CHEMICAL-LOOPING COMBUSTION FOR CO_2 CAPTURE - WHAT HAS BEEN ACHIEVED ?

Anders Lyngfelt,
Chalmers Tekniska Högskola, Göteborg

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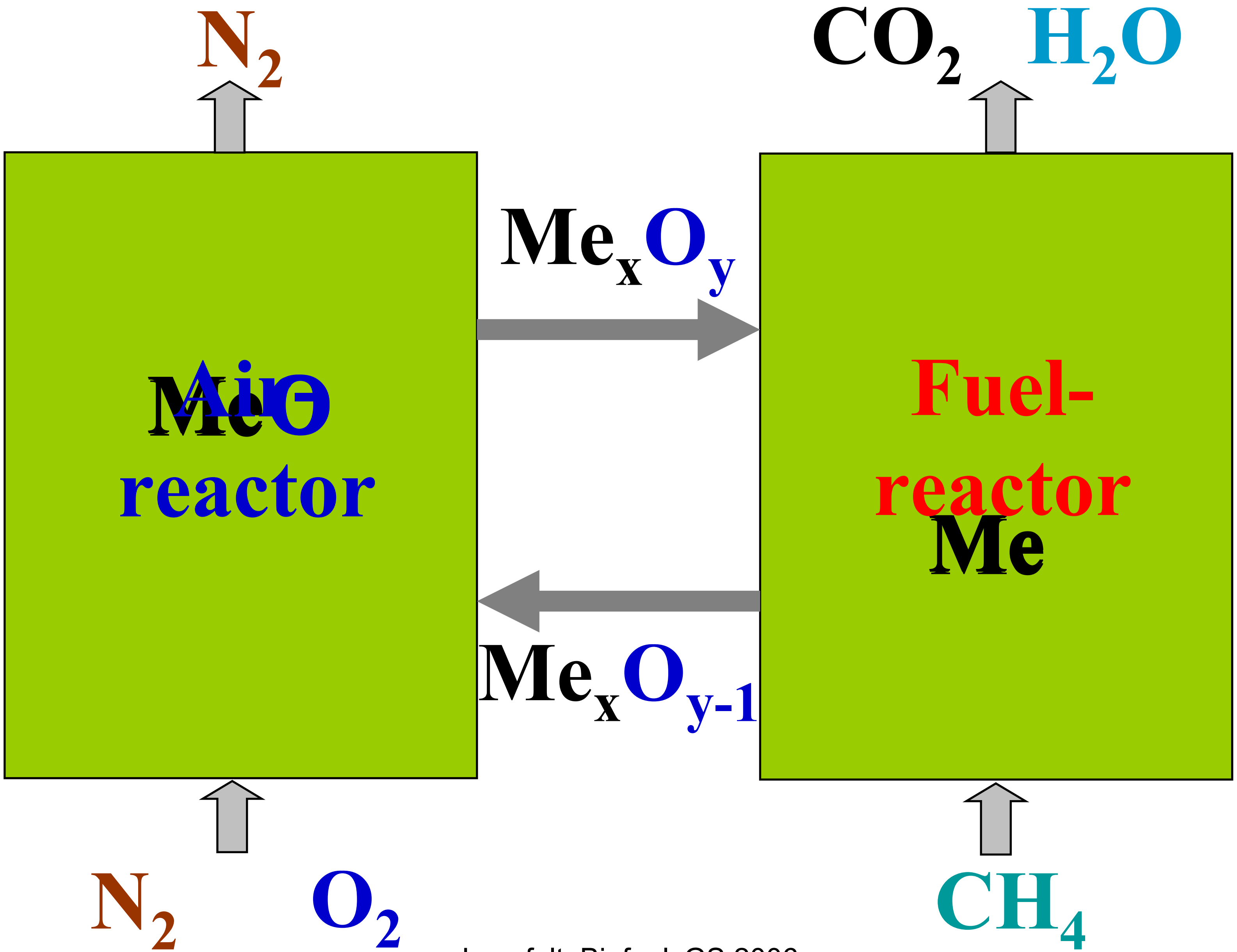
Chemical-looping combustion

- a new principle for oxidizing fuels using metal oxides as oxygen carriers, transferring oxygen from combustion air to fuel
- no mixing of combustion air and fuel => CO_2 can be obtained pure, without (!) separation of gases

Energy production from oxidation of hydrocarbons

respiration	~2 000 000 000 BC
fire	~500 000 BC
fuel cell	1839
chemical-looping combustion	2003



