Prospects for the use of biomass in steel industry

Juha Hakala, Ilkka Hannula, Pertti Koukkari

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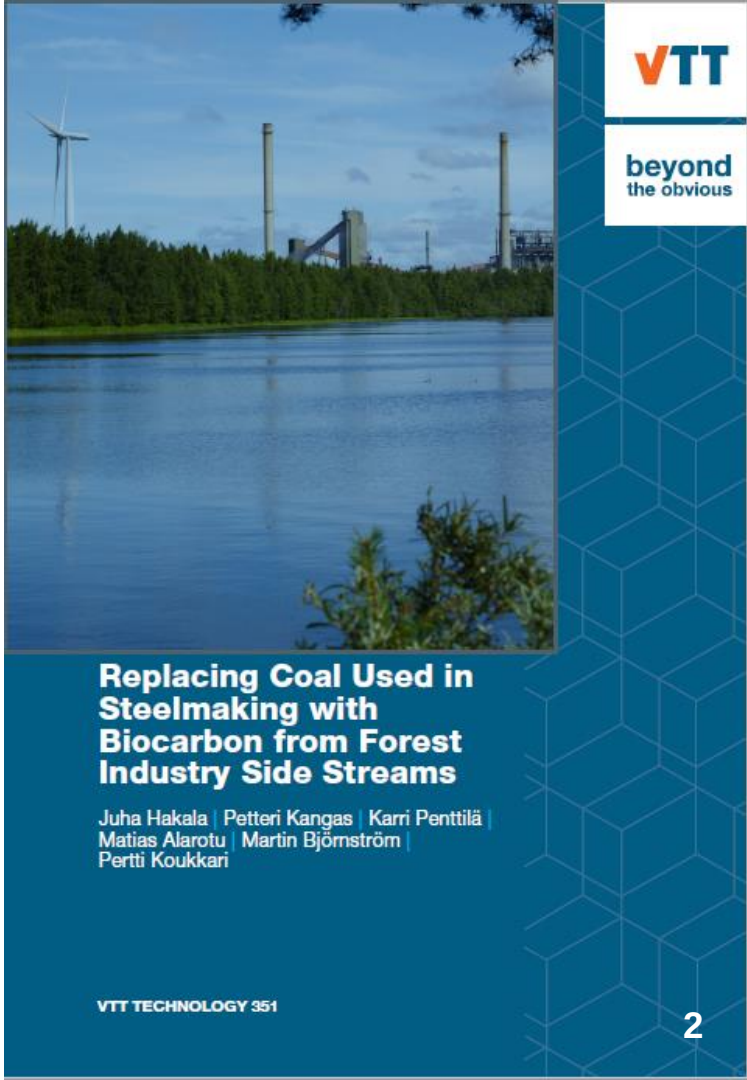
Background

Jointly funded projects, supported by Business Finland:

FOR&MET R&D project: *Added Value from Forest Industry for Metals Producing and Processing Integrates (2016–2019)*

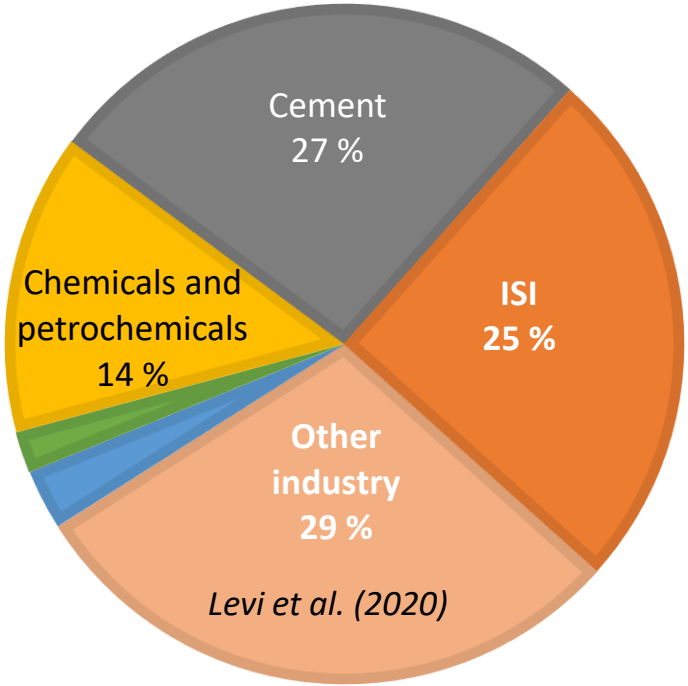
- Industrial consortium:
  - SSAB Europe Oy (Raahe works) - Leading producer of carbon steel
  - Finnpulp Oy – Forest industry partner, planning new biorefinery
  - ST1 Biofuels Oy – Energy company (biofuels, bioethanol)
  - Valmet Technologies Oy –Technology provider, novel cleantech processes

SYMMET R&D project: *Symbiosis of metals production and nature (2018–2020)*



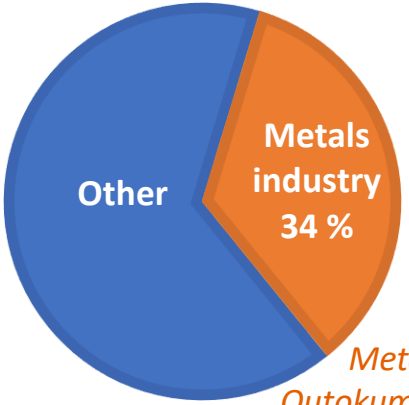
Metals industry emissions

DIRECT INDUSTRY EMISSIONS WORLD-WIDE 2018:
8 540 M TONNES CO2

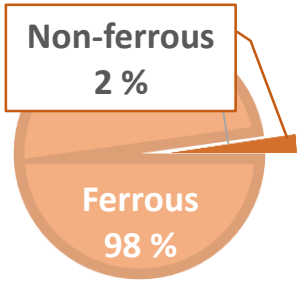


Levi et al. (2020)

