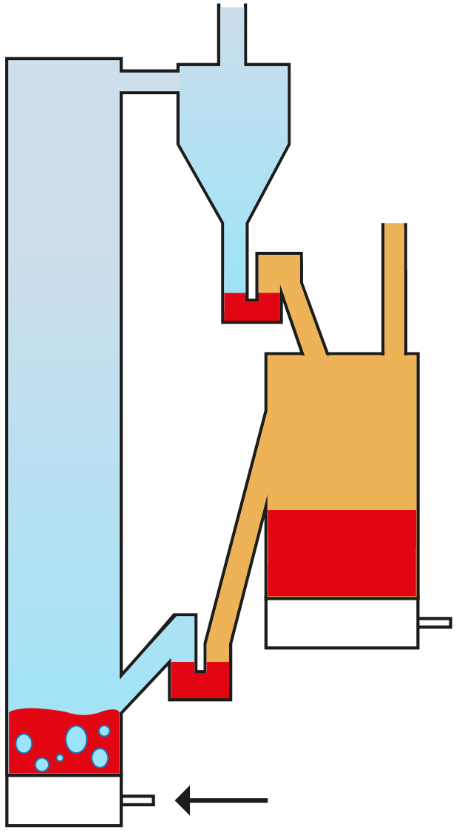
Chemical-Looping Combustion
–
Avoiding the Large Energy and Cost Penalty of BECCS



Anders Lyngfelt

2nd International Conference on Negative CO_2 Emissions
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Göteborg, Sweden

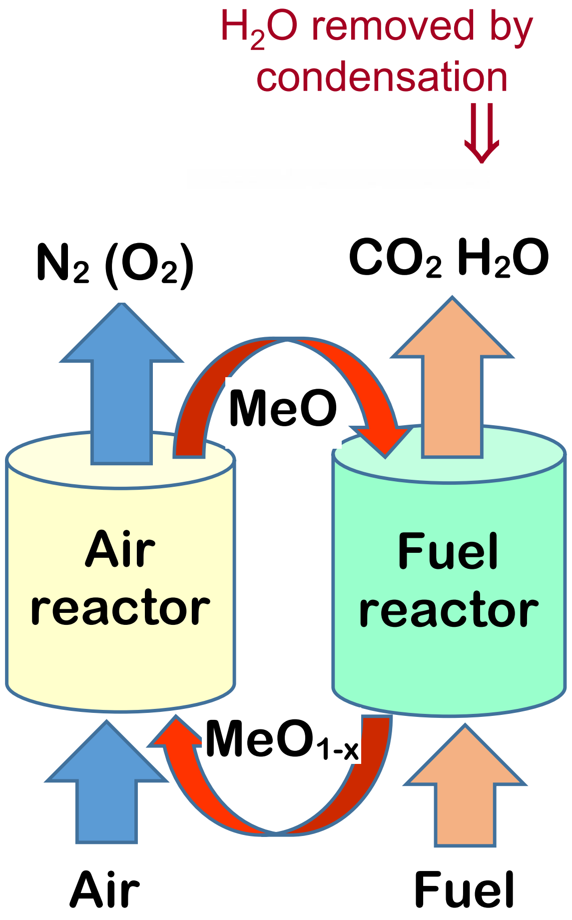
CHALMERS

Existing CO_2 capture technologies have
large costs/energy penalties of **<u>gas separation</u>**

But this can be avoided with
Chemical-Looping Combustion (CLC) !

- Oxygen is transferred from air to fuel by metal oxide particles
- Inherent CO_2 capture:
  - fuel and combustion air *never mixed*
  - *no active gas separation needed*

But does it work in practice ??



Yes, it works!!

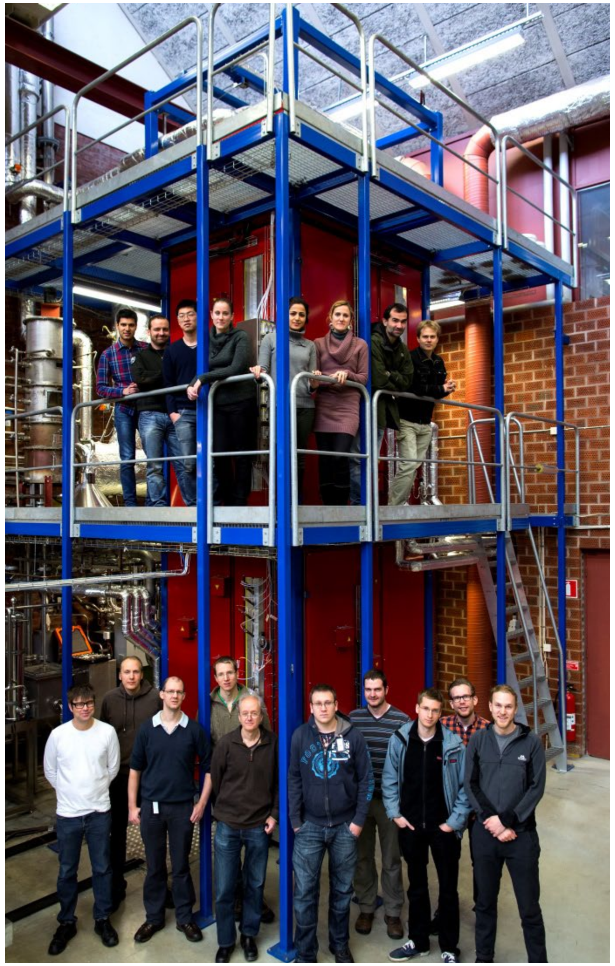
Total chemical-looping operation at Chalmers: 4 200 h in four pilots

Worldwide: 12 000 h in 50 pilots

10 kW gas, 2003

300 W gas, 2004

10 kW solid fuel, 2006



100 kW solid fuel, 2011

What is a fluidized bed?

