Nordic Energy Research

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The Necessity and the Allure of Negative CO_2 Emissions – A Question of Balance

CHALMERS

INTERNATIONAL CONFERENCE ON

NEGATIVE CO_2 EMISSIONS

MAY 22-24, 2018

Negative CO_2

Negative CO_2 Emissions with Chemical-Looping Combustion of Biomass

Negative Emissions

–

a Dangerous Game* **or** **Necessary for the Climate?**

TRUE! **TRUE!**

*in the sense:

- a primary solution to the climate problem,
- expecting very large negative emissions of CO_2 in a distant future to solve the problem,
- leaving our grandchildren with the burden and responsibility to clean up our emissions
- an excuse for not doing rapid reductions of fossil emissions

Negative CO_2 Emissions

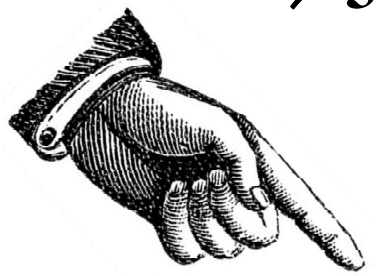
A Question of Balance

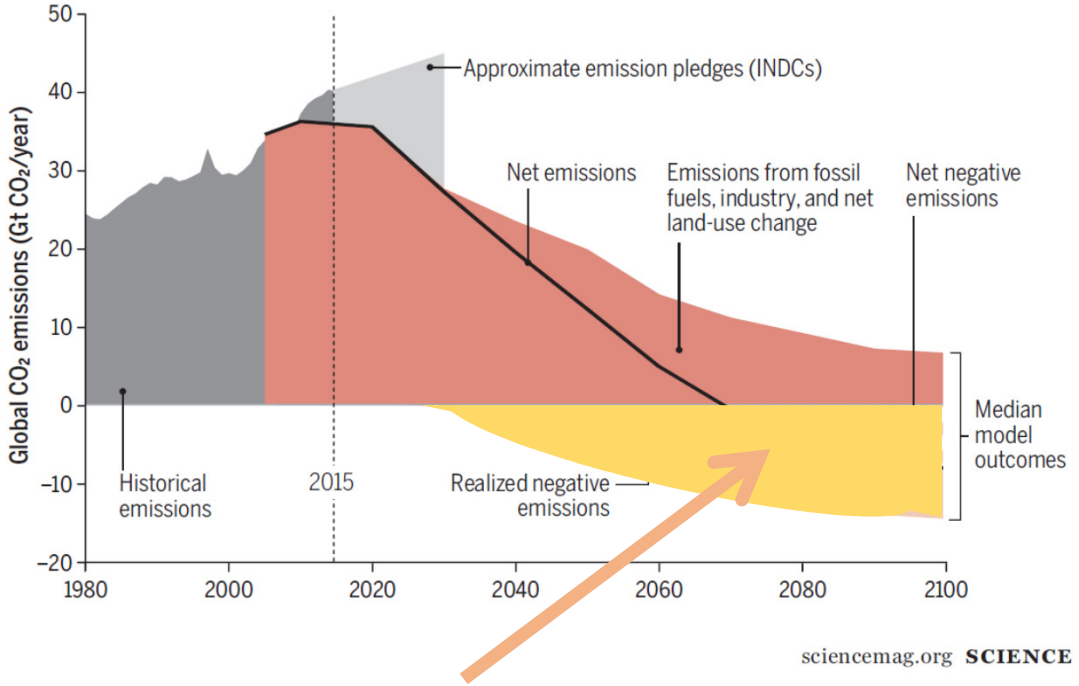
*The Paris agreement to stay **well below** 2°C*

*and pursue .... to limit .... to **1.5 degrees**:*

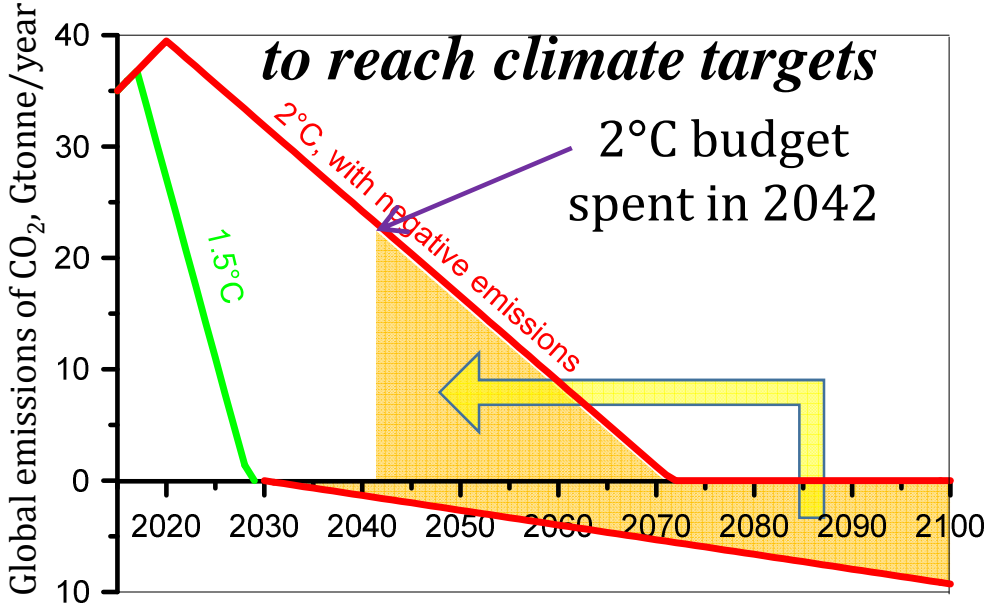
Carbon dioxide budget for max 1.5°C and 2°C :

