Capture and storage of carbon dioxide

Anders Lyngfelt

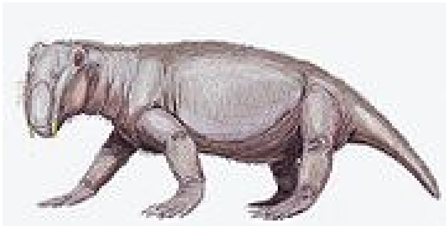
Contents

Storage

Transportation

Capture

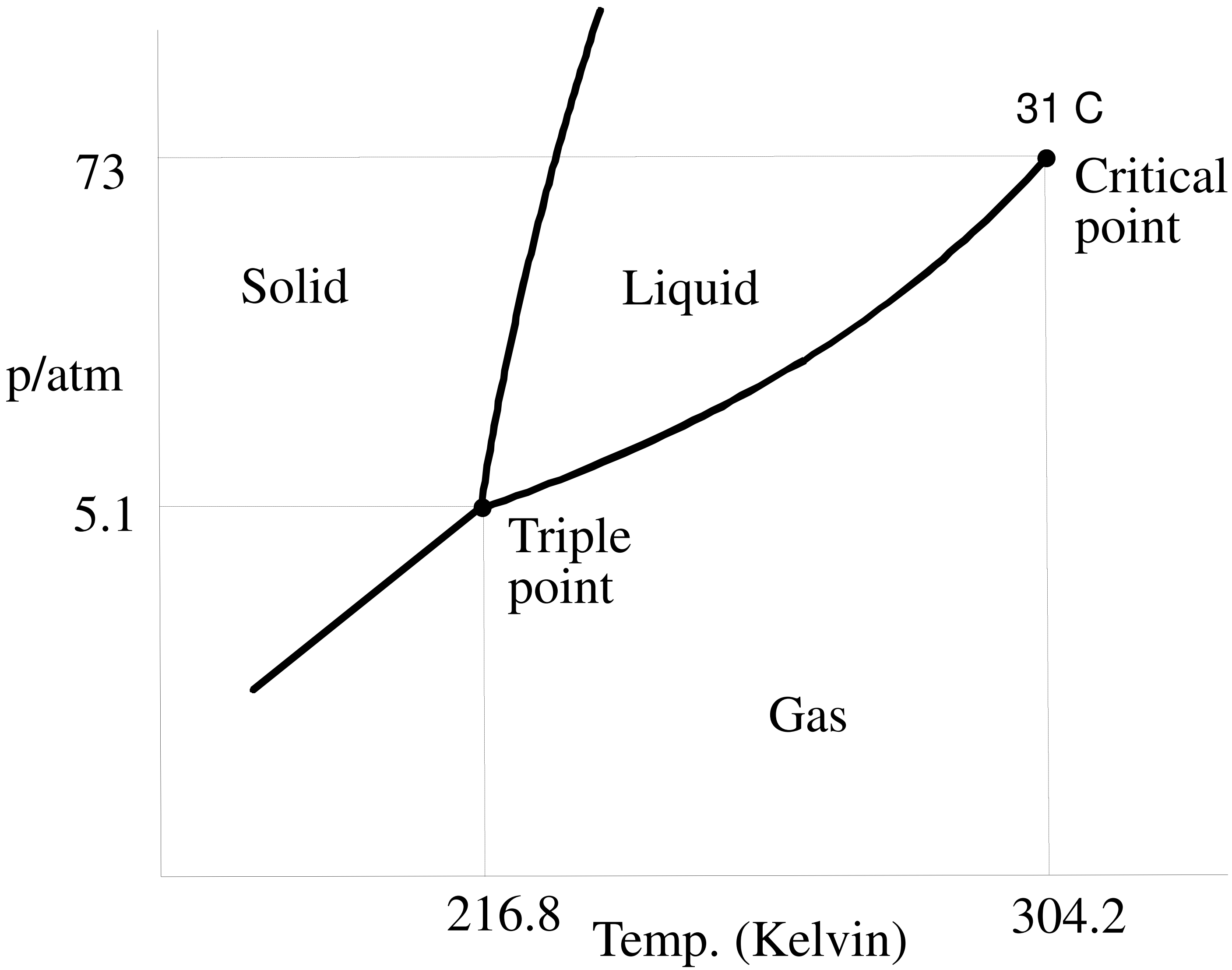
Is it expensive ?



