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Evaluation of Steel Mills as Carbon Sinks

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Aim & Scope

Aim:

- evaluate potential of BECCS concept in steel industry in terms of emission avoidance and cost.
- assess benefits of biomass introduction in steel industry regarding green products such as renewable electricity & carbon-neutral steel

Scope:

- BECCS concept as feasible near-term mitigation option:
  → Techno-economic assessment of pulverized bio-char injection (bio-PCI) into blast furnace + MEA capture from blast furnace gas with excess heat.

Agenda

Aim & Scope →

Background on biomass in steel industry →

Method on carbon balance, avoided emissions & economics →

Results on emission reductions & cost →

Synergies & Challenges of BECCS on steel →

Conclusions

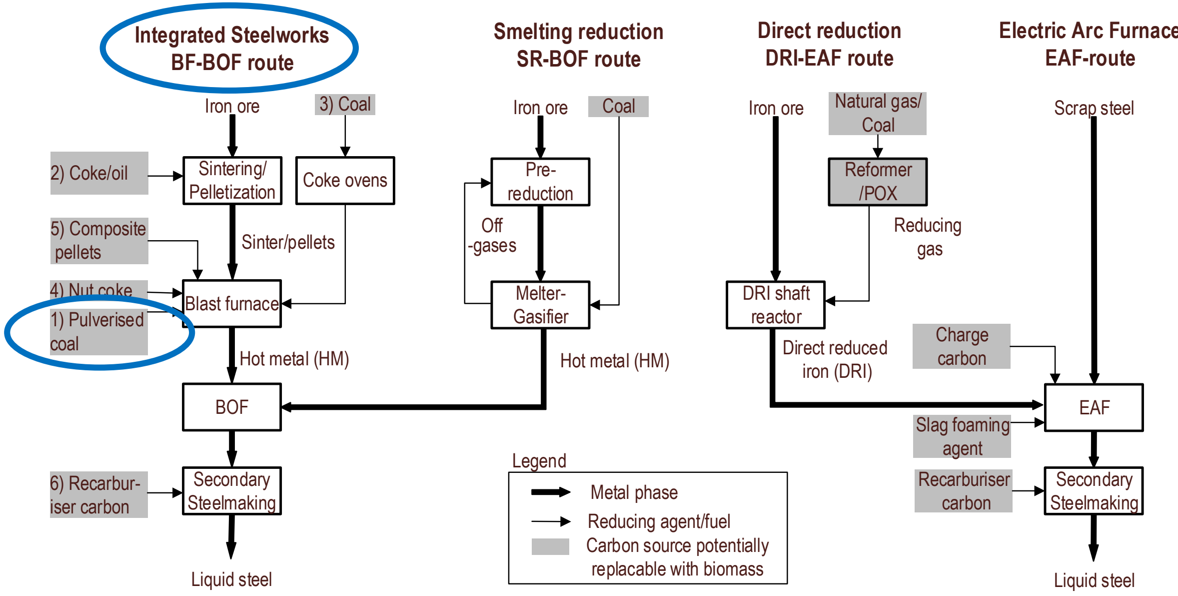
- BECCS on steel is cost effective, near term option
- 100 % Bio-PCI + 84 % CO_2 capture from BFG reduce site emissions by 61 % @ ~100 €/t CO_2
- Biogenic carbon in blast furnace can be used multi-fold and generates green steel & energy

Background

- Iron & Steel industry emits ca. 7% of global CO_2 emissions
- >70 % of the world's steel is produced in blast furnaces (BF-BOF route)

