Techno-Economics and Life Cycle Performance of Green Steel

Biocleantech Forum, Ottawa

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Contents

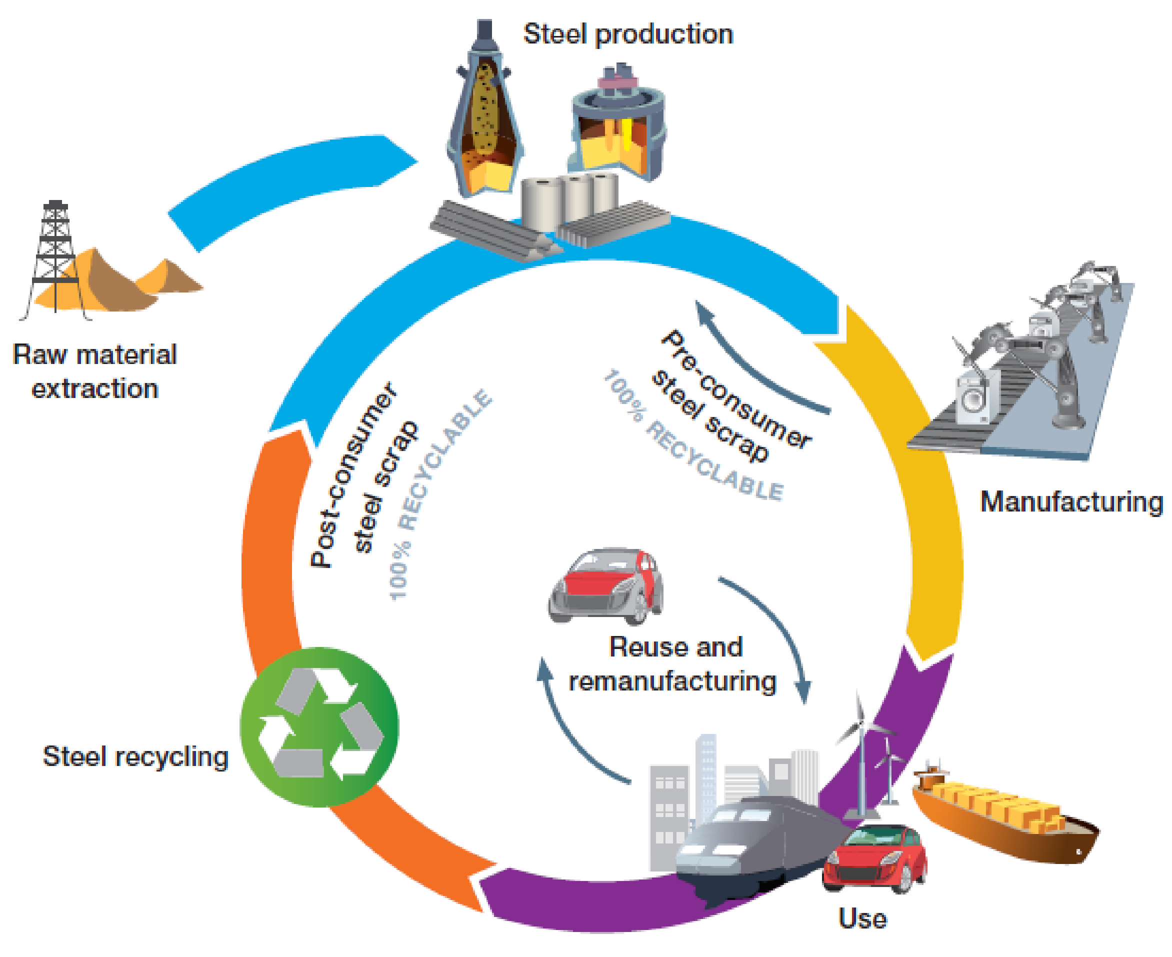
SSAB Europe, Raahe steel mill, Finland

http://www.ssab.fi/ssab-konserni/tietoja-ssabsta/toimipisteita-ympari-maailman#!di

- Steel production and GHG emissions
- Life cycle emissions of biomass-based reducing agents
- Production cost of biomass-based reducing agents and mitigation cost for global CO_2 emission reduction
- CO_2 reduction and mitigation cost at plant scale
- Conclusions