→ **3 - 19 years with today's emissions**





Negative emissions are needed to reach climate targets



700 Gt CO_2

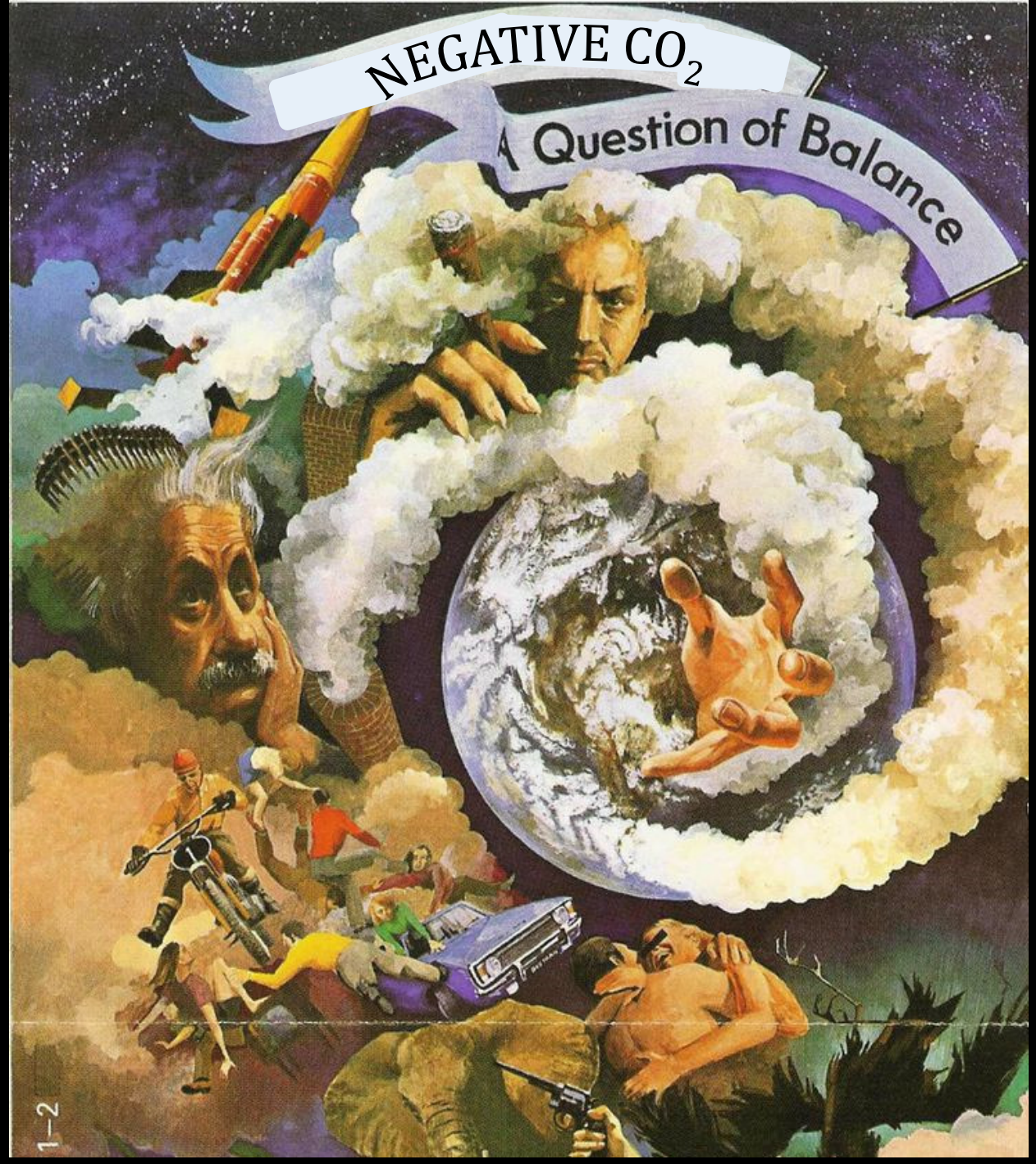
or

100 tonnes per now living human being

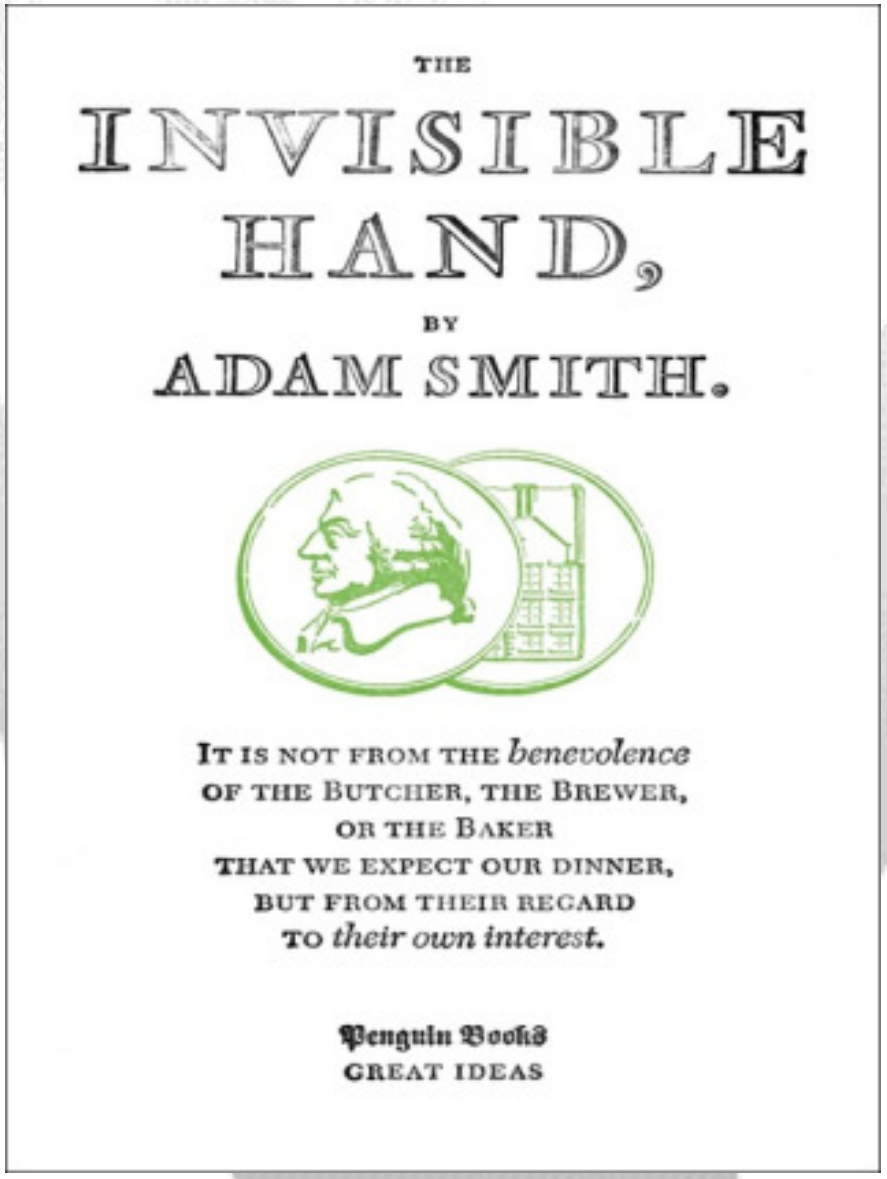
or

≈10.000 € per now living human being

Totally irresponsible to base climate policy on leaving the burden of removing our emissions to our grandchildren to clean up.



Totally irresponsible not to start using negative emissions (as well as all available means of reducing fossil emissions)

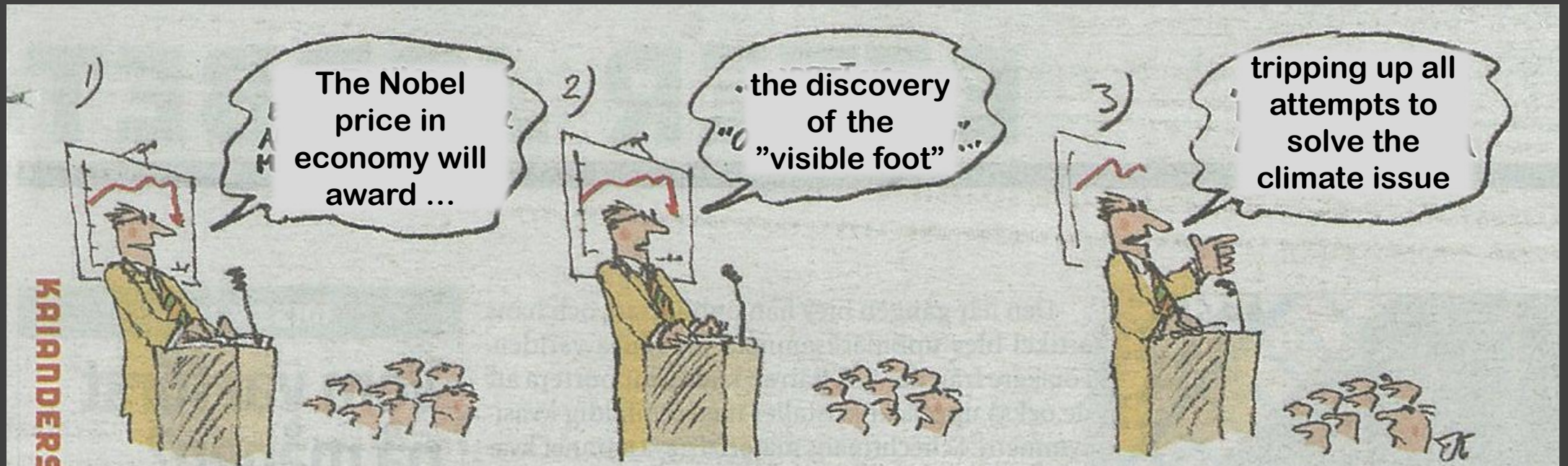


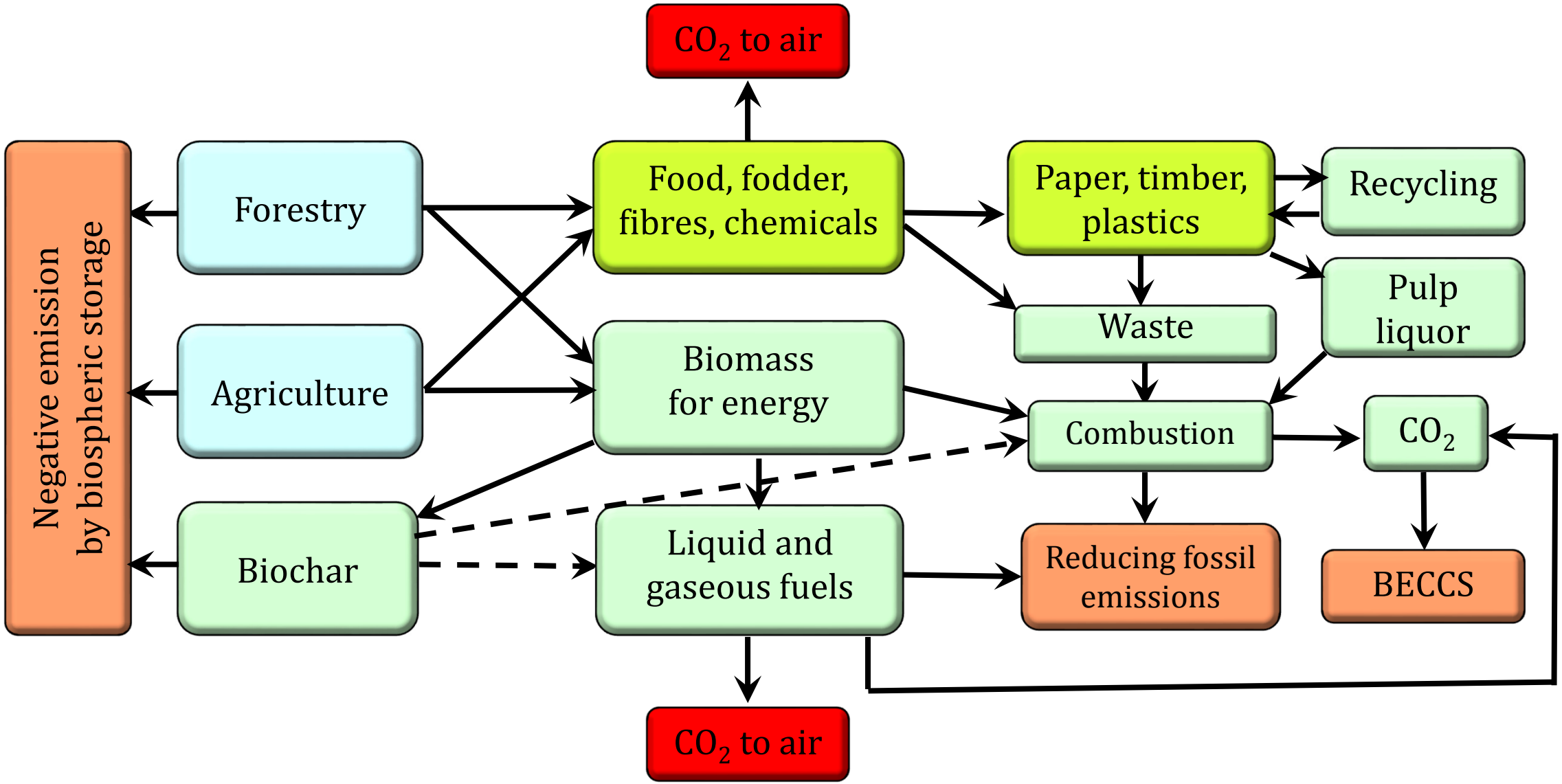
A price on CO_2 would make the ***invisible hand*** of the market find all known and unknown possibilities to reduce emissions.

