BECCS potential in the pulp and paper industry: Technical and practical considerations for oxyfuel firing in Kraft recovery boilers

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Introduction

- Pulp and paper industries (PPI) represent a source of biogenic CO_2 emissions
  - Ca. 92 Mt-CO_2/y in Europe [1], 101 Mt-CO_2/y in USA [2]
- Sequestering biogenic CO_2 from PPI can provide net-negative emissions as a BECCS system.
  - ~150-1200 Gt-CO_2 forecast for BECCS removal by 2100 [3]
  - ~2.5-20 Gt/y over 2040-2100

[1] Lipiäinen et al. (2023)
[2] US EPA (2022)
[3] IPCC (2018)

Oxy-fired black liquor recovery boiler

Introduction

- Pulp mill point source emissions:
  - ~15% from Multifuel boiler: combustion of bark, wood wastes, WWT sludge, etc. for energy/steam
  - ~75% from Recovery boiler: combustion of black liquor (biomass waste) for process steam, power, and recovery of pulping chemicals
  - ~10% Lime kiln: Burn fossil or biogenic fuels for regeneration of pulping chemicals.
  - Recovery boiler is largest source of CO_2 emissions
- Examine CCS applications for a Recovery Boiler, focusing on aspects of oxyfuel combustion

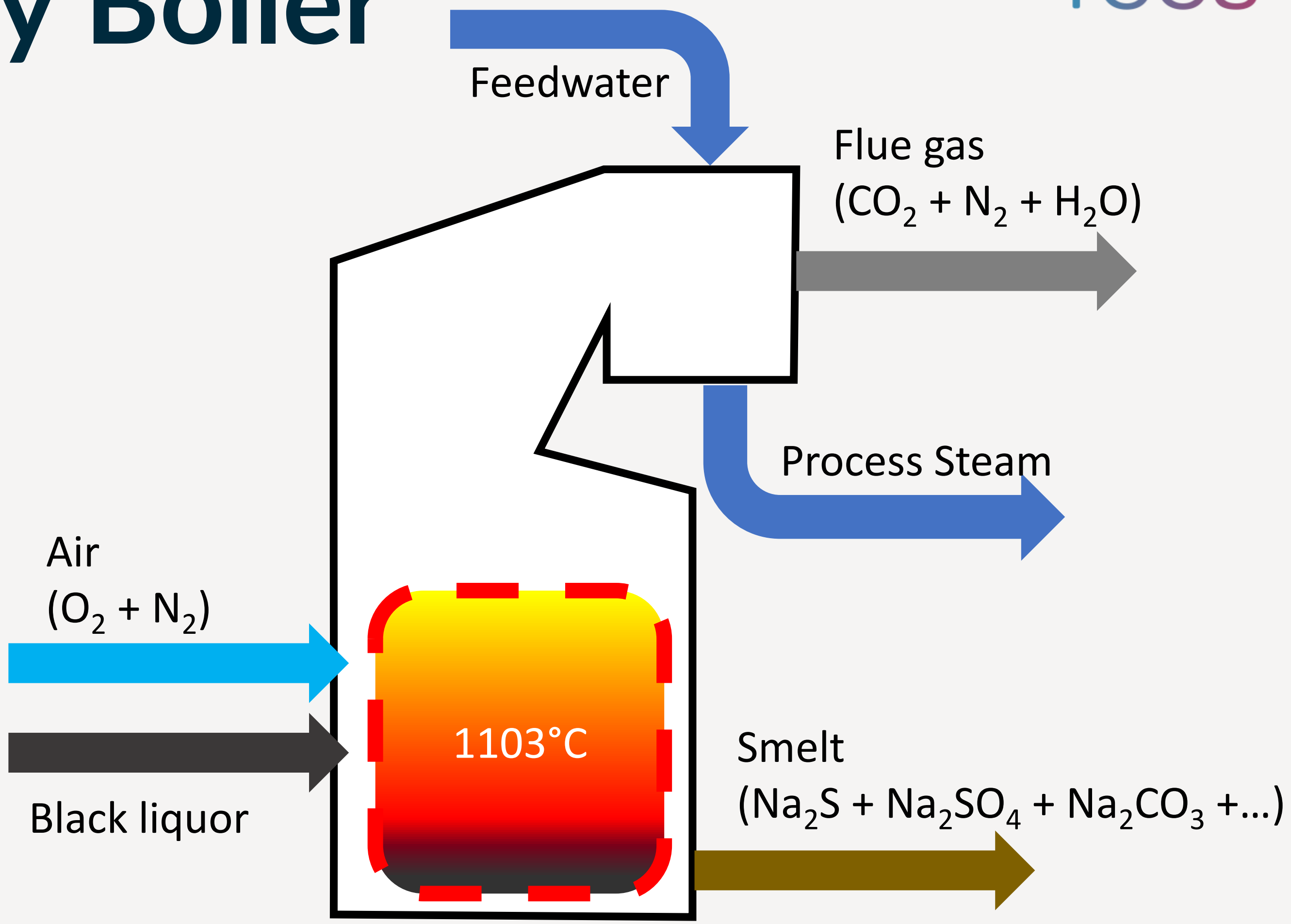
Methodology

- System boundary includes only recovery boiler, CCS process, and steam turbine
- Reference recovery boiler based on 2000 adt/d market pulp mill emitting 1.5 Mt-CO_2/y [4]
  - Includes specification of black liquor composition and flow rate
- Recovery boiler performance calculated by established TAPPI industry standards [5]
- Process simulation conducted in AspenPlus

