# Costs of Chemical-Looping Combustion for solid fuels

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### *Chemical-Looping Combustion (CLC) - Introduction*

Chemical-Looping Combustion is a novel combustion technology with inherent $CO_2$ separation, which uses a circulating oxygen-carrier to transfer oxygen from air to fuel. Other capture technologies are burdened with significant *costs and efficiency losses related to gas separation, which can be uniquely avoided in CLC*. The reactor system used involves two interconnected fluidised beds, a fuel reactor where the fuel reacts with the oxygen-carrier to form $CO_2$ and steam, and an air reactor where the oxygen carrier is regenerated, Figure 1. The metal oxide oxygen-carrier is denoted $MeO_x/MeO_{x-1}$ After condensation of the steam a flow of essentially pure $CO_2$ is obtained – without any active gas separation.

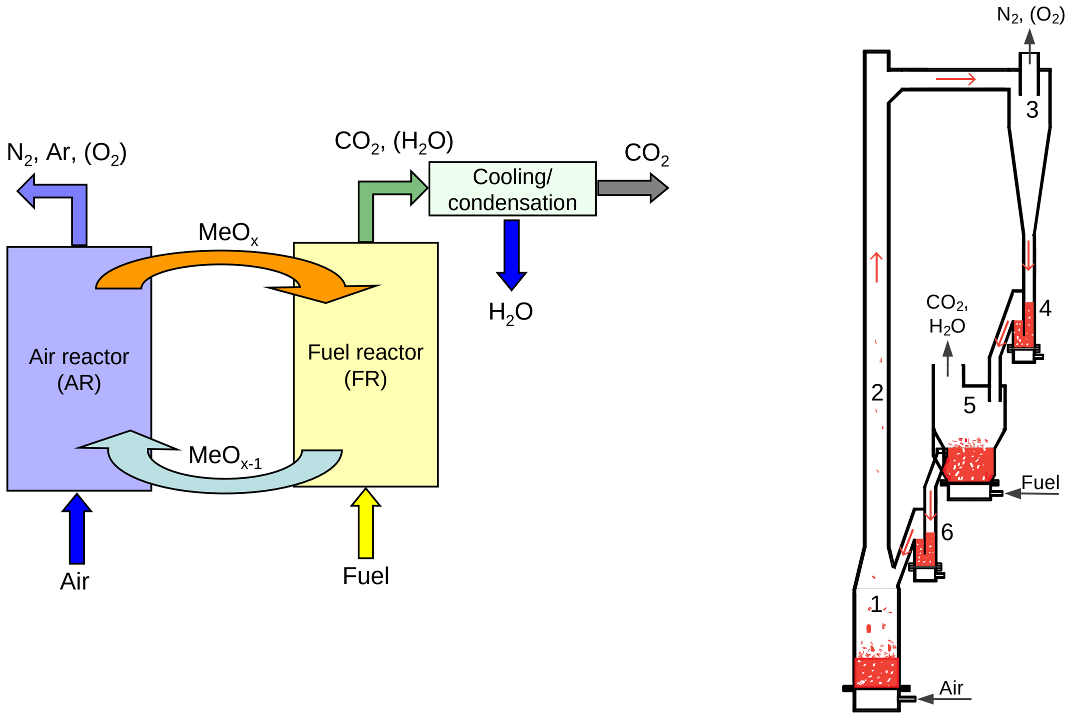


*Figure 1. Left: Chemical-looping Combustion principle;*
*Right: Example of Chemical-Looping combustor, i.e. a 10 kW gas-fired at Chalmers.*
*1+2) Air reactor and riser, 3) cyclone separator, 5) fuel reactor*
*4 + 6) Loop-seals preventing gas mixing between air and fuel reactor.*
*Red indicates oxygen-carrier particles and red arrows indicates oxygen carrier circulation.*

Chemical-looping combustion has been shown to work well in 34 pilots of sizes 0.3 kW to 3 $MW_{th}$ as shown in 150 scientific publications, [1]. Totally, operation in these units involves >9000 h with fuel, of which >3000 h with solid fuels.

The reactor system for CLC has large similarities with conventional circulating fluidised-bed (CFB) boilers, Figure 2. The important difference is the addition of a fuel reactor through which the bed material, i.e. the oxygen carrier, passes before returning to the air reactor.

