Can we reduce global CO_2 emissions without early deployment of CCS?

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NATURAL ENVIRONMENT RESEARCH COUNCIL

CO_2

-a wonderful regulator of Earth's climate (after Raypierre 2006)

Good infrared absorber even in small quantities so you don't need to much of it.

Radiative effect is logarithmic in concentration,
-so you don't have to tune its concentration too precisely to get a habitable climate.

Abundant in the form of carbonates in the Earth's crust,
-so you can always get more if you need some to keep the climate warm enough.

Interacts well with liquid water,
-so that if the planet gets too warm or too cold the rate of removal tends to adjust to reset the atmospheric CO_2 at a point where the climate will stay relatively equable.

Has thermodynamic properties that keep it from condensing out of the atmosphere (in contrast to water vapour), resulting in it having a long enough lifetime to even out the vicissitudes of climate forcing fluctuations.

Fundamental to the biosphere and its climate related feedbacks.

Conversion factors

1 Gt of carbon ~ 3.6Gt of CO_2

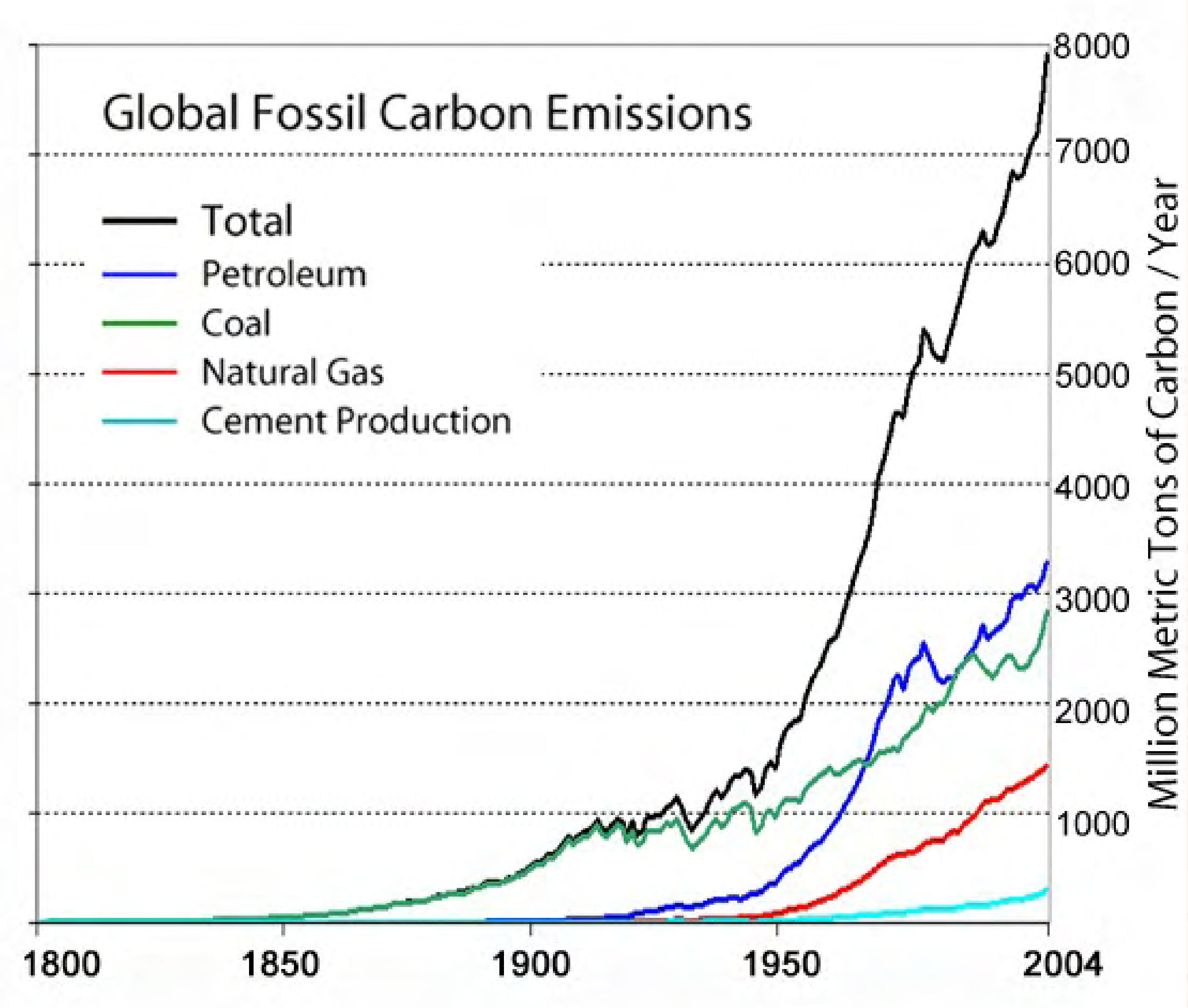
Volcanic CO_2 emissions

Anthropogenic emissions	~30Gt
Volcanic emissions	~0.3Gt

Volcanic emissions are ~1% of anthropogenic ones

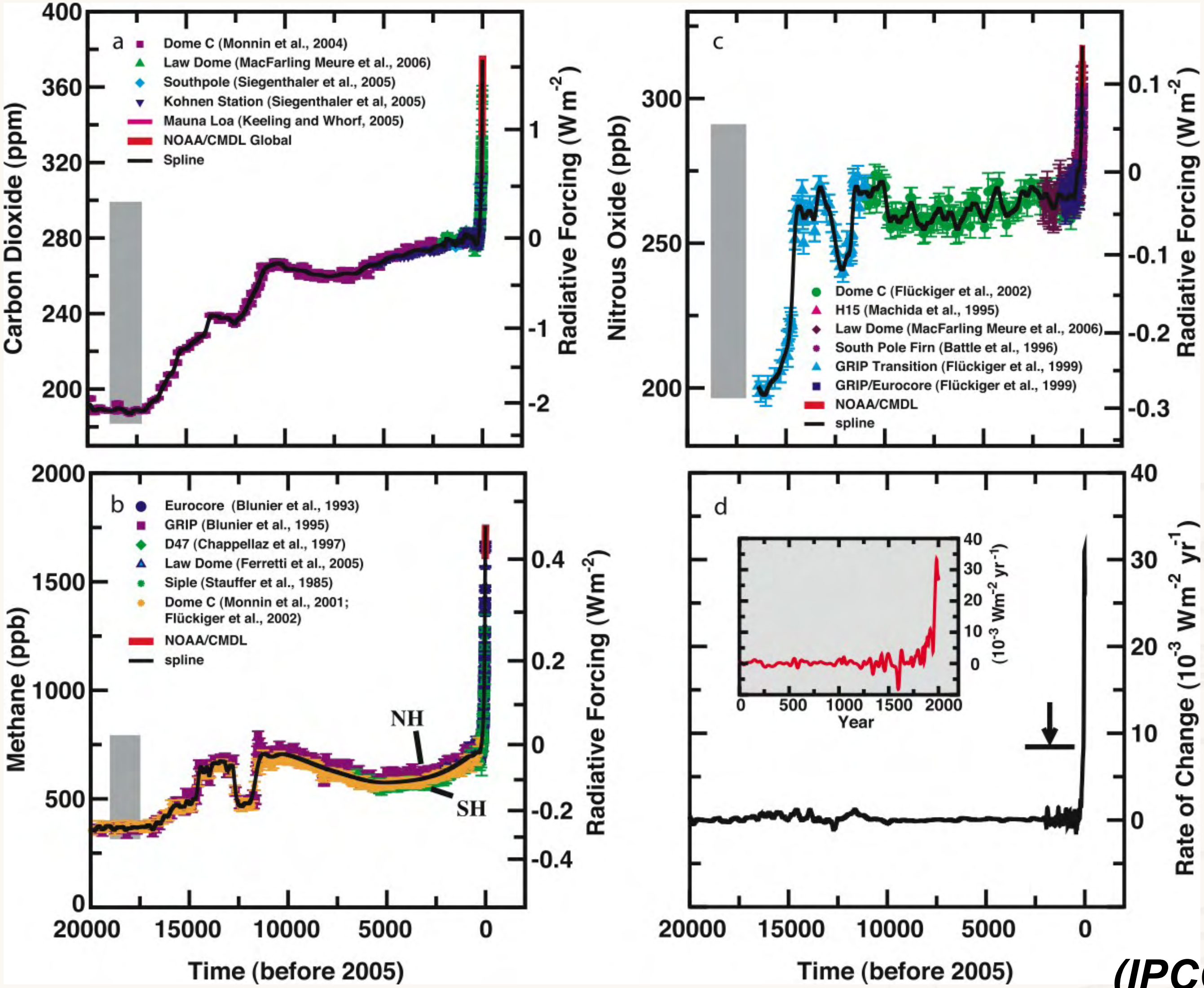
Anthropogenic emissions are rising at more than 2.5%/annum (~750Mt/annum)

Global fossil carbon emissions

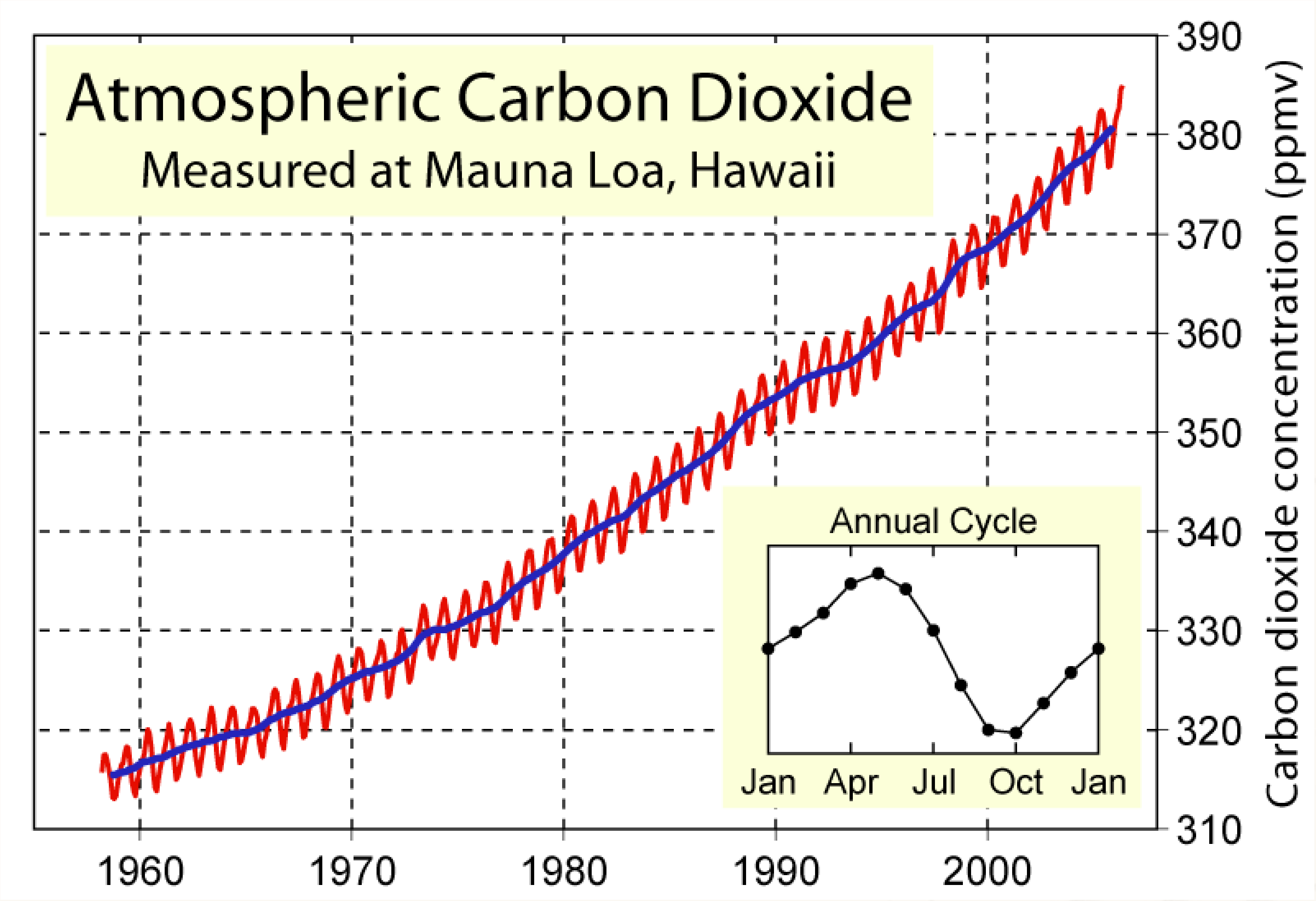


(US Department of Energy)