In small biomass boilers grate firing is used.

For larger boilers fluidized bed is common

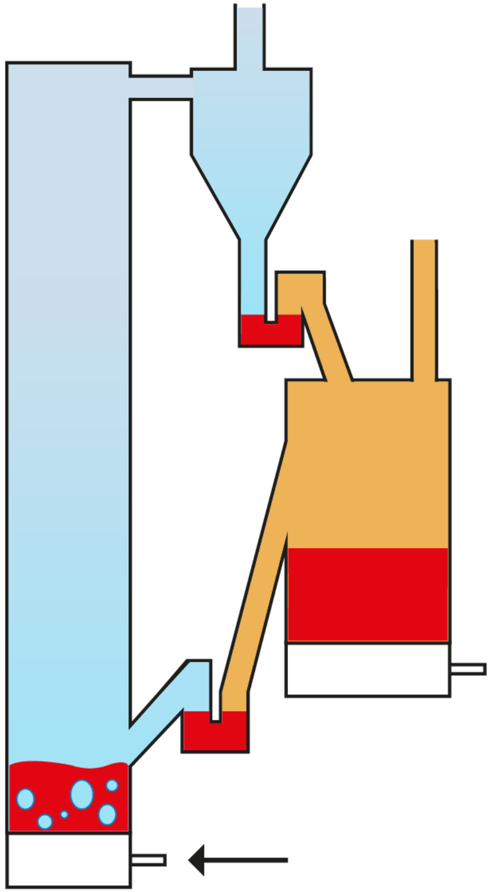
If gas (air) is blown through a bed av particles (e.g. sand) you get a fluidized bed.

↑

Behaves like a liquid

Circulating fluidized-bed boiler for burning biomass

Chemical Looping Combustion



Conventional biomass combustion is similar to Chemical-looping Combustion:
>>>Low added cost for CLC

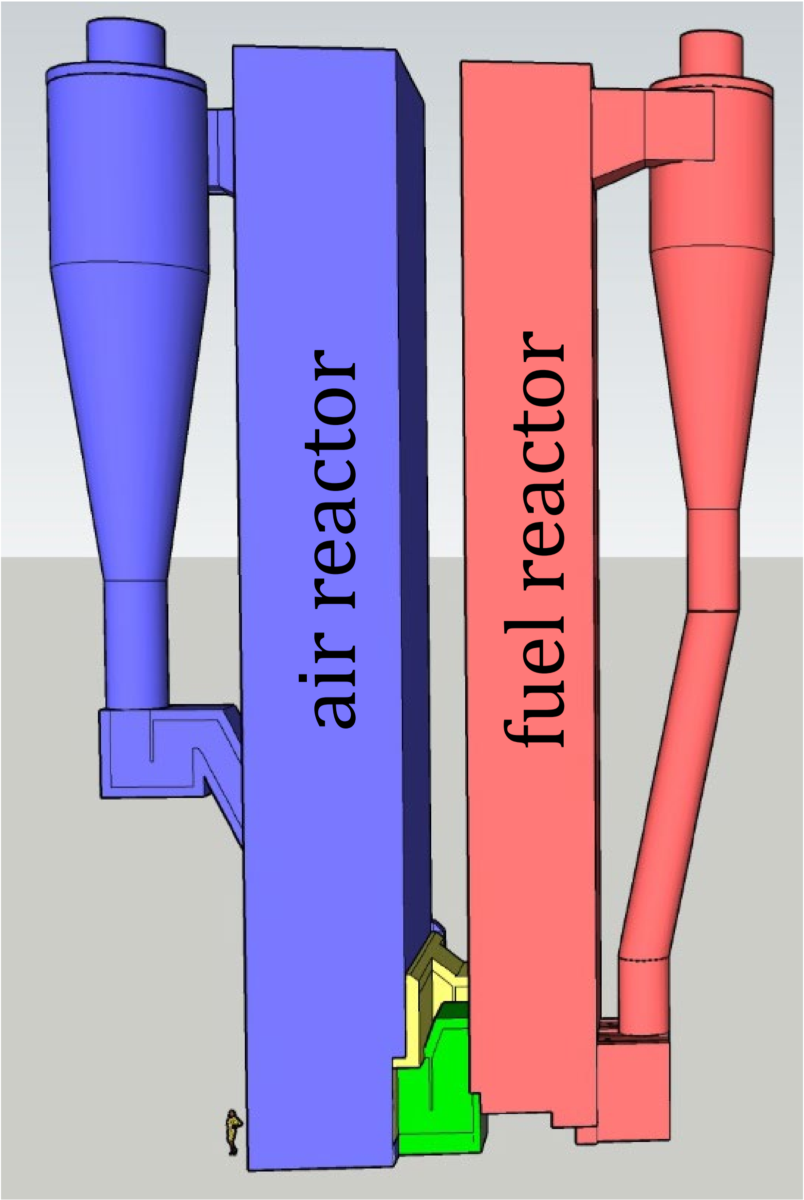
Actual circulation in CFB boilers is 5-50% of what is needed for CLC