[4] Onarheim et al. (2016)
[5] TAPPI (2007)

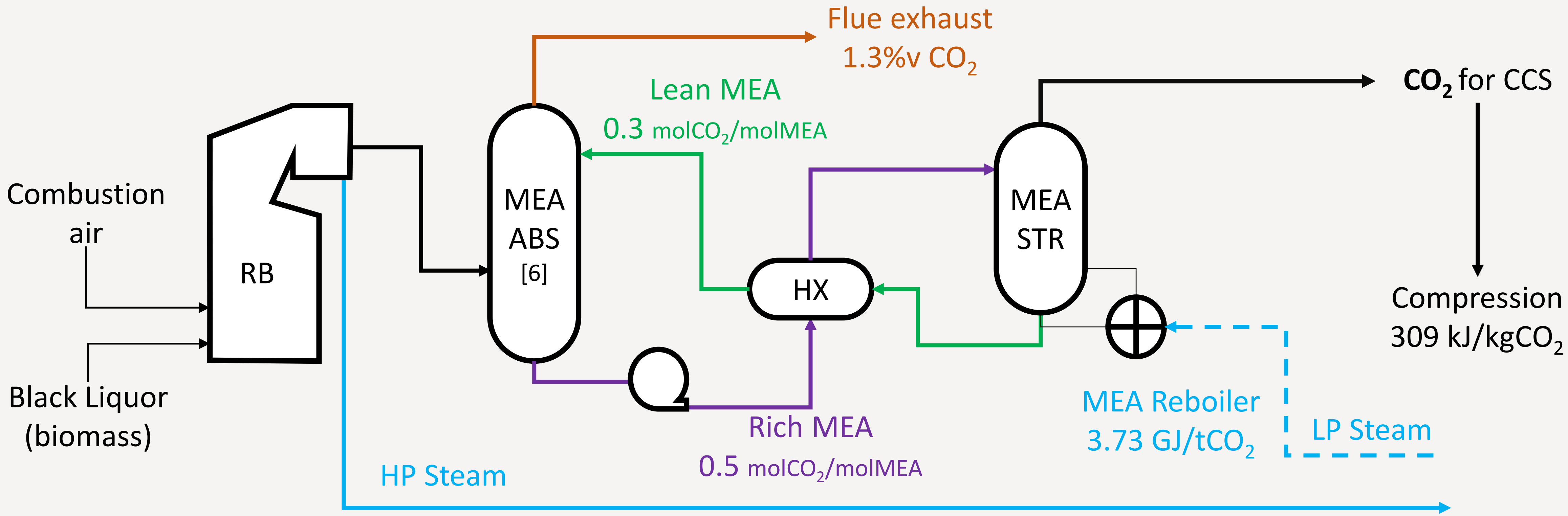
Reference Recovery Boiler (RefRB)

- Black liquor input:
  - 4473 tDS/d
  - 82%m DS
  - 14.4 MJ/kgDS HHV
- Flue gas generated:
  - 4.94 kg/kgDS
  - 11.5%v CO_2
  - 3.0%v O_2
- HP steam:
  - **2.784** kg/kgDS
  - **766.8** kWh_e/tDS in a turbine



