Hardwood Lignin Production and Application

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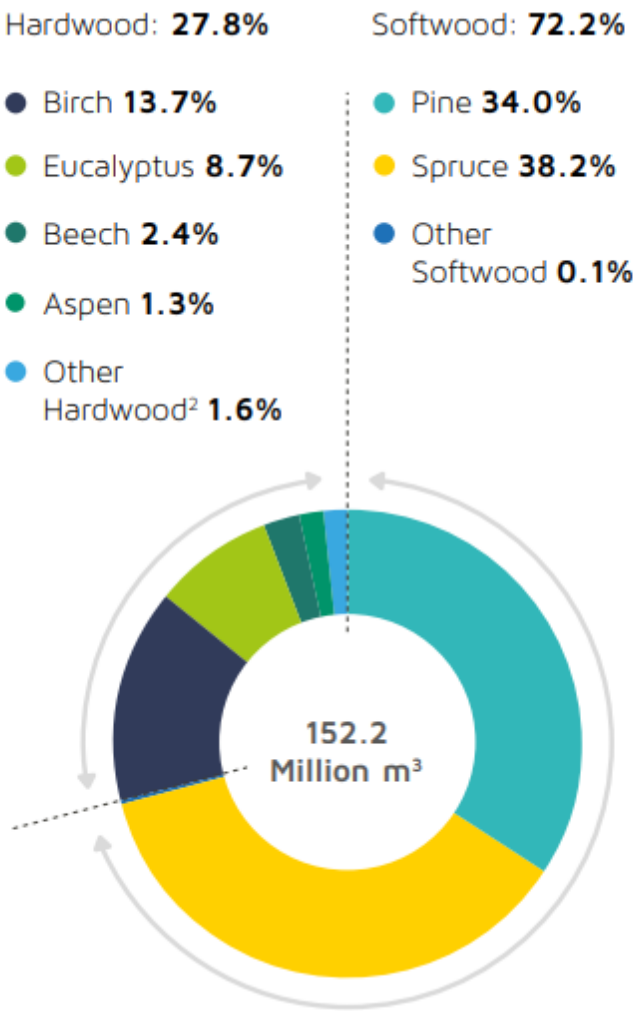
February 2024

Wood consumption in 2021



Other Hardwood = hornbeam, ash, maple, accacia, quercus-cerris, oak, alder, poplar, willow, chesnut

Biomass Composition

Carbohydrates	Lignin	Extractives
60-70	20-30	3-10

Biomass	Main components (%)		
	Cellulose	Hemicellulose	Lignin
Softwoods	~ 42	~ 25	25-30
Hardwoods	~ 45	~ 20	20-25
Grasses	25-40	25-50	10-30
Agricultural residues	27-50	20-40	3-30

Reddy & Yang, 2005; Saini et al., 2015

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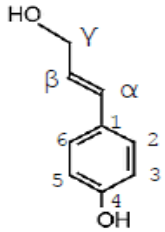
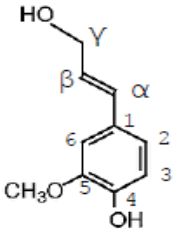
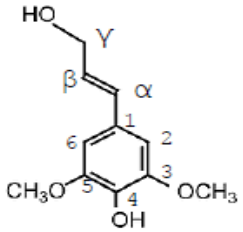
Lignins Structure and Properties



p-coumaryl alcohol



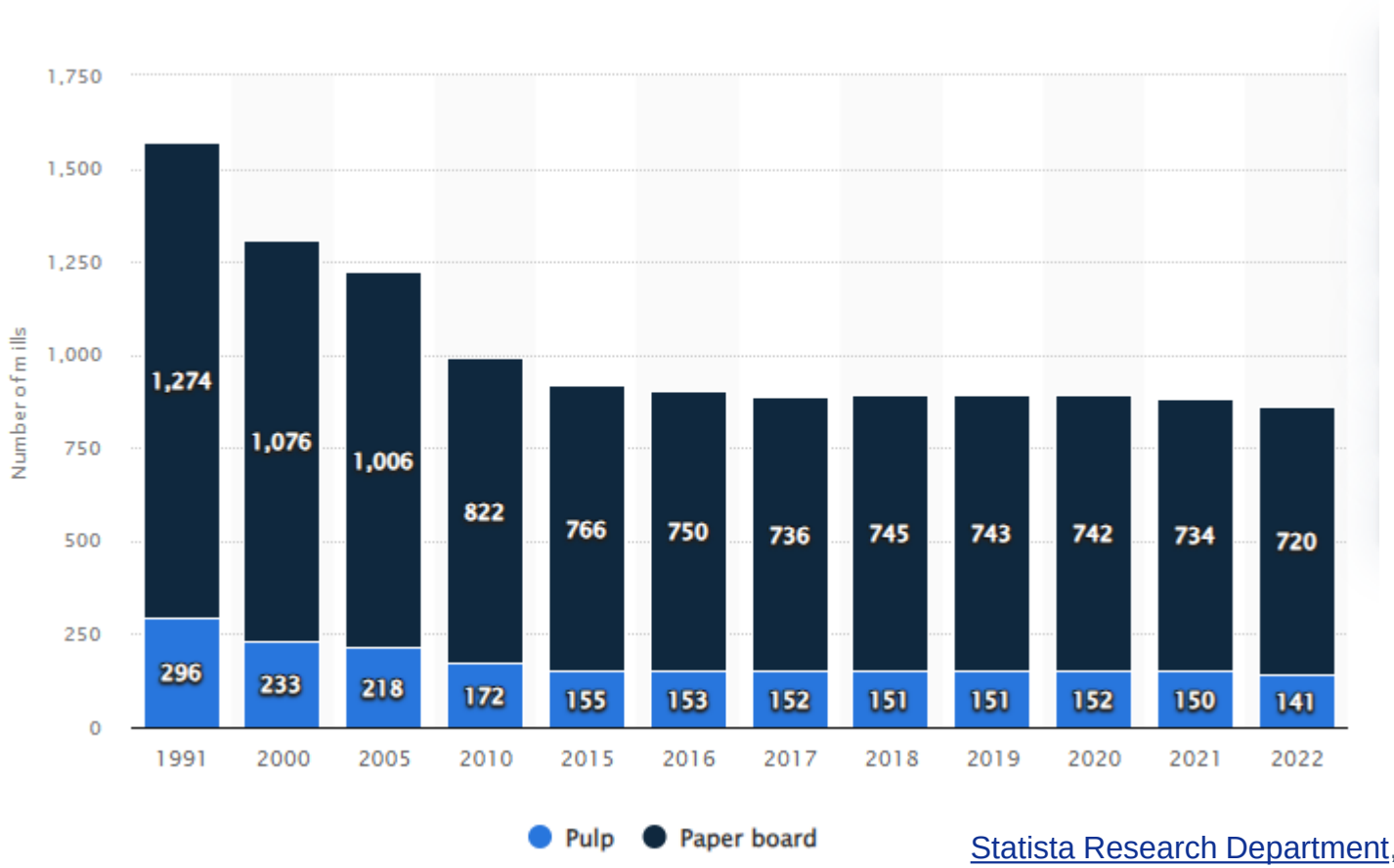
coniferyl alcohol



sinapyl alcohol

Balakshin et al., ChemSusChem, 2021, 14, 1 – 22

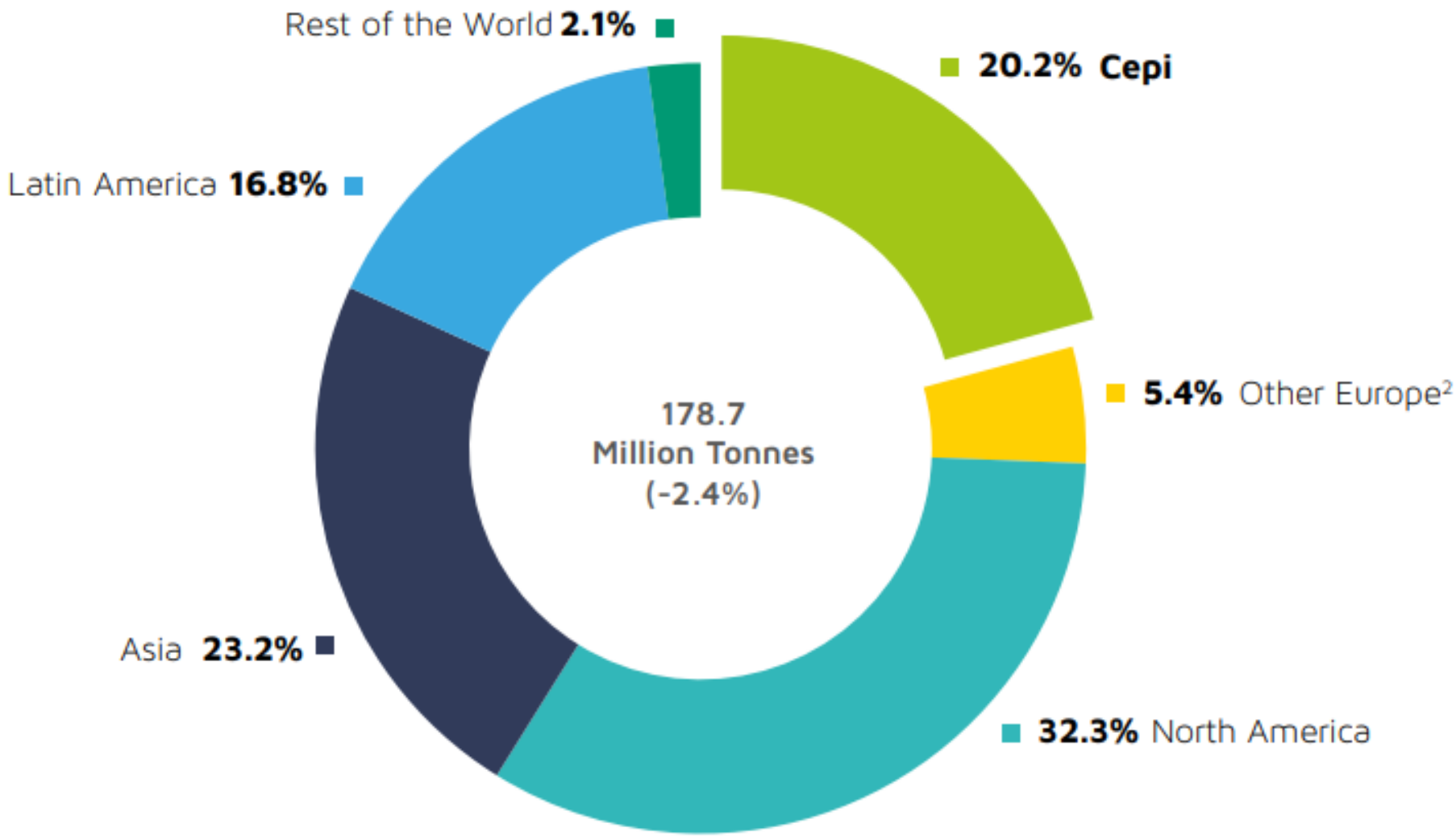
Number of CEPI paper and pulp mills in Europe 1991-2022