DIRECT INDUSTRY EMISSIONS IN FINLAND 2019:
12.2 M TONNES CO2



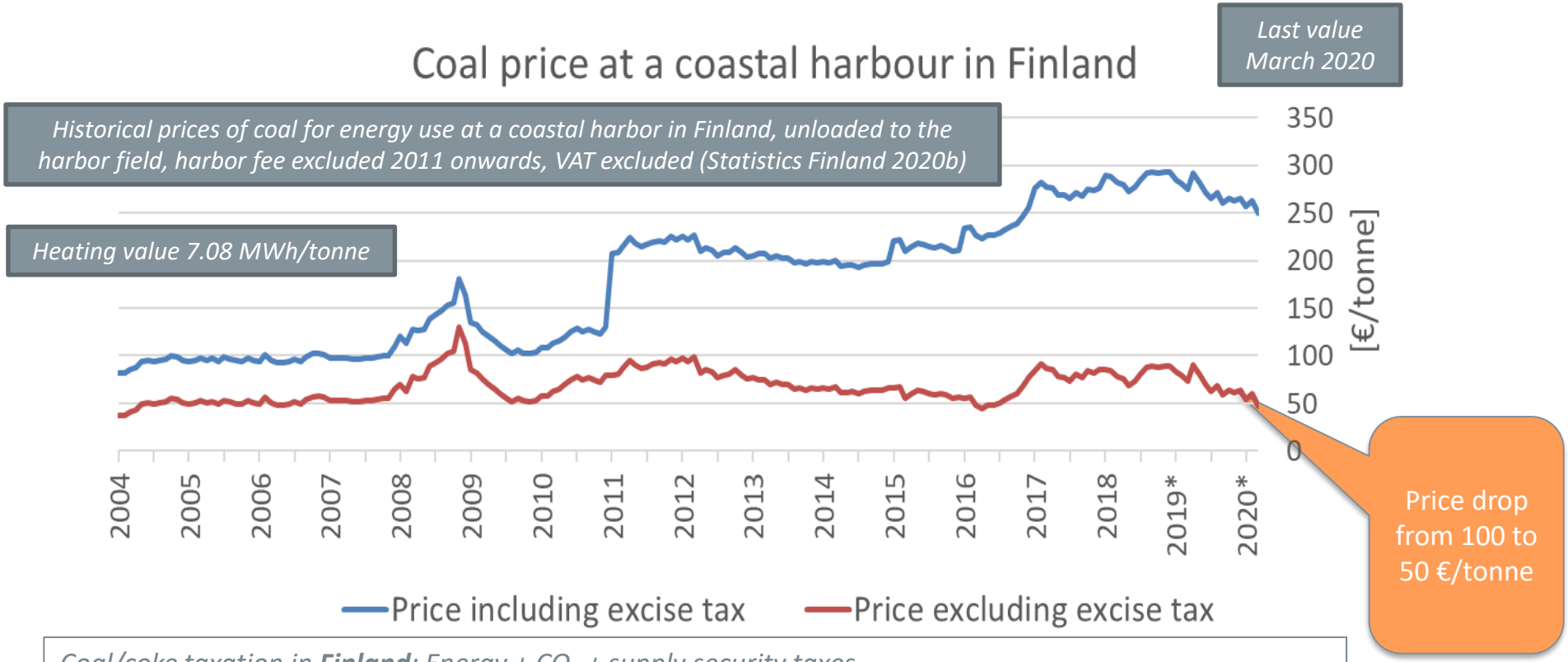
DIRECT METALS INDUSTRY EMISSIONS IN FINLAND 2019:
4,2 M TONNES CO2



Metals industry: SSAB, Outokumpu, Boliden and Ovako

Verified -Energy Authority (2020)

Price trends –Thermal coal (FIN)



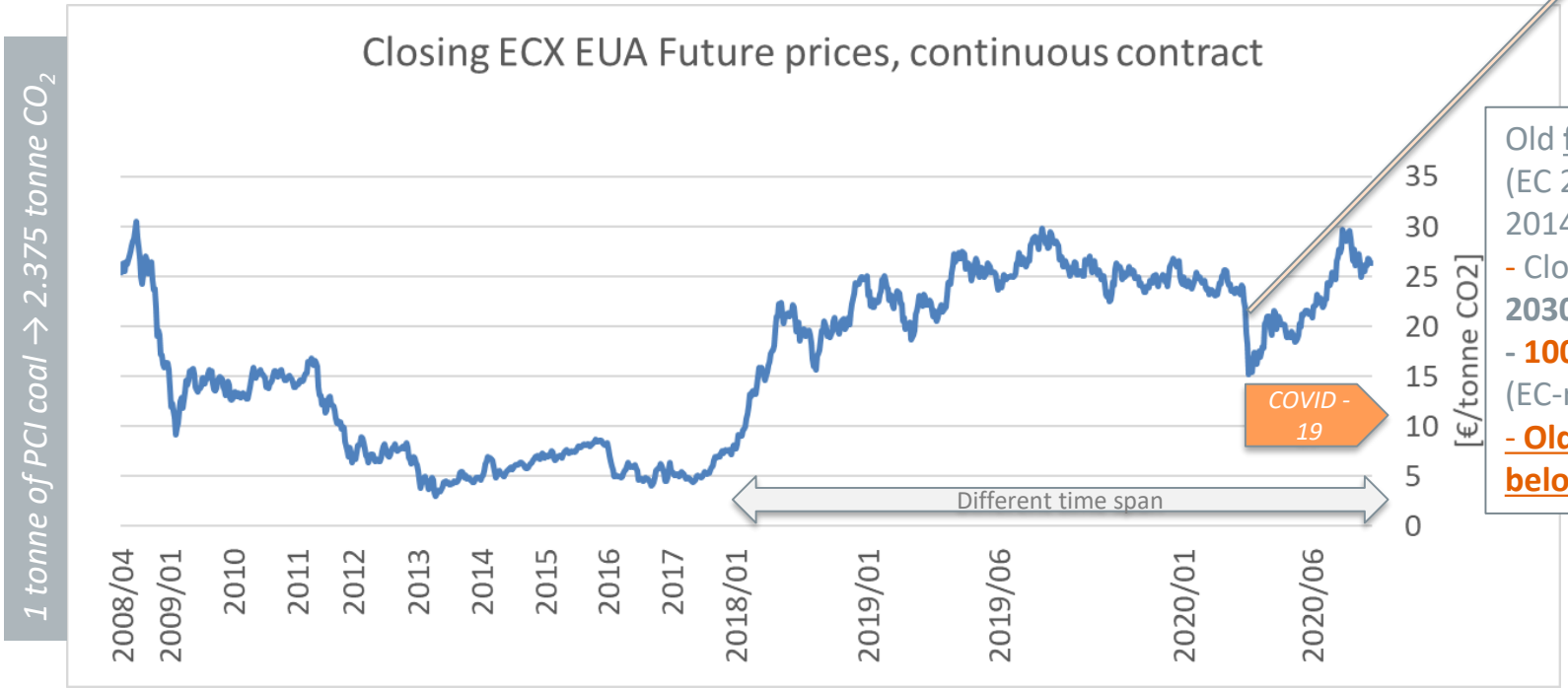
*Coal/coke taxation in **Finland**: Energy + CO_2 + supply security taxes*

- *For heating purposes liable of taxation/ electricity production non-liable*
- ***Non-taxed if used as a raw/auxiliary material, or in imminent primary use in goods manufacturing***

Price trends - EUA

In 2030 /2050 ?

