Techno-Economics and Life Cycle Performance of Green Steel
Biocleantech Forum, Ottawa

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SSAB Europe, Raahe steel mill, Finland

http://www.ssab.fi/ssab-konserni/tietoja-ssabsta/toimipisteita-ympari-maailman#ldi
Steel production and GHG emissions
Life cycle of steel

- Steel production in 2015 was 1,623 Mt
- Steel is produced from virgin raw materials and from recycled steel
- Steel production emits considerable amount of CO₂ to the atmospheres
- Concerns about the global warming → Reduction of GHG emissions is needed
- Future of iron and steel industry
  - Blast furnace process will dominate the industry for decades

https://www.worldsteel.org/publications/position-papers/lca.html
GHG emissions

- Majority of steel is produced via blast furnace-basic oxygen furnace route
- CO$_2$ emissions mainly occur because carbon is needed
- In iron oxide reduction
- In iron melting
GHG emissions

- Majority of steel is produced via blast furnace-basic oxygen furnace route
- CO₂ emissions mainly occur because carbon is needed
  - In iron oxide reduction
  - In iron melting
- The major CO₂ source is the blast furnace
  - The amount of C in top gas is around 400 kg/tHM
  - Top gas is used in several locations in the plant
  - Life cycle emissions of steel are 1.8-2.3 tCO₂/t steel

- Top gas: C ~ 400 kg/t (as CO and CO₂)
- Coke: 300-350 kg/tHM
- Sinter, pellets, Briquettes, fluxes: ~ 1500 kg/tHM
- Pulverized coal: 150-200 kg/tHM
- Hot metal: 1000 kg C ~ 45 kg/tHM
- Slag: 200 kg/tHM
Life cycle emissions of biomass-based reducing agents
Life cycle emissions of bioreducers

- In principle, several fuels produced from biomass could be used in BF
- The scientific literature is abundant with biomass fuel LCAs
- Several papers with life cycle (LC) view were reviewed
- There is no large variety in CO$_2$ emissions when compared in (gCO$_2$/MJ) (except methanol)
- Differences in raw material base, assumptions, etc. makes it difficult to compare the LC performance of bioreducers to each other
Carbon footprint of bioreducers: Finnish case

- Finland has abundant forest biomass resources, 2 305 Mm³ (annual growth 104 Mm³)
- The use of wood is considerably lower than the sustainable use potential
- There were no life cycle studies available in Finnish context concerning the upgraded biomass fuels
- Carbon footprint model was developed to evaluate and compare the environmental performance of charcoal, torrefied biomass and Bio-SNG
- Raw materials were logging residues (LR), stumps (ST) and small-diameter wood (SDW) from first thinnings

Assumptions can be found from Suopajärvi et al. (2014)
Carbon footprint of bioreducers: Results 1/2

- Carbon footprint without co-product credits, fertilizer production or indirect carbon emissions (carbon stock change) are:
  - 214-267 kg/t charcoal
  - 106-122 kg/t torrefied wood
  - 368-426 kg/t Bio-SNG
- In Bio-SNG production, the electricity-based CO₂ emissions are dominant
- CFP of bioreducers is considerably lower than the CFP of fossil-based reducing agents
• Indirect emissions occur, because energy wood (LR, SDW and ST) is burnt instead of letting it decompose in the forest. The carbon in the wood is released instantly to the atmosphere, instead of being released gradually through decomposition.
Production cost of biomass-based reducing agents and mitigation cost for global CO$_2$ emission reduction
Production cost of bioreducers

- Environmental performance is feasible, what about economics?
- Plant capacity 50 MW<sub>RM</sub>
- Finnish cost data was used whenever possible
- Production costs:
  - Charcoal 360-490 €/t
  - Torrefied wood 140-180 €/t
  - Bio-SNG 690-830 €/t
- Raw material costs dominate
- Production costs are high compared to fossil-based reducing agents

Assumptions can be found from Suopajärvi et al. (2014)
Global CO$_2$ reduction and mitigation cost

- It was assumed that coke would be replaced with charcoal, torrefied wood and Bio-SNG.
- The global CO$_2$ reduction potential with by-product credits:
  - 1.29-1.39 MtCO$_2$/a with charcoal
  - 0.4 MtCO$_2$/a with torrefied wood
  - 0.89-0.97 MtCO$_2$/a with Bio-SNG
- CO$_2$ mitigation cost with by-product credits:
  - 26-54 €/tCO$_2$ with charcoal
  - 22-53 €/tCO$_2$ with torrefied wood
  - 107-143 €/tCO$_2$ with Bio-SNG
CO$_2$ reduction and mitigation cost at plant scale
CO₂ reduction potential and mitigation costs

- Simple excel-based carbon flow model was developed to track the carbon flows at plant scale
- Five different bioreducer injection cases were evaluated
  - Charcoal, torrefied biomass, Bio-SNG, hydrogen and bio-methanol
  - Coke replacement ratios derived from several references
- Two other replacement cases
  - 5 wt% charcoal to coking coal mix
  - Replacement of liquefied petroleum gas (LPG) (12 kg/t steel) with Bio-SNG in rolling mills

Estimated fuel rates (kg/tHM) in different cases, based on the literature

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<th>C3</th>
<th>C4</th>
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Assumptions can be found from Suopajärvi et al. (2016a)
CO₂ reduction potential at plant scale

- The achievable CO₂ reduction is 9–43% at plant scale
- Charcoal injection represents the best single alternative to mitigate CO₂ emissions
- Modest injection rate was assumed (150 kg/tHM)
- Higher injection rate would result further CO₂ reduction
- Injection of torrefied biomass and methanol are not efficient measures
- Low coke replacement ratios

Total achievable CO₂ emission reduction per produced ton of steel product when all the measures are taken (injection, charcoal in coke plant and Bio-SNG in rolling mill)
Mitigation cost calculation:
- With average and minimum bioreducer prices (literature review)

Mitigation cost in BF injection:
- Average price: 92-325 €/tCO$_2$
- Minimum price: 51–248 €/tCO$_2$

Abatement cost is negative for LPG replacement with Bio-SNG

CO$_2$ reduction potential ~ 2%

Higher carbon tax/emission allowances would favor the use of bioreducers
Conclusions

- Steel production in integrated steel plants produces vast amount of CO$_2$ emissions to the atmosphere
- Biomass-based reducing agents and fuels are one possibility to decrease the fossil CO$_2$ emissions
- The CO$_2$ reduction potential is significant
  - 25% reduction at plant scale CO$_2$ emissions with biochar injection
  - Total CO$_2$ emission reduction 43% at plant scale
  - Life cycle emission reduction could be even higher → production stage emissions are higher with fossil-based reducing agents
- The economics of bioreducers is challenging
  - Mitigation cost is high, however, it is high also with other CO$_2$ reduction alternatives
- Biomass use could be partial solution towards sustainable steelmaking!
Acknowledgements

The presentation was based on the following papers:


Suopajärvi, H., Kemppainen, A., Haapakangas, J., Fabritius, T., 2016b. Extensive review of the possibilities to use biomass-based fuels in iron and steelmaking (sent for publication).

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More information:
http://www.oulu.fi/pyometen/renepro
http://www.oulu.fi/pyometen/carbo
Thank you for your kind attention!

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