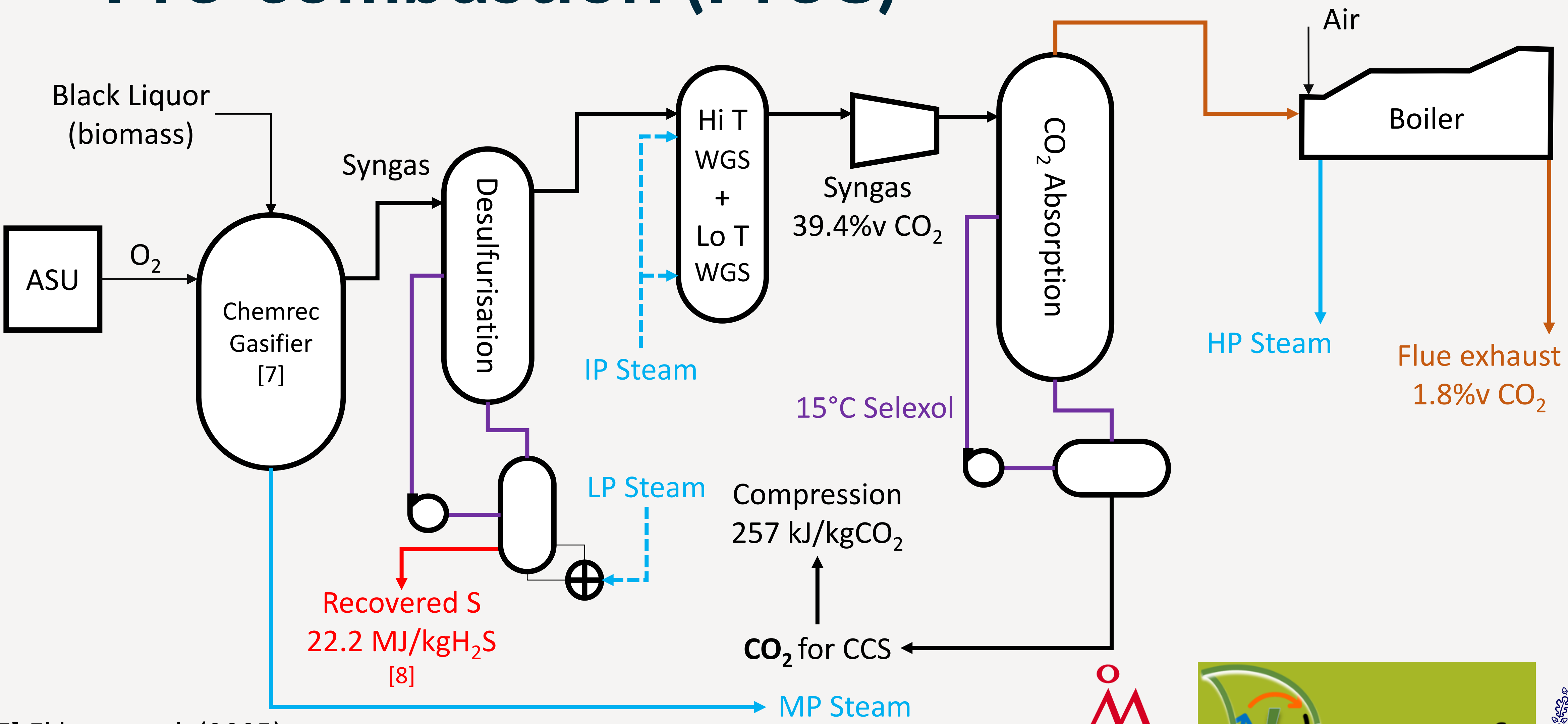
Steam Properties	Temperature	Pressure
High pressure	505 °C	103 bar
Intermediate pressure	352 °C	30 bar
Medium pressure	200 °C	13 bar
Low pressure	154 °C	4.2 bar

Post-combustion (PostC)



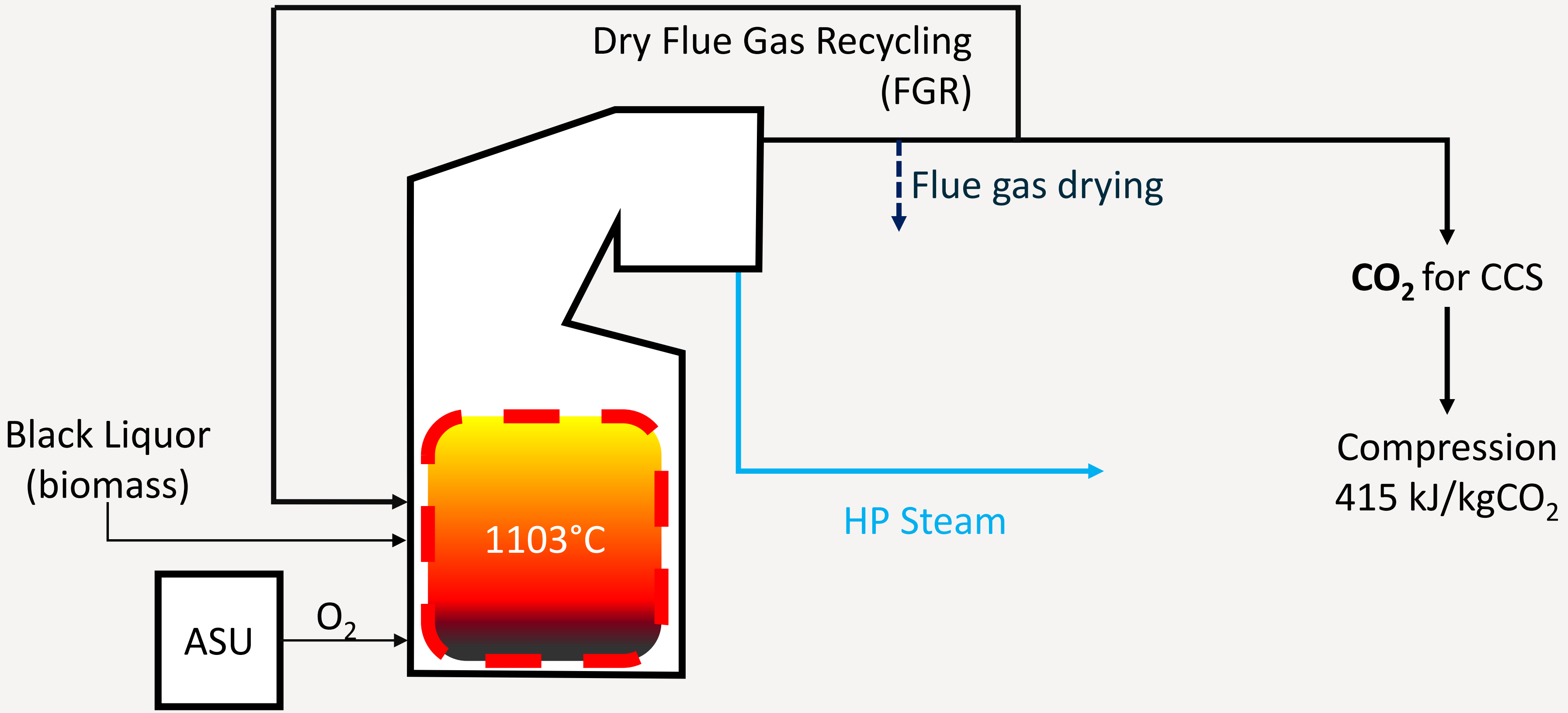
[6] Madeddu et al. (2019)