Lystrosaurus

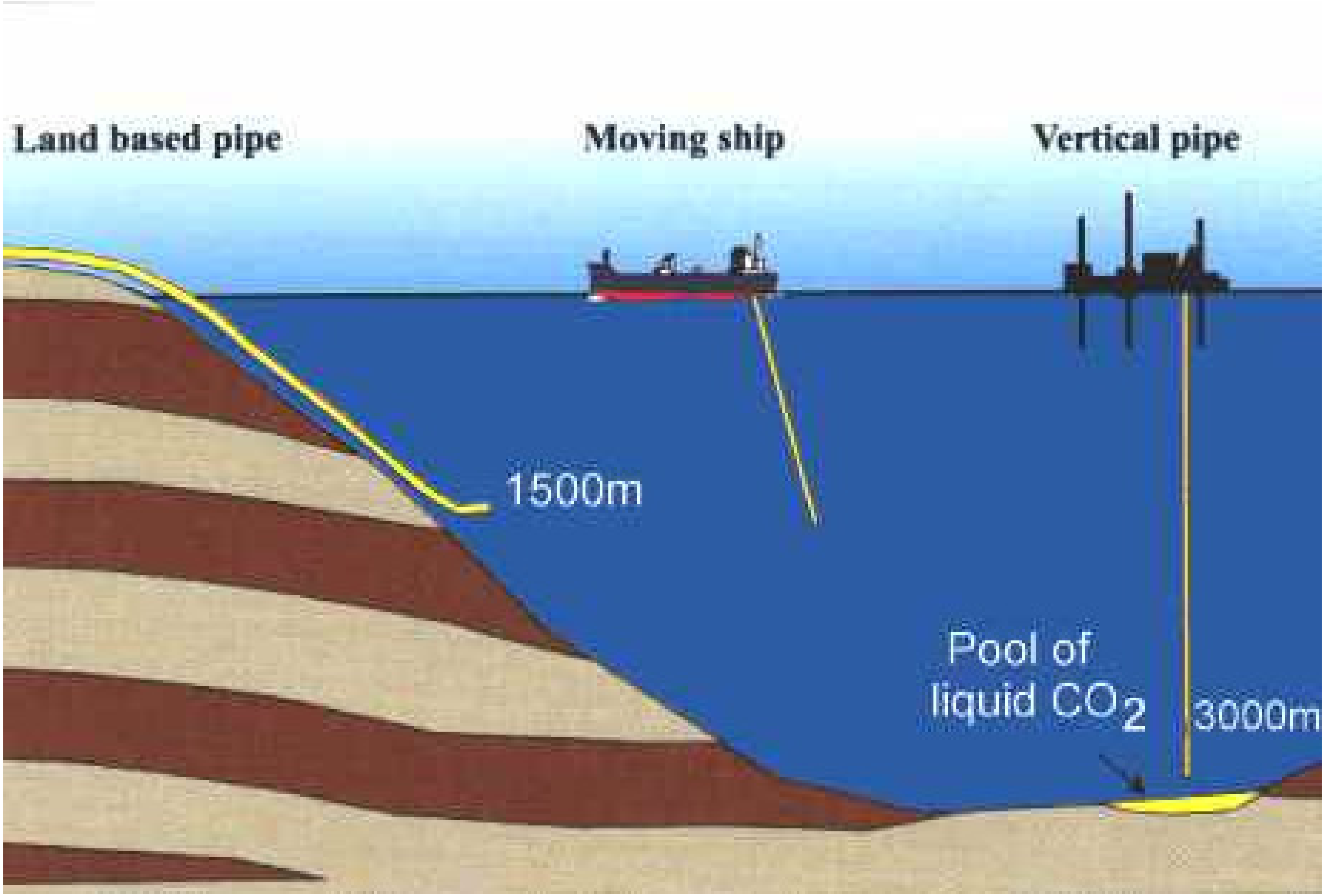
CO_2 STORAGE

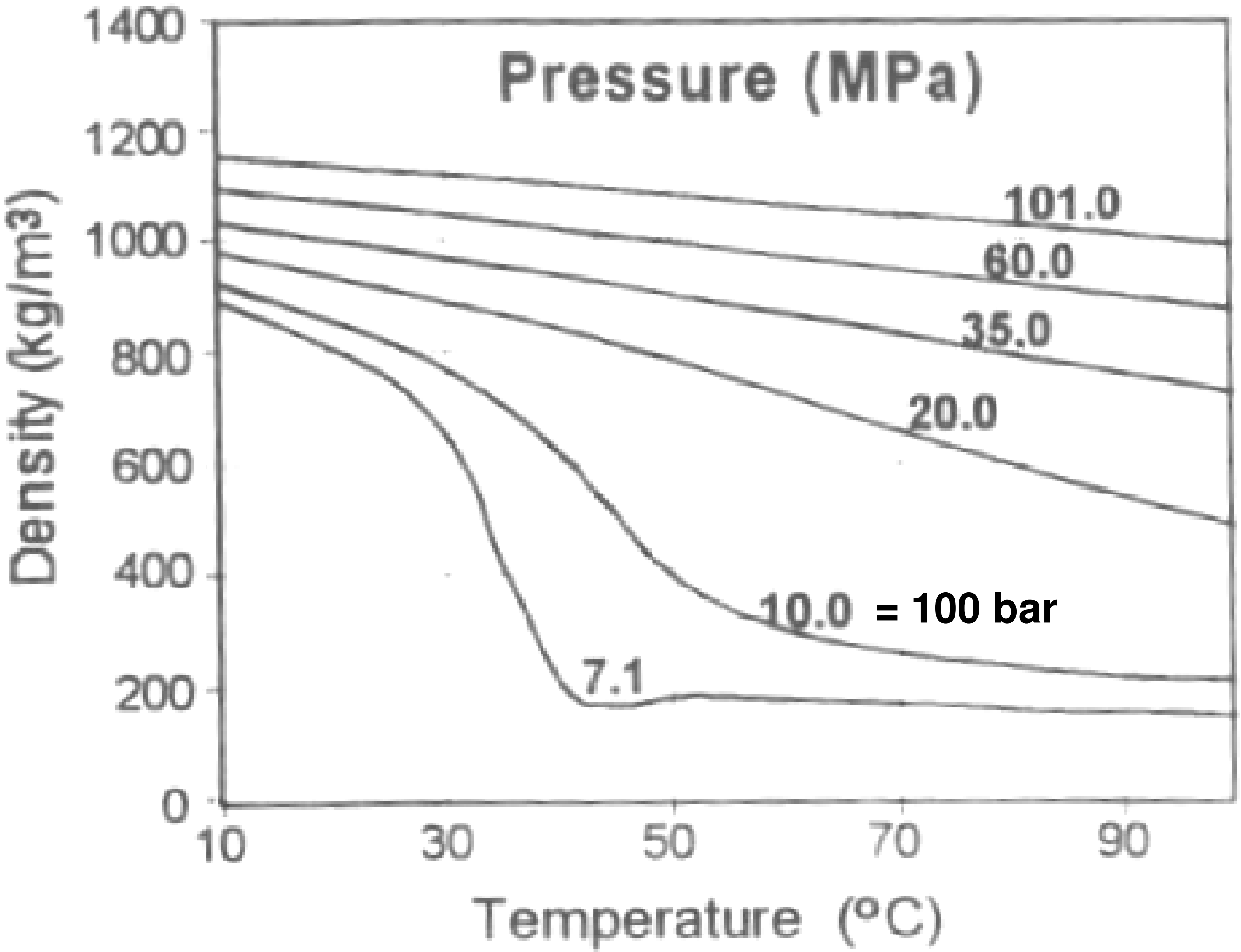
- gas and oil fields
- aquifers
- coal beds
- deap ocean
- mineral carbonation



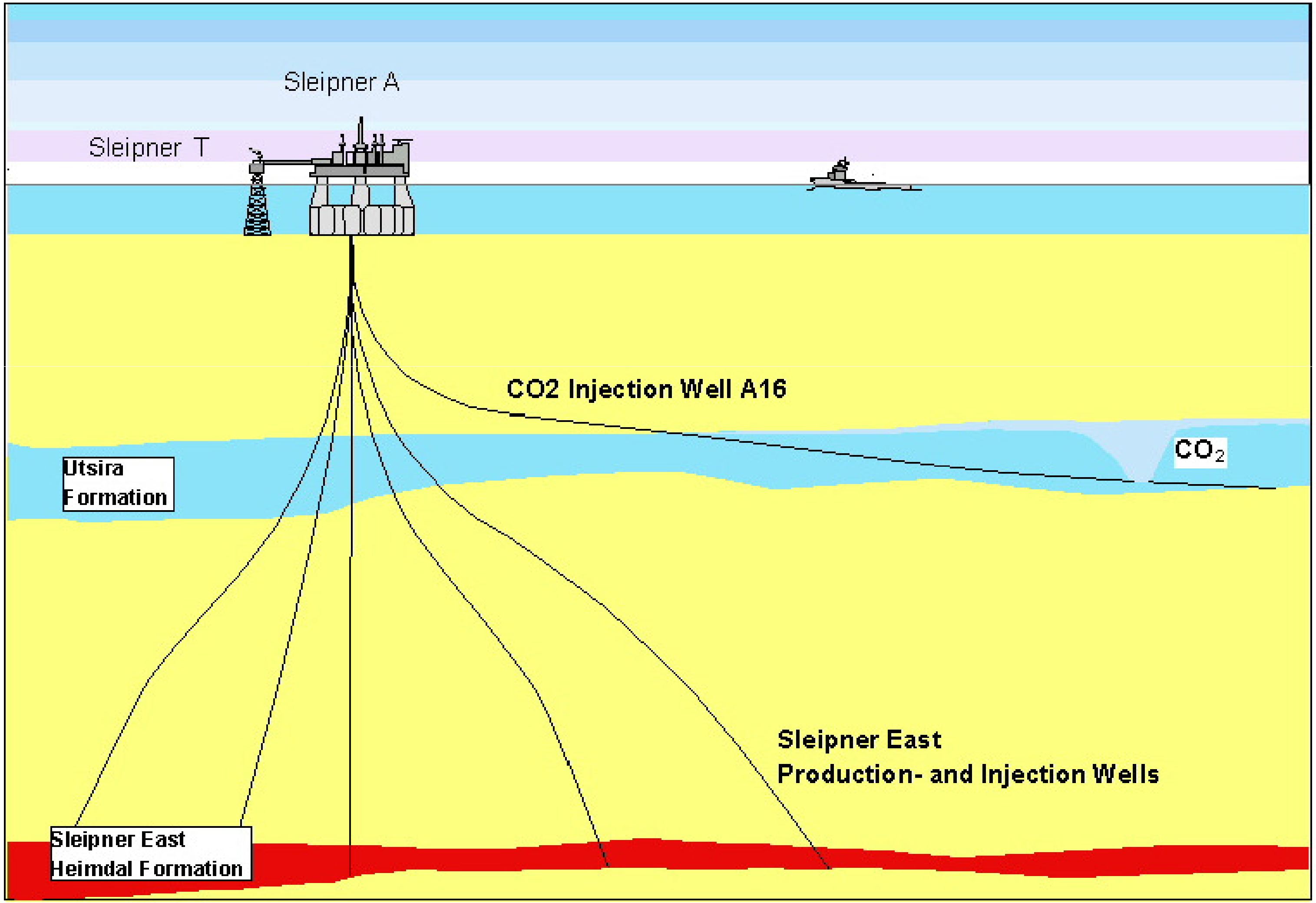
<u>Cold (ocean):</u>
liquid > 50 bar
ρ > ρ(saltwater) for > 300 bar

