Negative CO_2 Emissions
Using
Bio-CCS

Anders Lyngfelt

Symposium Geoengineering
Luleå, May 22, 2024

Large potential for <u>negative</u> CO_2 emissions in Sweden

>30 Mt/year biogenic CO_2 emissions from point sources >100.000 ton/year

to be compared with 43 Mt/year total fossil CO_2 emission

Need for more research ?

Need for technology development

⇑

Building full scale plants!
Learning by doing!

⇑

Market

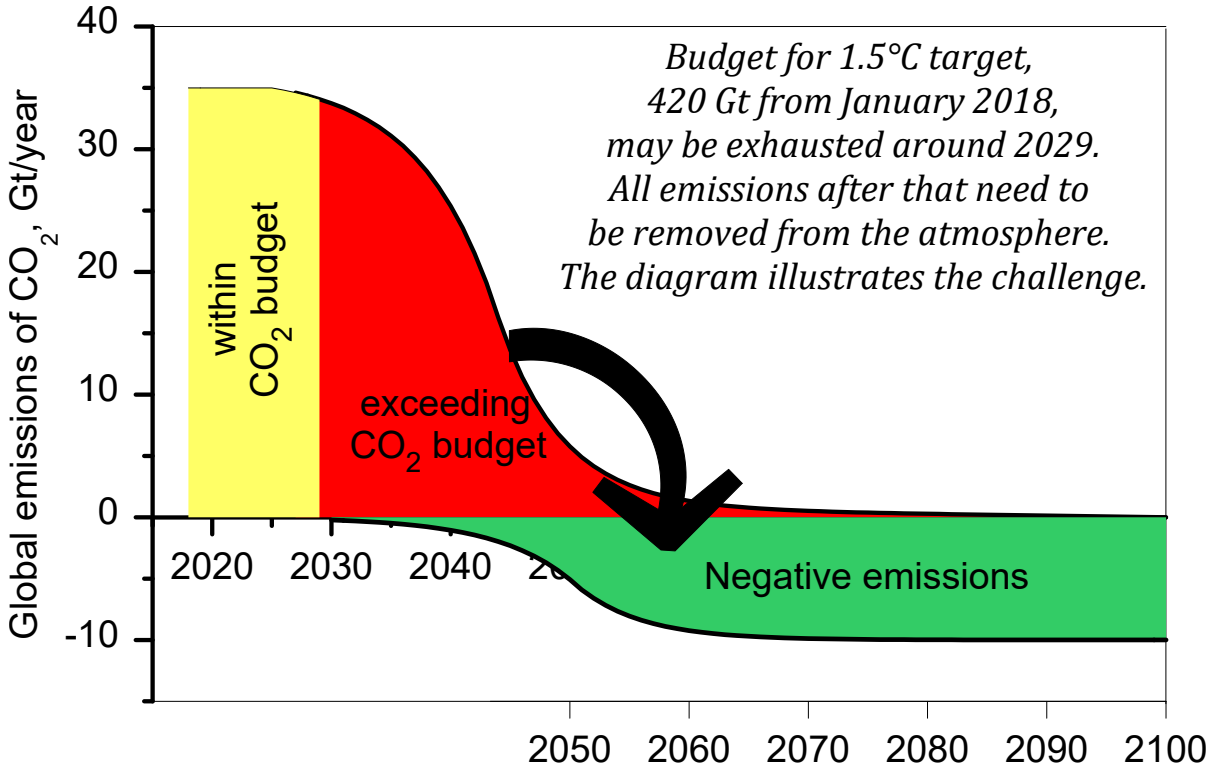
⇑

Proponents → Bold & costly political decisions ← Sceptics

Perceptions/misconceptions of Bio-CCS: **1. Not needed / Not needed now / not priority / comes with risk of reduced ambitions on CO_2 reduction**

.

- Global carbon budget for +1.5°C likely spent around 2029
- To meet max 1.5°C, ***all CO_2 emissions after 2029 must be removed from the atmosphere.***
- Leaves our children with a **climate debt**, to remove perhaps 800 Gt CO_2, or 100 t/capita (>10.000 €/capita) globally.



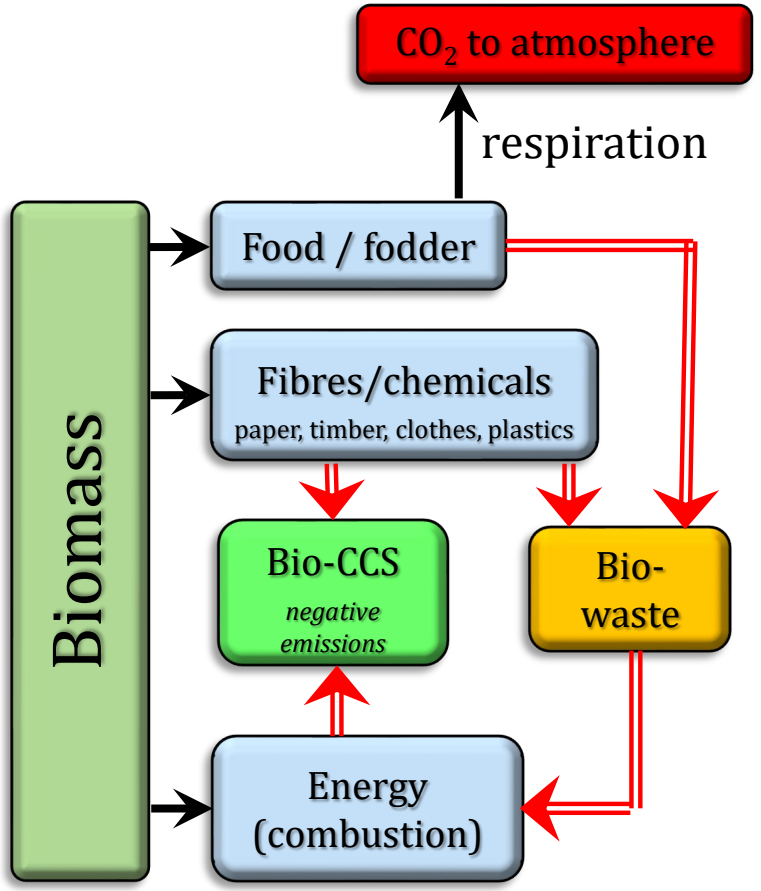
Perceptions of bio-CCS : **2. Not enough ("One more India needed …")**

