Institute for European Environmental Policy

Carbon Dioxide Capture and Storage: Potential and Pitfalls

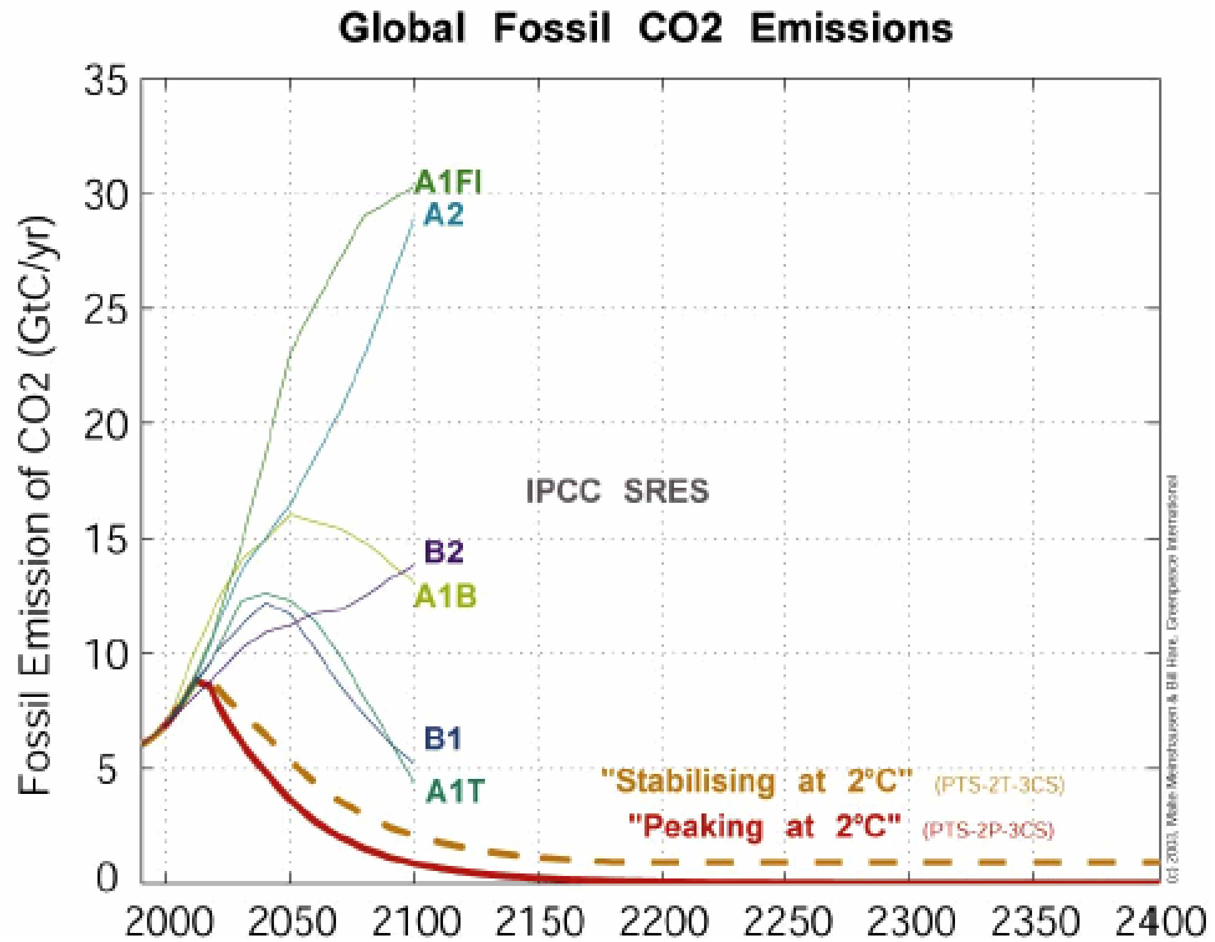
Jason Anderson, IEEP

Overview of issues

1. **Background on CCS**
2. Can it be done (economically)?
3. Is it safe?
4. Is it acceptable?
5. Will it happen?
6. Conclusions

The 2 degree challenge

A limit to global warming of 2 degrees Celsius above pre-industrial levels has been endorsed by the Council, Parliament and Commission, as well as many stakeholders



Source: Meinshausen, 2005

The ‘portfolio of options’

CO_2 source

Power plant combusting fossil fuel or biomass, with CO_2 captured through:

- Pre-combustion decarbonisation
- Post-combustion decarbonisation
- Oxyfuel combustion

Separated in industrial processes from natural gas or in hydrogen or ammonia production

Transport

Pipeline (large volume – considered most likely)

Tanker truck (small volumes)

Ship (possibly for long-rage international or offshore transport)