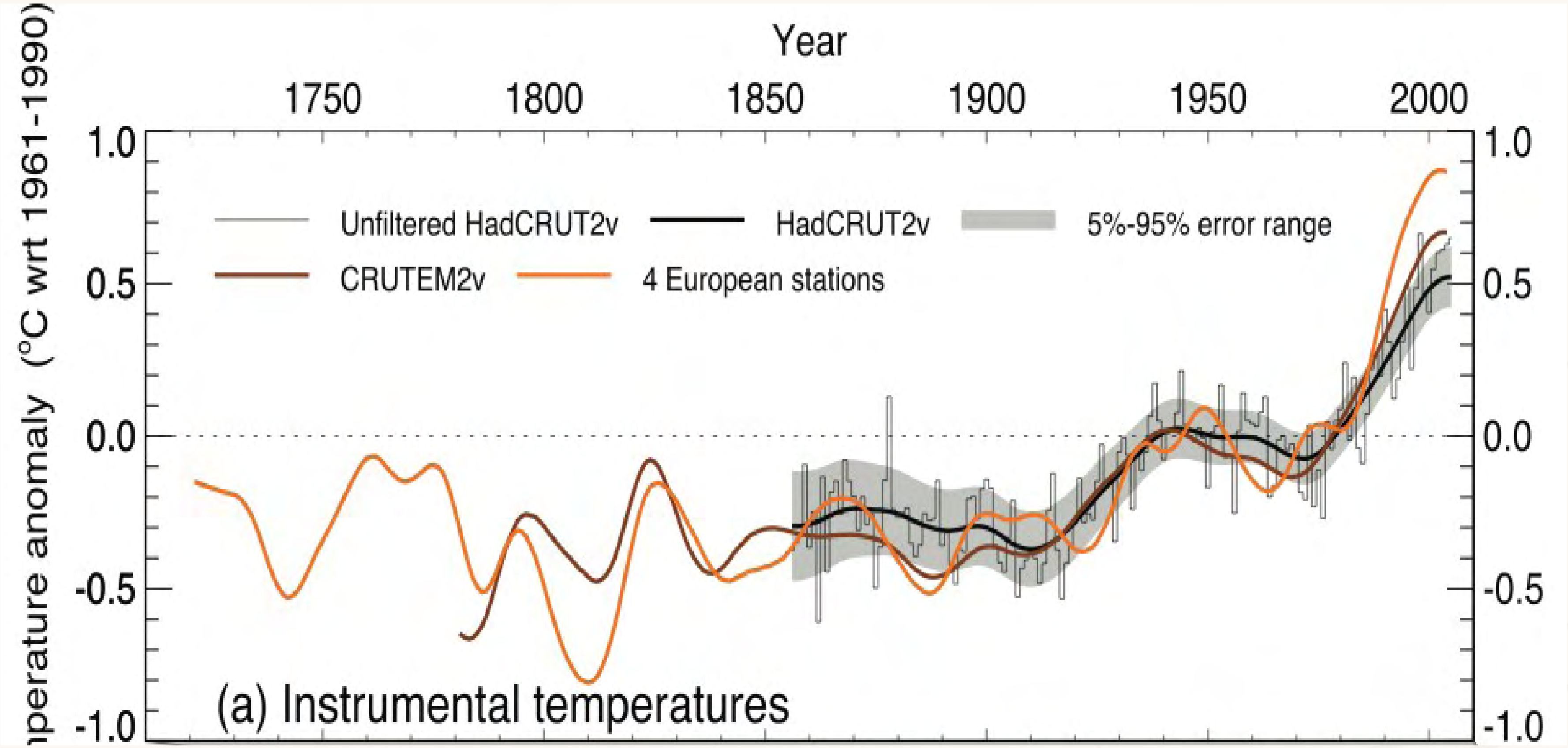
Greenhouse gases through the last 20ky



(IPCC 2007)

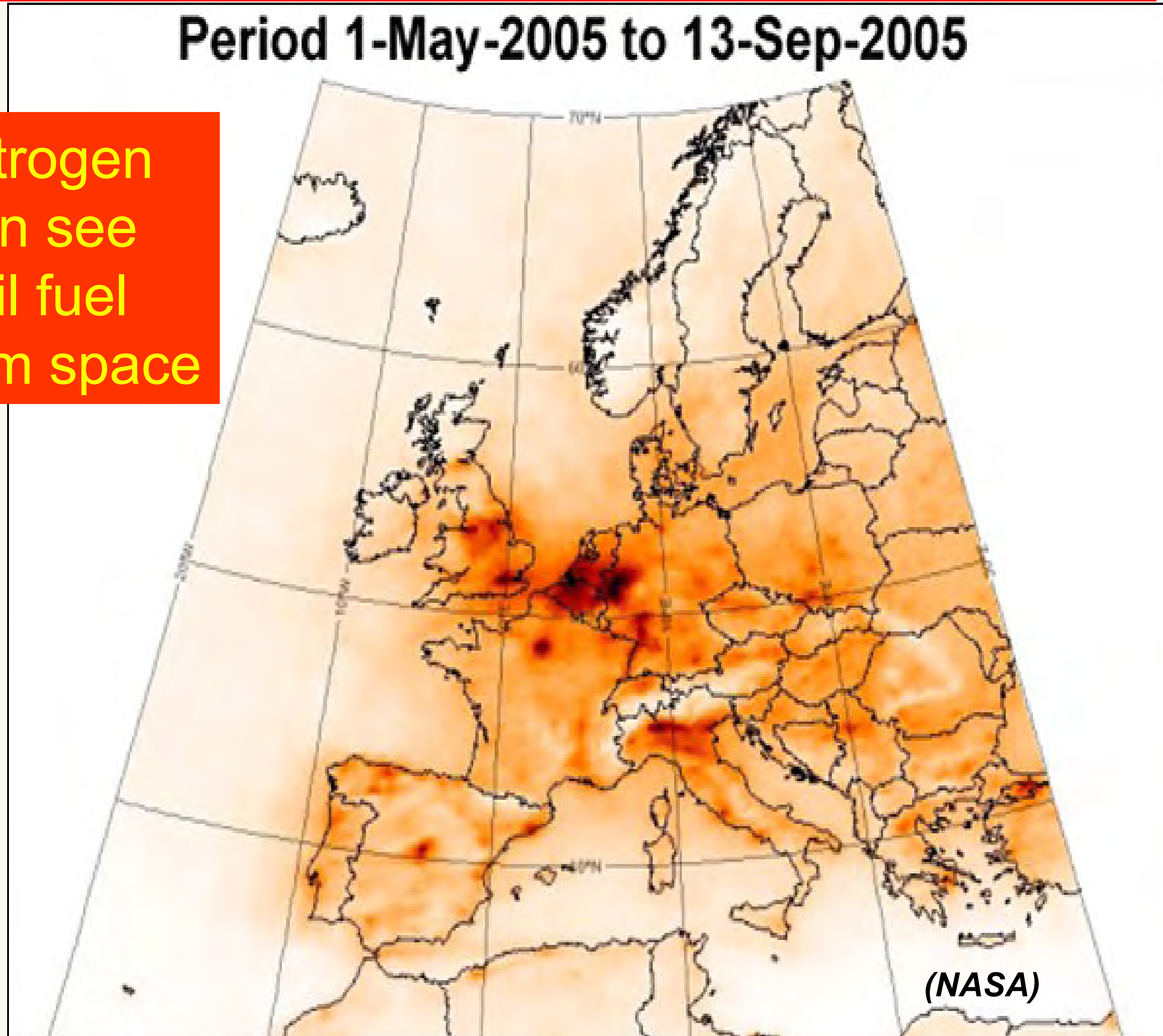

Atmospheric Carbon Dioxide
Measured at Mauna Loa, Hawaii
Annual Cycle
Jan
Apr
Jul
Oct
Jan
390
380
370
360
350
340
330
320
310
1960
1970
1980
1990
2000
Carbon dioxide concentration (ppmv)

Instrumental temperatures 1700 to 2005

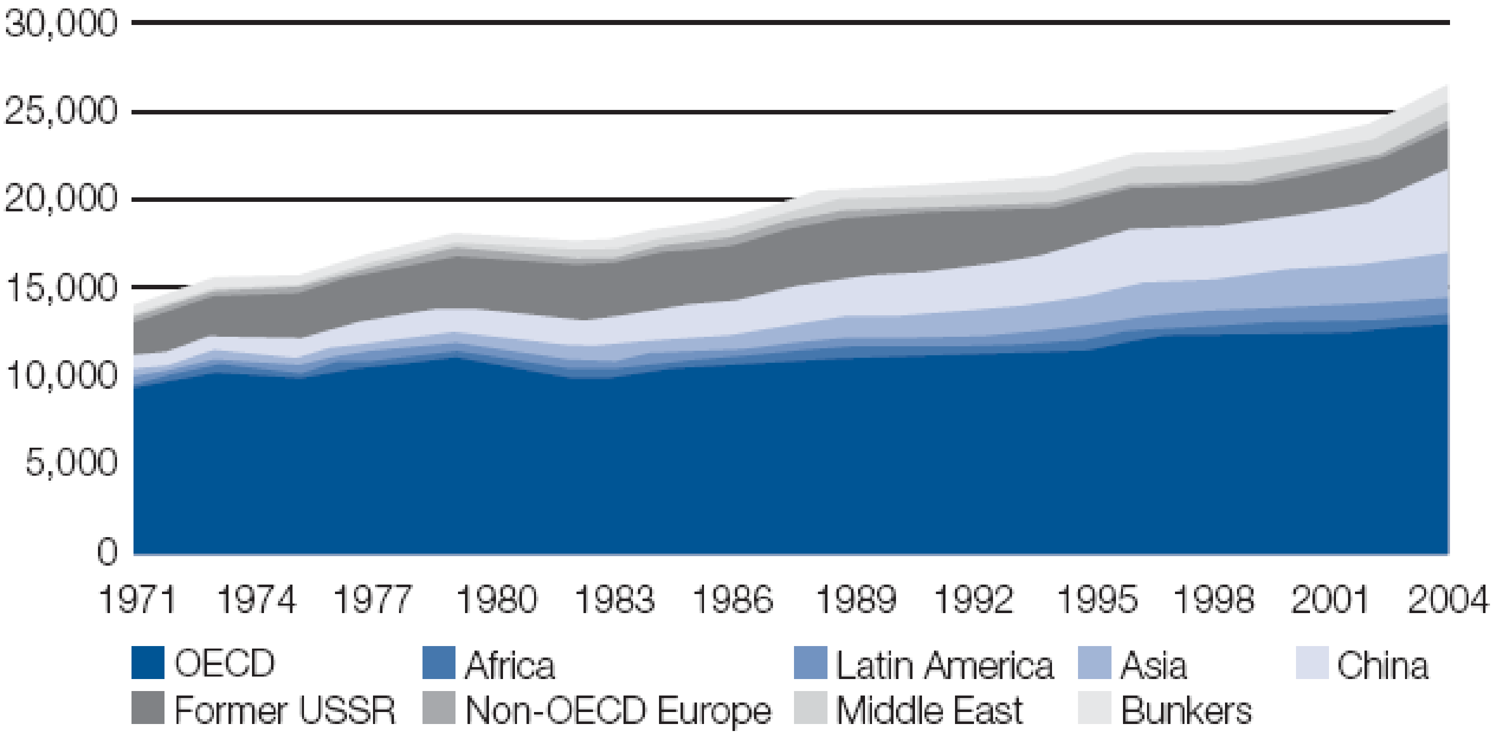


(IPCC 2007)

By imaging nitrogen oxides you can see Europe's fossil fuel emissions from space



Evolution from 1971 to 2004 of world CO_2 emissions by region (Mt of CO_2)



Note: "Bunkers" refers to oil used for marine transportation, which cannot readily be allocated to particular regions.
Source: Key world energy statistics 2006, IEA Paris.

