CAPTURE OF CO_2 USING
Chemical-Looping Combustion (CLC)

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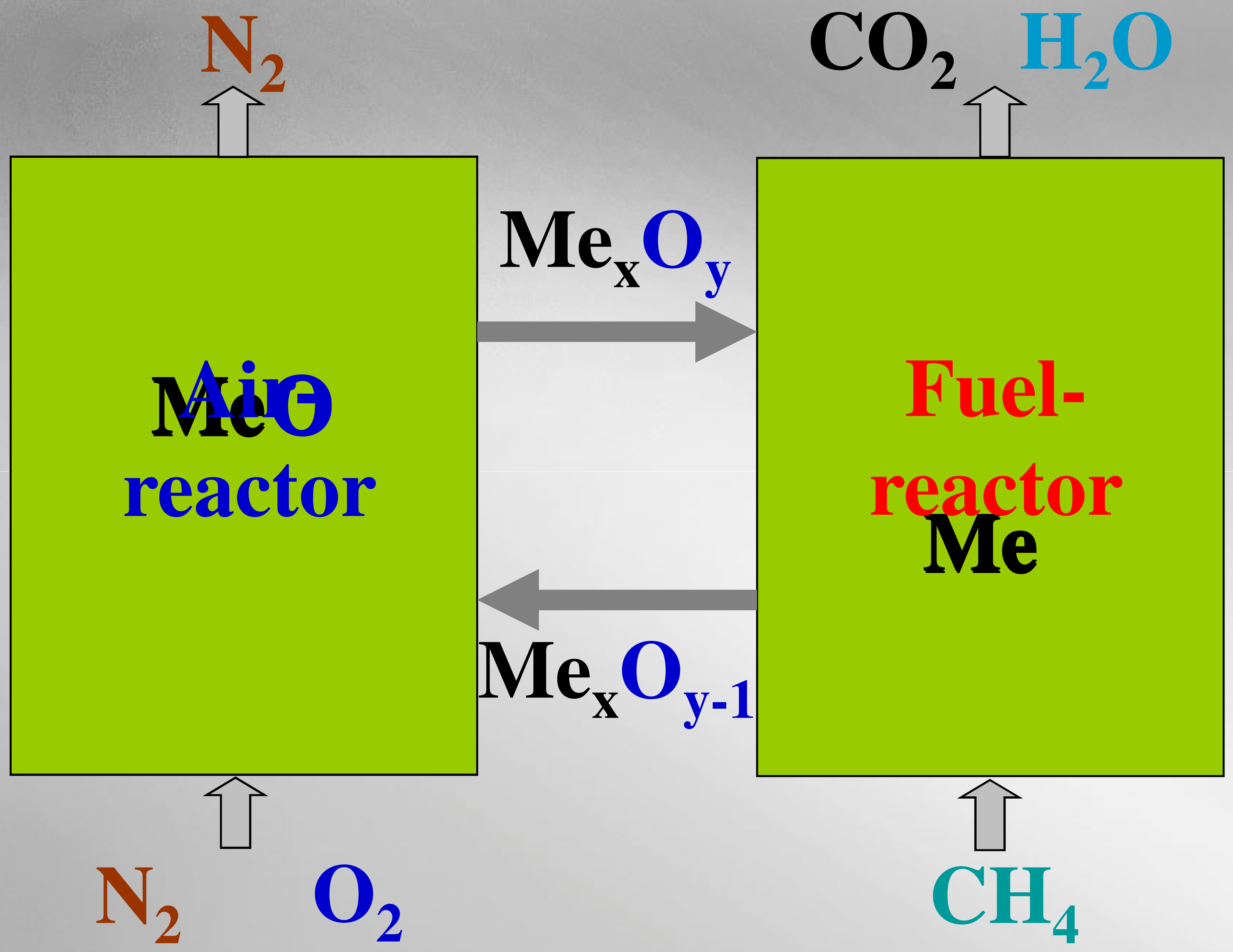
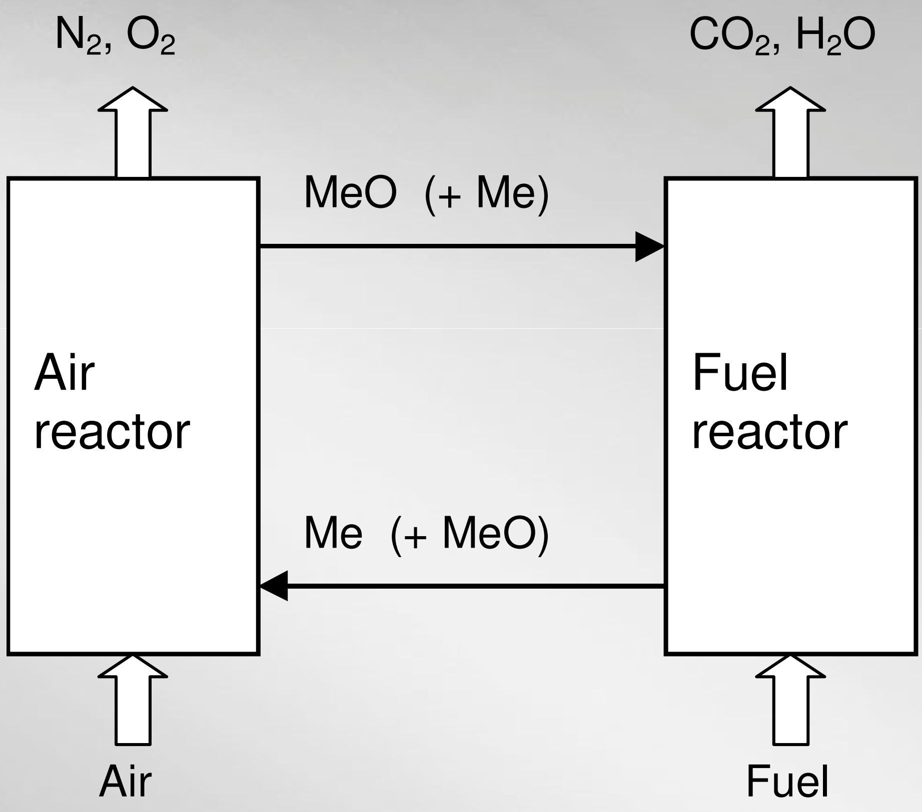
CO_2 capture and storage