Sep 25th, 2020: 26.15 €/tonne

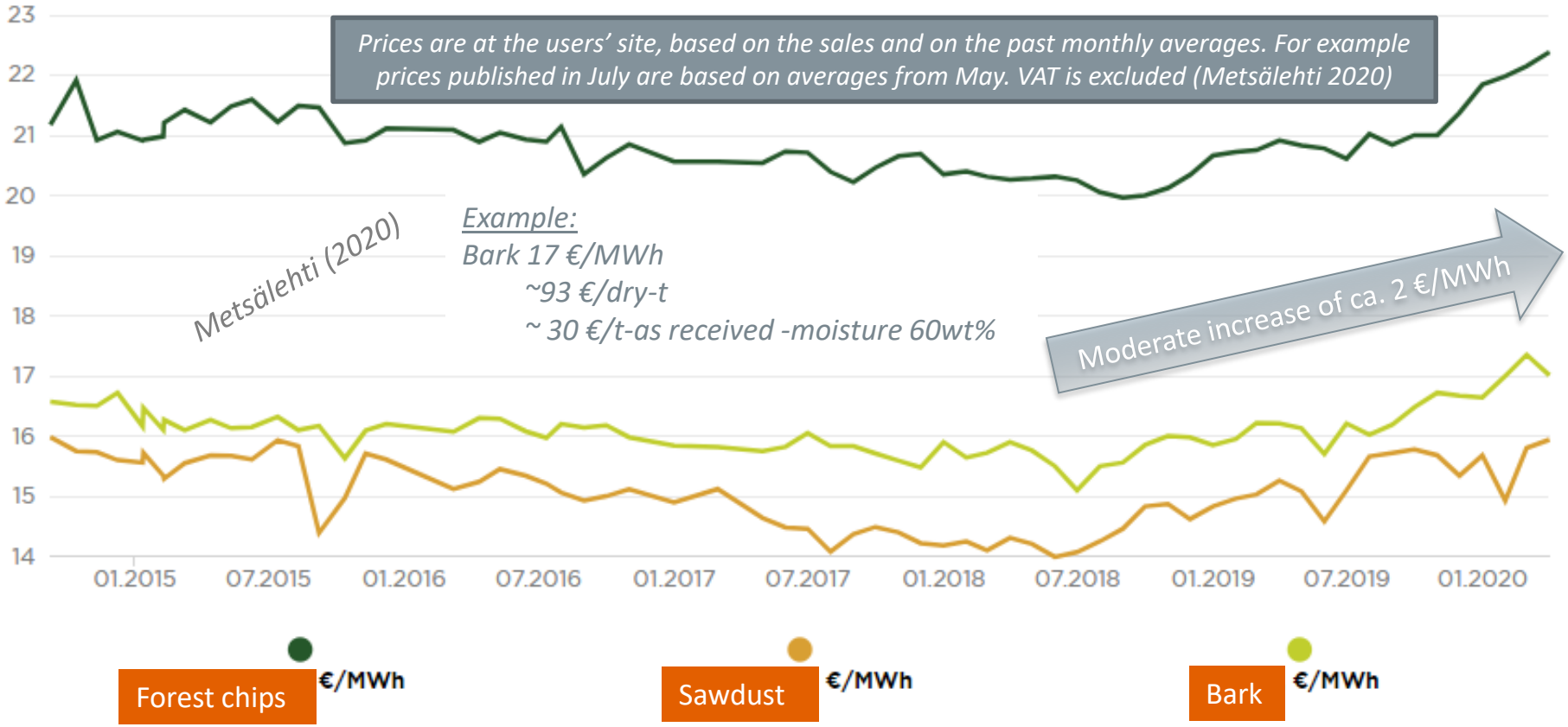


Old **forecasts examples** (EC 2013, Schjølset 2014):
- Close to **50 €/tCO2 in 2030**
- **100 €/tCO2 in 2050** (EC-reference proposal)
- **Old Forecasts: 10 € or below for year 2020..**

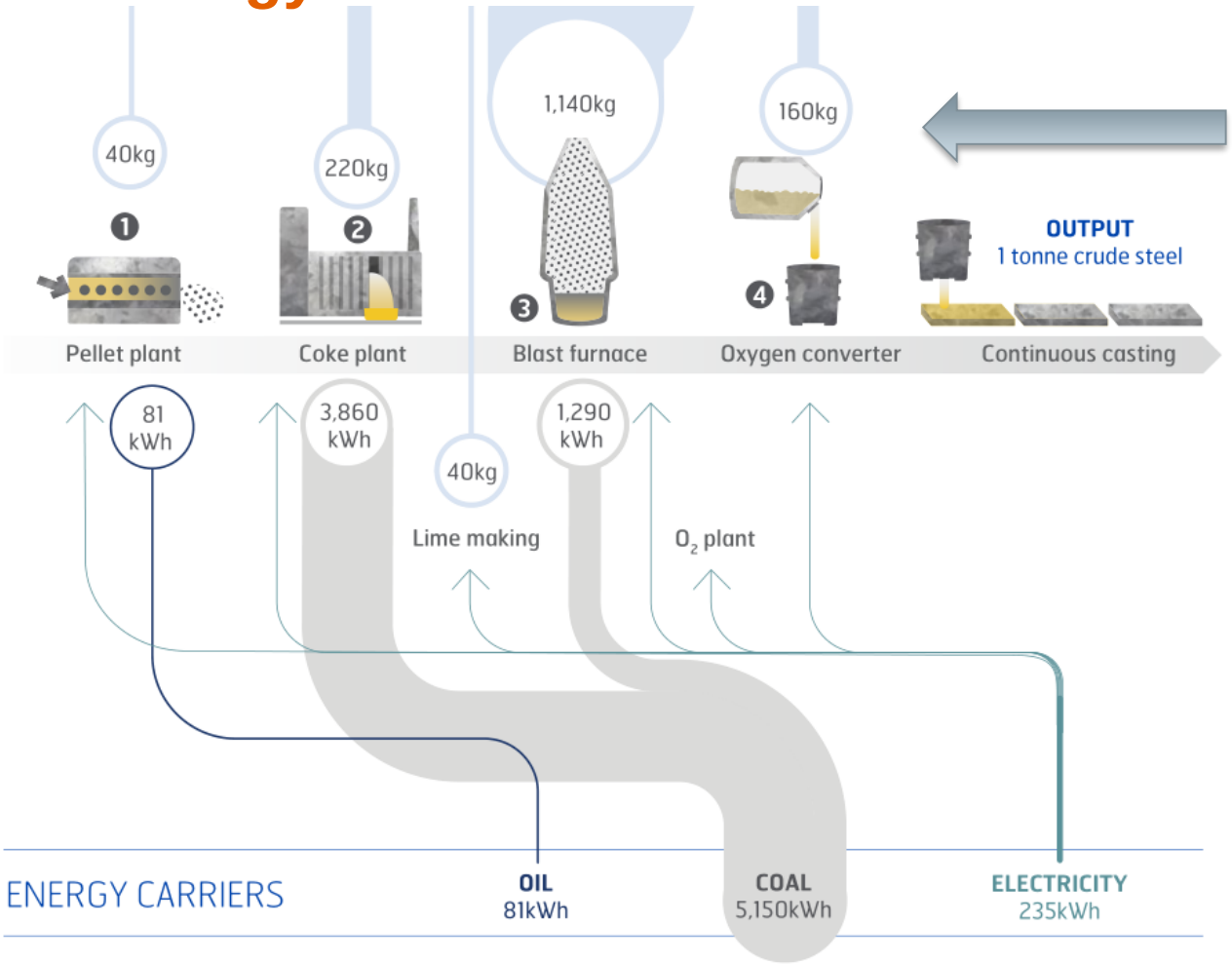
European Union Emissions Trading System carbon market price. Closing ECX EUA Futures prices, Continuous Contract. Data source Sandbag (2020). Based on statistics updated on August 7th, 2020.