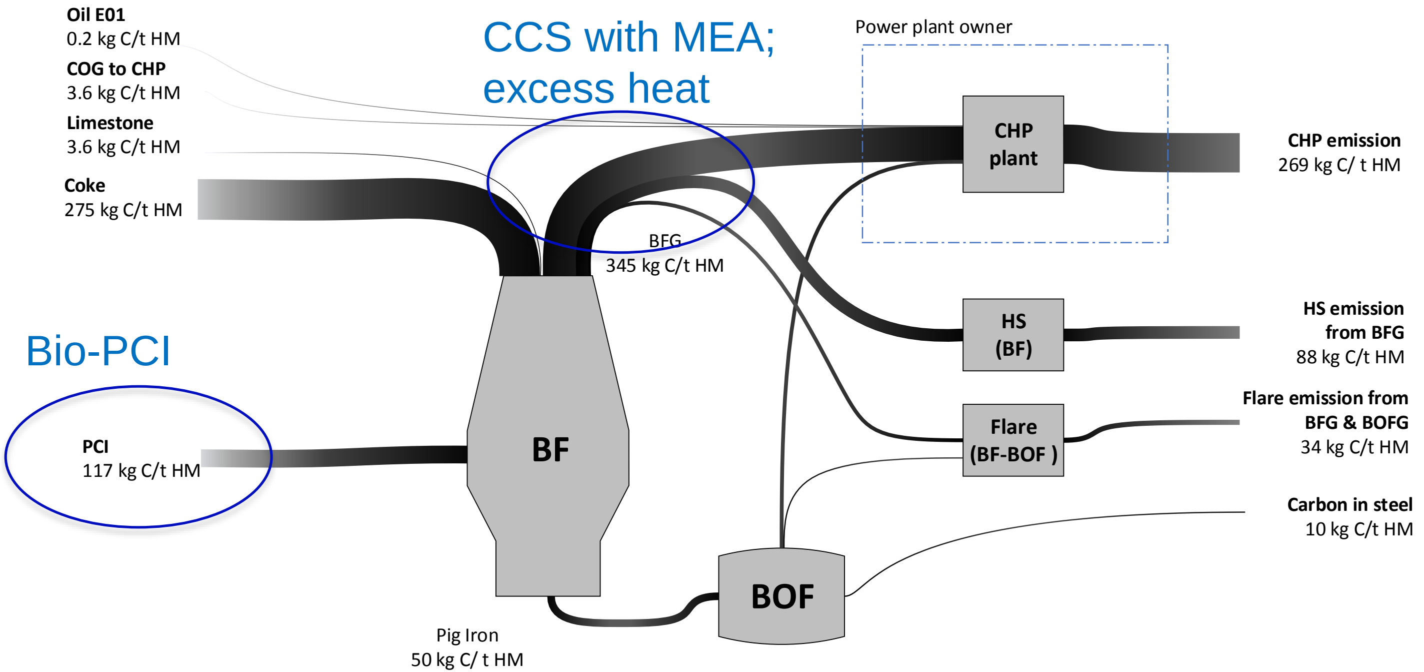
6 principle ways of introducing biomass into BF-BOF route

→ Replacing pulverized coal injection (PCI) most feasible



Adapted from Norgate et al. "Biomass as a source of renewable carbon for iron and steelmaking," *ISIJ Int.*, vol. 52. 2012

Background: Use of fossil carbon



Scope:
Bio-PCI + CO_2 capture from blast furnace gas with MEA using excess heat

Method: Carbon balance

- Reference plant: SSAB's plant in Luleå, Sweden
- Carbon balance around BF & downstream units – assumptions:
  - Balance based on 2.26 Mt HM /yr (2006); Reference site emissions: 1574 kg CO_2/ t HM
  - The top gas composition does not change with biomass injection
  - No re-allocation of steel mill gases with CO_2 capture/biomass injection
  - Biogenic carbon from BF allocated to all downstream units in equal share
- Capture: 30 wt.% MEA absorption cycle – result from CO_2stCap project [1]
- 2 woody biomasses (carbon neutral) studied: from pyrolysis & torrefaction
  feasible injection amounts according to modelling work [2]*

* Considers top gas T, RAFT, oxygen enrichment;

[1] GCCSI Webinar 23.11.2017; http://www.globalccsinstitute.com
[2] Wang *et al.*, *Energy Convers. Manag.*, vol. 102, 2015.