For 25 years we have failed to price CO_2 emissions.

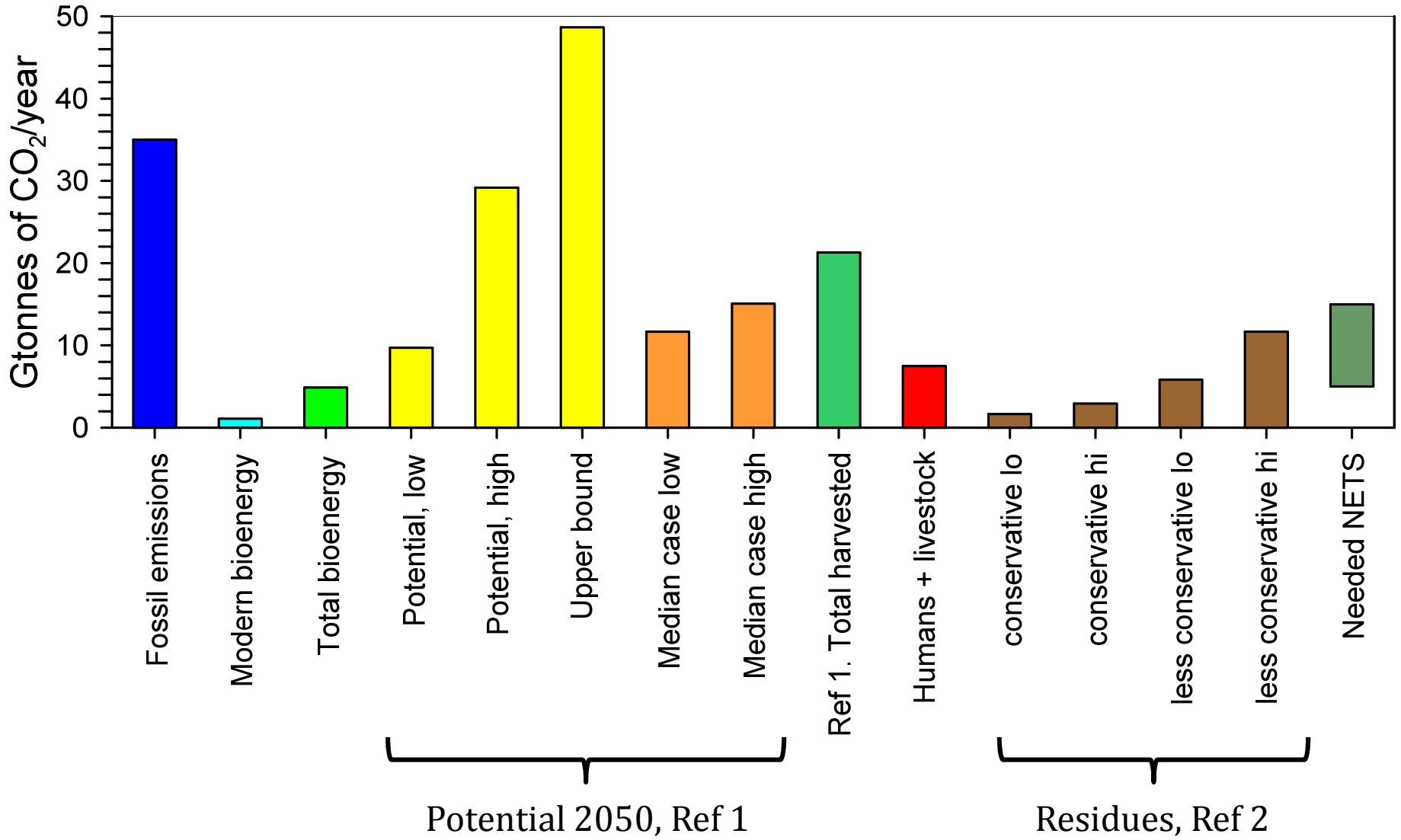
We need to make the market work ***for*** the climate, instead of against

Without a CO_2 price,
the very visible foot of
the market tramples
down most of our efforts





Biogenic CO_2: ***A valuable waste that can be used to amortize our gigantic climate debt***

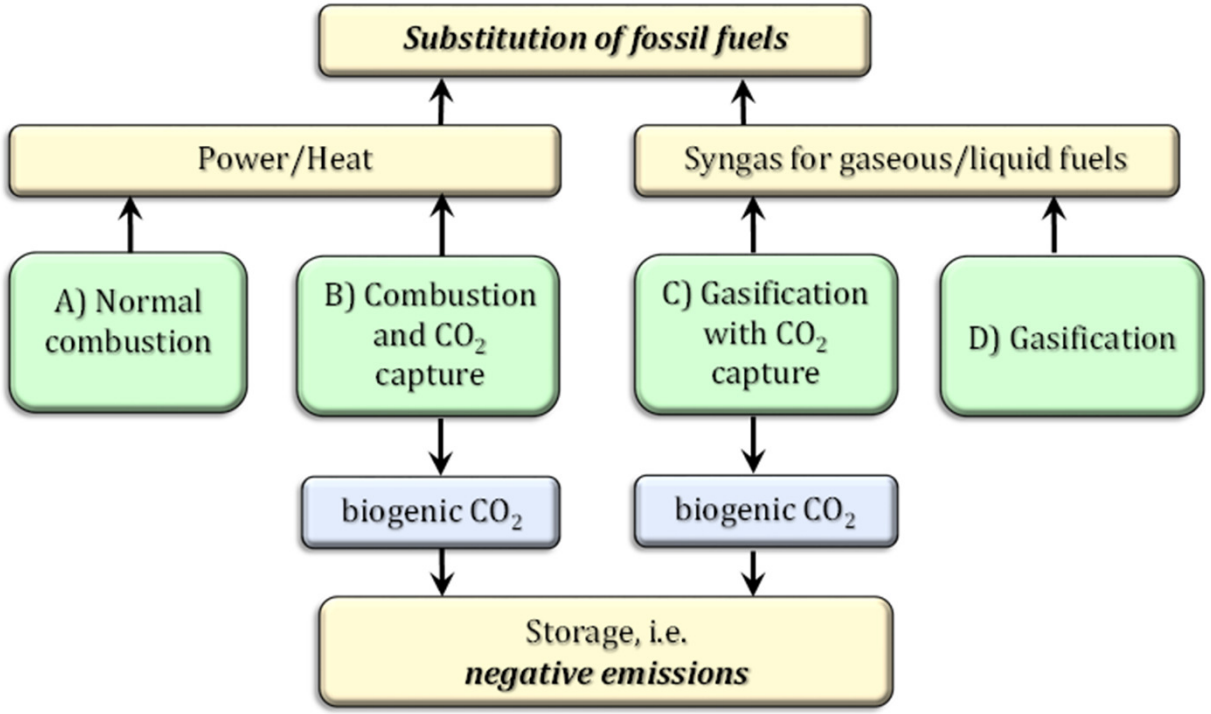


Ref 1. Renewable Energy Sources and Climate Change Mitigation, Special Report of the Intergovernmental Panel on Climate Change, Chapter 2. Bioenergy
By Helena Chum, Andre Faaij, José Moreira, Göran Berndes, Parveen Dhamija, Hongmin Dong, Benoît Gabrielle, Alison Goss Eng, Wolfgang Lucht, Maxwell Mapako, Omar Masera Cerutti, Terry McIntyre, Tomoaki Minowa, Kim Pingoud, Richard Bain, Ranyee Chiang, David Dawe, Garvin Heath, Martin Junginger, Martin Patel, Joyce Yang, Ethan Warner, David Paré, Suzana Kahn Ribeiro

Ref 2, Global Bioenergy Resources, Slade, Bauen and Gross, Nature Climate Change 29 jan 2014, vol 4 s. 99-105