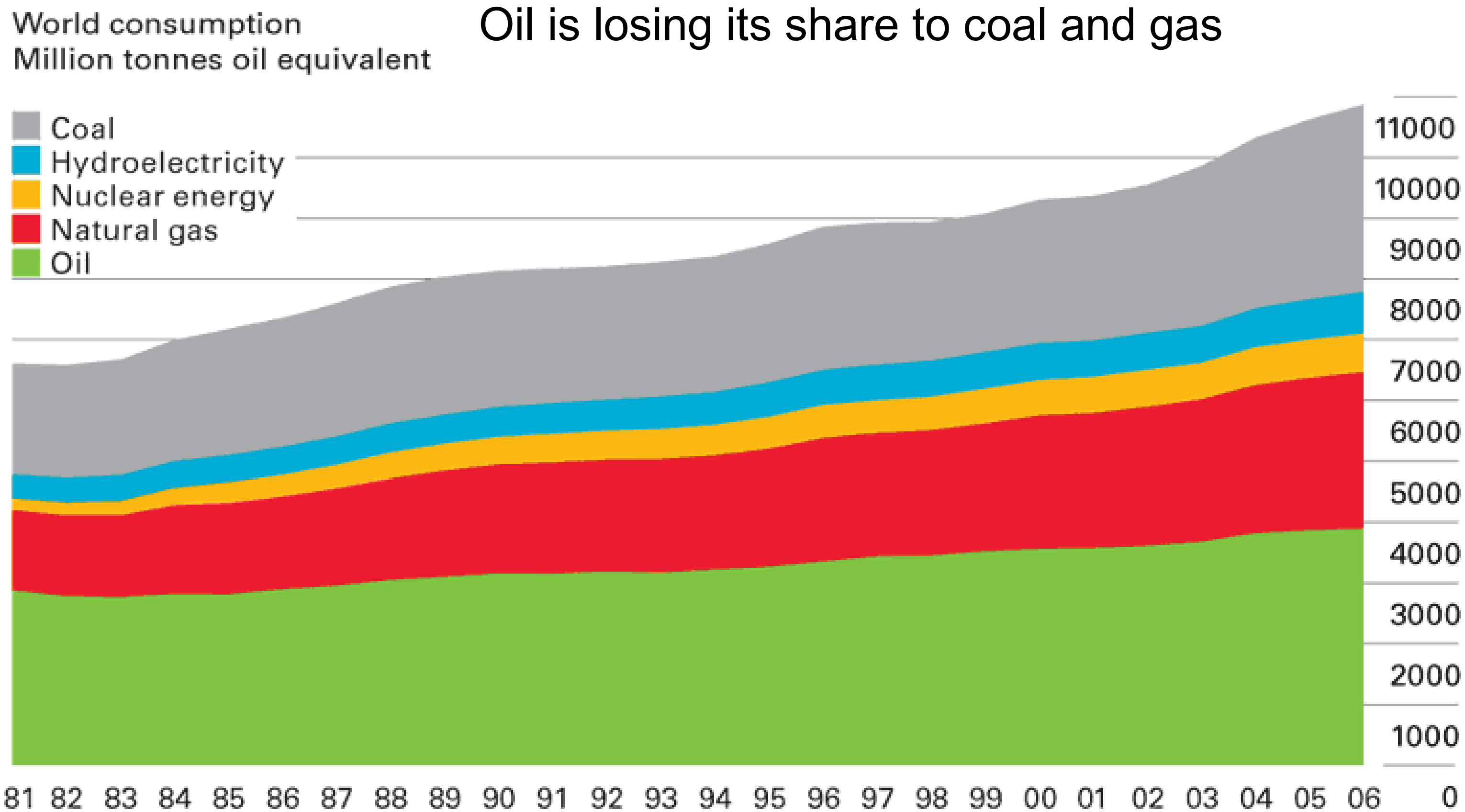
2003 CO_2 emissions by sector

Sector	2003 emissions (Gt CO_2) and % of total	
Electricity	9.9	(41%)
Fuel Conversion	1.7	(7%)
Industry	4.5	(18%)
Transport	5.1	(21%)
Buildings	3.2	(13%)

Source: Energy Technology Perspectives 2006 IEA Paris. "Fuel conversion" includes refinery and other energy use in processing energy for retailing.

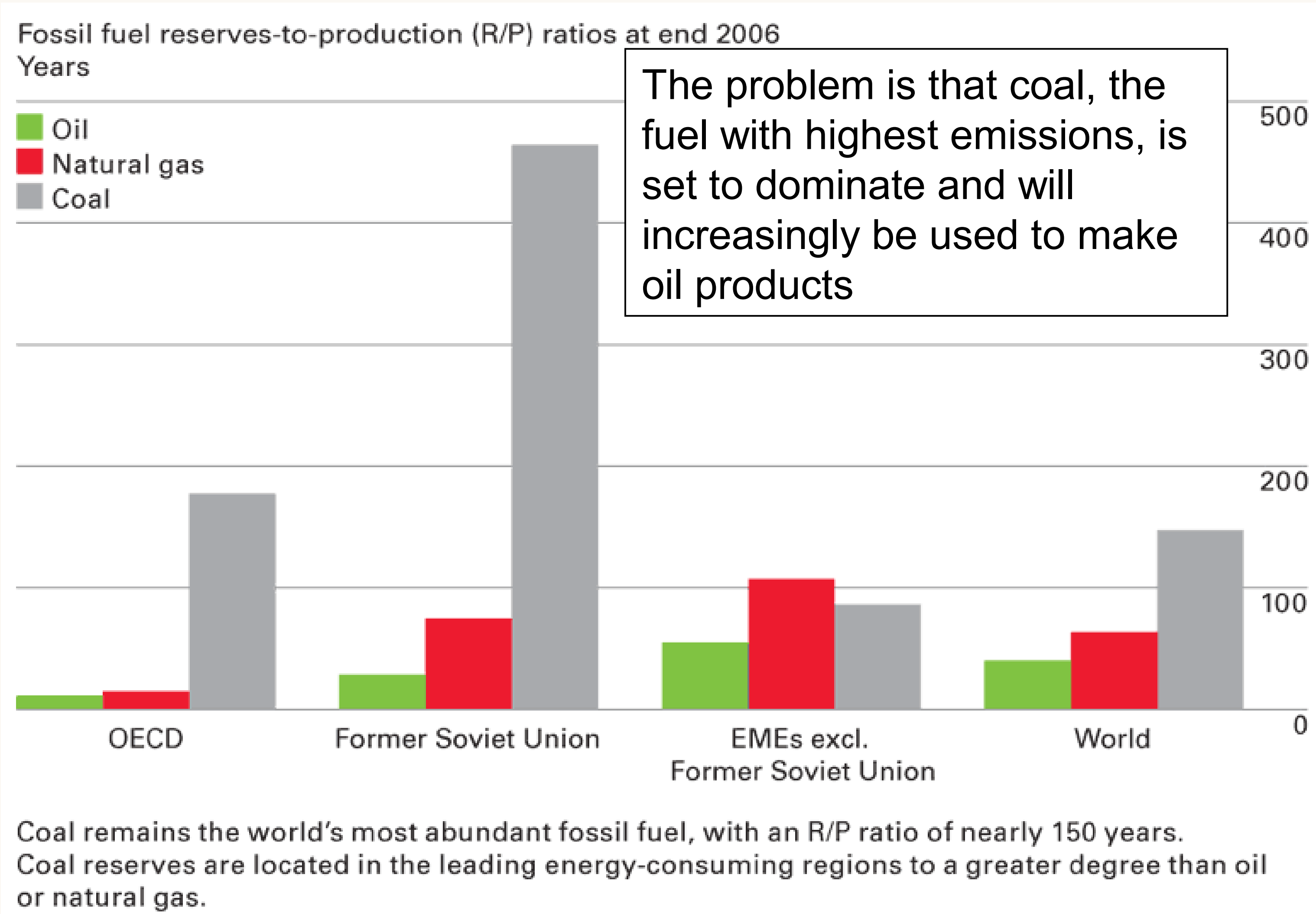
At least 34% of global emissions are from diffuse sources. This means that large point sources are going to have to take the main burden of emission reduction. Remember too that even if we electrify or move over to hydrogen with the transport and buildings sectors then these energy carriers will still need to be made from low emission technologies.

Oil is losing its share to coal and gas



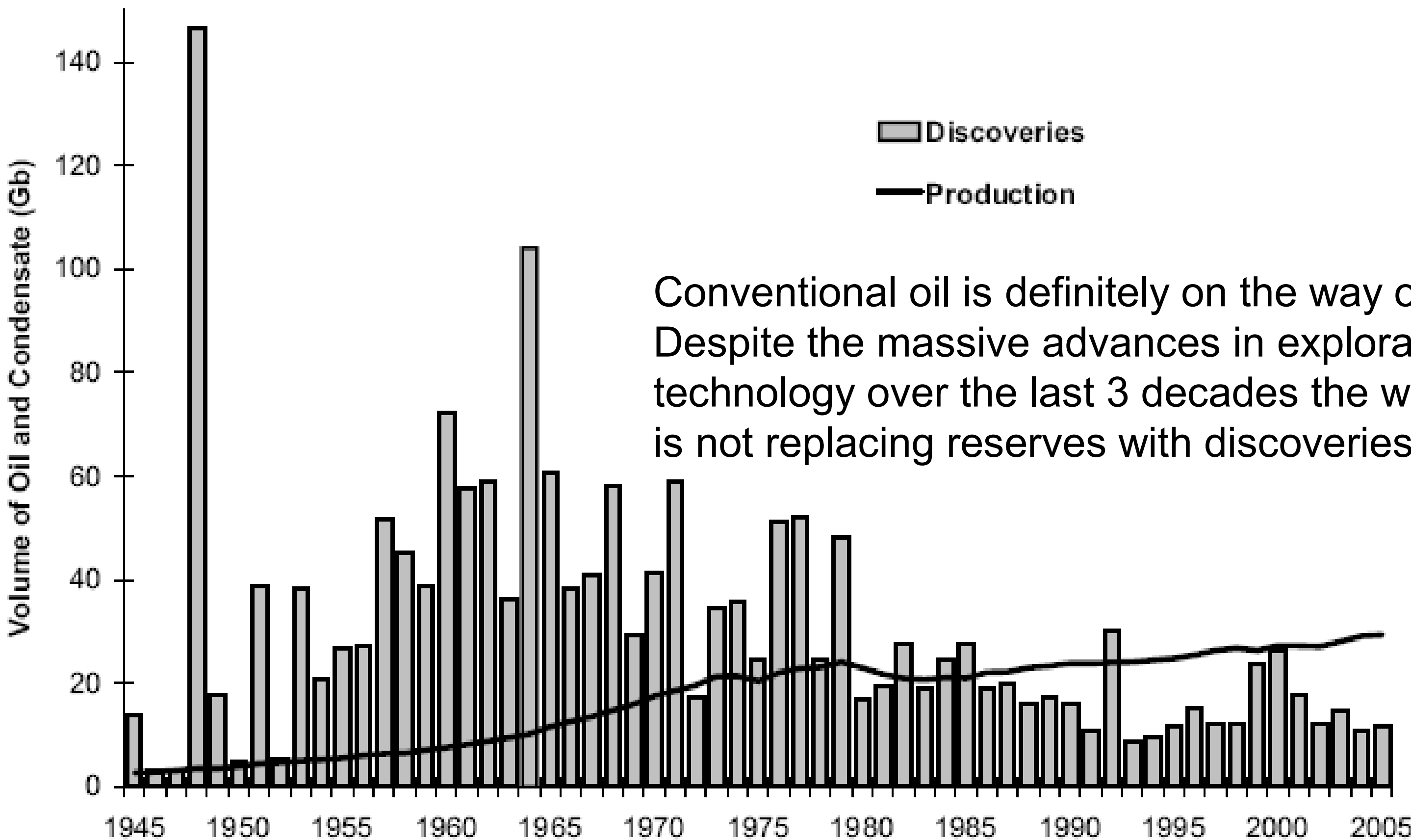
World primary energy consumption grew more slowly in 2006 but growth remained just above the 10-year average. Oil was the slowest-growing fuel, while coal was the fastest-growing. Although oil remains the world's leading energy source, it has lost market share to coal and natural gas in the past decade.

(source BP June 2007)



The problem is that coal, the fuel with highest emissions, is set to dominate and will increasingly be used to make oil products

(source BP June 2007)



Conventional oil is definitely on the way out. Despite the massive advances in exploration technology over the last 3 decades the world is not replacing reserves with discoveries

Figure 5.10: Global annual discoveries of both oil and condensate, and oil production in billion of barrels (Gb). *Source: Based on data from IHS Energy, ASPO and Oil & Gas Journal.* *(Robelius 2007)*

This means that oil products from conventional oil will be replaced by:

- Unconventional oil produced from tar sands and oil shales
- Gas to liquids technology based on natural gas
- Coal pyrolysis

This will accelerate emissions growth on top of the emissions from projected energy demand growth.

中国沿海及大陆架二氧化碳伴生天然气田(藏)气体主要成分表 (CO2含量小于80%)

CO2 Associated Gas Reservoirs Offshore China

Basin	Gas Reservoirs	Gas Composition (mol%)				
		CO2	N2	CH4	C2H6	C3H10
YingGeHai	DongFang1-1*	62.4	6.8	30.3	0.4	0.1
	Luo Dong 15-1	66.5	5.0	26.3	1.5	0.5
	Luo 8-1	68.0	4.35	25.9	0.7	0.6
	LuoDong22-1-I	21—35		59-50		
QiongDongNan	YaCheng13-1*	10		70-80		
ZhuJiangKou	PanYu 28-2	74.0	7.72	9.1	0.7	0.3
BoHai Bay	Wang 21	79.0	3.7	17.1	0.1	0.1
	JiJiaWu	67.4	--	15.3	5.8	6.9
	PingFangWang	75.3	0.5	20.9	1.3	1.1

* in production

What's more many natural gas fields with associated CO_2 will be produced as gas prices rise.

(Ren, Wang & Song, 2006)

How much CO_2 are we emitting?

- Anthropogenic emissions ~30Gt
- Volcanic emissions ~0.3Gt

- Volcanic emissions are ~1% of anthropogenic ones
- Anthropogenic emissions are rising at more than 2.5%/annum (~750Mt/annum)

So what is the challenge?

Current atmospheric CO_2 concentrations are 383ppm

Current CO_2_e (Total) are ~ 375ppm (includes negative and positive GHG forcings)

It is likely that 2°C above pre-industrial (1750, 278ppm CO_2) global average temperature will be reached when CO_2_e (Total) is ~450ppm provided emissions peak no later than 2015 (IPCC 2007)

2° C rise is defined by policymakers (e.g. EU member states) as the threshold above which warming is classed as "dangerous".

So to peak CO_2_e (Total) before 2015 seems highly unlikely as global policy is failing to be effective in reducing emissions.