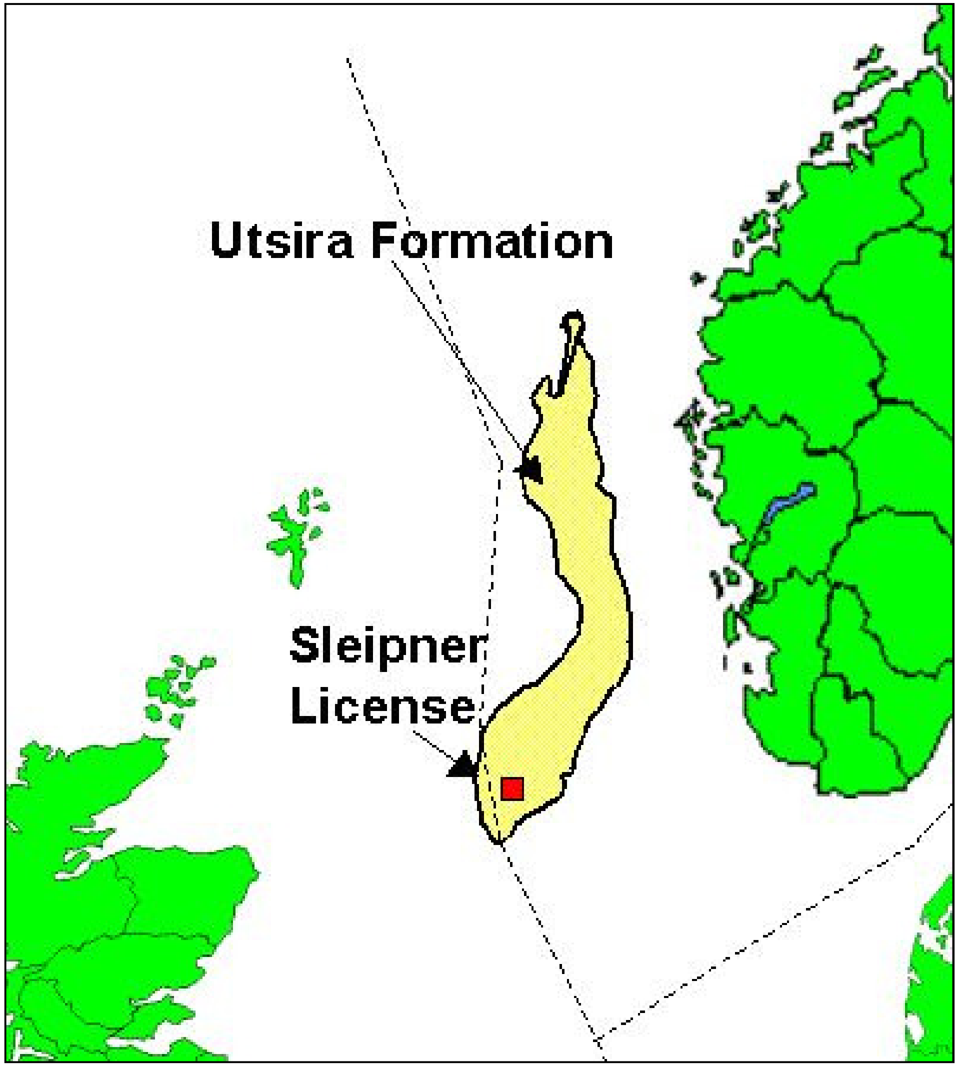
<u>Warm (geological):</u>
Supercritical, ρ < ρ(saltwater)


Land based pipe
Moving ship
Vertical pipe
1500m
Pool of
liquid CO2
3000m


Pressure (MPa)
101.0
60.0
35.0
20.0
10.0
= 100 bar
7.1
Density (kg/m3)
1400
1200
1000
800
600
400
200
0
10
30
50
70
90
Temperature (oC)

SLEIPNER AQUIFER CO2 STORAGE





Statistics
Area - 26 000 km^2
Depth - 550 to 1500 m
Height 200-300 m
Porosity 30-40%

Storage started 1996
1 million ton CO_2/year
(3% Norway's total emission)

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

Possible leakage, "What if"-strategy

1) **Careful study of storage site in advance**
2) **Careful surveillance for early detection of leak**
3) **Stop injection**
4) **Stop leak if possible**
5) **Move CO_2 to other storage site (low cost)**
6) **Recapture of CO_2 using biofuels (expensive)**

Note: 30% will be captured on surface areas,
CO_2 will also dissolve in water (most will be dissolved after 5-50 thousand years),
CO_2 will also be captured by topography.
=> a major fraction is always trapped even with leakage

CO_2 Pipelines

- 3100 km of pipelines
- Transport 114 Mt/y CO_2
- High purity CO_2 mostly
- CO_2 transported in dense phase
- Rated as Low Hazard
- USDOT statistics :
  - Incidents as likely as with gas pipelines
  - Impacts of failure much less significant

Post-combustion

separation of CO_2 from flue gas.

Oxyfuel

separation of O_2 from air, combustion in O2 and recycled CO_2 =>> flue gas of CO_2 and H_2O (removed by condensation).

Pre-combustion

H_2 production by partial oxidation/reforming, shift-reaction, and subsequent CO_2 removal.

Chemical-looping combustion

metal oxide particles transfer oxygen from combustion air to fuel =>> flue gas of CO_2/H_2O gas

Reduction in efficiency: ≈10%-units

Relative reduction in efficiency:

Coal: ≈20-25%

Natural gas: ≈15-20%

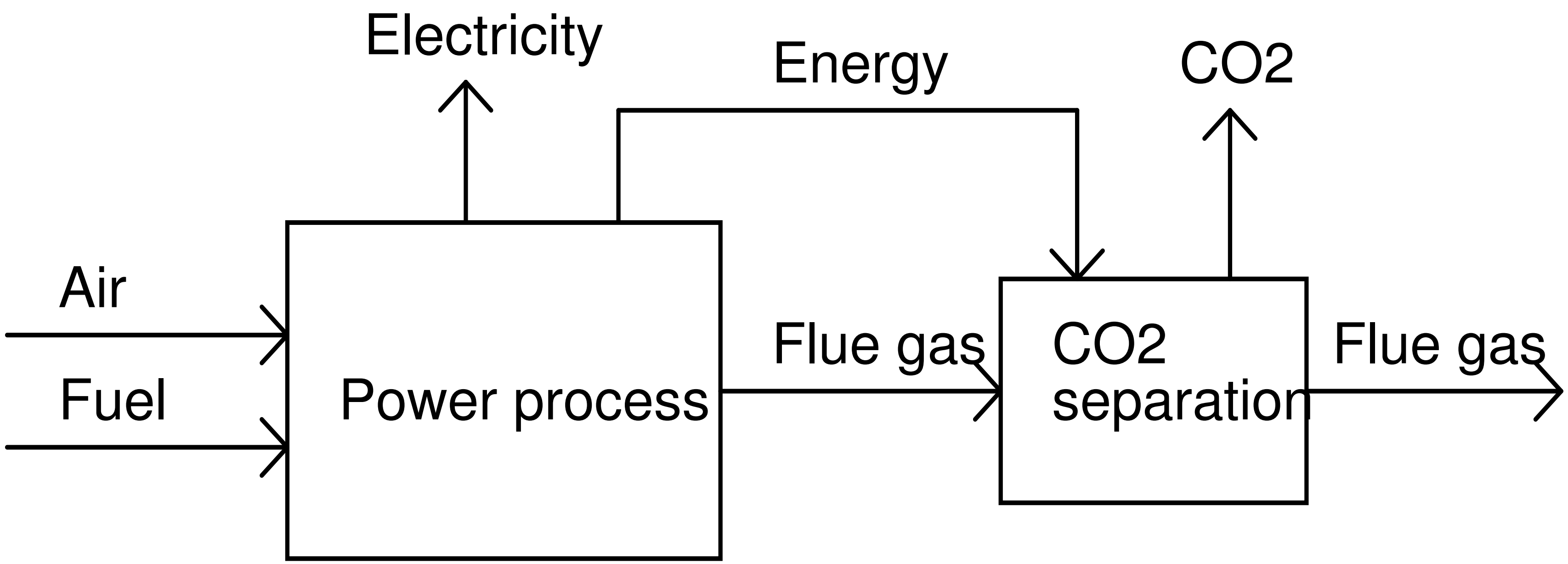
Cost increase for electricity production:

≈50-100%

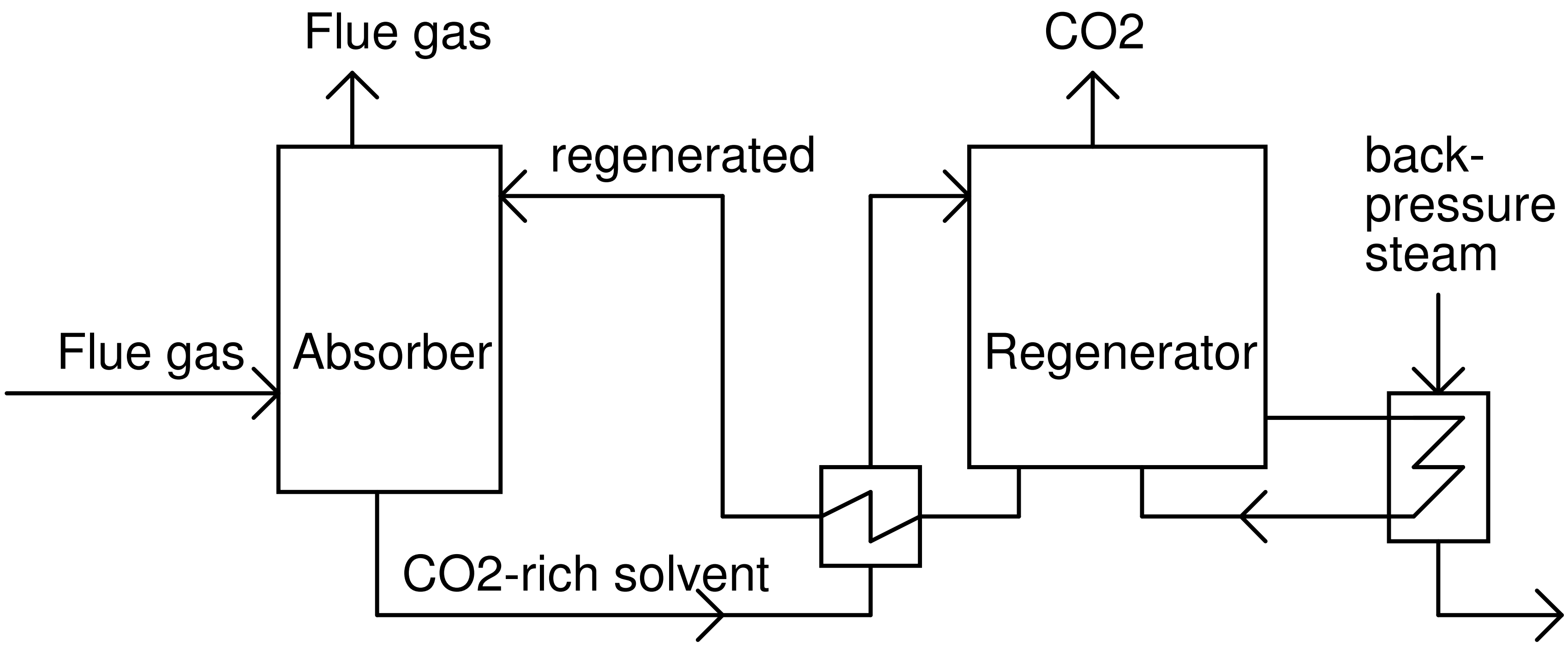
Specific cost (including transport and storage):