Pre-combustion (PreC)



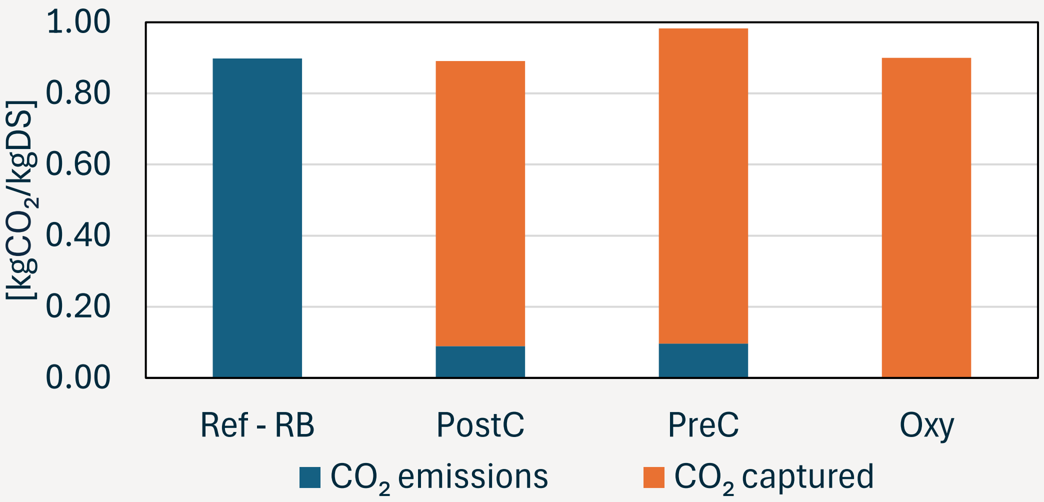
[7] Ekbom et al. (2005)
[8] Kapetaki et al. (2015)

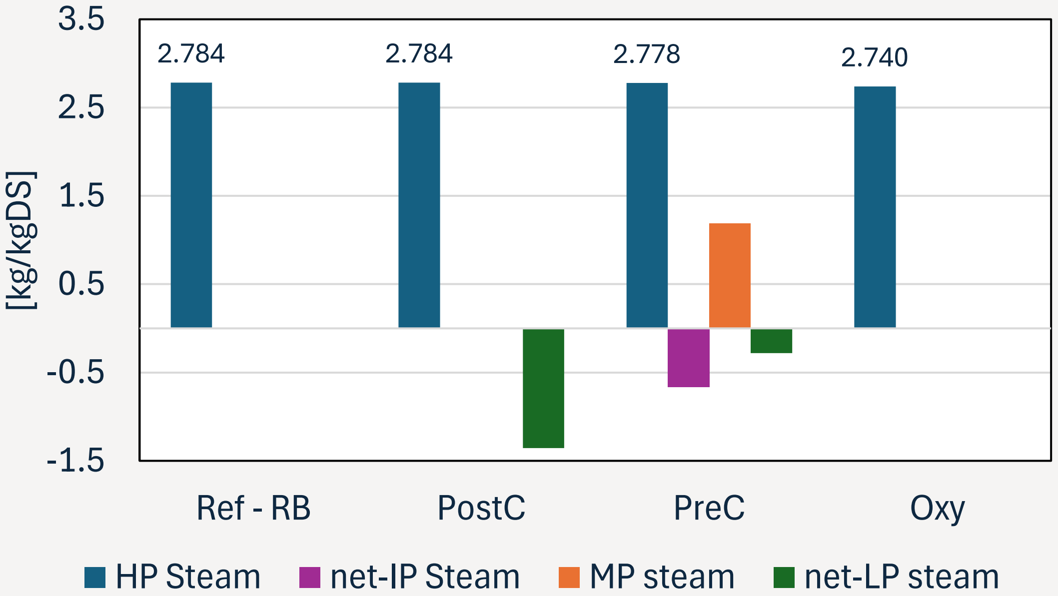
Oxyfuel combustion (Oxy)