Statista Research Department, Jul 17, 2023

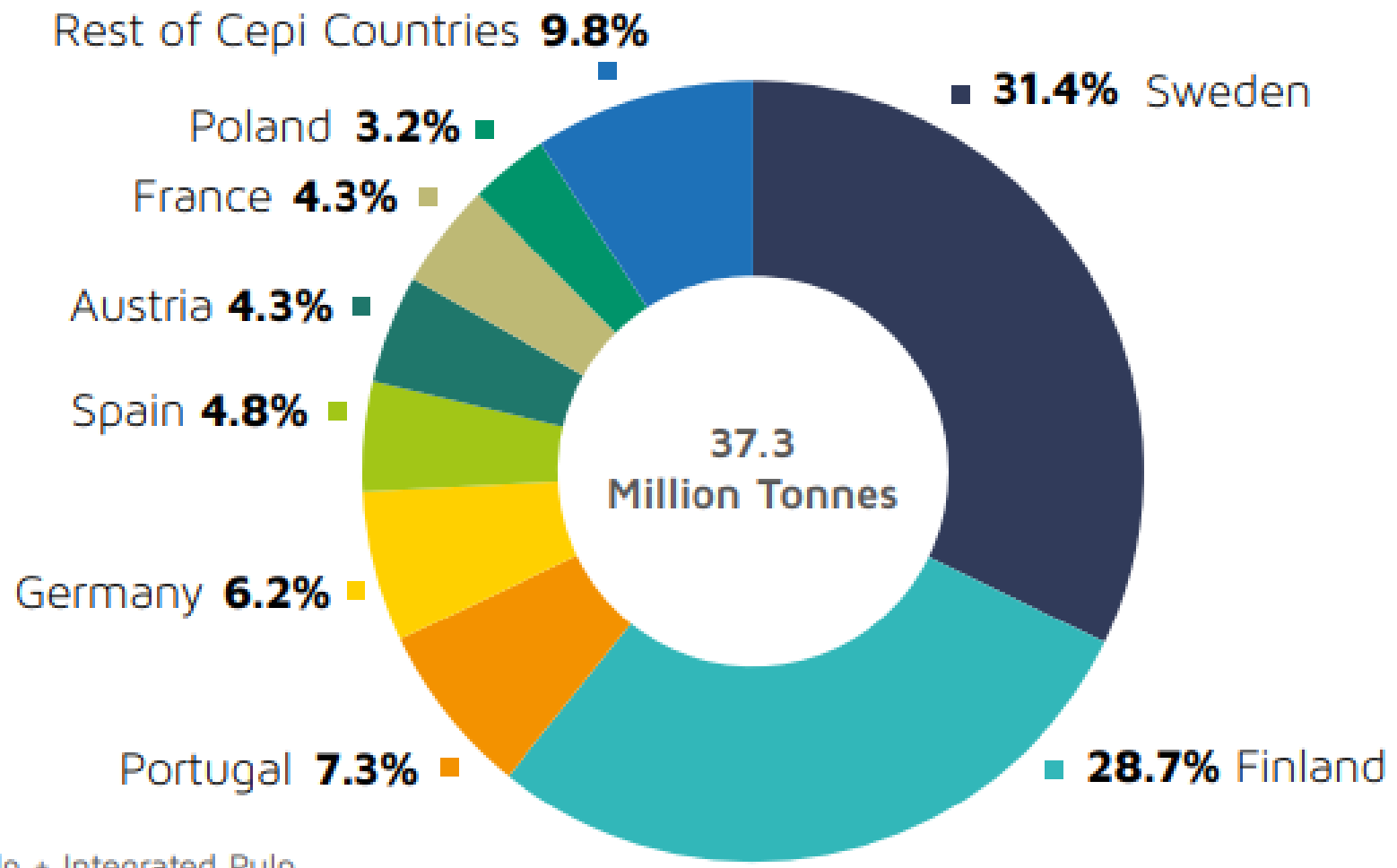
There were 720 paper and pulp mills across Europe in 2022 that were represented by the Confederation of European Paper Industries' (CEPI)

World Total Pulp[1] Production by Region in 2020[3]



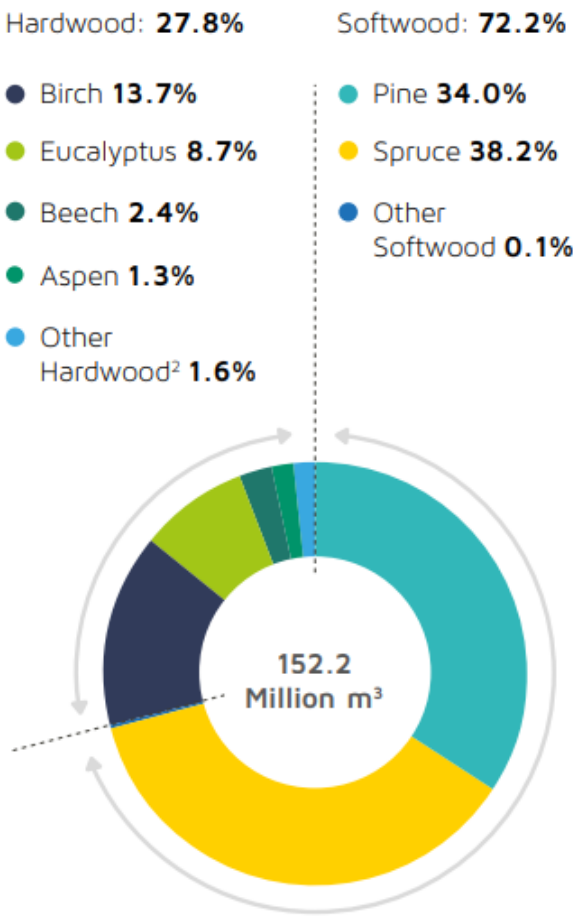
Cepi Key Statistics 2021

Total Pulp[1] Production by Country in 2021



[1] Total Pulp = Market Pulp + Integrated Pulp

Cepi Key Statistics 2021

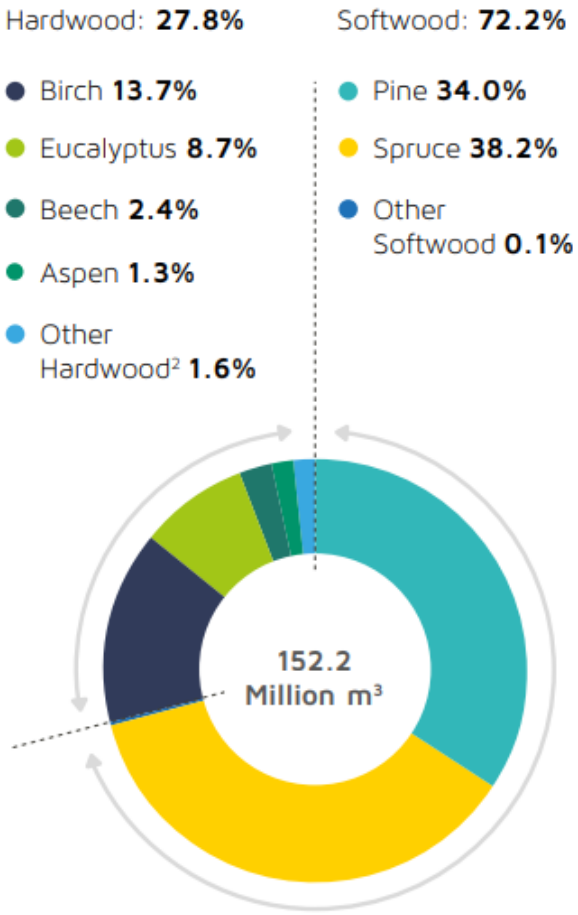


Report Attributes	Details
Hardwood Pulp Market Estimated Base Year Value (2021)	US$ 170 Billion
Hardwood Pulp Market Value in 2022	US$ 176 Billion
Hardwood Pulp Market CAGR 2022 to 2032	3.5%
Anticipated Hardwood Pulp Market Value (2032)	US$ 242Billion

https://www.futuremarketinsights.com/reports/hardwood-pulp-market

Other Hardwood = hornbeam, ash, maple, accacia, quercus-cerris, oak, alder, poplar, willow, chesnut