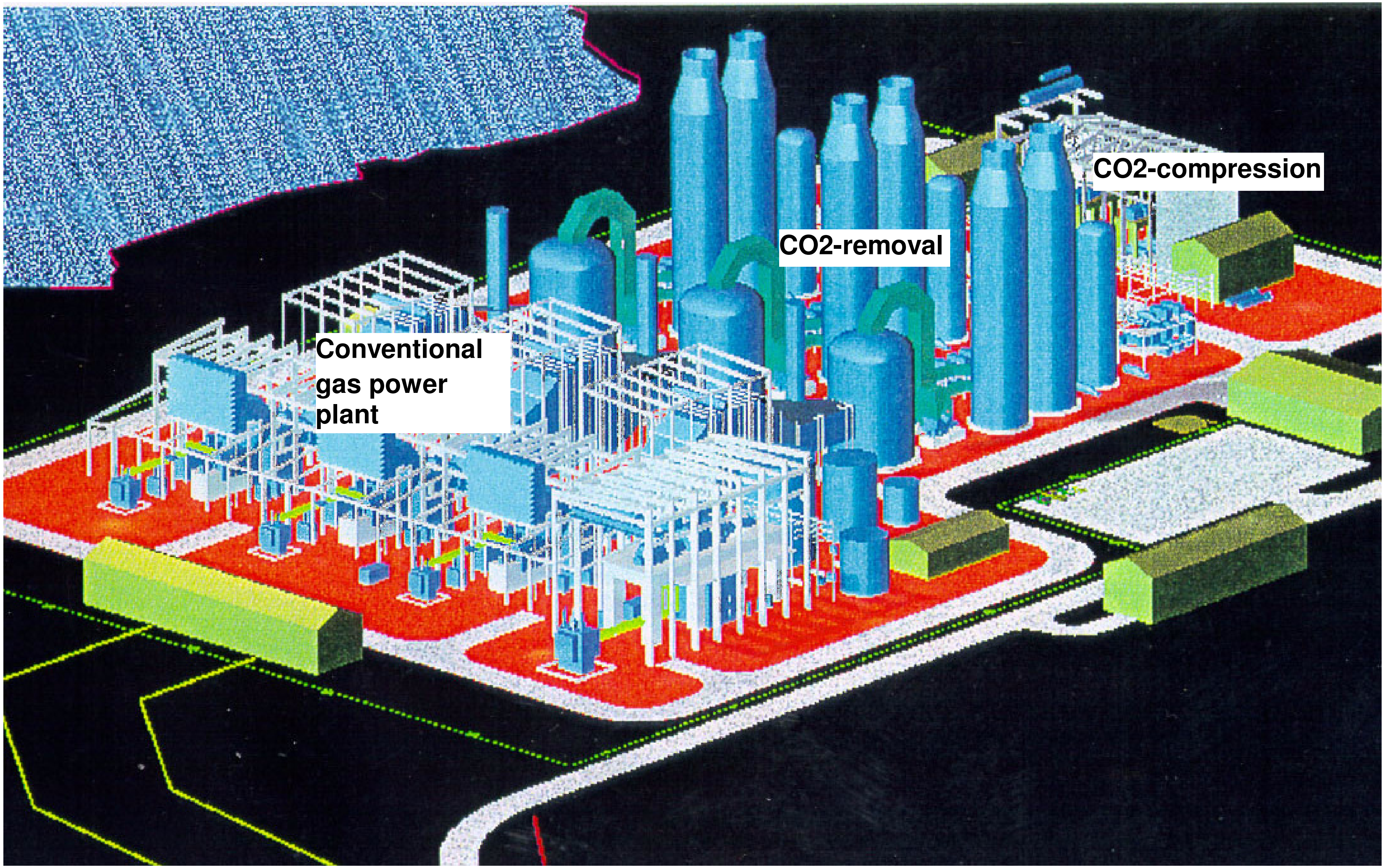
≈500 SEK/ton CO_2

POSTCOMBUSTION

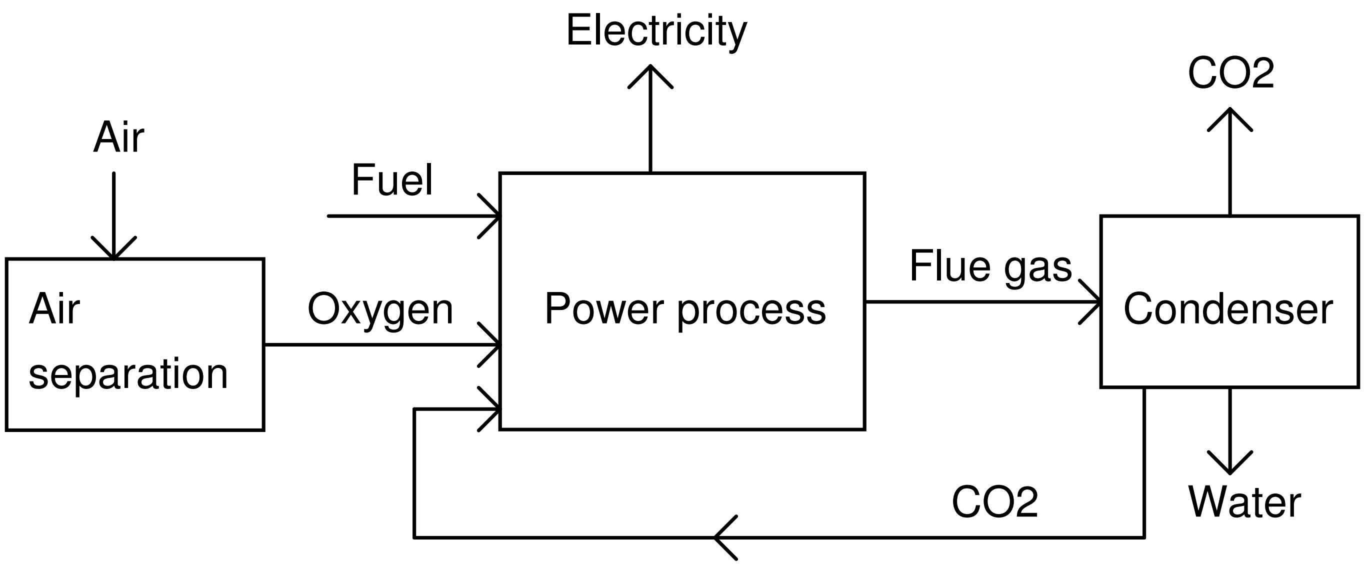


Absorption of CO_2 with monoethanolamine.

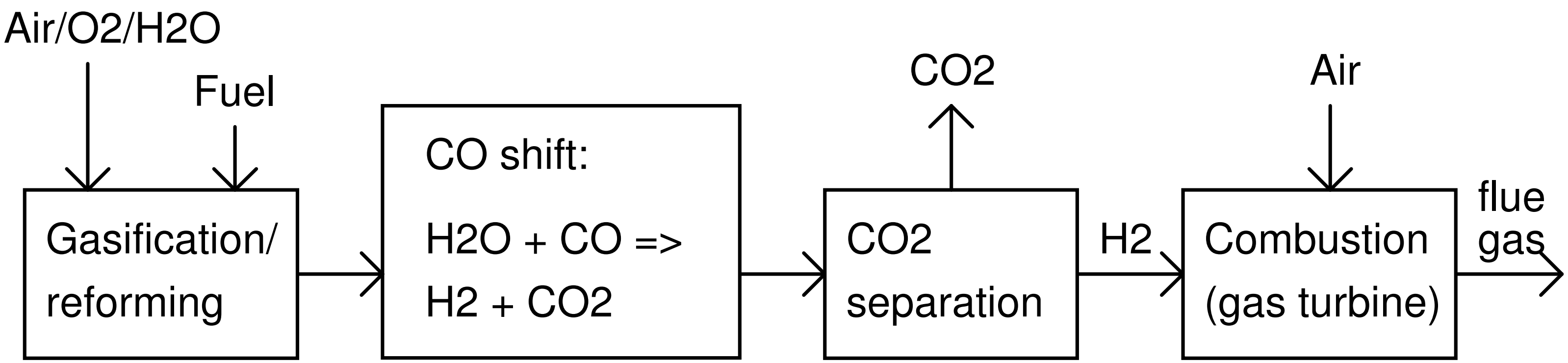



CO2-compression
CO2-removal
Conventional
gas power
plant

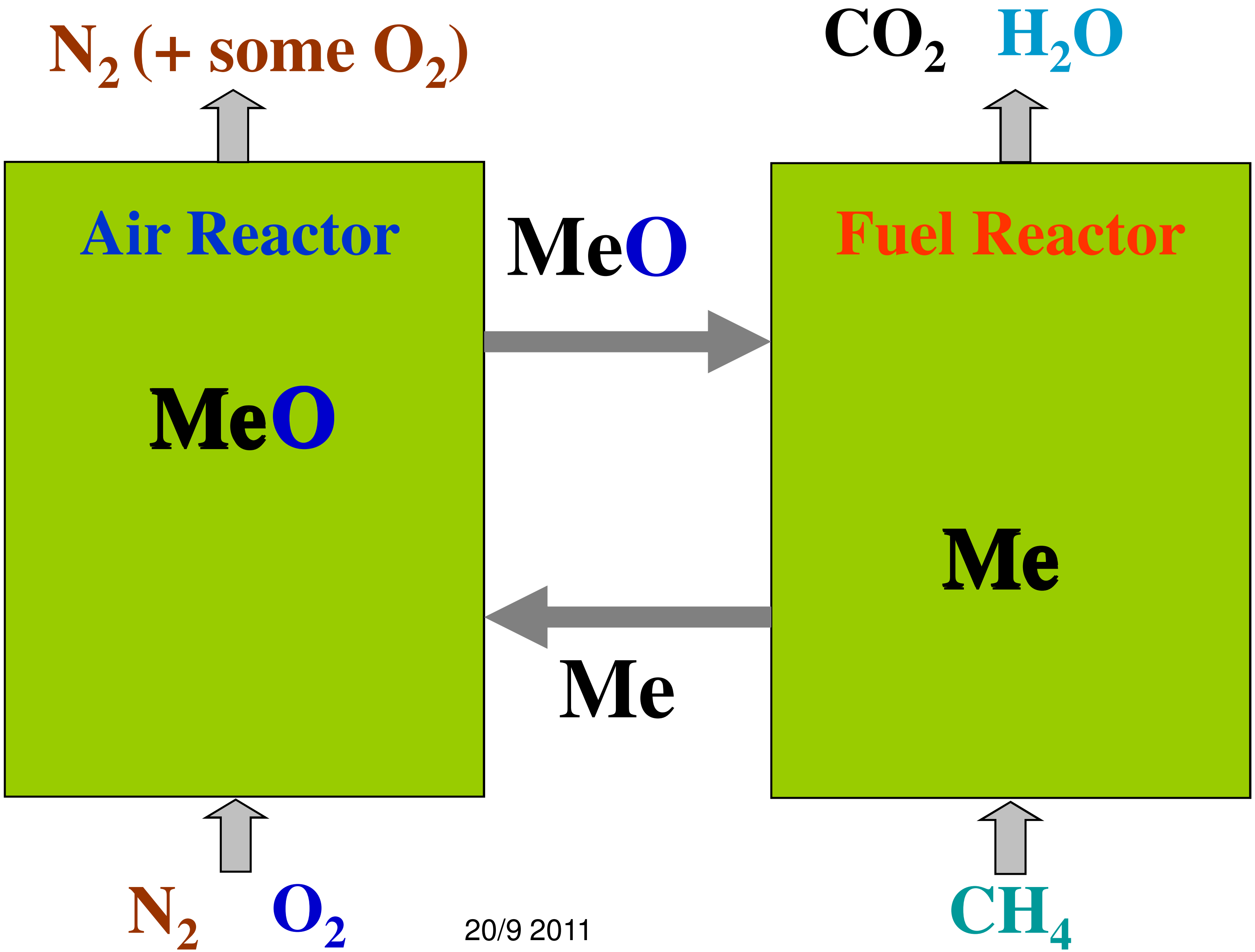
OXYFUEL


Electricity
CO2
Air
Fuel
Air separation
Oxygen
Power process
Flue gas
Condenser
CO2
Water