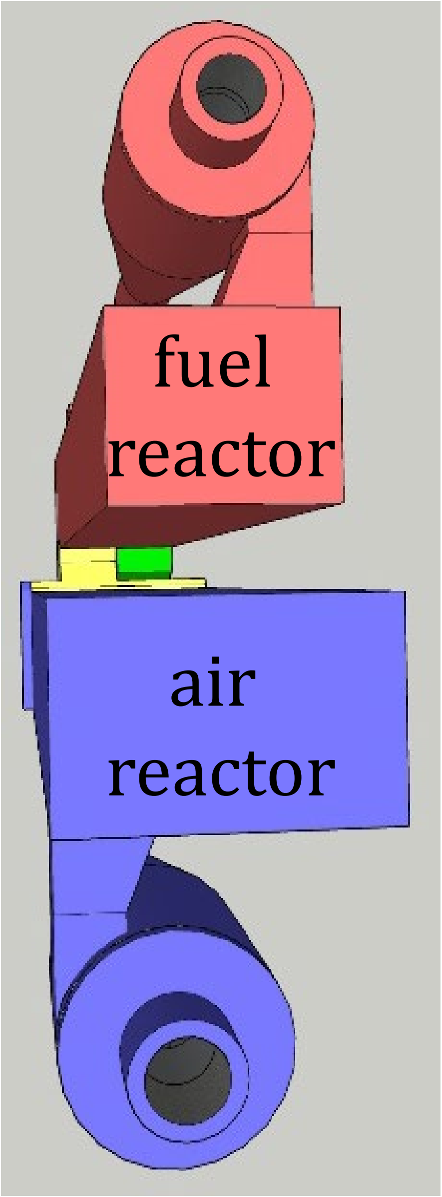
But the upwards flow decreases exponentially, and there is a corresponding downflow along the walls.

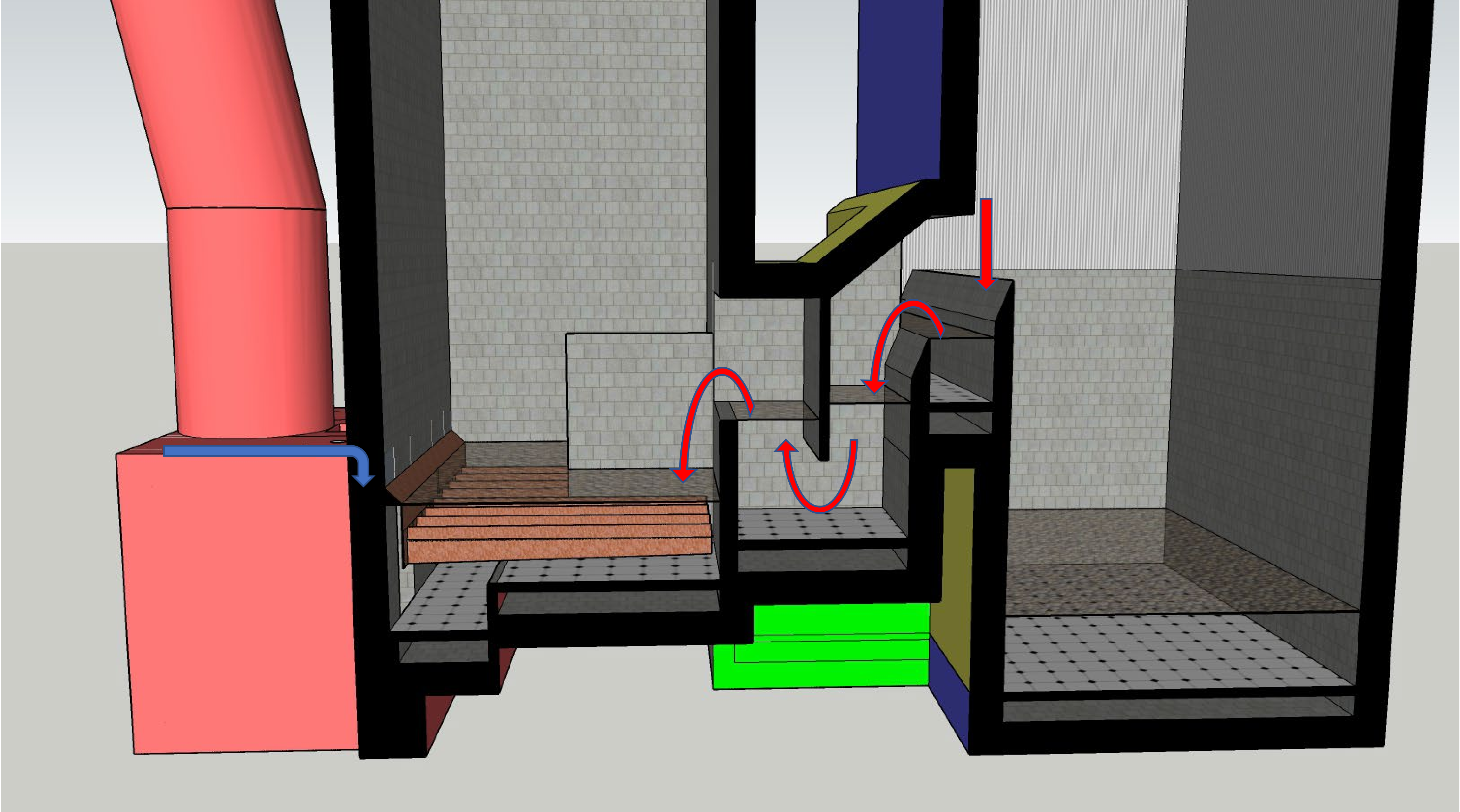
Thus, collection of down-flow along the walls, would be sufficient.

