CCS: Mature technology and known costs – implement in large-scale now

by

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TCCS-10 Trondheim Norway, 17 – 19 June 2019

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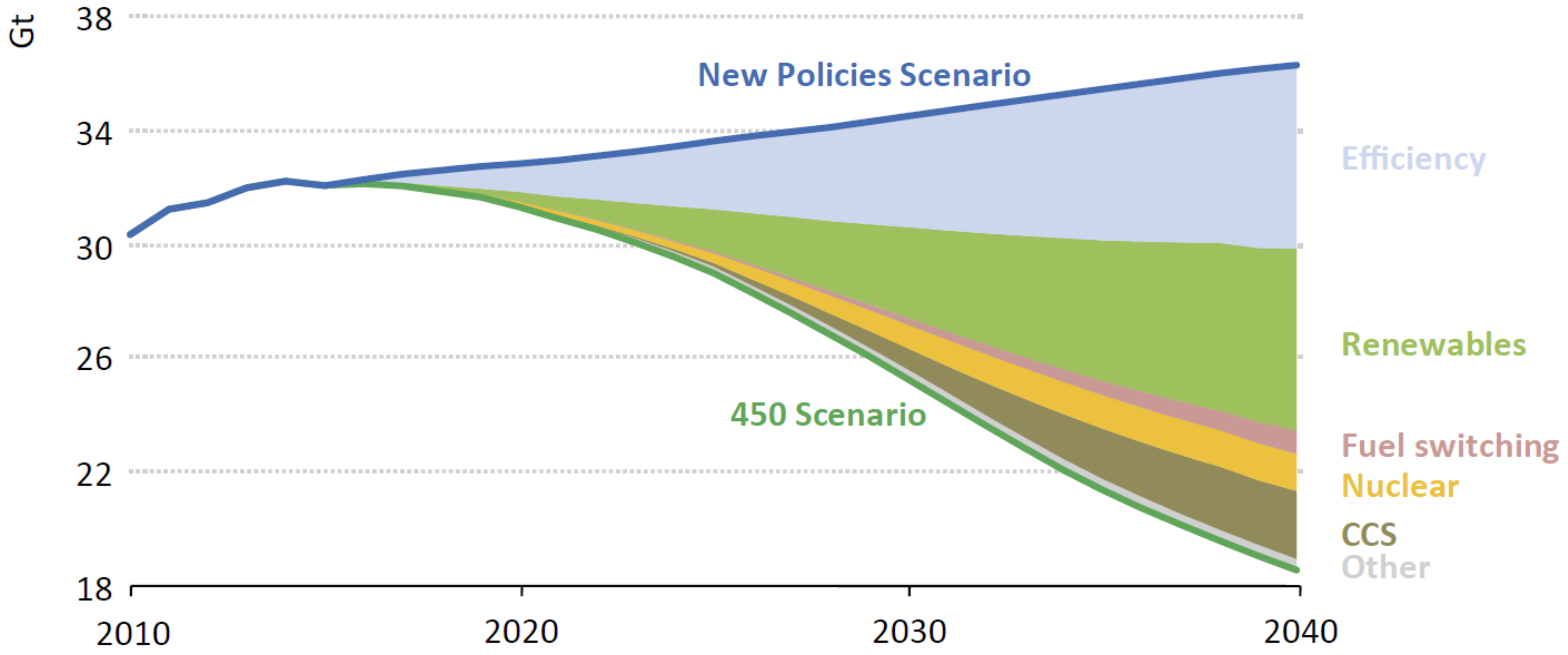
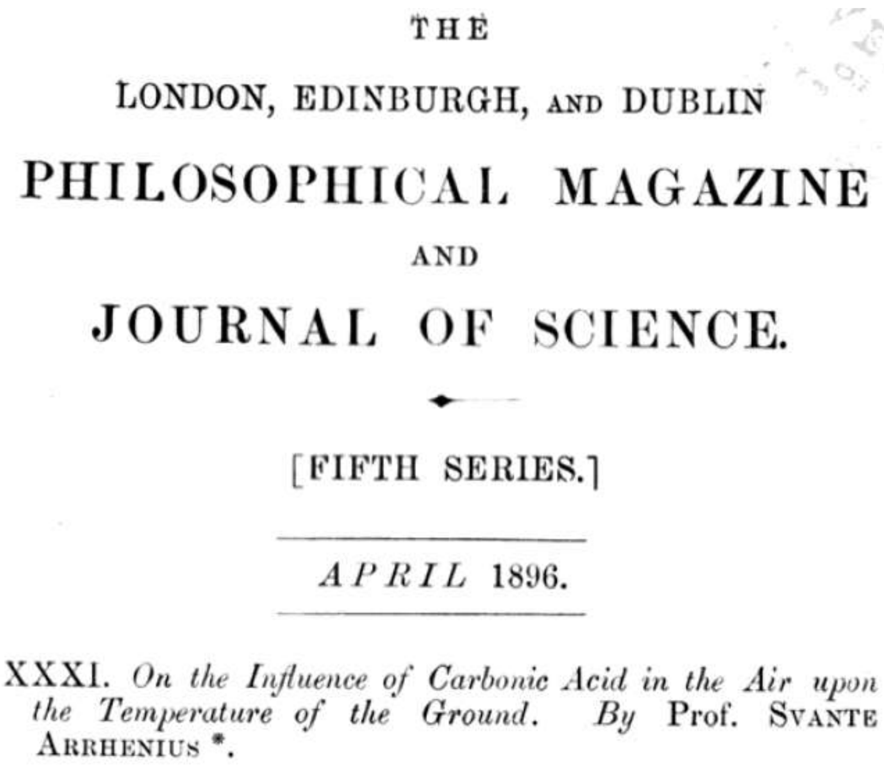
- Introduction
- CO_2 capture
- CO_2 transport
- CO_2 storage
- Economy
- CO_2 budget
- Conclusions

CO_2 emission reduction scenarios (IEA 2016)



The effect of CO_2 on global warming has been known for ages



THE

LONDON, EDINBURGH, AND DUBLIN

PHILOSOPHICAL MAGAZINE

AND

JOURNAL OF SCIENCE.

[FIFTH SERIES.]

APRIL 1896.

