Negative CO2

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Nordic Energy Research

Negative CO_2 Emissions

Techniques and thoughts on how to achieve this

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CHALMERS

LUBIRC seminar

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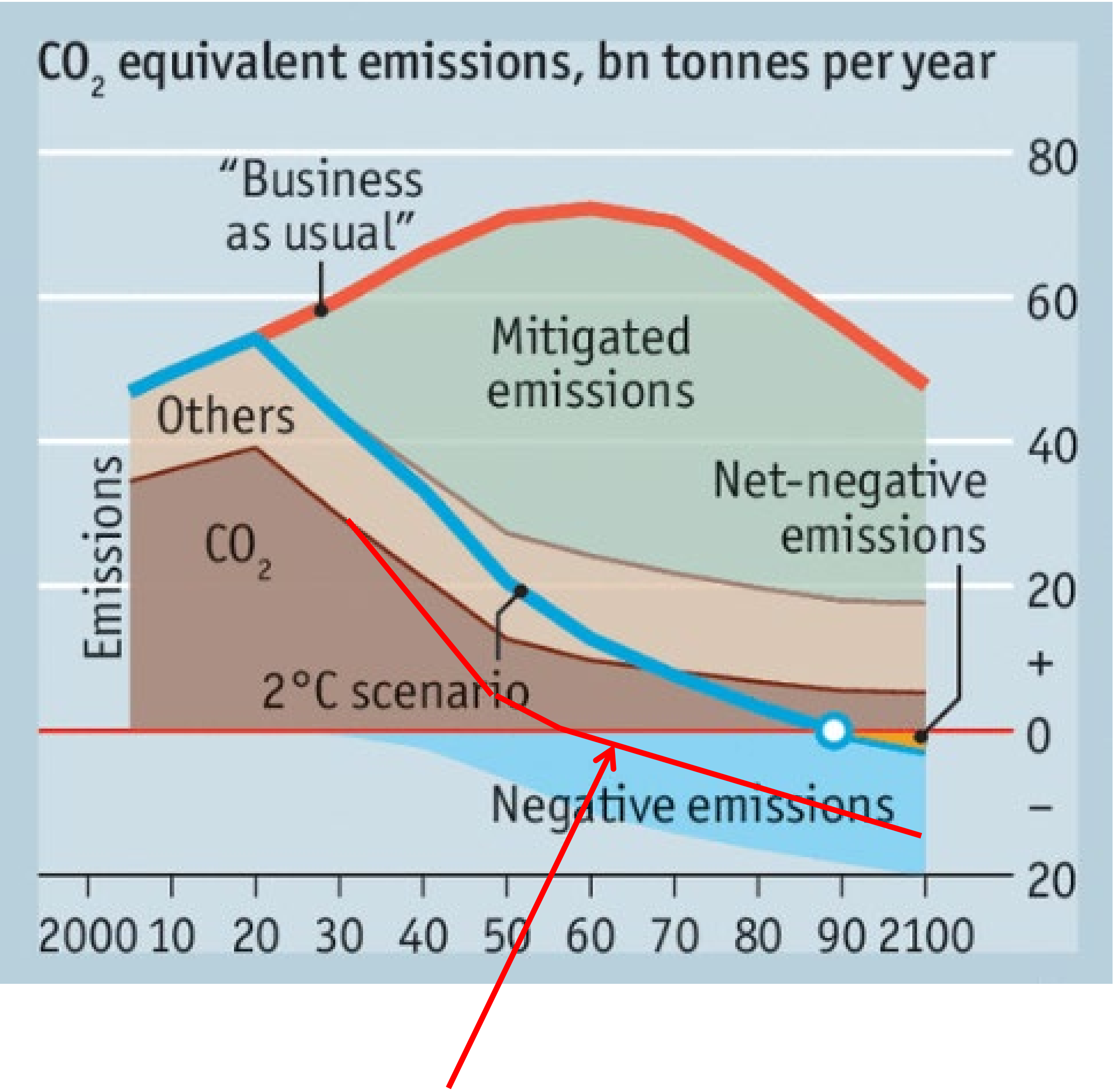


Net CO_2 emissions

Cumulative negative emissions:

≈ 700 Gt

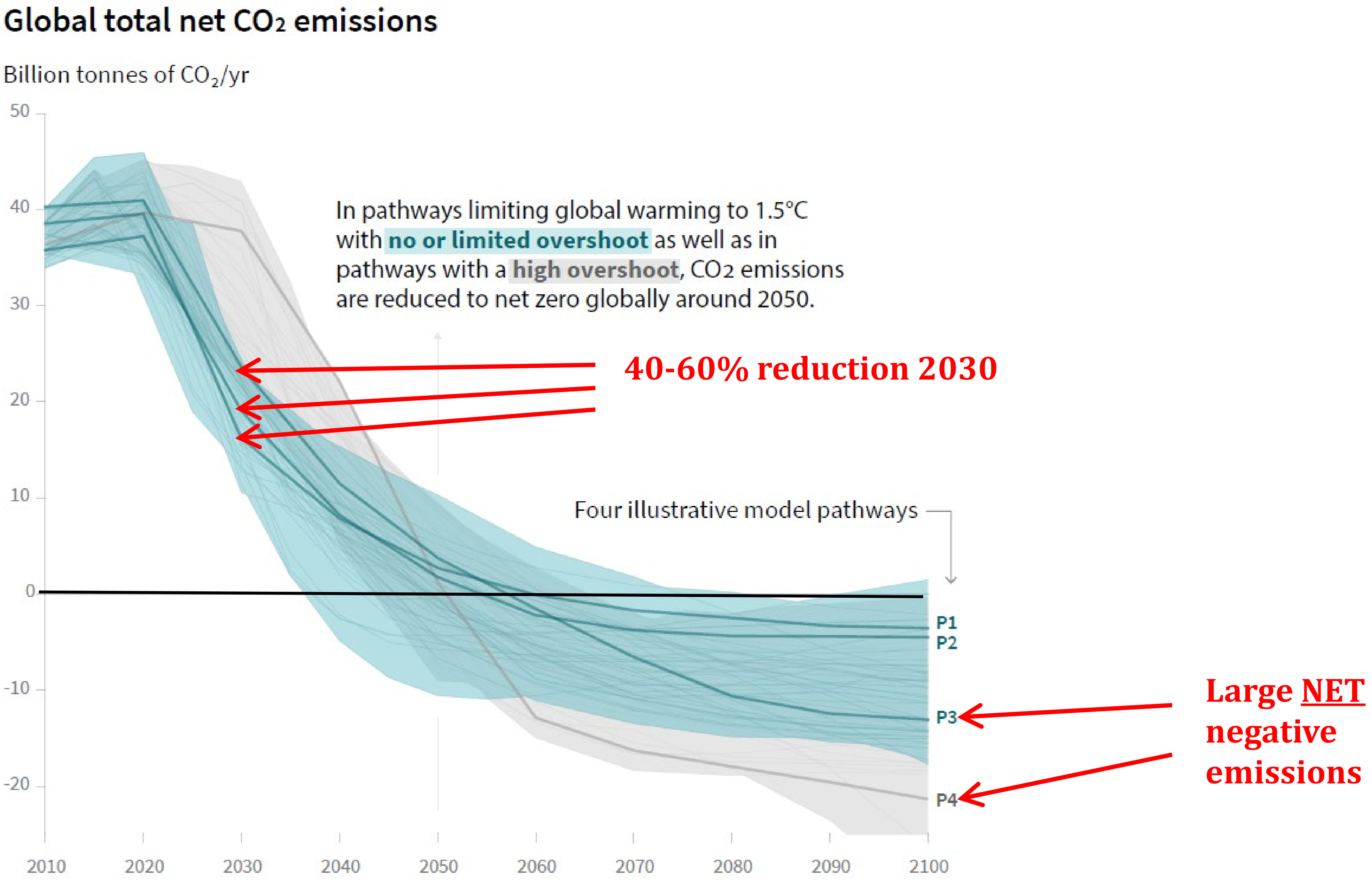
or

≈ 100 tonnes/capita

or

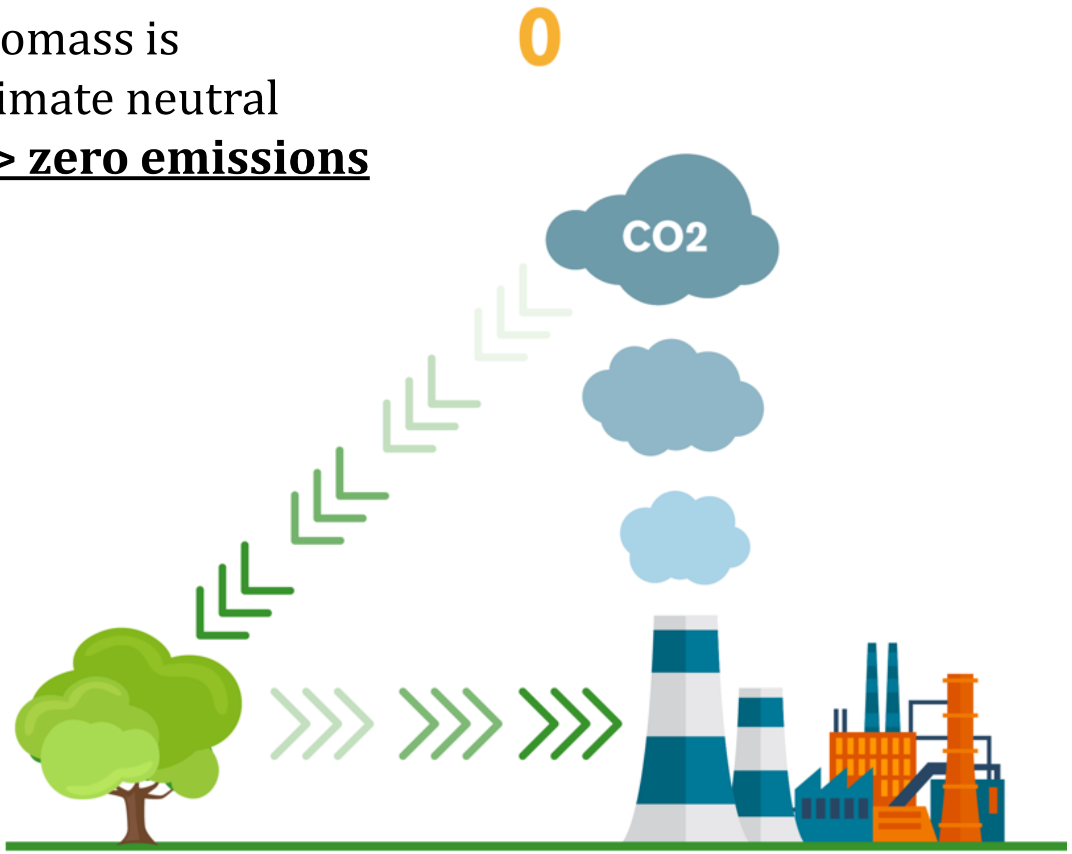
≈ 100.000 SEK/capita

1,5 degree target

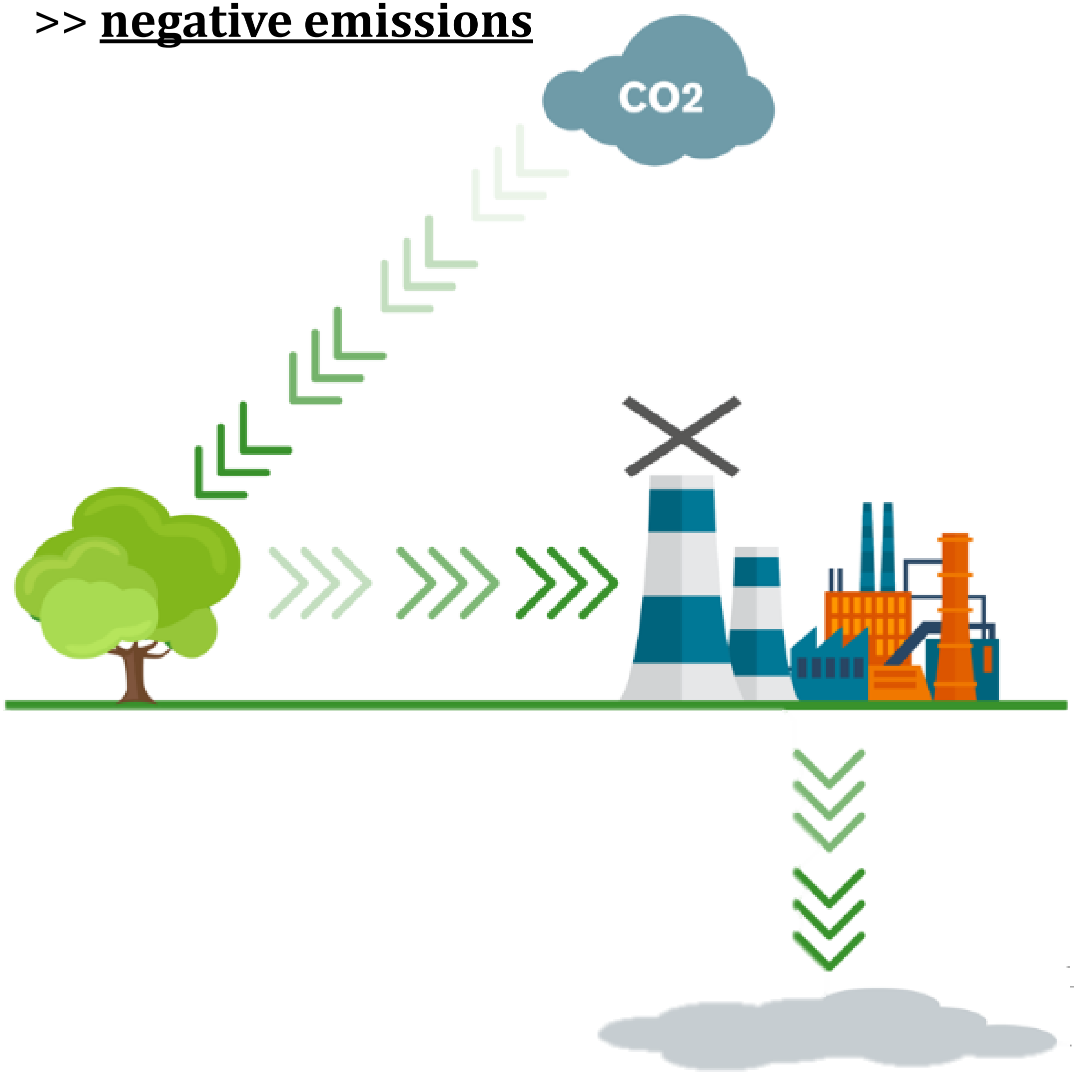


Negative emissions with Bio-CCS (CCS = Carbon Capture and Storage)

Combustion of
biomass is
climate neutral
<u>>> zero emissions</u>



Combustion of
biomass with
CO2 capture
>> **<u>negative emissions</u>**



Principles of Negative Emissions

Plants are good at capturing CO_2. Ways of preventing CO_2 from returning to atmosphere:

- **Capture and storage of CO_2 from combustion of biomass/biowaste, Bio-CCS**
- **Afforestation/Reforestation**
- **Bio-char for soil improvement**
- **Agricultural practices to increase carbon content in soil**

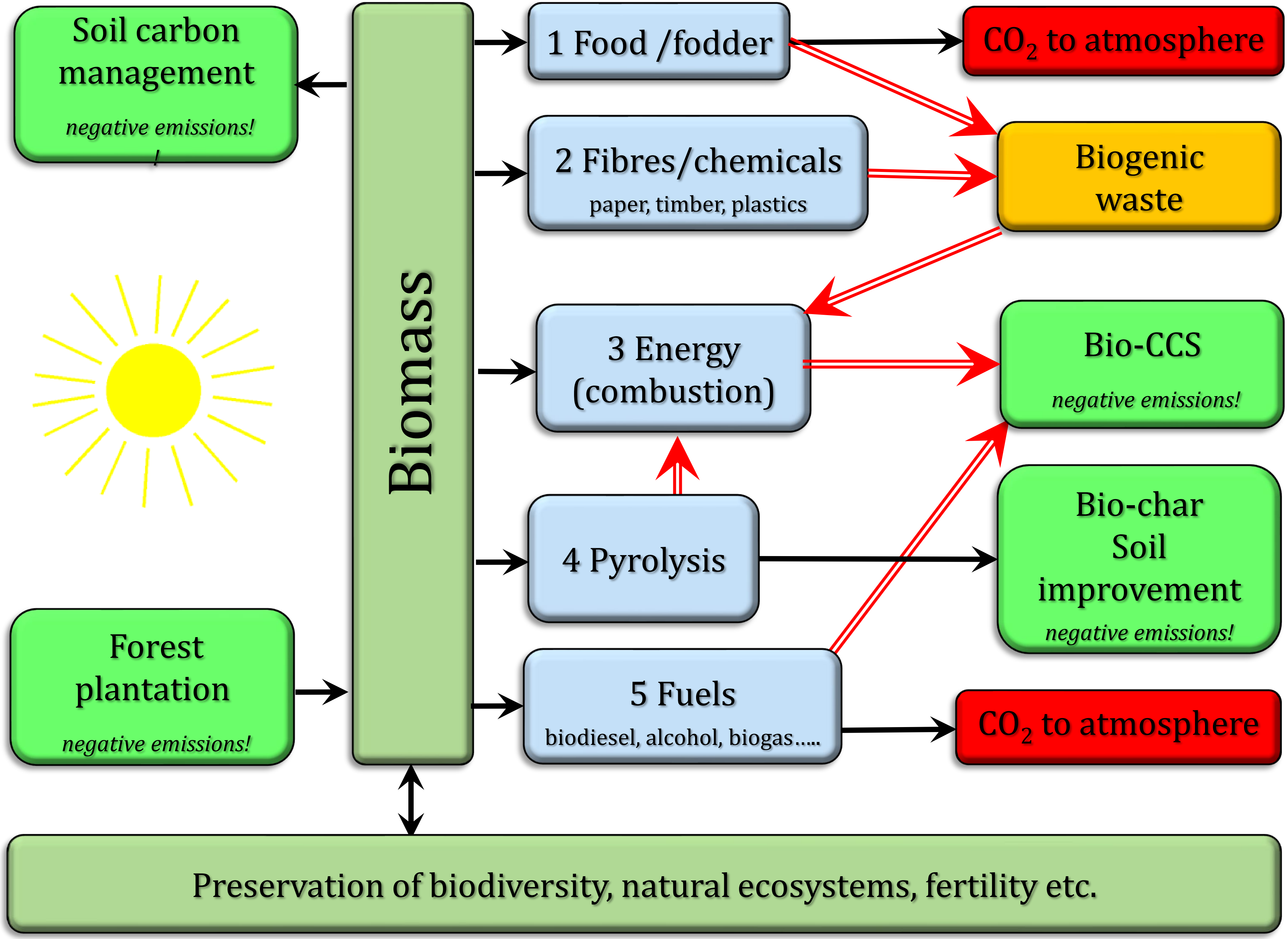
Non-biogenic paths:

- **Enhanced weathering**
- **Ocean liming (CO$_2$ capture and storage from lime calcination plus distribution of lime)**
- **Direct Air Capture (~300 times lower concentration as compared to ”chimney” capture)**

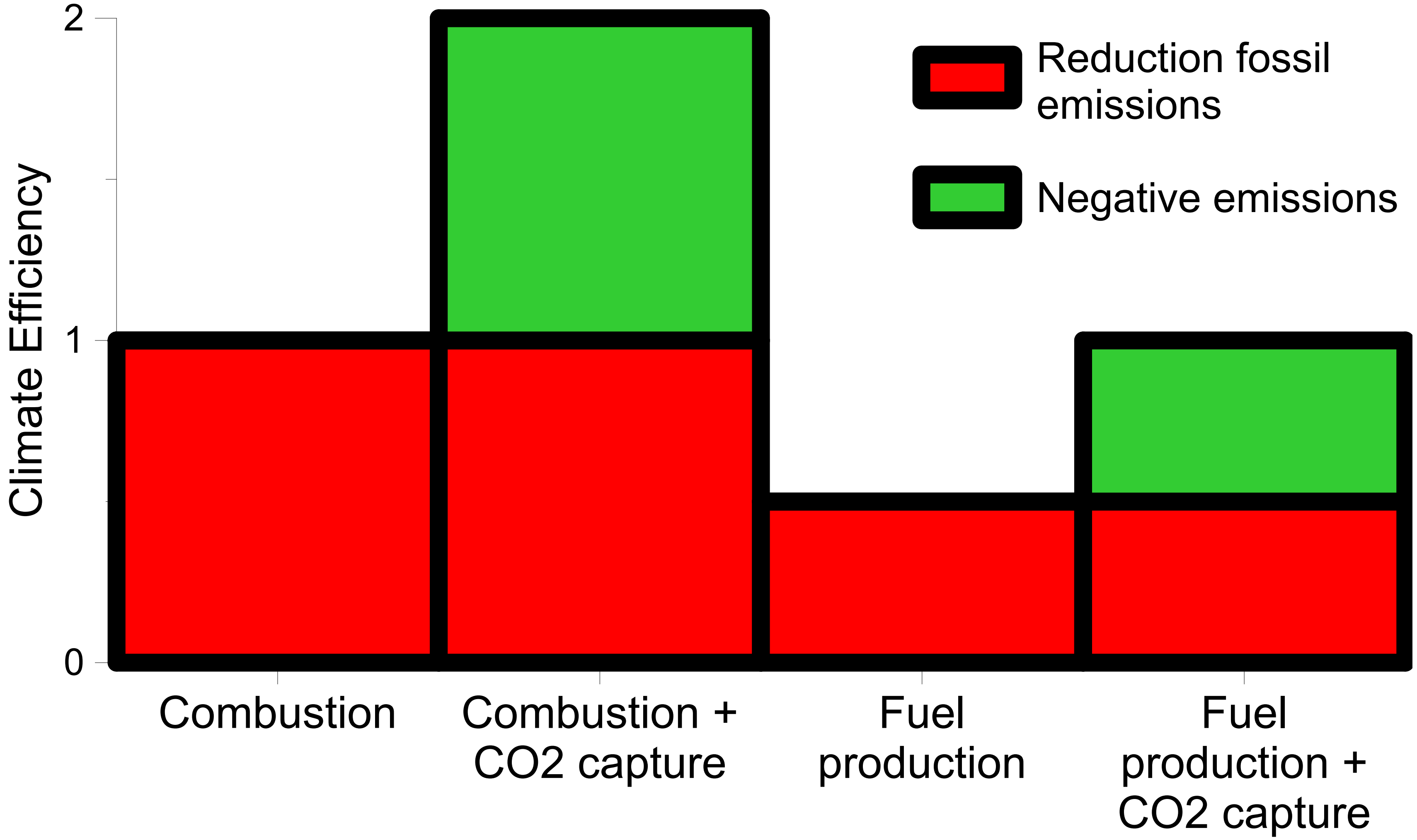
Bio-CCS/BECCS
Making good use of waste from our employment of biomass

Total biomass extraction today 20 Gt/year (as CO_2) (fossil emissions >35 Gt/år)

Of these 20 Gt is 1/3 respiration (human beings + live stock)
Ideally the rest could be used for negative emissions



How is the carbon captured by the biomass used most efficiently for the climate ?

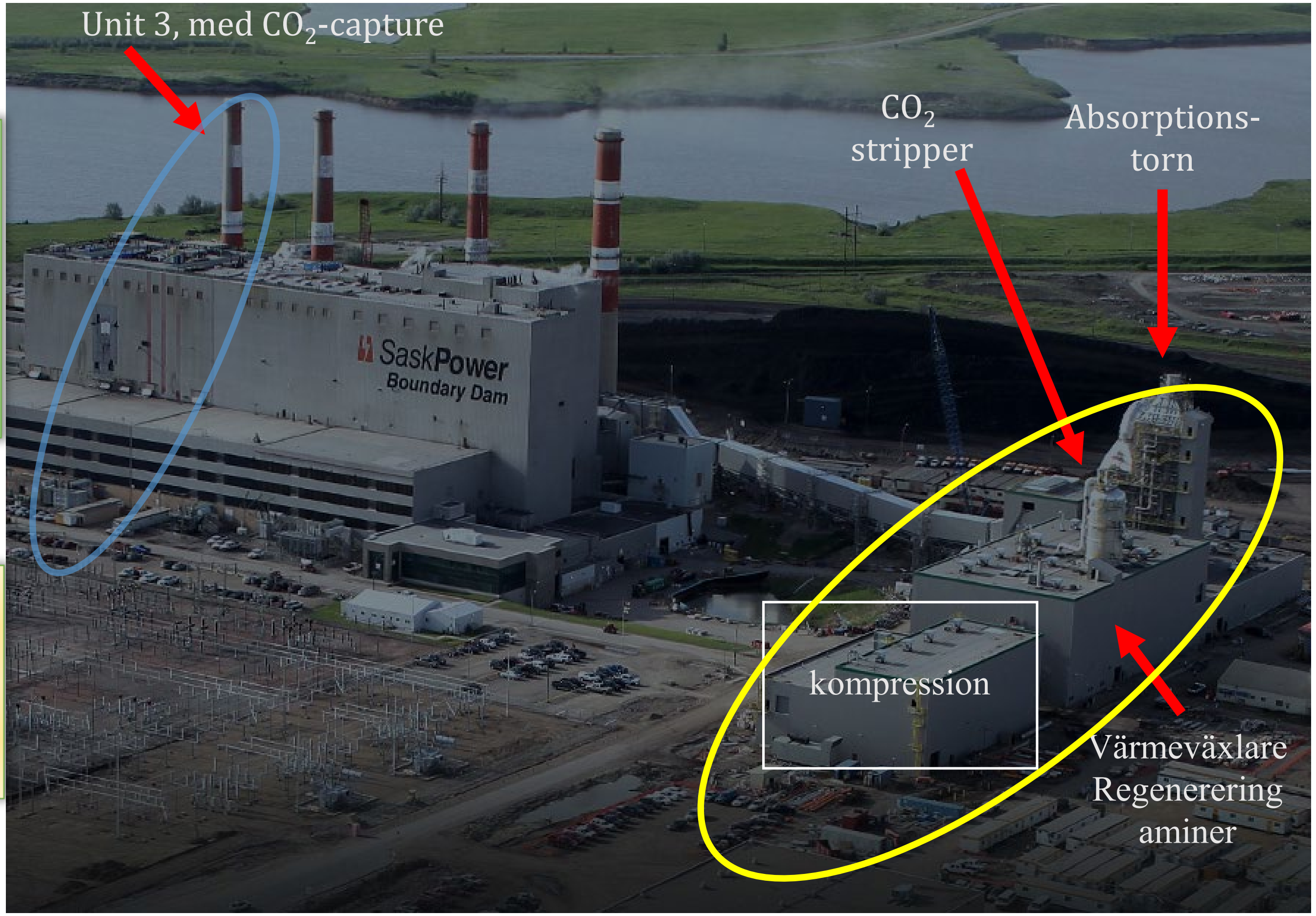


CO2 capture, an example

Boundary Dam, Canada. 115 MW_e

Coal power plant with CO_2-capture:
1 Mton CO_2/year

In operation since october 2014.