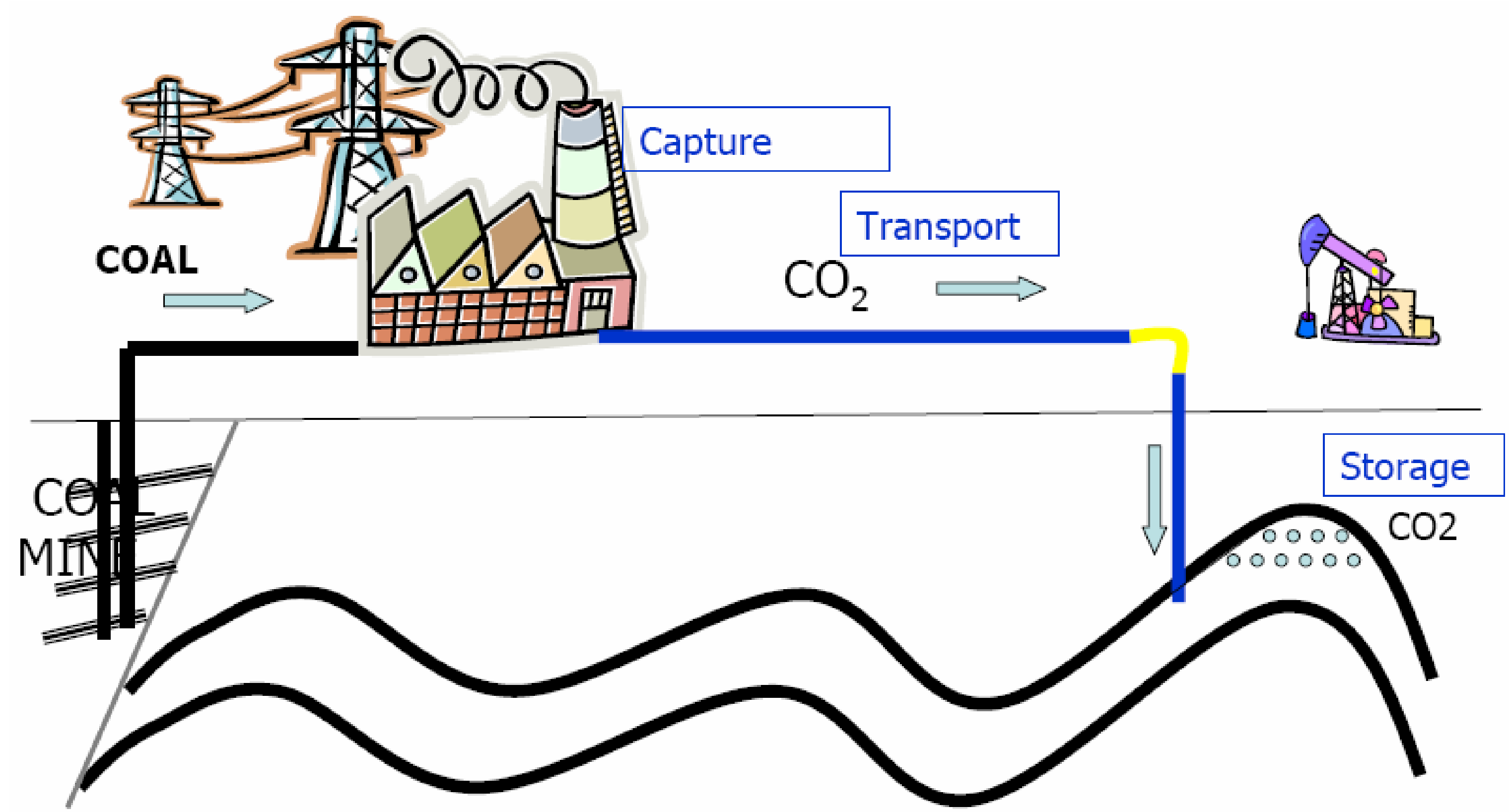
Storage

In abandoned oil or gas wells

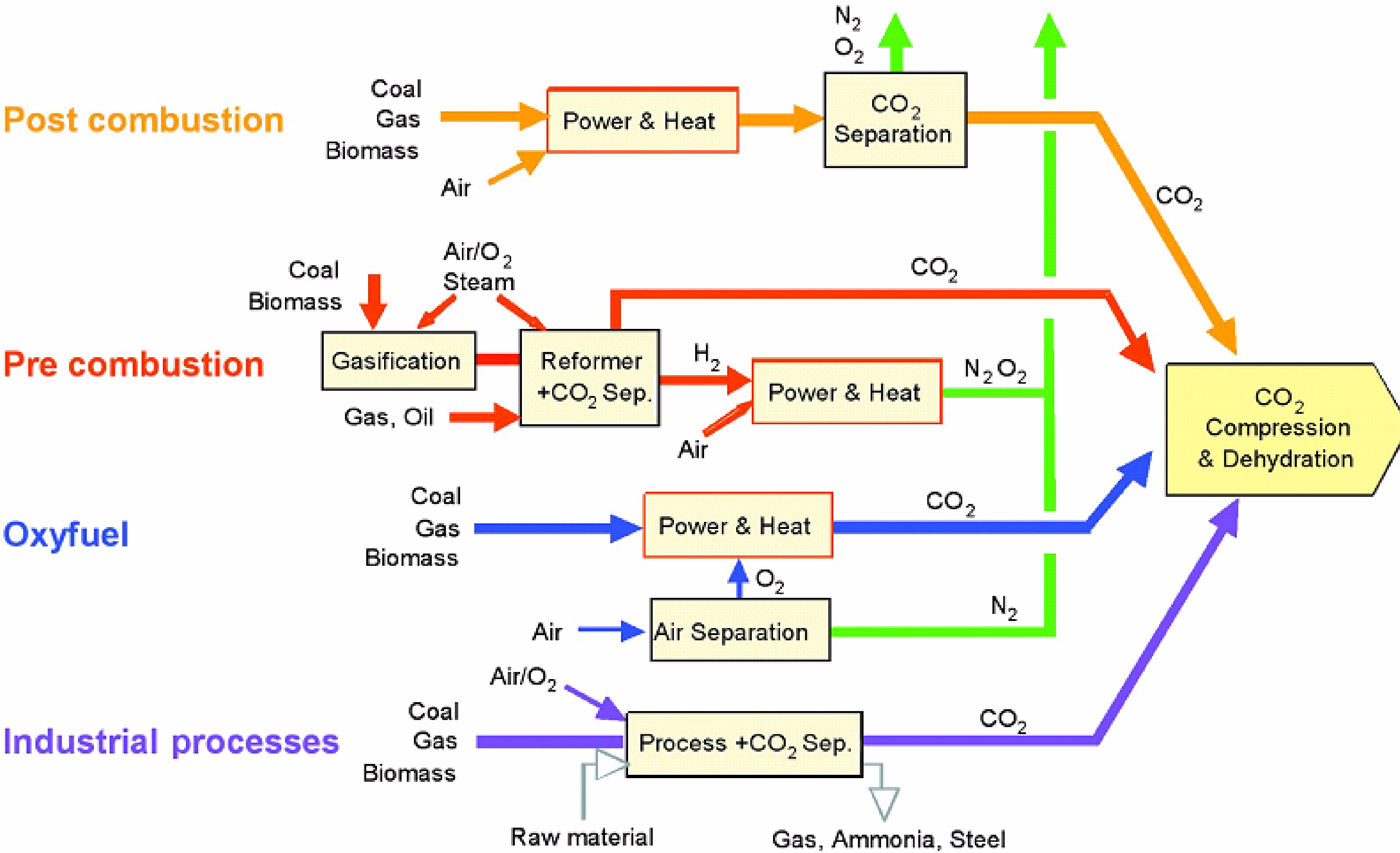
In operating oil or gas wells to enhance production