XXXI. *On the Influence of Carbonic Acid in the Air upon the Temperature of the Ground.* By Prof. SVANTE ARRHENIUS *.

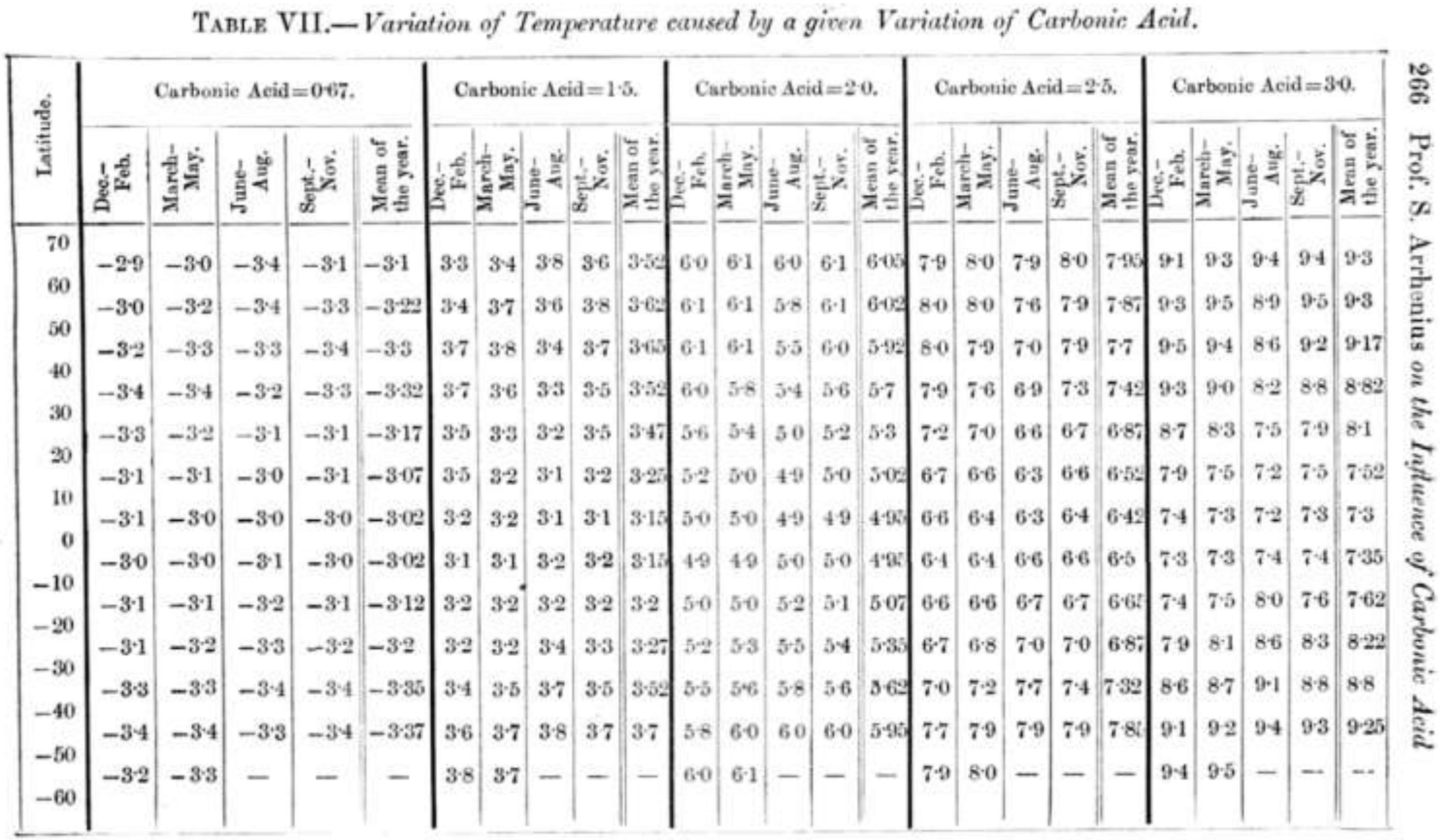
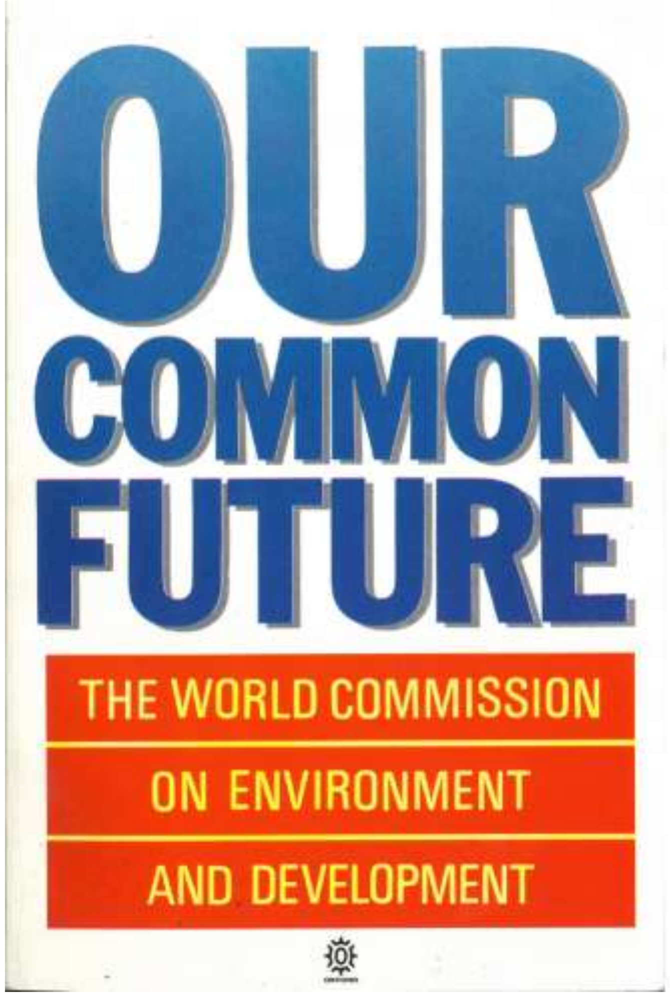
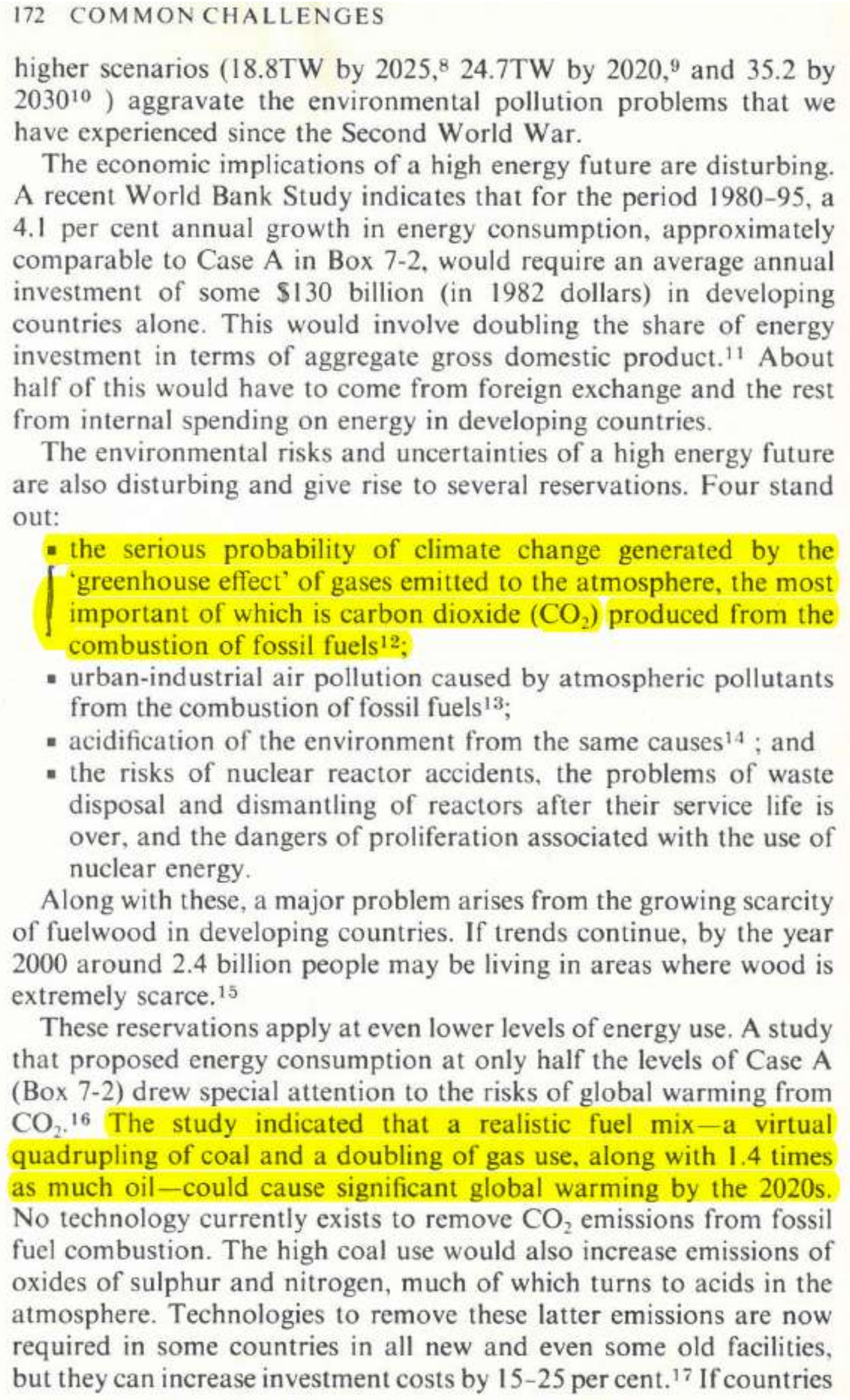


TABLE VII.—*Variation of Temperature caused by a given Variation of Carbonic Acid.*

Latitude.	Carbonic Acid=0·67.					Carbonic Acid=1·5.					Carbonic Acid=2·0.					Carbonic Acid=2·5.					Carbonic Acid=3·0.				
	Dec.–Feb.	March–May.	June–Aug.	Sept.–Nov.	Mean of the year.	Dec.–Feb.	March–May.	June–Aug.	Sept.–Nov.	Mean of the year.	Dec.–Feb.	March–May.	June–Aug.	Sept.–Nov.	Mean of the year.	Dec.–Feb.	March–May.	June–Aug.	Sept.–Nov.	Mean of the year.	Dec.–Feb.	March–May.	June–Aug.	Sept.–Nov.	Mean of the year.
70	−2·9	−3·0	−3·4	−3·1	−3·1	3·3	3·4	3·8	3·6	3·52	6·0	6·1	6·0	6·1	6·05	7·9	8·0	7·9	8·0	7·95	9·1	9·3	9·4	9·4	9·3
60	−3·0	−3·2	−3·4	−3·3	−3·22	3·4	3·7	3·6	3·8	3·62	6·1	6·1	5·8	6·1	6·02	8·0	8·0	7·6	7·9	7·87	9·3	9·5	8·9	9·5	9·3
50	−3·2	−3·3	−3·3	−3·4	−3·3	3·7	3·8	3·4	3·7	3·65	6·1	6·1	5·5	6·0	5·92	8·0	7·9	7·0	7·9	7·7	9·5	9·4	8·6	9·2	9·17
40	−3·4	−3·4	−3·2	−3·3	−3·32	3·7	3·6	3·3	3·5	3·52	6·0	5·8	5·4	5·6	5·7	7·9	7·6	6·9	7·3	7·42	9·3	9·0	8·2	8·8	8·82
30	−3·3	−3·2	−3·1	−3·1	−3·17	3·5	3·3	3·2	3·5	3·47	5·6	5·4	5·0	5·2	5·3	7·2	7·0	6·6	6·7	6·87	8·7	8·3	7·5	7·9	8·1
20	−3·1	−3·1	−3·0	−3·1	−3·07	3·5	3·2	3·1	3·2	3·25	5·2	5·0	4·9	5·0	5·02	6·7	6·6	6·3	6·6	6·52	7·9	7·5	7·2	7·5	7·52
10	−3·1	−3·0	−3·0	−3·0	−3·02	3·2	3·2	3·1	3·1	3·15	5·0	5·0	4·9	4·9	4·95	6·6	6·4	6·3	6·4	6·42	7·4	7·3	7·2	7·3	7·3
0	−3·0	−3·0	−3·1	−3·0	−3·02	3·1	3·1	3·2	3·2	3·15	4·9	4·9	5·0	5·0	4·95	6·4	6·4	6·6	6·6	6·5	7·3	7·3	7·4	7·4	7·35
−10	−3·1	−3·1	−3·2	−3·1	−3·12	3·2	3·2	3·2	3·2	3·2	5·0	5·0	5·2	5·1	5·07	6·6	6·6	6·7	6·7	6·65	7·4	7·5	8·0	7·6	7·62
−20	−3·1	−3·2	−3·3	−3·2	−3·2	3·2	3·2	3·4	3·3	3·27	5·2	5·3	5·5	5·4	5·35	6·7	6·8	7·0	7·0	6·87	7·9	8·1	8·6	8·3	8·22
−30	−3·3	−3·3	−3·4	−3·4	−3·35	3·4	3·5	3·7	3·5	3·52	5·5	5·6	5·8	5·6	5·62	7·0	7·2	7·7	7·4	7·32	8·6	8·7	9·1	8·8	8·8
−40	−3·4	−3·4	−3·3	−3·4	−3·37	3·6	3·7	3·8	3·7	3·7	5·8	6·0	6·0	6·0	5·95	7·7	7·9	7·9	7·9	7·8	9·1	9·2	9·4	9·3	9·25
−50	−3·2	−3·3	—	—	—	3·8	3·7	—	—	—	6·0	6·1	—	—	—	7·9	8·0	—	—	—	9·4	9·5	—	—	—
−60																									