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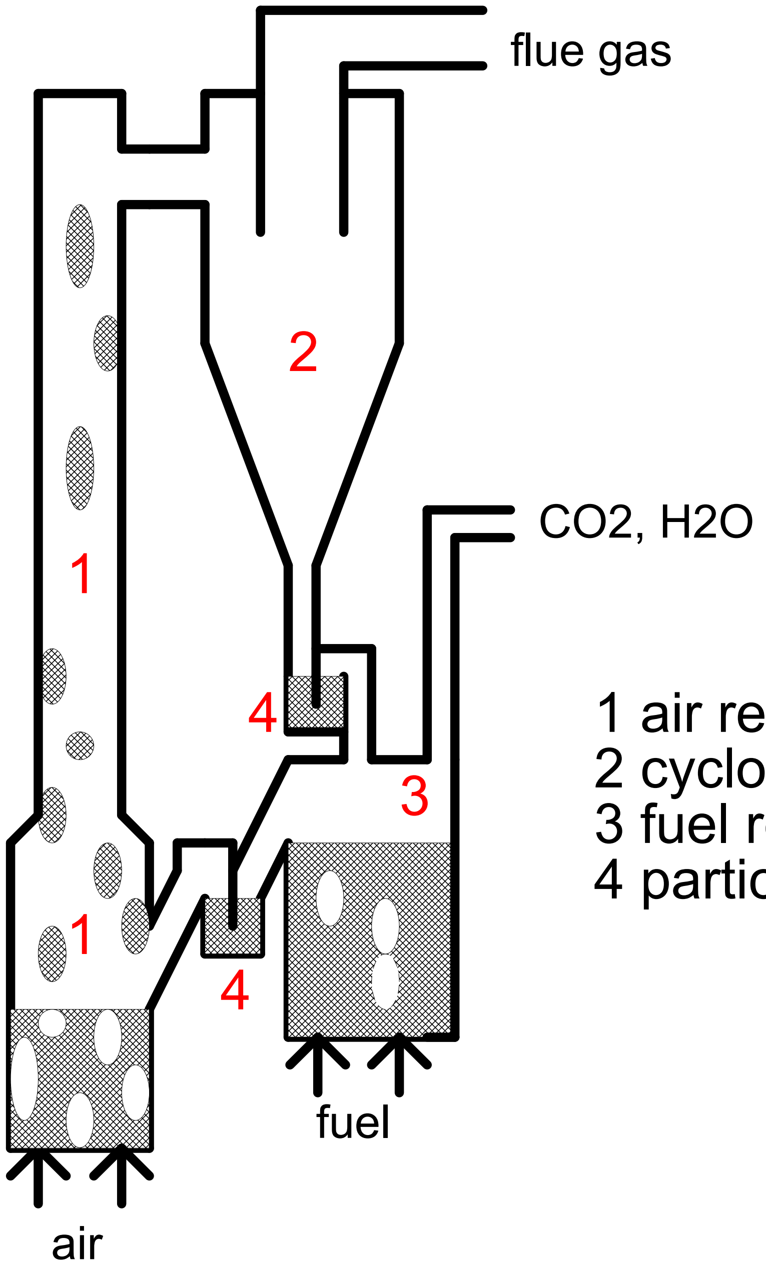

1 air reactor, riser
2 cyclone
3 fuel reactor
4 particle locks

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chemical-looping combustion, status 2002:

- **"paper concept",**
- **process never tested !**
- **a limited number of particles tested in a limited number of cycles**

What has happened since then ?

>300 particles have been tested:

- **active oxides primarily NiO, CuO, Mn_3O_4, Fe_2O_3**
- **support materials, e.g. Al_2O_3, TiO_2, SiO_2, ZrO, sepiolite, Al_2MgO_4 ...**
- **various mixing ratios active oxide/support**
- **production methods: extrusion, freeze-granulation, wet methods, impregnation ...**
- **heat treatment: typically 900-1300 C**