PRECOMBUSTION



Chemical-looping combustion



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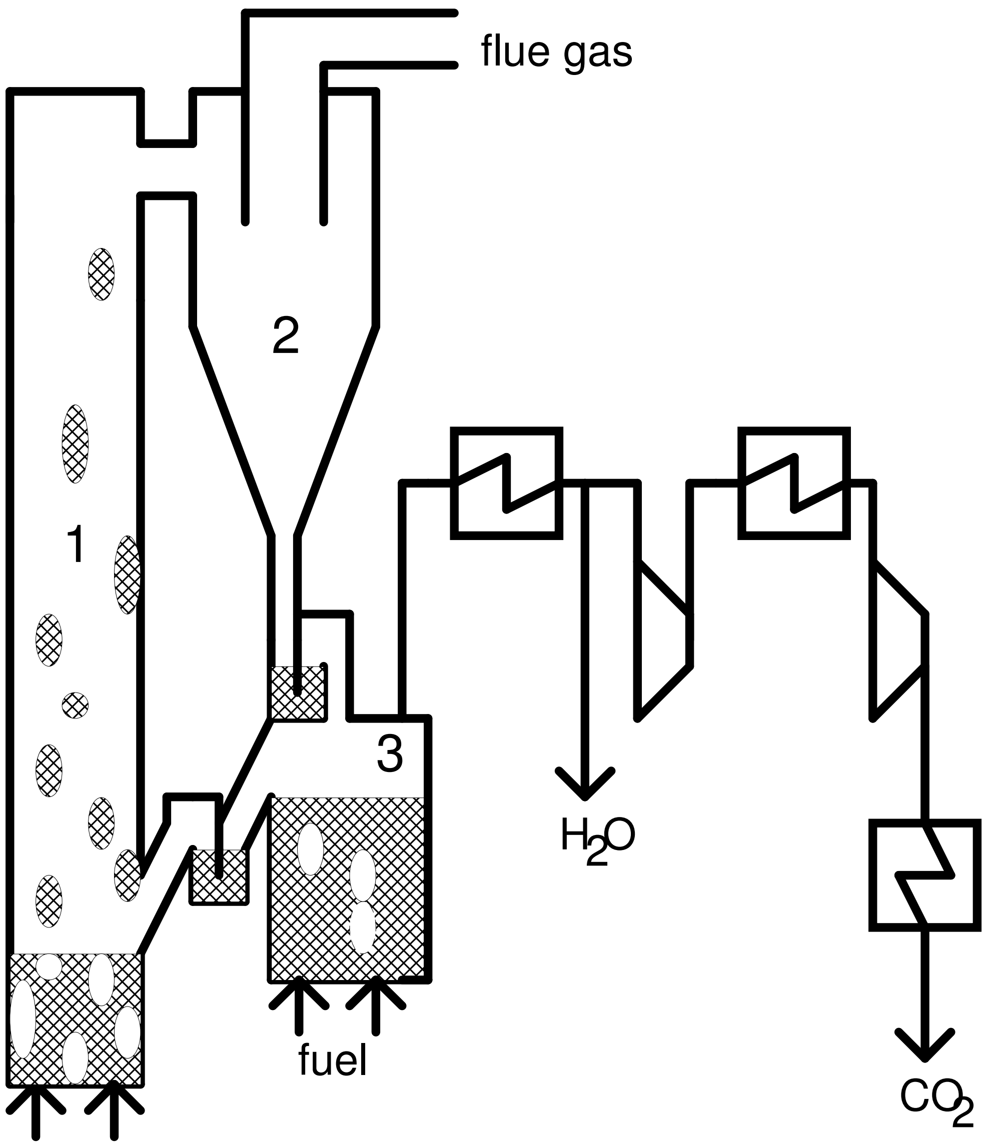
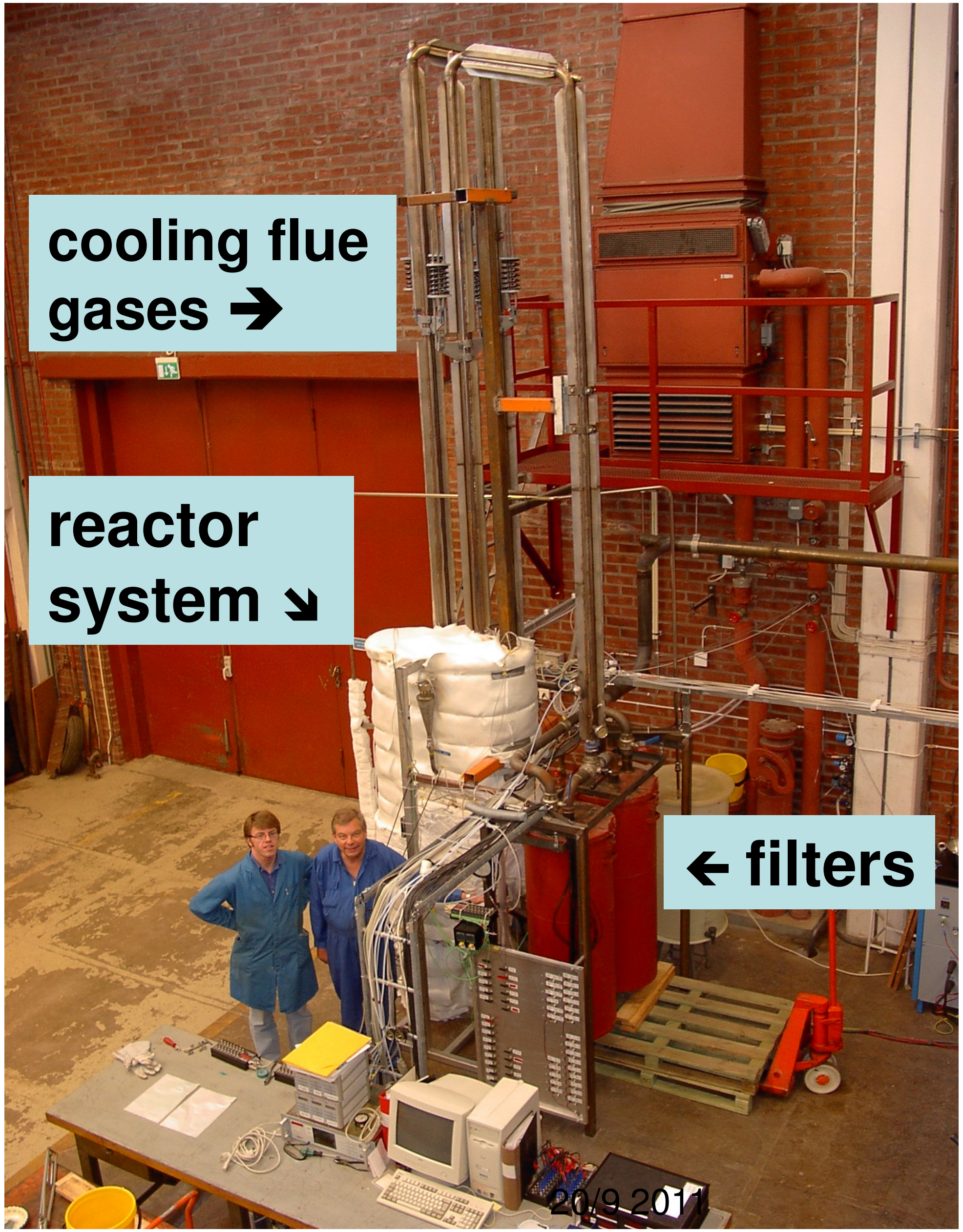
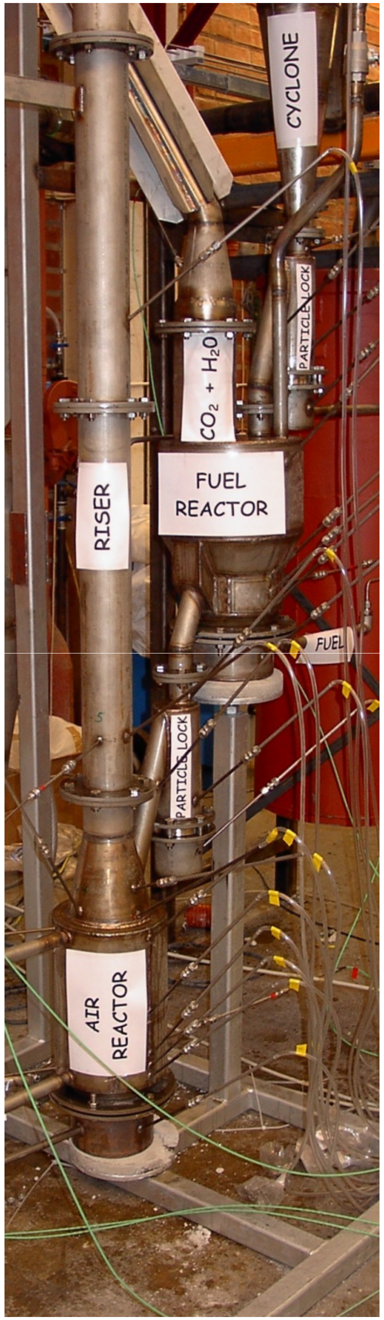
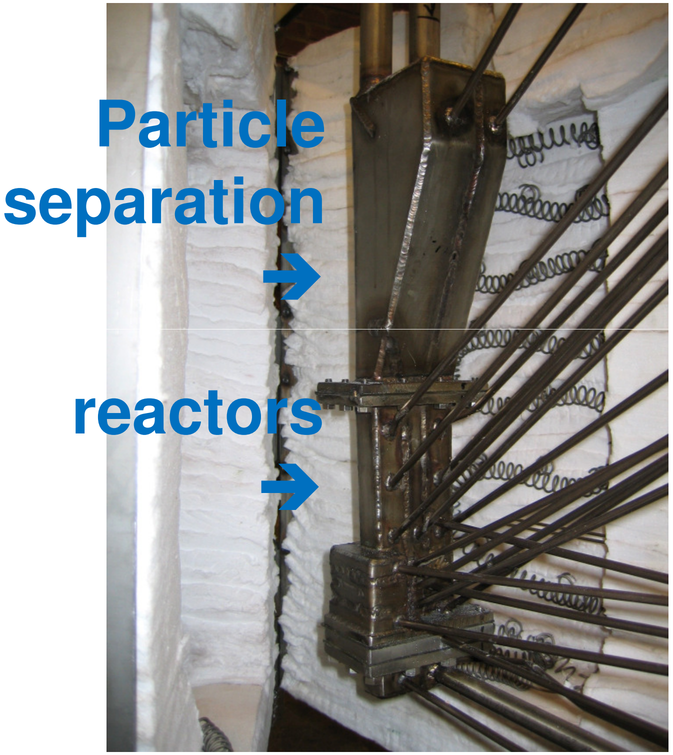