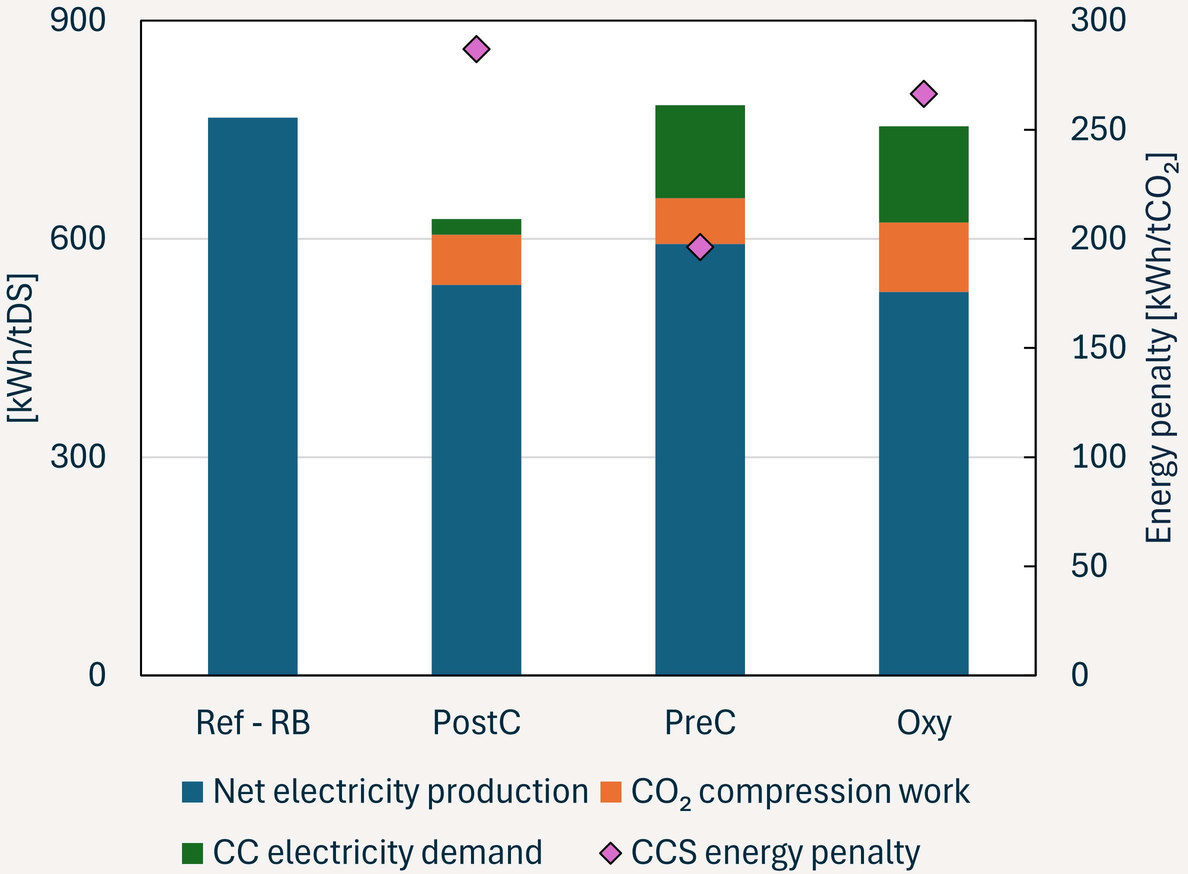


- Oxyfuel mixture 25%v O_2:75%v CO_2
  - FGR ratio: 0.813

Recovery Boiler CCS







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Oxy-fired black liquor recovery boiler