EU emission allowance (EUA) all-time price peak 30.44 EUR/tonne –Sep 14th, 2020

Price trends – Forest Biomass (FIN)



Energy and emissions in crude steel production



Combined CO_2 output from a energy efficient blast furnace process is 1 560 kg/t_{CS}

Carbon dioxide originates from

- Blast furnace
- Coke making
- Decarburisation of hot metal in the converter process, and
- Fossil fuels used in the pelletising process

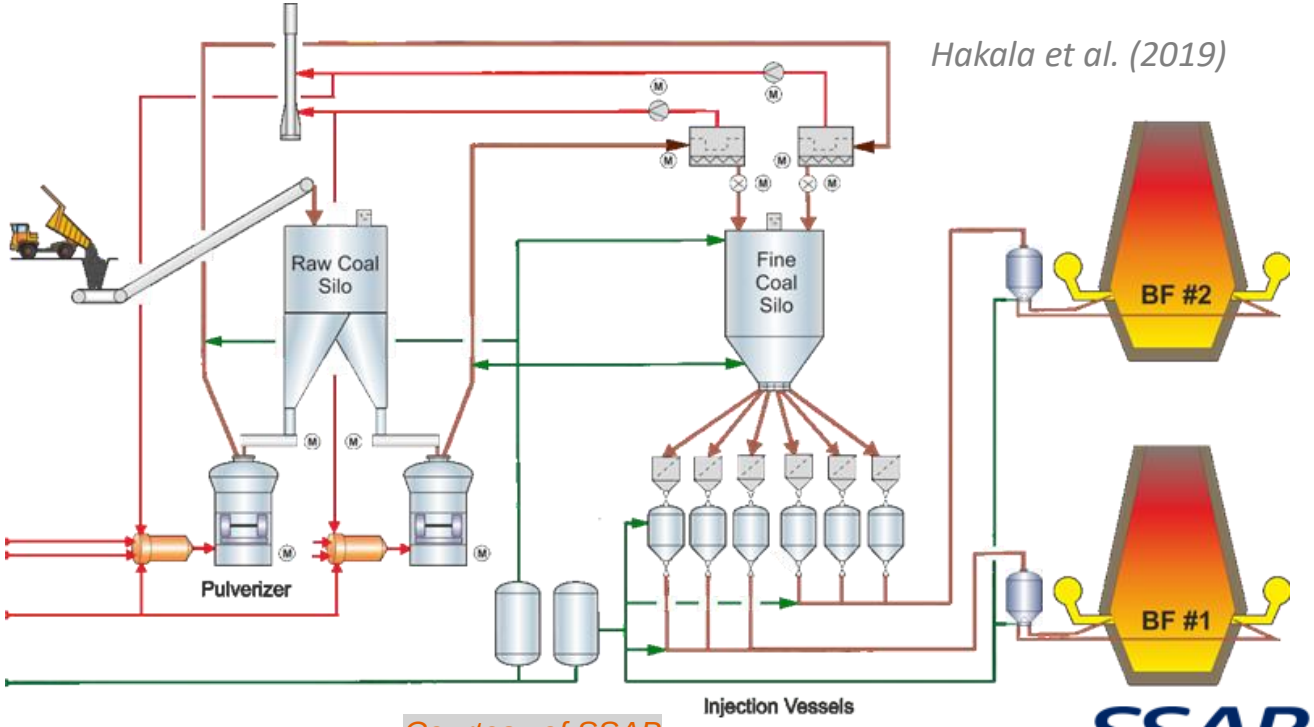
- High amount of carbon is required in the form of coke and PCI coal

HYBRIT (2017). Summary of findings from HYBRIT Pre-Feasibility Study 2016–2017

Handling, pulverizing and injection system of coal at SSAB Raahe, Finland

- System designed for fossil coal
- The most straightforward option would be to utilize existing system also for biocarbon…

Hakala et al. (2019)



Courtesy of SSAB

Hakala, J., Kangas, P., Penttilä, K., Alarotu, M., Björnström, M., Koukkari, P., 2019. Replacing Coal Used in Steelmaking with Biocarbon from Forest Industry Side Streams. VTT Technology 351. VTT Technical Research Centre of Finland Ltd. (Material provided by SSAB Raahe)

Focus on slow pyrolysis – Example

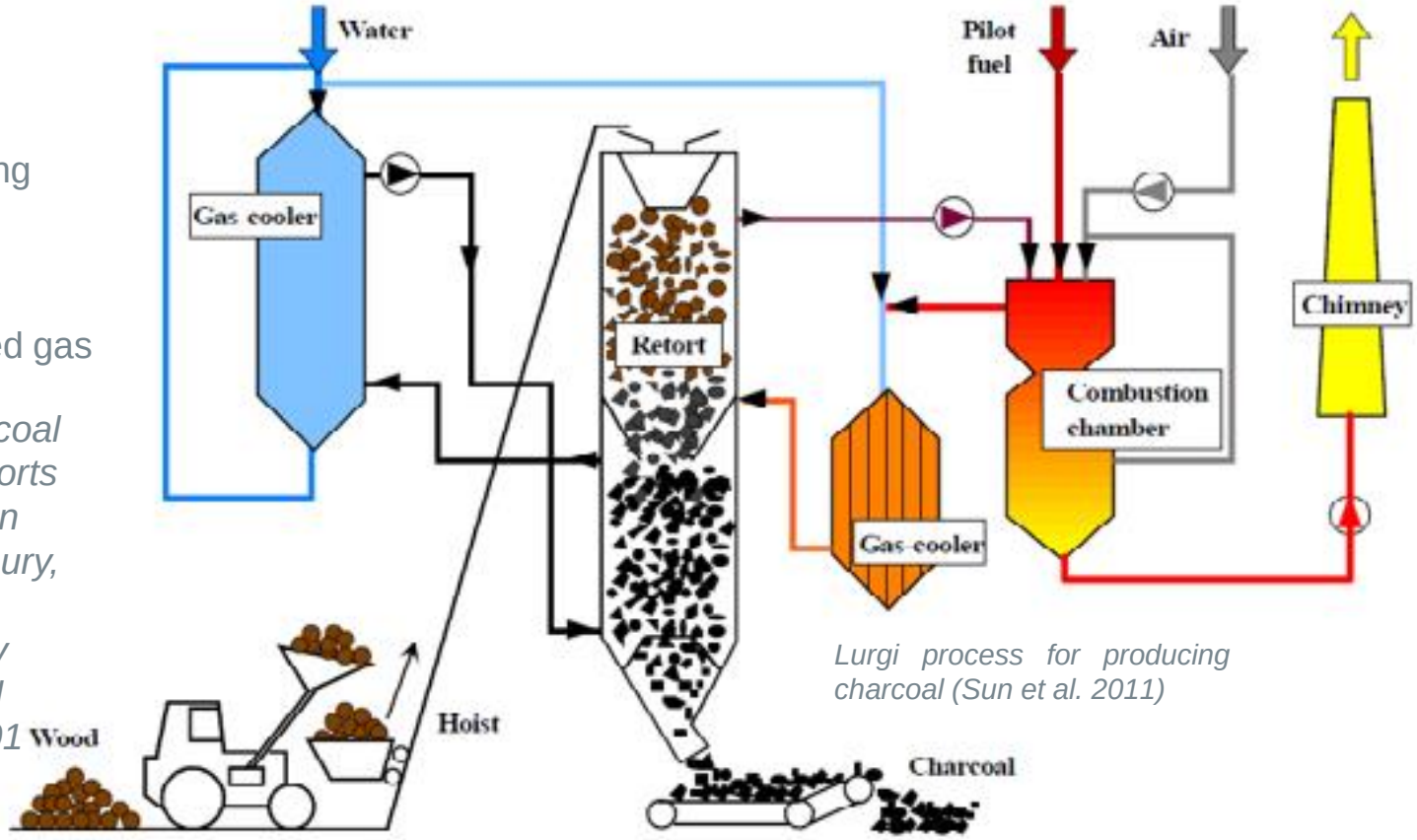
Slow pyrolysis - The most promising technology for upgrading biomass into a solid metallurgical reducer (Suopajärvi et al. 2018)