Steel production and GHG emissions

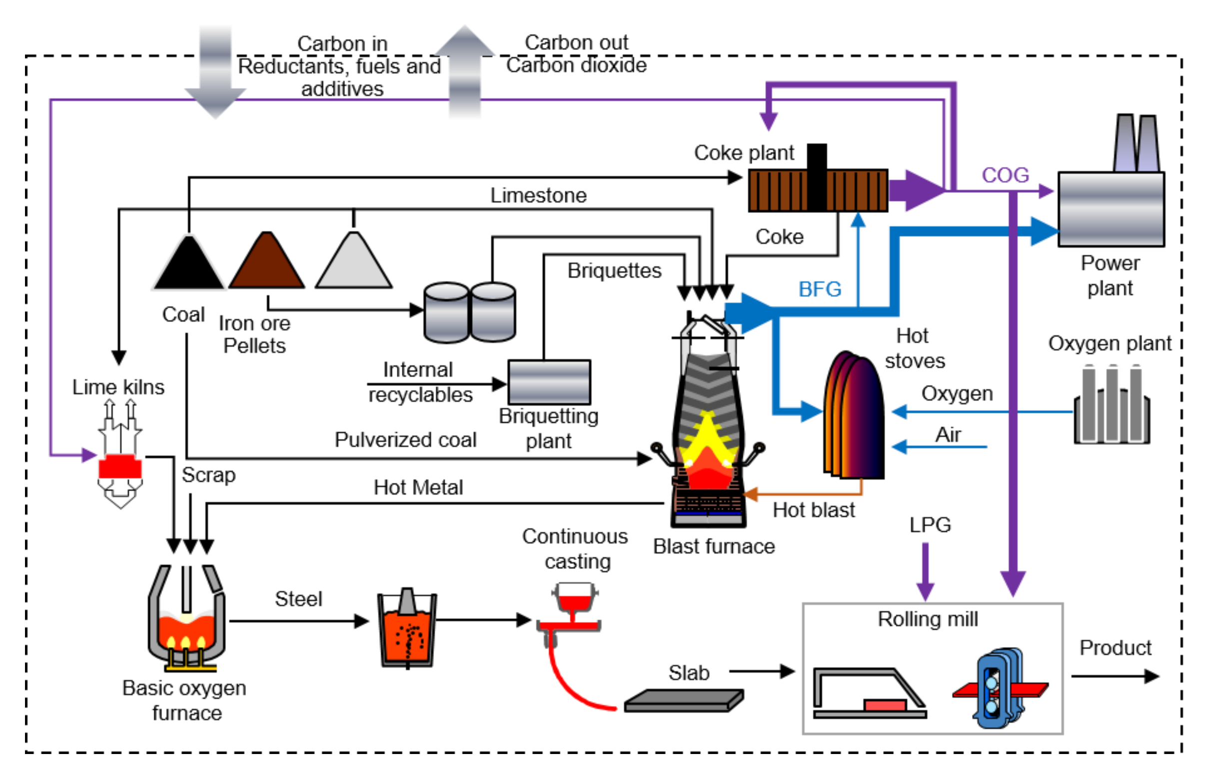
Life cycle of steel



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

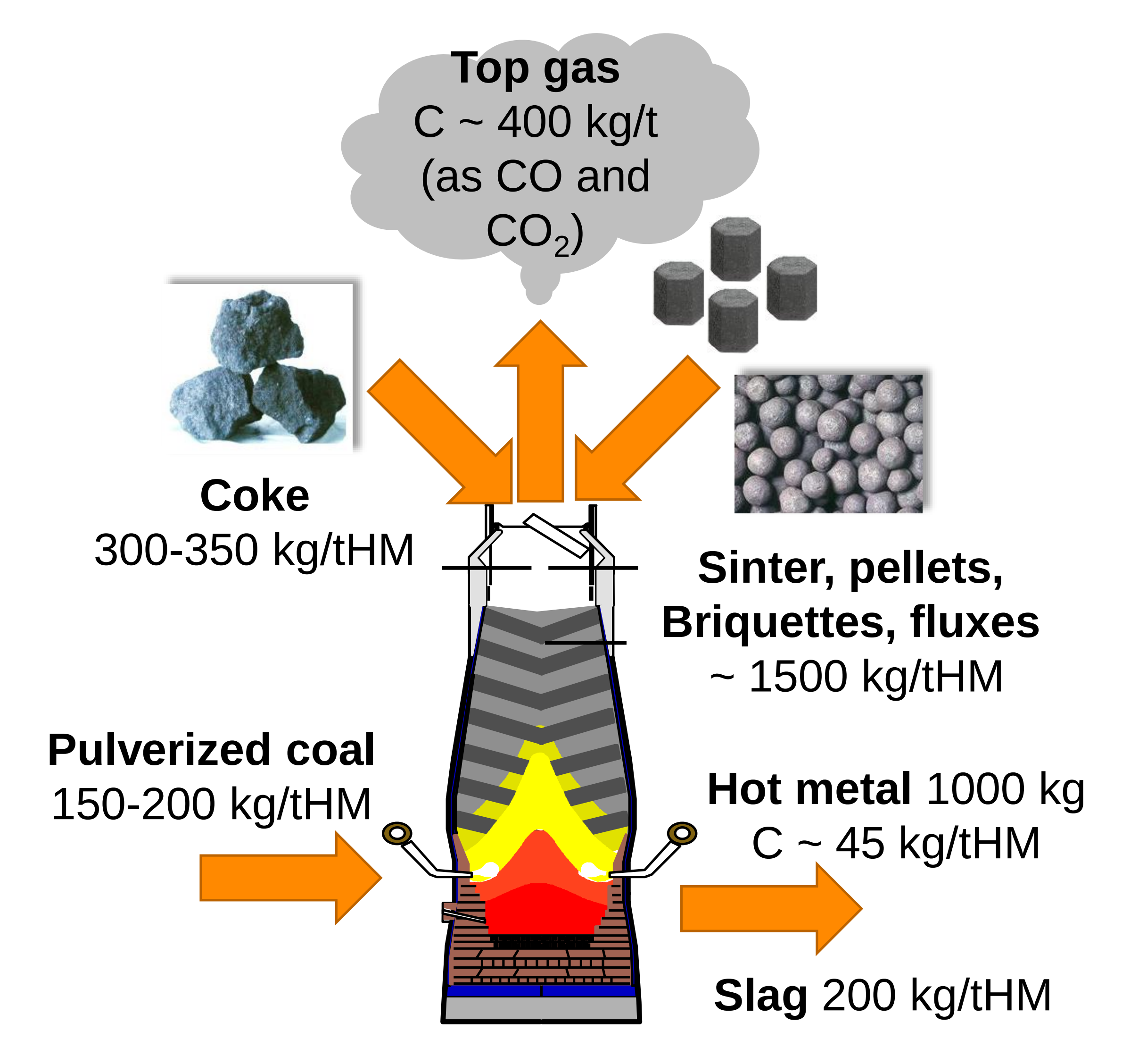
- Steel production in 2015 was 1,623 Mt
- Steel is produced from virgin raw materials and from recycled steel
- Steel production emits considerable amount of CO_2 to the atmospheres
- Concerns about the global warming → Reduction of GHG emissions is needed
- Future of iron and steel industry
  - Blast furnace process will dominate the industry for decades