Biomass is a limited resource

must be used efficiently wrt. climate



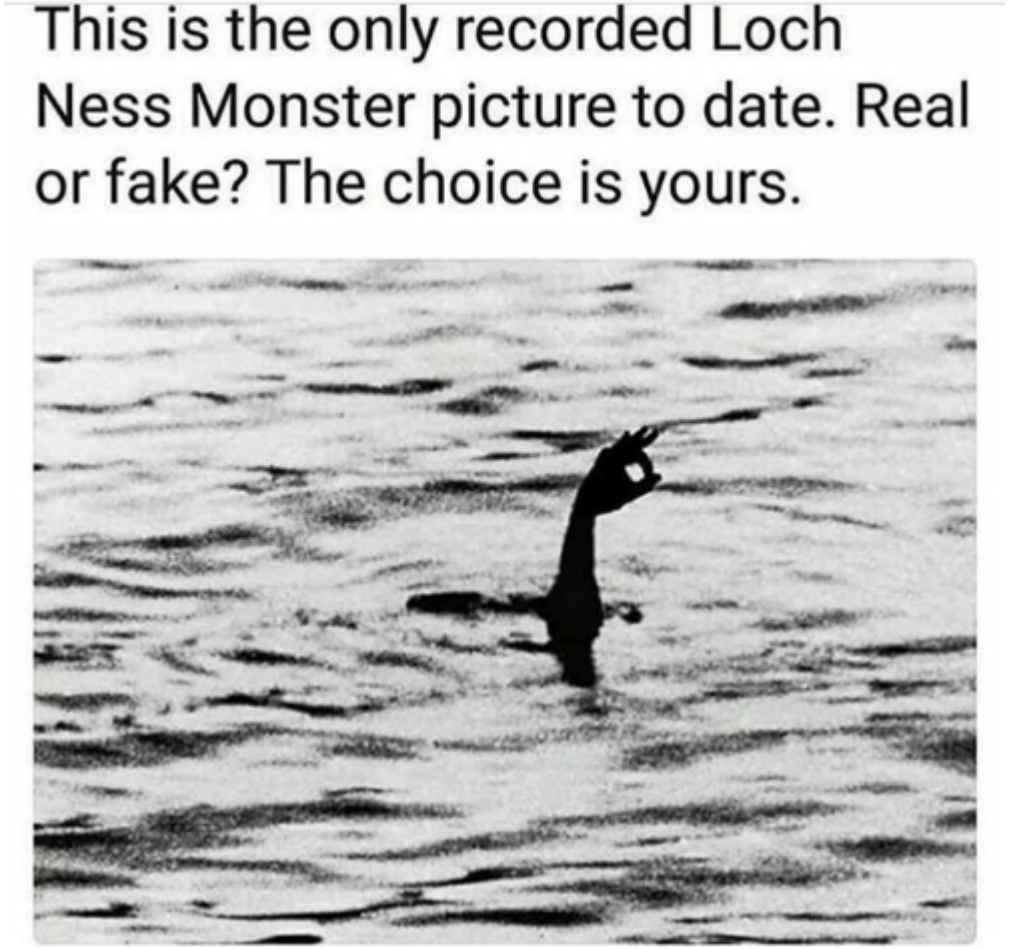
Climate efficiency	A	B	C	D
ϕ_{Em}, wrt. reducing fossil emissions	**1**[a]	**1**[a]	**½**[b]	**½**[b]
ϕ_{AtmRem}, wrt. atmospheric CO_2 removal	**0**	**1**	**½**	**0**
Total	**1**	**2**	**1**	**½**

$$\emptyset_{Em} = Climate\ Efficiency_{Emissions} = \frac{reduced\ emissions\ of\ fossil\ CO_2}{CO_2\ captured\ by\ biomass\ used\ when\ growing}$$

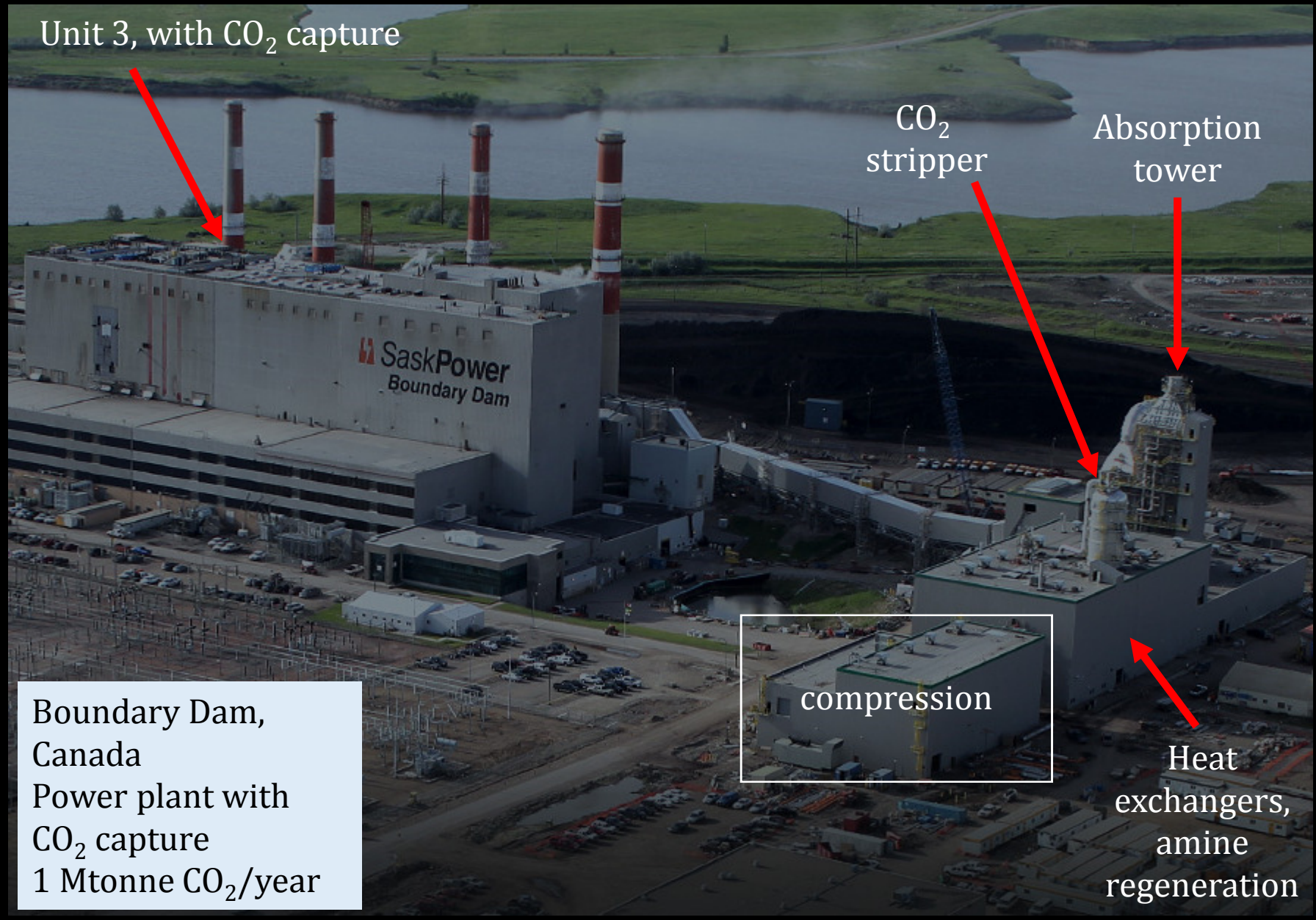
$$\emptyset_{AtmRem} = Climate\ Efficiency_{Atm.Removal} = \frac{CO_2\ removed\ from\ atmosphere}{CO_2\ captured\ by\ biomass\ used\ when\ growing}$$

BECCS uses CO_2 Capture and Storage (CCS) technology.

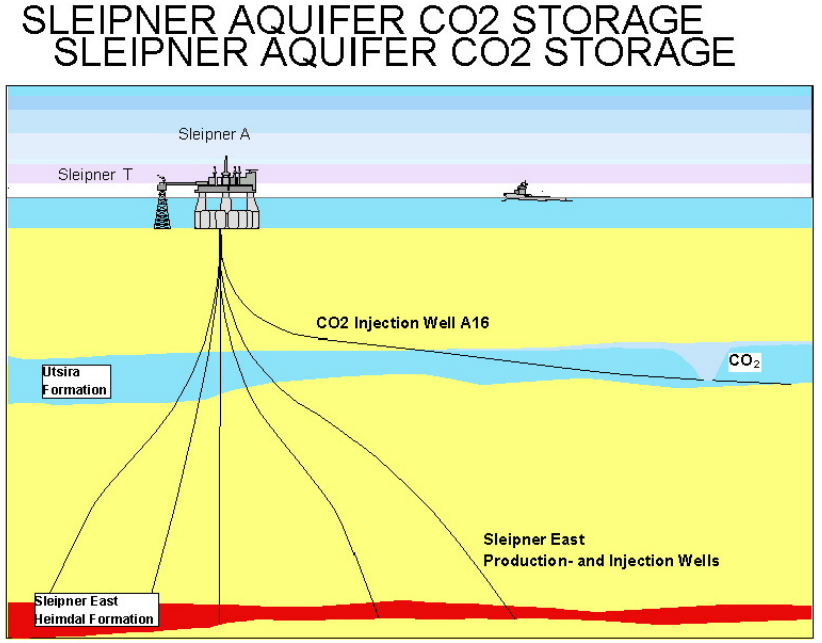
Does CCS exist ?