Lurgi process example:

- Retort design
- Heat provided by burning pyrolysis gases
- Drying zone at the top
- Carbonization zone
- Cooling zone –by cooled gas

- *Ca. 27 000 t/yr. of charcoal from hardwood, two retorts*
- *Forms part of the Silicon Metal Complex in Bunbury, Western Australia*
- *Outokumpu Technology (now Outotec) acquired Lurgi Metallurgie in 2001*

Hakala et al. (2019)



Lurgi process for producing charcoal (Sun et al. 2011)

Biocarbon demand and supply (FIN)

Example of the DEMAND (Bioenergy international 2018; Ahonen, 2019)

- Successful 9-days trial run by SSAB Raahe Steelworks to replace ca. 10wt% of PCI coal with biocarbon in May 2019
- Up to 20 wt% could be possible with the *current* technical solutions
- Would create a demand for **112 kt/yr** of biocarbon (20% of 560 kt/yr)

SUPPLY

- ~8 000 t/yr. of biocarbon can be produced today
- By mid 2021 the production can reach 18kt/yr. (Rautiainen 2019, Ylitalo 2019)
- *Further upscaling considerations-> 50 kt/a*
- Theoretical potential in Finland ~1.5 Mt/yr. (Updated from Hakala et al. 2019 based on Luke 2019 figures):
  - Present harvesting (2018) of roundwood (78,2 Mm^3)
  - Assuming all the side streams, after inhouse use, would be converted to biocarbon
  - Side streams: Bark, saw dust and wood chips

Cost of using fossil PCI coal

Cost of burning PCI coal, including emission trading EUA costs											
Coal price [€/tonne]	EUA price [€/tonne CO_2]										
	0	5	10	15	20	25	30	35	40	45	50
	PCI coal and emission trading cost [€/tonne]										
25	25	37	49	61	73	84	96	108	120	132	144
50	50	62	74	86	98	109	121	133	145	157	169
75	75	87	99	111	123	134	146	158	170	182	194
100	100	112	124	136	148	159	171	183	195	207	219
125	125	137	149	161	173	184	196	208	220	232	244
150	150	162	174	186	198	209	221	233	245	257	269
175	175	187	199	211	223	234	246	258	270	282	294
200	200	212	224	236	248	259	271	283	295	307	319
225	225	237	249	261	273	284	296	308	320	332	344
250	250	262	274	286	298	309	321	333	345	357	369
275	275	287	299	311	323	334	346	358	370	382	394
300	300	312	324	336	348	359	371	383	395	407	419

EUA trading

IEA (2017): PCI coal 130% of thermal Coal (~77 €/t)

1 tonne of PCI coal = 2.375 tonne CO_2

Cost comparison coal vs. biomaterial
–Integrated biocarbon production from bark

VTT

Cost	Biocarbon not competitive

Cost	Biocarbon close being competitive

Cost	Biocarbon competitive (-10€ margin)

Cost of burning PCI coal, including emission trading EUA costs

What if…

Coal price [€/tonne]	EUA price [€/tonne CO_2] 0	5	10	15	20	25	30	35	40	45	50
	PCI coal and emission trading cost [€/tonne]										
25	25	37	49	61	73	84	96	108	120	132	144
50	50	62	74	86	98	109	121	133	145	157	169
75	75	8[illegible]	[illegible]	111	123	134	146	158	170	182	194
100	100	1[illegible]	[illegible]	136	148	159	171	183	195	207	219
125	125	137	149	161	173	184	196	208	220	232	244
150	150	162	174	186	198	209	221	233	245	257	269
175	175	187	199	211	223	234	246	258	270	282	294
200	200	212	224	236	248	259	271	283	295	307	319
225	225	237	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
250	250	262	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
275	275	287	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
300	300	312	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Current…

Cost routes examples to biocarbon (Hakala et al. 2019) – see additional slides

- Lowest cost: Bark as a raw material and Integrated to a biorefinery

- At bark price 17 €/MWh -> Biochar cost ca. 220 €/t (no transportation costs)

Conclusions

- Use of biocarbon in steelmaking is becoming a feasible option under current CO_2 price projections
  - Reaching the levels of 50-100 €/t CO_2 ?/ time frame 2030-2050?