- Capture costs >> costs of storage/transportation
- Dominating concepts for CO_2 capture (postcombustion, oxy-combustion and precombustion) have significant costs and energy penalties for gas separation
- Gas separation is mature technology, no very major break-throughs expected
- Chemical-looping combustion provides inherent separation of CO_2. Thus, gas separation can be completely avoided.


N_2
CO_2 H_2O
Me_xO_y
MeO
Air-reactor
Fuel-reactor
Me
Me_xO_{y-1}
N_2 O_2
CH_4

Chemical-looping combustion (CLC)

- Oxygen transferred from combustion air to fuel by metal oxide particles
- Inherent CO_2 capture:
  - fuel and combustion air never mixed
  - no active gas separation needed
  - large costs/energy penalties of gas separation avoided
- Potential for real breakthrough in costs of CO_2 capture



New principle of combustion

respiration	~2 000 000 000 B.C
combustion	~500 000 B.C
fuel cells	1839
chemical-looping combustion	2003

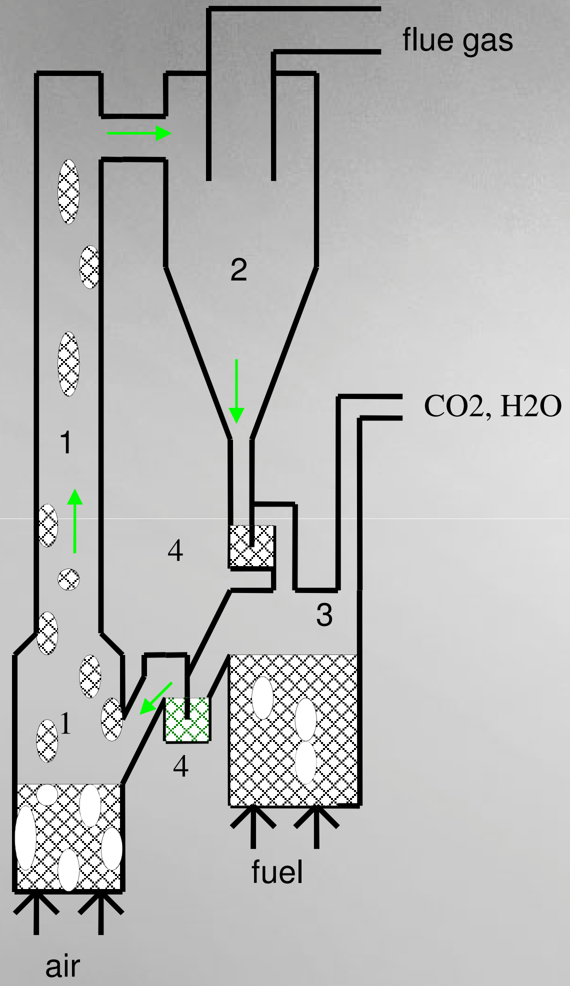
Chemical-Looping Combustion (CLC)