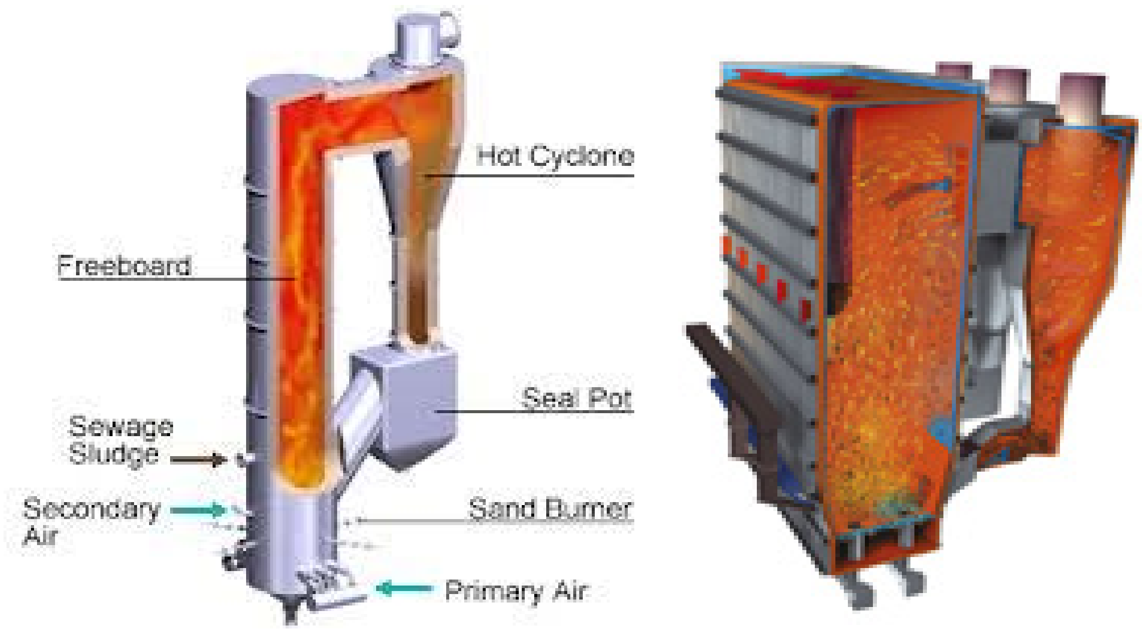


*Figure 2. Examples of circulating fluidized bed boilers.*
*Left: CFB with one cyclone; Right: larger CFB with three cyclones.*

## ***Costs of Chemical-Looping Combustion***

A comprehensive comparison of CFB and CLC technology shows that the main difference is that a part of the combustion chamber of a CFB, around 27% of the cross-section, will be a “fuel reactor”, whereas the remaining area will be the “air reactor” where the heat is generated. The fuel reactor is adiabatic, i.e. it will have no cooling, because the reactions in the fuel reactor are slightly endothermic. This means that the insulated walls of the fuel reactor will constitute an additional cost, as these will not be used for the heat transfer as normal walls of a combustion chamber.

Figure 3 shows a comparison of a CFB boiler of 1000 $MW_{th}$[1] with a CLC boiler of similar thermal power. The comparison highlights the main difference i.e. the inclusion of an insulated fuel reactor, and the paths to transfer the bed material between the reactors.

The important added cost is the insulated walls of the fuel reactor, around 1800 $m^2$, as well as walls of the fuel reactor cyclones and channels for solids transfer. For the 1000 $MW_{th}$ CLC boiler this could amount to up to 2500 $m^2$ of insulated wall at a cost of 1500 €/$m^2$, i.e. a total additional investment cost of 4 M€. With a yearly depreciation of 10%, the yearly added cost would be 0.4 M€. A plant of this size will capture 2 Mtonnes of $CO_2$/year. ***Consequently the added cost of a CLC boiler would be 0.2 €/tonne of $CO_2$ captured.*** A detailed technology and cost comparison is made in [2][2]

[1] Similar in size and thermal power to the 460 $MW_e$ CFB plant in Łagisza, Poland.
[2] This publication can be downloaded (Open Access) from:
http://www.sciencedirect.com/science/article/pii/S030626191500519X