Cepi Key Statistics 2021



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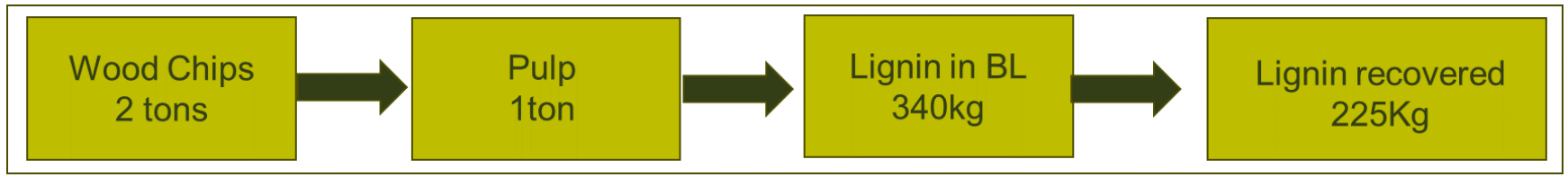
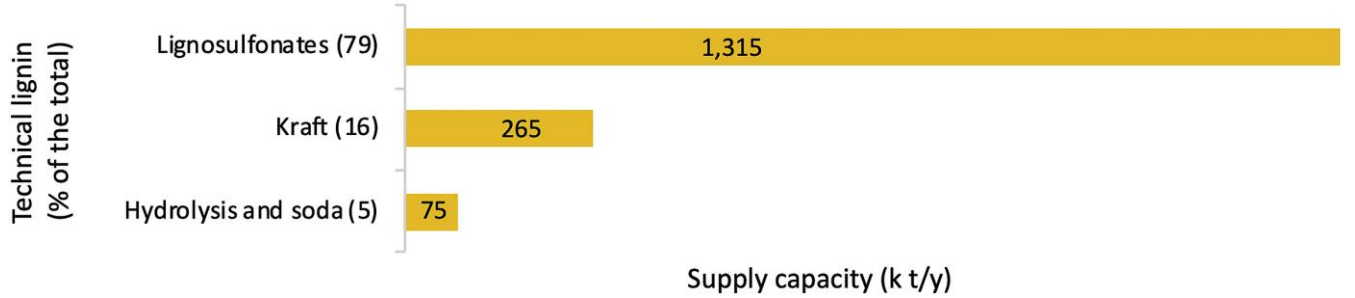


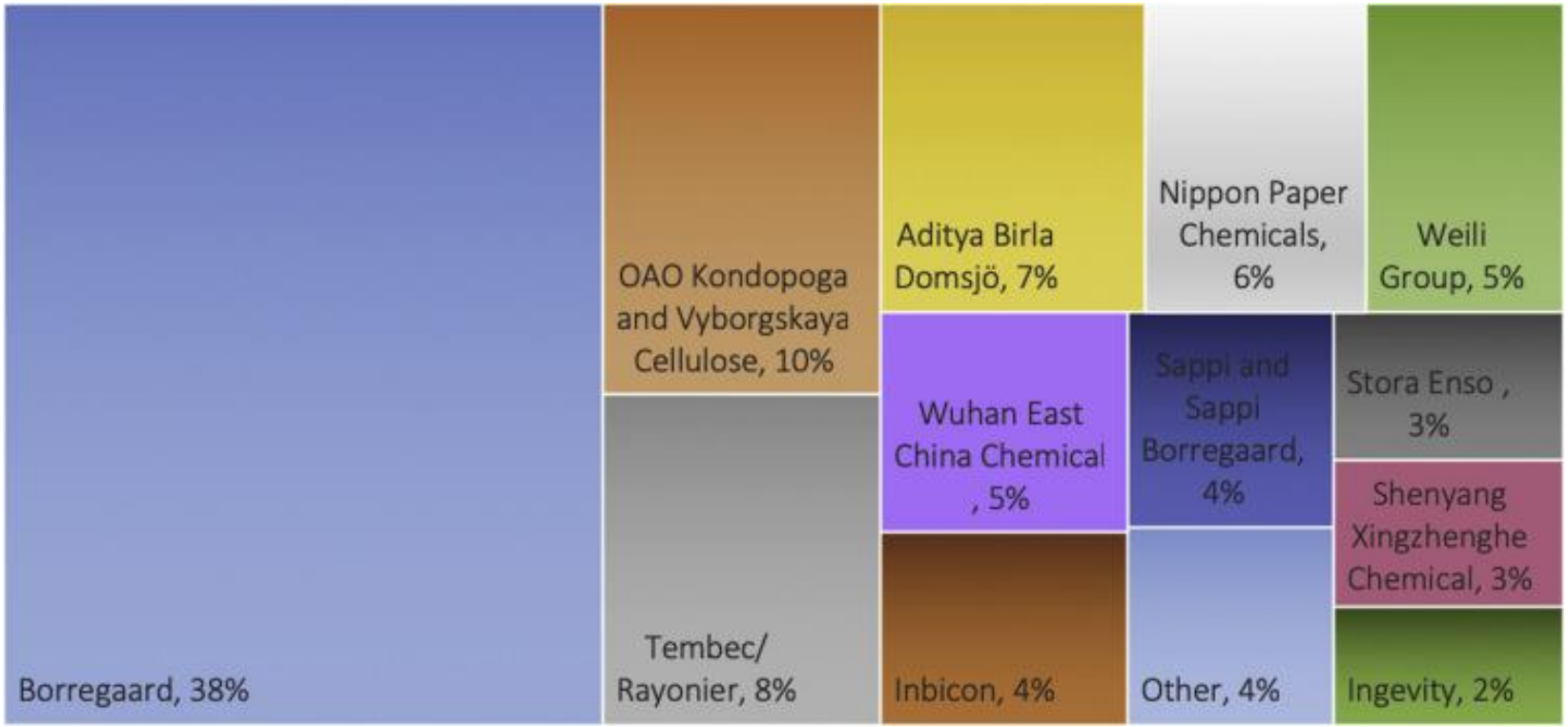
Potential Lignin production

Fiber type	Mtons (2022)	Recovered Lignin potential (kg/Adt)	Lignin potential (Mtons/year)
HW Kraft Pulp	80	225	18