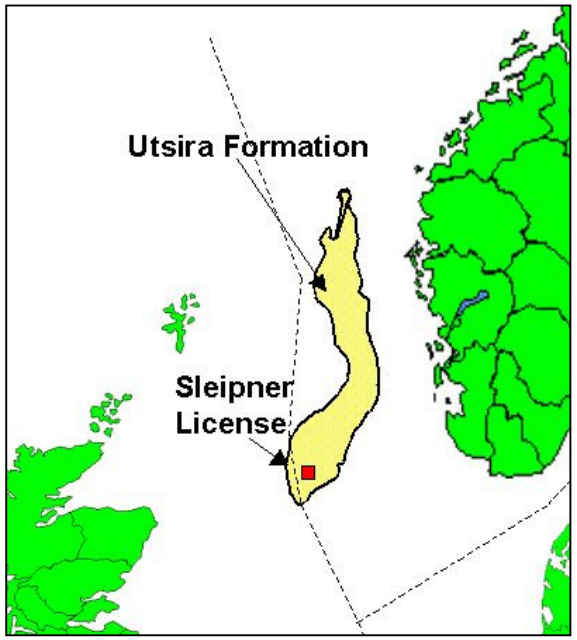
In operation since October 2014




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



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%

TOTAL CO_2 STORAGE TODAY

30 Mt CO_2 yearly

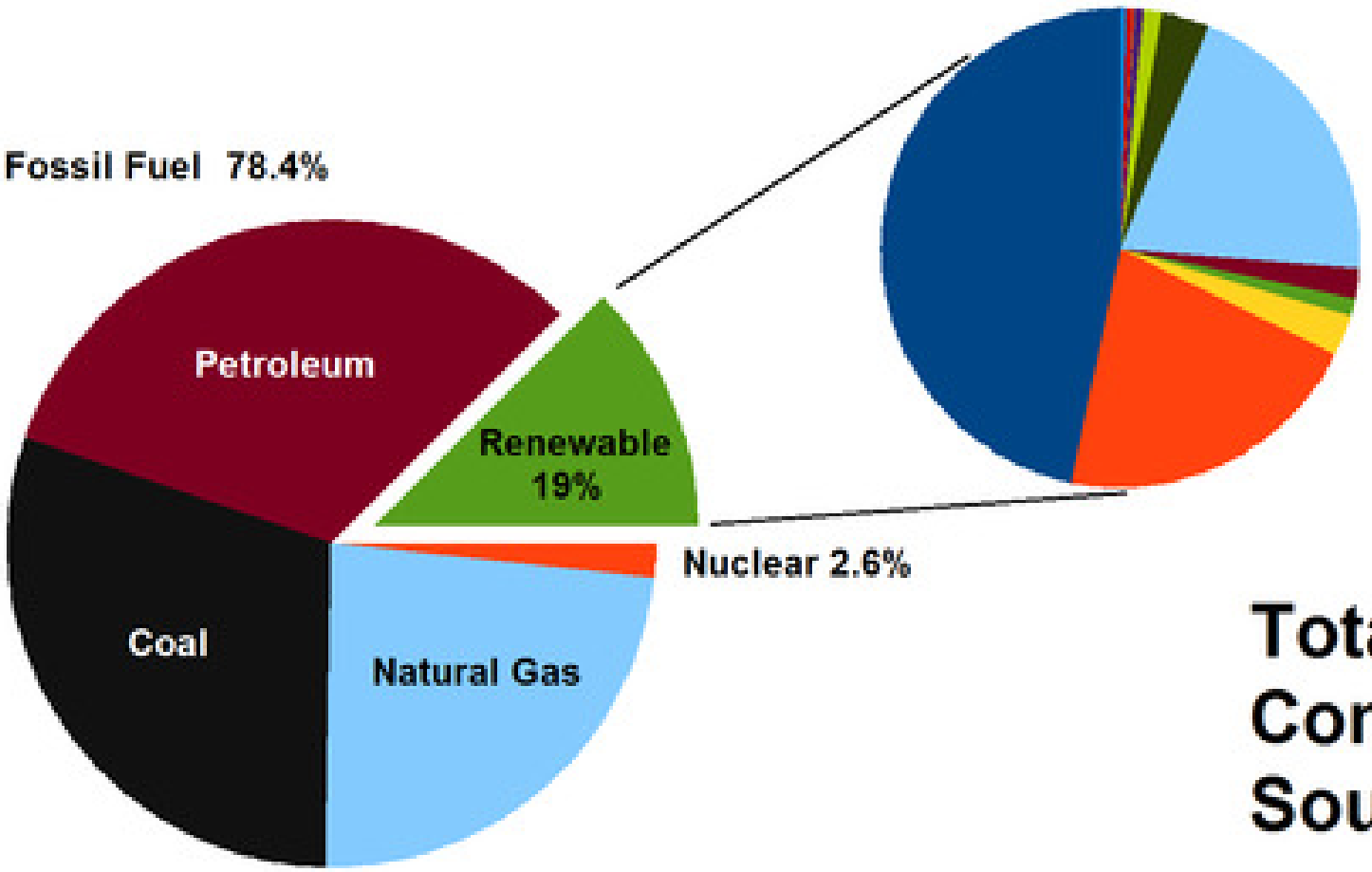
or 0.1%* of global emissions

includes one BECCS unit of 1 Mt/year

Technology exists:

Despite incentives being

very, very rare.



Renewable

Traditional biomass	9%
Bio-heat	2.6%
Ethanol	0.34%
Biodiesel	0.15%
Biopower generation	0.25%
Hydropower	3.8%
Wind	0.39%
Solar heating/cooling	0.16%
Solar PV	0.077%
Solar CSP	0.0039%
Geothermal heat	0.061%
Geothermal electricity	0.049%
Ocean power	0.00078%

Total World Energy Consumption by Source (2013)

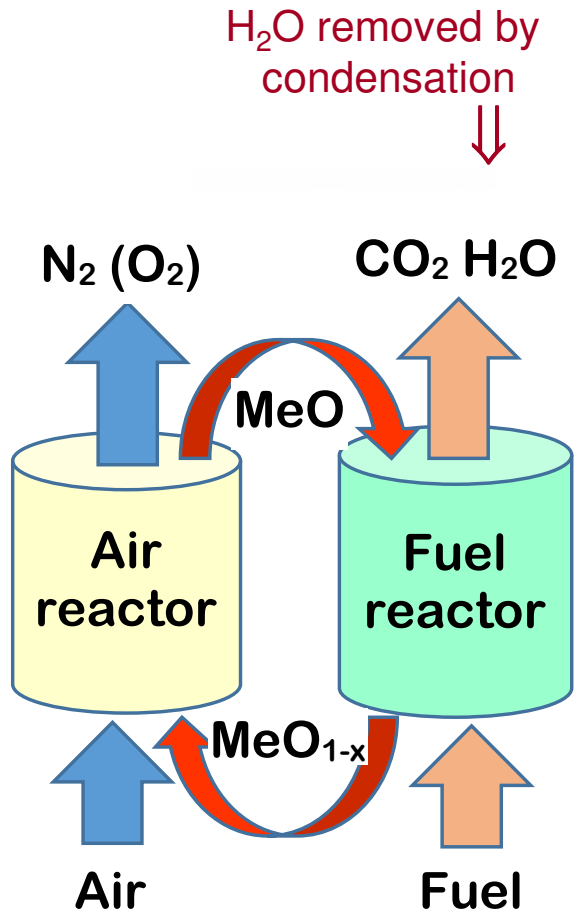
Problem to solve:

Existing CO_2 capture technologies have
large costs/energy penalties of **gas separation**

But this can be avoided with
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*



But does it work in practice ??

Yes, it works!!

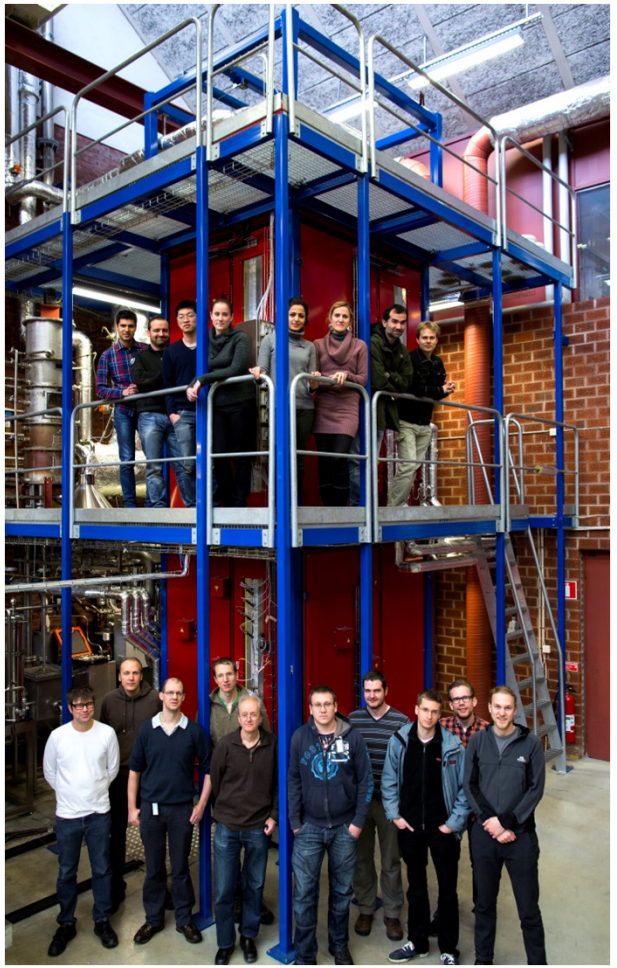
Total chemical-looping operation at Chalmers: 4 000 h in four pilots

