics of fermentations processes**

Chemical building blocks by fermentation of sugars

Building block	Formula	g/mol	#	Theoretical efficiency	Remarks
Succinic acid	C4H6O4	118	2	131%	>100% by incorporation of CO_2 (commercial)
Lactic acid	C3H6O3	90	2	100%	Corbion (commercial)
3-HPA	C3H6O3	90	2	100%	Novozymes (R&D)
Propane diol	C3H8O2	76	2	84%	DuPont (Commercial)
Itaconic acid	C5H6O4	130	1	72%	Commercial
Isopropanol	C3H8O	60	2	67%	Mitsui (R&D)
Ethanol	C2H6O	46	2	51%	Commercial
Butane diol	C4H10O2	90	1	50%	Commercial
Methacrylic acid	C4H6O2	86	1	48%	Mitsubishi (R&D)
Isobutanol	C4H6O2	86	1	48%	Gevo (Commercial)
Butanol	C4H10O	74	1	41%	Cathay (Commercial)
Isoprene	C5H8	68	1	38%	Ajinomoto (Pilot/R&D)

Products of the pyrolysis platform

- **The general concept of fast pyrolysis is to produce pyrolysis oil close to the location of the biomass.**
- **The pyrolysis oil can be transported much more efficiently than the raw biomass, and will often be further processed at another location.**
- **In the database a couple of separate entries were combined into new ones, in order to provide examples of value chains**
  - These examples were not meant to cover all the possibilities regarding the production of bio-based products from biomass through the fast pyrolysis process.

Techniques from pulp and paper industry (VTT)

Conversion process:

- **Pulping in paper industry**
  - Kraft pulping based processes
    - Kraft (existing)
    - Kraft with LignoBoost process, (TRL 9)
  - Sulphite pulping (existing)
  - Soda, soda-oxygen, soda-AQ pulping (existing)
- **Pulping in dissolving pulp production**
  - Prehydrolysis Kraft processes:
    - autohydrolysis stage done by pre-steaming (existing)
    - autohydrolysis done in water phase (hot water pretreatment) (existing)
  - Sulphite pulping processes (existing)
- **Organosolv pulping**
  - Organic acid processes
    - Formic acid based Formico (TRL 9) and CIMV (TRL 9)
    - Acetic acid based Acetocell (TRL 7-8)
  - Ethanol based Alcell (TRL 9) and its further developed process Lignol
- **Ionic liquid-aided fractionation (TRL 3)**

Techniques from pulp and paper industry (VTT)

- **Main products: different pulp products: paper grade pulp, dissolving pulp, NFC, CMC etc.**
- **Main side products in existing processes:**
  - energy
  - tall oil and turpentine
  - lignosulphonates (Sulphite)
  - vanillin, furfural, xylose etc. (Sulphite)
- **Possible side product in the future:**
  - lignin (LignoBoost, organosolv processes)
  - hemicelluloses as polymers, monomers, hydroxy acids from (Kraft, sulphite, prehydrolysis Kraft and Organosolv processes)

Techniques from pulp and paper industry (VTT)

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Selection for description in database

- **Kraft process with LignoBoost process (TRL 9)**
  - In near future LignoBoost process will be built to reduce the CO_2 emissions of the pulp mill by replacing a significant amount of natural gas with dried lignin fired in the lime kilns
  - Separation of the lignin from black liquor for lignin product
- **Prehydrolysis Kraft process in water phase (existing)**
  - In future there will be possibility to separate hemicelluloses for the valuable intermediate products and chemicals (TRL 4-5)

Overview of technology criteria and characteristics in the database

General information

- Name and subcategories
- Description of main operating principle of technology
- Level of commercial application
- Current Technology Readiness level in 2014
- References

Technology parameters

- Type and capacity of outputs (typical values)
- Conversion efficiencies
- Number of typical full load hours per year
- Typical lifetime of equipment
- Investment costs
- Labour requirements for typical installation (FTE for typical installation)

Overview of technology criteria and characteristics in the database

Biomass input specifications

- Biomass input common for the technology used
- Traded form of biomass
- Dimensions of biomass
- Maximum moisture content (% wet basis)
- Minimum bulk density (kg/m3, wet basis)
- Maximum ash content (weight %, dry basis)
- Minimal ash melting point (= initial deformation temperature) (°C)
- Maximum allowable content of nitrogen (wt%, dry basis)
- Maximum allowable content of chlorine (wt%, dry basis)
- Maximum allowable content of lignin (g/kg dry matter)
- Minimum allowable content of cellulose (g/kg dry matter)
- Minimum allowable content of hemicellulose (g/kg dry matter)
- Minimum biogas yield (m^3 gas/ton dry biomass)

Conversion technologies database

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s2biom.alterra.wur.nl/web/guest/conversion