In deep saline aquifers

In coal seams

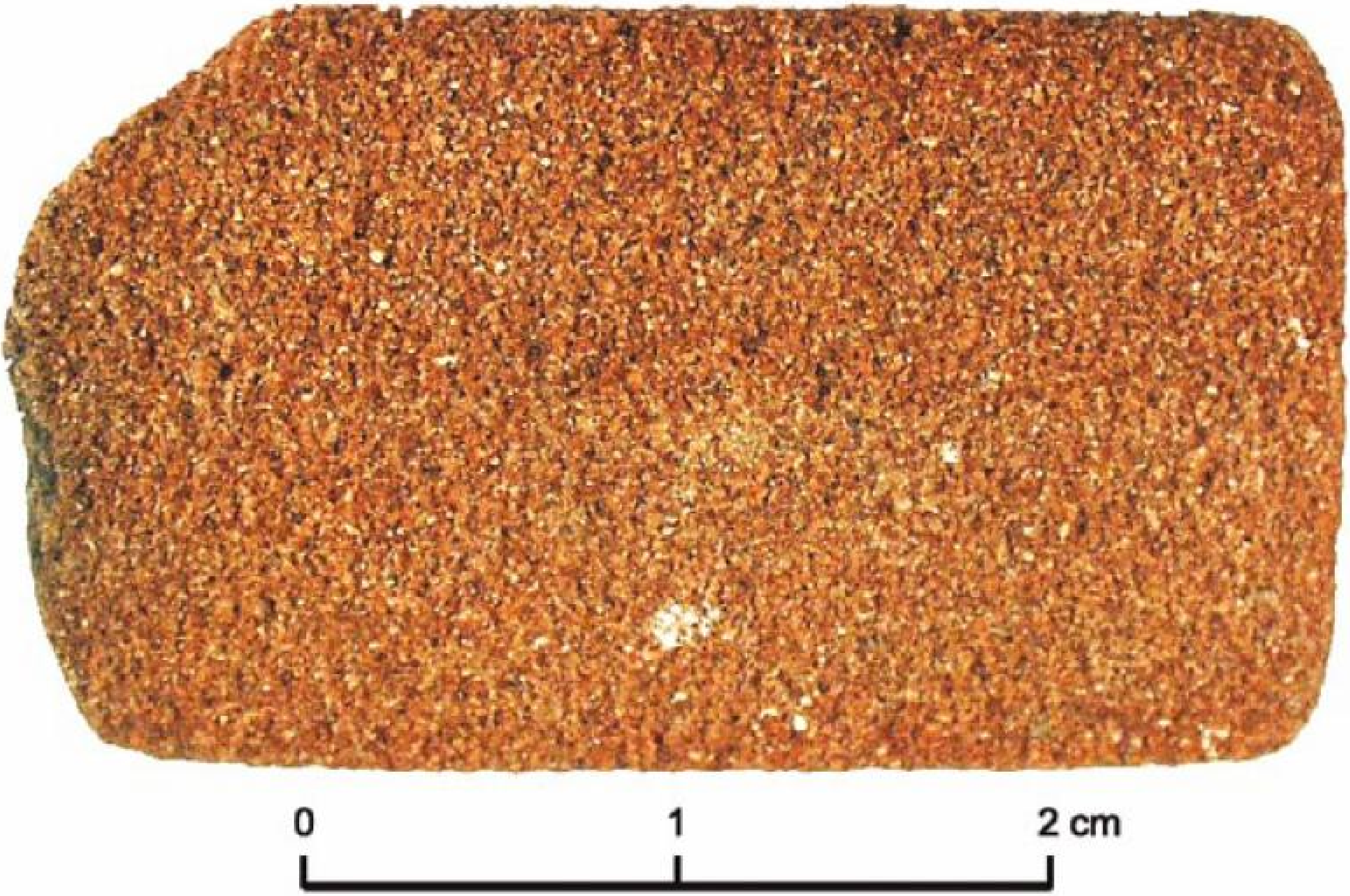


Overview of CO2 capture processes and systems



Source: IPCC special report

28 May 2008



Source: IEA GHG