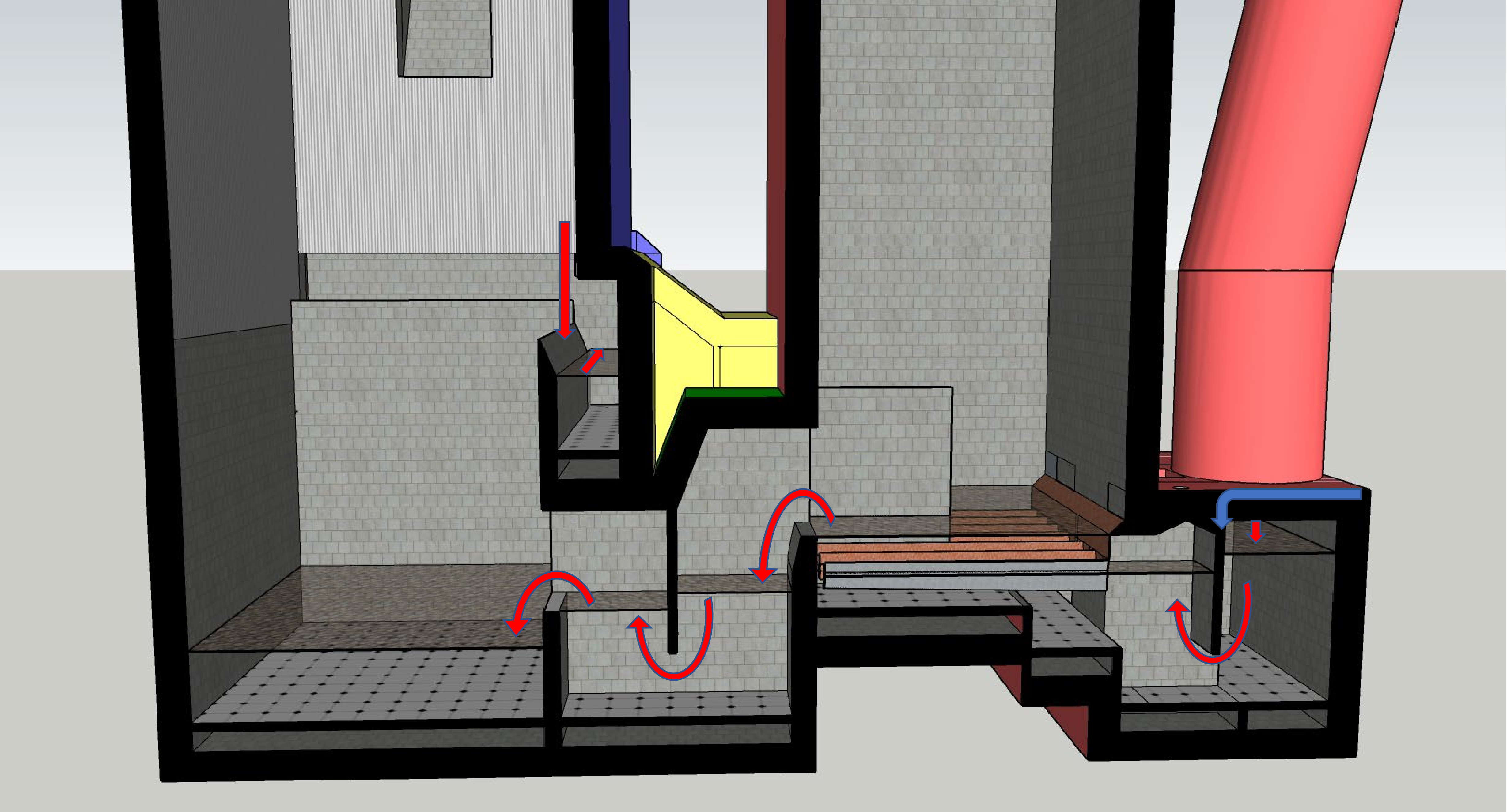
Lyngfelt, A., Pallarés, D., Linderholm, C., Lind, F., Thunman, H., and Leckner, B., Achieving Adequate Circulation in Chemical-Looping Combustion – Design Proposal for a 200 MW_{th} CLC Boiler, *Energy & Fuels (in press) 2022*