Bio-CCS, can/should be combined with other uses of biomass

Fossil emissions are 37 Gton CO_2/year

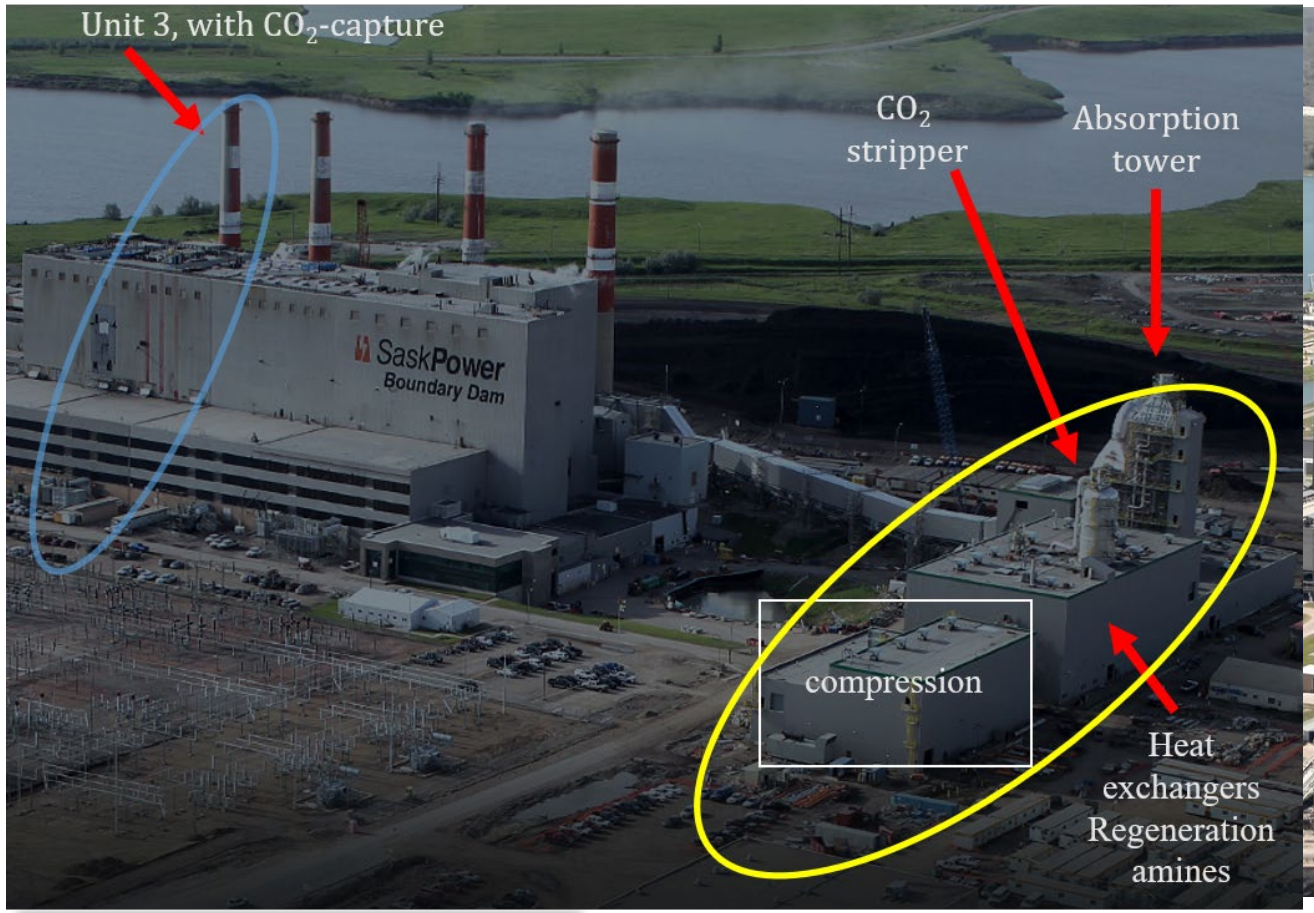
Total primary production: 220 Gton CO_2/year

Global extraction of biomass (as captured CO_2) 22/32 Gton CO_2/year (net/gross)