Examples

28 May 2008

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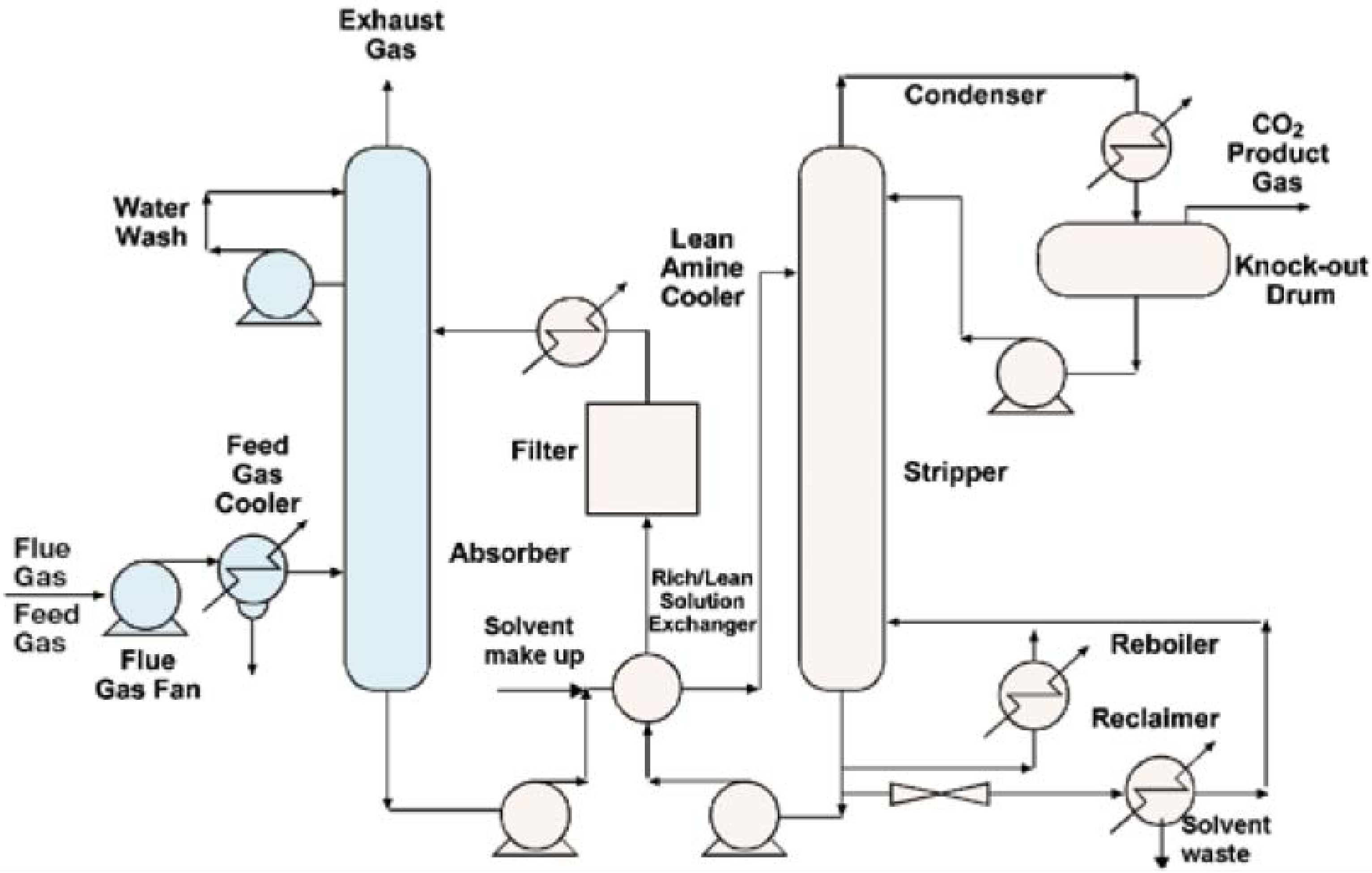
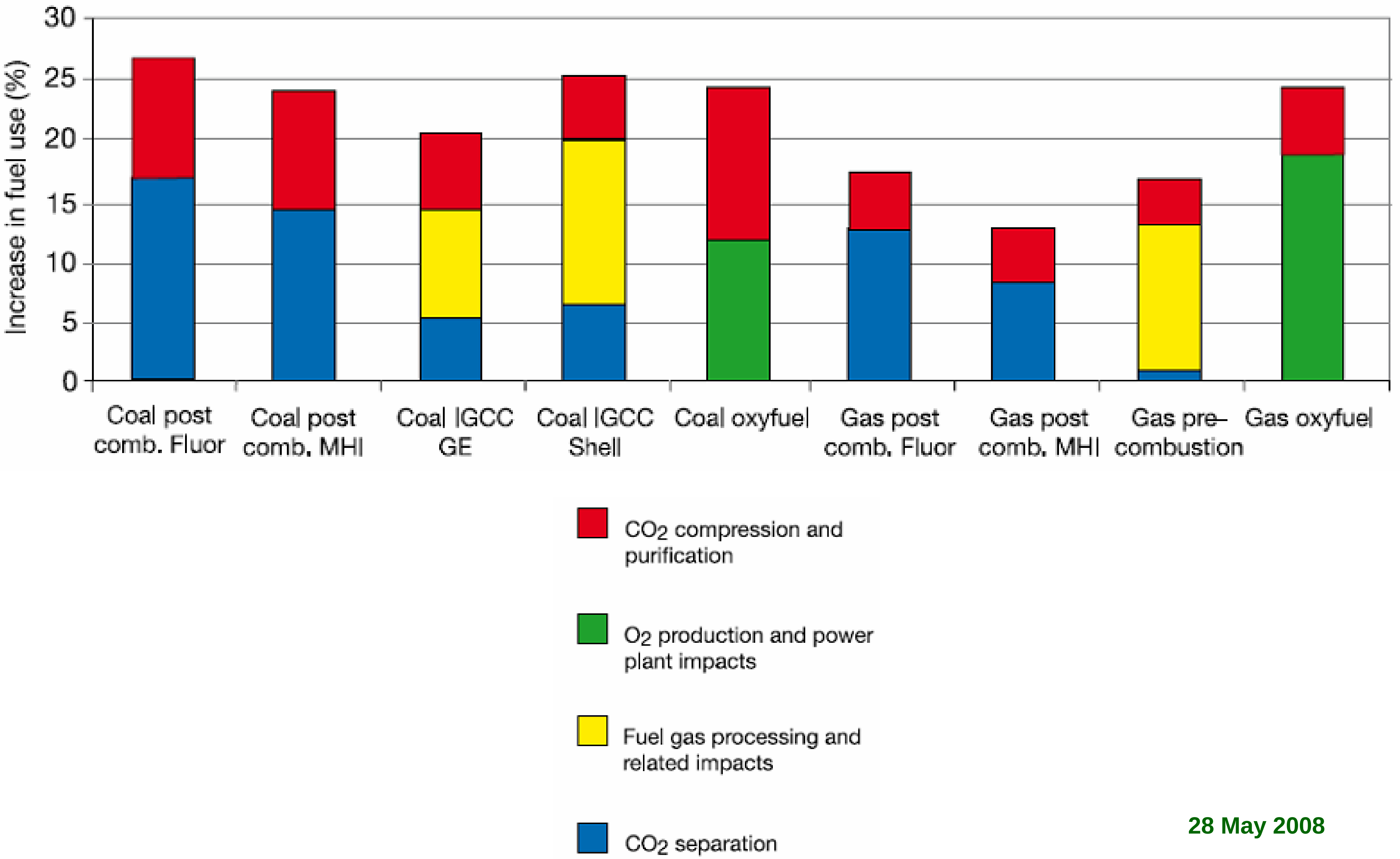
Using energy to save emissions…