- 2002: paper concept, a few metal oxides tested in simple laboratory tests, 2-4 publications/year
- 2003: 100 h successful demonstration of process (Chalmers, 10 kW with natural gas)
- 2006: first demonstration with solid fuels (Chalmers, 10 kW unit for solid fuels)
- 2010: c:a 4000 h operational experience in 12 units, 0,3-120 kW (of which 3500 h for Chalmers with close partners and 2200 h for Chalmers)

CLC can be used for

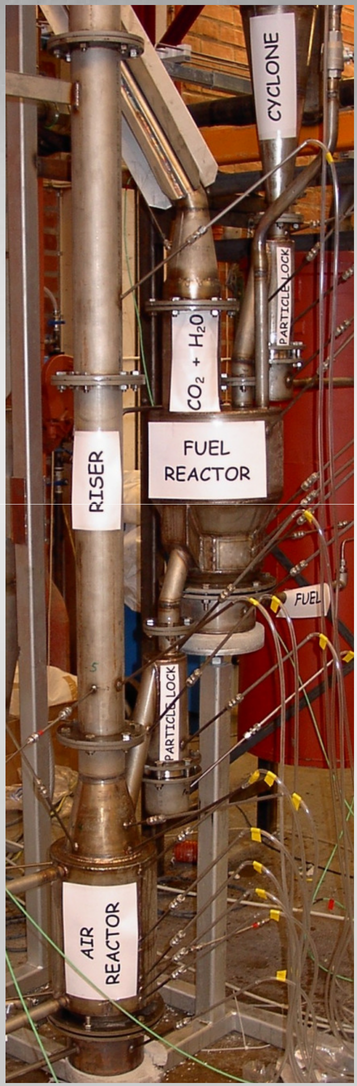
- CO_2-free combustion of fossil fuels
- CO_2-negative combustion of biofuels (atmospheric CO_2 capture)
- Conversion of fossil fuels to CO_2-free fuels (presentation by Magnus Rydén)