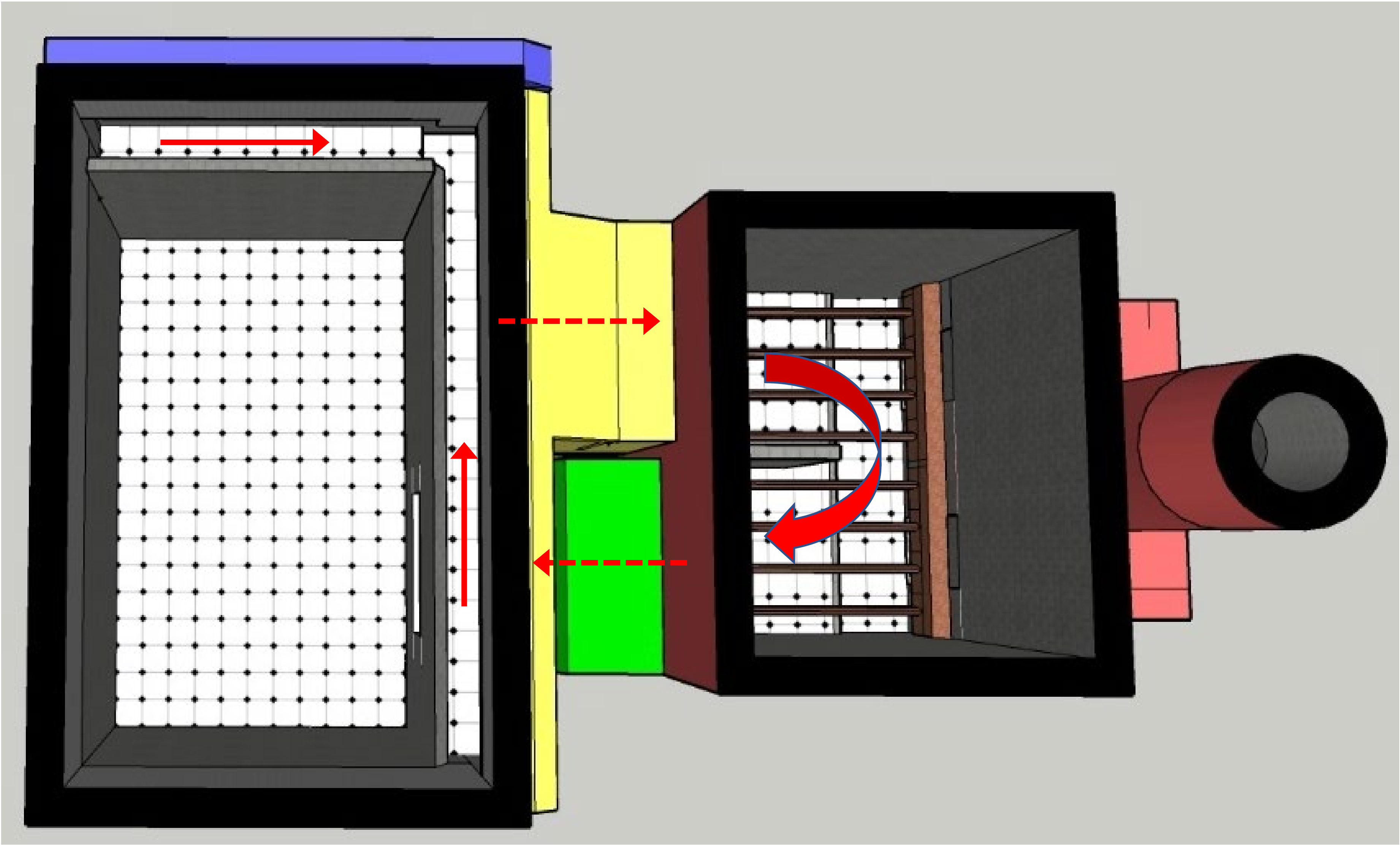
200 MW CLC-CFB boiler, 40 m high



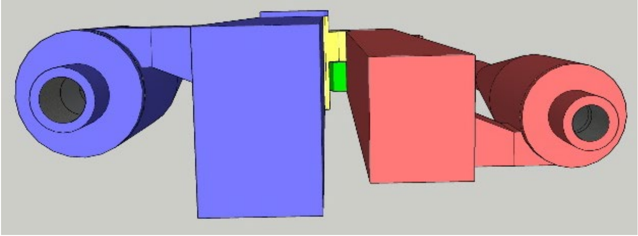



fuel reactor
air reactor

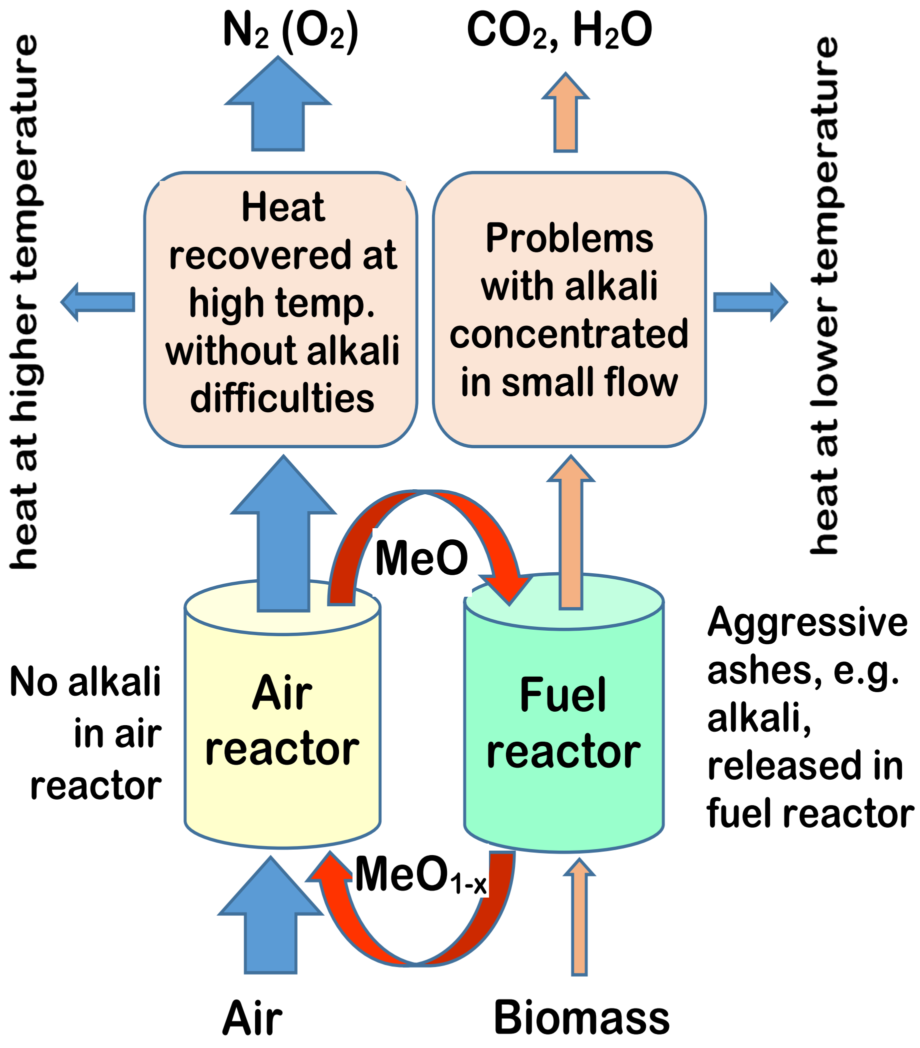

air reactor
fuel reactor



air reactor



fuel reactor



Alkali in biomass gives low ash-melting temperature together with silica (i.e. sand).

With ilmenite oxygen carrier ($FeTiO_3$) the alkali forms non-sticky titanates.

>20,000 h of OCAC (oxygen-carrier aided combustion) in 75 MW CFB with ilmenite

Could range of possible fuels be extended?

Similarly, NO in concentrated flow