Pros and cons for the active oxides

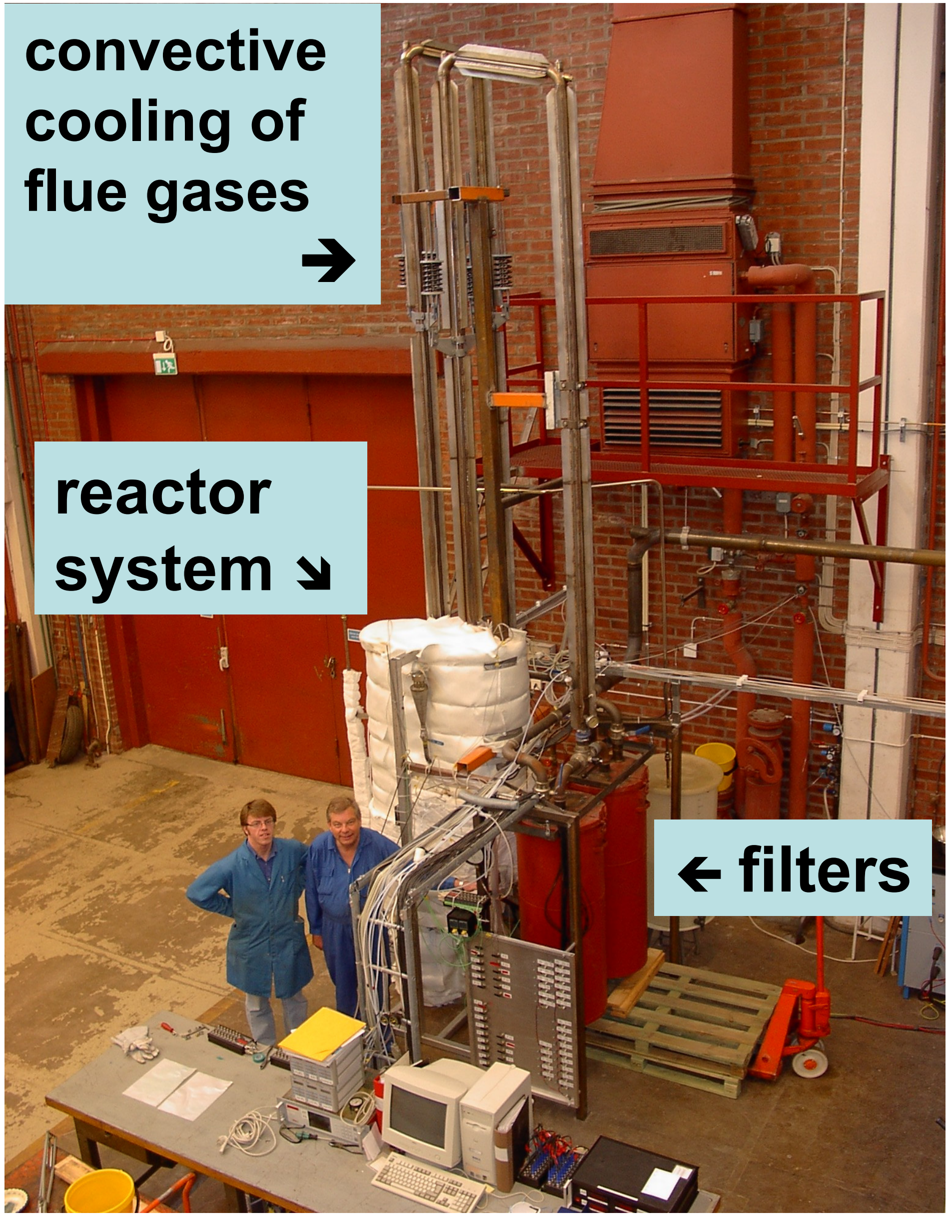
	Fe	Mn	Cu	Ni
Reactivity	--	-	+	++
Cost	++	+	-	--
Health				-
Thermodynamics				-[1]
Reaction with CH_4			+[2]	
Melting point			-[3]	