Worldwide: 10 000 h in 35 pilots

10 kW gas, 2003

300 W gas, 2004

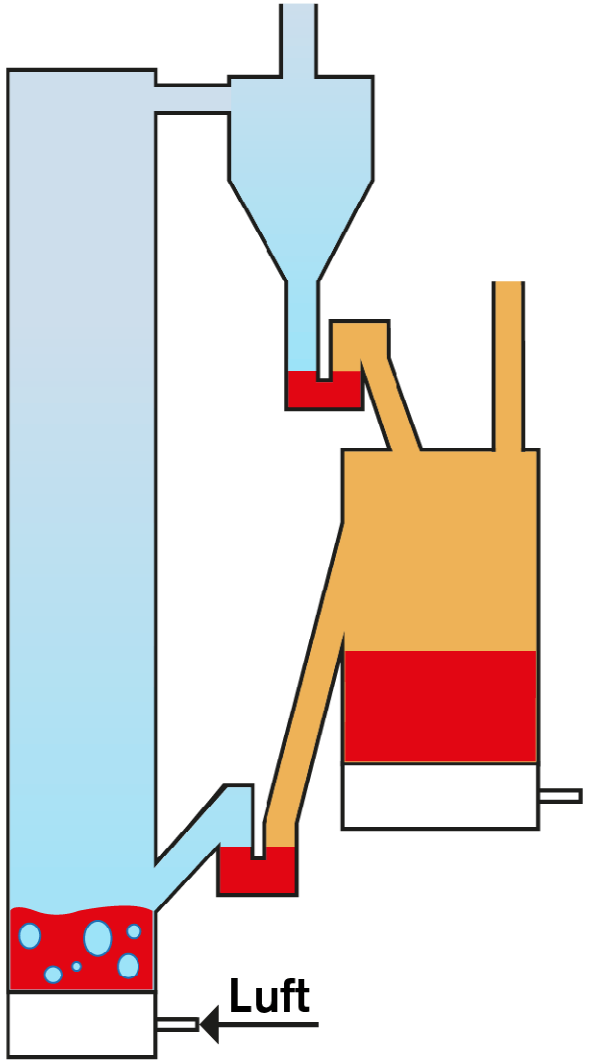
10 kW solid fuel, 2006



100 kW solid fuel, 2011

Circulating fluidized-bed boiler for burning biomass

Chemical Looping Combustion



Conventional biomass combustion is similar to Chemical-looping Combustion:
>>>Low added cost for CLC

What is a fluidized bed?

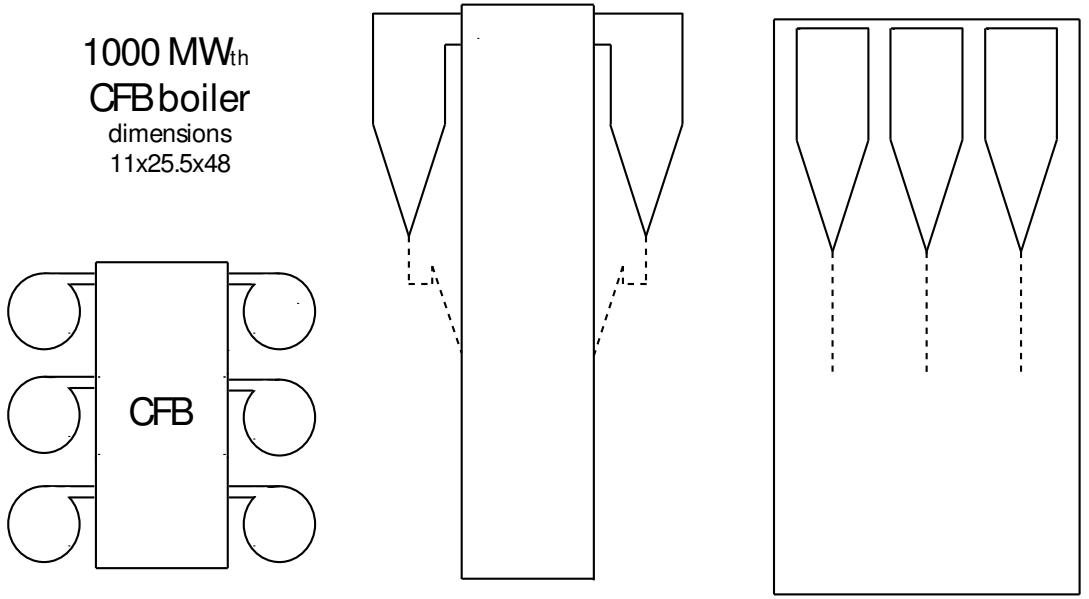
In small biomass boilers grate firing is used.

For larger boilers fluidized bed is common

If gas (air) is blown through a bed av particles (e.g. sand) you get a fluidized bed.

