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.
**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 CO₂ 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

Background: Use of fossil carbon

Scope:
Bio-PCI + CO₂ 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 CO₂/ t HM
  • The top gas composition does not change with biomass injection
  • No re-allocation of steel mill gases with CO₂ capture/biomass injection
  • Biogenic carbon from BF allocated to all downstream units in equal share
• Capture: 30 wt.% MEA absorption cycle – result from CO₂stCap 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;  
Method: negative emissions

Avoided CO\(_2\) emissions – contribution of negative emissions:

\[
\text{CO}_2 \text{ avoided} = \text{Emissions}_{\text{Ref. PCI}} - \text{Emissions}_{\text{BioPCI+CCS}}
\]

\[
= \text{Emissions}_{\text{Ref. PCI}} - (\text{Fossil emissions} - \text{Captured biogenic CO}_2)_{\text{BioPCI+CCS}}
\]

adapted from [1]

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 CO₂ captured [1]
- Transport & storage included @ 16 €/t CO₂ [2]
- Biomass enters system already upgraded: assumed 0 - 500 €/t [3]

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%

→ 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% CO₂)
    (requires additional heat supply)
- Also: shifting CO to CO₂ (less power production)
Results: Mitigation cost

- BECCS cost sensitive to price & substitution rate (24 – 103 €/t CO₂)

- 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 CO₂)

- Low-cost biomass (e.g. waste wood) can reduce avoidance cost compared to CCS alone

Practically feasible substitution?
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 CO₂ compared to 35 % with CCS only @ 43 €/t CO₂;*

• **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 CO₂ mitigation**
Thank you for your attention!

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<th>Reductant type/feedstock</th>
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<th>charcoal</th>
<th>torrefied biomass</th>
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<td>pyrolysed softwood</td>
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