Fastmarket RISI 2022

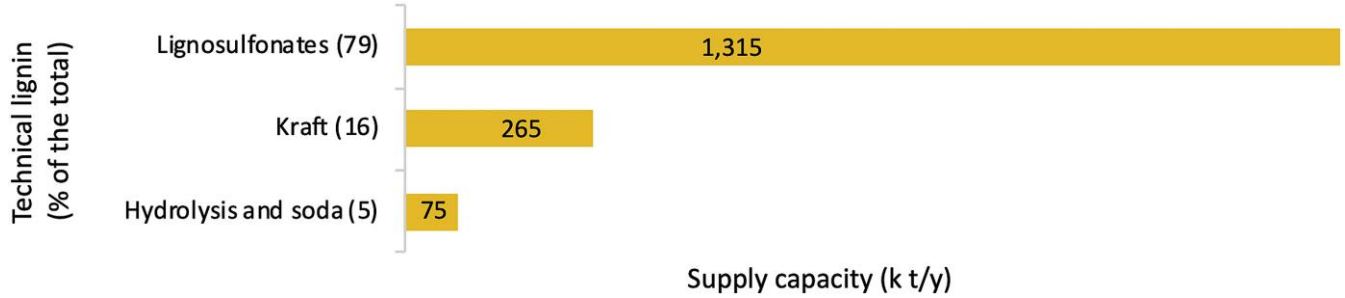
Lignin Producers





https://doi.org/10.1016/j.rser.2020.109768

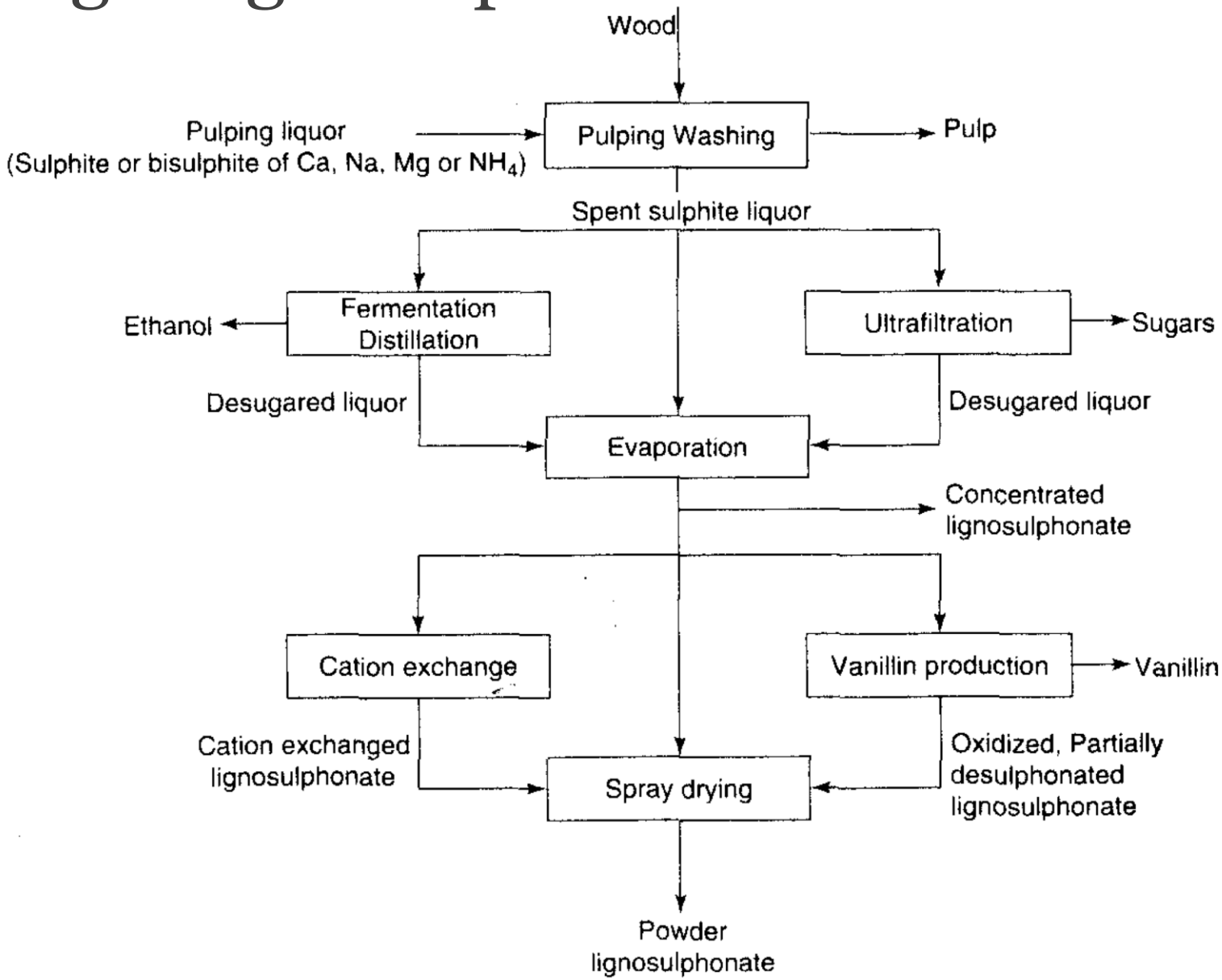
Lignin Producers



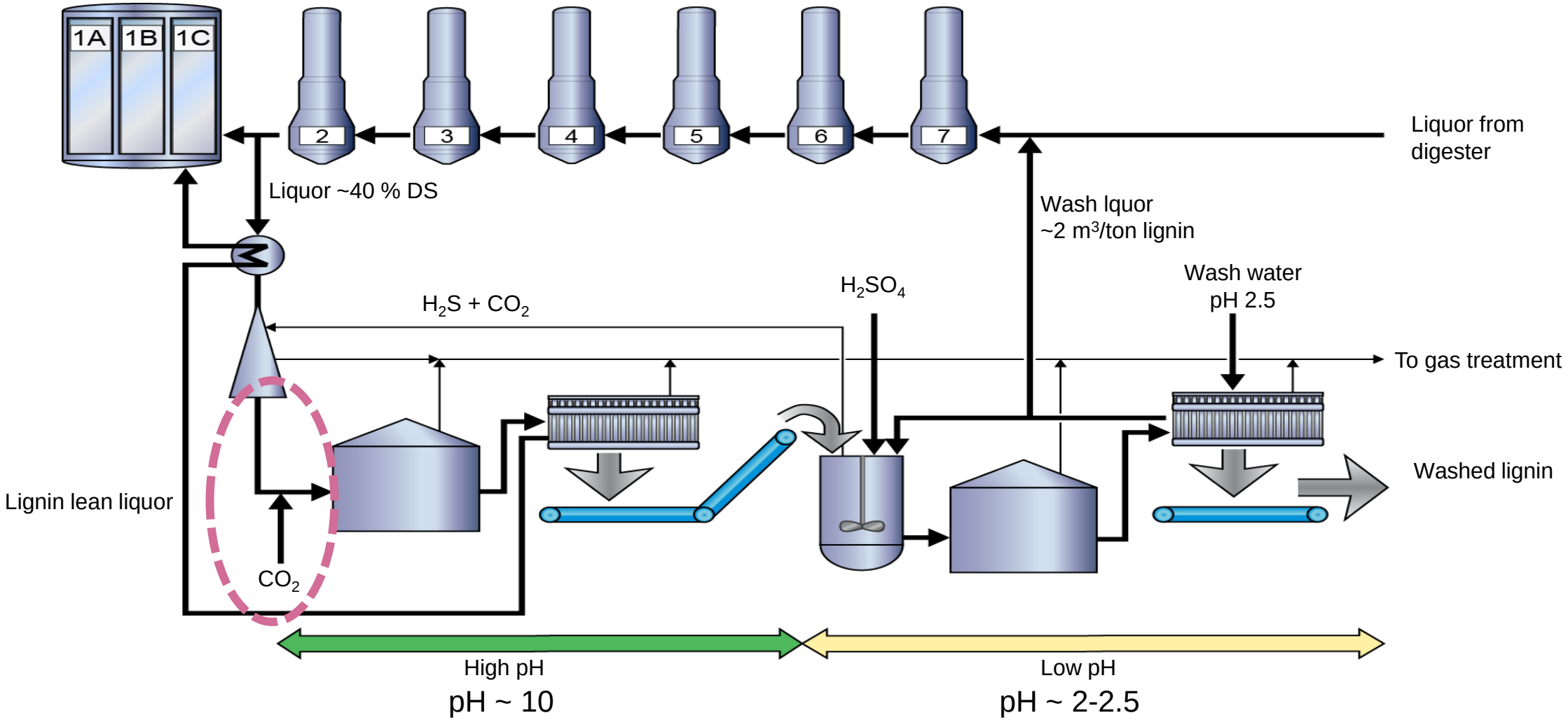
- LignoBoost pilot plant 10,000 t/year kraft lignin
- UPM/Domtar Plymouth - BioChoice® - 25 kton/y lignin
- ~~Stora Enso – 50 Kt/year~~
- Suzano – 20 kt/year Eucalyptus
- Klabin – 500 t/year
- Fibenol – 20 kt/year
- Renmatix - xt/yr