Owner (Sask Power) says:

Next time 1/3 of cost:

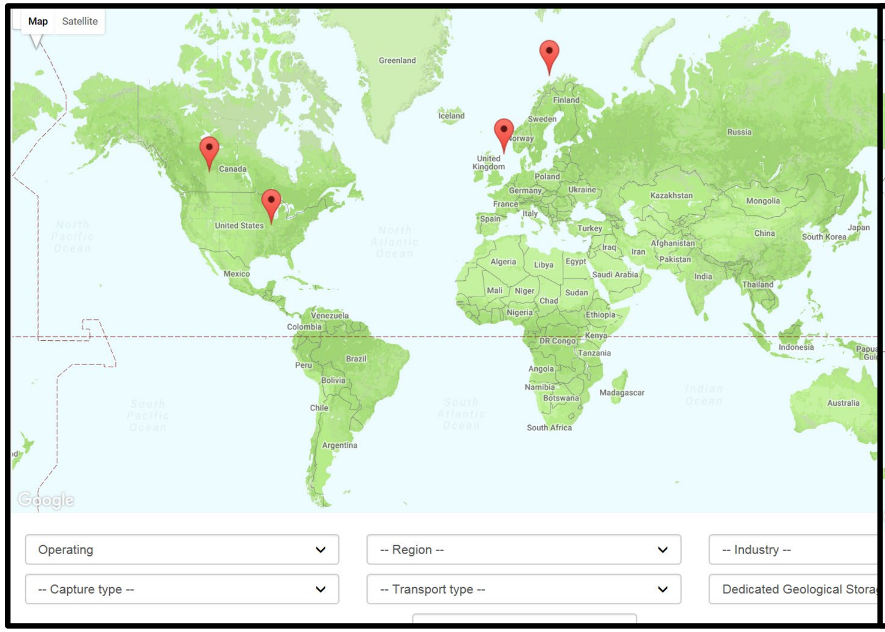
45 $/ton CO_2

Significant cost and energy penalty of gas separation

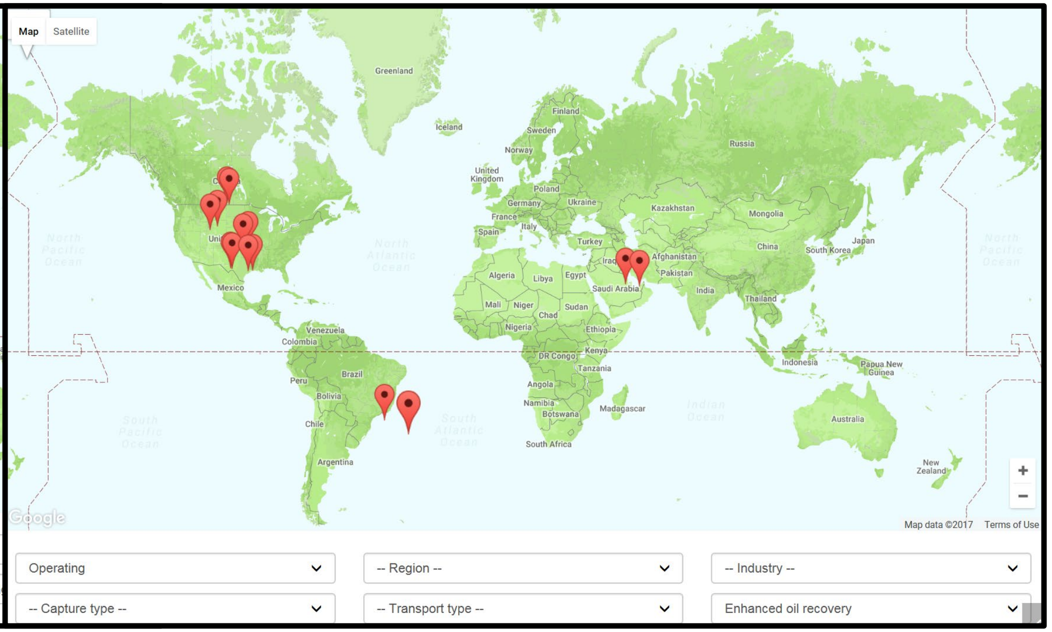

Petra Nova, Texas,
coal fired power plant
>1 Mton/year
Operation since
January 2017