Chalmers 10 kW CLC, 2003

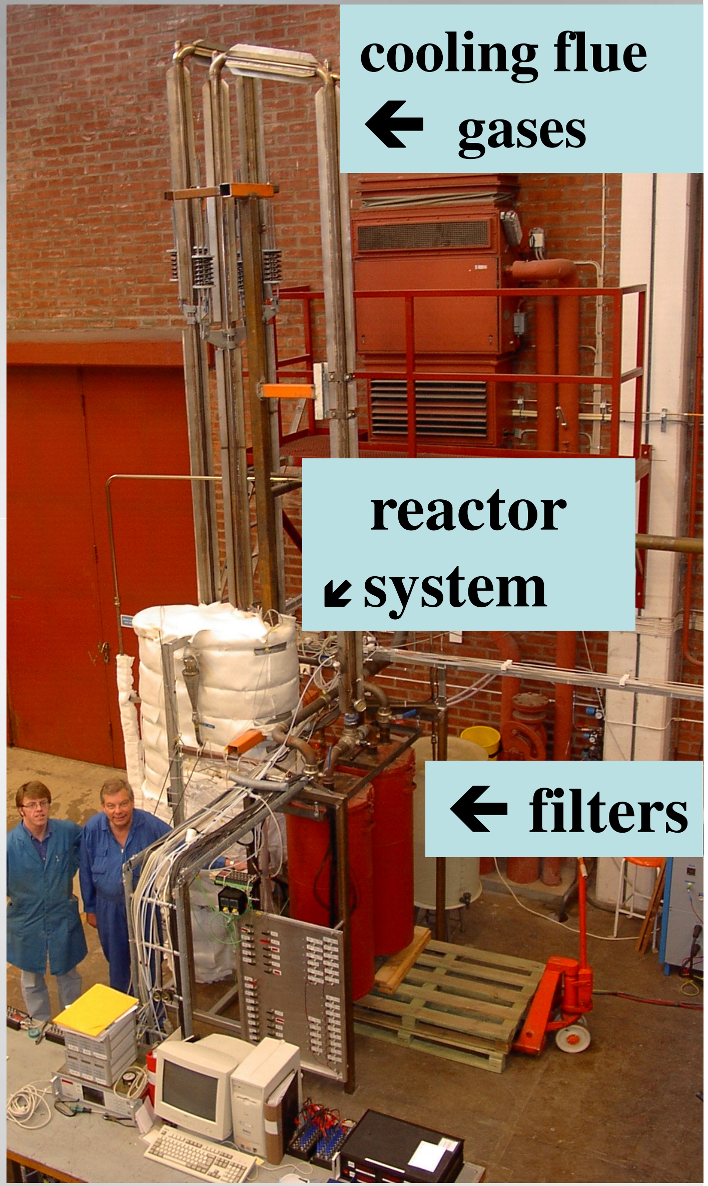


1 air reactor, 2 cyclone

3 fuel reactor, 4 loop seals

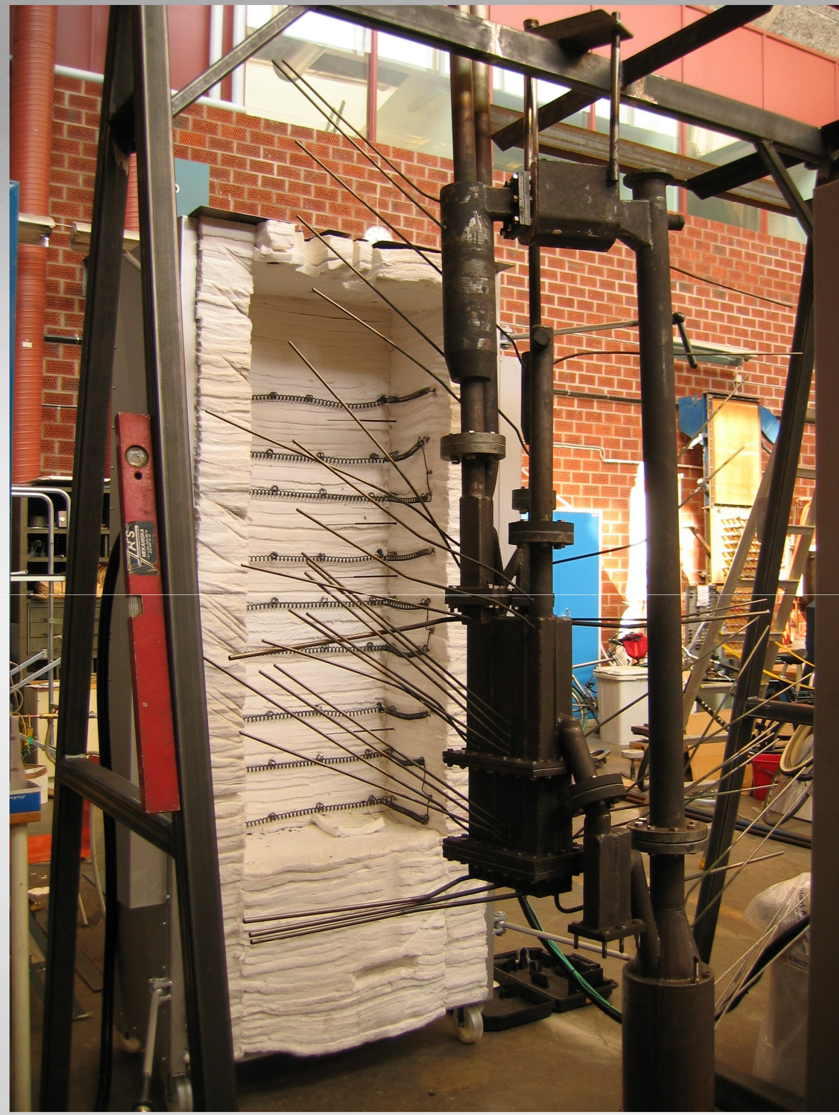


without insulation



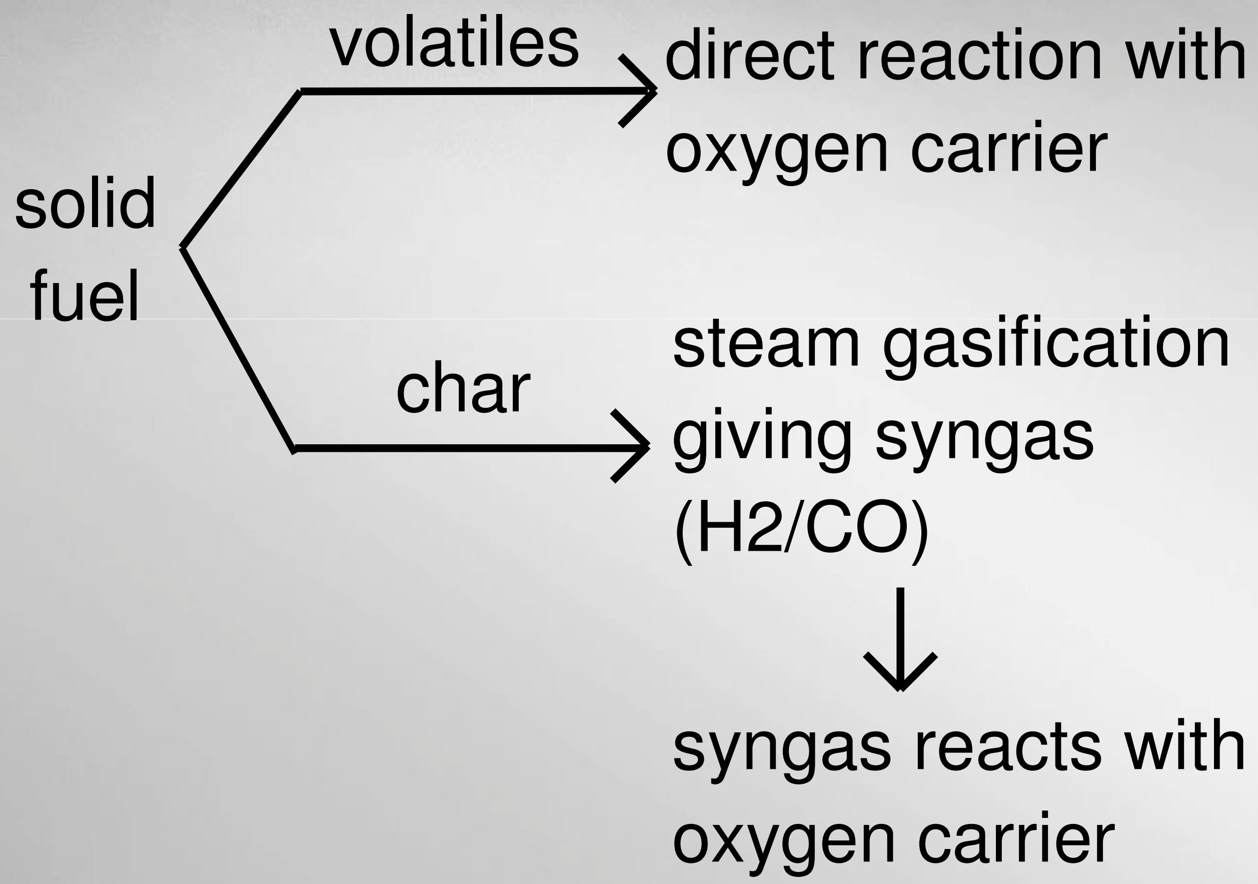
CLC gaseous fuels

- 10 kW tests:
  - 100% capture of CO_2
  - 98% fuel conversion
  - 1400 h operational experience
  - long lifetime of material demonstrated
- a number of oxygen carriers tested in operation
  - best so far is nickel oxides
- work on-going with other oxygen carriers (better/cheaper)
- ready for scaling up to 1-10 MW_{th}