Options for eliminated/reduced NO ?

Equilibrium NO concentration in a fuel reactor is well below 1 ppm.

Data from pilot operation with biomass, indicate NO concentrations of the order of 100 ppm.

However, more detailed studies of the fate of added NO or NH_3 in an inert/fuel gas stream to a bed of ilmenite oxygen carrier shows:

With fully oxidized oxygen carrier:
  NO is not reduced
  Some NH_3 is oxidized to NO

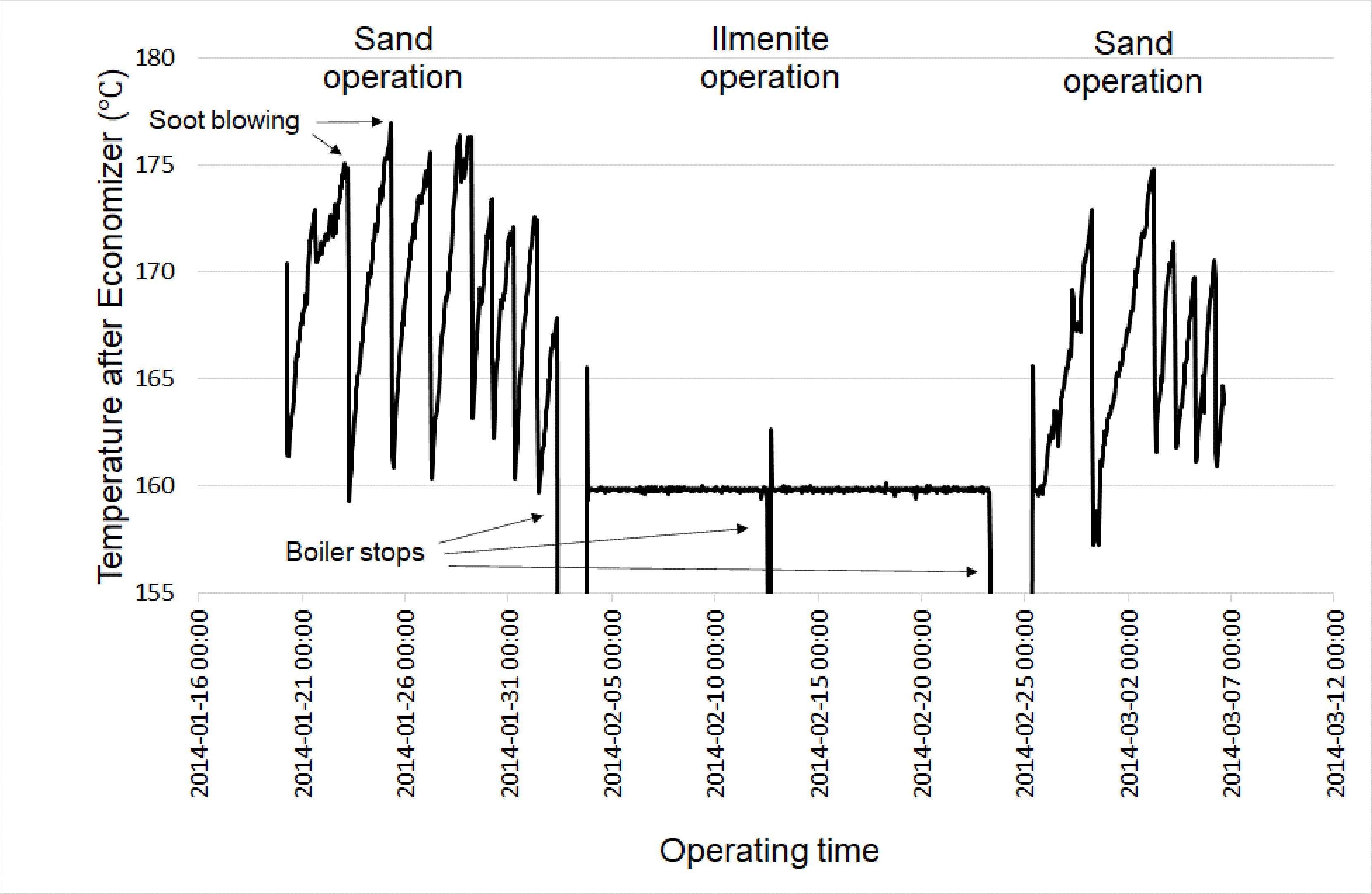
In presence of fuel,
  NO is completely reduced to N_2
  No NH_3 is oxidized to NO