Large-scale storage today

For climate only



Enhanced oil recovery

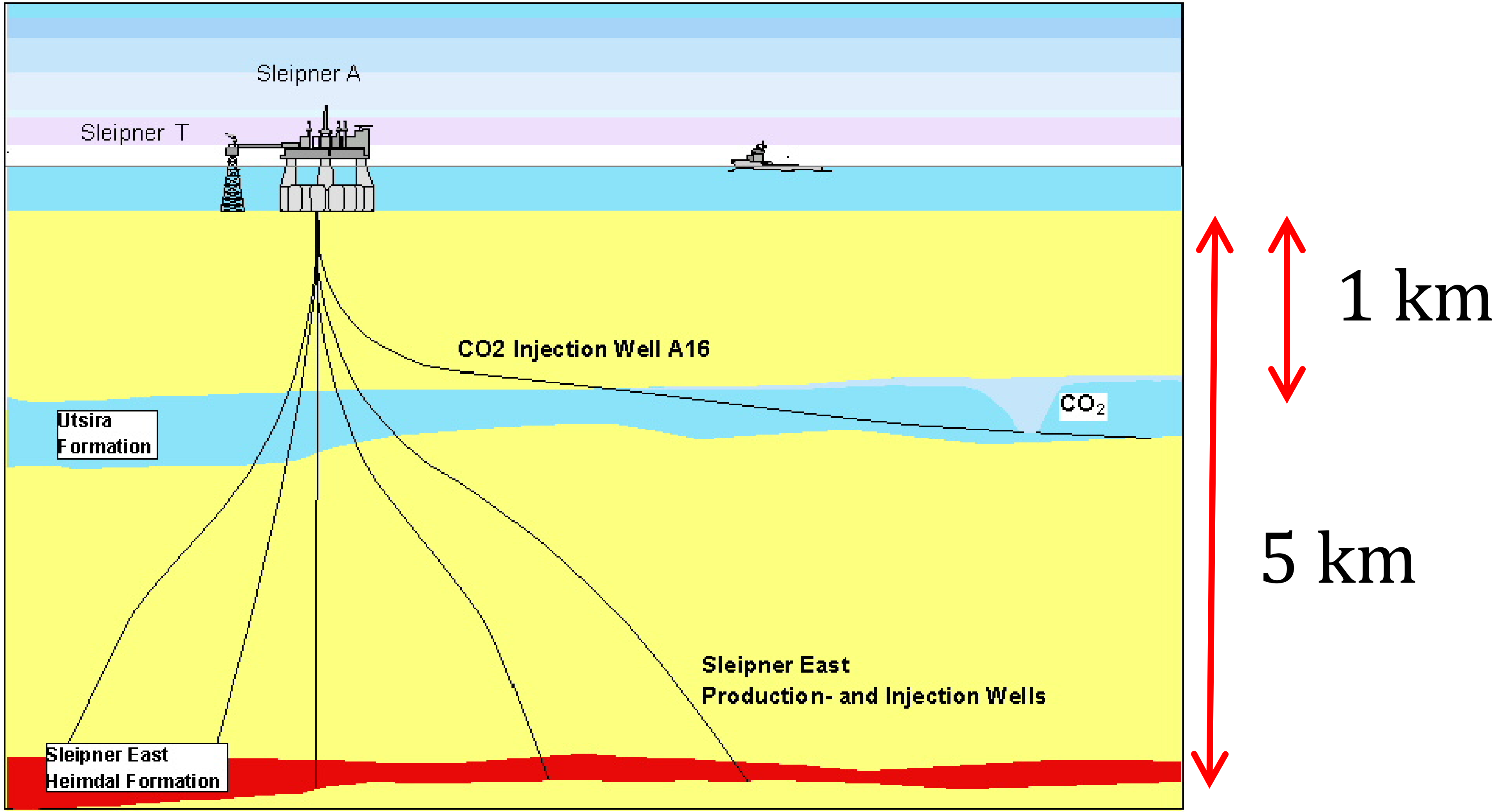


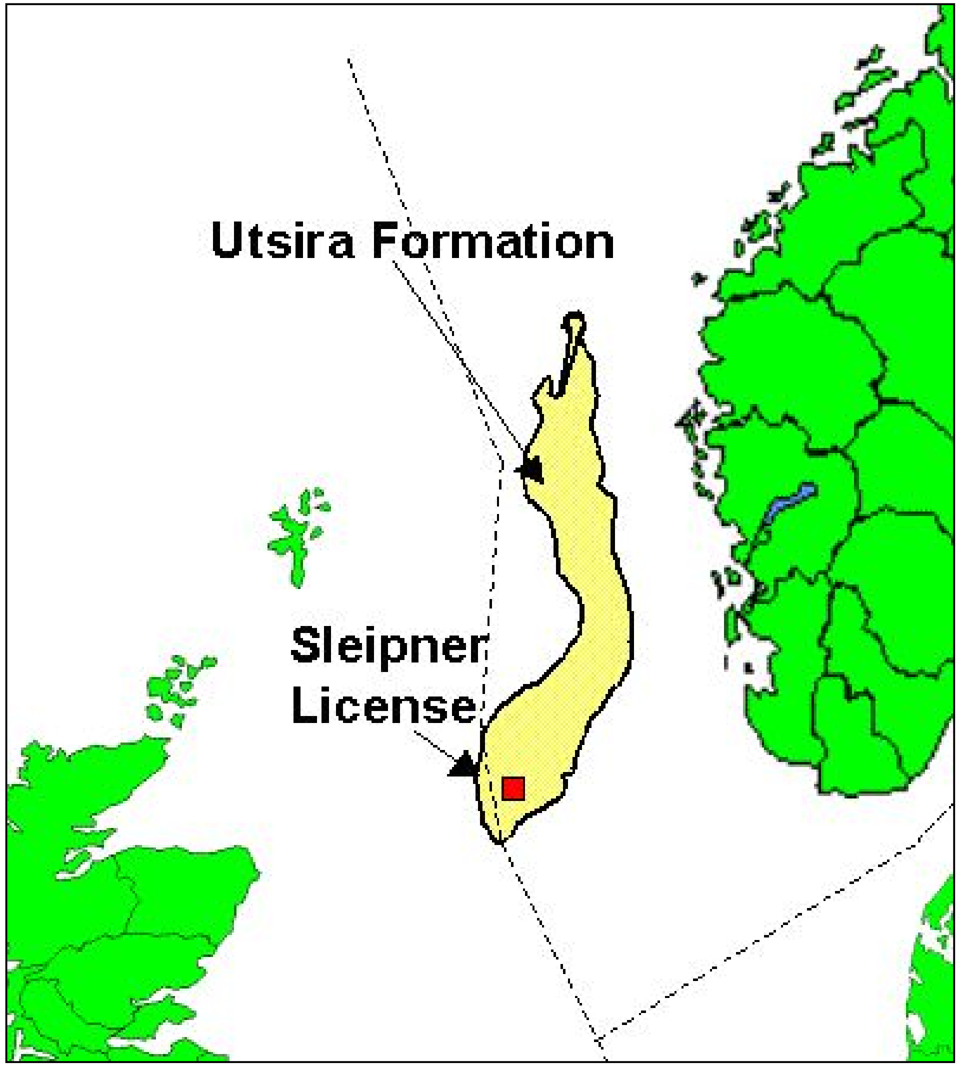
Totally stored 30 Mton CO_2/year

Appr. 0.1% of global emissions

Sleipner gas platform

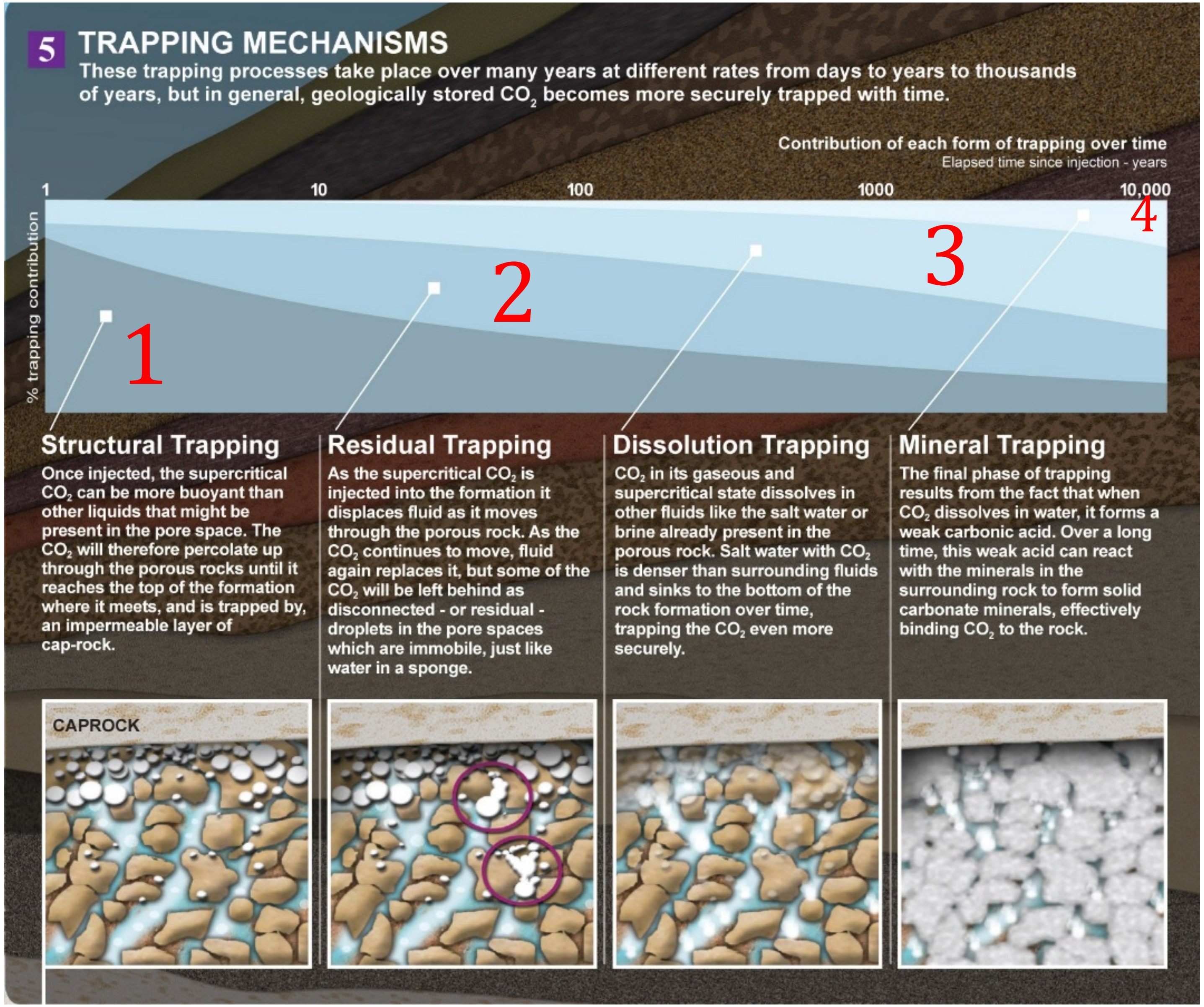
SLEIPNER AQUIFER CO2 STORAGE





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

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



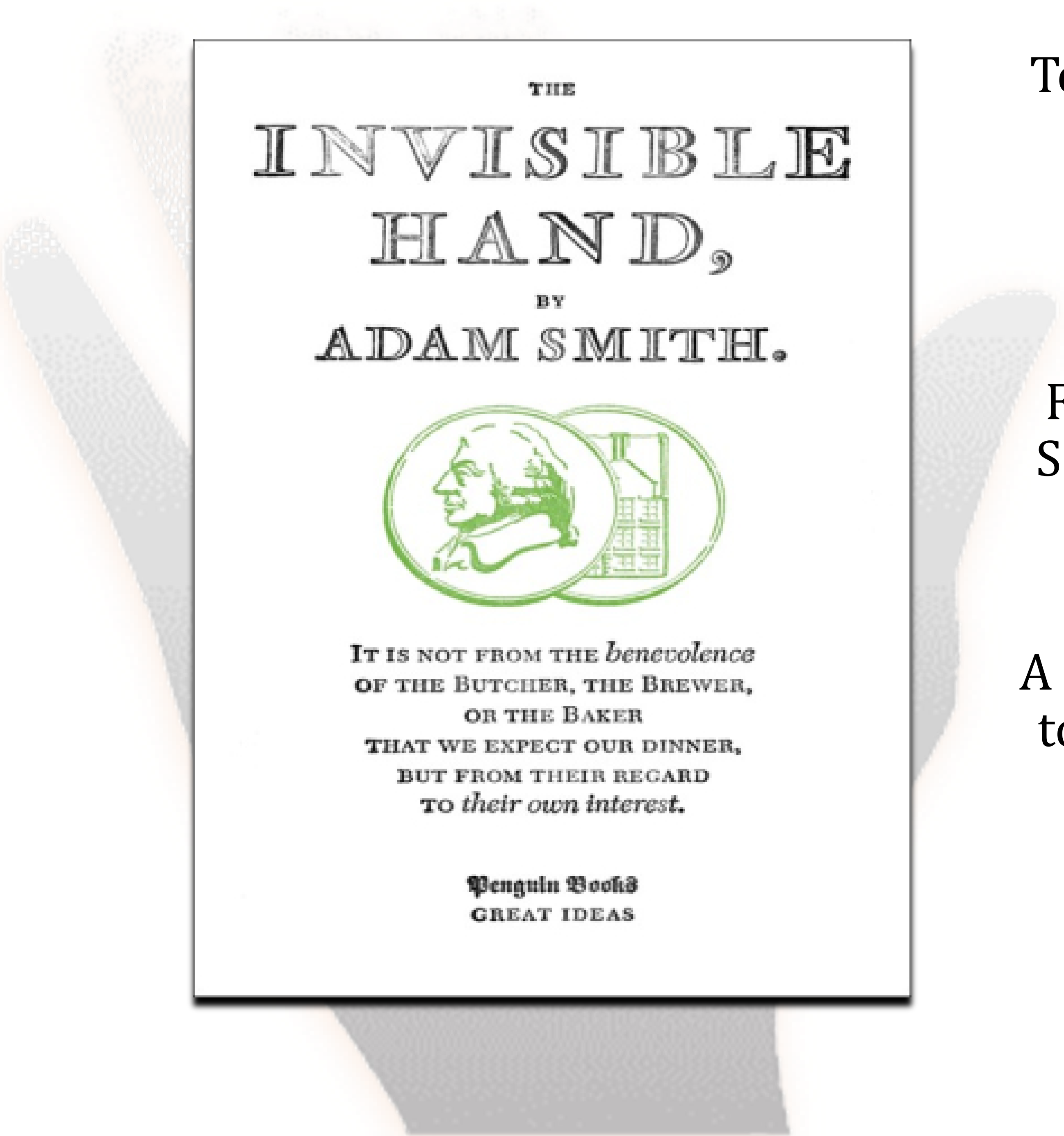
Trapping mechanisms:

1) Structural: Tight roof / caprock
2) Residual: gets stuck in pores
3) Dissolution: dissoved in water
4) Mineral: reacts with minerals

Expected leakage:

<1% per thousand years

Greatest risk: other wells (gas, oil)



To meet climate targets we need the help of the ”invisible hand” of the market.