- Softwood bark, black pellets (bark) and hydrolysis lignin potential sources for biocarbon
  - About 20wt% of PCI coal could be replaced with biocarbon in the BF with existing technologies
  - Higher biocarbon share maybe possible via coal injection system re-design (sizing of handling & pulverizing line, re-designing co-feed) and by optimization of detrimental elements (NPE)
  - Variation in physical and chemical properties requires attention (both pelletizing and BF injection system)

Conclusions

- Cost routes examples to biocarbon (Hakala et al. 2019):
  - Lowest cost: Bark / Integrated to a pulp mill – Clear benefits of the production integration
  - Hydrolysis lignin / Integrated to a pulp and paper mill (+10% higher costs)
  - Hydrolysis lignin and black pellets /non-integrated (+44% -> +60% higher costs)

- Theoretical potential of biocarbon in Finland ~1.5 Mt/yr

- Hydrogen reduction may be available in 2035
  - Both Finland and Sweden have ambitious plans to convert BFs by 2045 -Are the targets going to be met (time-frame, feasibility)?
- Biocarbon a straightforward solution for the transition period to DRI, but also for other metal reduction processes (e.g. ferro-chrome, non-ferrous), smelting and recarburizing, and as energy carrier.
- Carbon is required in the steel (iron + carbon = steel)

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-Additional slides

Biomaterial conversion to biocarbon

- Slow pyrolysis: The most promising technology for upgrading biomass into a solid metallurgical reducer (Suopajärvi et al. 2018)
  - Low heating rate, long residence time, large particle size and moderate temperature to maximize char yield
  - Bottle-necks: Capacities of the existing sites, scattered biomaterial sources
  - Optimizing Biocarbon physical (e.g. strength, pellet/particle size, porosity, rheology) and chemical properties (carbon/oxygen ratio, unwanted elements) for the targeted use:
    - Raw material selection / pyrolysis conditions (e.g. temperature, time).
  - Binders may be required to pelletize the biocarbon

- FOR&MET project:
  - Bark derived black pellets, bark, and hydrolysis lignin considered applicable as sources for biocarbon for reduction processes (Hakala et al. 2019; Toloue Farrokh et al. 2019)
    - high enough carbon to oxygen ratio
    - calorific heating values, flow and transport characteristics, water uptake, ash content and ash chemical composition varied significantly
    - Bark based biocarbon: The higher alkali and phosphorus content requires attention
      - Less or equal than 20wt% of PCI coal may be replaced

Supply examples

EXAMPLES OF THE POTENTIAL FROM INDUSTRIAL SOURCES FOR THE SELECTED SIDE STREAMS:

Industrial factory	Side stream	Biochar (rough estimate)
Modern pulp mill / 1,2 M-tonne of pulp	Bark (50 - 100% bark utilization)	40 – 90 k-tonnes
Sawmill / 200 k-m3 of timber	bark, wood chips and/or sawdust	6—7 k-tonnes
Bioethanol production plant -50 M-ltr of EtOH	Lignin	45 k-tonnes

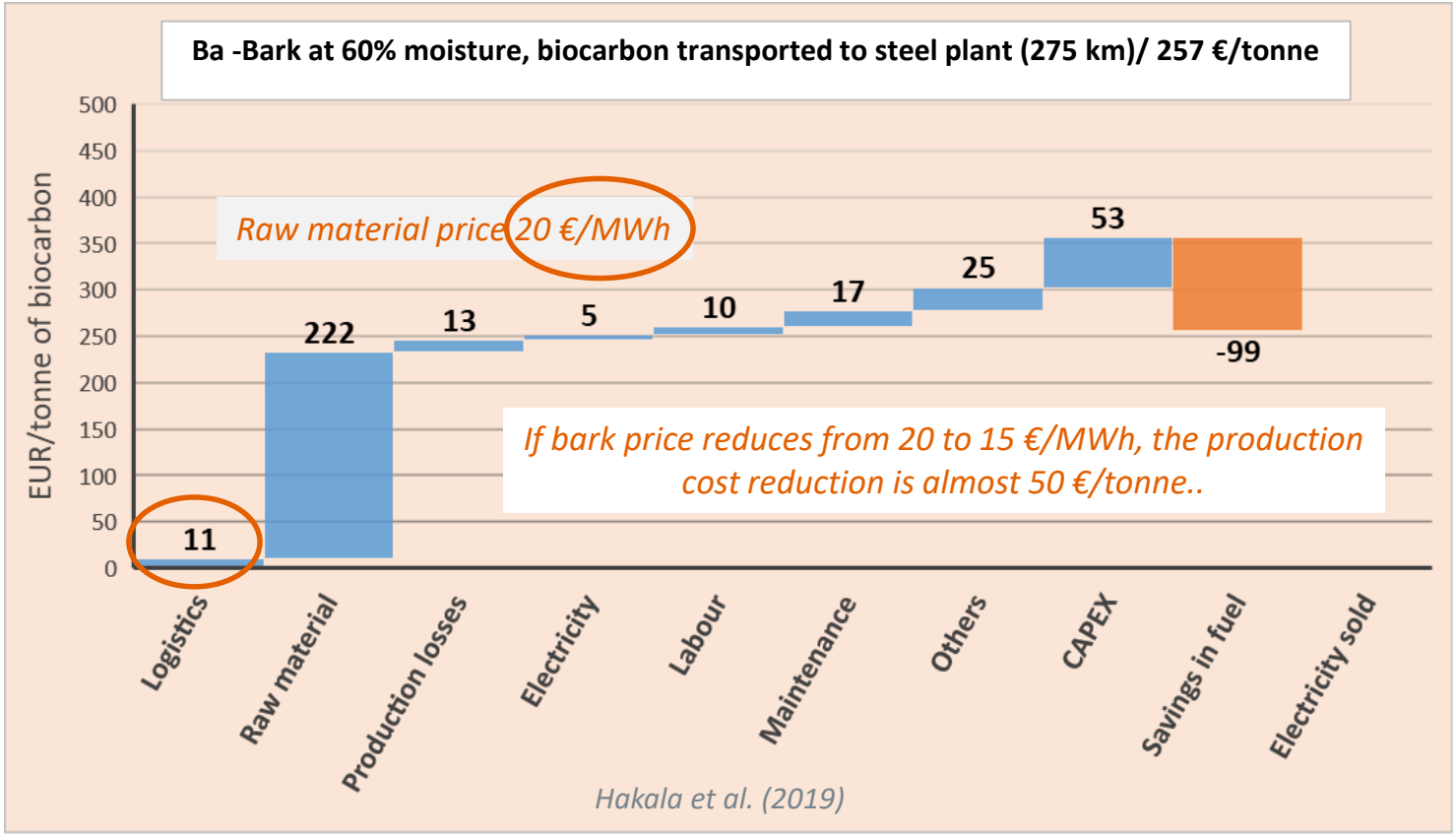
Expired biochar production plans of Finnpulp (2019a):

- Investment reservation for biocarbon production of 100 000 tonne/a from bark
- Solution for the storage and logistic challenges of bark
- Energy-economic optimal utilization of biocarbon would be possible around the year, minimizing the waste heat generation
- Environmental permit for the new mill was rejected (Finnpulp (2019b)

Finnpulp, 2019a. Finnpulpin investointia päivitetty 1,6 miljardiin euroon. Finnpulp tiedotteet. September, 26th, 2019. Available at: https://www.finnpulp.fi/2019/09/26/finnpulpin-investointia-paivitetty-16-miljardiin-euroon/

Finnpulp, 2019b. Korkein hallinto-oikeus hylkäsi Finnpulpin ympäristöluvan. Finnpulp tiedotteet. December 19th, 2019. Available at: https://www.finnpulp.fi/2019/12/19/korkein-hallinto-oikeus-hylkasi-finnpulpin-ymparistoluvan/

Cost structure –Integrated bark scenario



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Production costs –ca. 250 - 400 €/tonne