If we go for staying within a 3°C threshold above pre-industrial then we need to peak CO_2_e (Total) no later than 2030 (IPCC 2007). This is still achievable provided we deploy CCS on a global scale over the next two decades. But is 3°C acceptable?

At high latitudes this may mean >5°C rise because the Arctic is warming at twice global average.

EC intends to have all new European fossil power plant build fitted with CCS after 2020 with existing plant progressively retrofitted.

UK intends to demonstrate retrofit on commercial scale by 2014.

So the challenge is political- we can already deliver CCS technology and constantly improve on this.

Rapid political progress has been made in the last 5 years

G8 now recognises the need to engage BRICS (2005,7)

London Convention and its Protocol now recognise CO_2 storage beneath sea bed (2007)

IPCC has defined recognition of CCS in national GHG inventories (2007)

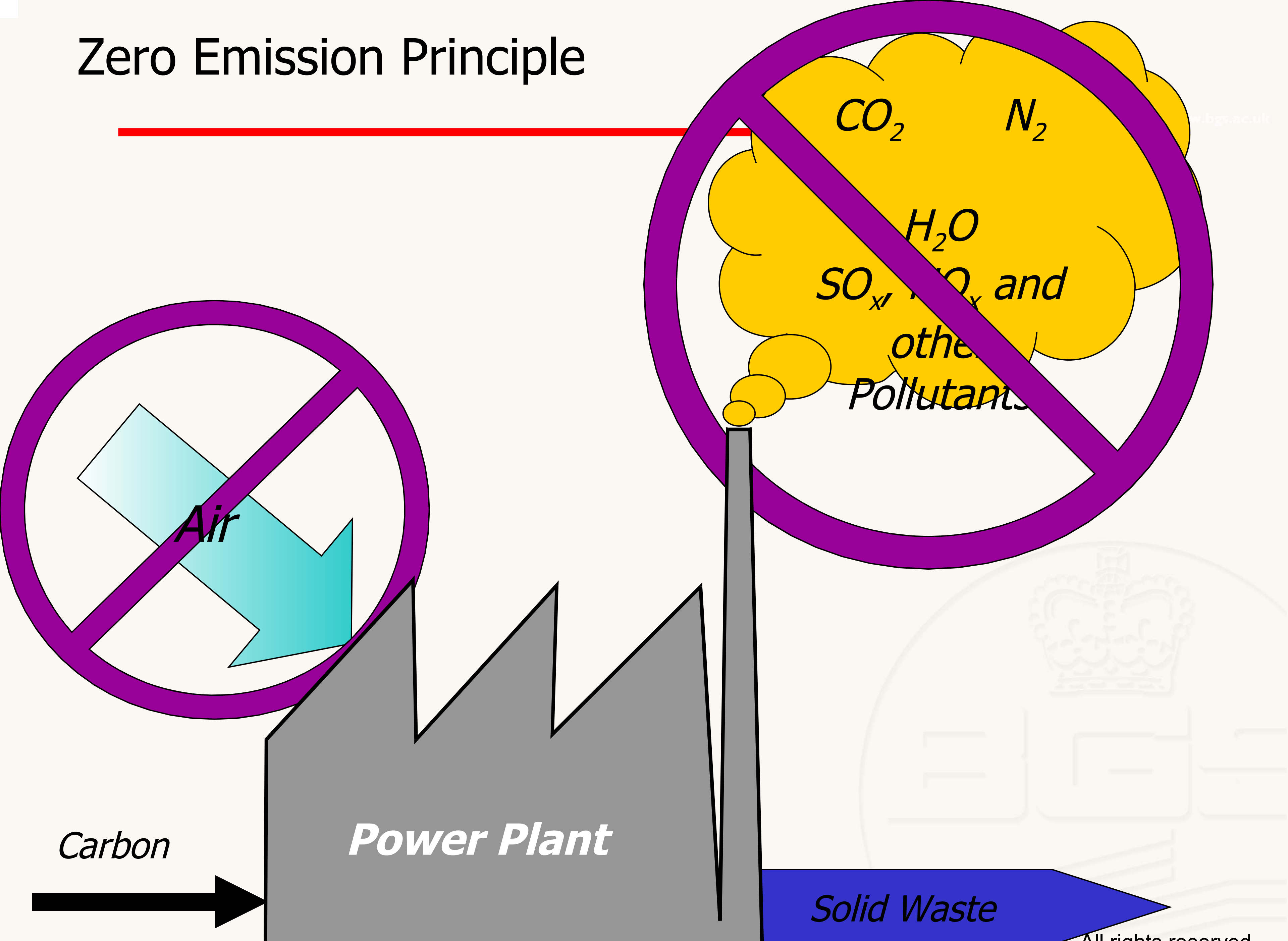
OSPAR has recommended adopting CO_2 storage but this is yet to be ratified (2007/8?)

EC will issue a Directive on CCS (2008)

UK will have commercial scale CCS demo by 2014

No agreement yet on CCS in Kyoto phase 1 & 2 or post Kyoto agreements- this is vital if CCS is to be deployed in the BRICS.

Zero Emission Principle



So will CO_2 storage work?

Net Zero Carbon Economy

CO_2 from concentrated sources

Capture from power plants, cement, steel, refineries, etc.

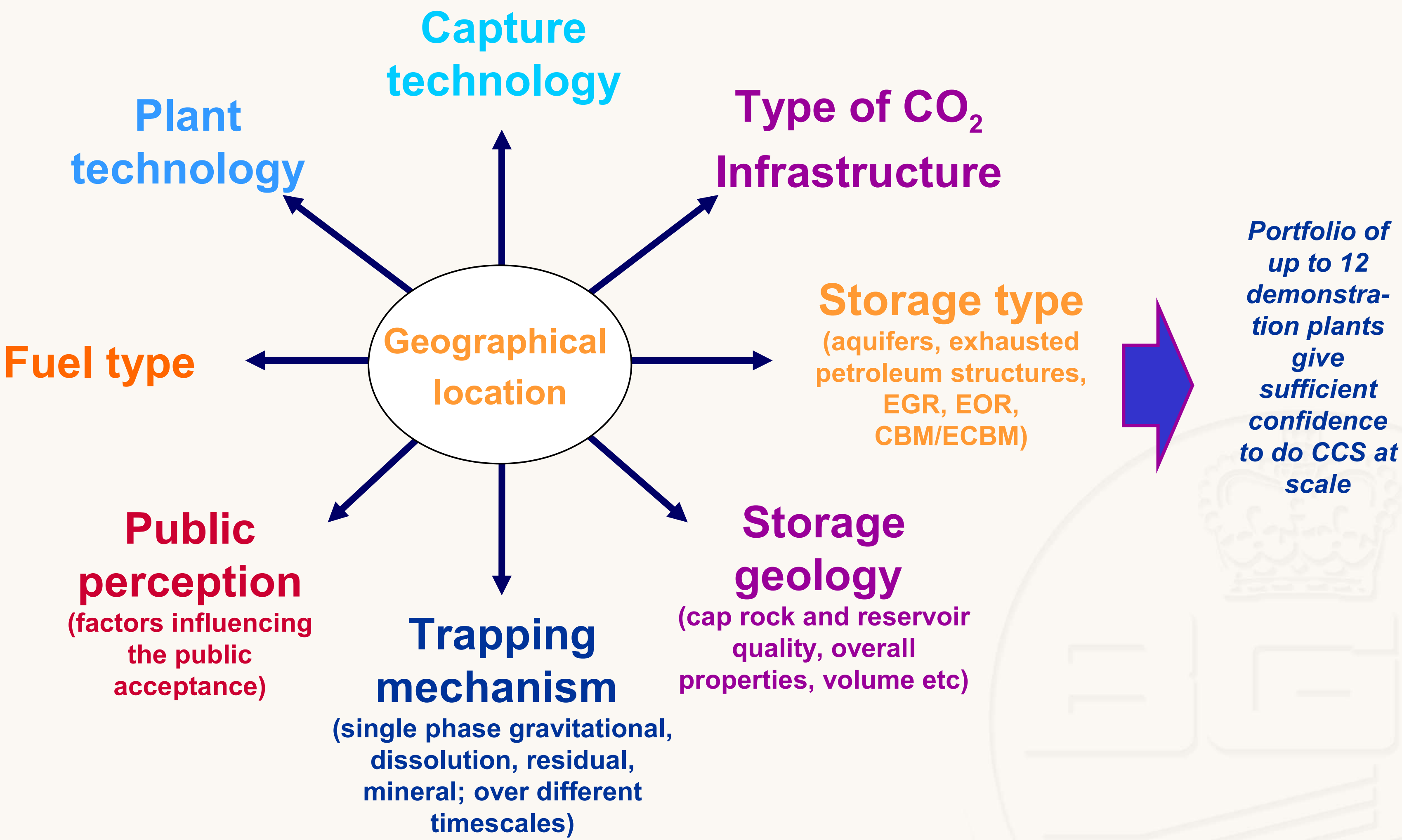
CO_2 from distributed emissions

Capture from air

Permanent & safe disposal

Geological Storage
Mineral carbonate disposal

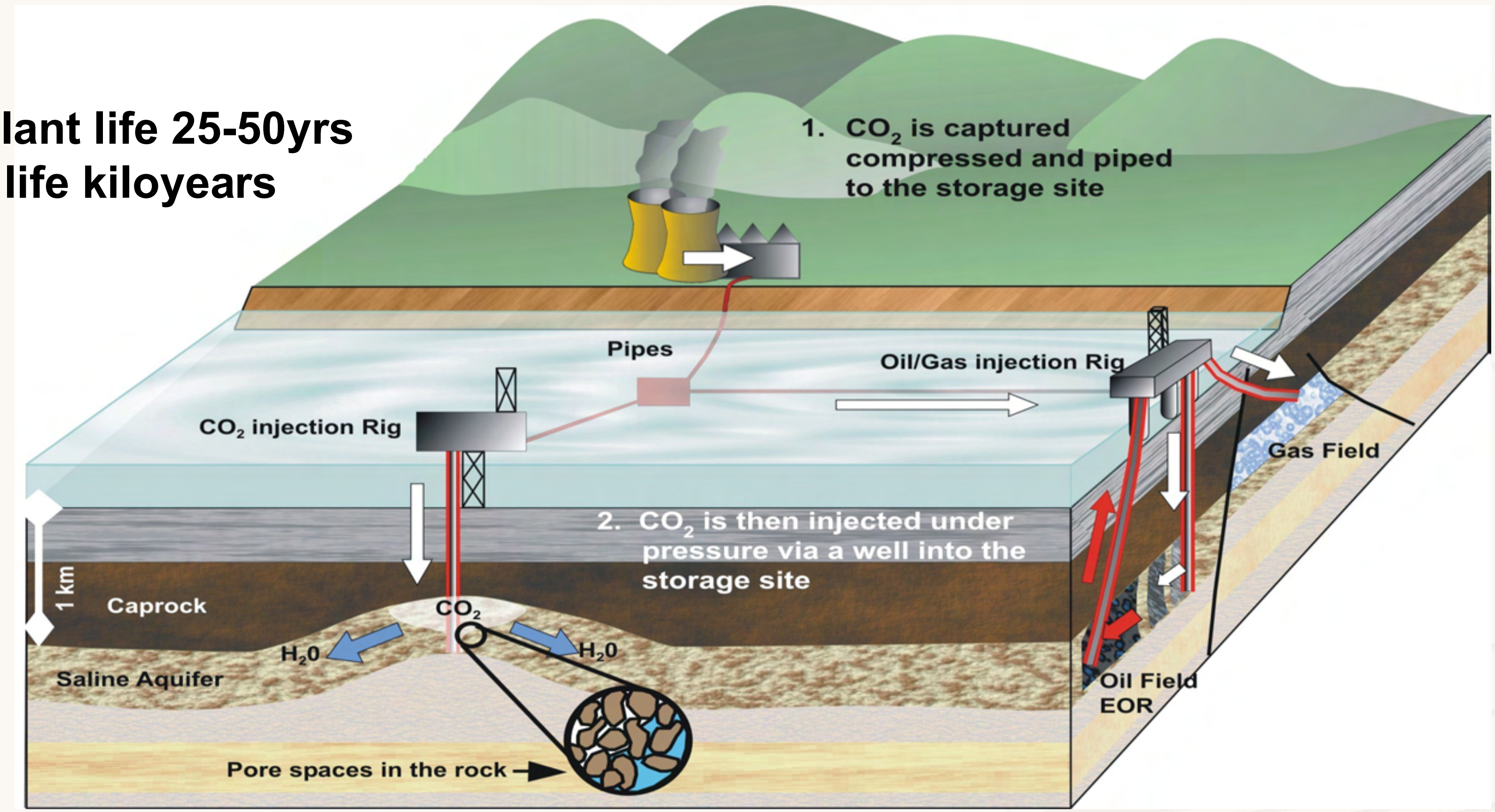
Scope of the EU Flagship Programme



Storage- scenarios

Note: Engineered infrastructure is movable/adaptable- geology is not!
Finding appropriate storage is the most critical path to any CCS project