United nations 1987




172 COMMON CHALLENGES

higher scenarios (18.8TW by 2025,[8] 24.7TW by 2020,[9] and 35.2 by 2030[10]) aggravate the environmental pollution problems that we have experienced since the Second World War.

The economic implications of a high energy future are disturbing. A recent World Bank Study indicates that for the period 1980-95, a 4.1 per cent annual growth in energy consumption, approximately comparable to Case A in Box 7-2, would require an average annual investment of some $130 billion (in 1982 dollars) in developing countries alone. This would involve doubling the share of energy investment in terms of aggregate gross domestic product.[11] About half of this would have to come from foreign exchange and the rest from internal spending on energy in developing countries.

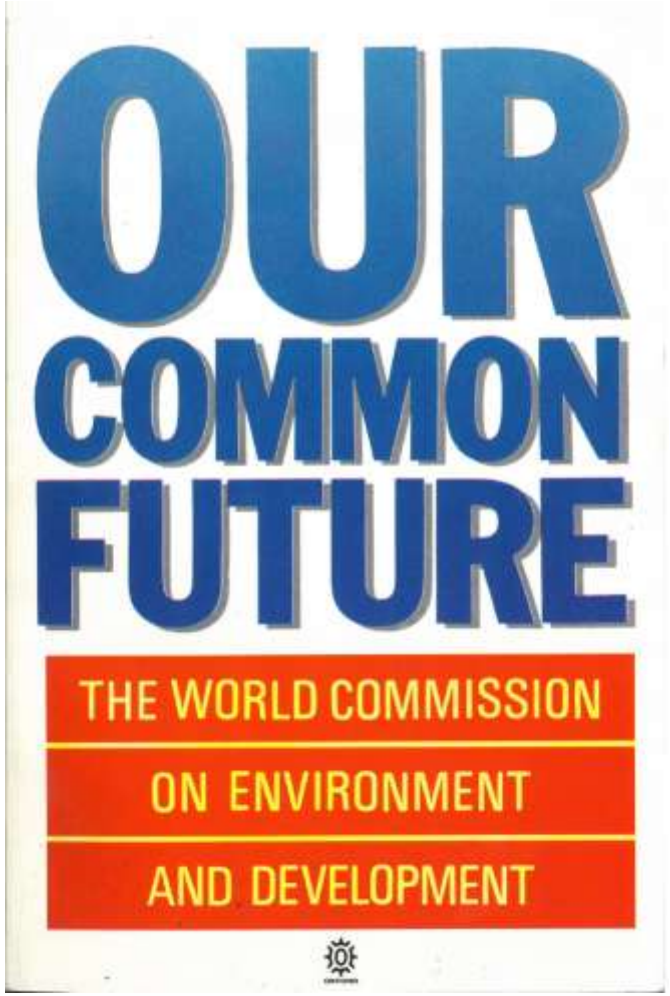
The environmental risks and uncertainties of a high energy future are also disturbing and give rise to several reservations. Four stand out:

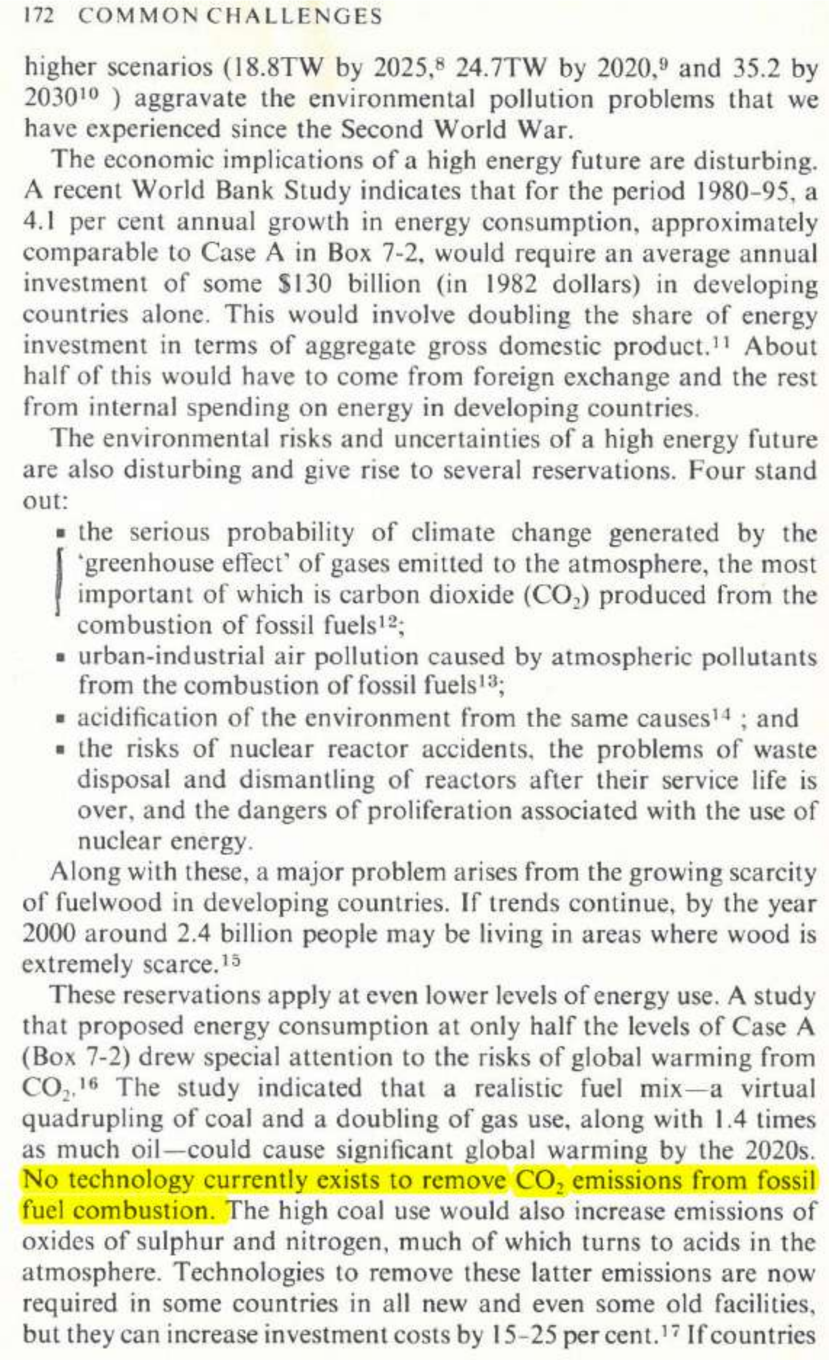
- the serious probability of climate change generated by the 'greenhouse effect' of gases emitted to the atmosphere, the most important of which is carbon dioxide (CO_2) produced from the combustion of fossil fuels[12];
- urban-industrial air pollution caused by atmospheric pollutants from the combustion of fossil fuels[13];
- acidification of the environment from the same causes[14] ; and
- the risks of nuclear reactor accidents, the problems of waste disposal and dismantling of reactors after their service life is over, and the dangers of proliferation associated with the use of nuclear energy.