Isolation of Lignins from spent liquor

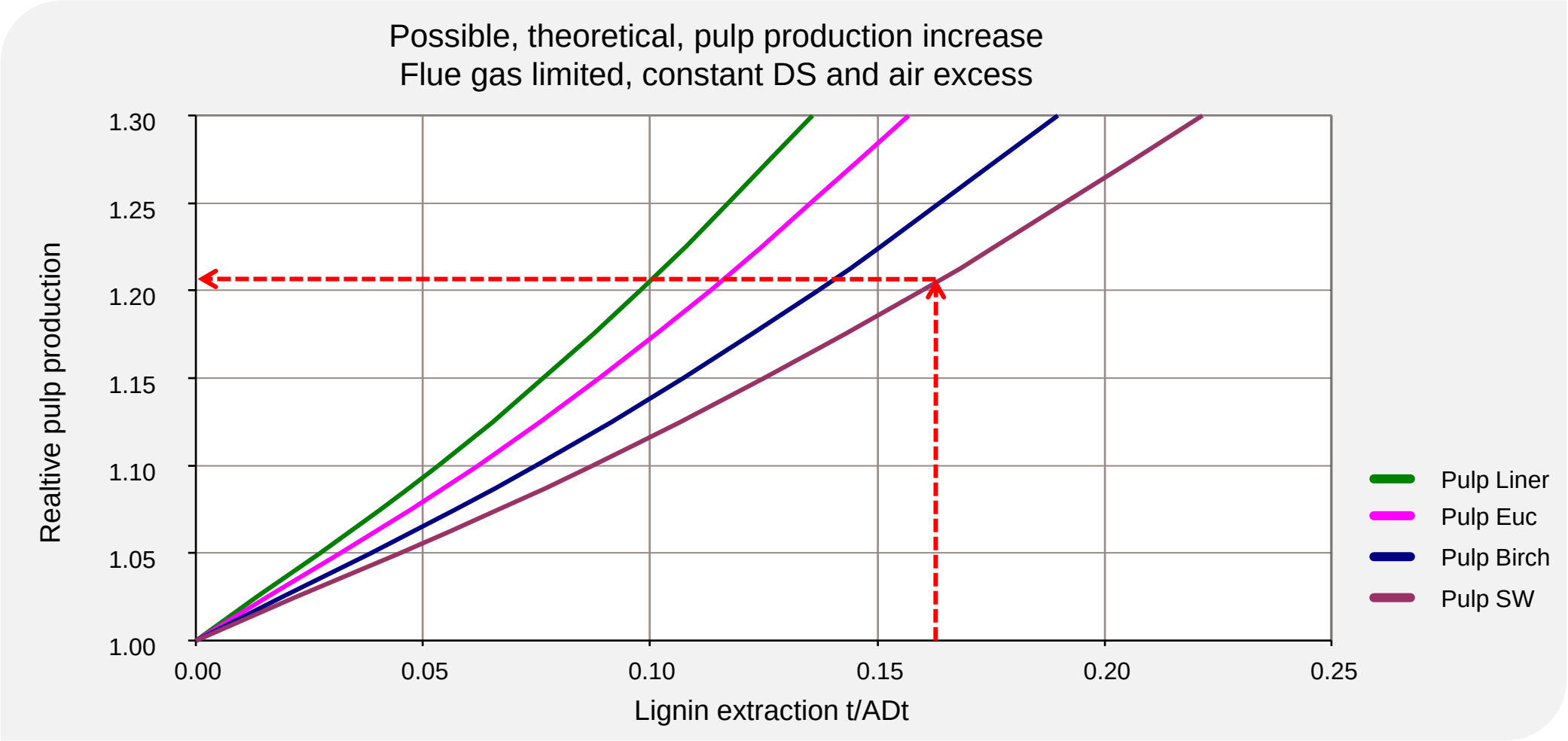
Sulfite Pulping - Lignosulphonates



Lignin production using LignoBoost

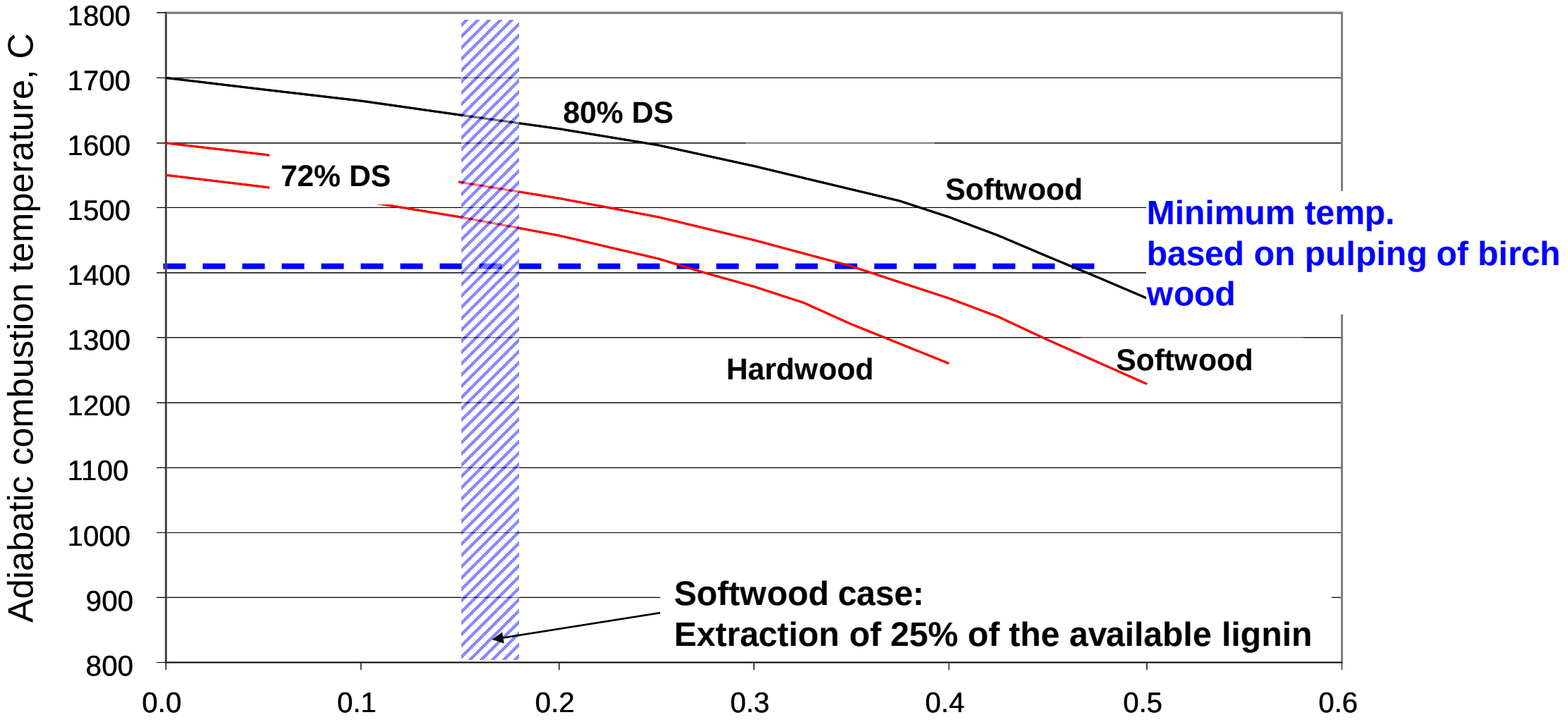


Pulp capacity increase - theoretical



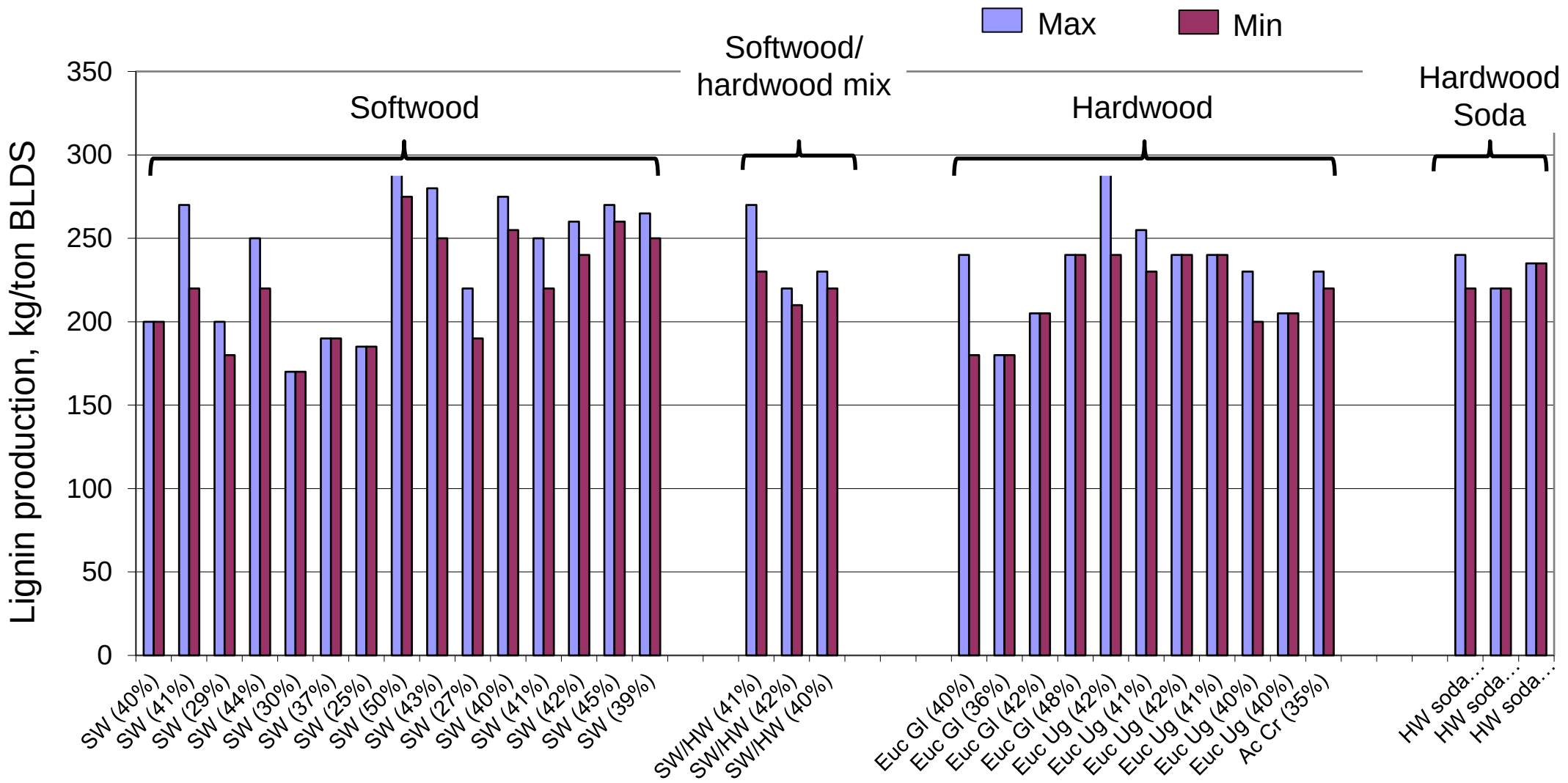
0.15-0.18 ton/ADt = about 25% of available SW lignin is removed