Power plant life 25-50yrs
Storage life kiloyears



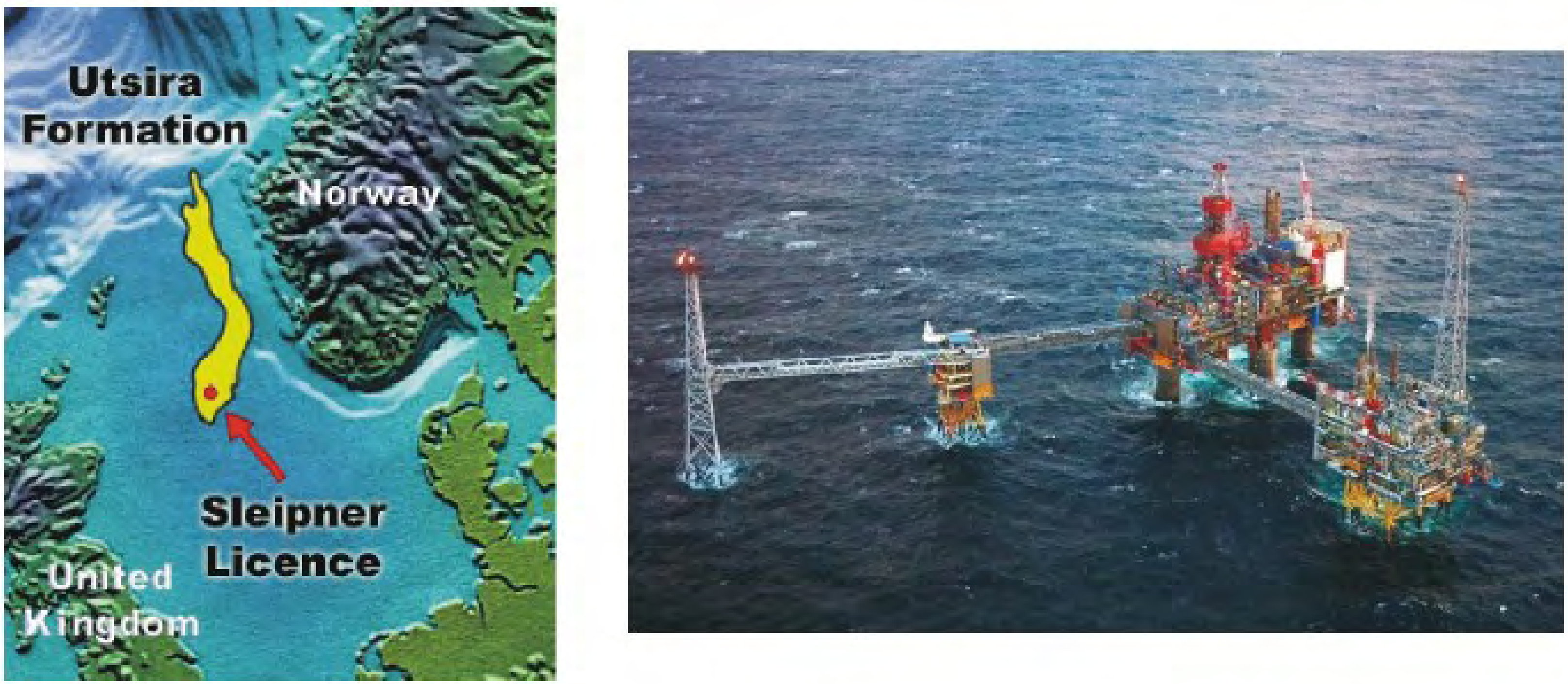
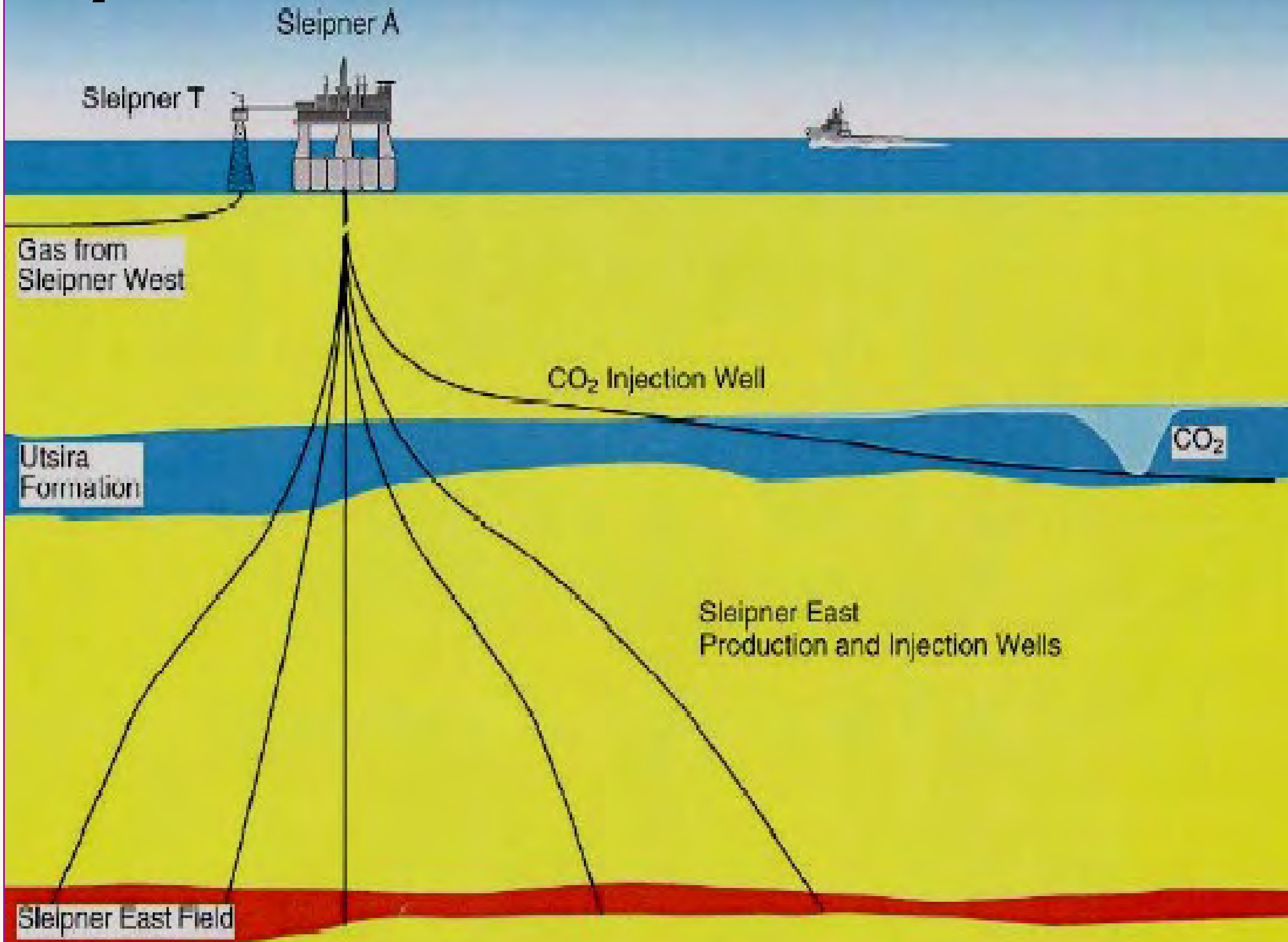
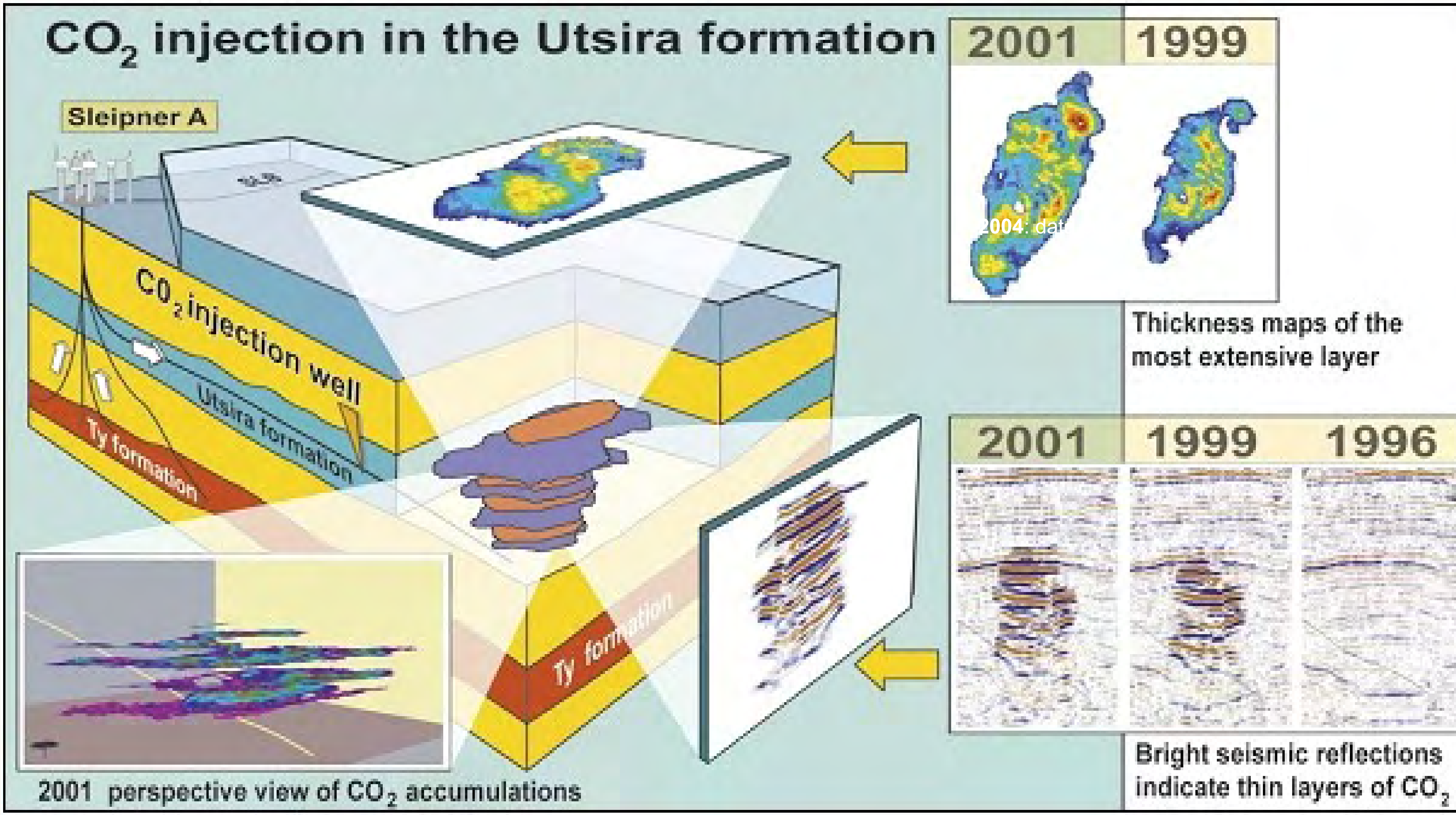


Figure 1.2 The Sleipner injection operation showing the extent of the Utsira Sand reservoir (yellow) and platform infrastructure.

(CO2 Store 2007)