Along with these, a major problem arises from the growing scarcity of fuelwood in developing countries. If trends continue, by the year 2000 around 2.4 billion people may be living in areas where wood is extremely scarce.[15]

These reservations apply at even lower levels of energy use. A study that proposed energy consumption at only half the levels of Case A (Box 7-2) drew special attention to the risks of global warming from CO_2.[16] The study indicated that a realistic fuel mix—a virtual quadrupling of coal and a doubling of gas use, along with 1.4 times as much oil—could cause significant global warming by the 2020s. No technology currently exists to remove CO_2 emissions from fossil fuel combustion. The high coal use would also increase emissions of oxides of sulphur and nitrogen, much of which turns to acids in the atmosphere. Technologies to remove these latter emissions are now required in some countries in all new and even some old facilities, but they can increase investment costs by 15-25 per cent.[17] If countries

United nations 1987





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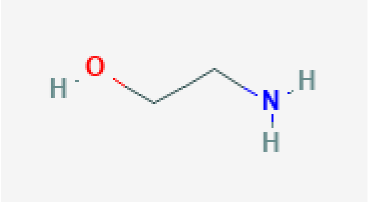
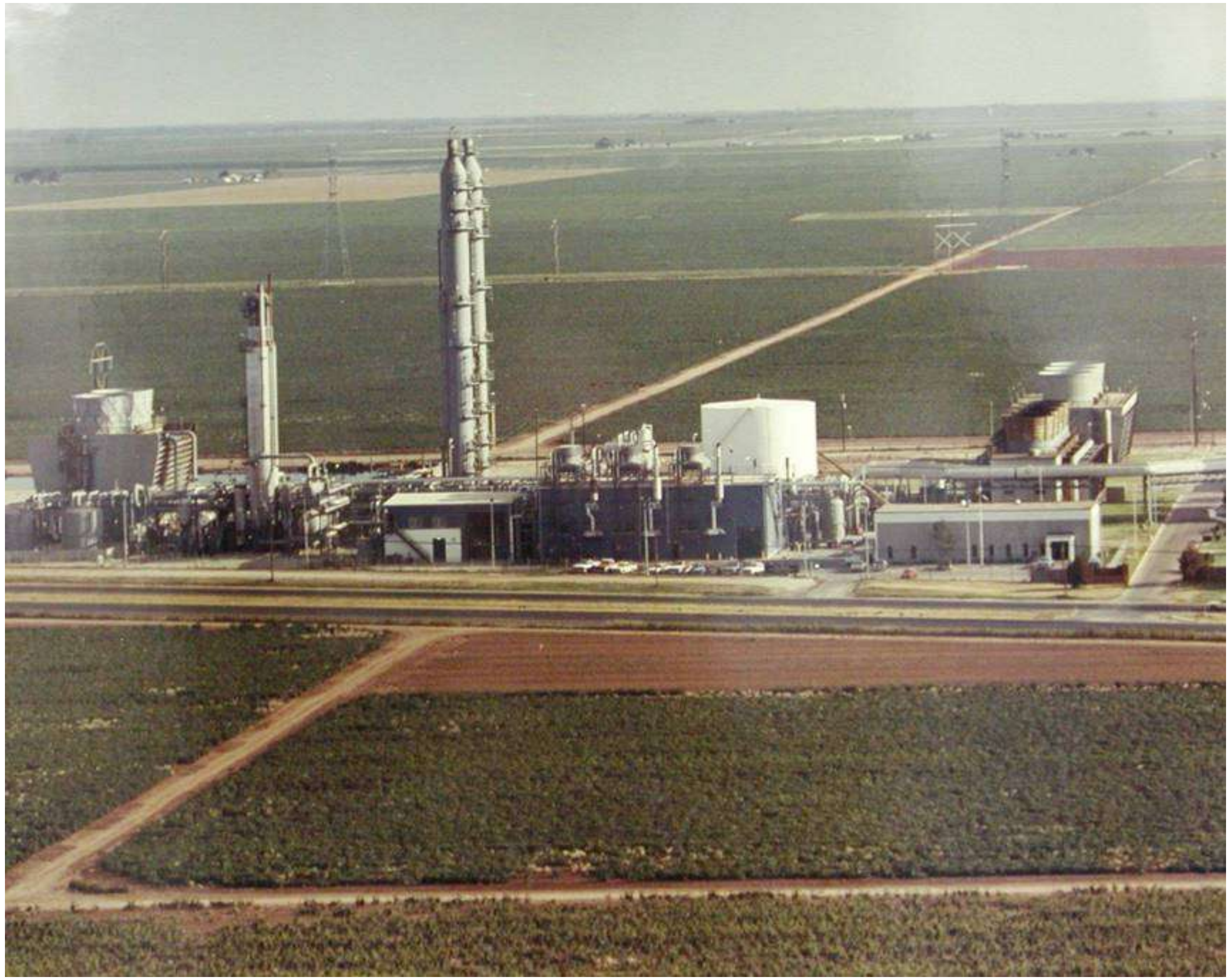
Chemical active absorption processes have been used for decades for cleaning of sour gasses

- CO_2 removal by MEA absorption from inert gasses was described in Chemical Engineering textbooks for almost 50 years ago
  - *e.g.*: C. J. King 1971: Separation processes, McGraw-Hill Inc.
  - in an example 99.5 % of the CO_2 was removed from the gas
- In the same book a hydrogen production plant from natural gas by steam reforming is also shown
  - CO_2 was removed by an absorption process



Monoethanolamine - MEA

Power production with CO_2 capture



- Gas power with CO_2 capture in 1982 Lubbock, Texas
- Capacity: ~ 400 000 tonnes CO_2/year
- The capture plant was based on an oil price of 30$/barrel and was discontinued when the oil price was sinking later in the 80this
- The power plant itself continued running

Recent large capture plants

If you use the information from this map you must credit Scottish Carbon Capture & Storage and include the url www.sccs.org.uk/map

Great Plains Synfuel Plant

Location: near Beulah, North Dakota, USA
Company: Dakota Gasification Comp
Status:
Fuel: Coal
Injection: 3 million tonnes CO_2 per year
Capture: Pre-combustion
Storage: EOR with MVR

Boundary Dam

Location: Estevan, Saskatchewan, Canada
Company: Saskpower
Status:
Fuel: Coal
Injection: 1 million tonnes CO_2 per year
Capture: Post-combustion
Storage: EOR with MVR

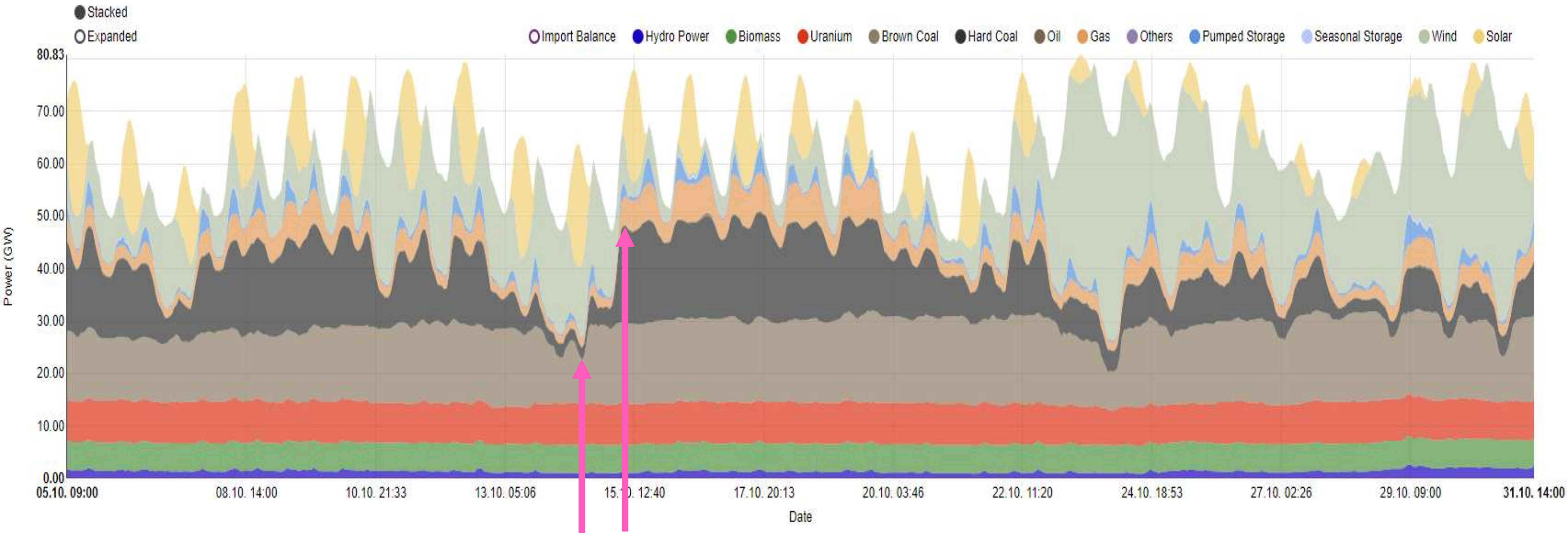
Petra Nova Carbon Capture Project

Location: Smither's Lake, near Houston, Texas, USA
Company: NRG Energy, JX Nippon Oil and Gas Exploration
Status:
Fuel: Coal
Injection: 1.6 million tonnes CO_2 per year
Capture: Post-combustion
Storage: EOR with MVR

CO_2 capture technologies

- Capture processes
  - absorption
    - chemical active
    - physical
  - adsorption
  - membranes
  - cryogenic
  - oxy fuel
  - ....
- More periodic power will be taken into use
- The dynamics of the capture process is important when it is integrated with a power plant

Electricity production in Germany October 2018
Large daily variations in power from coal