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

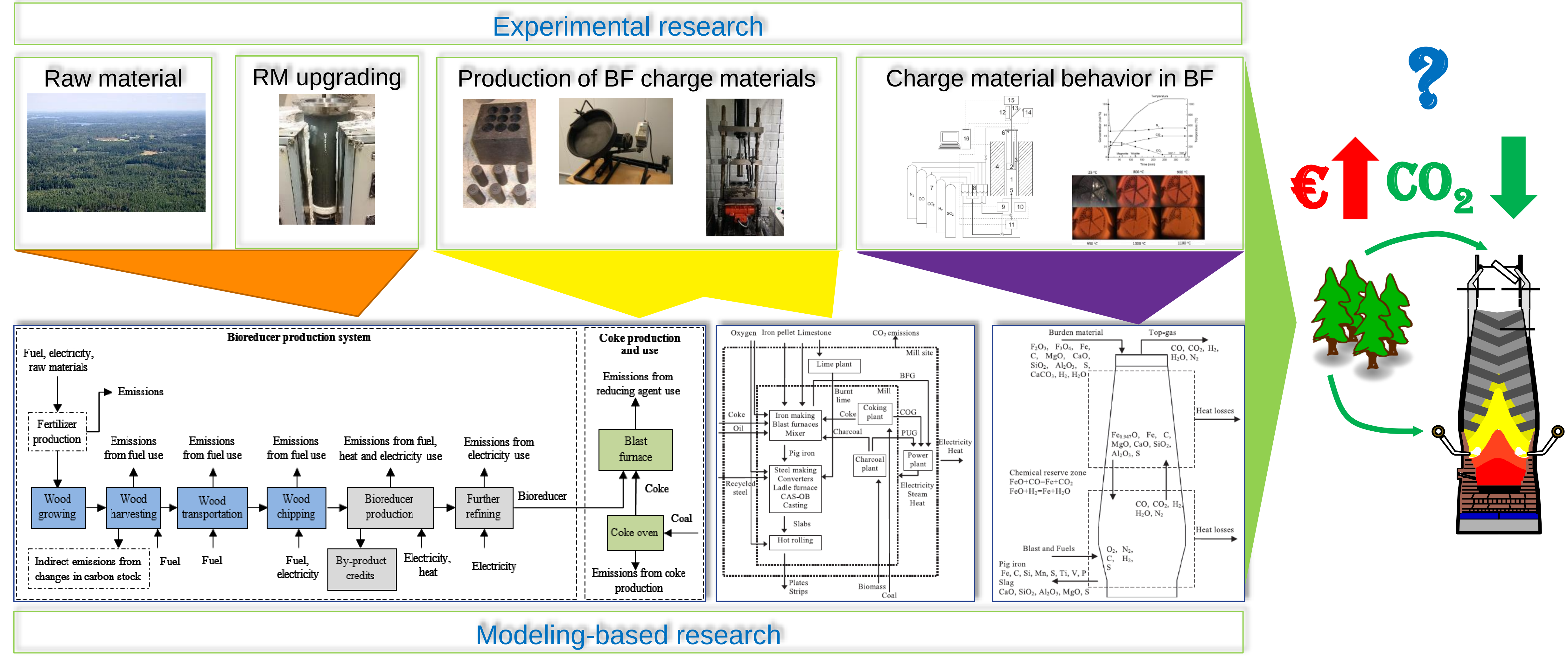
GHG emissions



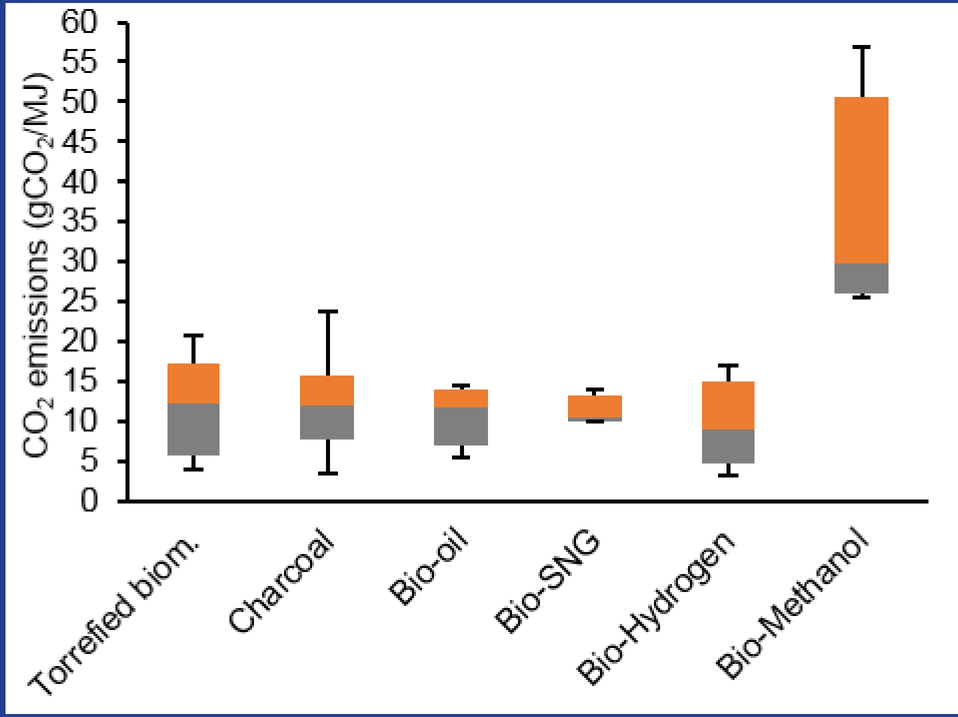
- **Majority of steel is produced via blast furnace-basic oxygen furnace route**
- **CO_2 emissions mainly occur because carbon is needed**
- In iron oxide reduction
- In iron melting
- **The major CO_2 source is the blast furnace**
- The amount of C in top gas is around 400 kg/tHM
- Top gas is used in several locations in the plant
- Life cycle emissions of steel are 1.8-2.3 tCO_2/t steel

Life cycle emissions of biomass-based reducing agents

