Prospects for the use of biomass in steel industry

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October 20th, 2020
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

DIRECT INDUSTRY EMISSIONS IN FINLAND 2019:
12.2 M TONNES CO2

Chemicals and petrochemicals 14 %
Cement 27 %
ISI 25 %
Other industry 29 %
Levi et al. (2020)

Other

Metals industry 34 %
Ferrous 98 %

Metals industry: SSAB, Outokumpu, Boliden and Ovako
Verified - Energy Authority (2020)

DIRECT METALS INDUSTRY EMISSIONS IN FINLAND 2019:
4.2 M TONNES CO2

Non-ferrous 2 %
Price drop from 100 to 50 €/tonne

Price trends – Thermal coal (FIN)

Coal price at a coastal harbour in Finland

Historical prices of coal for energy use at a coastal harbor in Finland, unloaded to the harbor field, harbor fee excluded 2011 onwards, VAT excluded (Statistics Finland 2020b)

Heating value 7.08 MWh/tonne

Coal/coke taxation in Finland: Energy + CO₂ + 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

Last value
March 2020

Price drop from 100 to 50 €/tonne
Price trends - EUA

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

Old forecasts examples (EC 2013, Schjølset 2014):
- Close to **50 €/tCO\(_2\)** in 2030
- **100 €/tCO\(_2\)** in 2050 (EC-reference proposal)
- Old Forecasts: 10 € or below for year 2020.
Price trends – Forest Biomass (FIN)

Prices are at the users’ site, based on the sales and on the past monthly averages. For example prices published in July are based on averages from May. VAT is excluded (Metsälehti 2020).

Example:
Bark 17 €/MWh
~93 €/dry-t
~30 €/t-as received -moisture 60wt%

Moderate increase of ca. 2 €/MWh

Metsälehti (2020)
Energy and emissions in crude steel production

Combined CO₂ 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
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)
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 Mm³)
  • 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

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

<table>
<thead>
<tr>
<th>Coal price [€/tonne]</th>
<th>EUA price [€/tonne CO₂]</th>
<th>PCI coal and emission trading cost [€/tonne]</th>
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<tbody>
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1 tonne of PCI coal = 2.375 tonne CO₂
## Cost comparison coal vs. biomaterial - Integrated biocarbon production from bark

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<th>Coal price [€/tonne]</th>
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**What if...**

- **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)**
Use of biocarbon in steelmaking is becoming a feasible option under current CO₂ price projections
• Reaching the levels of 50-100 €/t CO₂ ?/ 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)

• Bioenergy International, 2018. SSAB powering up for fossil-free steel production. Bioenergy International. February 1st, 2018


• Ylitalo, L. 2019. Tampereelle on suunnitteilla maailman suurin biohiililaitos – "Konsepti on suoraan monistettavissa". Kauppalehti July 10th, 2019. In Finnish only
-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
EXAMPLES OF THE POTENTIAL FROM INDUSTRIAL SOURCES FOR THE SELECTED SIDE STREAMS:

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

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))
Cost structure – Integrated bark scenario

Ba - Bark at 60% moisture, biocarbon transported to steel plant (275 km)/ 257 €/tonne

If bark price reduces from 20 to 15 €/MWh, the production cost reduction is almost 50 €/tonne.

**Production costs** – ca. 250 - 400 €/tonne

**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

**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

**Comparison of the scenario production costs**

*Hakala et al. (2019)*

*At raw material price of 20 €/MWh*
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
- 35 Electricity generation

Steam from recovery boiler

Bark
(40% solids)

Hydrolysis lignin
(50% solids)

Drying
(90% solids)

Pelletizing

Biochar
(100% solids)

To steel plant

96000 t/a

96000 t/a

264000 t/a

Multi-fuel boiler

Steam Hot water

Reference lime kiln fuel

Electricity -36 GWh/a
- 245 GWh/a

Electricity reduction related to biochar production.

Electricity reduction related to both biochar production and reduced combusted bark in the multifuel boiler.
Availability – Biocarbon potential in Finland

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 Mm³ (Luke 2020) is already close to the 2018 level

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<td>[vol%]</td>
<td>[Mm³/a]</td>
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<td>[Mm³/a]</td>
<td>[kg/m³]</td>
<td>[w%]</td>
<td>[k-tonne/a]</td>
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<td>Pulpwood -pine</td>
<td>17.6</td>
<td>bark</td>
<td>12.5 %</td>
<td>2.2</td>
<td>1.1</td>
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<td>40 %</td>
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<td>Pulpwood -spruce</td>
<td>11.2</td>
<td>bark</td>
<td>12.5 %</td>
<td>1.4</td>
<td>365</td>
<td>40 %</td>
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<td>Pulpwood-hardwood</td>
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<td>Pulpwood-not specified</td>
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<td>40 %</td>
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<td>Pulpwood -pine</td>
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<td>11.0 %</td>
<td>1.3</td>
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<td>80</td>
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<td>Logs -pine</td>
<td>15.3</td>
<td>bark</td>
<td>11.0 %</td>
<td>1.7</td>
<td>0.8</td>
<td>365</td>
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<td>Logs -hardwood</td>
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<td>n.a.</td>
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<td>Energywood</td>
<td>(stemwood: wood chips heat and power plants, fuelwood of detached houses)</td>
<td>8.9</td>
<td>wood chips</td>
<td>65 %</td>
<td>5.8</td>
<td>70 %</td>
<td>1.7</td>
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<td>Round wood total removal</td>
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<td>Saw mill -logs pine and spruce</td>
<td>27.3</td>
<td>wood chips</td>
<td>29.0 %</td>
<td>7.9</td>
<td>80 %</td>
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<td>430</td>
<td>42 %</td>
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<td>Saw mill -logs pine and spruce</td>
<td>27.3</td>
<td>Saw dust</td>
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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)

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
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