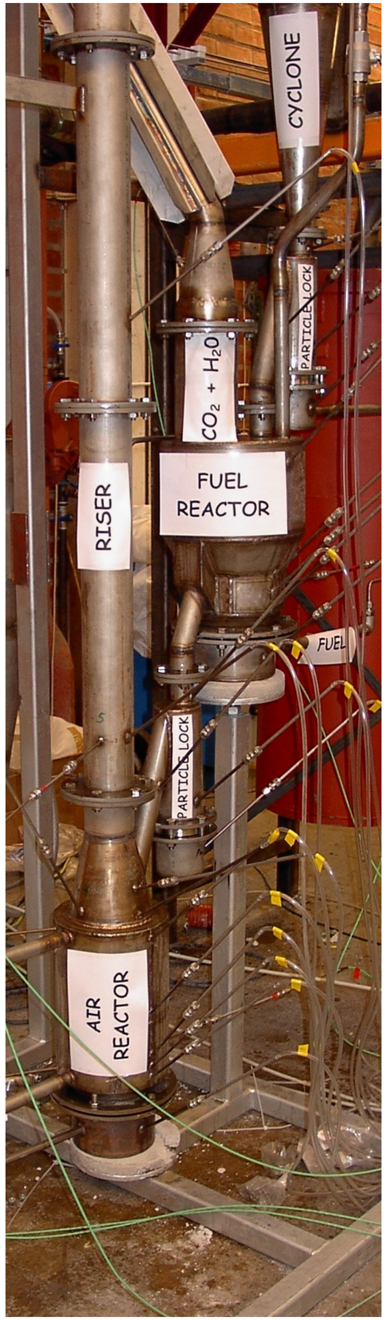
[1]maximum conversion 99-99.5%

[2]exothermic reaction in fuel reactor

[3]melting point Cu: 1085 C

Chalmers' 10 kW chemical-looping combustor 2003





Conclusions (Ni-based particles):

No CO_2 from air reactor:

- No leakage between reactors
- No significant carbon formation
- → 100% CO_2 capture

Sand tests show no leakage from air to fuel reactor:

- Almost pure CO_2 possible

  1.2% H_2, 0.6% CO with NiO

Conversion of fuel:

- 99.5% at 800

Operation

- Stable and easy to control
- 105 h operation CLC (13 days) without change of particles
- ~300 h circulation

Investigation of particles after 105 h

- No loss in reactivity
- No loss in particle strength

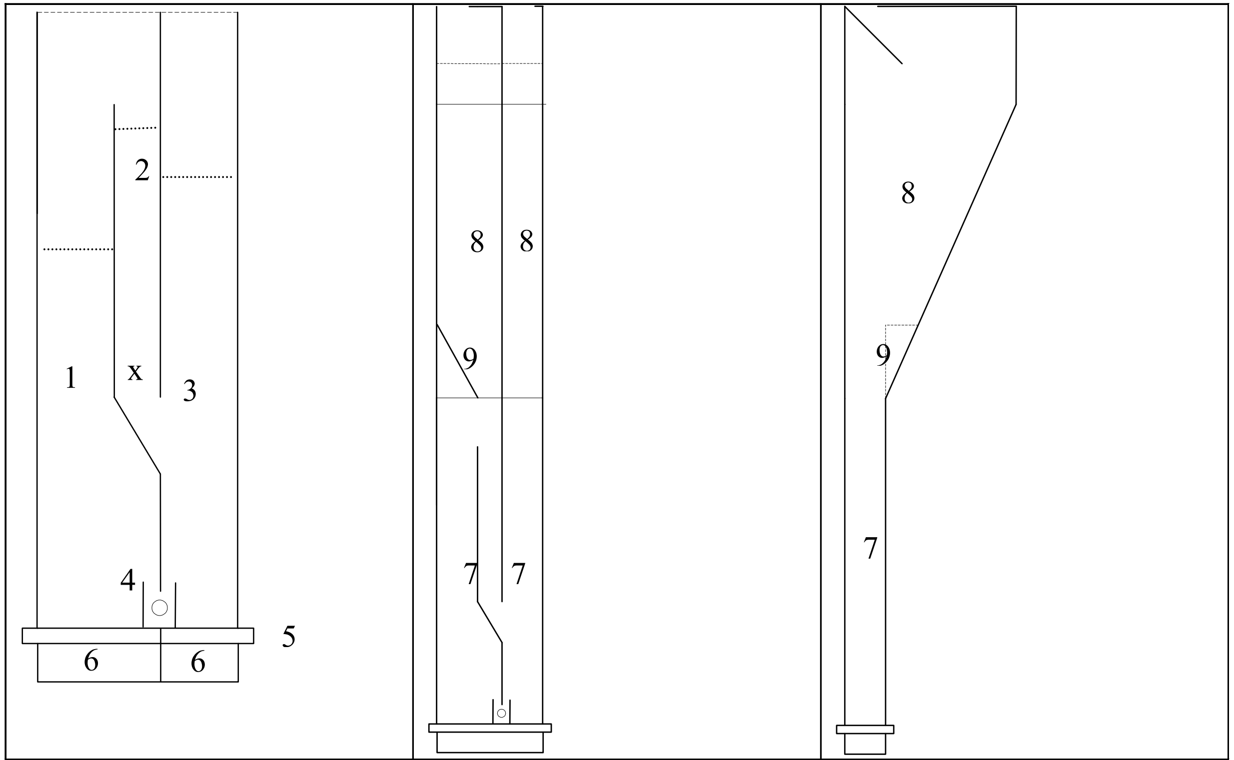
Loss of fines very low:

- Particle lifetime >40,000 h (?)