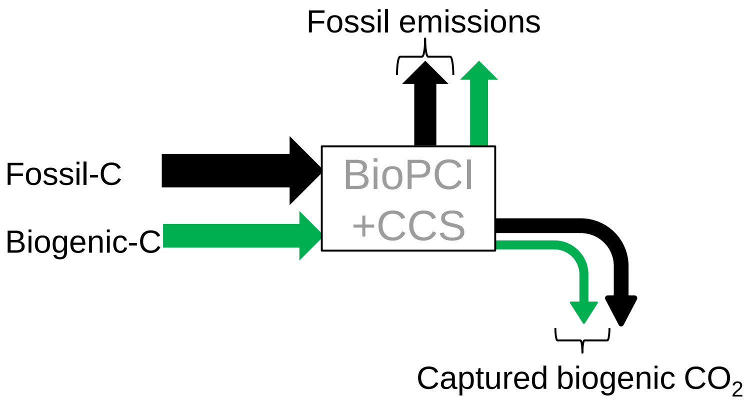
Method: negative emissions

Avoided CO_2 emissions – contribution of negative emissions:

CO_2 avoided = Emissions $_{\text{Ref. PCI}}$ – Emissions $_{\text{BioPCI+CCS}}$

= Emissions$_{\text{Ref. PCI}}$ – (Fossil emissions – Captured biogenic CO_2)$_{\text{BioPCI+CCS}}$

adapted from [1]



[1] IEAGHG, "Techno economic evaluation of retrofitting CCS in a market pulp mill and an integrated pulp and board mill," 2016.

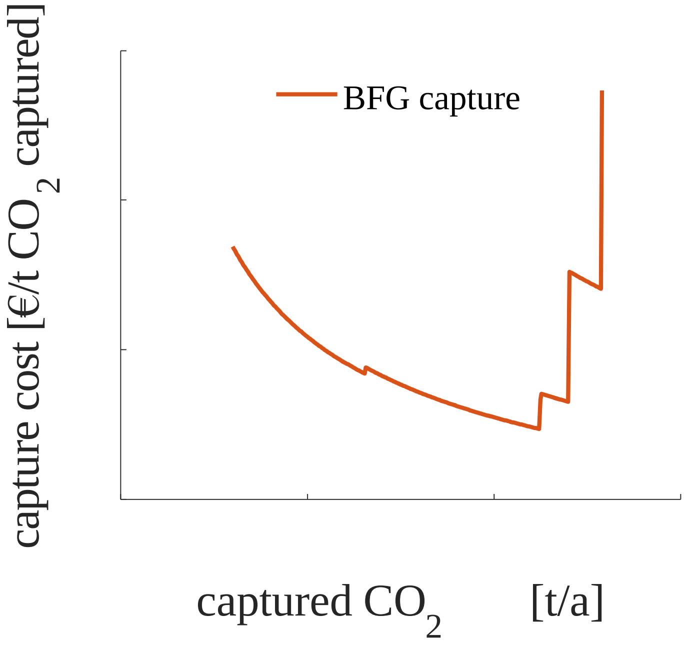
Method: Economics

- ”Nth of a kind” MEA capture plant

- Cost include excess heat recovery, necessary piping to capture site, compression
  →Choosing cost efficient capture rate of 84 %
  @ 26 €/t CO_2 captured [1]

- Transport & storage included @ 16 €/t CO_2 [2]

- Biomass enters system already upgraded:
  assumed 0 - 500 €/t [3]