Black liquor properties



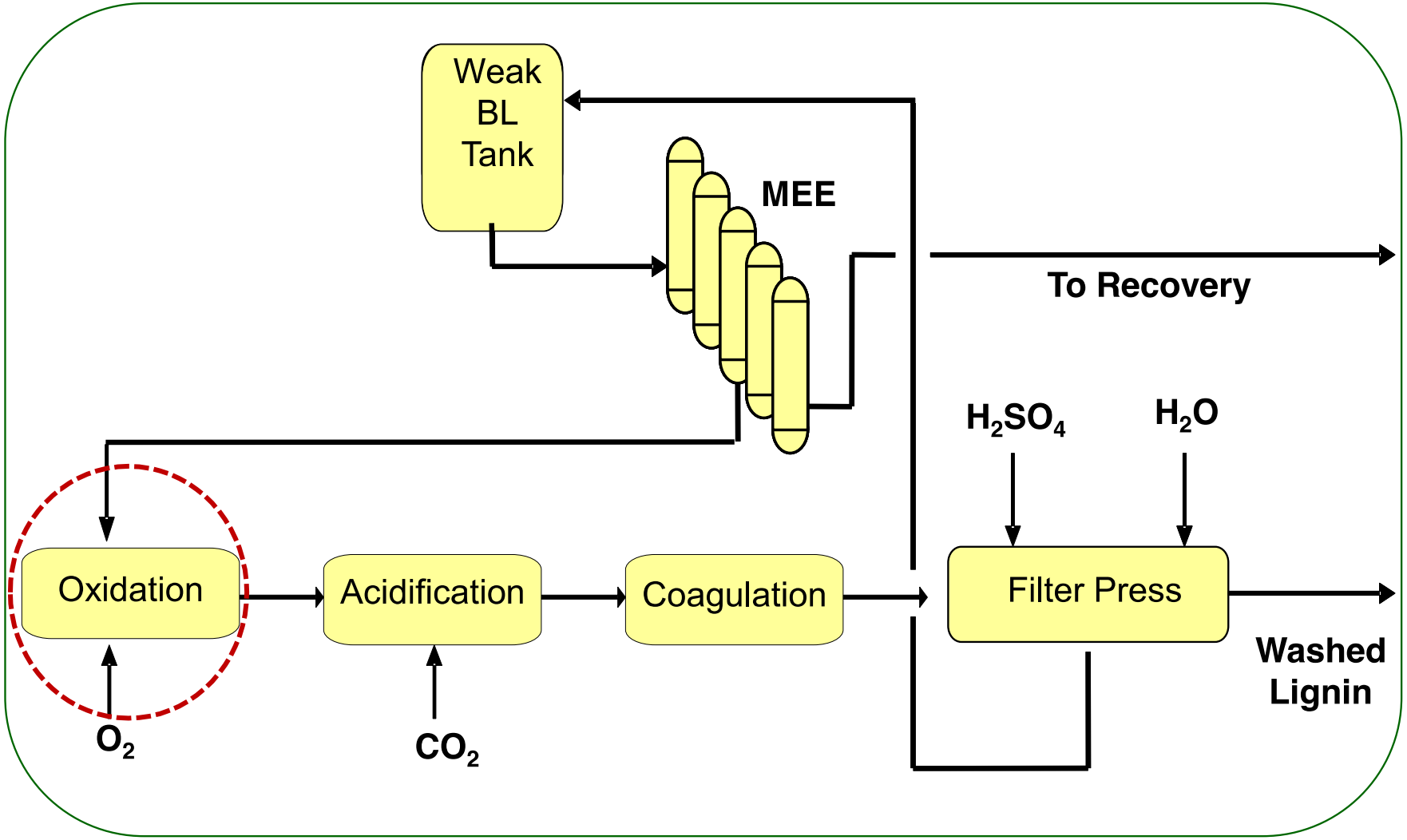
Source: ÅF

Lignin separation yield - Normal alkaline black liquors

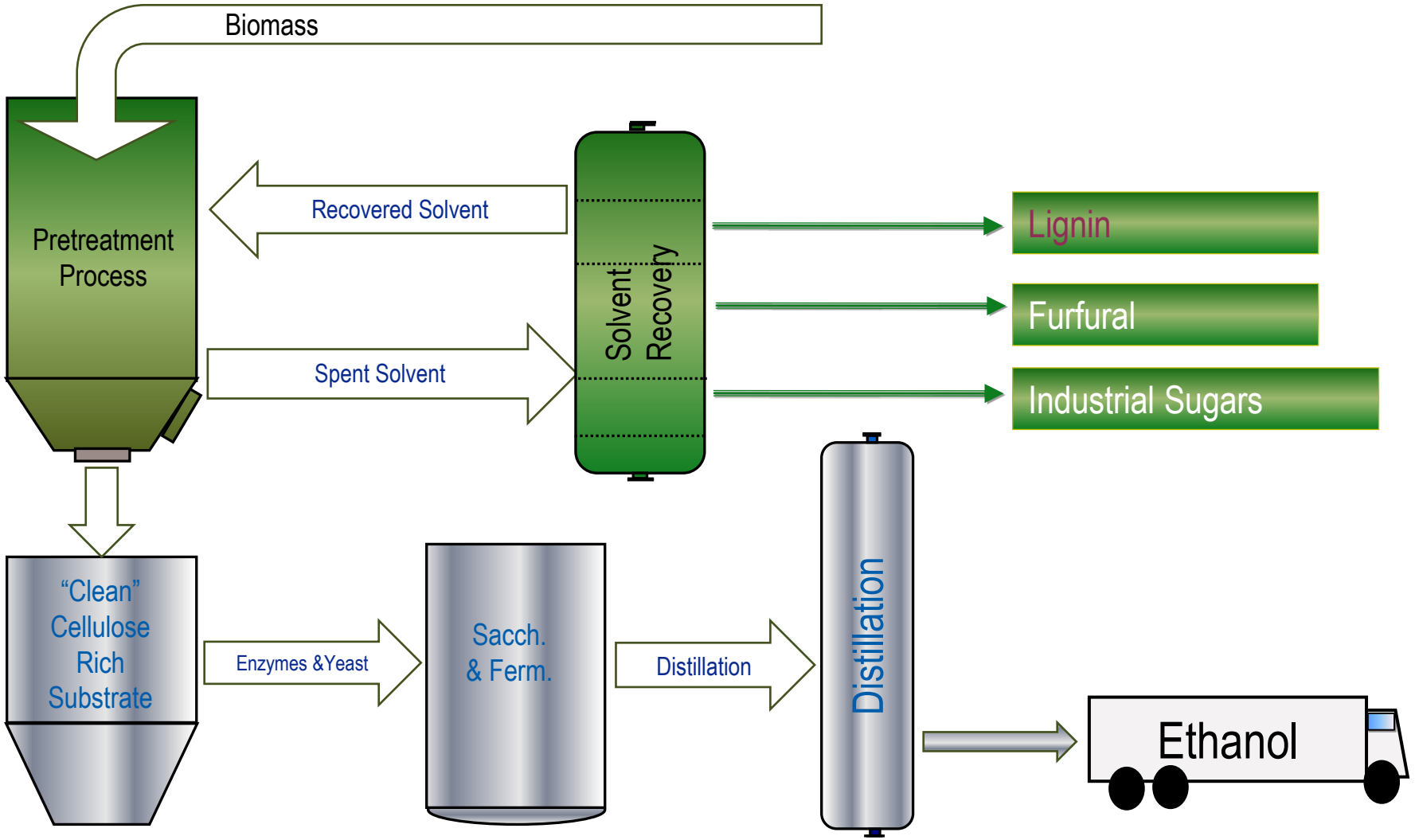


Yield average
SW: 230-250 kg/ton solids in BL; HW: 220-240 kg/ton solids in BL

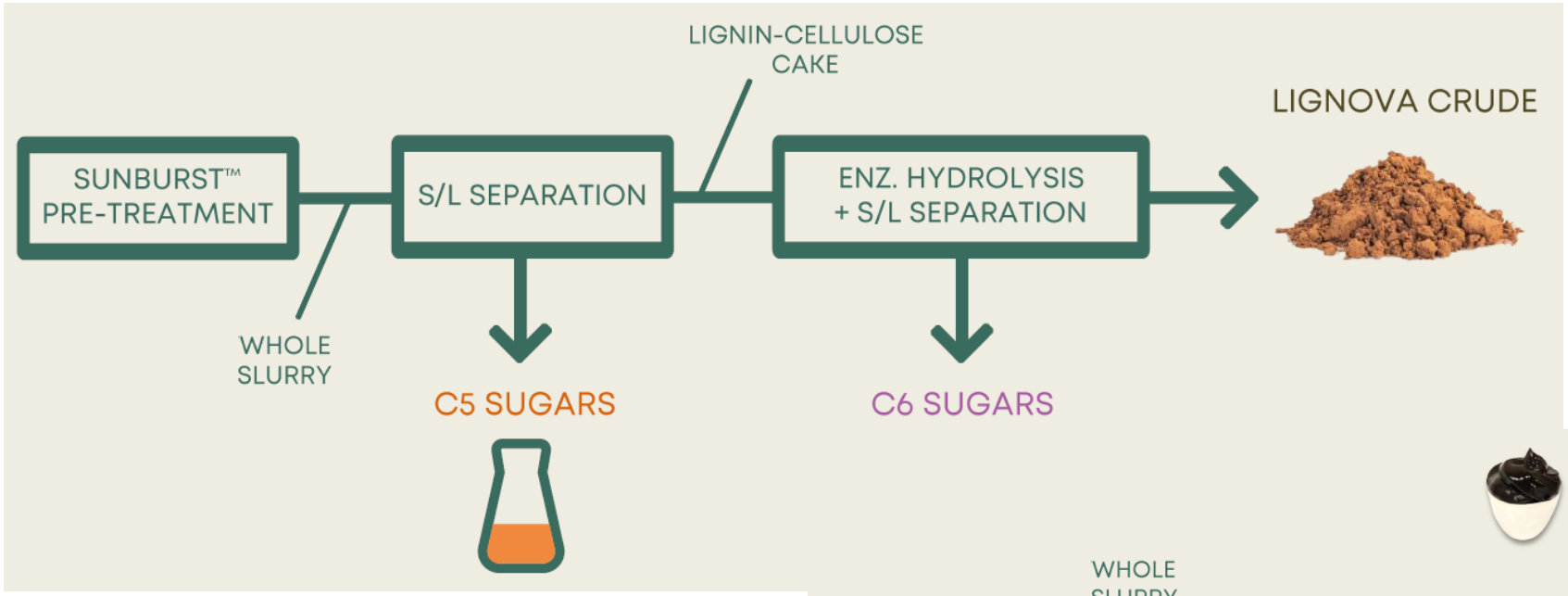
LignoForce recovery Process

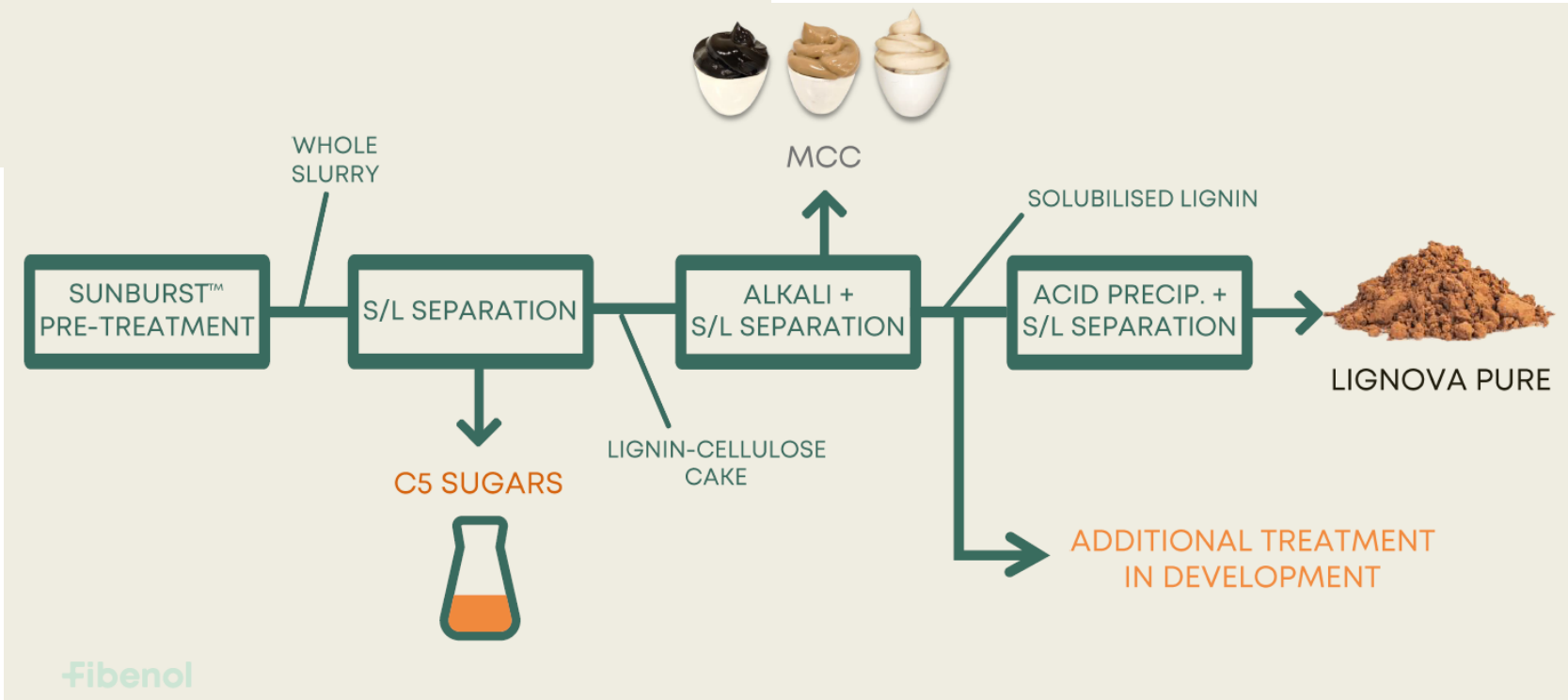


Organosolv Process



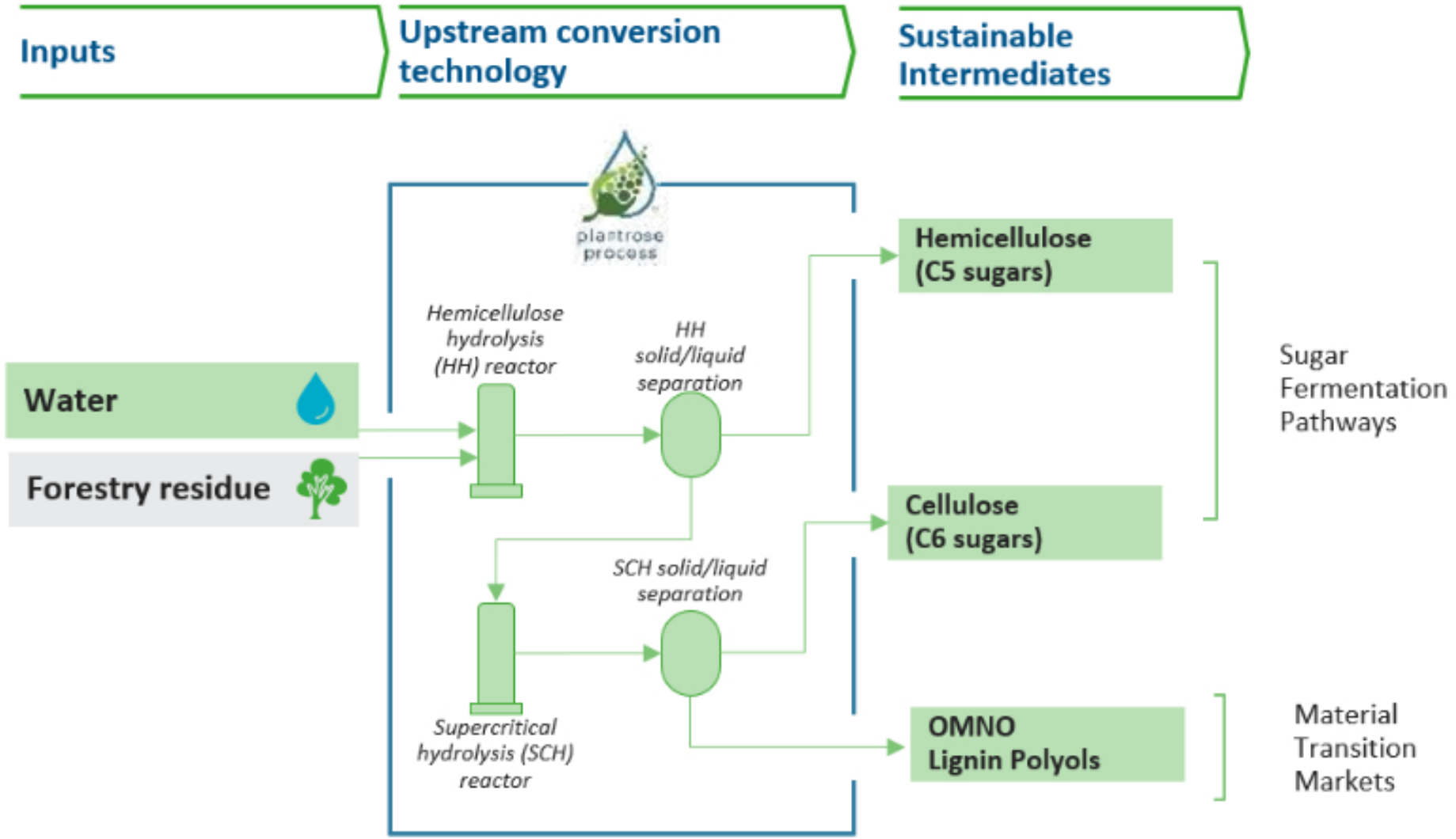
Biorefinery - Fibenol Process





Fibenol

Biorefinery - Renmatix Process



Comparison of commercial and emerging lignin products

Lignin type	Feedstock	Scale	Production Chemistry	Sulfur content	Carbohydrates	Ash
Kraft	HW, SW	Industrial	Alkaline	1-3%	0.2-3%	0.5-5%
Soda	HW, Non wood	Industrial	Alkaline	Free*	0.2-3%	0.5-5%
Lignosulphonates	HW, SW	Industrial	Acid	4-8%	1-35%	0-20%
Organosolv	All	Pilot	Acid	Free*	<0.5	<0.2
Acid Hydrolysis	All	Industrial/pilot	Acid	Low-free*	1-20%	…
Steam Explosion	All	Pilot	Acid	Low-free*	1-5	…
SC Hydrolysis	All (data for HW)	Pilot	SC	0.1-0.9%*	0.8-40%	0.1-1%

* Dependent on washing efficiency during lignin isolation

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Comparison of Some Current and Emerging Lignins