Low particle cost:

- <1 €/ton CO_2 (lifetime 4,000 h)

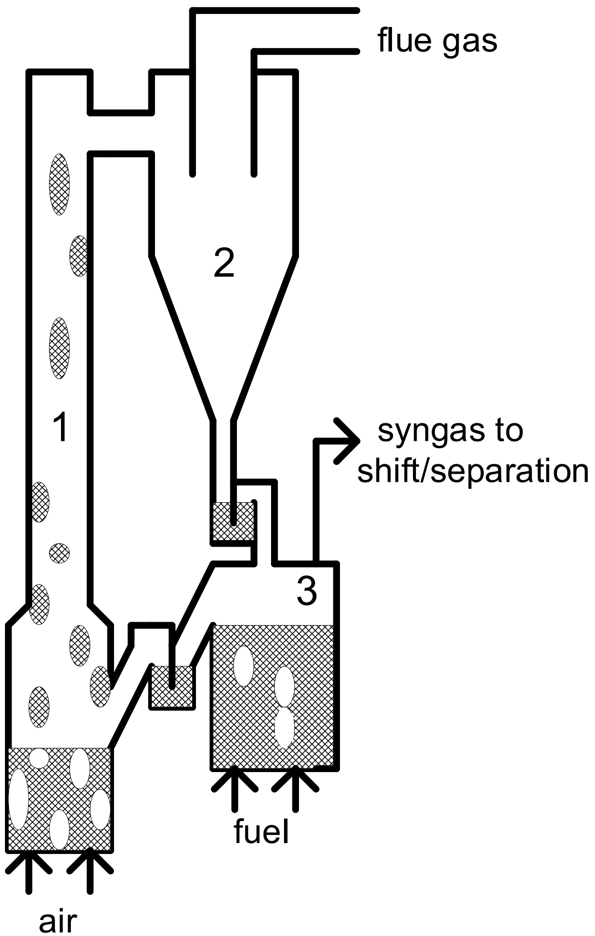
Small 300 W chemical-looping combustor



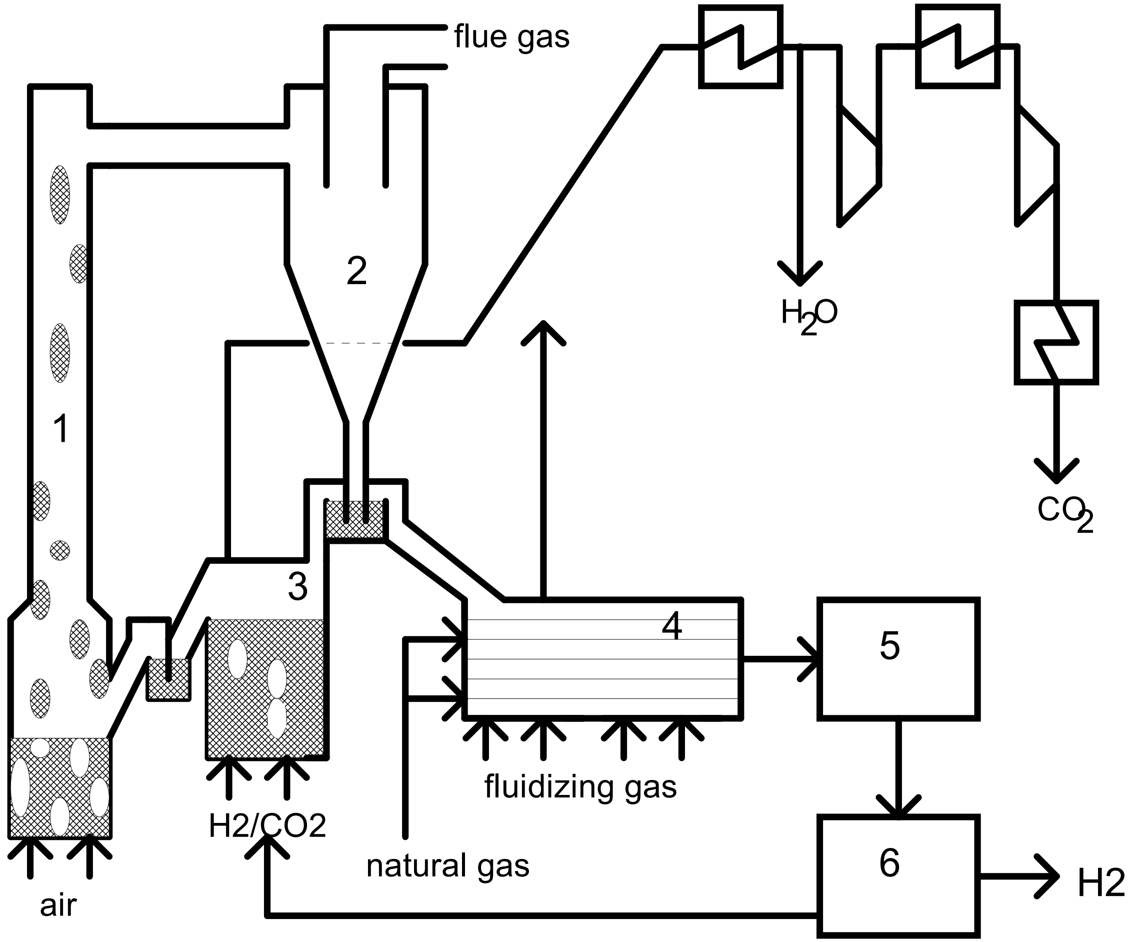
a) the lower part, frontview | b) entire reactor, frontview | c) entire reactor, sideview