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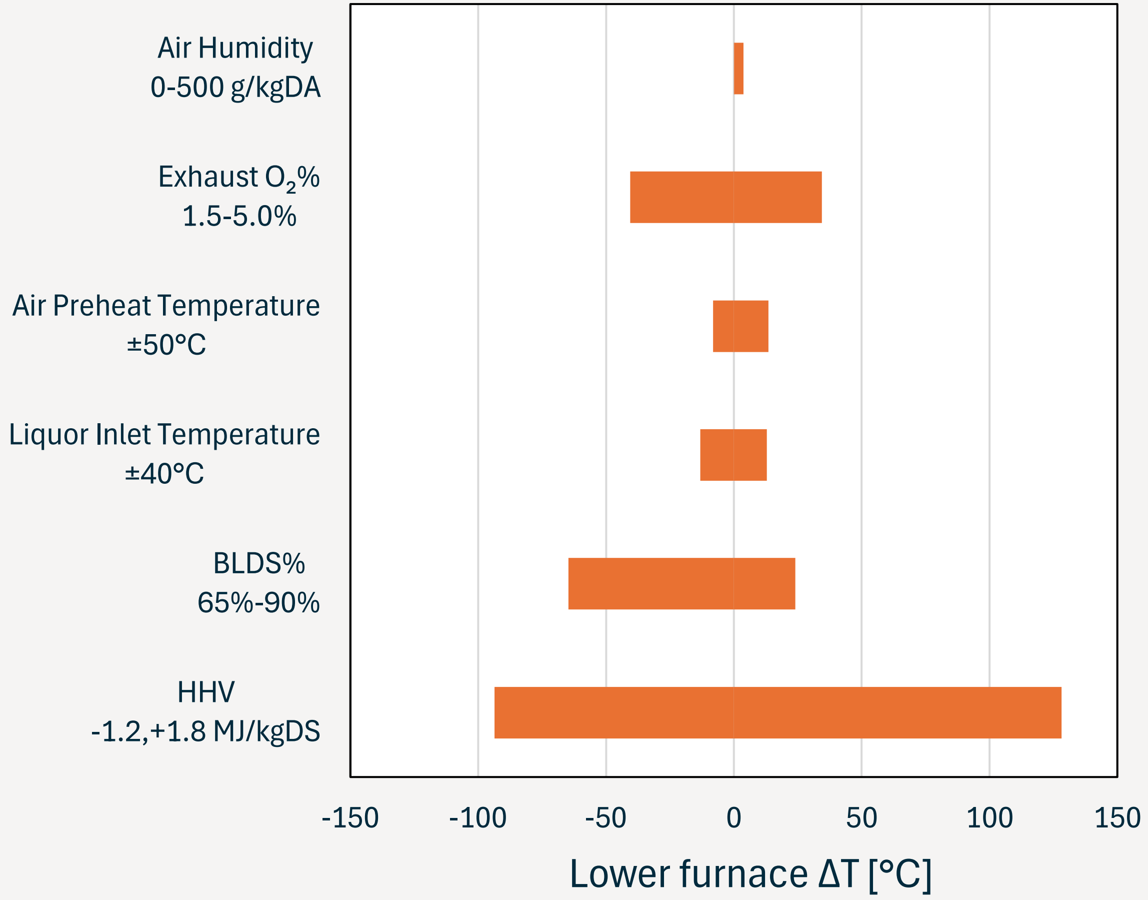
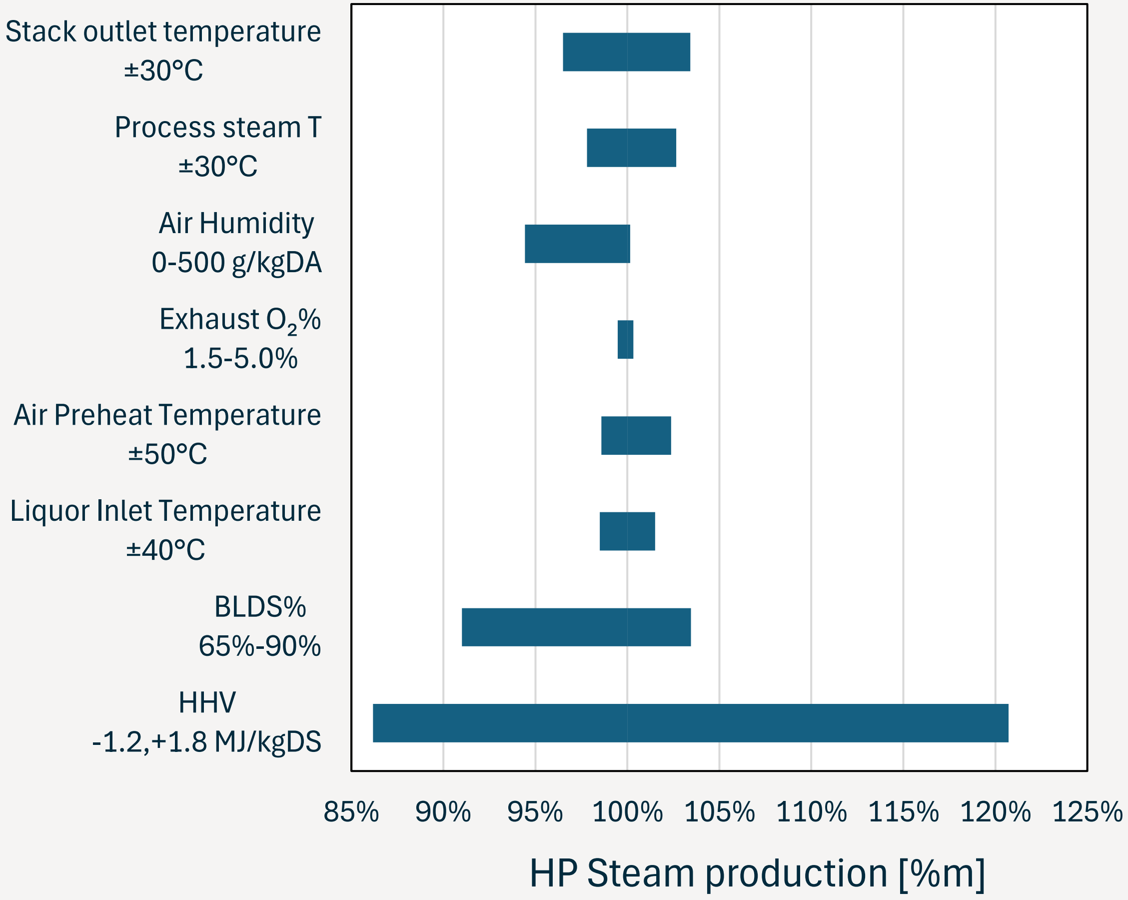
Recovery Boiler CCS Summary