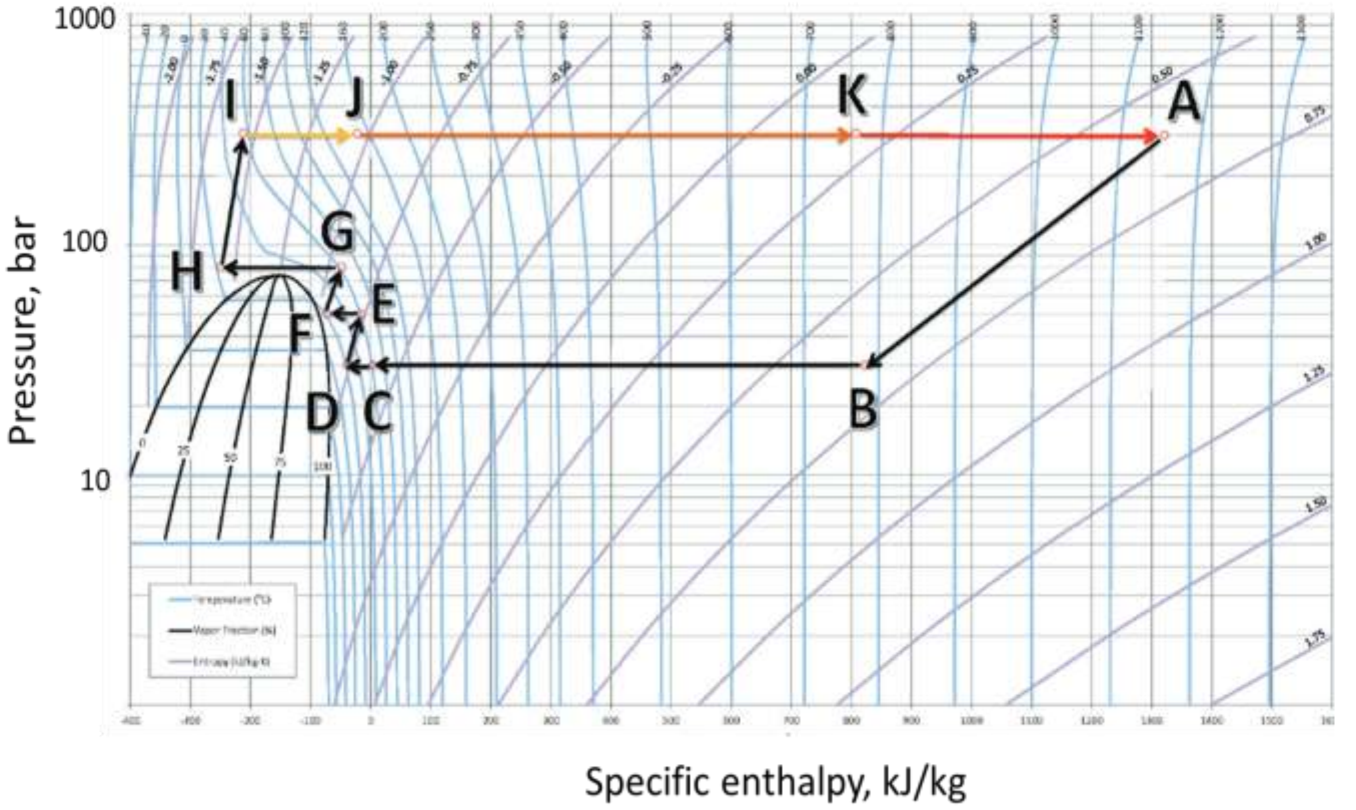
https://www.energy-charts.de/power.htm?source=all-sources&year=2018&month=10

When CCS becomes a large contribution to climate solution, the separation efficiency becomes important

- Typical post combustion separation by absorption is optimized with approximately 90% separation efficiency
- Increasing the efficiency from 90 to 99% will double the height of of the absorber and increase the size of the reboiler with 9%
- The associated extra cost most be balanced with the savings of reduced need for future negative CO_2 emissions
- An interesting alternative yielding almost 100% separation efficiency is the oxy-fuel power cycle
- A new interesting oxy-fuel scheme is the high-pressure Allam cycle

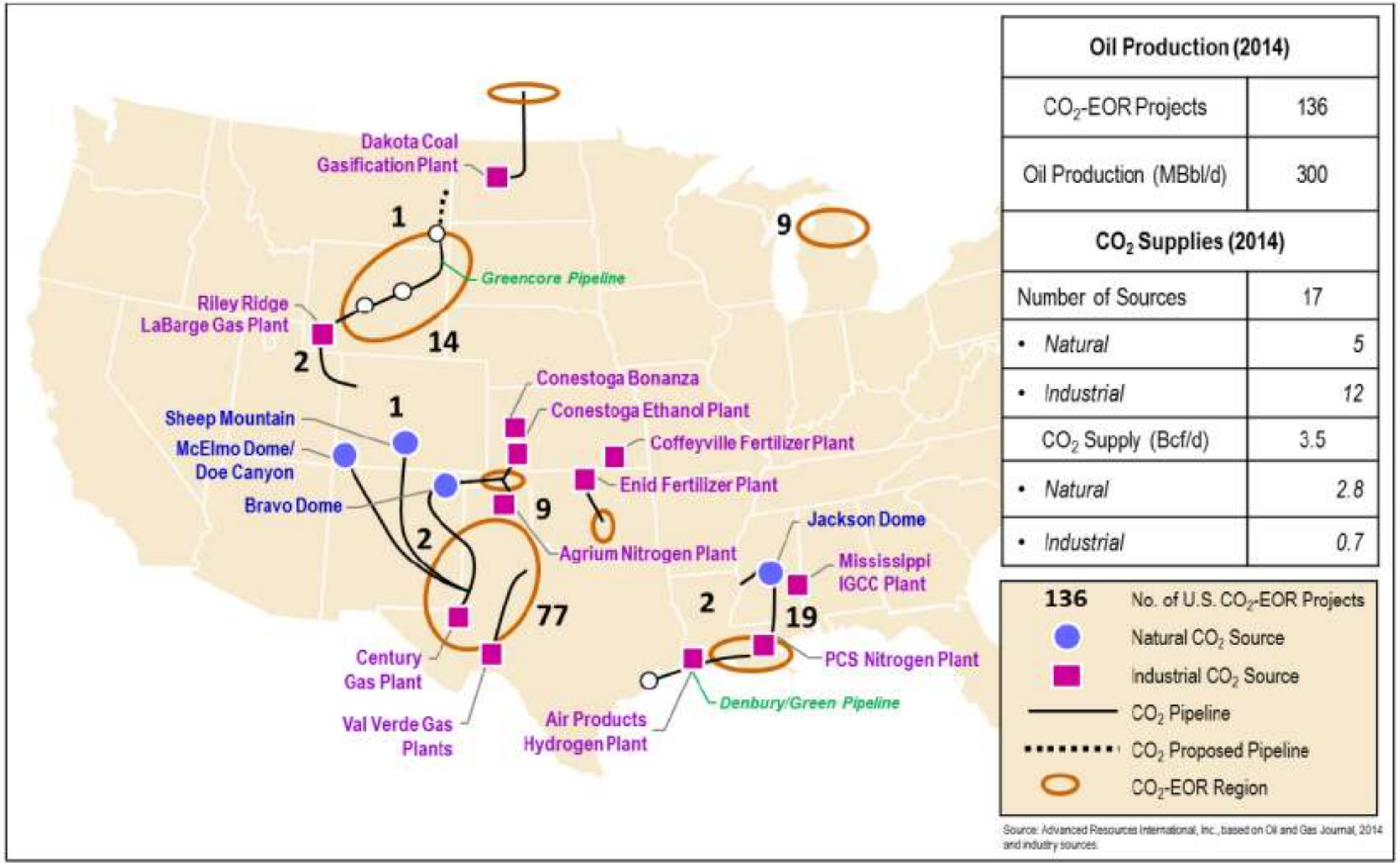
Oxy fuel; The Allam cycle. A possible new process for 100 % CO_2 capture

- Single cycle turbine
- High working pressure
- Fast process dynamics
  - liquid oxygen can be stored allowing optimal running of the air separation plant
- Possibly lower costs compared with combined cycle oxy fuel
- Net efficiency less than 40 %, however
  - air separation included
  - CO_2 compression partly included



Allam *et al.* 2017: Energy Procedia 114, 5948 – 5966
Zhu *et al.* 2019: Energy 174, 478 - 487

The CO_2 transport infrastructures in the US transports 68 million tonnes CO_2/year. 80 % is from natural sources



Oil Production (2014)	
CO_2-EOR Projects	136
Oil Production (MBbl/d)	300
CO_2 Supplies (2014)	
Number of Sources	17
• *Natural*	5
• *Industrial*	12
CO_2 Supply (Bcf/d)	3.5
• *Natural*	2.8
• *Industrial*	0.7

Source: Advanced Resources International, Inc., based on Oil and Gas Journal, 2014 and industry sources.