Biomass use in iron and steelmaking: Finnish perspective

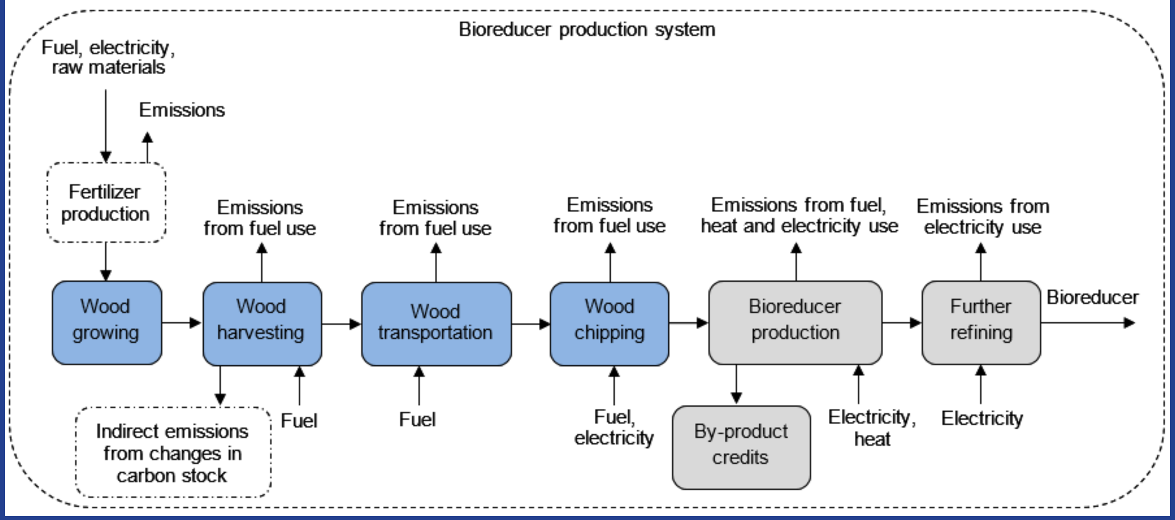


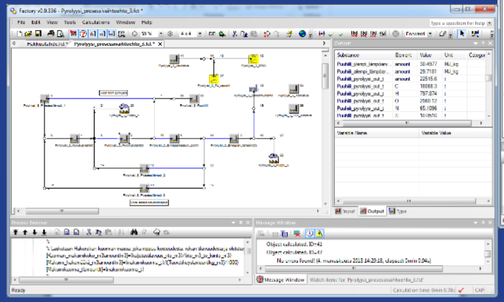
Life cycle emissions of bioreducers

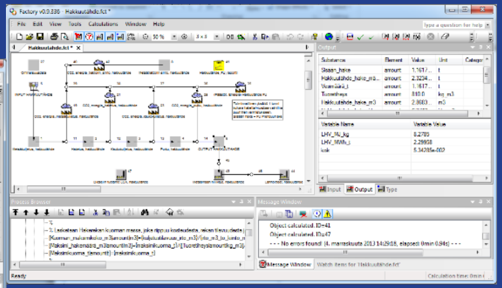


- In principle, several fuels produced from biomass could be used in BF
- The scientific literature is abundant with biomass fuel LCAs
- Several papers with life cycle (LC) view were reviewed
- There is no large variety in CO_2 emissions when compared in (gCO_2/MJ) (except methanol)
- Differences in raw material base, assumptions, etc. makes it difficult to compare the LC performance of bioreducers to each other