CO_2 Sequestration

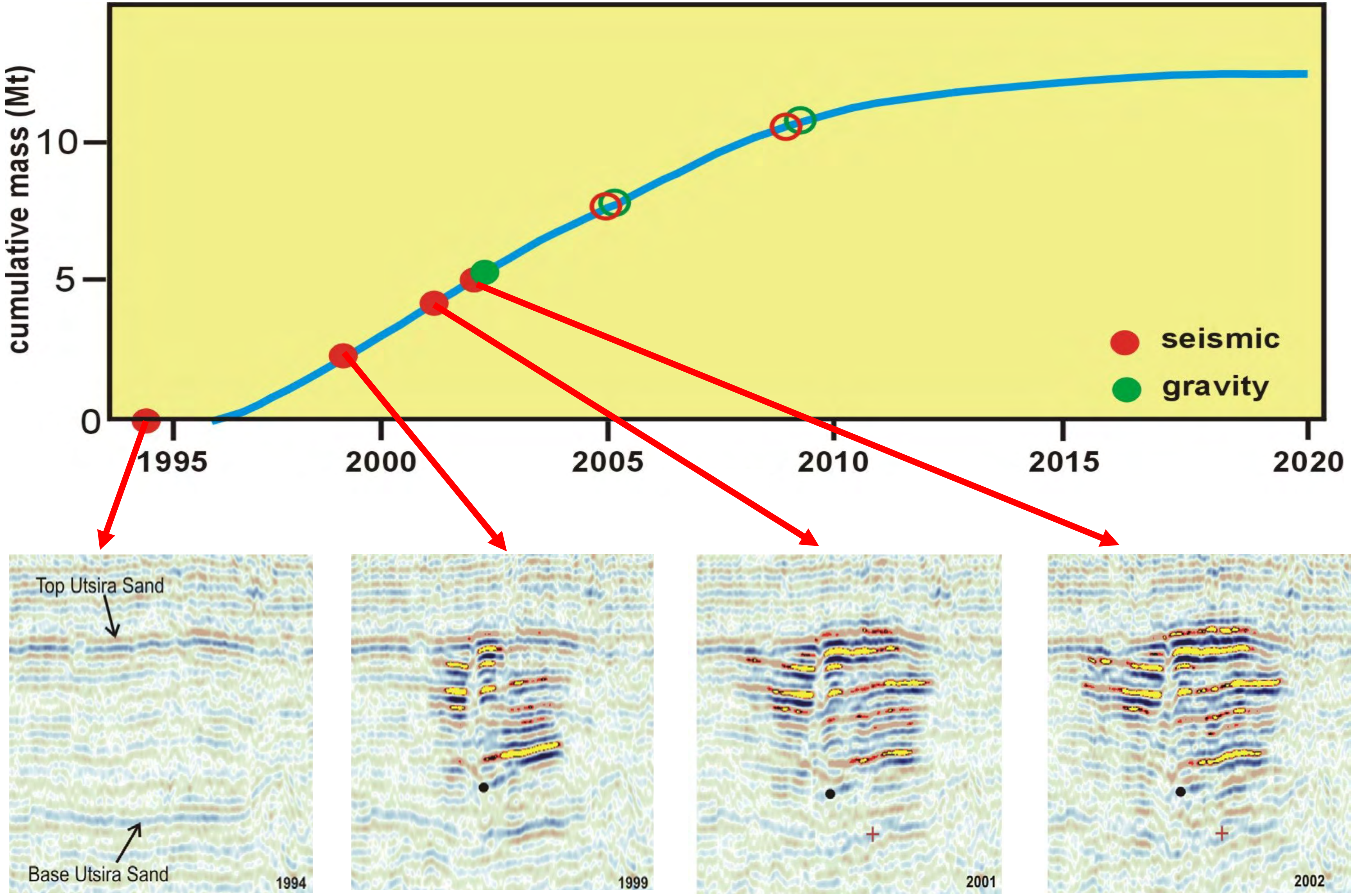




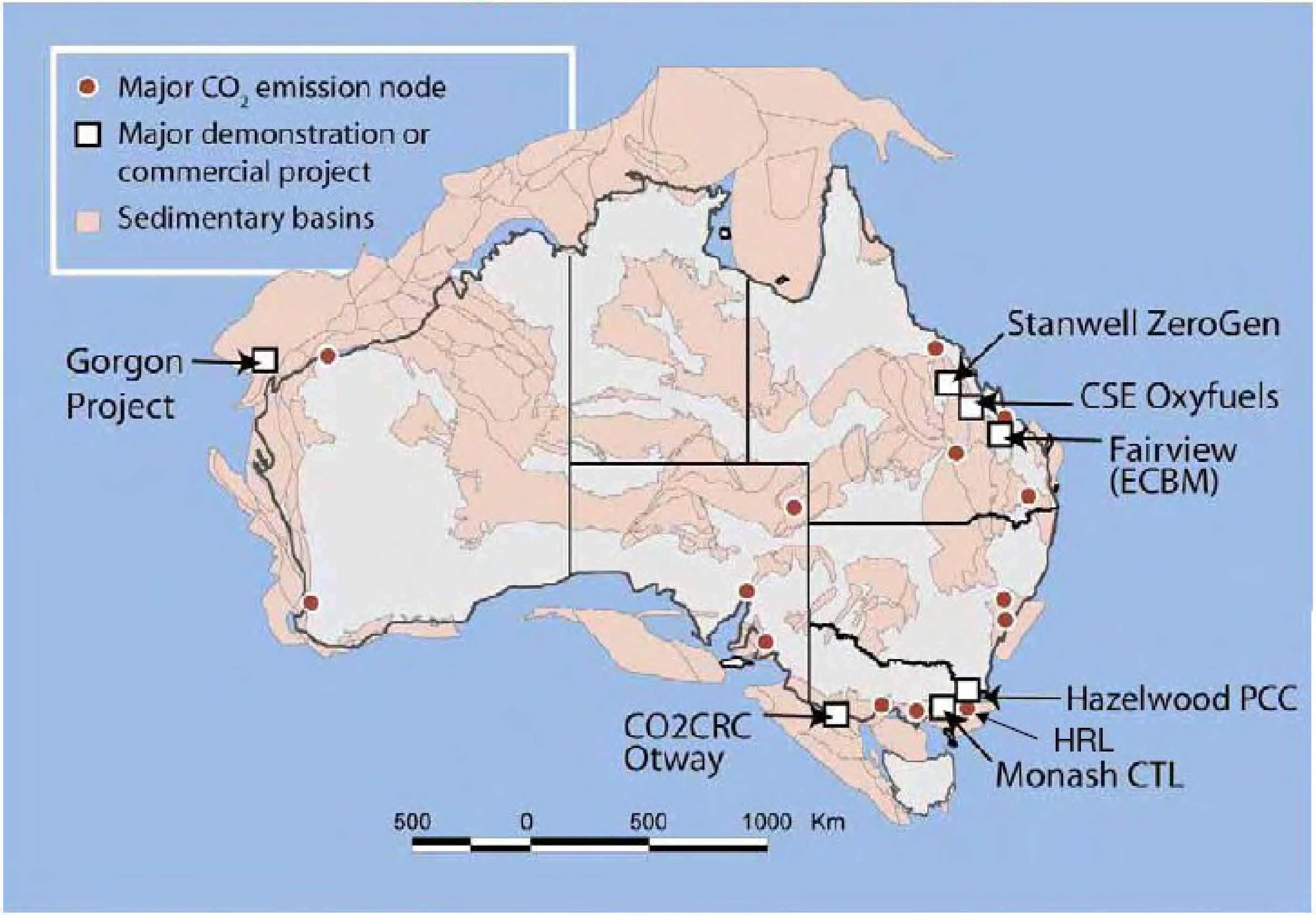
Sleipner, North Sea. 1Mt CO_2/annum

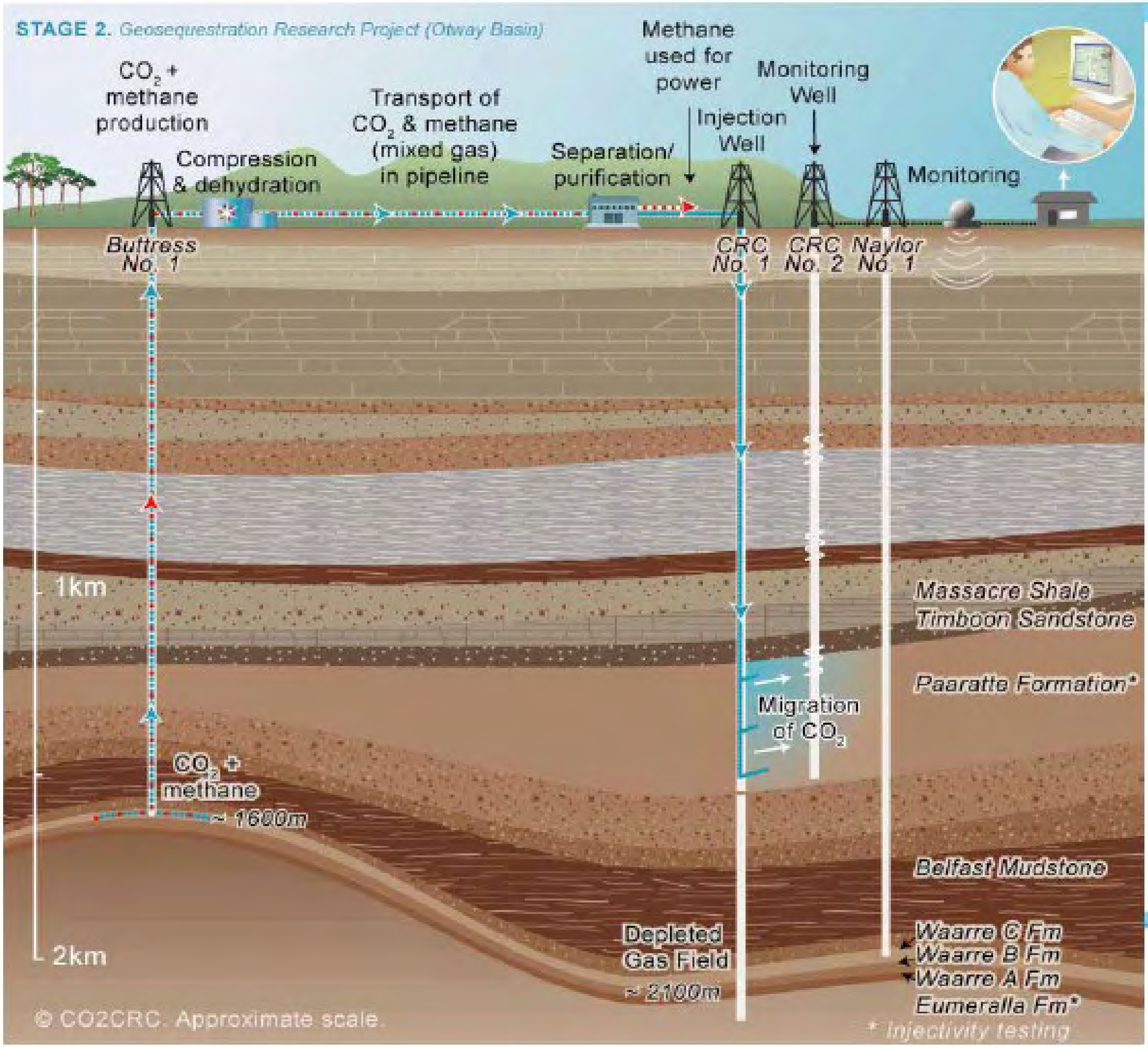
Courtesy of Statoil & SACS/CO2 Store

Sleipner: 3D seismic and gravity surveys



CCS projects in Australia





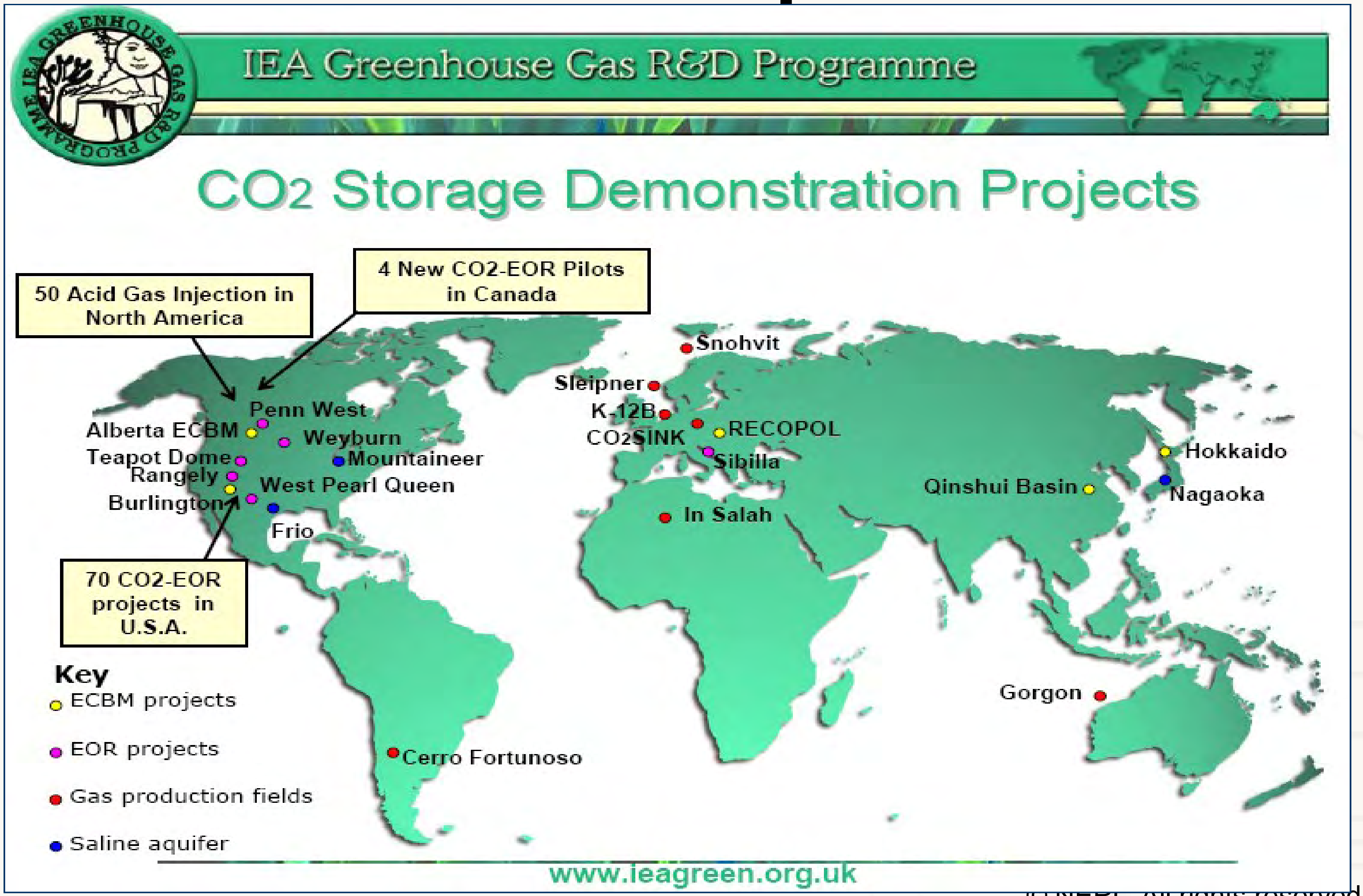
CO2CRC Geosequestration Research Project (Otway Basin)