flue gas
2
1
3
H_2O
CO_2
fuel
air

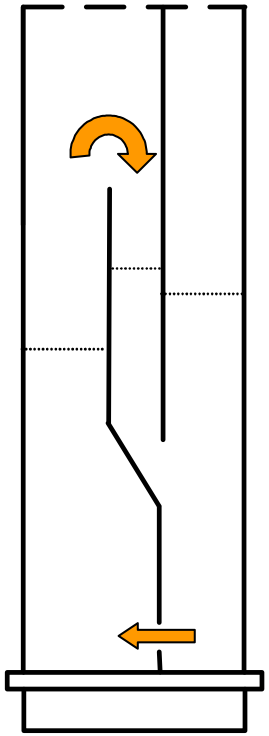
Chalmers' 10 kW chemical-looping combustor 2003

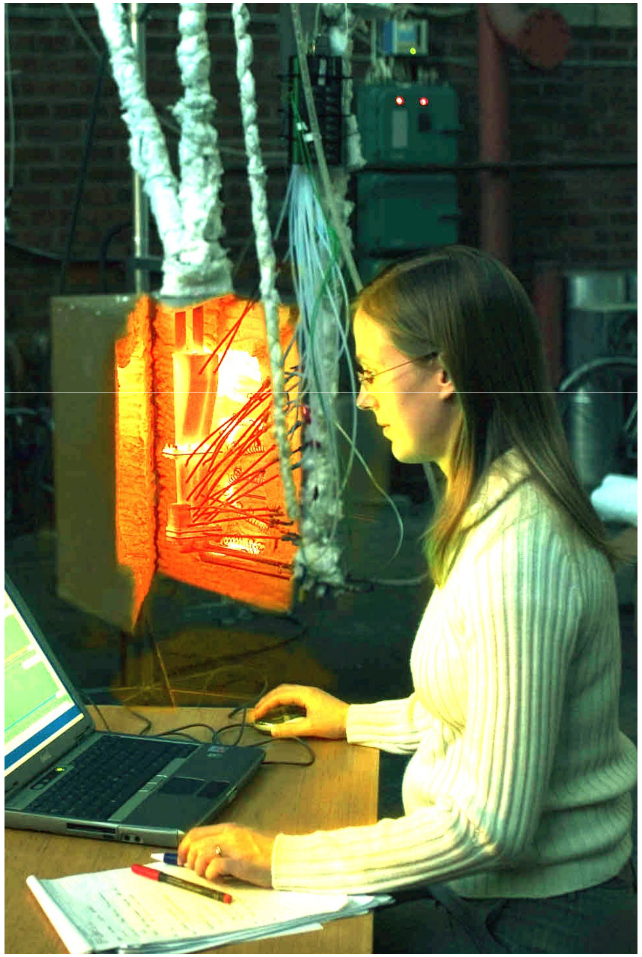




Chalmers' 300 W chemical-looping combustor 2004

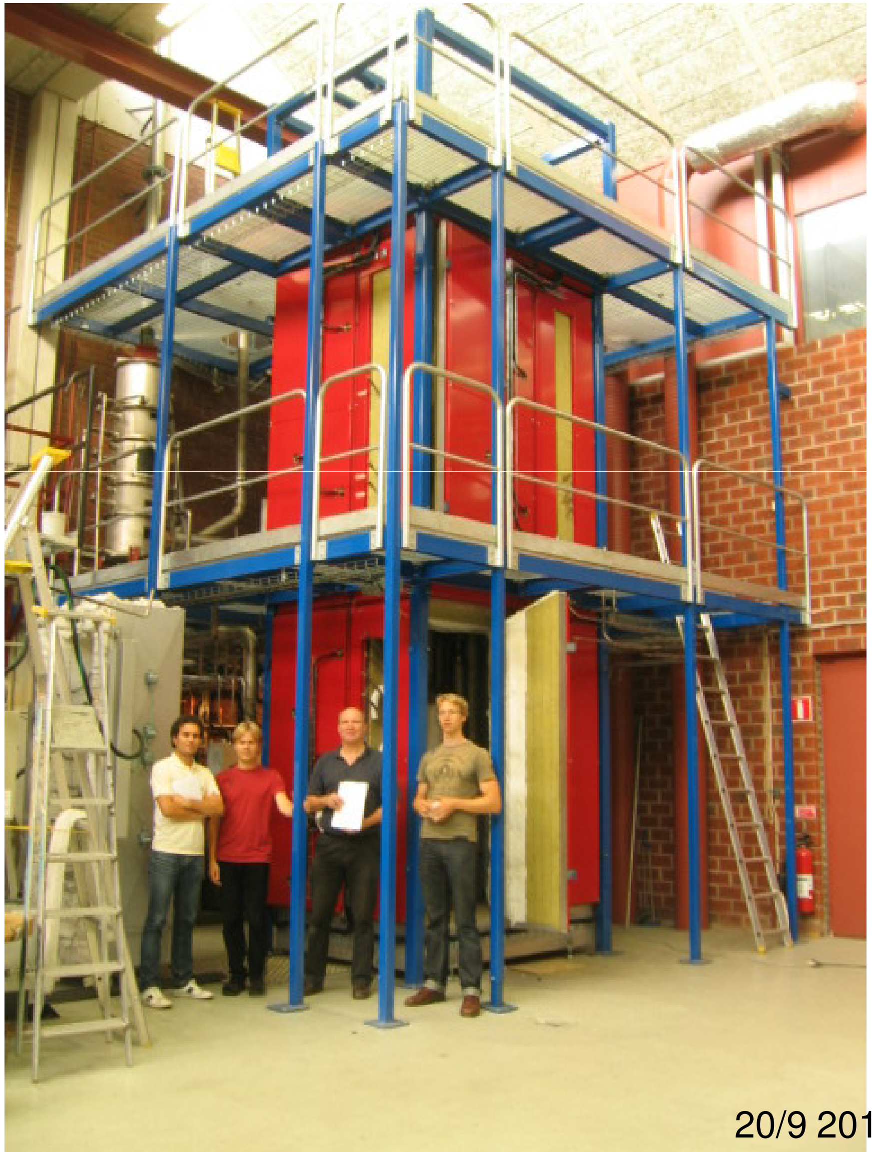


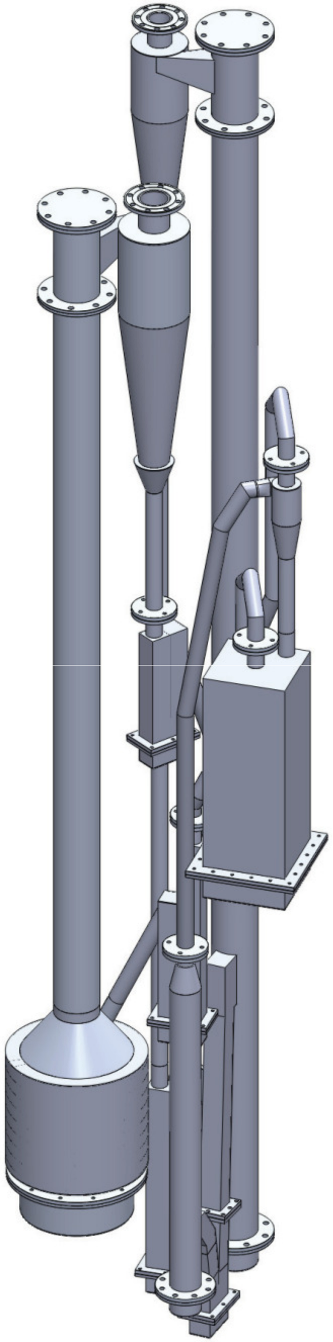




Chalmers' 10 kW chemical-looping combustor for ***solid fuels,*** 2005

Chalmers' 100 kW CLC for solid fuel, first operation: August 25, 2011





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Status chemical-looping combustion:

- Technology demonstrated in small scale, >2500 h of operation at Chalmers
- Oxides of nickel, iron, copper and manganese successfully tested in operation
- 130 h of operation with solid fuels
- Cost estimate solid fuels: 10 €/tonne CO_2
- Expected efficiency penalty solid fuels, 2-3%
- Low-cost natural mineral suitable for solid fuels successfully tested
- Chemical-looping reforming: hydrogen production with CO_2 capture: hydrogen cost: 0.38 kr/kWh

CO_2 CAPTURE AND STORAGE COSTS

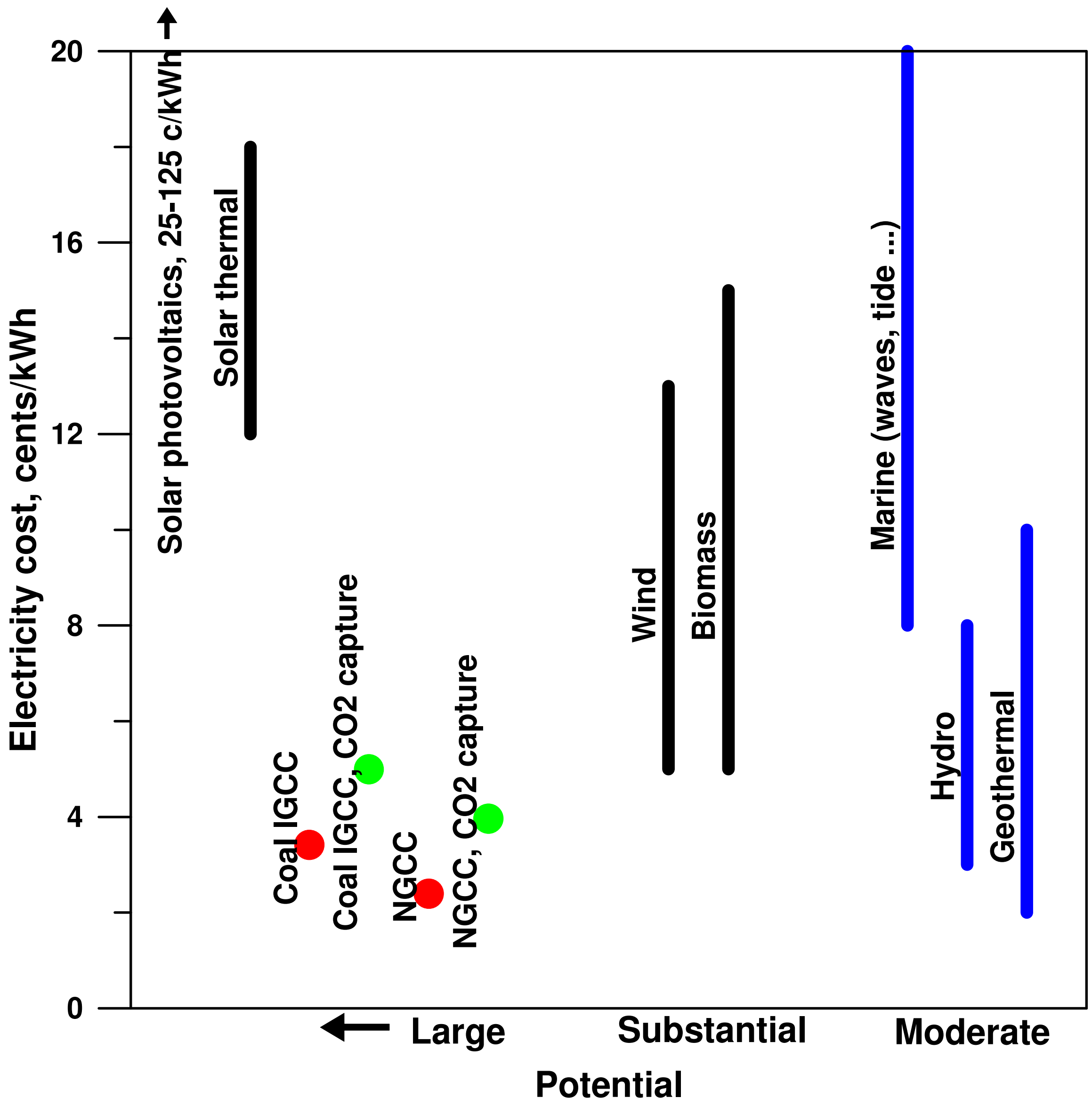
	€/ton CO_2
Storage	>2-3
Transport, 100 km	>2-3
Compression	7