The same also applies in absence of fuel, if the oxygen carrier is slightly reduced.

=>There is good reason to assume that in a high riser, any NO formed would be reduced.

REF: Fate of NO and Ammonia in Chemical-Looping Combustion – Investigation in a 300 W CLC Reactor System, Lyngfelt, Hedayati and Augustsson, accepted for publication in *Energy & Fuels*

OCAC operation Chalmers 12 MW CFB



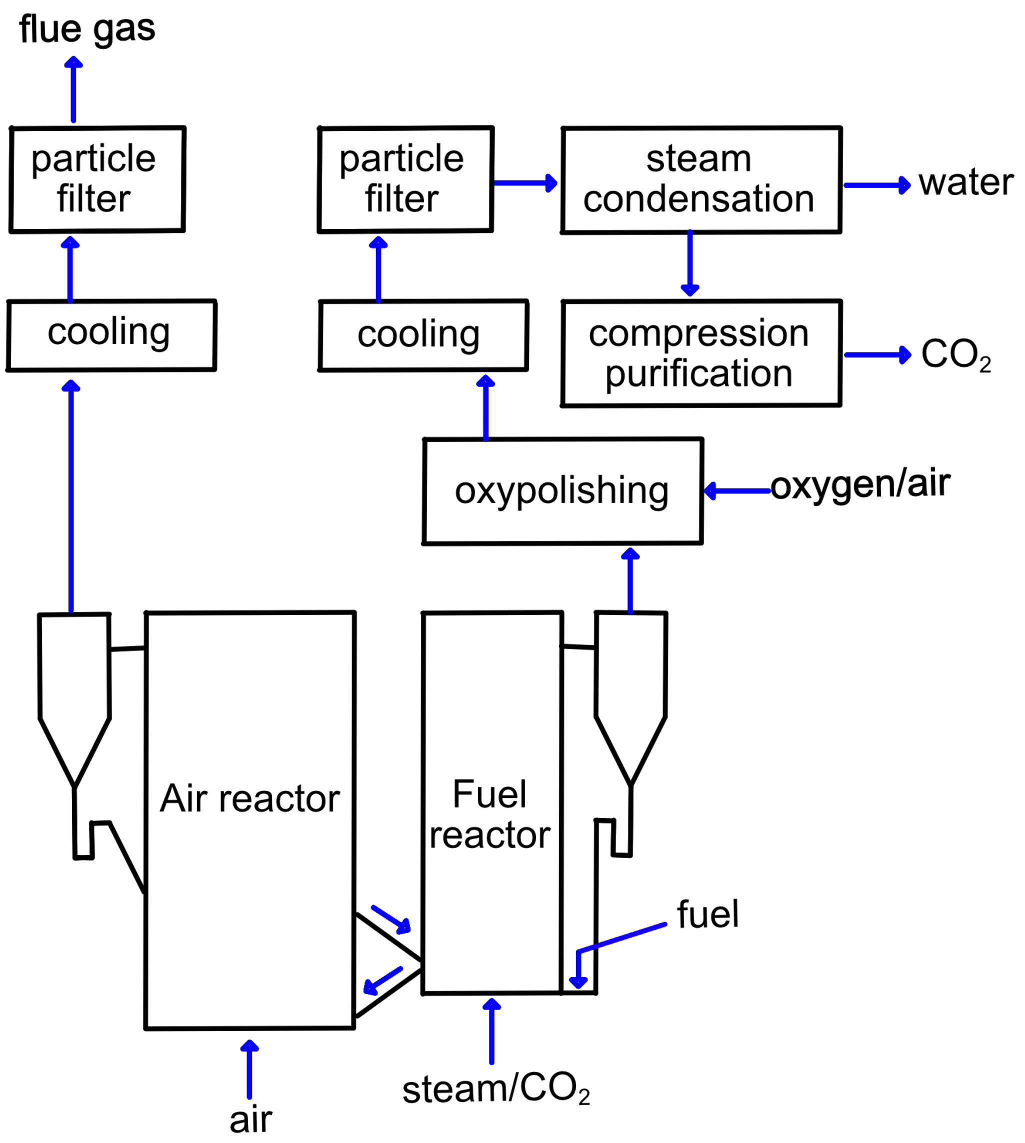


Table 1. Required purity of CO_2.[62,63]