Stage 2

This involves:

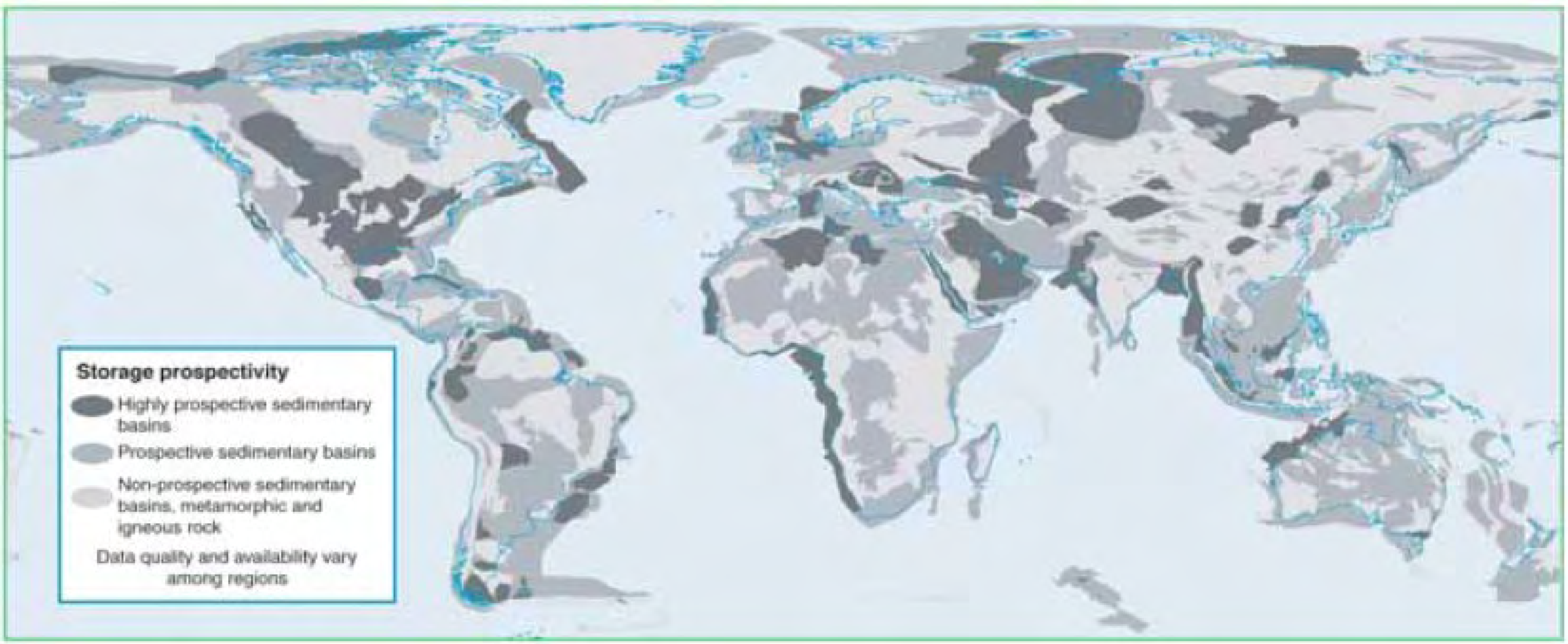
- Separation of CO_2
- Injection of pure CO_2 into the Paaratte Fm
- Injectivity testing in the Eumeralla Fm
- M&V

None in the UK at present, unless we count Sleipner!



- To hold CO_2 emissions at current levels, the world needs to be deploying CCS at a rate equivalent to over 750 Sleipners/annum, but we are deploying at <2/annum

Is there the storage capacity?



(Geoscience Australia)

Reservoir type	Lower estimate of storage capacity ($GtCO_2$)	Upper estimate of storage capacity ($GtCO_2$)
Oil and gas fields	675[a]	900[a]
Unminable coal seams (ECBM)	3-15	200
Deep saline formations	1,000	Uncertain, but possibly 10^4

[a] These numbers would increase by 25% if 'undiscovered' oil and gas fields were included in this assessment.

(IPCC 2005)

Table 0-1 Estimated CO_2 storage capacity of the UK and its continental shelf

Category	Location	Estimated CO_2 storage capacity (million tonnes)
Oil fields	Offshore	1175
Gas fields	Offshore	5140
Gas/condensate fields	Offshore	1200
Saline aquifers	Southern North Sea Basin	Up to 14250
	East Irish Sea Basin	Up to 630
	Northern and Central North Sea Basin and other offshore basins	Not quantified but potentially large
	Onshore	Not quantified but potential small
TOTAL QUANTIFIED CO_2 STORAGE CAPACITY		Up to **22395**

(BGS for DTI 2006)

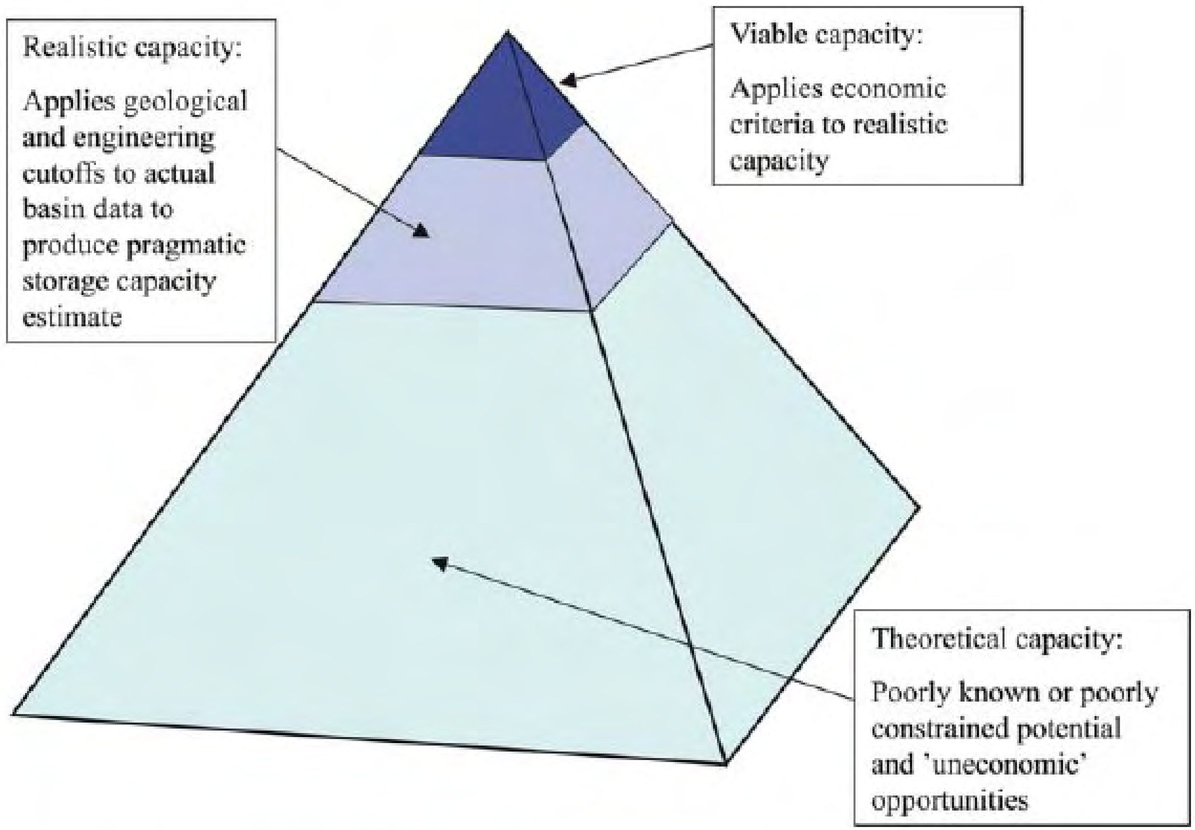


Figure 3-1. A techno-economic resource pyramid for geological CO_2 storage space. Adapted from Bradshaw et al. *in press*.

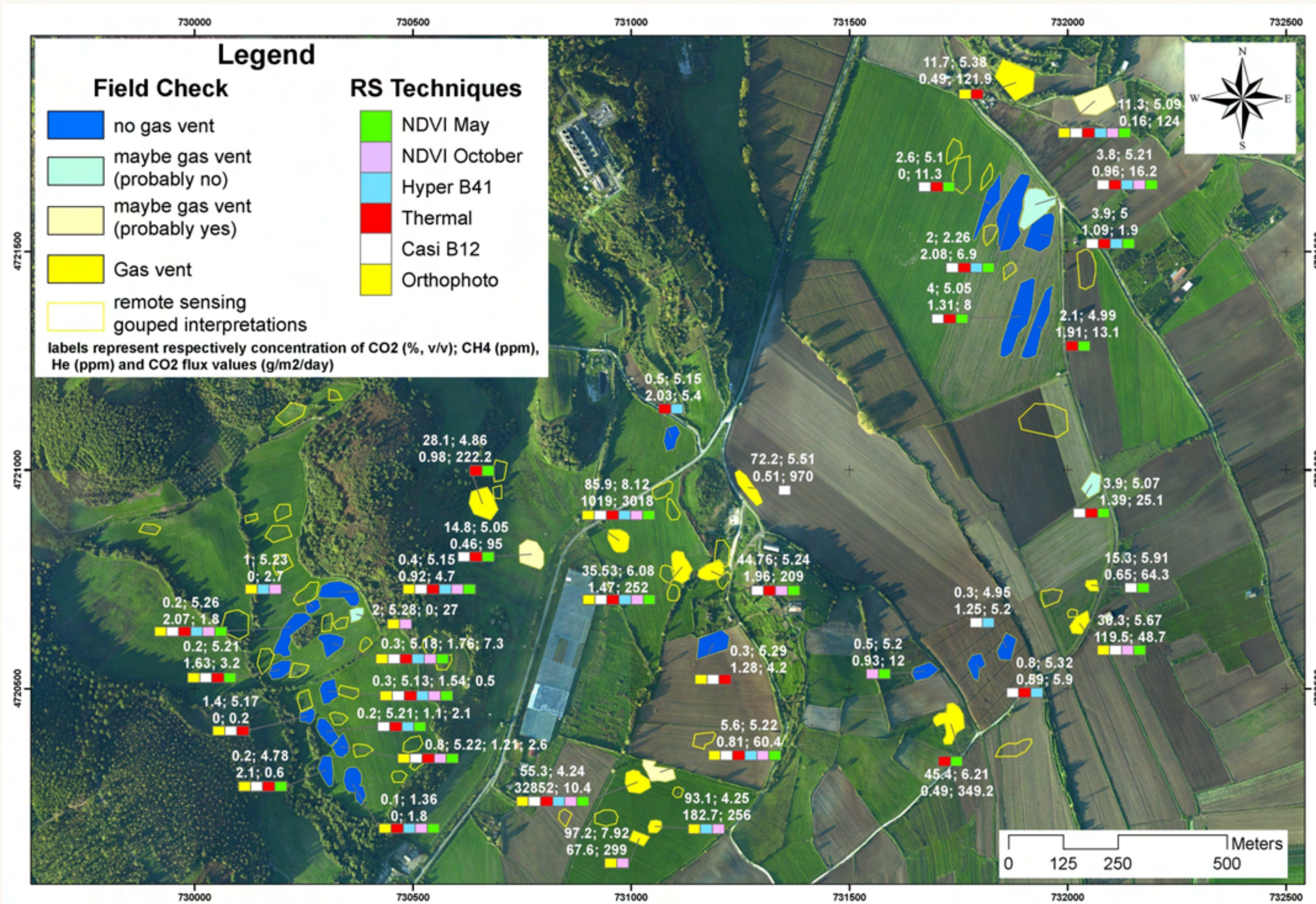
Can we monitor storage?

Careful site selection
Public acceptance
Geological Characterisation:
especially hydrogeological and geomechanical
Modelled and tested
Monitored

What happens if storage leaks?