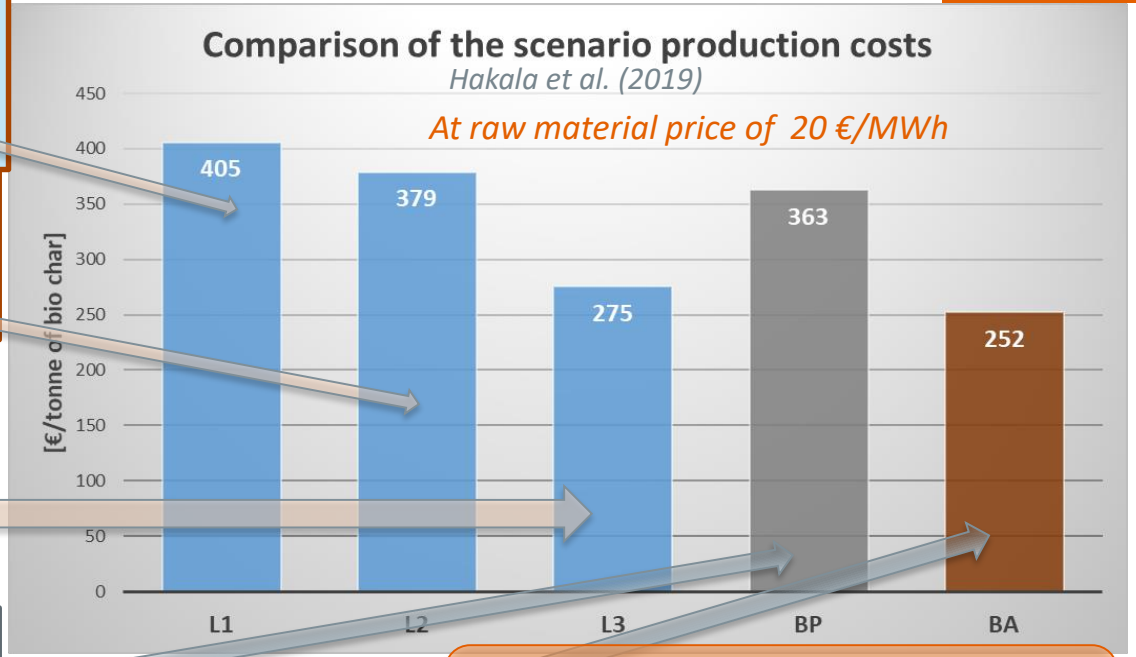
VTT

LIGNIN:

L50: Non-integrated bioethanol plant:
- Transporting lignin at 50 wt% moisture 200 km
- Pyrolysis close to steel mill
- 48% higher production costs than L3

L90: Non-integrated bioethanol plant:
- Transporting dried lignin 200 km
- Pyrolysis close to steel mill
- 38% higher production costs than L3

L50-I: Bioethanol plant integrated to a pulp and paper mill:
- Biochar transport to steel mill 160 km
- 10% higher production cost than Ba



Bark:

BP: Black pellets made of bark at a pulp mill
- Transporting black pellets 275 km
- -pyrolysis close to steel mill
- 44% higher production costs than Ba

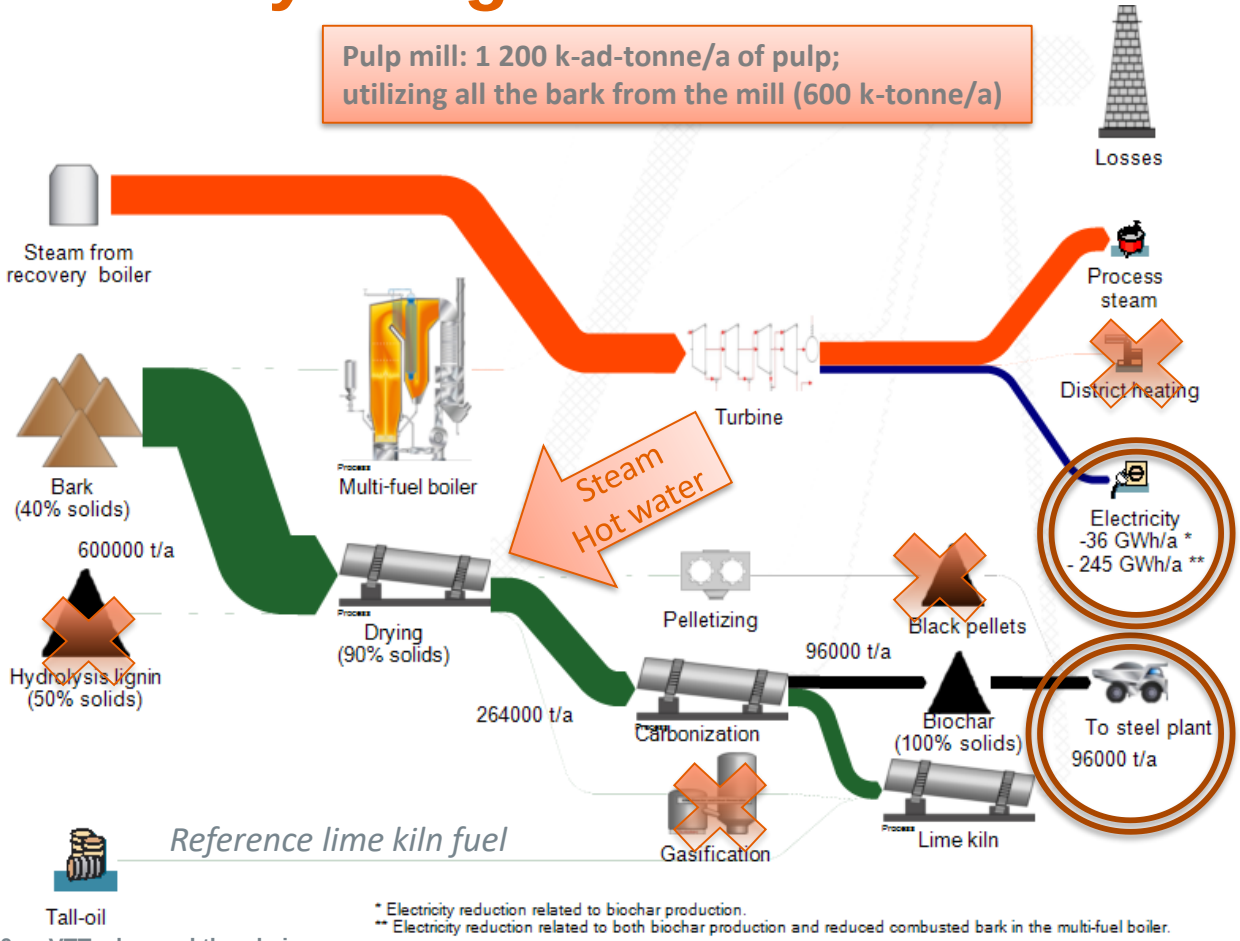
Ba: Biochar made of bark at an integrated pulp mill:
- Biochar transport to steel mill 275 km
- 96 k-tonnes/a of biochar (*others 44 k-tonnes*)

Integrated scenarios L3 and Ba:
- *Pyrolysis gases burned at the lime kiln*
- *No electricity generation*

Non-integrated
- *Electricity generation from excess heat*
- *Costs may be reduced by heat and/or fuel gas integration with the steel mill*

Biorefinery integration – Bark to biocarbon

Pulp mill: 1 200 k-ad-tonne/a of pulp;
utilizing all the bark from the mill (600 k-tonne/a)



Losses [kWh/tonne of steam]:
- 35 Electricity generation

* Electricity reduction related to biochar production.
** Electricity reduction related to both biochar production and reduced combusted bark in the multi-fuel boiler.