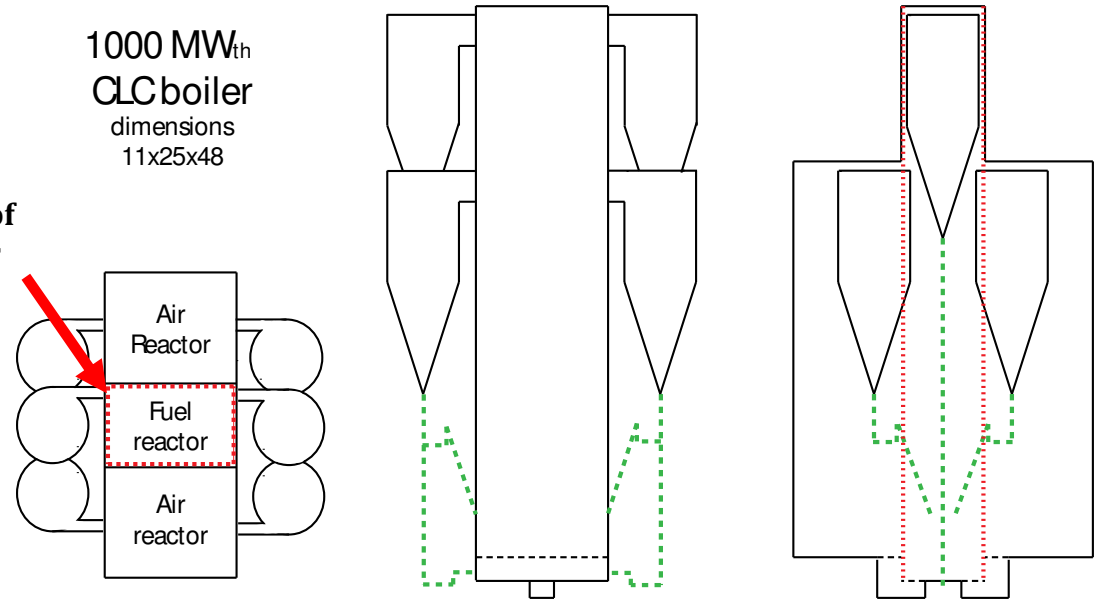
Behaves like a liquid

1000 MW_{th}
CFB boiler
dimensions
11x25.5x48



1000 MW_{th}
CLC boiler
dimensions
11x25x48

Added cost: insulation of fuel reactor



Walls of fuel reactor, cyclones, ducts and post-oxidation chamber:
→ 2500 m^2

Cost: 1500 €/m^2

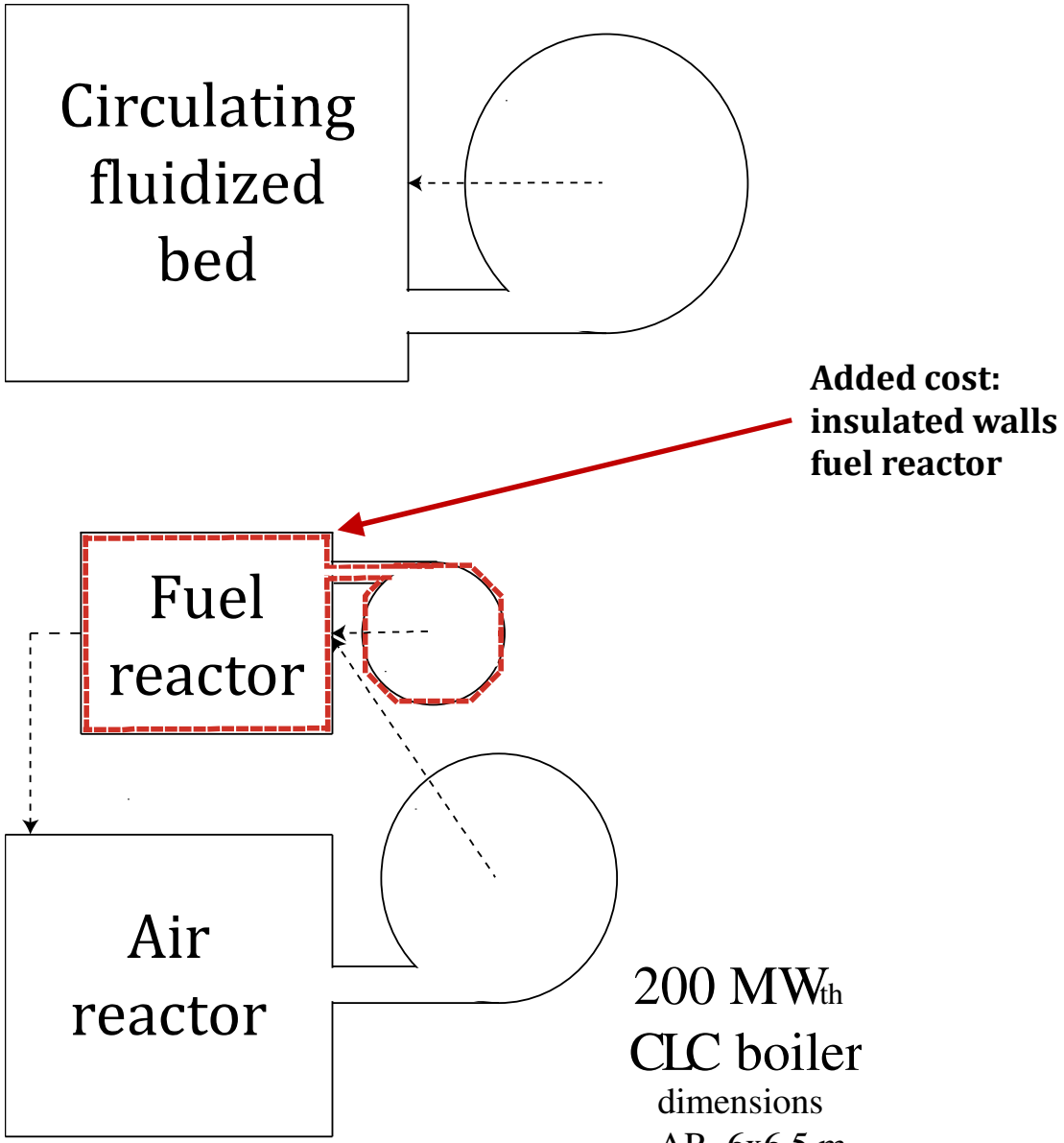
<u>Thus, added cost of CLC fuel reactor:</u>

≈ 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)*



<u>Added investment cost:</u>
walls fuel reactor:
→ 850 m^2

Price: 1300 €/m^2

<u>Thus 1300x850:</u>

≈ 1.1 M€

⇒ 0.11 M€/year
÷
0.28 Mt CO_2/year

= 0.4 €/ton CO_2

•Added cost relative to CFB[1]

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

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

Different NETs comes with different safety of storage and estimated retention time

For how long do we need to store the carbon ?

How long does CO_2 need to be stored ?
Examples for CCS from 2003

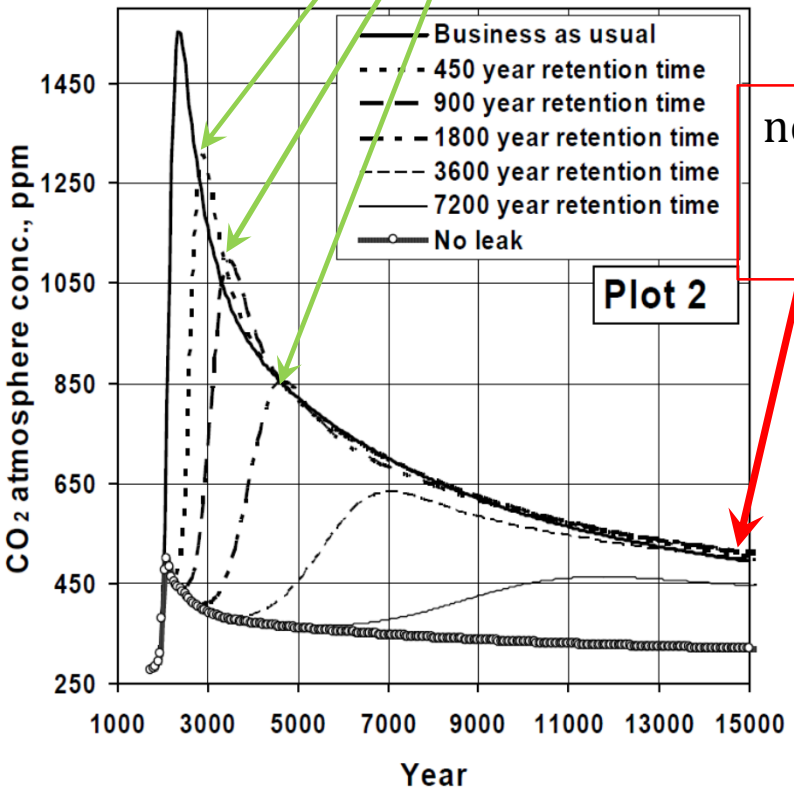
Both cases:
<u>Business as usual:</u>
Large release:
Left 20 000 Gt CO_2
Right 8 000 Gt CO_2

<u>No leak:</u>
80% of large release permanently stored

<u>Leakage cases</u>:
Fraction permanently stored increases with time constant:
Left: 7000 years
Right: 1078 years

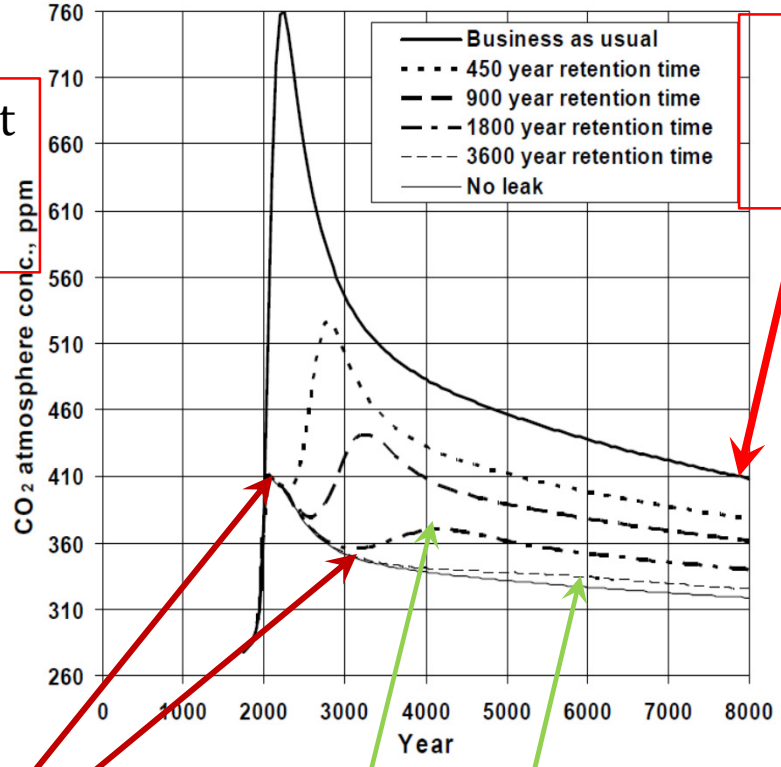
Lower peak, eventually joins Business-as-usual

Extreme release, slow trapping



not back at starting point

Very high release, fast trapping



back at starting point

Well below starting point

a millenia to go from 410 to 350 ppm

Median 2°C case stores <800 Gton (<10% of right)
➔ Leakage should not be a problem if not very fast

What is a reasonable cost?

The global CO_2 emissions divided by
the global GDP, gives the:

carbon dioxide intensity ≈ 0.5 kg CO_2/€

If multiplied by a tax, or cost for avoiding emissions,
you get the tax/cost as *fraction of global GDP*