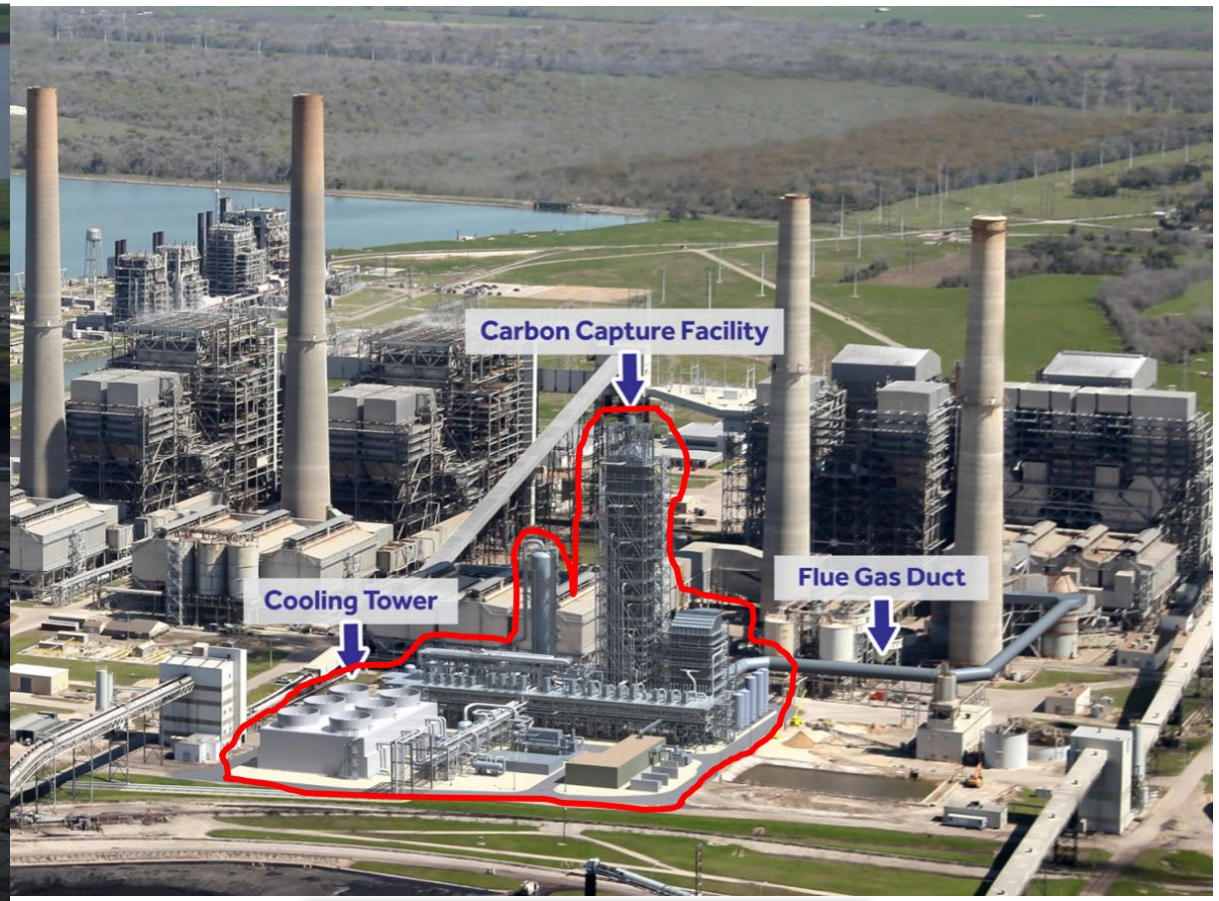


…. ***except*** when used as transportation fuel.

Perceptions : 3. Not existing technology / not existing at scale

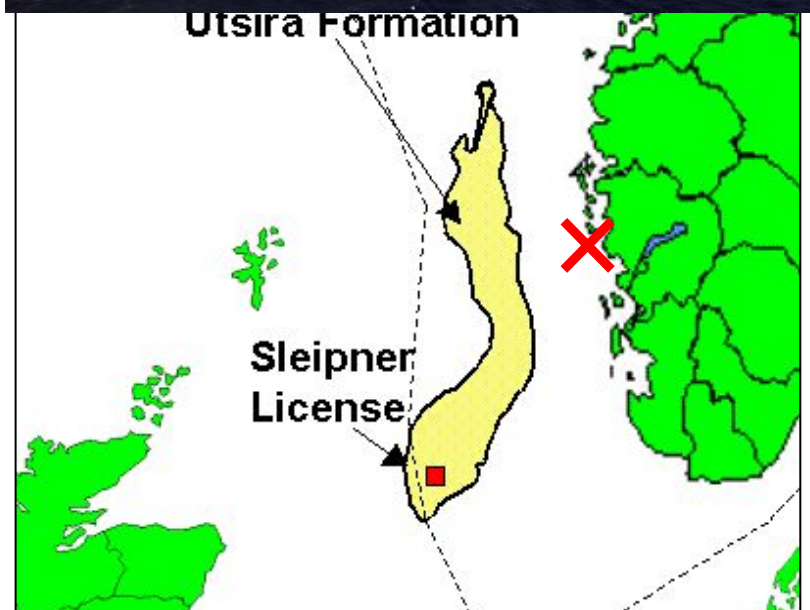


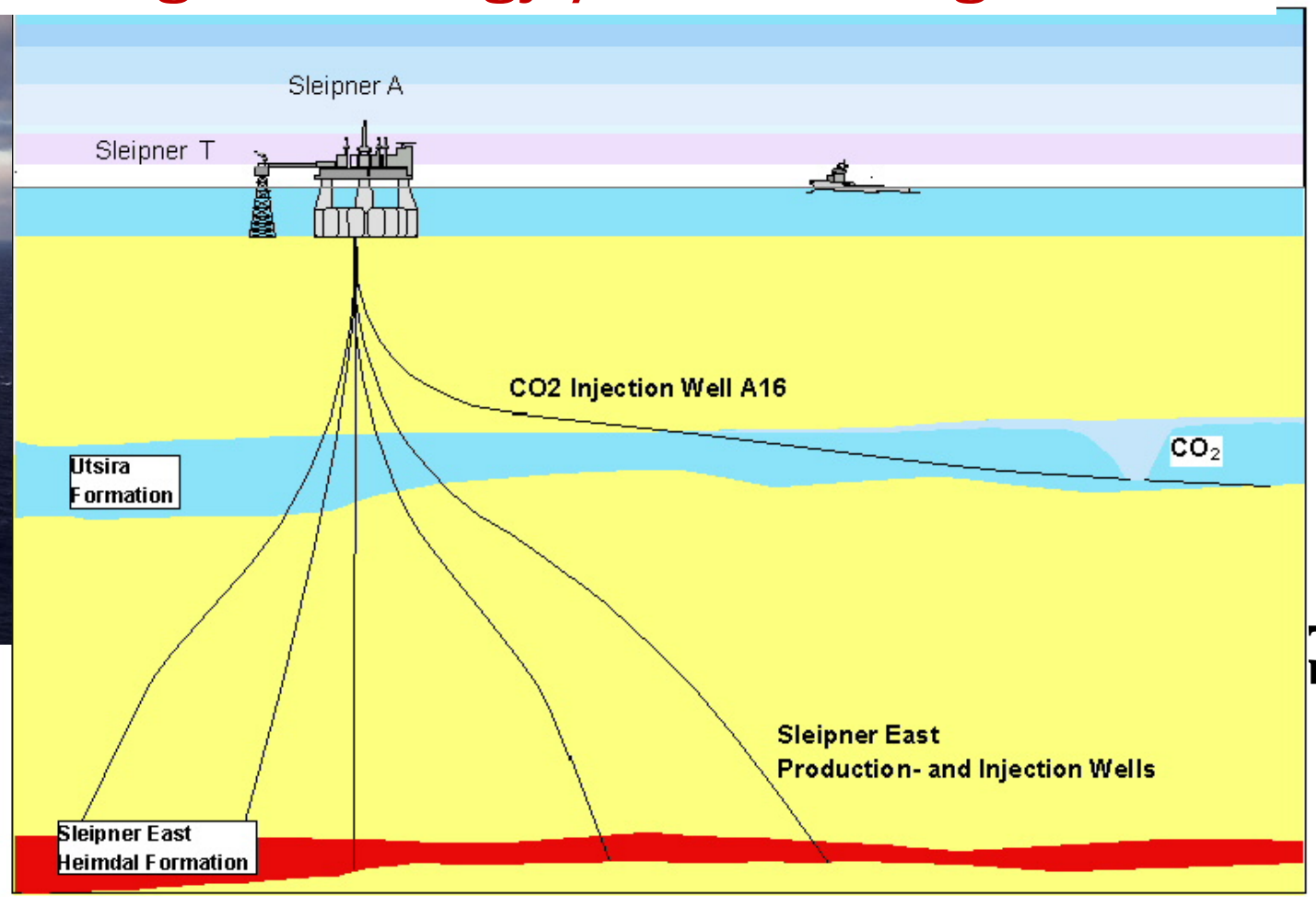
Boundary Dam, Canada.
1 Mton CO_2/year since 2014.