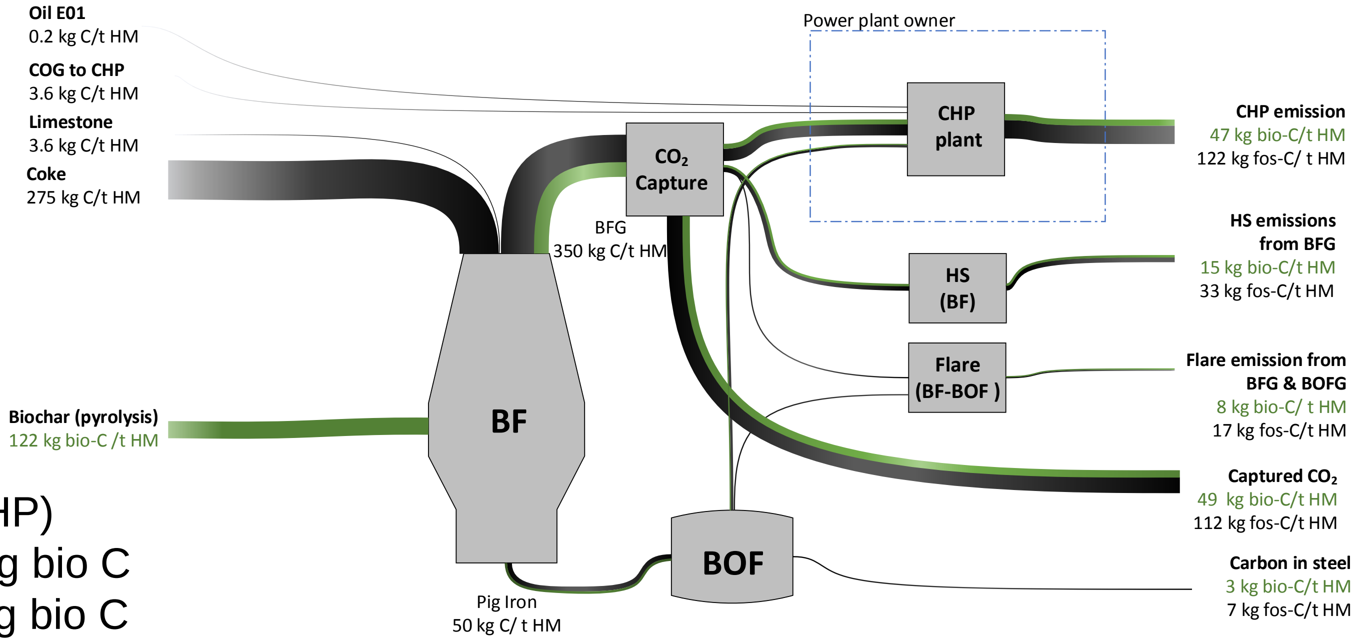
CO2stCap: preliminary result [1]

[1] GCCSI Webinar 23.11.2017; http://www.globalccsinstitute.com
[2] Kjärstad et al. — *Int. J. Greenh. Gas Control* **2016**, *54*, 168–184.
[3] Wei et al. “Utilization of biomass for blast furnace in Sweden: Report I: Biomass availability and upgrading technologies,” pp. 1–97, 2013.

Results: Carbon balance of bio-PCI + BFG capture

Valuable products:

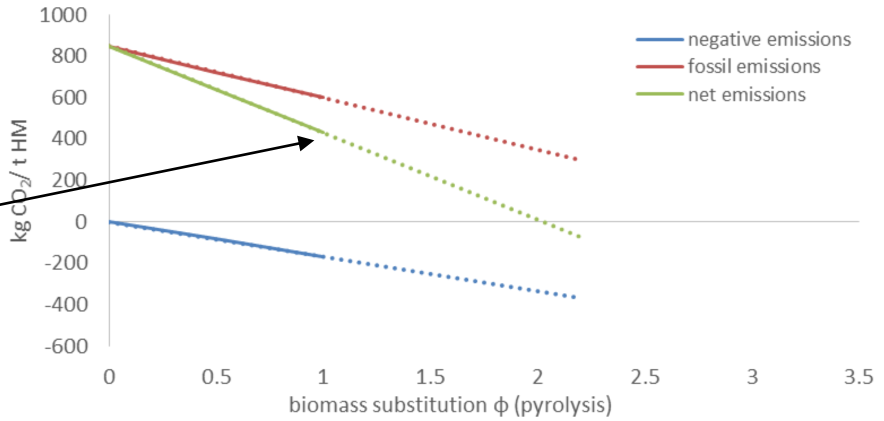
- Negative emissions
- Carbon neutral steel
  1.35 Mt/yr
- Renewable energy (CHP)
  - 0.60 kWh electricity/kg bio C
  - 0.77 kWh hot water/kg bio C