Carbon footprint of bioreducers: Finnish case



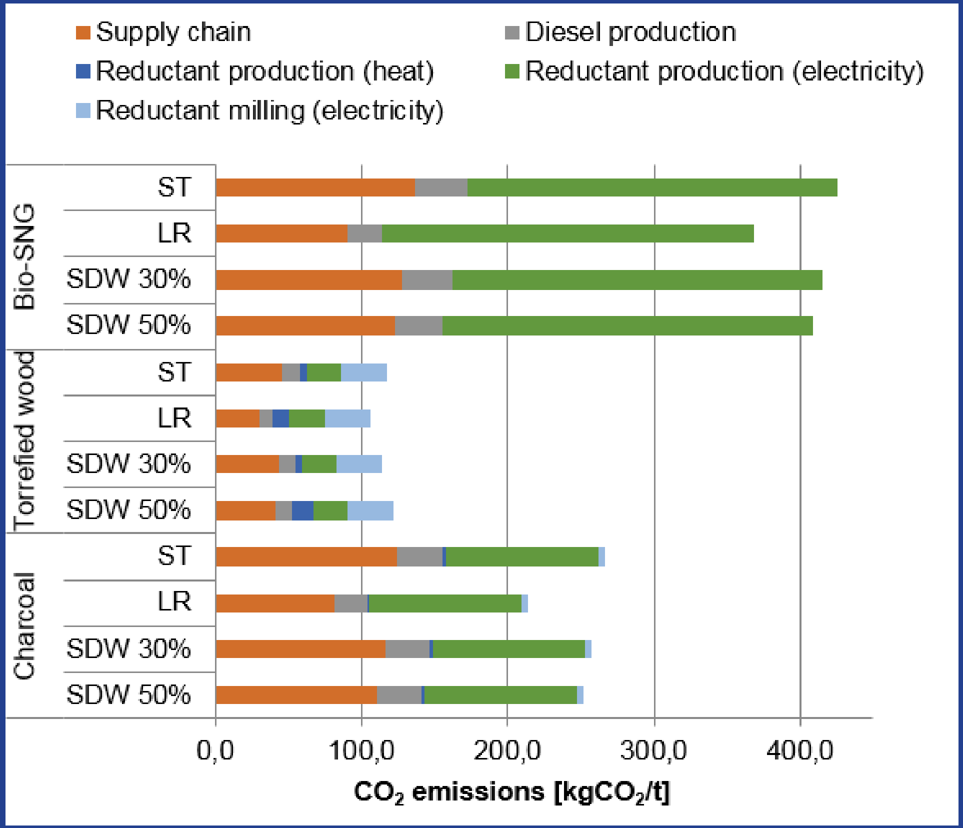




Assumptions can be found from Suopajärvi et al. (2014)