Petra Nova, Texas,
1.4 Mton/year, started 2017

Perceptions : 3. Not existing technology / not existing at scale



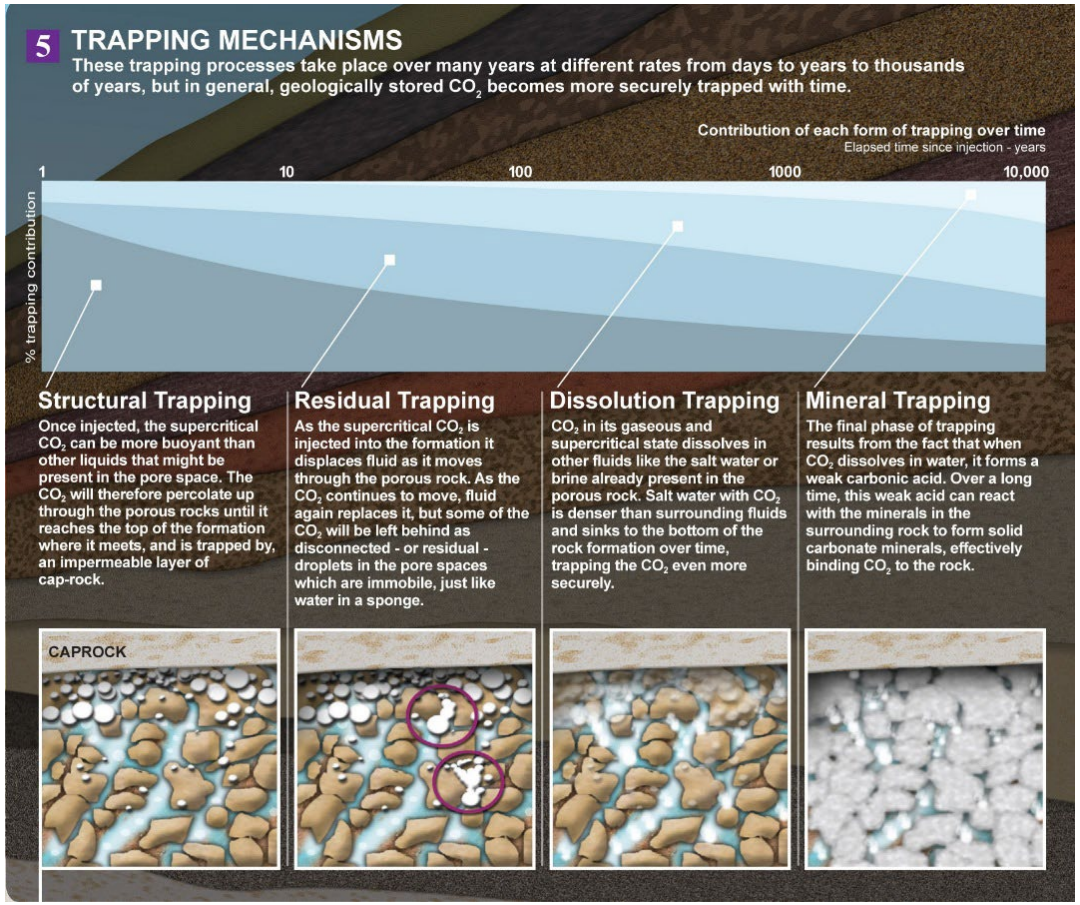


1 million ton CO_2/year, since 1996 Area: 26 000 km^2,
Depth: ~1000 m, Height: 200-300 m, Porosity: 30-40%

Worldwide: 40 Mton/year captured and stored (0.1% of global emissions)

Perceptions of bio-CCS: **4. Not safe**

True for nature-based NETs, but not for bio-CCS



Uses similar geological formations that have stored oil and gas for 10-100 millions of years