Fossil fuels are too cheap. So we need a price on CO2 emissions.

A more difficult challenge is to find someone to pay for negative emissions.

Who will be willing … ?

Cost CCS/BECCS: ≈0.1 €/kg CO_2

Reasonable ?

Carbon dioxide intensity in global economy: 0.5 kg CO_2/€

Thus: 0.1 €/kg CO_2 corresponds to 5% of global economy

Proposal: "Emitter Recovery Liability". Emitters are responsible, and need to pay, for removing any emitted CO_2 from atmosphere. (cf. "*Producer liability*")

Normally, the cost to avoid CO_2 emission is lower than atmospheric CO_2 capture.

Thus: The cost for the economy could be considerably less than 5%.

Proposal for Sweden

Emitter Recovery Liability for non ETS-emissions.

- 23 Mt/year, >half Swedish domestic CO_2 emissions
- mainly transportation fuels

Cost: 23 billion kr/year
0.5% of GDP
2300 kr/Swede,year
2.3 kr/L petrol

In practice, a halving of Swedish emissions.

Chemical-Looping Combustion (CLC)

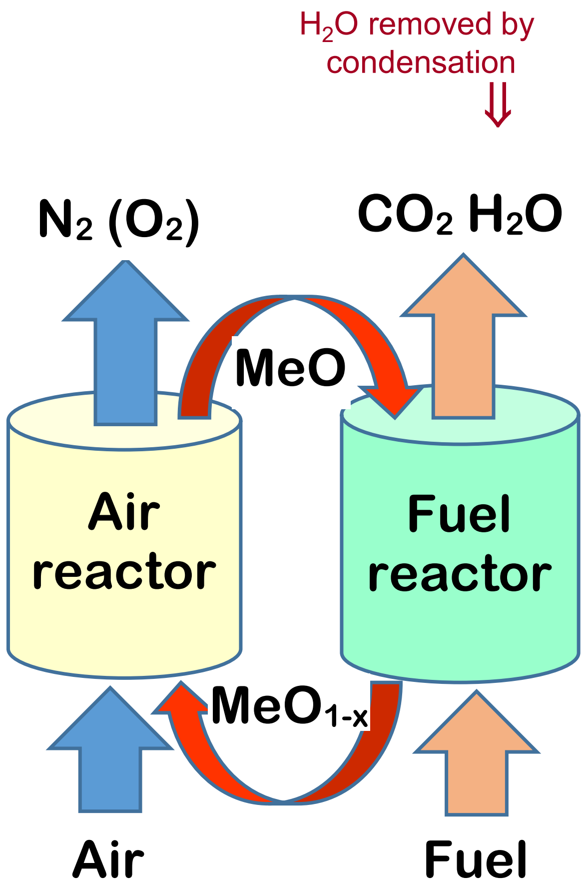
Oxygen is transferred from air to fuel by metal oxide particles

Inherent CO_2 capture:

- fuel and combustion air *never mixed*
- *no active gas separation needed*

Potential for large cost reduction of capture

But does it work in practice ??



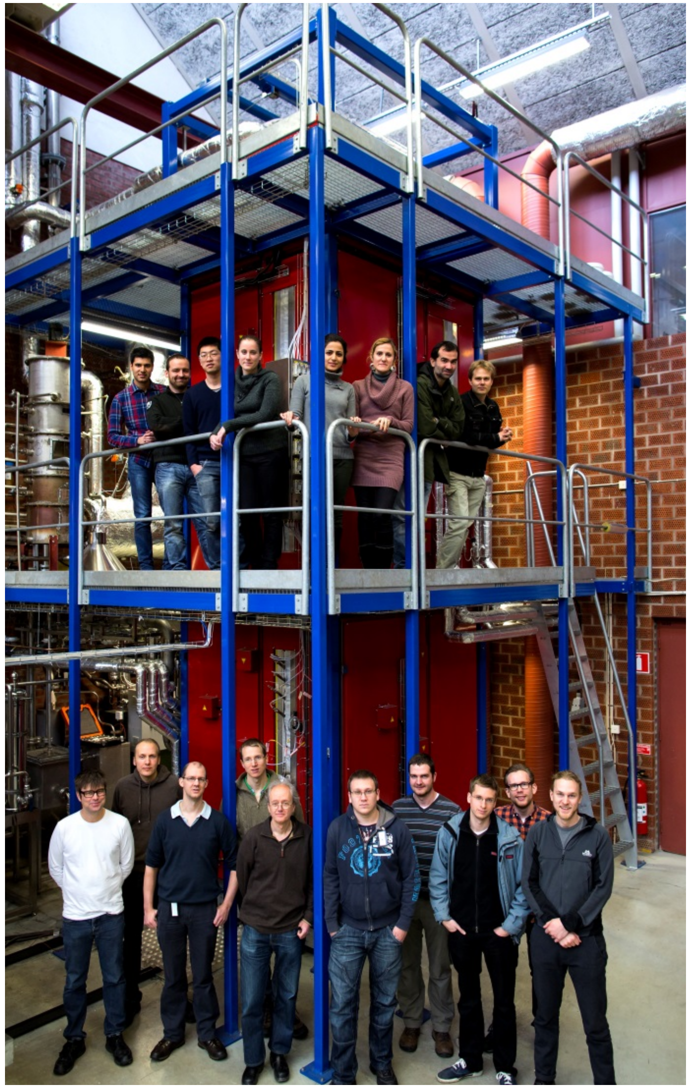
Yes, it works!!