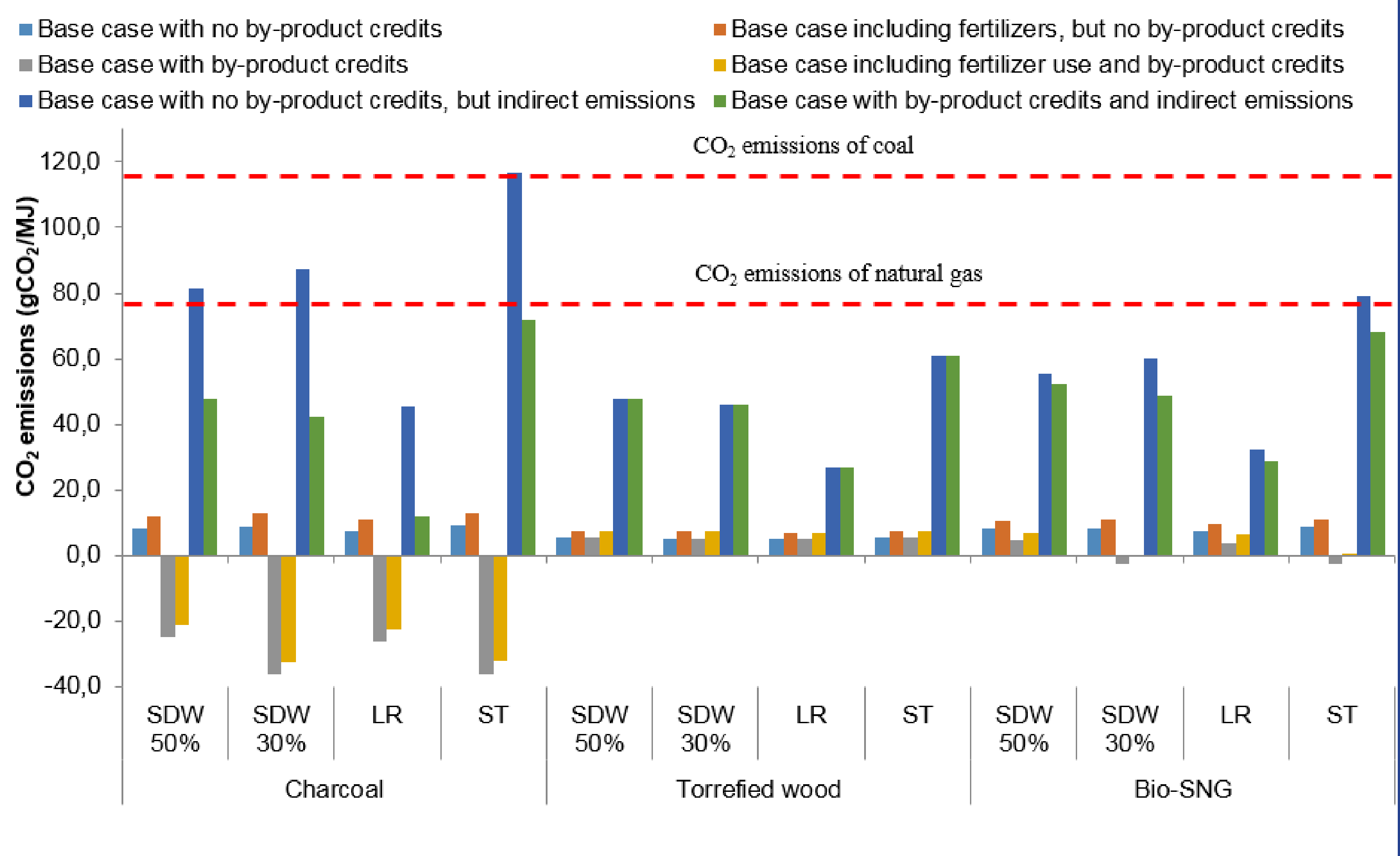
- Finland has abundant forest biomass resources, 2 305 Mm^3 (annual growth 104 Mm^3)
- The use of wood is considerably lower than the sustainable use potential
- There were no life cycle studies available in Finnish context concerning the upgraded biomass fuels
- Carbon footprint model was developed 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

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 CO_2 emissions are dominant**
- **CFP of bioreducers is considerably lower than the CFP of fossil-based reducing agents**

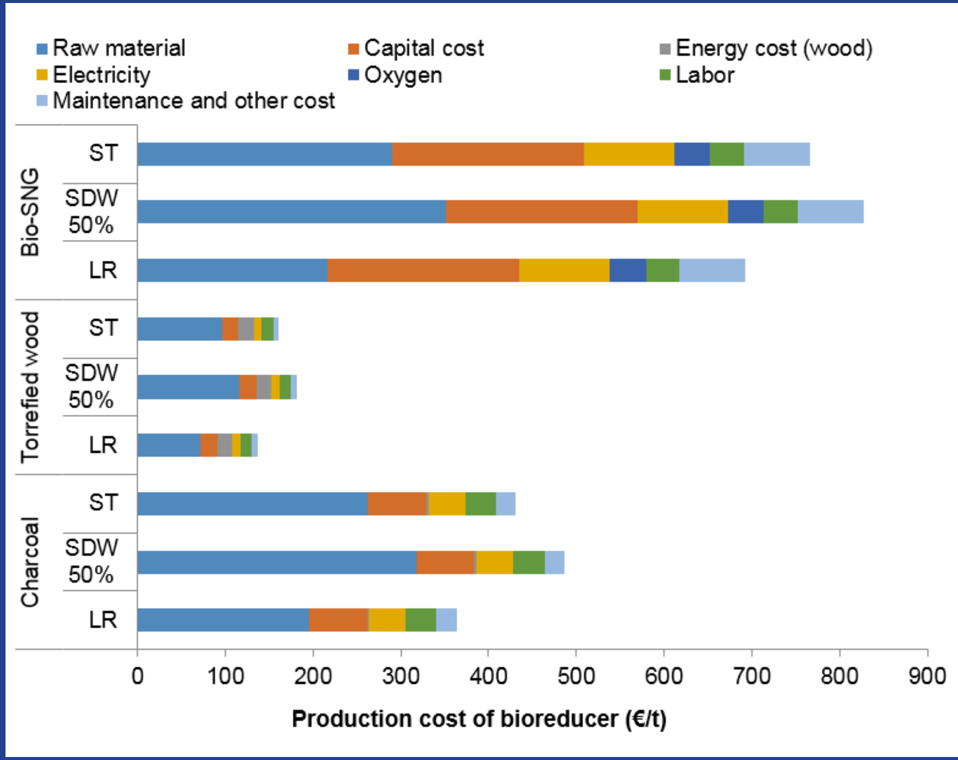
Carbon footprint of bioreducers: Results 2/2