Efficiency loss due to capture



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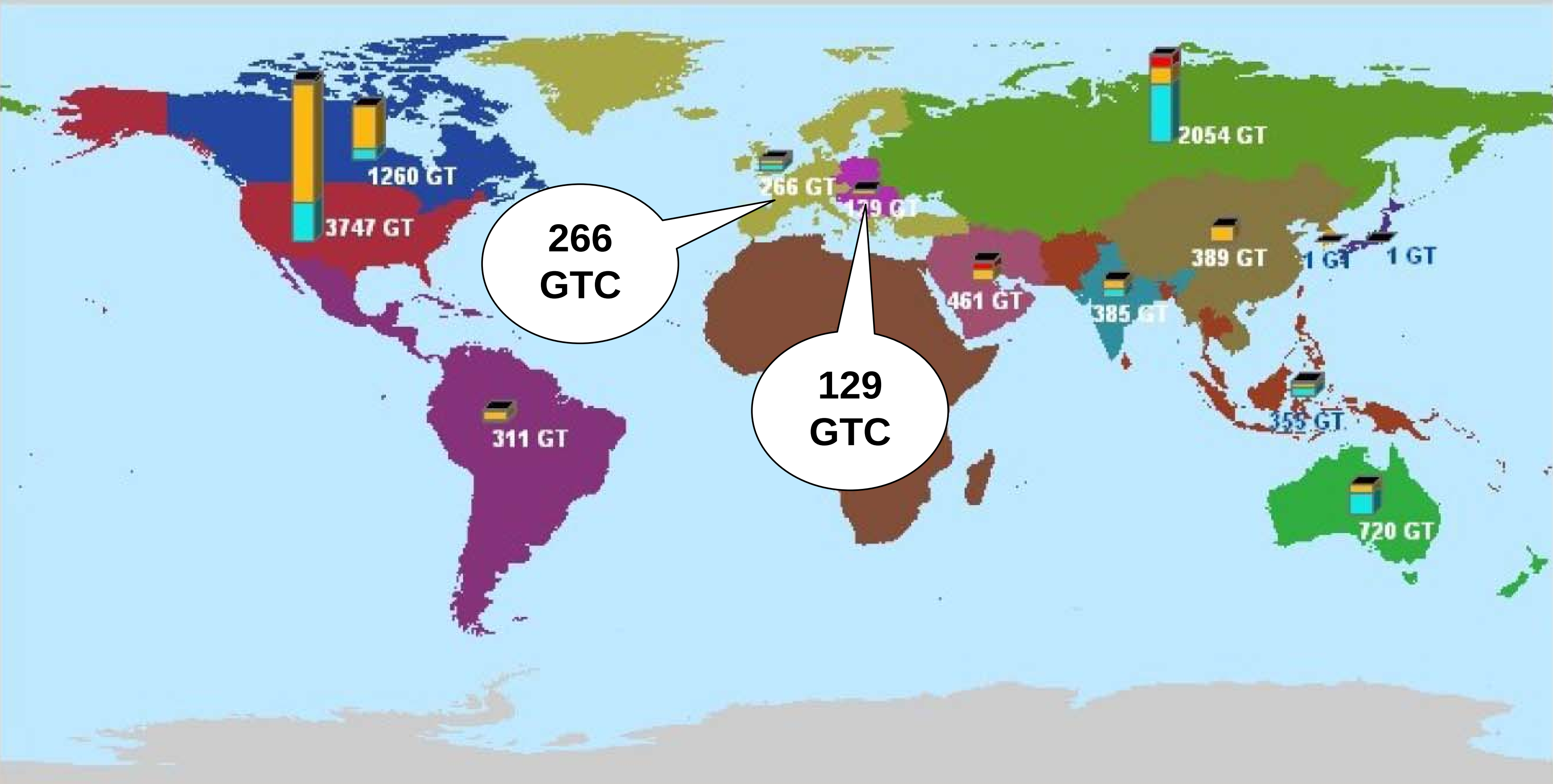
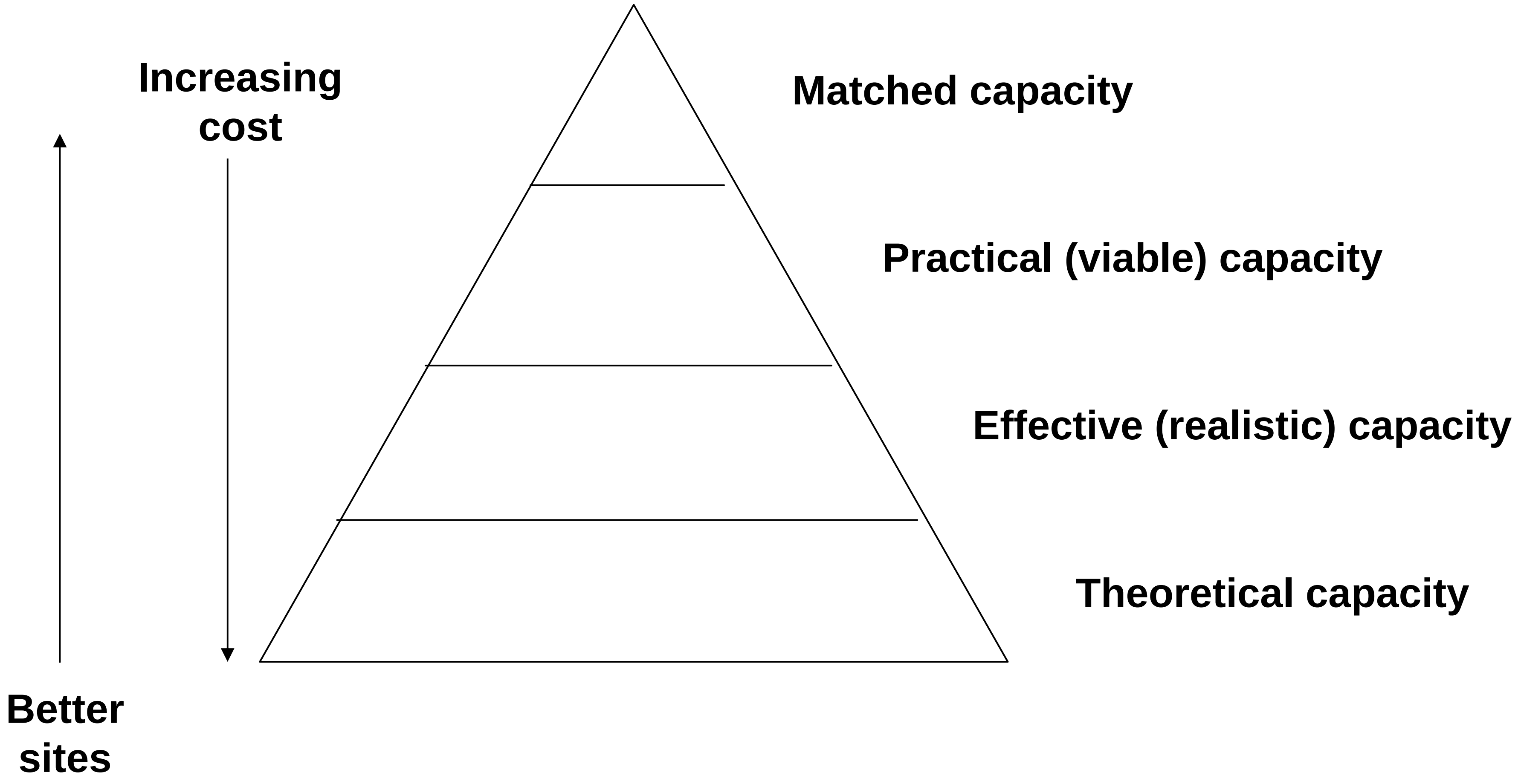
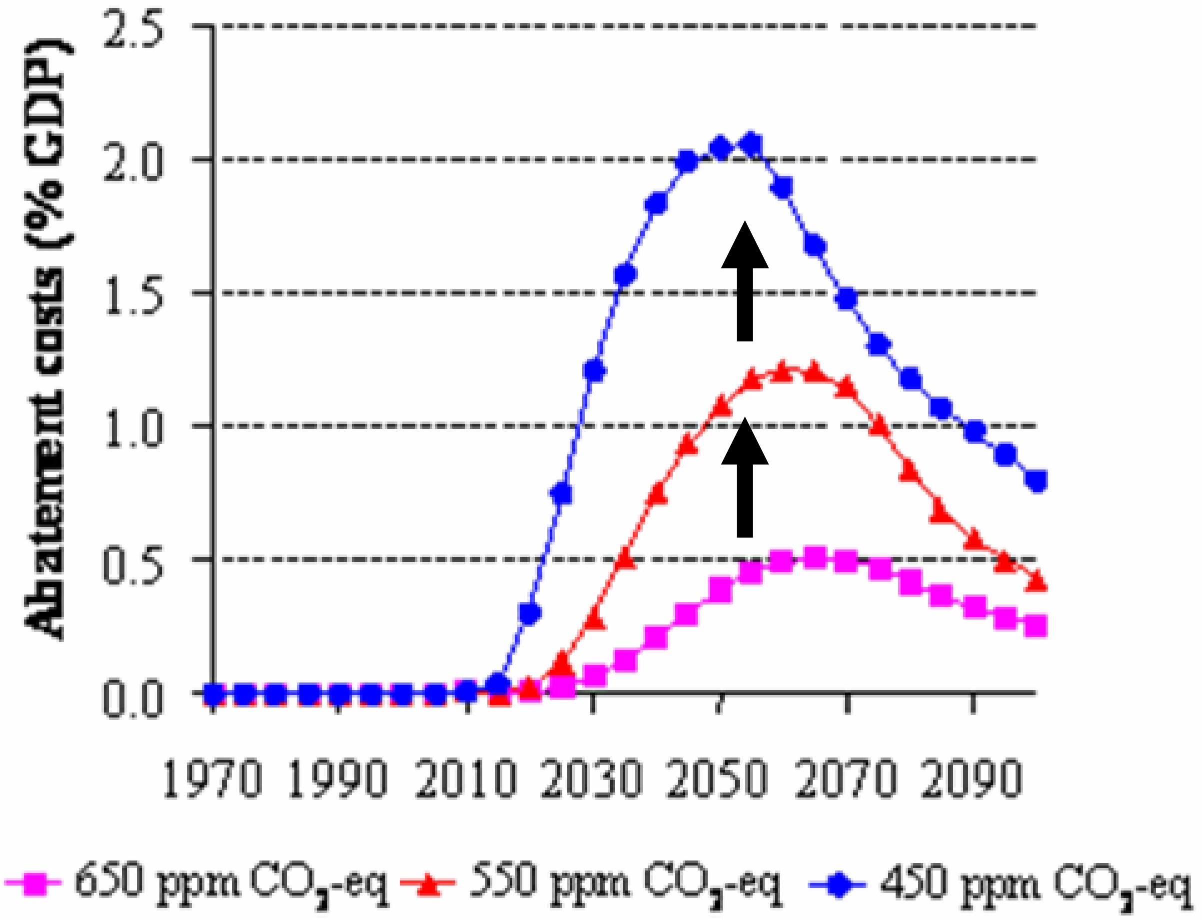
Global storage capacities