Hakala, J., Kangas, P., Penttilä, K., Alarotu, M., Björnström, M., Koukkari, P., 2019. Replacing Coal Used in Steelmaking with Biocarbon from Forest Industry Side Streams. VTT Technology 351. VTT Technical Research Centre of Finland Ltd.

Availability –Biocarbon potential in Finland

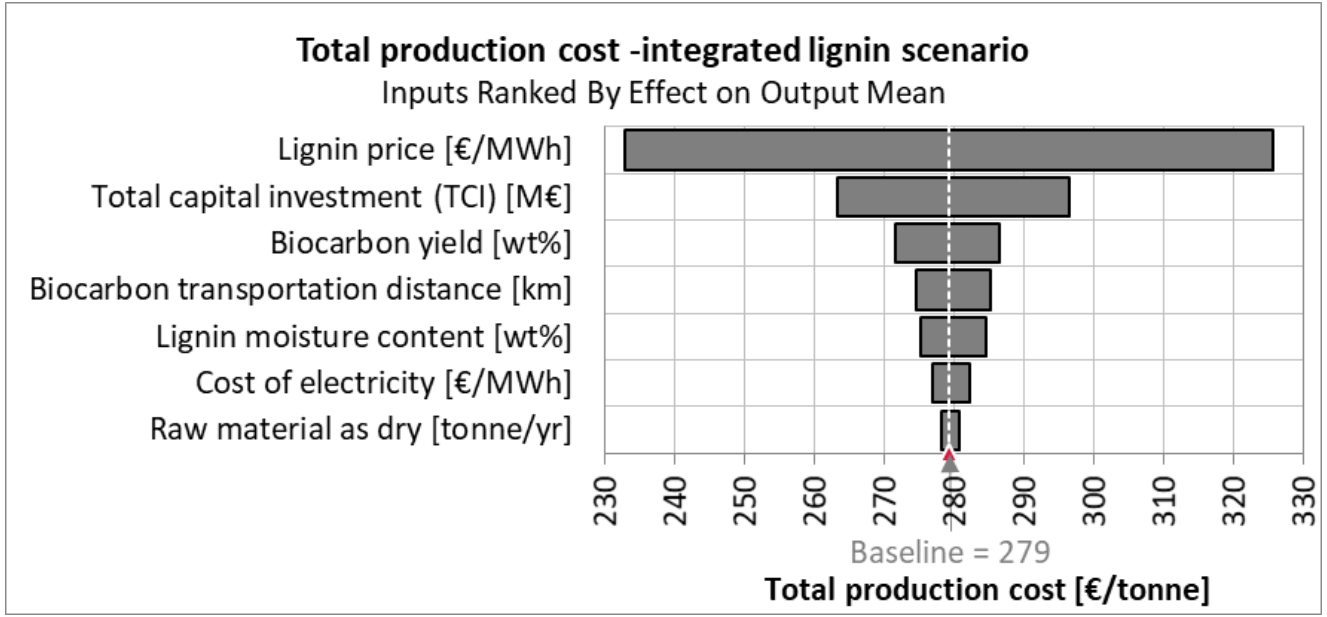
VTT

Present-day sources: The estimated amount of available biocarbon ca. 1.5 million tonnes/a

- Estimate is based on round wood removal statistics 2018, side stream shares, In-house use estimates, biocarbon yield estimates and on basic densities. Updated based on Hakala et al. (2019).
- The largest maintainable harvesting 80,5 Mm^3 (Luke 2020) is already close to the 2018 level

2018	Wood origin vol.	Side-stream	Side-stream share	Side-stream vol.	Share of in-house use	Potential side-stream vol.	Basic density	Yield	Biocarbon potential
	[Mm^3]		[vol%]	[Mm3/a]	[vol%]	[Mm3/a]	[kg/m3]	[w%]	[k-tonne/a]
Pulpwood -pine	17.6	bark	12.5 %	2.2	50 %	1.1	300	40 %	132
Pulpwood -spruce	11.2	bark	12.5 %	1.4	50 %	0.7	365	40 %	102
Pulpwood-hardwood	9.8	n.a.	n.a.						
Pulpwood-not specified	1.0	n.a.	n.a.						
Logs -pine	12.1	bark	11.0 %	1.3	50 %	0.7	300	40 %	80
Logs - spruce	15.3	bark	11.0 %	1.7	50 %	0.8	365	40 %	123
Logs -hardwood	1.3	n.a.	n.a.						
Logs -not specified	1.1	n.a.	n.a.						
Energywood (stemwood: wood chips heat and power plants, fuelwood of detached houses)	8.9	wood chips no slash/ stumps	65 %	5.8	70 %	1.7	457	41 %	326
Round wood total removal	78.2								
Saw mill -logs pine and spruce	27.3	wood chips	29.0 %	7.9	80 %	1.6	430	42 %	286
Saw mill -logs pine and spruce	27.3	Saw dust	14.0 %	3.8	40 %	2.3	430	42 %	415
SUM -potential						8.9			1463

Sensitivity – integrated hydrolysis lignin scenario L50-I (L3)



Monte Carlo Method

-Simulation runs of 30,000 pcs

-The analysis tool @Risk (Palisade Corp., 2015)

-The baseline value based on the given distributions (not on the static values directly)

Palisade Corp., 2015. @Risk. Risk Analysis Add-in for Microsoft Excel. Version 7.0.1., Professional Edition Build 396.

Parameter varied	MIN	STATIC	MAX
Raw material as dry [tonne/yr] **)	81,850	98,200	114,600
Transportation distance – biocarbon [km]	1	160	450
Total capital investment (TCI) [M€] ***)	19.2	27.4	35.7

Parameter varied	MIN	STATIC	MAX
Lignin price [€/MWh]	15.0	20.0	25.0
Cost of electricity [€/MWh]	35.0	35.0	68.0
Lignin moisture content [wt%]	40.0%	50.0%	60.0%
Biocarbon yield [wt%] *)	41.8%	45.0%	48.2%

**) The biocarbon yield MIN value is set 93% and MAX to 107% of the static value*
***) The lignin feed as dry is set to 83% and MAX to 117% of the static value yield*
****) The TCI MIN value is set to 70% and MAX 130% of the static value*