Figure 2. The principal sketch of the reactor. 1) air reactor, 2) downcomer, 3) fuel reactor, 4) slot, 5) gas distributor plate, 6) wind box, 7) reactor part, 8) particle separator, 9) leaning wall. Fluidization in the downcomer (x) and slot (o) is also indicated. The dashed lines indicates the bed heights during combustion.

Chalmers’ 300 W chemical-looping combustor 2004



Chemical looping reforming by partial oxidation



Hydrogen production by steam reforming with chemical-looping as heat source and separation off-gas as fuel.

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Chalmers' 10 kW chemical-looping combustor for ***solid fuels,*** 2005

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Testing in chemical-looping combustors:

	unit	particle	operation h (hot time[d])	fuel[f]
1	[a]Chalmers 10 kW	$NiO/NiAl_2O_4$	105 (300)	n.gas
2a	[a]Chalmers 10 kW	Fe_2O_3-based	17	n.gas
2b	Chalmers 10 kW	Fe_2O_3-based	16	n.gas.
3	[a]S Korea 50 kW	$Co_3O_4/CoAl_2O_4$	25	n.gas
4	[a]S Korea 50 kW	NiO/bentonite	3[i]	n.gas.
5	[b]Chalmers 300 W	$NiO/NiAl_2O_4$	8 (18)[g]	n.gas
6	[b]Chalmers 300 W	$NiO/MgAl_2O_4$	30 (150)	n.gas/syngas
7	[b]Chalmers 300 W	$Mn_3O_4/ZrO_{2,\ Mg\text{-}st.}$	70 (130)	n.gas/syngas
8	[c]Chalmers 300 W	Fe_2O_3/Al_2O_3	40 (60)	n.gas/syngas
9	[b]CSIC, 10 kW	$CuO_{impregnated}$	2x100	n.gas
10	[b]Chalmers 300 W	$NiO/MgAl_2O_4$	41 (CLR[g])	n.gas(CLR[g])
11	Chalmers SF[j]	confidential	18	bit. coal

[a]published 2004, [b]published/accepted 2005-2006, [c]submitted [d]total time fluidized at high temperature, [e]same particle as used 100 h in 10 kW unit, [f]n.g. = natural gas, s.g. = syntesgas, [g]chemical-looping reforming, [i]particles fragmentated, [j]10 kW solid fuel CLC,

Chemical-Looping Combustion

Reactor system (fluidized beds):

- well established
- commercially available
- simple
- moderate costs

Oxygen-carrier particles:

- very encouraging results
- scale-up of particle manufacture
- raw materials
- long-term testing needed

Applications of chemical-looping combustion for CO_2 capture:

Combustion of gaseous fuel, natural gas, refinery gas, syngas

Chemical-looping reforming, i.e. hydrogen production

Combustion of solid fuels

Conclusions

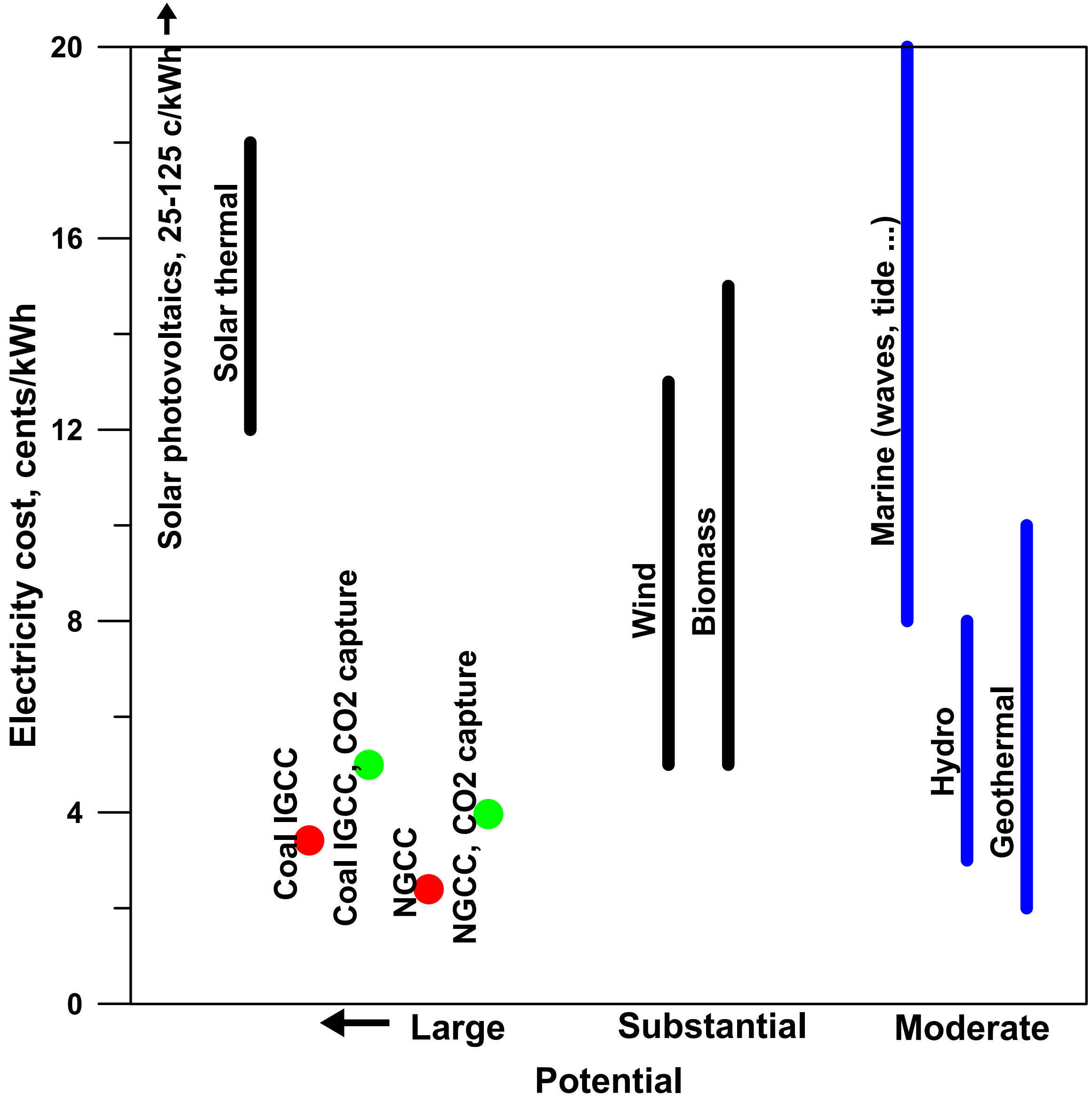
Successful testing of:

oxygen carriers based on Ni, Fe, Mn, Cu and Co in actual chemical looping combustors

chemical-looping reforming for hydrogen production.

chemical-looping combustion with solid fuels (potential: <10 €/ton CO_2 captured)

Anders Lyngfelt, Chalmers University of Technology



Costs from: United Nations Development Programme, UNs Department of Economic and Social Affairs, and World Energy Council (2000) *World Energy Assessment: Energy and the Challenge of Sustainability*