Chalmers 10 kW CLC for solid fuels, 2006

CLC solid fuels



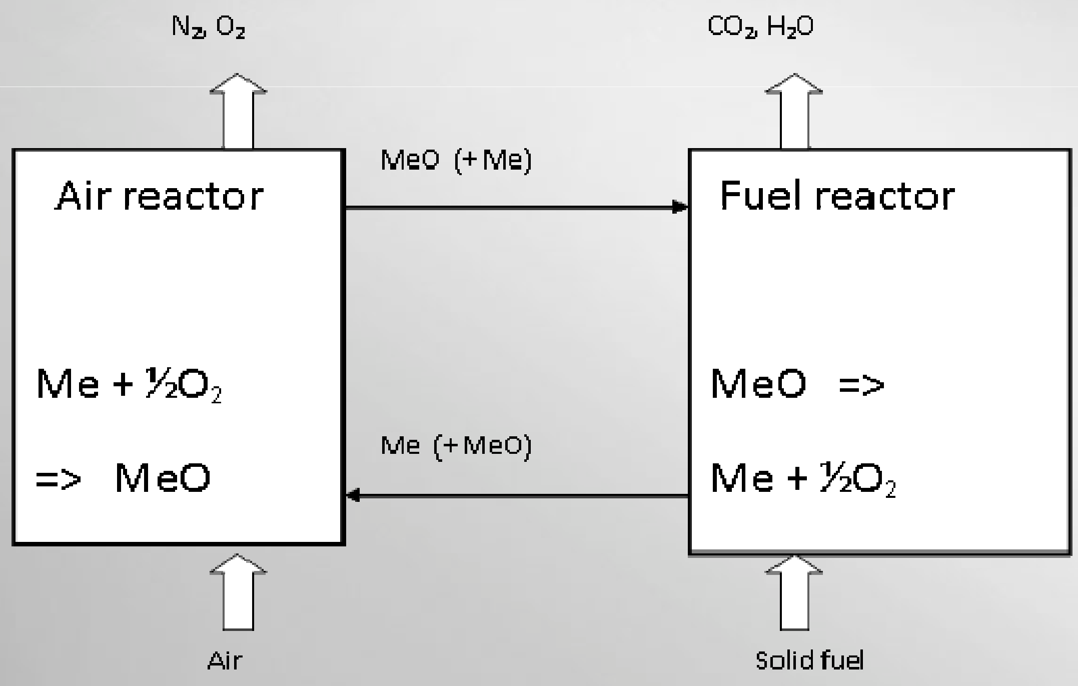
Solid fuel CLC, adaptations/challenges

- cheap oxygen carriers because of fuel ash
  - e.g. ilmenite $FeTiO_3$ (natural mineral, 1 kr/kg)
- bottom bed feeding of fuel (for conversion of volatiles)
- sufficient residence time of solids in fuel reactor (for char conversion)
- carbon stripper, converting/stripping char in solids flow to air reactor
- oxygen polishing, addition of oxygen to gas leaving fuel reactor to reach full gas conversion

Solid fuel CLC, alternate approach

Chemical-Looping with Oxygen Uncoupling "CLOU"

- uses oxygen carrier that releases gaseous oxygen



CLOU

- oxygen carrier with suitable equilibrium partial pressures of O_2
- Example: $CuO \Leftrightarrow Cu_2O + ½O_2$
  - $p(O_2)_{equilibrium}$ = 2.5% at 925 C
- Copper oxide releases oxygen extremely fast. Char conversion rate may increase by 10-100 times, compared to steam gasification.

CLOU

Two types of oxygen carriers for CLOU	
full CLOU	”partial” CLOU
copper oxide materials	manganese oxide combined with iron, calcium, magnesium, silica
extremely fast release of large amounts of oxygen	slower release and smaller amounts of oxygen released… (release of oxygen and direct reaction with reducing gases in parallel)
• very rapid conversion of char • complete conversion of gas	• complete conversion of gas • increased conversion rate of char

CLOU with combined manganese oxides

- A number of potential oxide combinations possible
- Potential for low cost materials
- Impact of oxygen release controlled by ratio of bed material to fuel

pipes for gas/steam supply etc.

100 kW CLC solid fuel, ready for commissioning

100 kW for solid fuel (June 2010)

Cold-flow model of 100 kW unit



Solid fuel CLC

Only known technology that has potential for a major break-through in cost and energy penalty of CO_2 capture

Potential:

- cost 10 €/ton CO_2 (reference 50 €/ton, ??)
- 3% loss in energy penalty (reference 10%)

Chemical-Looping Combustion at Chalmers

- 300 oxygen carriers investigated at Chalmers (oxides of Ni, Fe, Mn, Cu and combined oxides)
- CLC with gaseous, liquid and solid fuels investigated
- CLC-units: 10 kW; 0.3 kW; 10 kW solid fuels; 100 kW solid fuel (under commissioning)
- 8 PhD theses, ~130 publications
- funding : mainly seven EU-projects, Sw. Energy Agency, Industry, Nordic Energi Research

Summary

- Major cost of CO_2 capture and storage is capture
- Capture cost CO_2 is caused by ***gas separation*** (fundamentally and technically well understood, no very fundamental break-throughs likely)
- CLC is a new principle of combustion, where ***no gas separation*** is needed, because air and fuel are not mixed
- CLC has major potential to reach real ***breakthrough*** in costs and energy penalty for CO_2 capture
- CLC can be used for combustion of gaseous, liquid and solid fuels
- CLC can be used to produce"CO_2-free" fuel, hydrogen
- Chalmers is world-leading

Questions ?