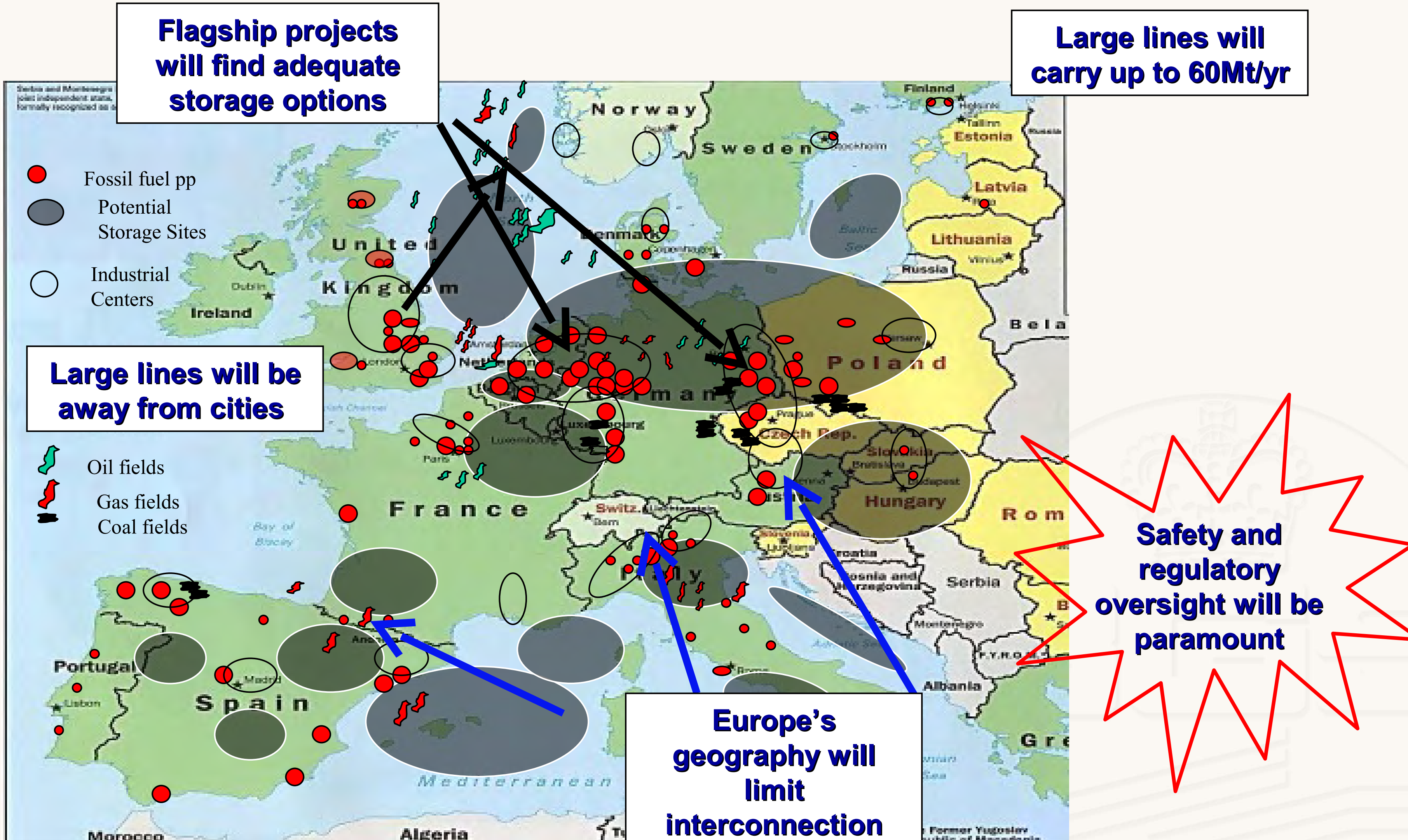
- CO_2 GeoNet is looking at natural analogues and conducting controlled release experiments. Indications are that leakage has only local ecological effects.
- People who live on natural CO_2 seeps are being interviewed by about how they live with the hazard and their views on CO_2 storage as a technology.
- The highest risk of leakage is with the engineered infrastructure, not the geology. We know where borehole are so they can be monitored and fixed if needed
- Thorough geological characterisation and operation of storage with due diligence are essential to minimise leakage risk

CO_2GeoNet partners is focussing on shallow subsurface/surface monitoring



Joint BGS/OGS/URS airborne monitoring of natural CO2 seeps at Latera, Italy

EU Flagship programme "Mainline" system for large CO_2 volumes will have regional flavour



Mineral Reactions to capture CO2

- $CaO + CO_2 \text{ --> } CaCO_3$ (-179kJ/mol)
- $MgO + CO_2 \text{ --> } MgCO_3$ (-118kJ/mol)
- $Mg_3Si_2O_5(OH)_4$ (serpentine) + $3CO_2 \text{ --> } 3MgCO_3 + 2SiO_2 + 2H_2O$ (-209 kJ/mol)
- Mg_2SiO_4 (fosterite/olivine) + $2CO_2 \text{ --> } 2MgCO_3 + SiO_2$ (-67 kJ/mol)

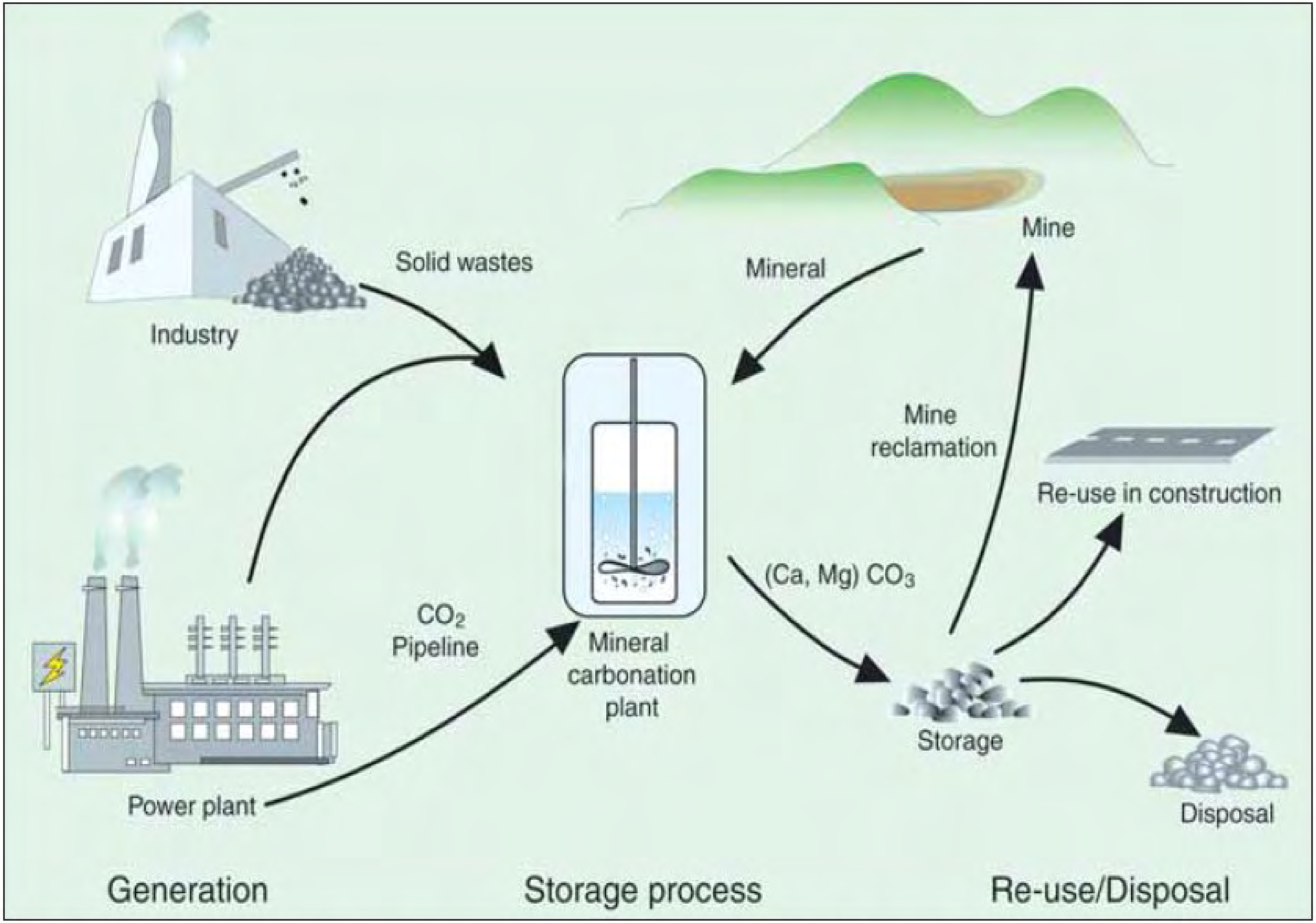


Figure TS.10. Material fluxes and process steps associated with the mineral carbonation of silicate rocks or industrial residues (Courtesy ECN).

Mineral Sequestration

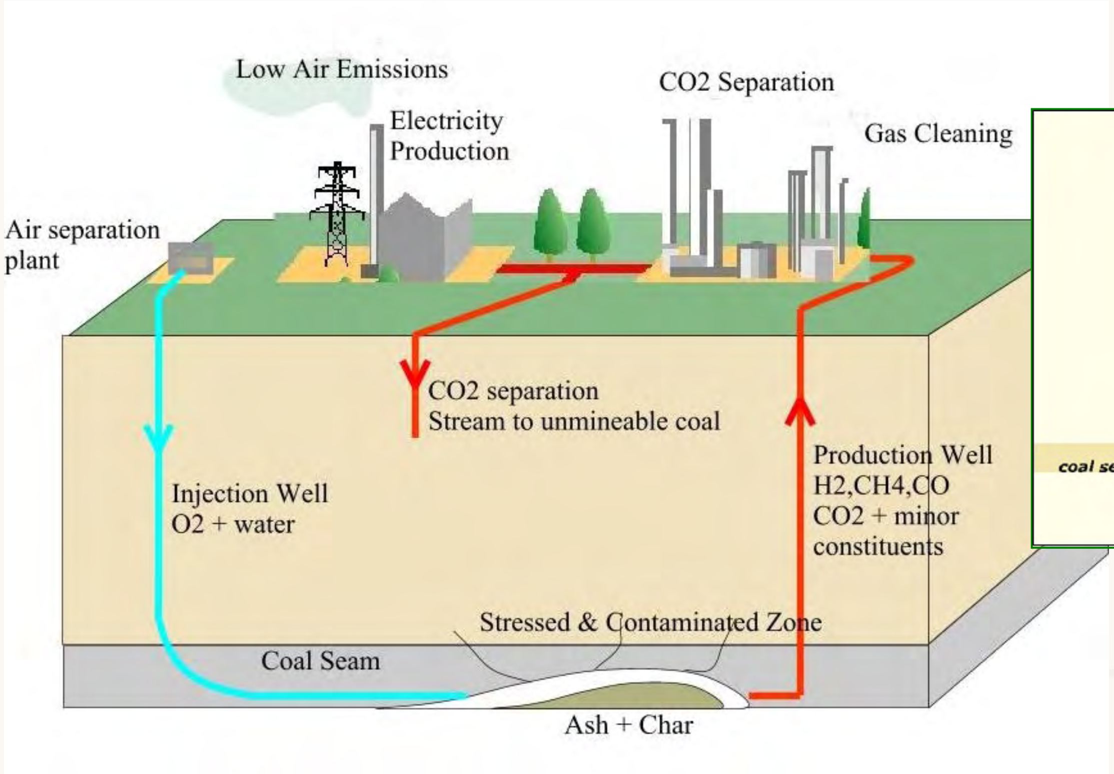
$$Mg_3Si_2O_5(OH)_4 + 3CO_2(g) \rightarrow 3MgCO_3 + 2SiO_2 + 2H_2O(l) + 63kJ/mol\ CO_2$$

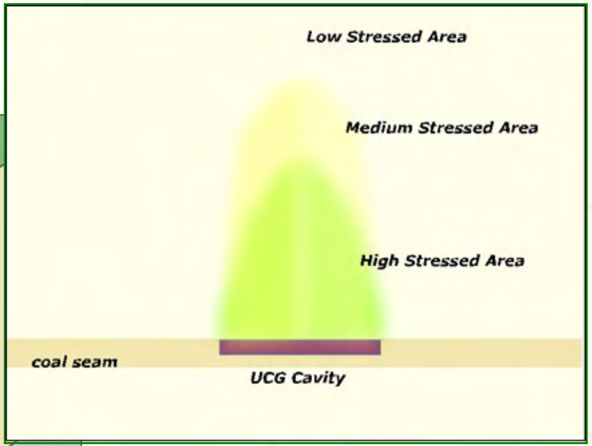
Rockville Quarry

How to get Gas from Coal?

- Mine it & bring it to surface and gasify as we used to.
- Extract it from the atmosphere of old coal mines: Coal Mine Methane (CMM),
- ***Drill laterally into the coal seam and pump water until gas is released. Coal Bed Methane (CBM)***)
- Gasify it underground by igniting the coal in the presence of water and oxygen and get pressurised gas at surface. Underground Coal Gasification (UCG)

Underground Coal Gasification (UCG) can and should be combined with sequestration of CO_2 in coal seams





Conclusions

- There is no single technology/strategy that can reduce emissions to the level required
- Global emissions are still rising despite the focus on renewables, energy efficiency etc.
- CCS is the only technology that deals with fossil fuels directly and can deliver deep cuts in fossil fuel emissions
- Its looks like its already too late to prevent global emissions peaking before 2015- hence we are on the trajectory for a >2^{o}C rise above pre-industrial (contrary to EU policy)
- If we are to cut and reverse CO_2 emissions no later than 2030 we must deploy CCS now. Or we will be on the trajectory for a >3^{O}C global temperature rise and risk ocean acidification.