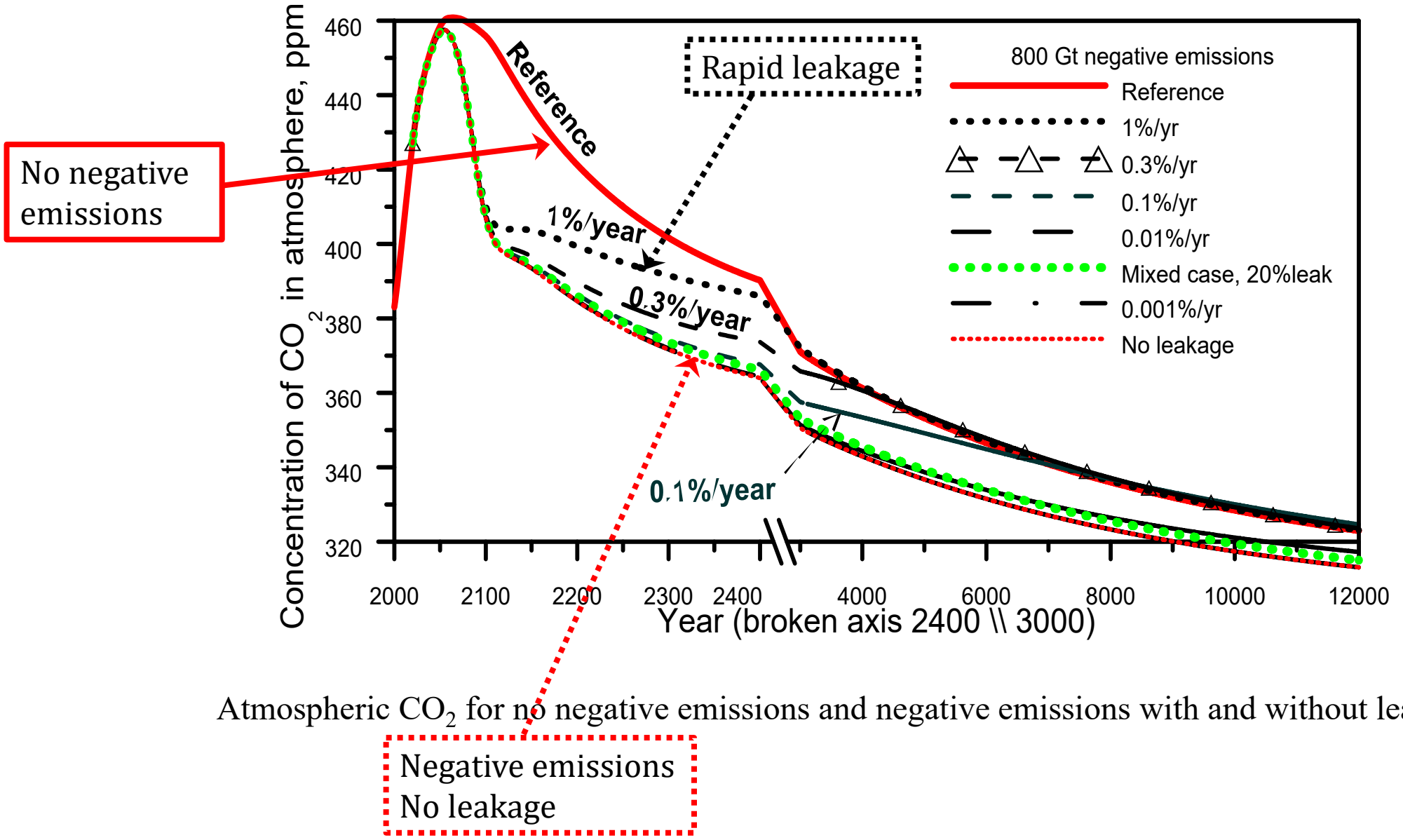
Trapping mechanisms:

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

Expected leakage:

<1% per thousand years

Greatest risk: other wells (gas, oil)



Atmospheric CO_2 for no negative emissions and negative emissions with and without leakage.

REF: Lyngfelt A, Johansson D, and Lindeberg E. Negative CO2 Emissions - An Analysis of the Retention Times Required with Respect to Possible Carbon Leakage. *International Journal of Greenhouse Gas Control* **87** (2019) 27–33.

Perceptions of bio-CCS: **5. It's expensive**

Cost of CCS/Bio-CCS ≈ 0.15 €/kg CO_2

Carbon dioxide intensity in global economy: 0.2 kg CO_2/€

Thus: a CO_2 fee/tax of 0.15 €/kg corresponds to ***3% of global economy***

But, the cost to avoid CO_2 emission is often lower than this.

Thus: The cost for the economy would be considerably less than 3%.

New technology may significantly reduce cost of Bio-CCS

Chemical-Looping Combustion (CLC)

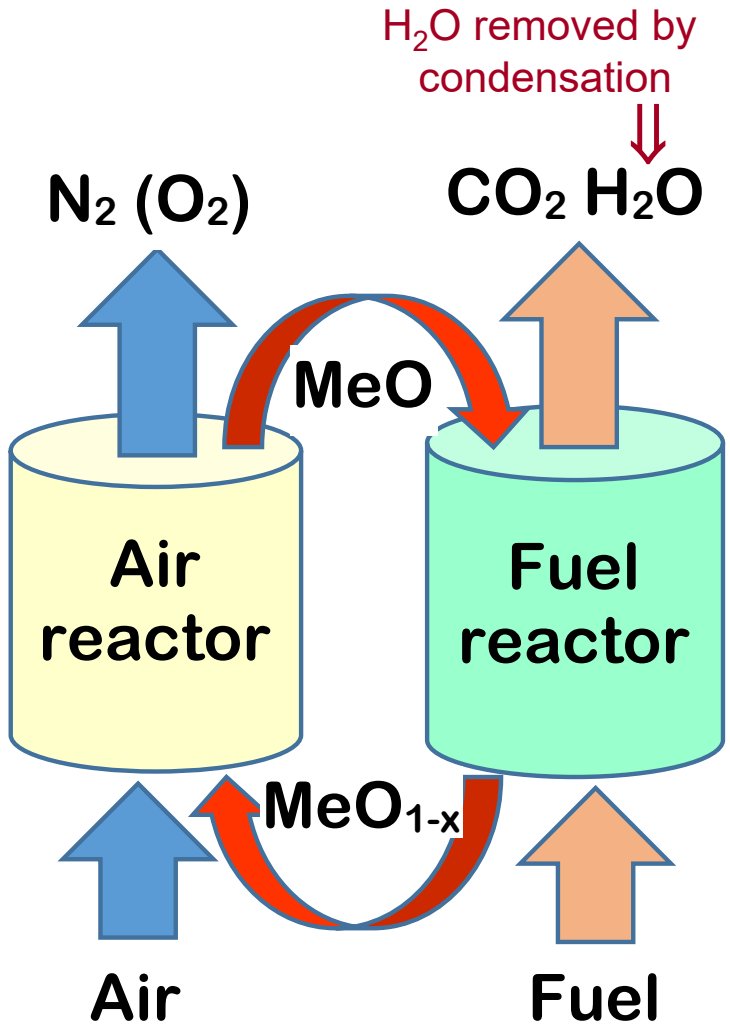
Oxygen is transferred from air to fuel by metal oxide particles

Inherent CO_2 capture:

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

Unique potential for reducing costs of CO_2 capture

But does it work ?