Total chemical-looping operation
at Chalmers:
4 000 h in four pilots

10 kW gas, 2003

300 W gas, 2004

10 kW solid fuel, 2006



100 kW solid fuel, 2011

Worldwide: 11 000 h in 46 pilots

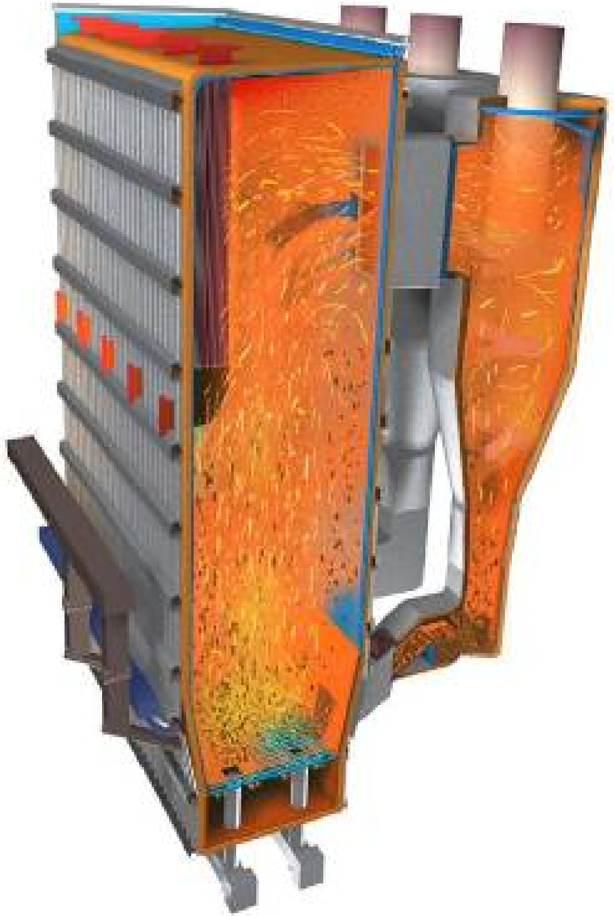
Hours of operation

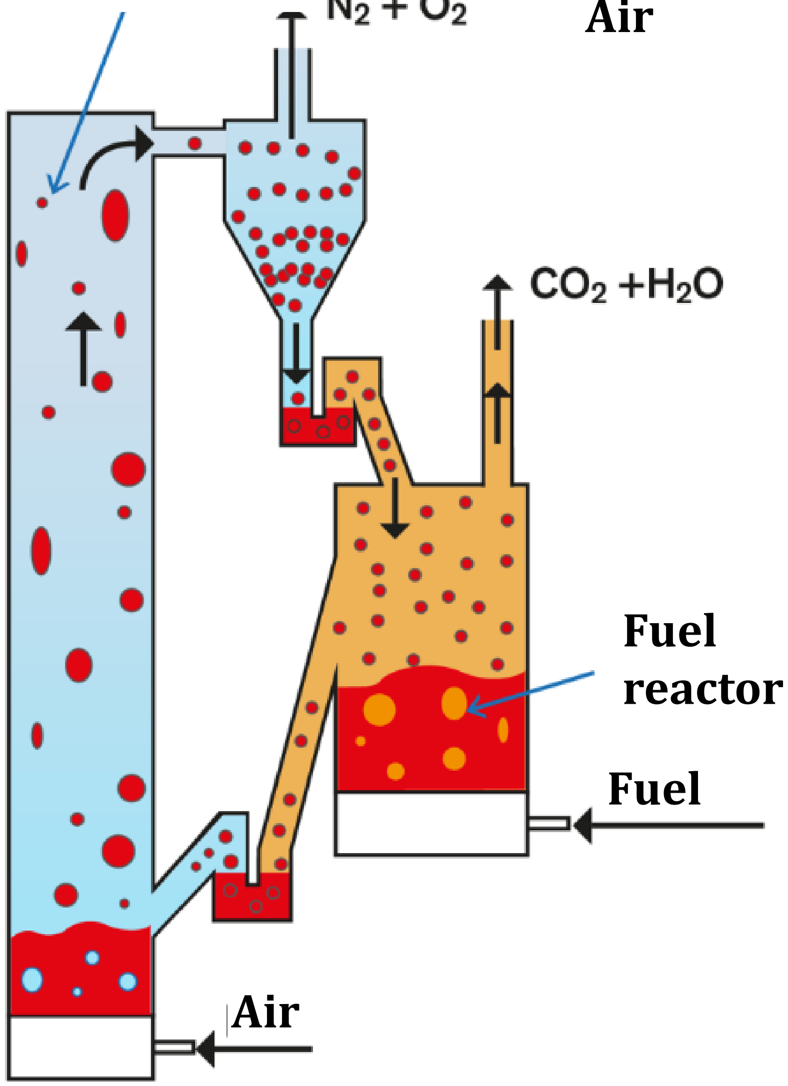
Type	Oxygen carrier	Gaseous fuel	Liquid fuel	Solid fuel	**Total**	%
Manufactured	NiO	2677	377	237	**3291**	29%
	CuO	1130	122	173	**1425**	13%
	Mn_3O_4	74	17	0	**91**	1%
	Fe_2O_3	617	77	1072	**1766**	16%
	CoO	178	0	0	**178**	2%
	Combined oxides	918	10	289	**1217**	11%
Natural ore or waste material	Fe ore	488	0	576	**1064**	9%
	Ilmenite	538	150	788	**1496**	13%
	Mn ore	354	0	381	**735**	6%
	CaSO4	0	0	75	**75**	1%
Total manufactured		5594	603	1771	**7968**	70%
Total natural/waste		1380	150	1820	**3370**	30%
Total		6974	753	3591	**11338**	100%
Publications					212	

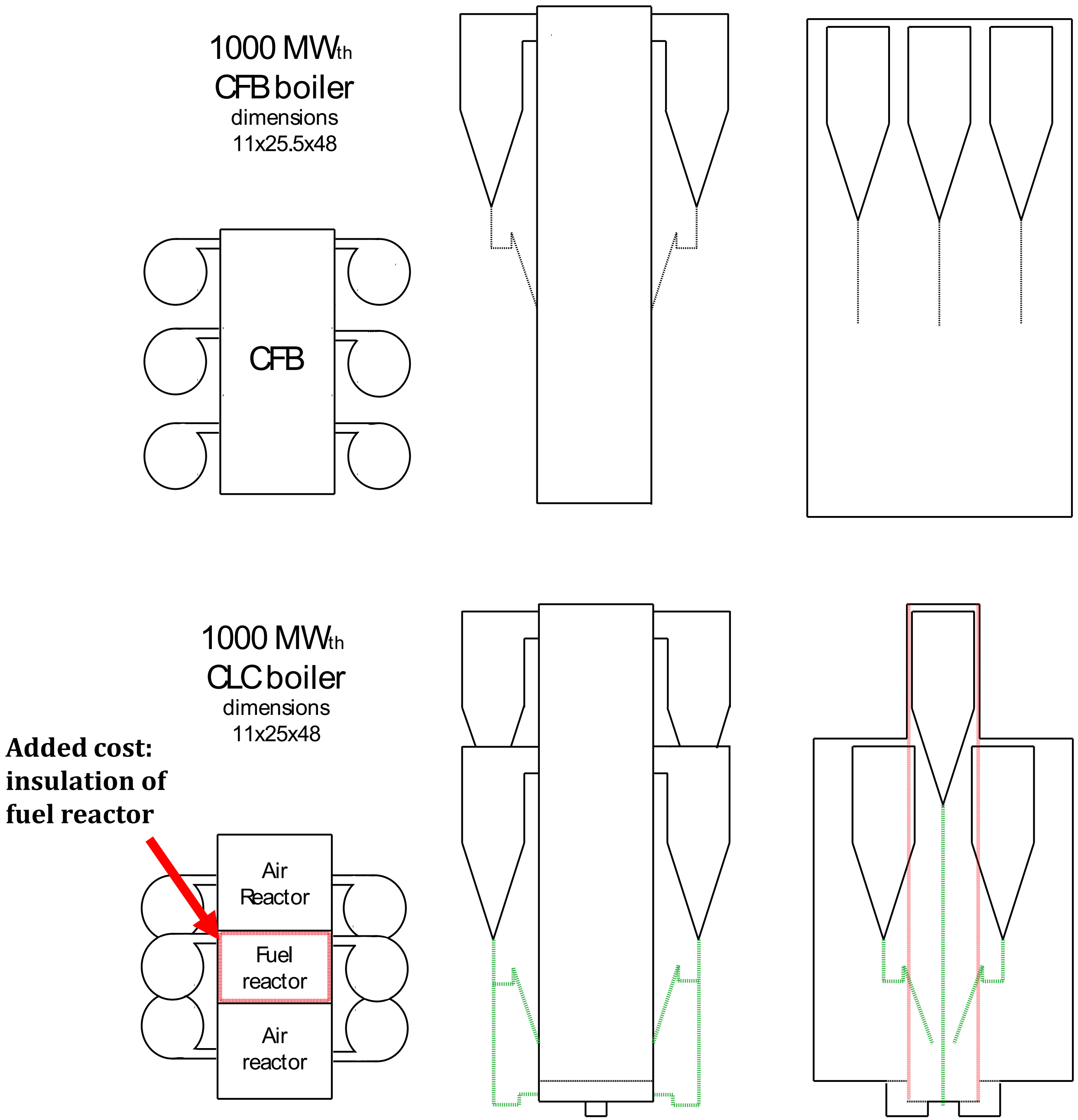
In addition there is >20 000 h of operation with oxygen carriers in commercial circulating fluidized bed boilers.

Chemical Looping Combustion

Circulating fluidized-bed boilers







Walls of fuel reactor, cyclones, ducts and post-oxidation chamber:
→ 2500 m²

Cost: 1500 €/m²

Thus, added cost of CLC fuel reactor:

≈ 4 M€

⇒ 0.4 M€/year
÷
2 Mton CO_2/year

= 0.2 €/ton CO_2

From: Lyngfelt, A., and Leckner, B., A 1000 MWth Boiler for Chemical-Looping Combustion of Solid Fuels - Discussion of Design and Costs, *Applied Energy* 157 (2015) 475-487 *(Open Access)* 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

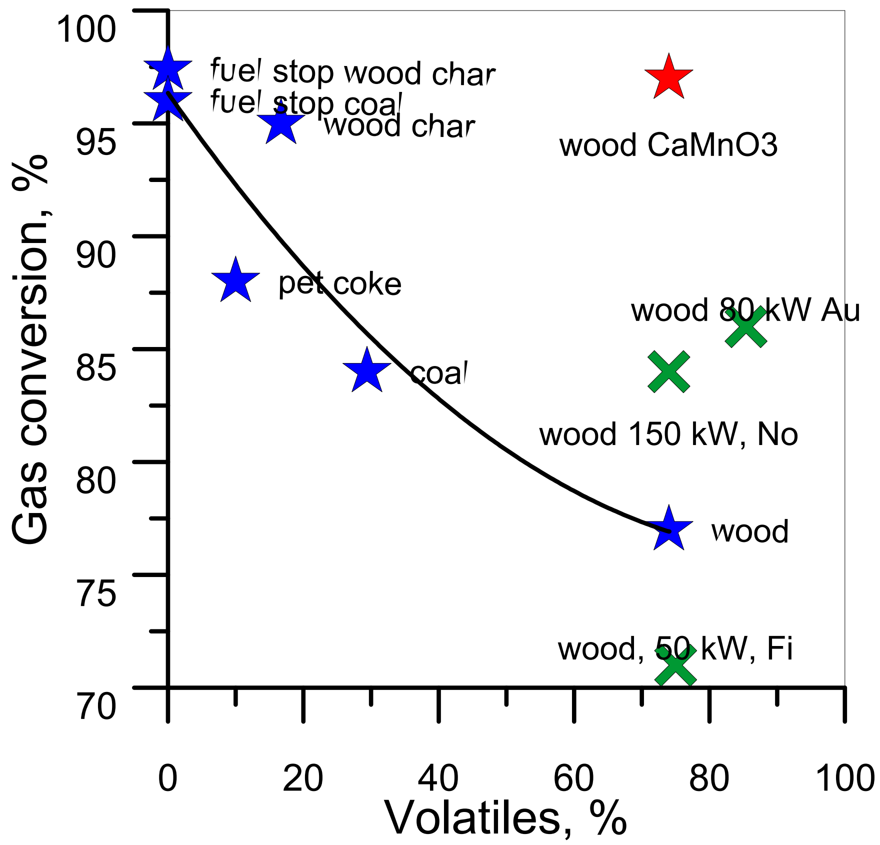
Demonstration without CO_2 capture can significantly reduce costs.