Lignin	mmol/g lignin			UV Detection			°C
	Total OH	PhOH	AliphOH	Mn	Mw	D	Tg
Indulin AT*	6.98	3.25	3.73	1300	4300	3.3	169
Pine AH	3.7	2.39	1.31	800	40000	50	96
Pine OS	4.81	3.72	1.09	500	1400	2.8	91
straw SE	5.01	3.16	1.85	400	1100	2.7	125
poplar SE	5.78	2.53	3.25	900	3000	3.3	113
aspen AH	5.15	3.18	1.98	660	10100	15.3	95
Aspen SE	5.64	2.5	3.14	800	2300	2.9	139
Aspen OS	4.77	3.18	1.59	600	2100	3.5	97
Alcell OS	5.16	3.58	1.58	810	2100	2.6	98
Onmo (SCHW)	116	65	46	1240	4200	3.4	92
AKL	5.41	3.99	1.42	710	1700	2.4	120
EgKL	6.62	4.04	2.58	830	2110	2.7	131
Euc. KL1	6,86	4,91	1,22	760	2000	2.6	133
Euc. KL2	7,23	5,19	1,30	800	2090	2.6	141

Dogmas Around Lignins

- Low purity causes low performance
- Challenges in production of high-purity lignins from crude biorefinery lignins
- Inferior performance of HW lignins as compared to SW lignins

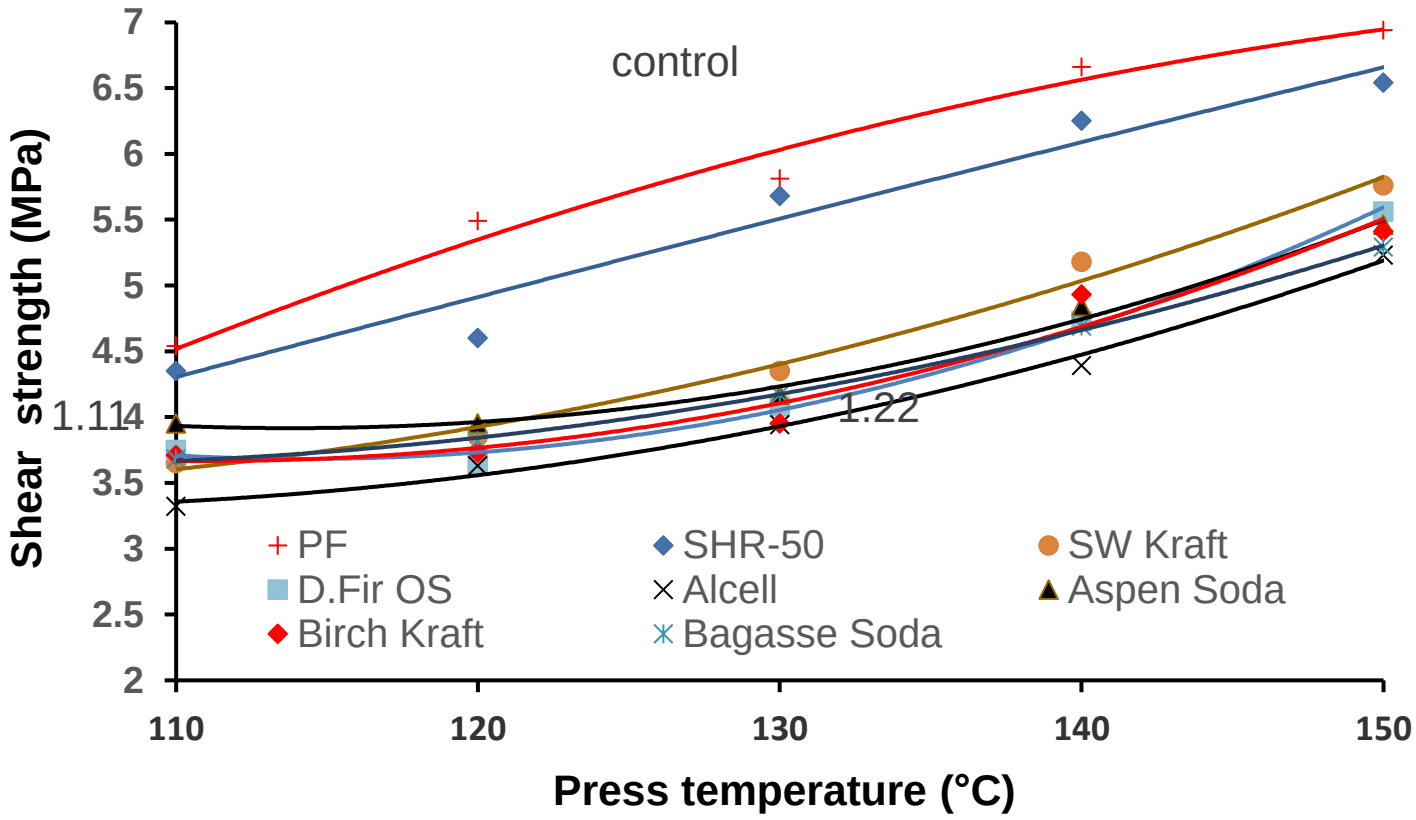
Biorefinery Lignins are considered as low-value products

These dogmas are challenged in publications

Balakshin and Capanema, 14th EWLP, V.I, 63 (2016)
Balakshin et al. *ChemSusChem, 2021, 14, 1016*

Example of Structure - Performance Correlation (PF Adhesives)

ABES test, 30% plywood PF substitution, Press time 90 sec.