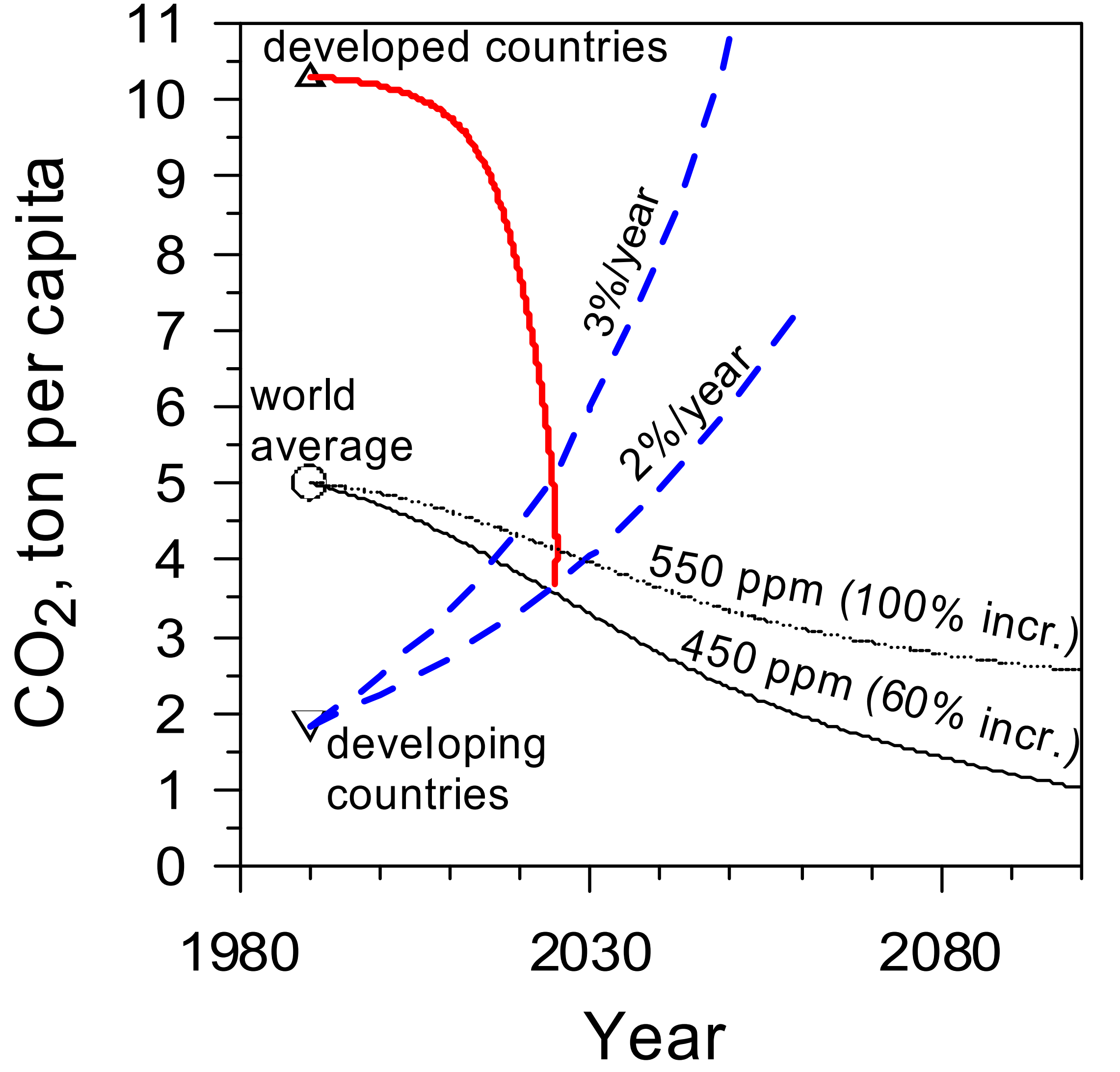
CI = Carbon Intensity = 0.9 kg CO_2/$

AC = avoidance cost ~ 0.05 $/kg CO_2

Cost as fraction of GDP = CI*AC = 4.5%

	AC, $/kg CO_2
Biofuel	0.06
Wind	=0.07
Solar thermal	=0.15
Solar photovoltaics	=1.5
CO_2 storage	0.002
CO_2 capture & storage	0.02-0.05
CLC CO_2 capture solid fuels	0.01 ?
Swedish CO_2 tax	0.1

Year 1800: 280 ppm
Today: 360 ppm (30% incr.) +0.6 C
Future: 550 ppm (100% incr.), +2.5 (1.5-4.5) C



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IPCC report on CO_2 capture and storage:

Geologic storage potential estimated to 1,700 – 10,000 Gton CO_2

corresponds to today's global emissions for 50 – 300 years