1) Verify concept, and potential advantages wrt. alkali and NO_x
2) Add CO_2 capture

[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

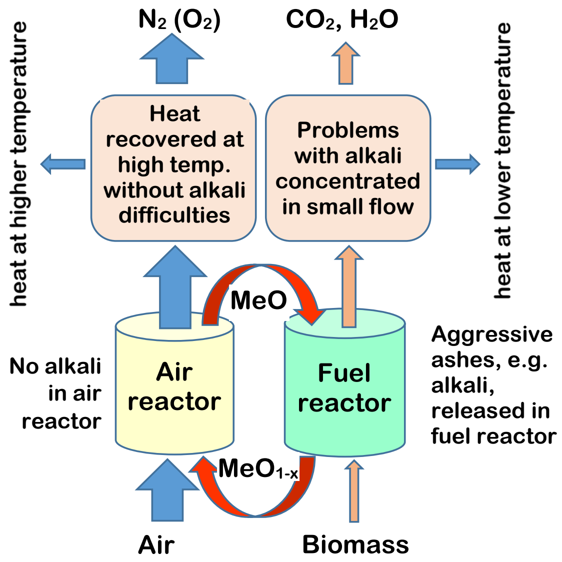
Biomass in CLC

High volatiles content could give problems with gas conversion



Could low ash content make manufactured oxygen carriers possible ?

Biomass difficult fuel
alkali gives low
ash-melting temperature



Could CLC facilitate the use of biomass in boilers ?
(positive experience with OCAC)

Could range of possible fuels be extended?

STATUS OF CLC

>11 000 h of operation in 46 pilots with >70 different oxygen carrier materials, of which >3000 h with low-cost materials (e.g. ores of ilmenite, iron and manganese)

SOLID FUELS:

- >3000 h of operation in 20 pilots
- major cost of CO_2 capture, i.e. gas separation, is uniquely avoided (depending on gas conversion)
- unique potential for low energy penalty
- transparent cost evaluation based on difference compared to circulating fluidized bed boiler: 16-26 €/ton
- cost expected: less than half of competing technologies
- could likely be demonstrated at low moderate cost using existing biomass gasifier (e.g. GobiGas)
- no incentives for negative emissions

Conclusions CLC

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

Highly concentrated CO_2 stream can be obtained at small added cost

Major cost likely downstream

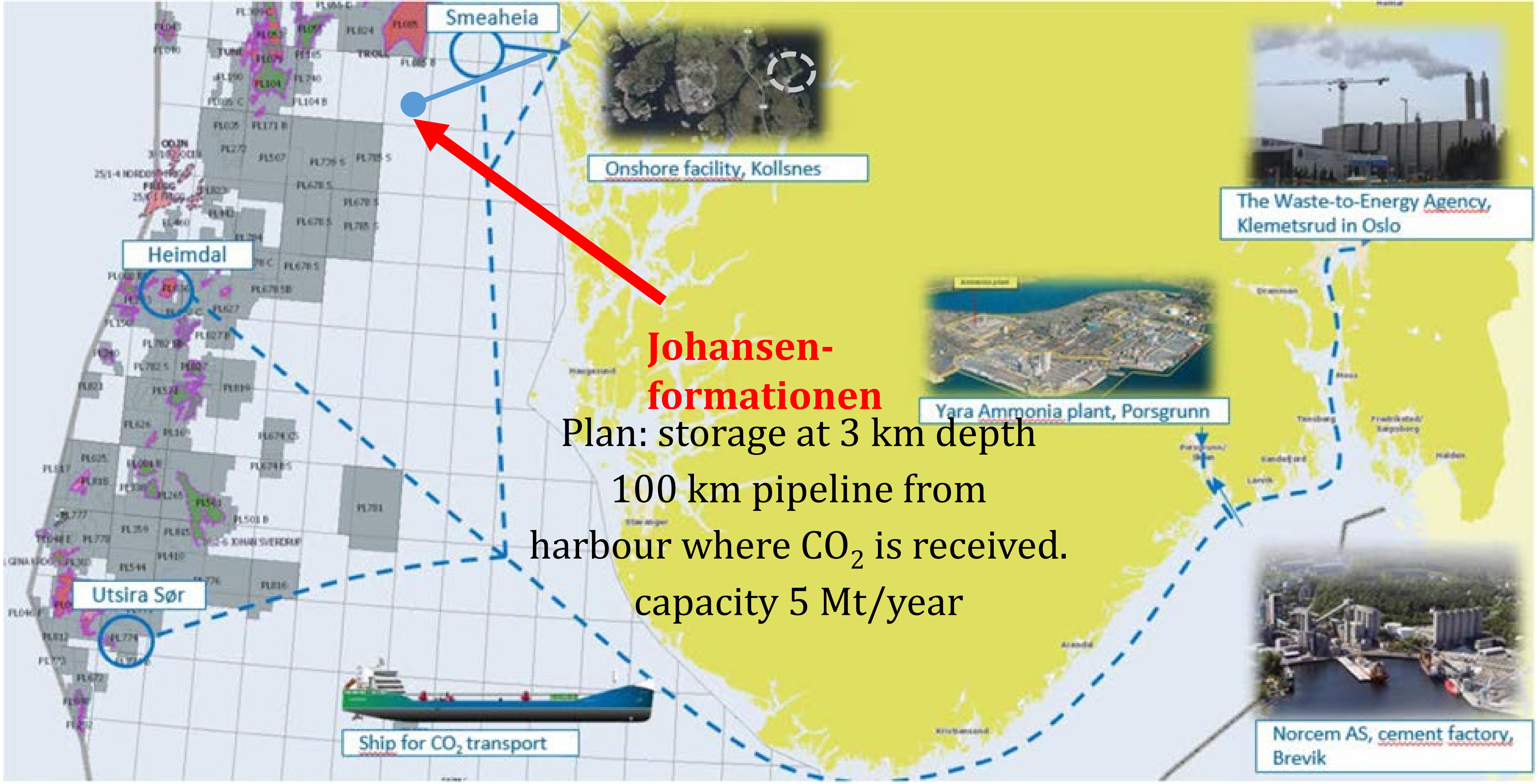
CLC can be demonstrated at lower cost without capture

Swedish CO_2 emissions from biomass, (larger point sources):

31 Mt/år

Sweden's domestic fossil CO_2 emissions are:

43 Mt/year



Johansen-formationen

Plan: storage at 3 km depth

100 km pipeline from

harbour where CO_2 is received.

capacity 5 Mt/year

Key Messages

Carbon dioxide budget soon exhausted - large negative emissions are needed

Several principles for negative emissions

Bio-CCS safest
- capture of CO_2 from biomass + geological storage

Storage - eternal storage is not needed, less safe storage also relevant ("e.g. forestation")

Bio-CCS
- climate-efficient use of limited resource
- biogenic carbon dioxide is valuable waste (can give minus emissions) - significant potential
- technology well known (simple), but few large-scale plants

Key Messages

Negative emissions must be financed

Chemical-Looping Combustion of biomass, Bio-CLC, has potential for dramatic reduction of CO_2 Capture cost

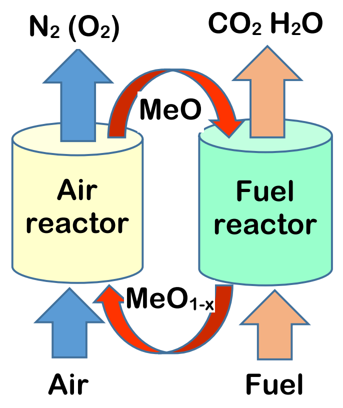
CCS not really expensive - corresponds to a few% of global GDP

-Rational solution, “Emitter Recovery Liability “, emitters pay for removing the CO_2 from the atmosphere

Applying “Emitter Recovery Liability” on half of Swedish emissions. Cost:

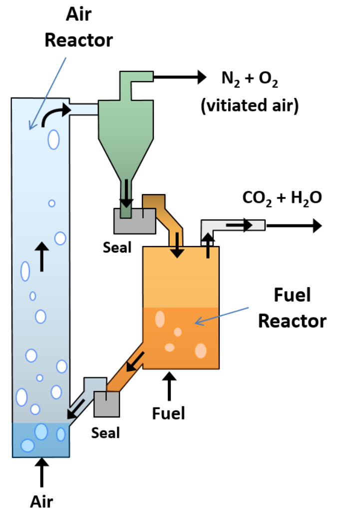
- 2300 kr/Swede
- 0.5% of GDP
- 2,3 kr/L petrol

http://negativeco2emissions2020.com/



PRINCIPLE

metal oxide (MeO) transfers oxygen from air to fuel
⇒
no separation needed



PRACTICE

well established circulating fluidized-bed technology

PURPOSE

Thank you!!! Questions