A Review of the CO_2 Pipeline Infrastructure in the U.S., DOE/NETL-2014/1681, April 21, 2015

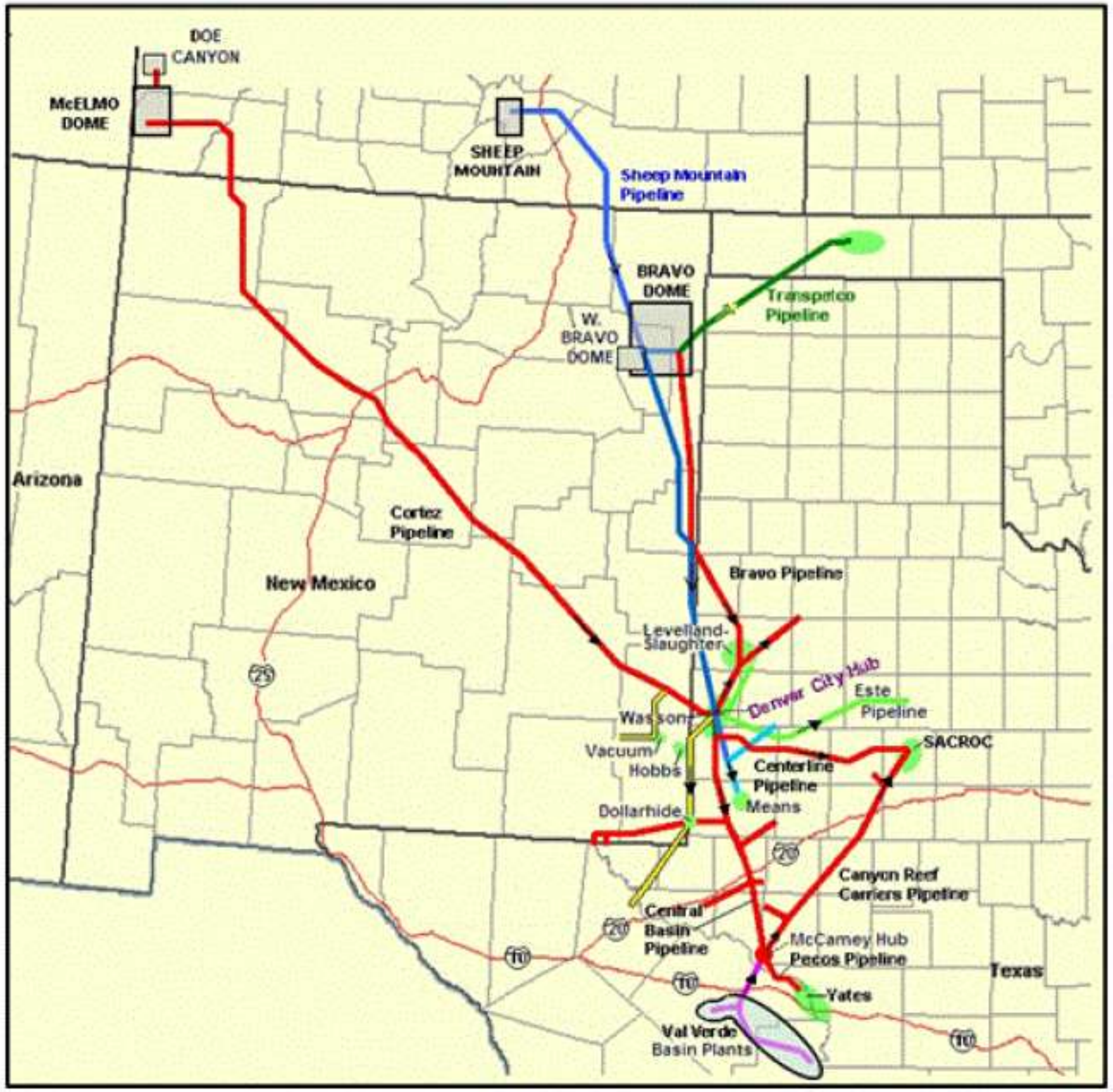
Mid-West CO_2 transport infrastructure

Cortez pipeline

- McElmo Dome-Denver
  - 808 km
  - 30"

Safety of pipeline transport in US 2010 - 2015

- 2000 hazardous accident release incidents
- 21 incidsents for CO2 transport pipelines
  - no fatalities
  - no injuries



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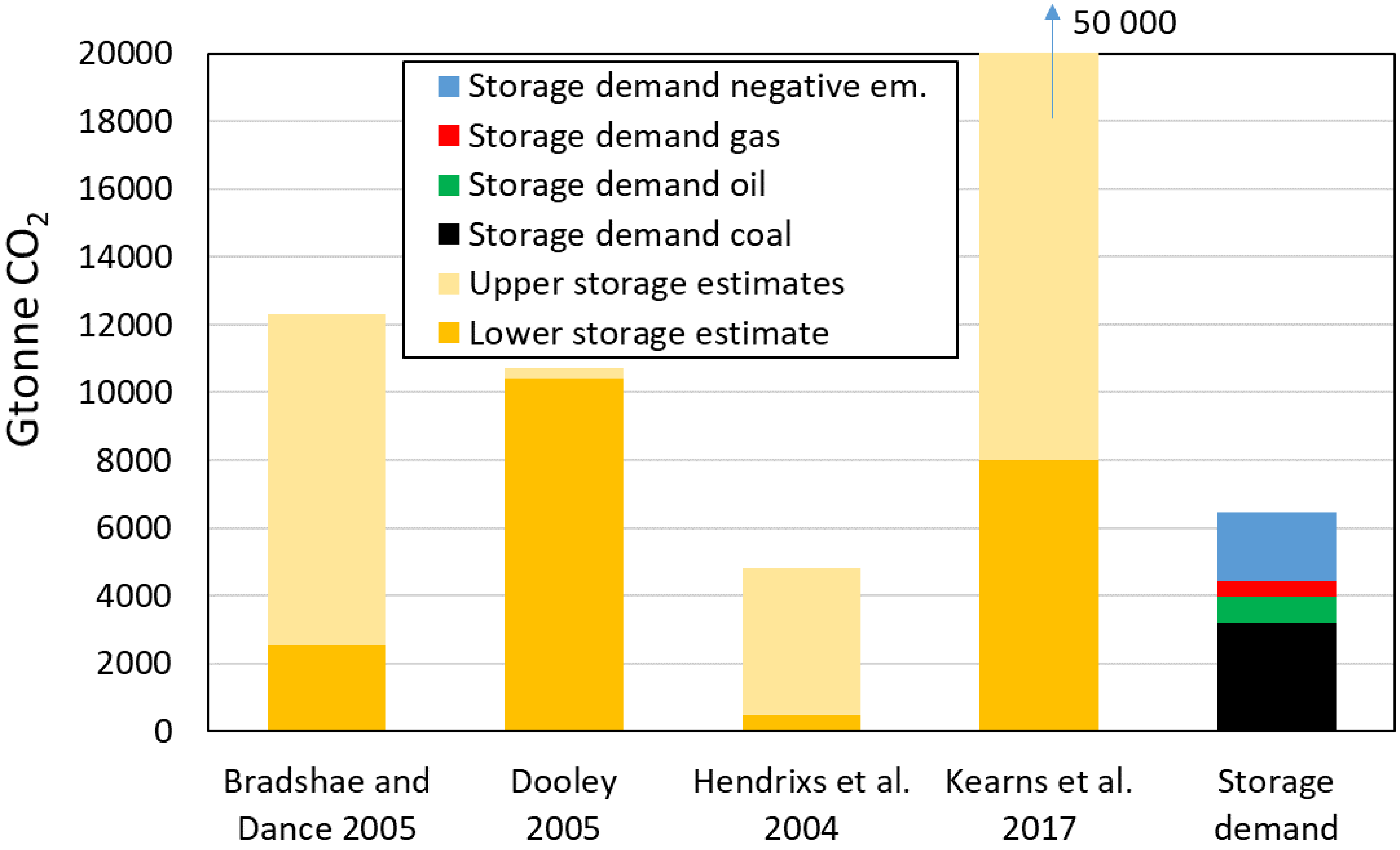
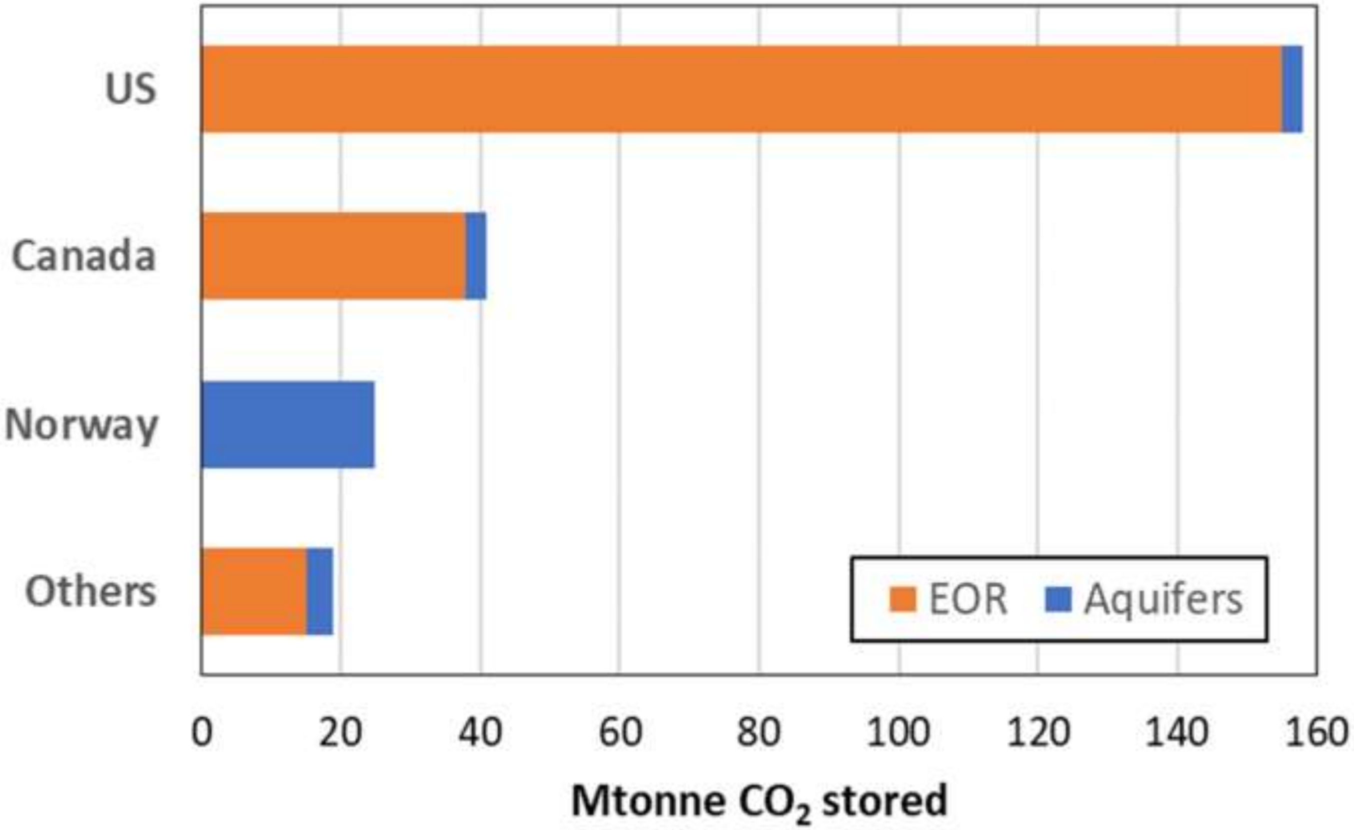
Comparison of storage capacity and demand