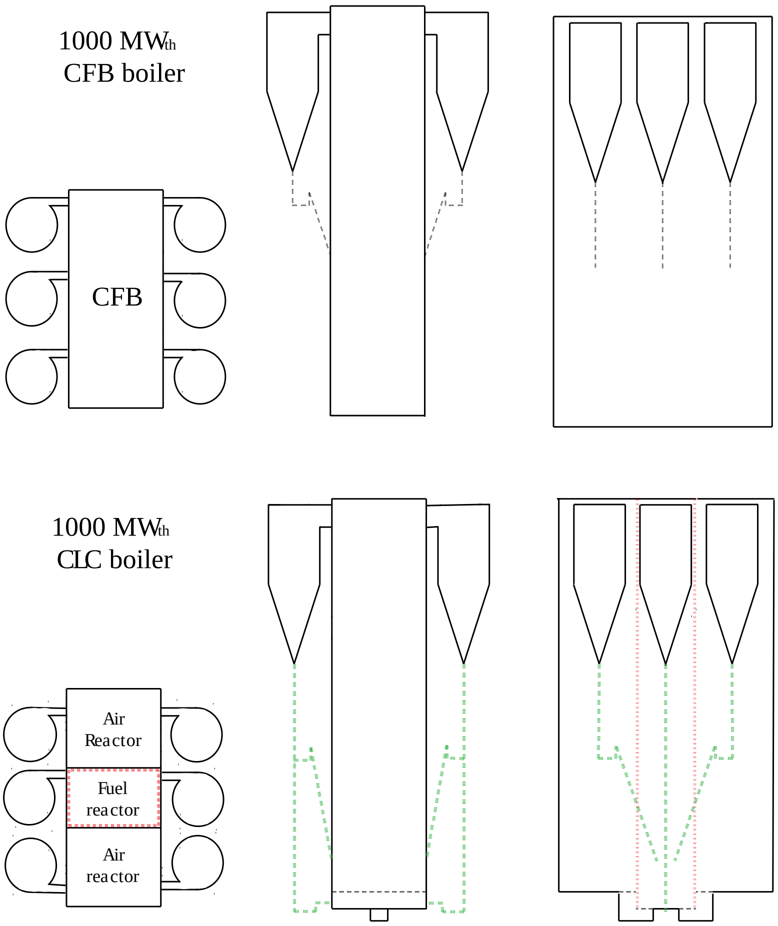


*Figure 3. A comparison between a 1000 $MW_{th}$ CFB and a 1000 $MW_{th}$ CLC.*

In addition to the cost difference between a CLC boiler and a conventional boiler the extra costs of CLC are:

- $CO_2$ compression
  - Similar to other capture technologies, assumed to be 10 €/t$CO_2$.
- Oxygen production
  - Oxygen is needed for "oxypolishing" of gas from fuel reactor because of incomplete conversion. Gas conversion is estimated to 80-90%. Thus 5-10 times less oxygen is needed as compared to oxyfuel technology.
- $CO_2$ purification
  - Cost should be similar as in oxyfuel. There is an option for cost-efficient $SO_2/NO_x$ capture because the gases have much higher concentration and the total flow is much smaller as compared to normal flue gas cleaning.
- Oxygen carrier
  - With low cost ores, estimated to 1-4 €/tonne $CO_2$
- Minor costs, >1 €/tonne
  - Fuel grinding and steam for fluidization

In total the additional costs when compared to CFB combustion are estimated to around 20±5 €/tonne $CO_2$, with the major costs being compression and oxygen production. For details in the cost estimations see [2][2]. It should be said that CFB is a very widely used technology for burning various solid fuels, including coal and biomass.

***Summary***

As shown by the example the added cost for a CLC boiler as compared to a CFB boiler should be very small, <1 €/tonne $CO_2$. Instead the major costs are associated with $CO_2$ compression, needed for all $CO_2$ capture technologies, and oxygen production, similar to oxyfuel but 5-10 times less oxygen needed. The total cost is estimated to 20 €/t$CO_2$.

## REFERENSER

[1] Lyngfelt A and Linderholm C. Chemical-Looping Combustion of Solid Fuels – status and recent progress. In: *13th International Conference on Greenhouse Gas Control Technologies, GHGT-13*. Lausanne, Switzerland; 2016

[2] Lyngfelt A and Leckner B. *A 1000 $MW_{th}$ Boiler for Chemical-Looping Combustion of Solid Fuels – Discussion of Design and Costs*. Applied Energy 157 (2015) p. 475-487.