Biomass

HW

SW
SW
HW
Grass

Balakshin and Capanema EWLP-2016

No correlation with the amount of reactive centers and molecular mass
No disadvantage of hardwood lignins

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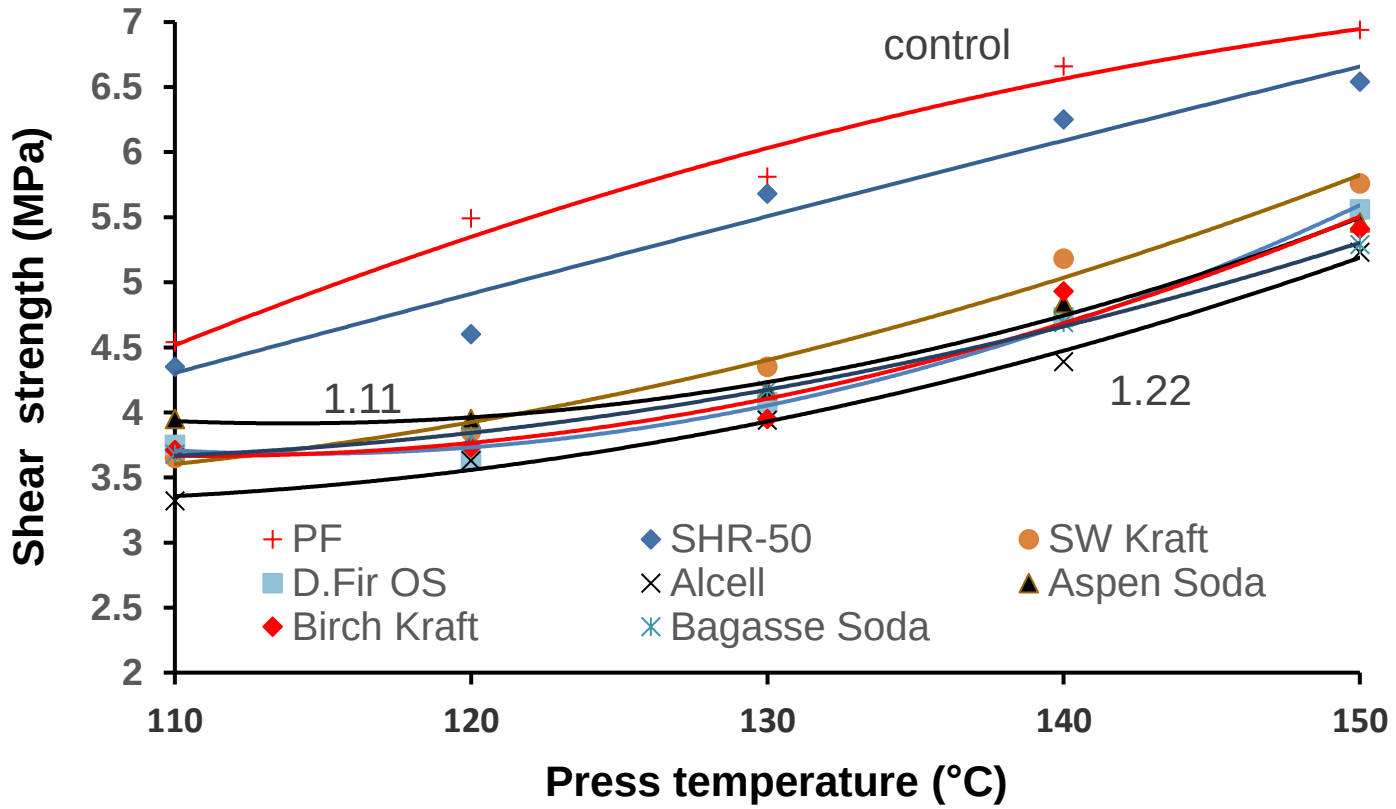
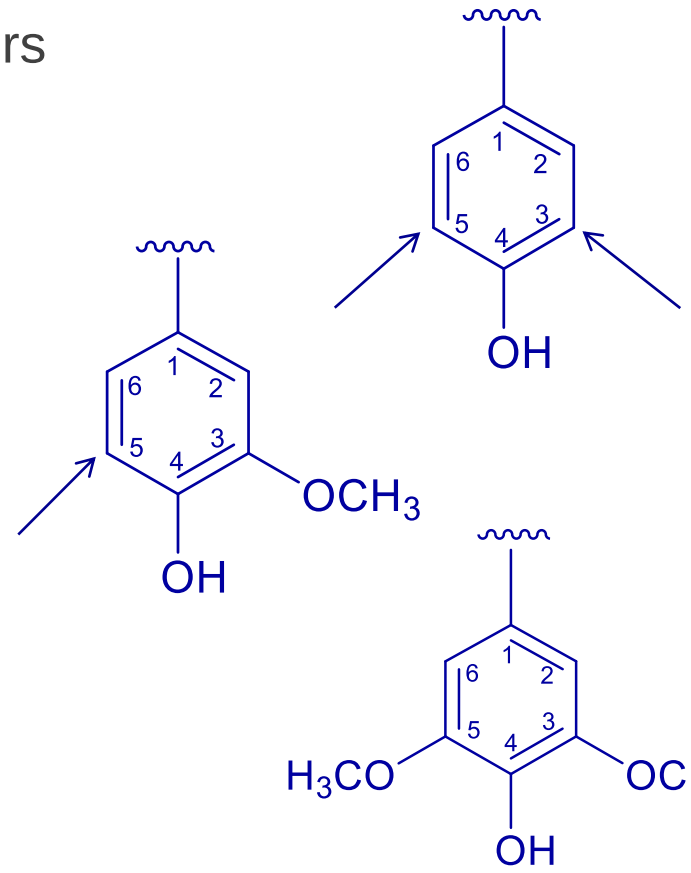


Reactive centers mmol/g

0.65

2.36
2.61
1.04
2.26



Balakshin and Capanema EWLP-2016

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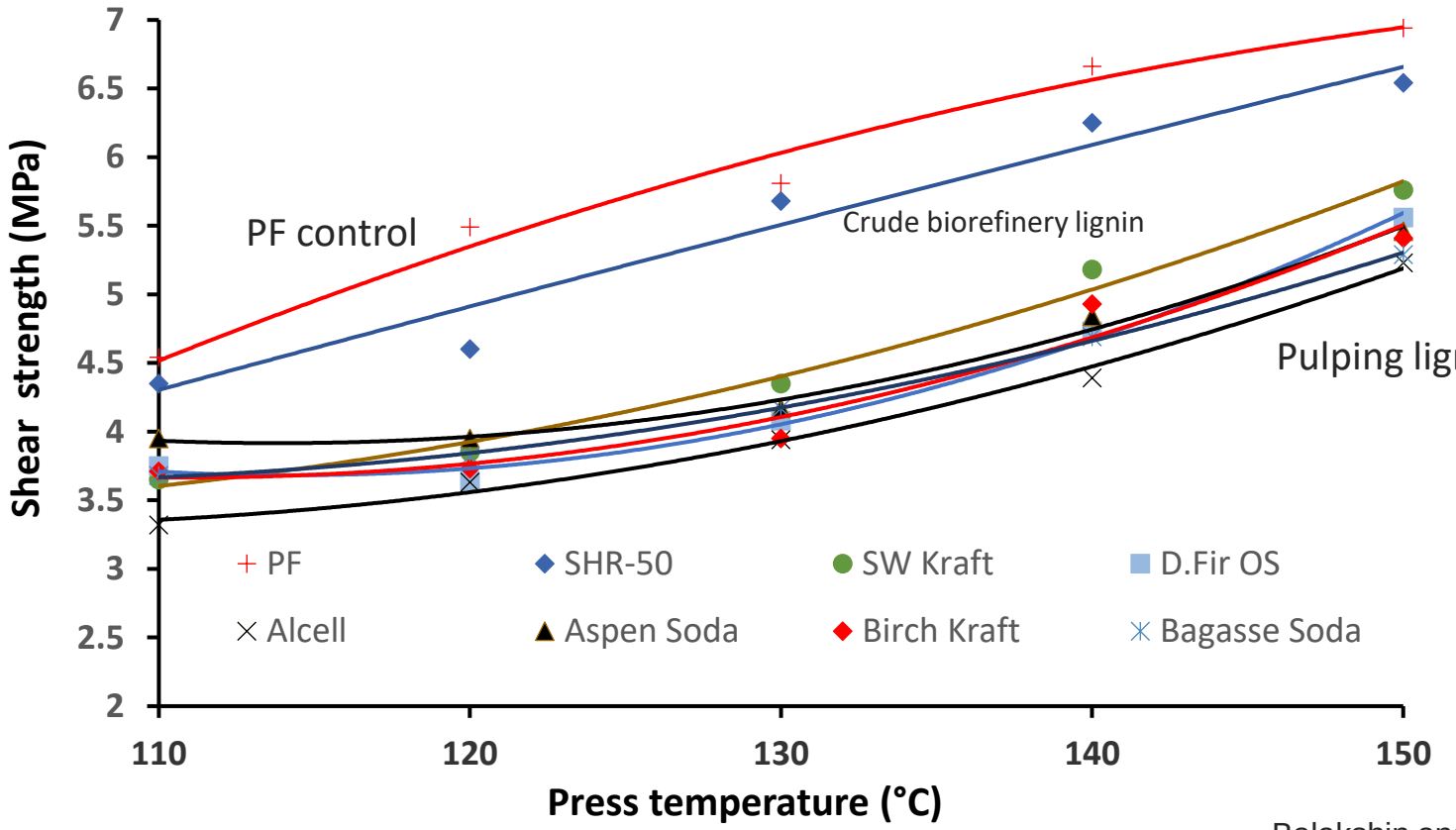
Is Lignin Purity a Must?

ABES test, plywood PF resin, 30% substitution, 90 sec press time



Carbohydrates content:

40%

0.3-2%

Biorefinery: Super Critical Water Hydrolysis (SCWH)

Balakshin and Capanema, 14th EWLP, V.I, 63 (2016)

Crude biorefinery lignin performs better than high-purity lignins


Thank You!