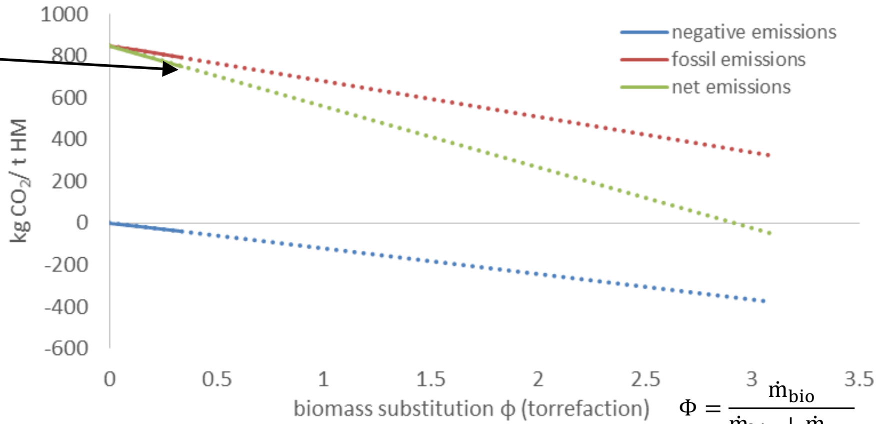
Tuyere injection 100 % biochar from pyrolysis + 84% BFG capture (excess heat)

Results: Avoided emissions

100% bio-char **(pyrolysis)** + 84% capture:
avoided site emissions ~ **61 %**



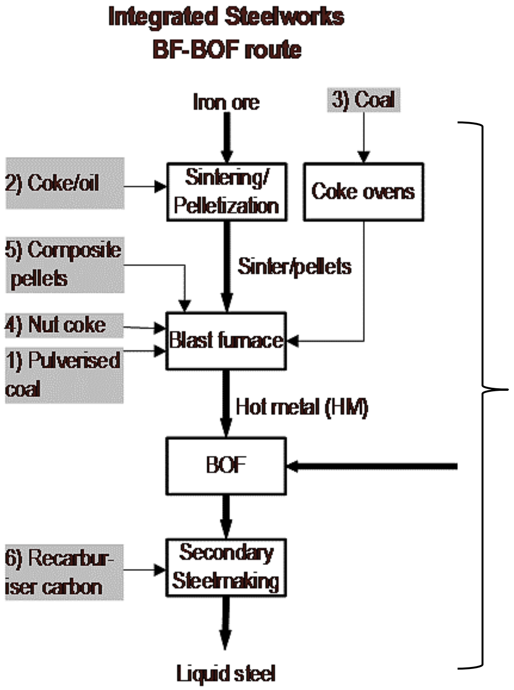
34% bio-char **(torrefaction)** + 84% capture:
avoided site emissions ~ **41 %**



$$\Phi = \frac{\dot{m}_{bio}}{\dot{m}_{bio} + \dot{m}_{PC}}$$

→ We can't reach net negative emissions with BECCS concept limited to bio-PCI (BF) + MEA capture (BFG)

Side note: How to reach net-zero after all?