Component	*ppm*
Water, H_2O	≤30
Oxygen, O_2	≤10
Sulphur oxides, SO_x	≤10
Nitric oxides/nitrogen dioxide, NO_x	≤10
Hydrogen sulphide, H_2S	≤9
Carbon monoxide, CO	≤100
Amine	≤10
Ammonia, NH_3	≤10
Hydrogen, H_2	≤50
Formaldehyde	≤20
Acetaldehyde	≤20
Mercury	≤0.03

Options for purification

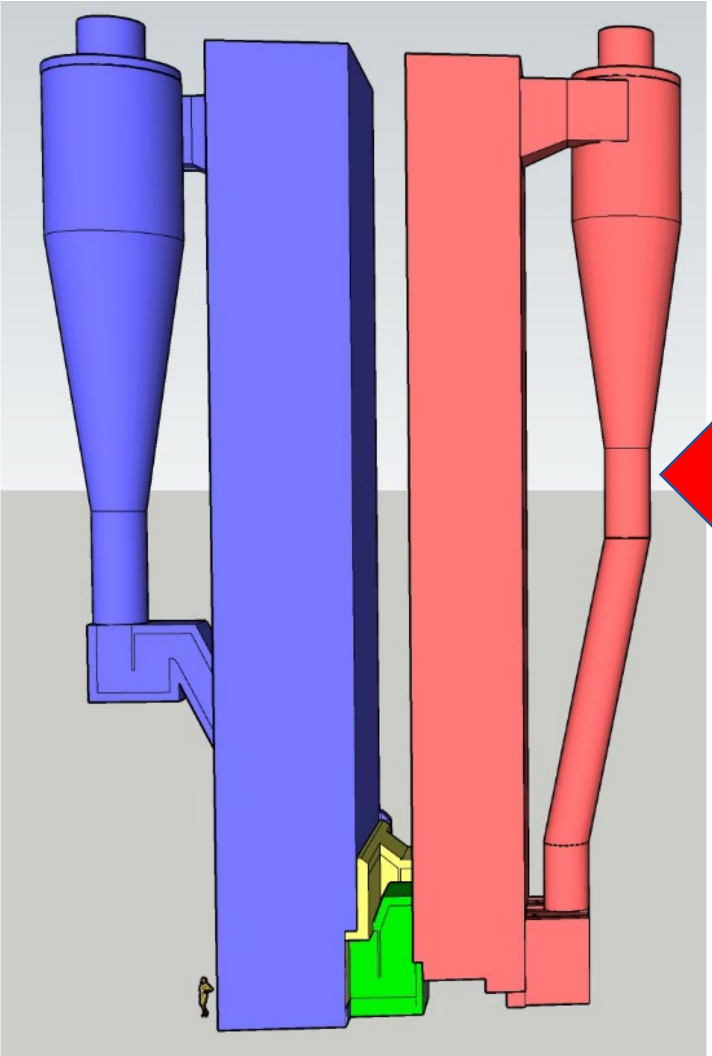
Cryogenic distillation of CO_2 - to remove O_2, NO, CO, N_2 etc.

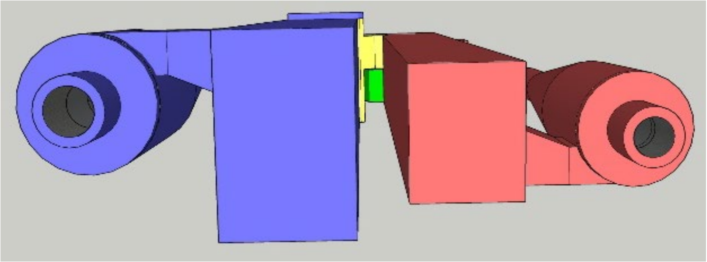
Catalytic combustion of O_2 at 80°C with H_2 - NO ?

Catalytic combustion of O_2 at 450°C with CH_4 - NO ?

NO – oxidation to NO_2 with ClO_2

NO_2 and SO_2 removal can be done in connection with compression and condensate removal





Added cost:

1500 m^2 insulated wall
at
2000 €/m^2

>>> 3 M€

or

0.3 M€/year

capture: 0.4 Mt CO_2/year

cost of fuel reactor : **0.75 €/t CO_2**

big cost

Type of cost	estimation, €/tonne CO_2	range, €/tonne CO_2	Efficiency penalty, %
CO_2 compression	10	10	3
Oxy-polishing	6.5	4-9	0.5
Boiler cost	1	0.1-2.3	-
Oxygen carrier	2	1.3-4	-
Steam and hot CO_2 fluidization	0.8	0.8	0.8
Fuel grinding	0.2	0.2	0.1
Lower air ratio	-0.5	-0.5	-0.5
Total	20	15.9-25.8	3.9

small cost

[1]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) 475-487

Chemical Looping combustion (CLC)

CLC boiler very similar to CFB boiler (=circulating fludized-bed boiler)

Highly concentrated CO_2 stream can be obtained at small added cost

Cost: 25-50% of competing technologies

Works with biomass

Eliminate/reduce emissions of NO_x

Eliminate/reduce problems with alkali ash components

Presently no market – poor interest from industry to engage in development

Thank you!