Yes, it works!!

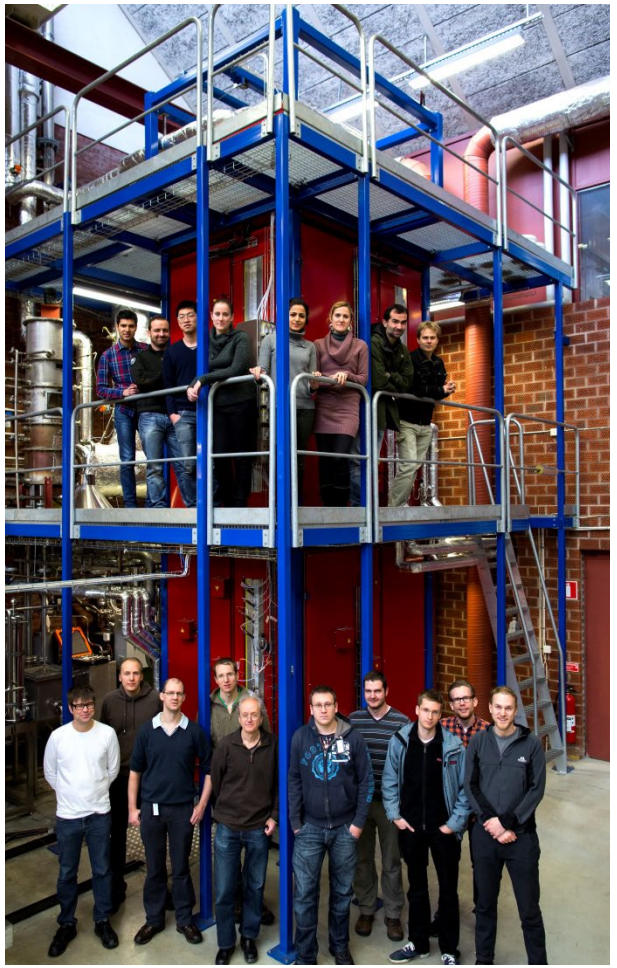
Total chemical-looping operation at Chalmers: 4 200 h in four pilots

Worldwide: 12 000 h in 50 pilots

10 kW gas, 2003

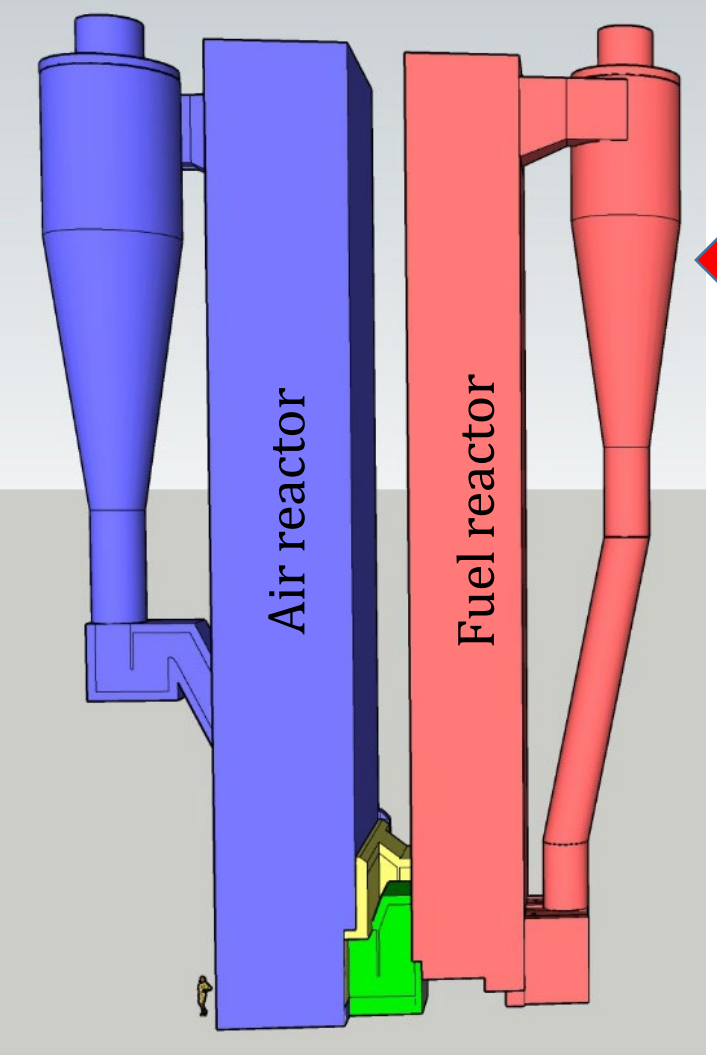
300 W gas, 2004

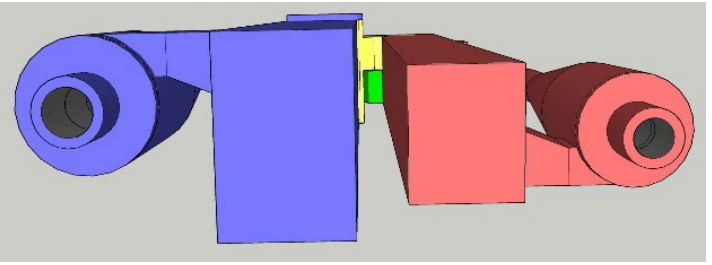
10 kW solid fuel, 2006



100 kW solid fuel, 2011


b)
CHEERS





200 MW CLC-CFB, added cost of Fuel Reactor:

1500 m^2 insulated wall
at
2000 €/m^2

⇒ 1500 x 3000 = 3 M€

10% depreciation

⇒ **0.3 M€/year**

capture: 0.4 $MtCO_2$/year

cost of fuel reactor : $\frac{0.3\ M€/year}{0.4\ MtCO_2/year}$ = **0.75 €/t CO_2**

Cost of post-combustion CO_2 capture: 100 €/t CO_2

Costs, CLC of solid fuels, estimated at around 20 €/tCO_2

Type of cost	estimation, €/tonne CO_2
CO_2 compression	10
Oxy-polishing	6.5
Boiler cost	1
Oxygen carrier	2
Steam and hot CO_2 fluidization	0.8
Fuel grinding	0.2
Lower air ratio	-0.5
Total	20

big costs

small costs

[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

Perceptions of bio-CCS: **7. Handing over a gigantic climate debt, the challenge to clean up the atmosphere, to our children and grandchildren is a moral hazard or moral collapse.**

True!