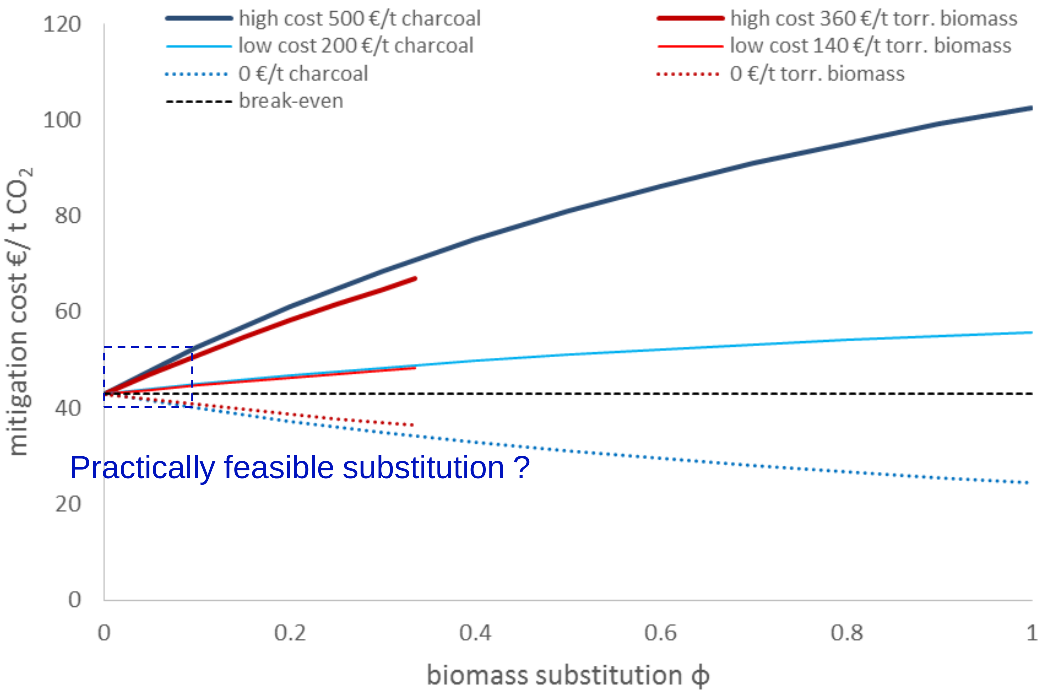


Zero-net emissions reachable, if:

- All 6 biomass technologies for BF-BOF applied
  → ca. 55 % of all fossil-C on site replaceable;
  → then 45 % C need to be captured
  → increased capture rate from BFG (99% CO_2)
  (requires additional heat supply)
- Also: shifting CO to CO_2 (less power production)

Results: Mitigation cost

- BECCS cost sensitive to price & substitution rate (24 – 103 €/t CO_2)
- Similar cost for torrefied biomass and charcoal from pyrolysis; torrefaction slightly cheaper yet less impact
- BECCS more economic than use of biomass alone (70 – 180 €/t CO_2)
- Low-cost biomass (e.g. waste wood) can reduce avoidance cost compared to CCS alone



Synergies & Challenges to consider
when combining CCS and biomass introduction

Synergies:

- green products: new markets for carbon-neutral steel? green power certificates?
  → dependent on allocation of biogenic C (negative emissions vs green power)
- Advantages in energy efficiency (off-gas re-allocation in steel mill)
- Possible heat integration: Excess heat from biomass upgrading; reboiler condensate

Challenges:

- Substitution rate of bio-PCI
- Biomass availability -100% PCI replacement requires ~ 0.45 t dry biomass/t steel
- Biomass treatment scale-up (~ 200 - 400 kt produced biochar/a)

Conclusions

- **Net-zero possible?**

  Carbon neutrality or net-negative emissions are possible, however considerable process changes required (all 6 BF-BOF technologies + high capture rates/shift)
- **what emission avoidance can be reached & at what cost?**

  100 % Bio-PCI + CCS can avoid site emissions by 61 % @ ~100 €/t CO_2

  compared to 35 % with CCS only @ 43 €/t CO_2 ;
- **Benefits besides emission reduction for steel industry?**

  Biogenic carbon introduced into a blast furnace can be used multi-fold and generates green products in a steel mill: carbon-neutral steel and renewable electricity & heat

→ Bio-PCI + CCS is a promising near-term and cost-effective option for CO_2 mitigation

Thank you for your attention!

Evaluation of Steel Mills as Carbon Sinks

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Reductant type/feedstock		**coke** metallurgic coking coal	**PCI-coal** Non-coking coal	**charcoal** pyrolysed softwood	**torrefied biomass** forest residue
C	wt.%$_{db}$	88.3	85.0	84.7	58.0
H	wt.%$_{db}$	n.a.	03.9	3.35	5.3
N	wt.%$_{db}$	n.a.	2.1	0.13	0.48
O	wt.%$_{db}$	n.a.	2.1	10.6	34.0
S	wt.%$_{db}$	0.58	0.4	0.02	0.03
Ash	wt.%$_{db}$	10.9	7.8	1.9	3.2
moisture	wt.%	3.5	1.0	4.5	7.7
LHV	MJ/kg	n.a.	33.5	31.6	21.6