Biomass chain data / Conversion technologies

Number	Category	Subcategory	Name	Output capacity
73	Direct combustion of solid biomass	Fixed bed combustion for CHP (steam cycle)	Grate boiler with agrobiomass for CHP	Power, Heat
72	Fast pyrolysis	Pyrolysis plus boiler for heat and steam	Fast pyrolysis of residues + CHP plant, value chain example	Power, Heat
71	Fast pyrolysis	Pyrolysis plus boiler for heat and steam	Fast Pyrolysis of residues + Boiler for heat, value chain example	Power, Heat
70	Fast pyrolysis	Pyrolysis plus boiler for heat and steam	Fast pyrolysis + CHP plant, value chain example	Power, Heat
69	Fast pyrolysis	Pyrolysis oil and diesel engine for electricity	Fast pyrolysis + Multiple diesel combustion engines, value chain example	Power, Heat
68	Fast pyrolysis	Pyrolysis plus boiler for heat and steam	Fast pyrolysis + Industrial steam boiler, value chain example	Power, Heat
67	Fast pyrolysis	Pyrolysis plus boiler for heat and steam	Fast pyrolysis + Boiler for heat, value chain example	Power, Heat
65	Biochemical ethanol and biobased products	Simultaneous saccharification and fermentation	Ethanol from lignocellulose (dilute acid pretreatment), value chain example	Power, Ethanol
63	Fast pyrolysis	Pyrolysis oil and diesel engine for electricity	CHP Gas Turbine	Power, Heat
62	Biochemical hydrolysis and fermentation	Fermentation	Fermentation acid pretreated	Ethanol

http://s2biom-test.alterra.wur.nl

Account: demo

Password: helsinki

Conversion technologies database

View details of BFB for syngas

GENERAL PROPERTIES

Name	BFB for syngas
Main category	Gasification technologies
Subcategory	Bubbling fluidized bed for syngas production
Image url	
Year of first implementation	
Estimated number of systems in operation	
Main operating principle:	

Biomass is gasified with steam and oxygen at pressurised BFB gasifier operated at ca. 8 bar and 870 C. Product gas is cooled to 600 C, filtered and led into catalytic reformer where tars and hydrocarbon gases are reformed. Then product gas is cleaned, conditioned and pressurised to fuel synthesis.

Level of commercial application	
Important pilots and EU projects	
Expected Developments	
Current Technology Readiness Level in 2014	Level 7, Integrated pilot system demonstrated
Expected Technology Readiness Level in 2030	Level 9, System ready for full scale deployment
Justify expected Level in 2030	
References:	

Carbona/Andritz

TECHNICAL PROPERTIES

Capacity of outputs (typical values)

Heat (MWth) 45
Conversion efficiencies: net returns usable heat(GJ/GJ biomass input) typical: 0.15 min: 0 max: 0.2 typical in 2020: 0.1 typical in 2030: 0.1

Methanol (m3/hour) 26 LHV (GJ / m^3) 25.3
Conversion efficiencies: net returns fuel(GJ/GJ biomass input) typical: 0.6 min: 0.5 max: 0.67 typical in 2020: 0.65 typical in 2030: 0.65

Data sources used to define conversion efficiencies in 2014:

VTT Technology 91, 2013 Hannula, Ilkka; & Kurkela, Esa. 2013. Liquid transportation fuels via large-scale fluidised-bed gasification of lignocellulosic biomass. Espoo, VTT. 114 p. + app. 3 p. VTT Technology; 91

External inputs (not generated by the biomass in the conversion process)

Power (kW): 5

Indication: experience based data	No
Number of possible full load hours per year (hours)	8500
Number of typical full load hours per year (hours)	8000
Typical Lifetime of Equipment (years)	40

Data sources used to define conversion efficiencies in 2020:

Data sources used to define conversion efficiencies in 2030:

General data sources for technical properties:

BIOMASS INPUT SPECIFICATIONS

Biomass input, common for the technology used:
Biomass input, technically possible but not common:

Traded form Wood chips
Dimensions P31: 3,15 mm < P < 31,5 mm Fine fraction F25: < 25 %

Moisture content	(% wet basis) typical 15	max 20
Minimal bulk density	(kg/m^3, wet basis) 120	
Maximum ash content	(% dry basis) 5	
Minimal ash melting point (= initial deformation temperature)	(°C) 1000	
Volatile matter (only for thermally trated material, torrefied or steam exploded)	(VM%)	

Maximum allowable contents
Nitrogen, N (wt%, dry) 1 Sulphur, S (wt%, dry) 0.3 Chlorine, Cl (wt%, dry) 0.3

Optional attributes

Net caloric value	(MJ/kg) min	max
Gross caloric value	(MJ/kg) min	max
Biogas yield	(m^3 gas/ton dry biomass)	% methane
Cellulose content	(g/kg dry matter) min	max
Hemicellulose content	(g/kg dry matter) min	max
Lignin content	(g/kg dry matter) min	max
Crude fibre content	(g/kg dry matter) min	max
Starch content	(g/kg dry matter) min	max
Sugar content	(g/kg dry matter) min	max
Fat content	(g/kg dry matter) min	max
Protein content	(g/kg dry matter) min	max
Acetyl group content	(g/kg dry matter) min	max

FINANCIAL AND ECONOMIC PROPERTIES

	in 2014 (€):	expected in 2020 (€):	expected in 2030 (€):
Investments costs	500000000	350000000	350000000

Labour needed Operators (FTE): 25 Staff and engineering (FTE): 20

Thank you for your attention!

www.s2biom.eu

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