Separation	~40
Total	50
Incr. prod. cost electr.	50-100%
	2-4 c/kWh

Example:

European Union (EU15): 3000 million ton CO_2/year
(1500 Mton from large point sources)

Reduce to half at 50 €/ton CO_2

75 000 000 000 €/year
200 €/citizen,year
1% of GDP



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* carbon intensity ≈ 1 kg CO_2/€ (EU half of that)

=> "avoidance cost" << 1 €/kg CO_2

	€/ton CO_2	€/kg CO_2
CO_2 trading, EU goal 2020*	80	0,08
avoidance costs:		
CO_2 storage	2	0,002
CO_2 capture & storage	20-50	0,02-0,05
CLC with solid fuels ?	10	0,01
example fuel cost:		
petrol, 11:50 kr/L	500	0,50
coal, 600 kr/ton	20	0,02

*corresponds to an increased cost of 60 öre/kWh_{el} for coal-fired power plant

This lecture:

http://www.entek.chalmers.se/~anly

click on “Föreläsningar/presentations”

CO_2 homepage:

http://www.entek.chalmers.se/~anly/co2/co2.htm

Lyngfelt, A., "Koldioxid kan slutlagras i jorden ", *Forskning & Framsteg*, nr. 7 (2001) 39-43.

Lyngfelt, A., "An Introduction to CO2 Capture and Storage" *Second Nordic Minisymposium on Carbon Dioxide Capture and Storage*, Göteborg, October 26, 2001, pp. iv-xii.