More realistic assessments



Choices under economic pressure



Source: Van Vuuren, 2006

CCS costs

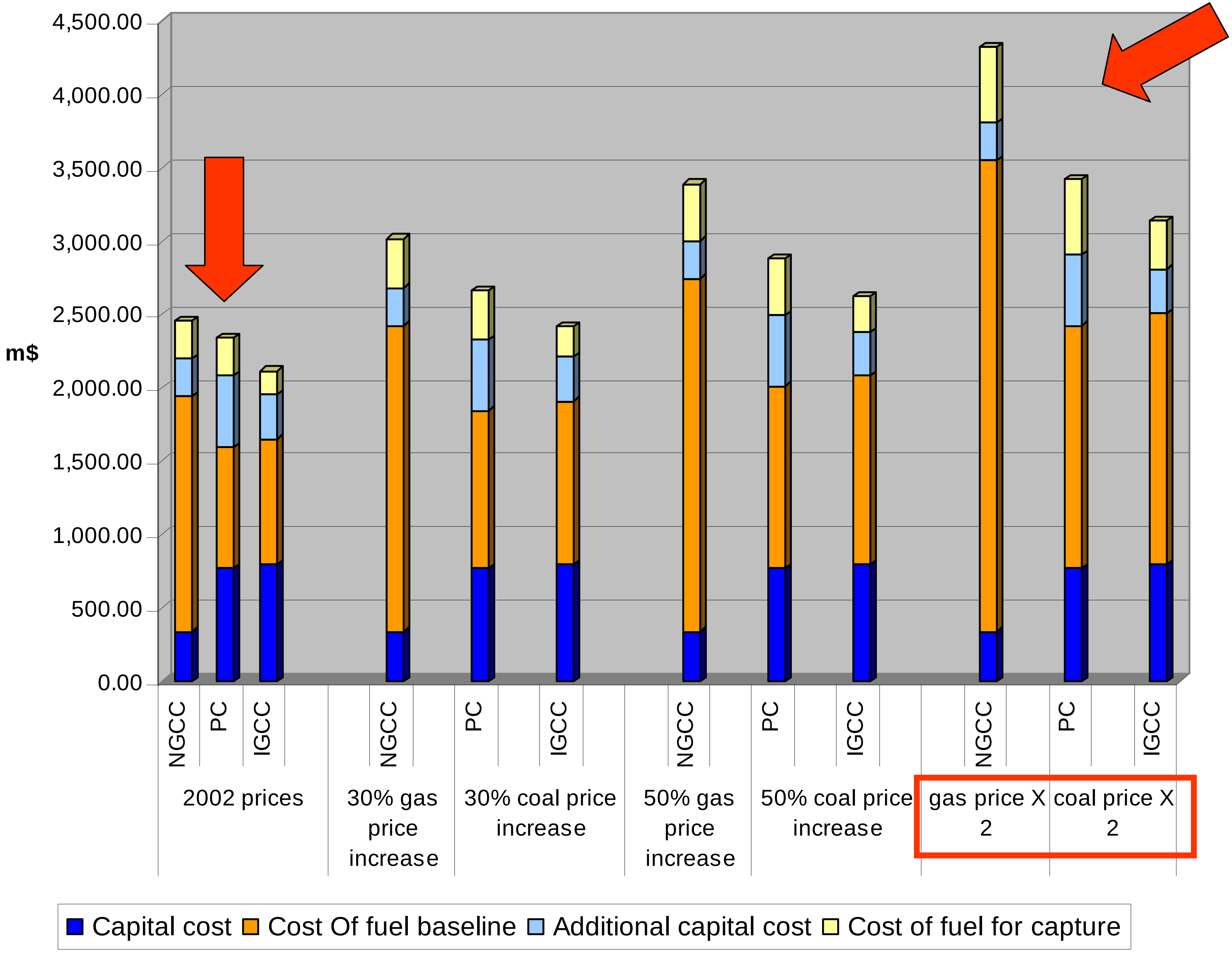
- Capture: $ 5 - 90 / tCO2 — $40-60 / tCO2 'typical'
  ↓
  acid gas processing, hydrogen, ammonia

- Transport: $ 0 - 20 / tCO2 — depends on volume, distance, terrain
  ↓
  on site storage

- Storage: $ 2 - 12 / tCO2 — depends on location/type of formation
  ↓
  onshore, with infrastructure in place

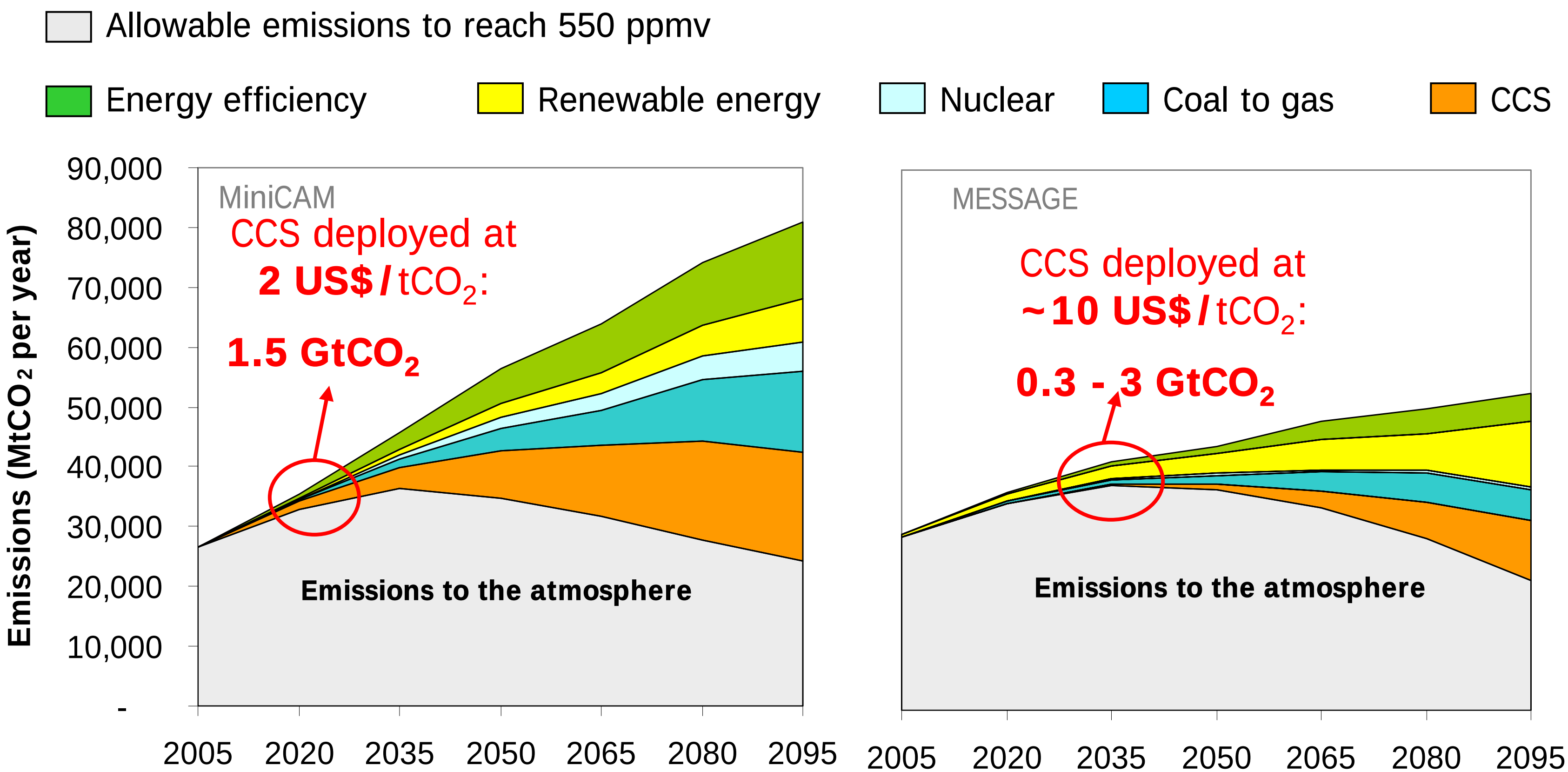
Future cost reduction potential: capture - 50%, others less