Post-Combustion	Pre-Combustion	Oxyfuel
Highest CCS energy penalty	Lowest CCS energy penalty	Energy penalty highly dependant on ASU efficiency
Significant loss of LP steam • Could impact mill	Process heat integration/recovery generates additional MP steam	Negligible reduction in HP steam production
Additional capture system equipment; no modification of RB	Highly complex, complete replacement of RB	Integration of ASU and FGR requires boiler redesign
Minimal impact on smelt recovery expected	Entirely different smelt recovery process required	**Unknown impact on smelt recovery processes**
Sequestered gas >96% CO_2	Sequestered gas >96% CO_2	Sequestered gas quality may be problem for transport/storage

Oxyfuel Sensitivity - Boiler





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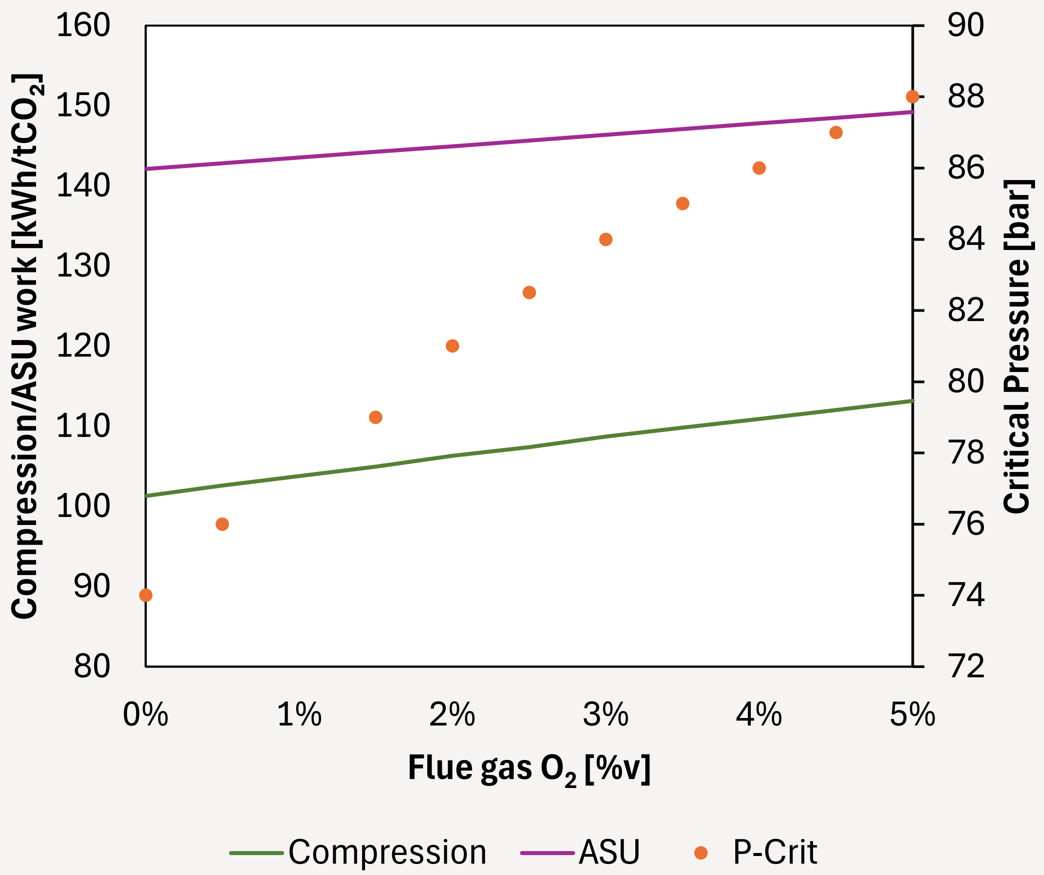
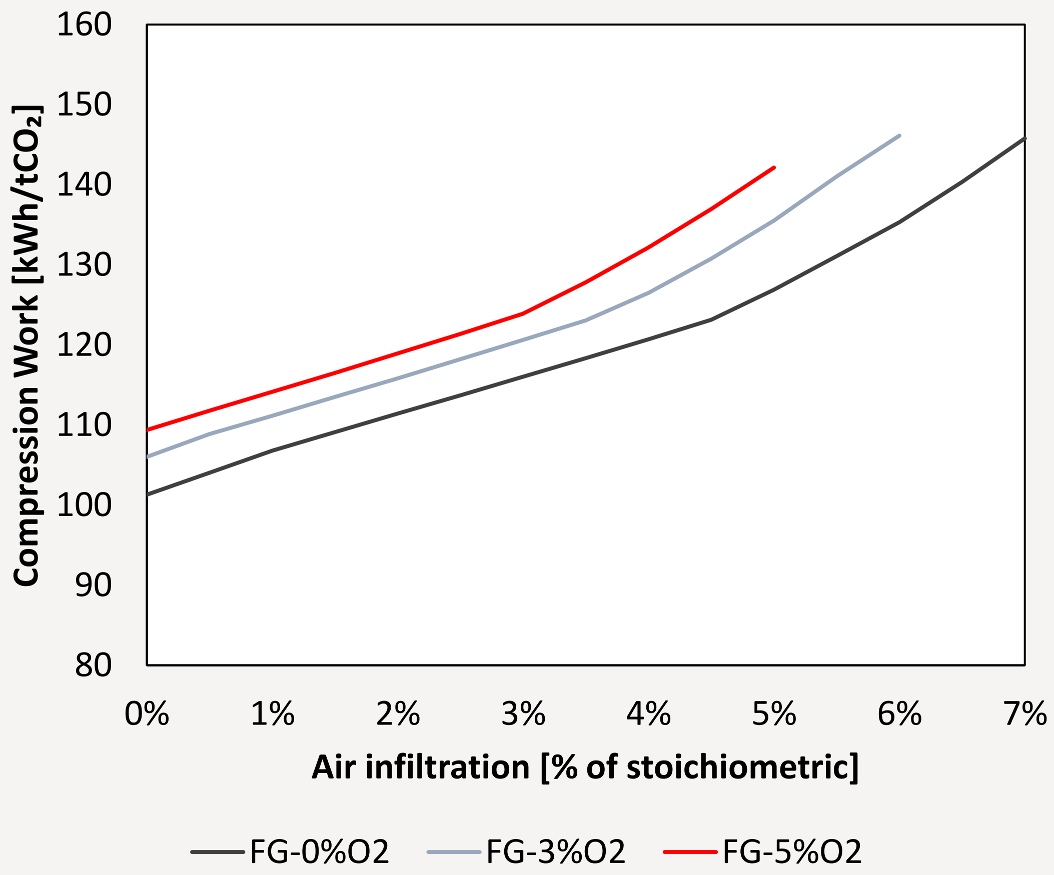
Oxyfuel Sensitivity – CCS





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Conclusions

- Oxyfuel combustion has specific CCS energy penalties comparable to post-combustion
  - 7% or 20kWh/tCO_2 < MEA
  - Less impact on LP process steam consumption, requires modification/redesign of boiler
- Oxyfuel combustion process preserves RB smelt recovery function
  - Ongoing research to determine effects of CO_2, O_2, and H_2O concentration on boiler chemical recovery reactions
- Boiler oxyfuel conditions are influenced by FGR, fuel HHV, and BLDS%
  - Other parameters have smaller effect
- O_2 and N_2 content in gas for sequestration have negative impact on compression for pipelining
  - 5% flue O_2 increases $\dot{W}_{comp}$ by 13%
  - 7% air infiltration increases $\dot{W}_{comp}$ by 45%
  - A compression and purification unit (CPU) may be required

Acknowledgements

- Research supported by the Clean Energy Transition Partnership (CETP) Oxy-Kraft RB project (Cetp-2022-00110) co-funded by the European Union.
- The Swedish partners are funded by the Swedish Energy Agency via project number P2023-00972.
- The Finnish partners are funded via Business Finland via project number 2625/31/2023.
- Follow project updates at: https://blogs2.abo.fi/oxykraft/

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