- **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

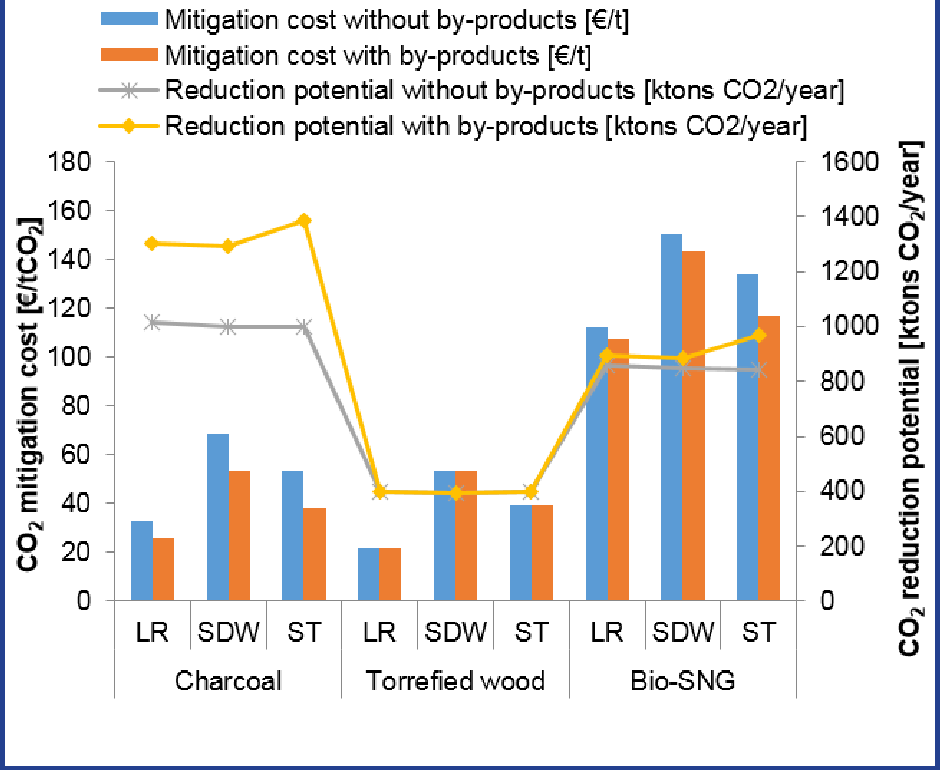
Production cost of bioreducers



- **Environmental performance is feasible, what about economics?**
- **Plant capacity 50 MW_{RM}**
- **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



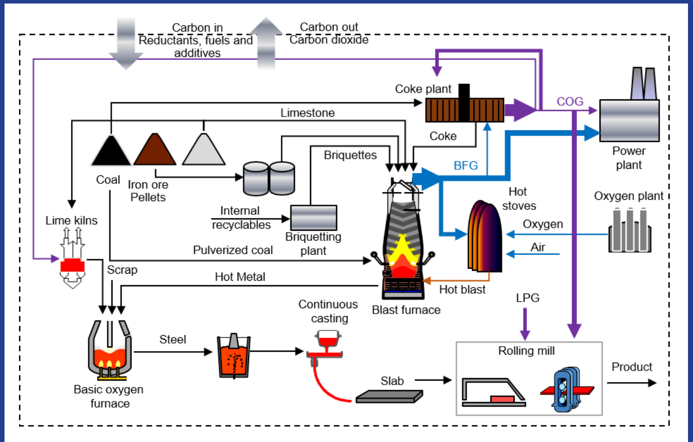
- **It was assumed that coke would be replaced with charcoal, torrefied wood and Bio-SNG**
- **The global CO_2 reduction potential with by-product credits:**
- 1.29-1.39 $MtCO_2$/a with charcoal
- 0.4 $MtCO_2$/a with torrefied wood
- 0.89-0.97 $MtCO_2$/a with Bio-SNG
- **CO_2 mitigation cost with by-product 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