Source: Senior et al. 2004



Source: IEEP analysis of IPCC special report

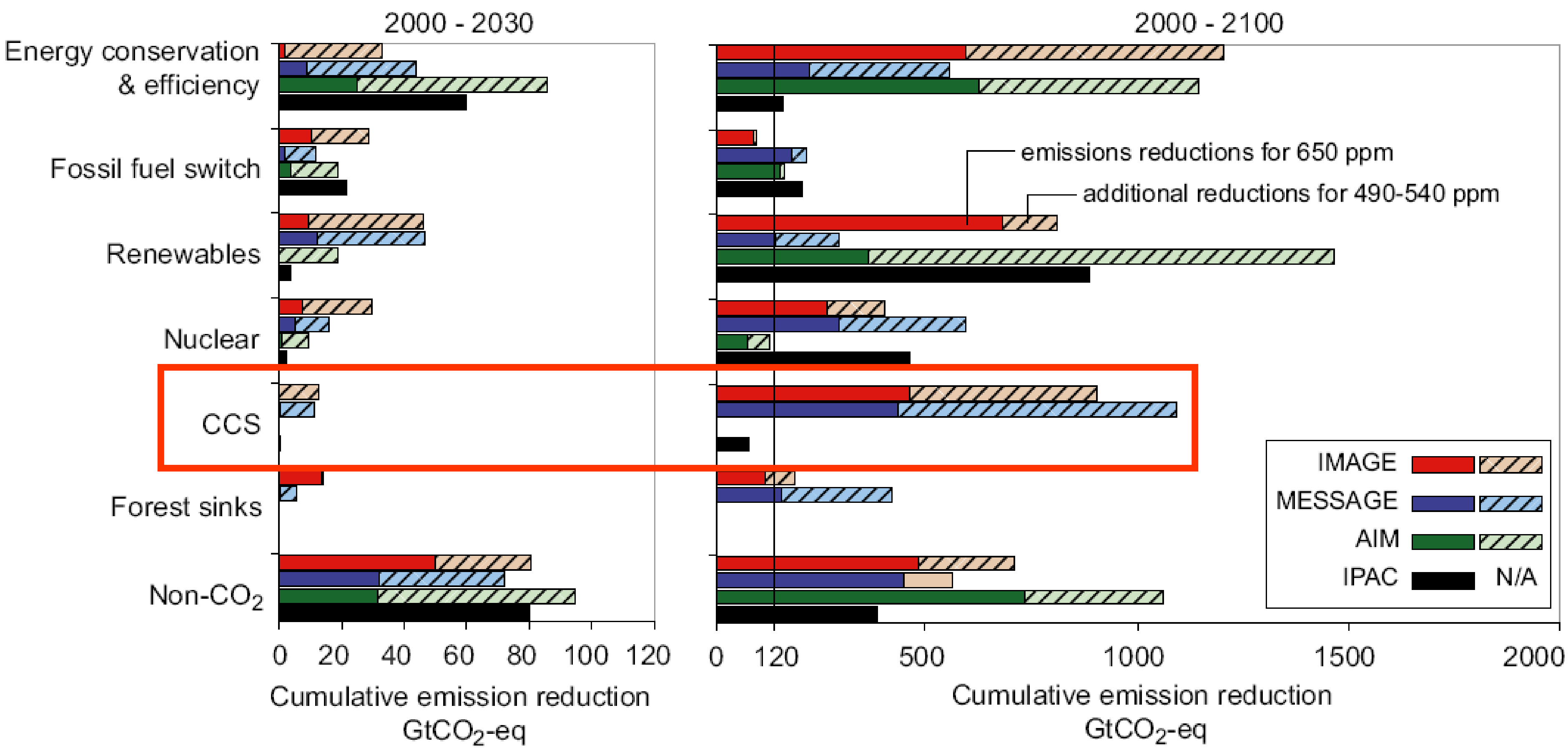
Economic potential at low prices



Cumulatively: 220 - 2200 $GtCO_2$ CCS used

Including CCS in the portfolio decreases overall mitigation costs by 30%

There is no *one* model

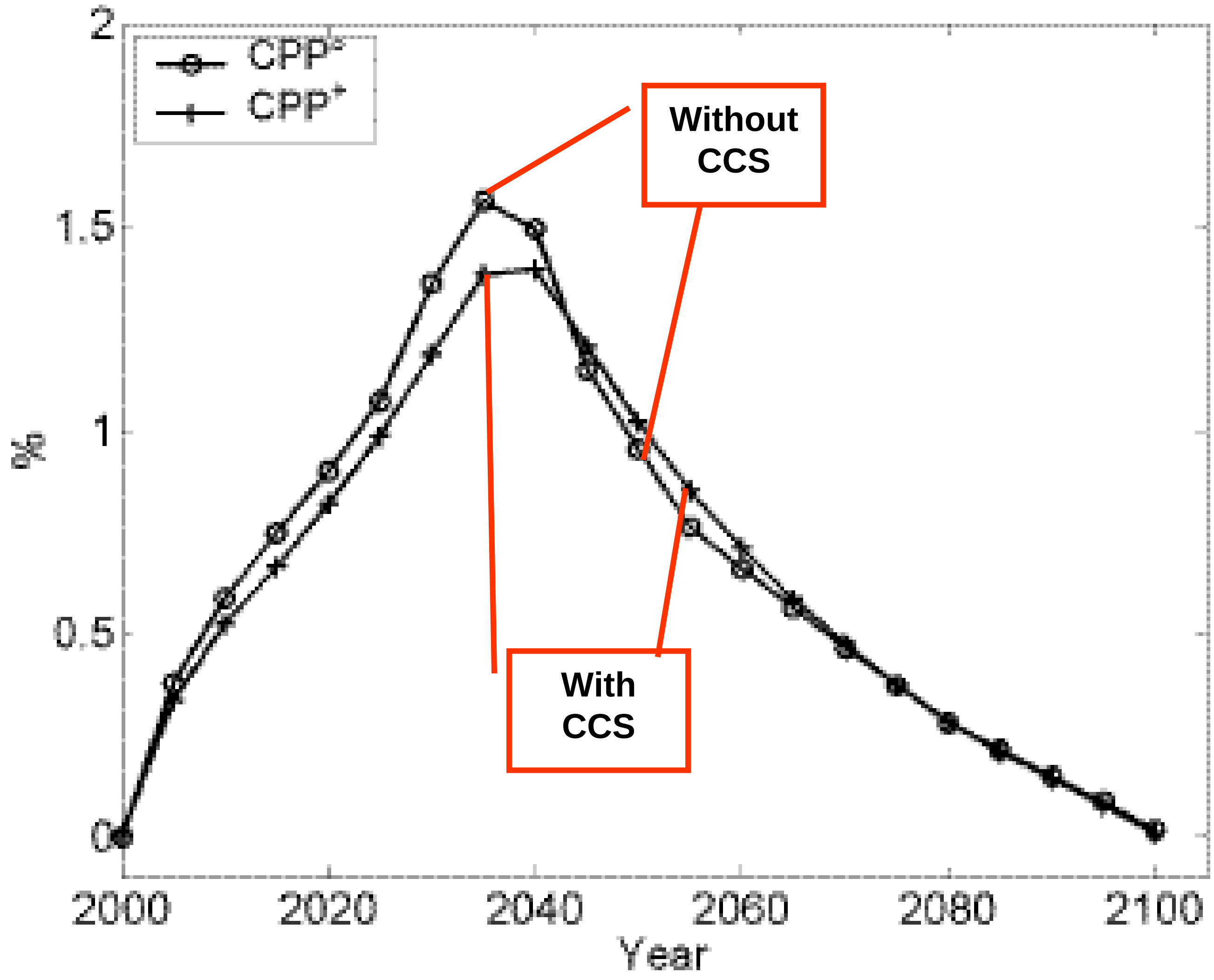


IPCC AR4, 2007

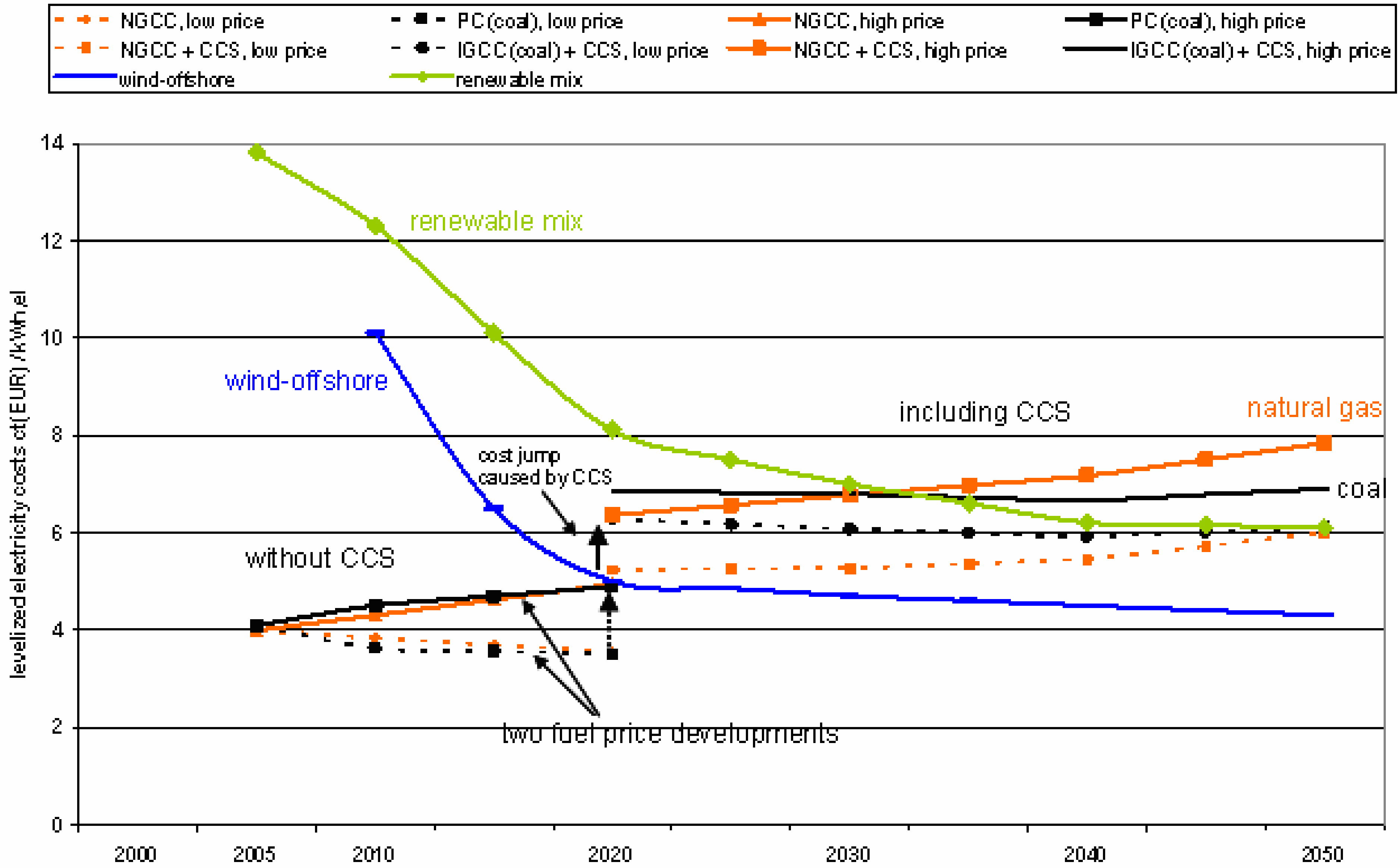
CCS Directive Primes model

EU27 Scenarios		CO2 Captured (Mt/year)			CO2 captured as % of CO2 from Power and Steam			Total Energy Cost as % of GDP		
		2020	2025	2030	2020	2025	2030	2020	2025	2030
1	Baseline	0.0	0.0	0.0	*0.0*	*0.0*	*0.0*	9.57	9.26	8.95
2	Base-CCS1	0.0	4.3	62.0	*0.0*	*0.2*	*3.6*	9.58	9.28	8.99
3	Base-CCS2	0.0	5.0	90.5	*0.0*	*0.3*	*5.2*	9.58	9.28	8.99
4	CVtar-G	53.3	142.2	490.7	*4.0*	*10.1*	*32.5*	9.80	9.55	9.46