Not because of

lack of potential for negative emissions

or lack of money

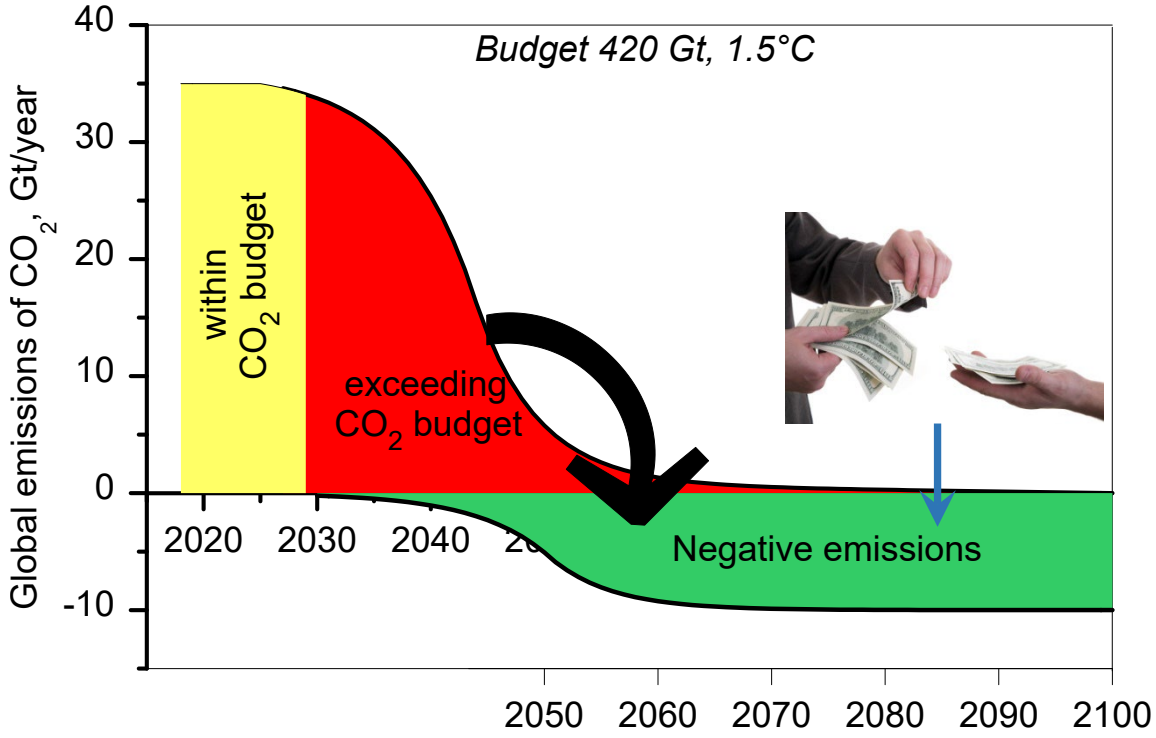
but because of the insoluble (?) challenge in sharing the gigantic climate debt, perhaps 100.000 €/capita

Major problem with negative emissions:
Who will pay?

No income associated with negative emissions

No strong proponents

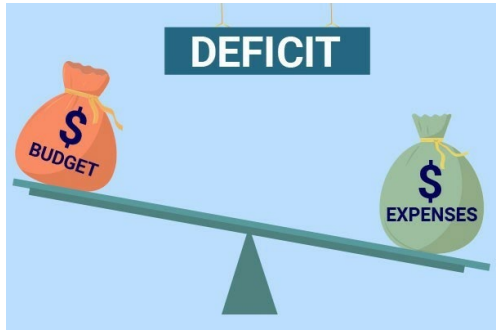
Will policymakers take the tough decisions and provide the gigantic financing needed ?



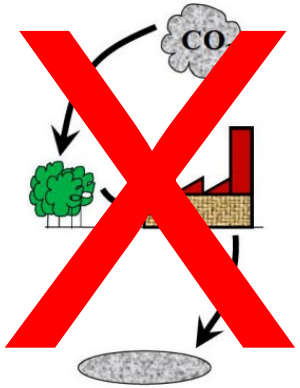
How can the responsibility to remove all this CO_2 from the atmosphere be shared between nations?

Which government will give priority to negative emissions in the budget?

Priorities:



Negative emissions



Will we leave our children and grandchildren with a problem that is **insoluble**?