CO_2 reduction potential and mitigation costs

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

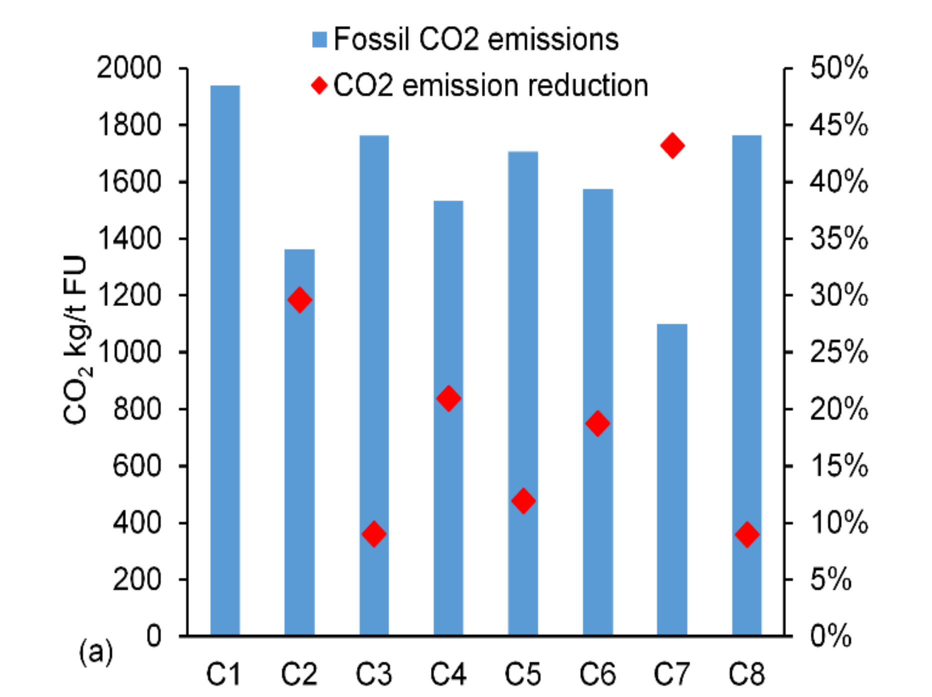
kg/tHM	C1	C2	C3	C4	C5	C6	C7	C8
Coke	327.5	320	332	365	292.4	257.3	249.8	336.8
PCI	150	0	120	0	150	150	0	115
Charcoal	0	150	0	0	0	0	150	0
Torr. biomass	0	0	60	0	0	0	0	0
Bio-SNG	0	0	0	100	0	0	0	0
H_2	0	0	0	0	13	26	26	0
Bio-methanol	0	0	0	0	0	0	0	60



Assumptions can be found from Suopajärvi et al. (2016a)

- **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

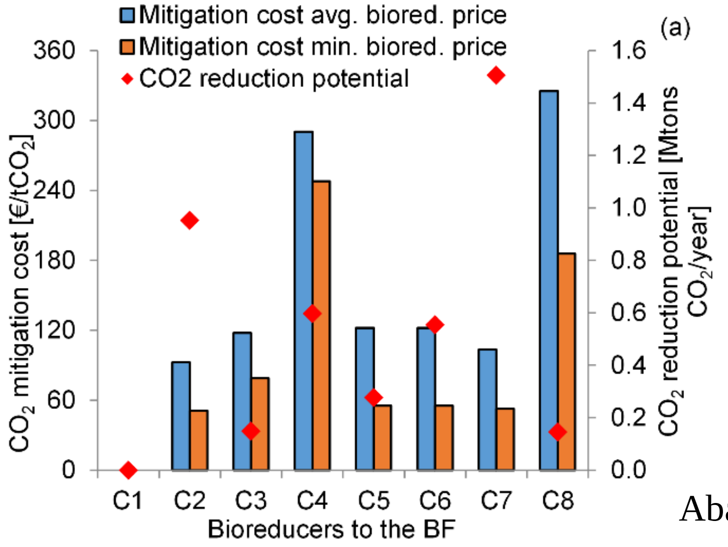
CO_2 reduction potential at plant scale



Total achievable CO_2 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)

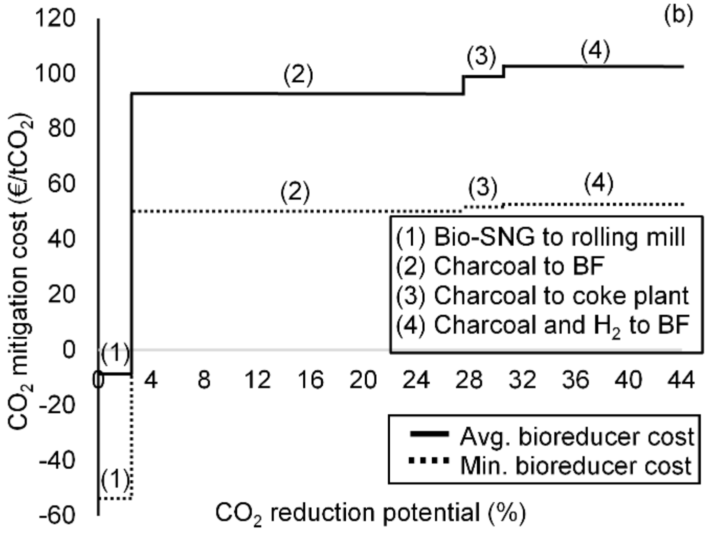
- **The achievable CO_2 reduction is 9–43% at plant scale**
- **Charcoal injection represents the best single alternative to mitigate CO_2 emissions**
- Modest injection rate was assumed (150 kg/tHM)
- Higher injection rate would result further CO_2 reduction
- **Injection of torrefied biomass and methanol are not efficient measures**
- Low coke replacement ratios

CO_2 mitigation costs



Abatement cost curve for biofuels

CO_2 mitigation cost for different bioreducers injected to BF



- **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., Pongrácz, E., Fabritius, T., 2014. Bioreducer use in Finnish blast furnace ironmaking – Analysis of CO_2 emission reduction potential and mitigation cost. Applied Energy 124:82-93.

Suopajärvi, H., Kemppainen, A., Haapakangas, J., Fabritius, T., 2016a. Bioenergy use in iron and steelmaking - opportunities and barriers, 5th International Conference on Process Development in Iron and Steelmaking, 12-15 June, Luleå, Sweden.

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

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