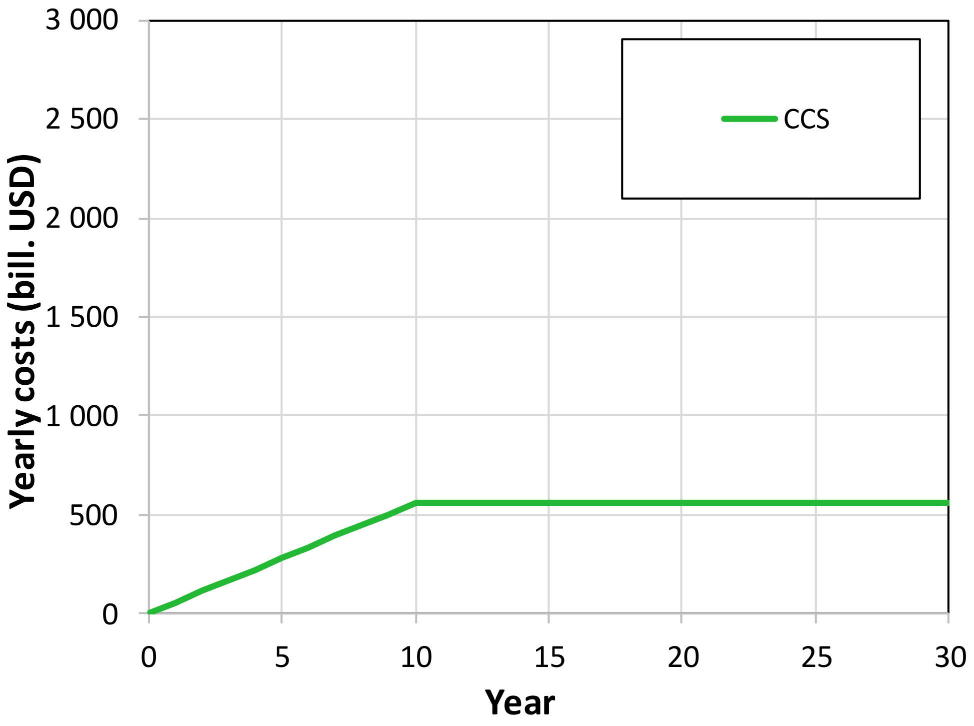
CO_2 storage: More than 230 million tonnes anthropogenic CO_2 stored

- 136 CO_2 EOR projects ongoing (2014)
  - natural sources
  - CO_2 from a variety of industrial sources (14 million tonnes/year in 2014, increasing)
- A few large scale aquifer storage projects
  - Quest project (1 million tonnes CO_2/year)
  - Illinoi CCS project (1 million tonnesCO_2/year)
  - Sleipner field (1 million tonnes CO_2/year)
  - Snøvit field (0.7 million tonnes CO_2/year)
  - ....



CCS– an example of economy

- 600 units per year for 10 years
- Unit capacity 1 million tonnes/year
- Total costs: 93 USD/tonne
  - Investment costs: 332 million USD/unit
  - Capital costs: 7 % of investment costs
  - Operation and maintenance: 5 % of inv.
  - Transport and storage: 25 USD/tonne
  - Lost energy production: 31 USD/tonne



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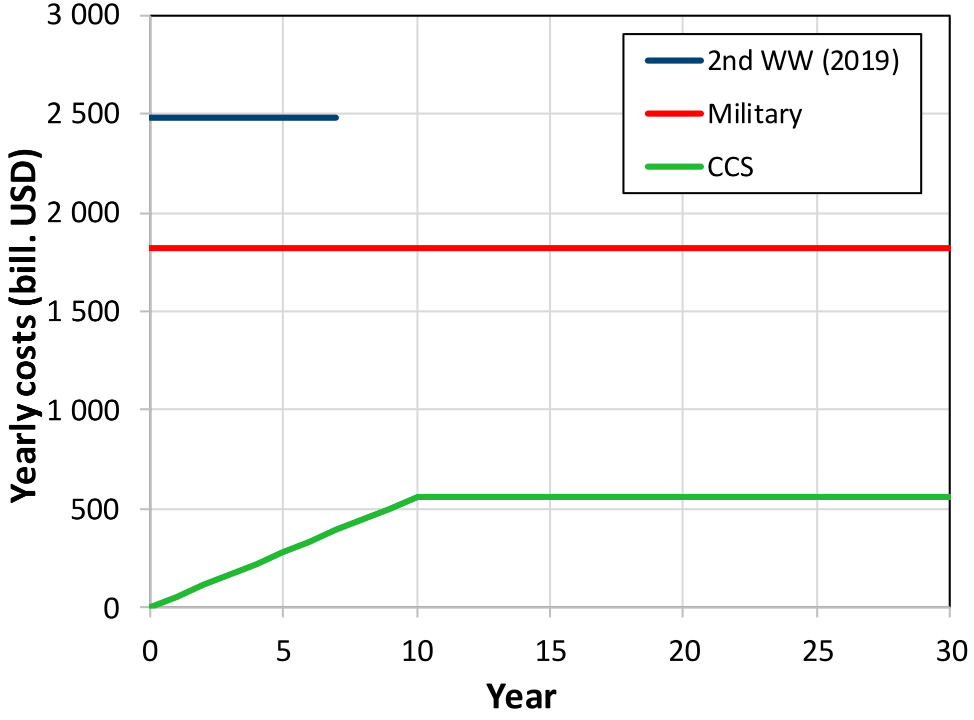
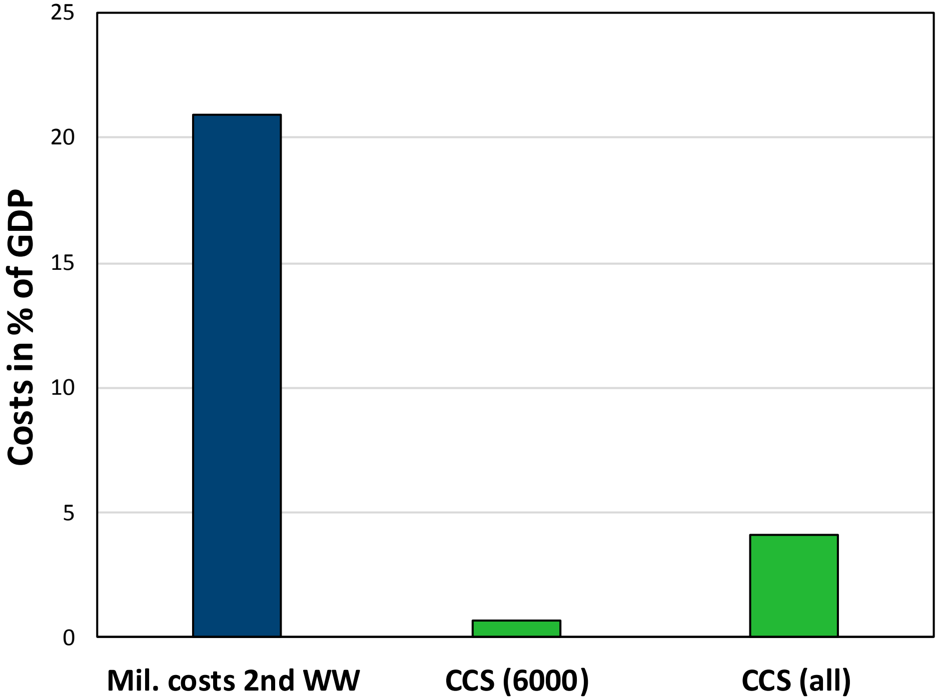
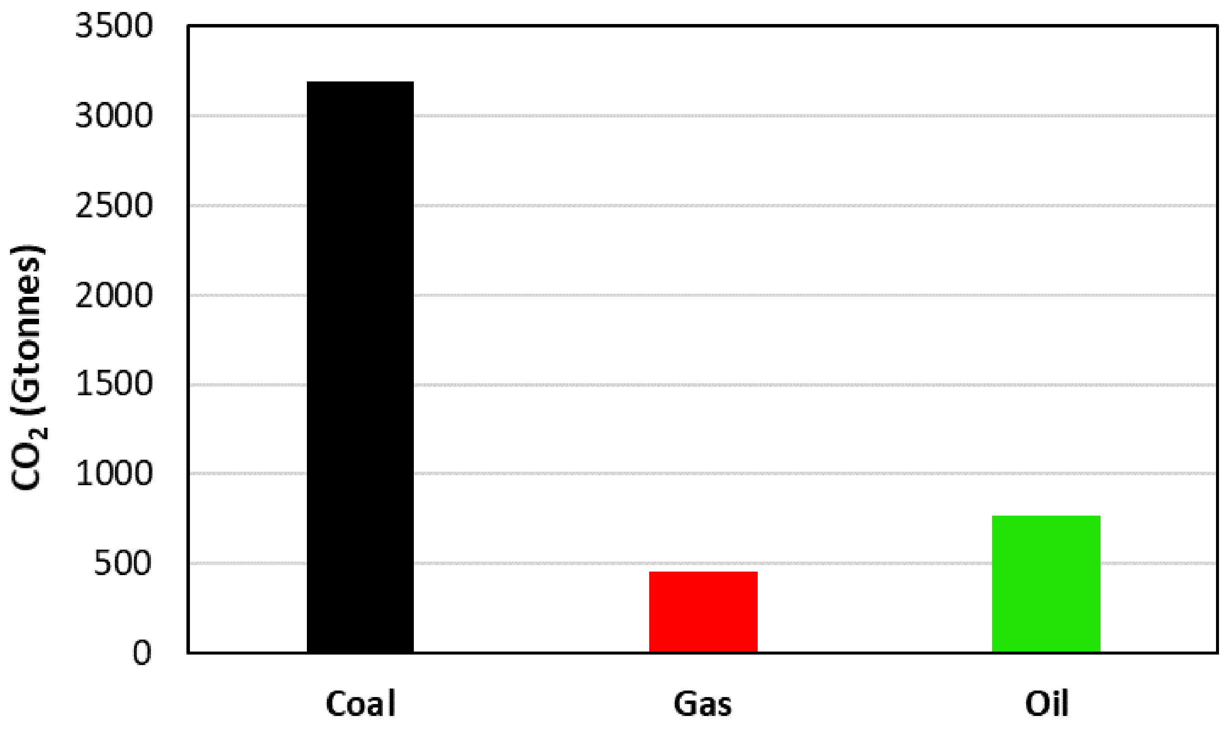