A possible solution is a **CO_2 recovery liability**

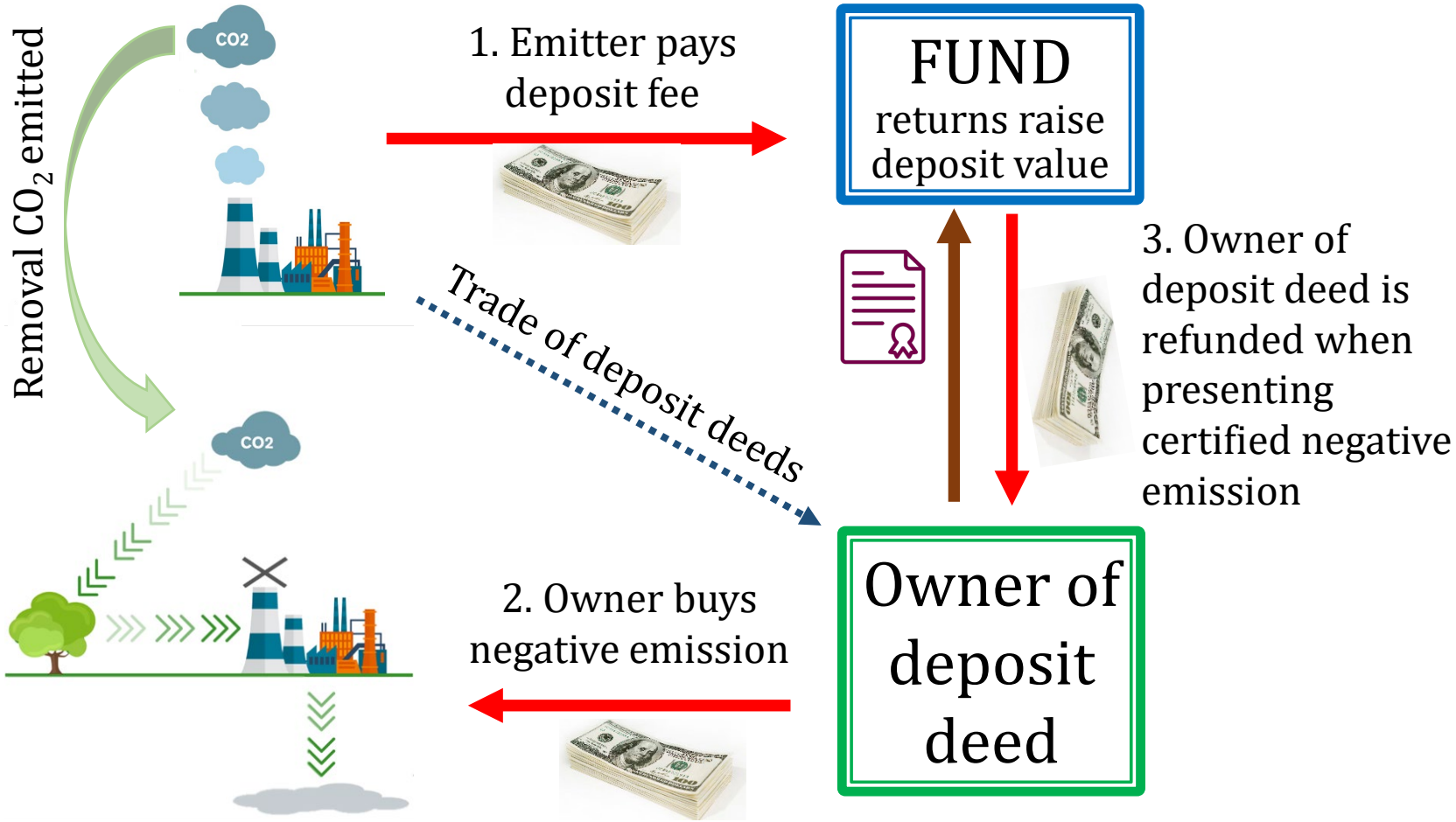
making emitters responsible for removing their emissions from the atmosphere

It would be simple, reasonable, comprehensible, fair, rational, sustainable,

which should facilitate acceptance.

It would also give a good incentive for not emitting CO_2

A CO_2 Emitter Liability can be operationalized by **Atmospheric CO_2 Removal Deposits (ACORDs)**



Lyngfelt, A., Fridahl, M., and Haszeldine, S., FinanceForFuture: Enforcing a CO_2 emitter liability using Atmospheric CO_2 Removal Deposits (ACORDs) to finance future negative emissions, *Energy Research & Social Science* **107** (2024) 103356

Overcompensation:

Emitter must buy deposits in excess of the actual emissions, e.g removal of 1.5 tonne of CO2 for every tonne emitted.

Why:

- To reach tougher climate goals
- Failure to introduce ACORDs in time
- Rich countries must take a greater share of negative emissions
- Overcompensation gives higher price, which also promotes lowering of fossil emissions
- To compensate for less safe carbon removal options, e.g. nature-based.

Conclusions

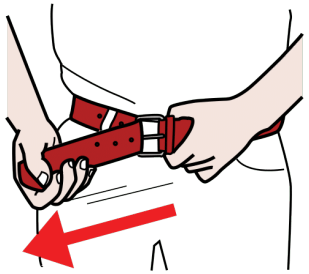
Emitter is obliged to buy deposit deeds corresponding to his emissions of CO_2, to secure the future removal of these emissions.

Trading in deposit deeds creates a market that enables long-term investments and technology development.

The **revenues** increase the value of the deposit deeds, thus raising the incentive to achieve negative emissions

The deposit deeds have **owners**, which means that the funds created should be protected from being used for other purposes, which is a risk if future negative emissions were instead financed by saved funds from e.g. a carbon tax.

The deposit fee will drive emission **reductions**.



The deposit system can be gradually tightened through **overcompensation**, so that whoever releases one tonne is forced to pay to remove, *e.g.*, two tonnes. This gives further emission reductions, while rich countries can begin to pay off their large historical carbon dioxide debts.

The deposit fee can, and should, be **combined** with other instruments that ensure rapid reductions in emissions.

The socio-economic cost is reasonable, **a few percent** of global GDP.

It's simple, fair, rational and puts the cost on whoever is causing the problem. Thus, it should gain **acceptance**.

The proposal can be seen as a way to reach zero emissions immediately, even if the removal of carbon dioxide from the atmosphere takes place with a delay. Thus, the proposal gives a real opportunity to meet **the 1.5°C target**.

We do not leave behind a huge carbon debt and an insoluble problem to **our grandchildren**.

Svenska Dagbladet, 20 januari 2024

Debatt

Redaktör Carina Stensson Bitr redaktör Björn Jorner
Debattredaktionen debatt@svd.se Telefon 08-13 51 49
Webb: SvD.se/debatt Twitter: twitter.com/SvDDebatt Facebook: SvD Debatt

Inför en pantavgift på koldioxidutsläpp

Genom en pantavgift på koldioxidutsläpp kan vi klara de minusutsläpp som är nödvändiga om vi skall klara 1,5-gradersmålet. Då kan vi undvika att lämna över ett olösligt problem till våra barn och barnbarn, skriver två forskare.