Thus, if the tax is 2 €/kg you get

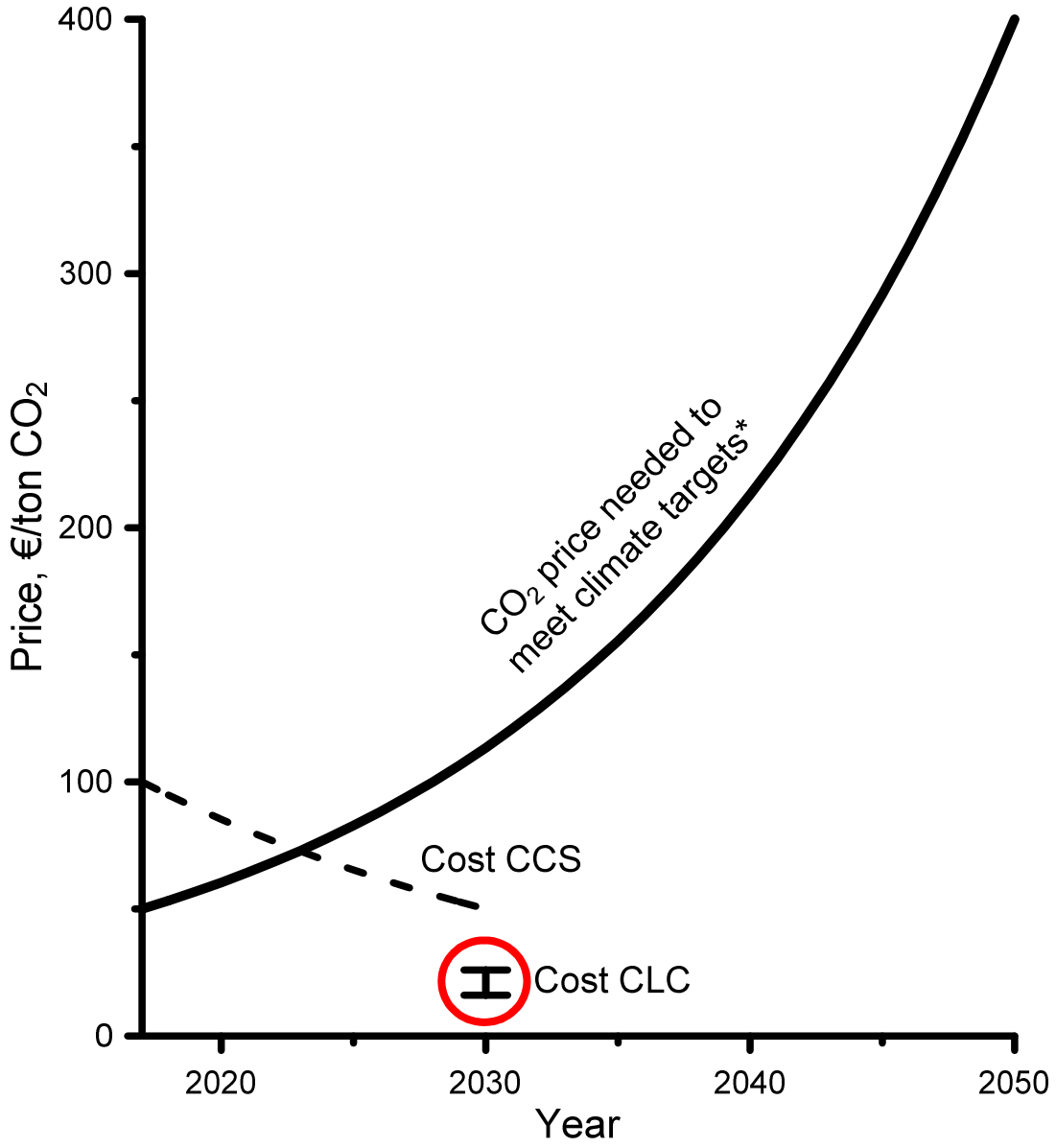
$2 \times 0.5 = 1$
(i.e. the tax is 100% of the global economy, which is not possible!!!)

but if it is 0.02 €/kg the fraction is 1%

What is a reasonable cost, cont'd

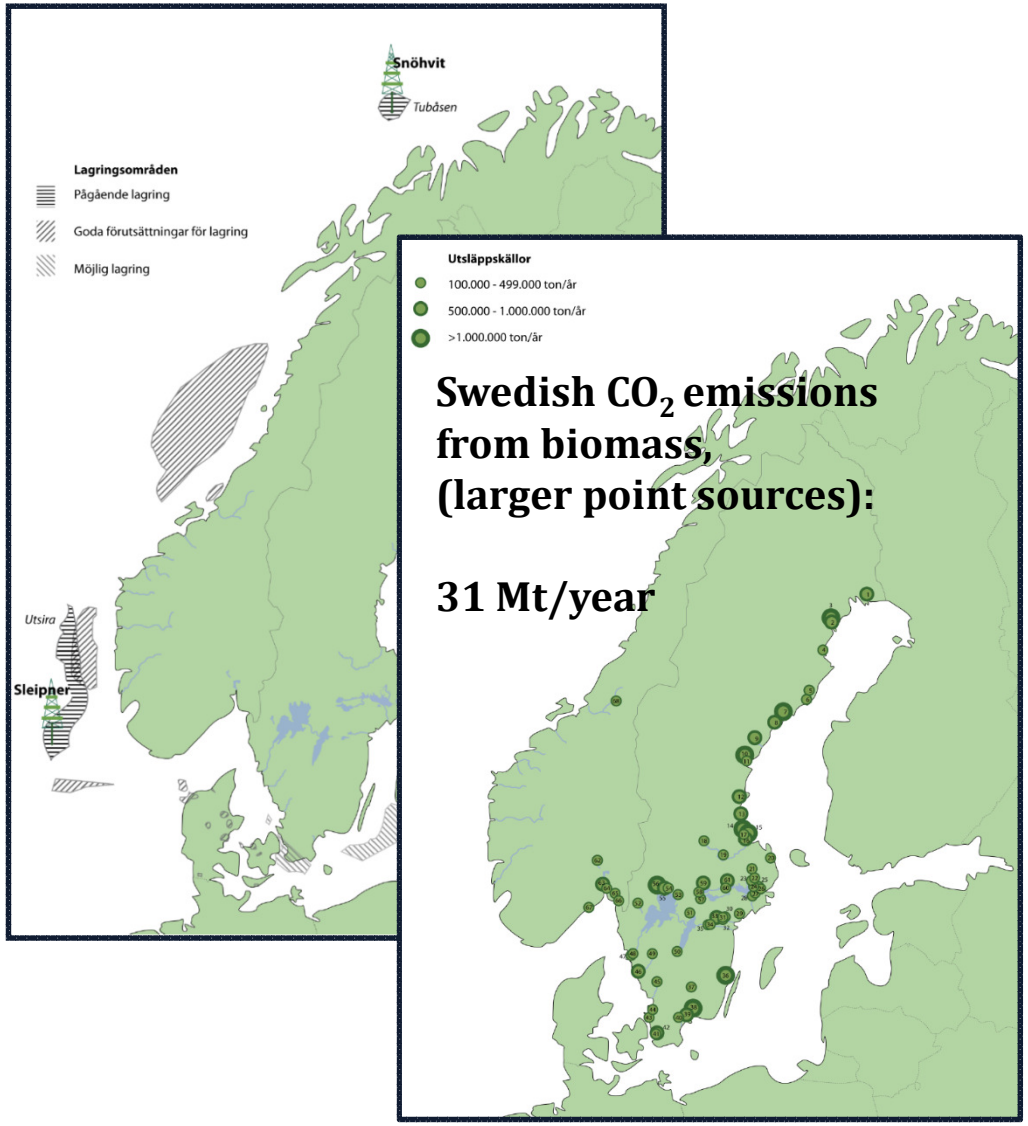
Example	Cost to avoid CO_2 emission, €/kg	Share of total economy
CLC, estimated	0.02	1%
CCS, estimated	0.05	2.5%
CCS, real, today?	0.10	5%
Price needed, now[1]	0.05	2.5%
Price needed 2050[1]	0.4	20%

[1] J. Rockström, O. Gaffney, J. Rogelj, et al. A roadmap for rapid decarbonization. *Science* 2017; **355**:1269-1271.



*Rockström J, et al., *Science* **355** (2017) 1269-1271

Possible storage in the Nordics



Sweden's total fossil CO_2 emissions are:

43 Mtonnes/year

If fossil CO_2 emissions are stopped and CO_2 emissions from biomass are captured, we can reduce emissions by

more than 150% !!!

Relative to the 2-degree target, Sweden has exceeded its legitimate share of the carbon budget twice.

It is time to start the clean-up of the atmosphere !

Rockström et al. (Science):
Needed price of CO_2 is 400 $/ton in 30 years.
This means that our emissions from biomass are worth:

> 10 billion €

or 2.5% of GDP

Key messages

- ”Balance”, we must be able to think two things
  - Negative emissions are needed
  - We must reduce CO_2 emissions rapidly, and not put a great burden of negative emissions on our grandchildren
- CCS is ***existing*** technology. It is practiced in large scale, 30 Mton/year, or 0.1% of global emissions.
  - Reason for not being more is lack of incentives. We need incentives to save the climate anyway.
- BECCS is normally the ***most efficient way of using biomass*** with respect to climate
- We do not need to store all the CO_2 forever.
- CCS/BECCS has ***reasonable costs***
  - CLC has potential for large cost reduction
- Negative CO_2 emissions is ***not instead of other use of biomass*** – *it can normally be combined with other uses of biomass, i.e. recovering a waste stream.*
- 2°C target with late NETs. Gigantic debt for our grandchildren to inherit. 100 ton or ≈10.000 €/capita
  - Personally I do not think the 2-degree target is acceptable. That’s not the world I want to leave for my grandchildren. I think we must assure we keep below 1.5 degrees.
- Start negative emissions now, in parallel with rapid fossil CO_2 reduction
  - Starting with negative emissions now will empasize the absurdity of releasing fossil CO_2 for free.
- Sweden has a very good position for negative emissions
- Tomorrow I will discuss possible financing of negative emissions

I have a dream

- that this conference will become a series, and that every time we meet the world will have taken a number of important and crucial steps towards substanially reduced emissions.
- of a world-wide cost for emitting CO_2, a costs that effectively reduces emissions, and that can be increased by and by
- of not leaving an immense CO_2 debt to our children's children, but that we start to clean the atmosphere in parallel with eliminating the fossil emissions
- of seeing a day when the atmospheric concentration of CO_2 starts to fall
- that we will meet the 1.5°C target and eventually be back to 350 ppm of CO_2 in the atmosphere

A bit less important:

- that Sweden will 1) be first nation to be CO_2 negative 2) will reduce the CO_2 emissions by at least 150%, 3) become a good example to the rest of the world.

- that CLC (chemical-looping combustion) is part of the solution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