CO_2 from reserves of fossil fuels – reduced use of coal

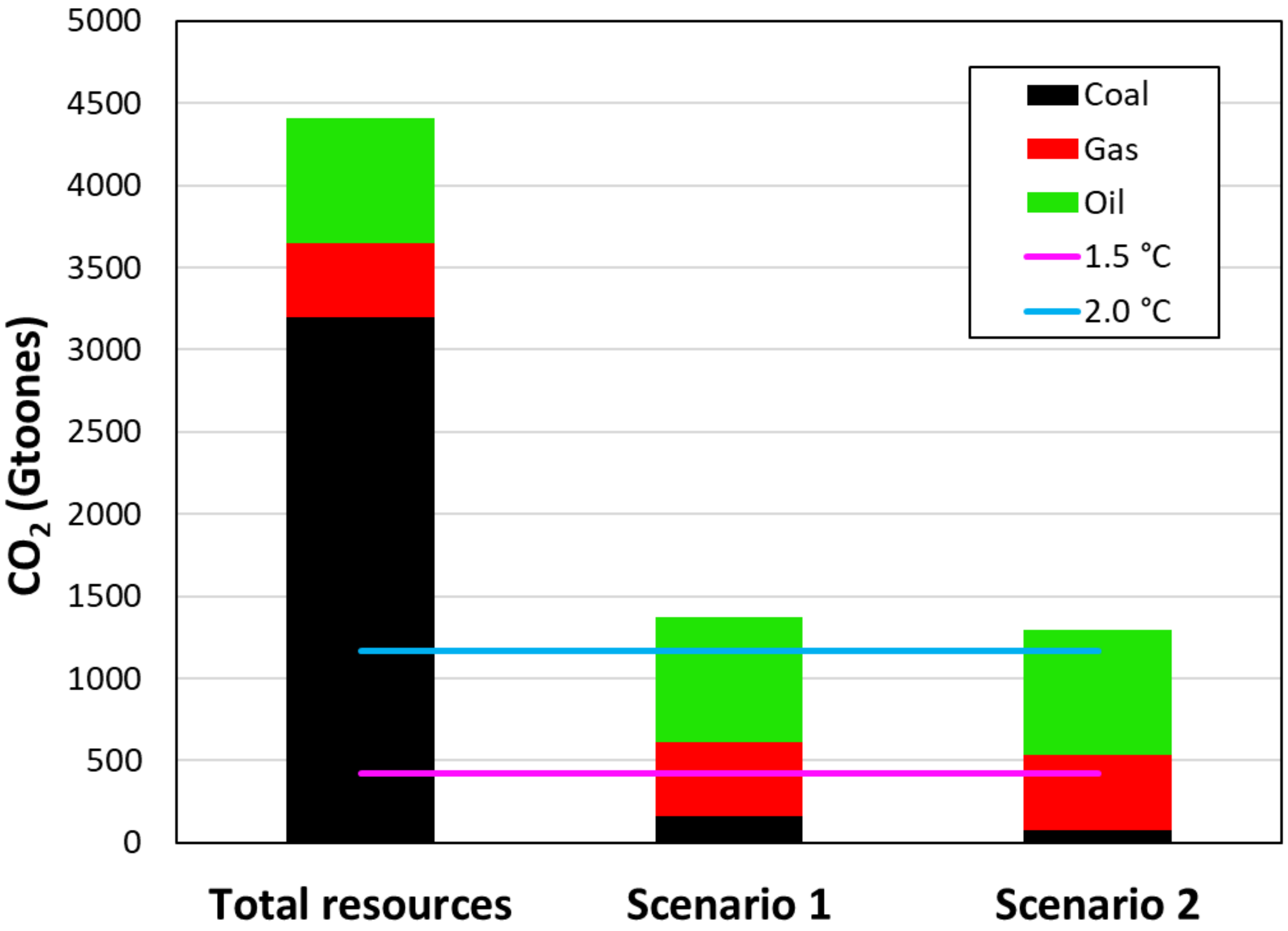


Calculated from BP Statistical Review 2018

Two scenarios

- 1: Coal phased out in 10 years from 2021
- 2: Coal phased out in 20 years from 2021

CO$_2$ from reserves of fossil fuels – reduced use of coal

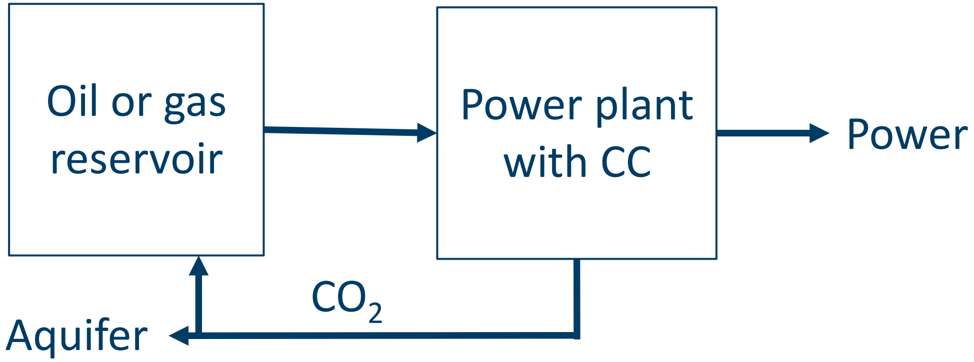


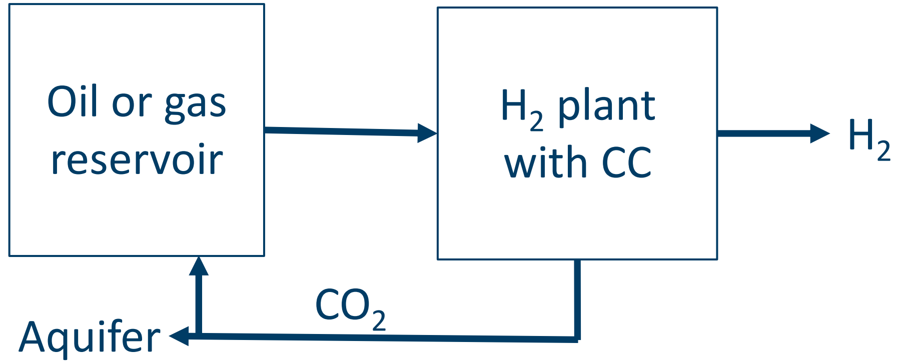
CO$_2$ budgets (IPCC 1.5 °C report 2018)

- 1.5 °C: 420 Gtonnes CO$_2$
- 2.0 °C: 1170 Gtonnes CO$_2$
  - 66 % chance to reach goals

Use of remaining petroleum resources will require CO_2 storage to reach the 1.5 °C goal

- Chemicals; synthetic materials, *etc*.
    - the carbon from the end products must be deposited after use
- Power and/or H_2
    - sales values
        - the value of regulative power will increase in a system with large shear of periodic power
    - marked
    - distribution system
    - energy efficiency
        - production
        - distribution
        - usage





Conclusions

- The threat of global warming has been public known for decades
- Technologies scale CO_2 capture, transport and storage exists and have been used for decades
- The costs for large scale implementation of CCS is not high compared to present military spending and efforts made in period where such efforts were required
- Large scale implementation of CCS must start now for any possibility to achieve the 1.5 °C target
- Implementation cannot await possible improvements in technology
- Improvements will emerge during large scale implementation
- The only factor missing for implementation of CCS is leadership

Acknowledgements

Support from the Researcher project: "Improved performance of CO_2 EOR and underground storage by mobility control of CO_2" (NFR grant 267859) is acknowledged