5	CVtar-A	27.2	150.5	483.3	*2.2*	*11.1*	*32.8*	10.19	9.94	9.75
6	RVCVtar-G	7.2	33.3	219.2	*0.6*	*2.7*	*17.5*	9.88	9.68	9.55
7	RVCVtar-A	7.0	19.7	160.7	*0.6*	*1.7*	*13.2*	10.14	9.93	9.75
8	RVCVtar-G-CCS1	7.2	33.1	300.7	*0.6*	*2.7*	*24.1*	9.88	9.69	9.59
9	RVCVtar-G-CCS2	7.2	52.1	424.3	*0.6*	*4.2*	*32.7*	9.90	9.70	9.63
10	RVCVtar-A-CCS1	6.9	20.6	266.9	*0.6*	*1.8*	*22.2*	10.14	9.94	9.79
11	RVCVtar-A-CCS2	6.9	26.5	391.3	*0.6*	*2.2*	*31.0*	10.15	9.95	9.81
12	RVCVtar-A-CCS1R	37.2	118.1	326.2	*3.2*	*10.0*	*26.9*	10.15	9.96	9.79
13	RVCVtar-A-CCS2R	75.0	176.5	517.1	*6.2*	*14.4*	*39.5*	10.17	9.99	9.82
14	RVCVtar-A-CCS2N	0.0	3.5	272.6	*0.0*	*0.3*	*22.7*	10.15	9.94	9.80
15	RVCVtar-A-CCS2Nuc	7.1	22.6	352.1	*0.7*	*2.1*	*29.7*	10.17	9.97	9.81
16	RVCVtar-A-noCCS	0.0	0.0	0.0	*0.0*	*0.0*	*0.0*	10.15	9.96	10.07
17	RVCVtar-A-subs	0.2	21.6	210.7	*0.0*	*1.8*	*17.3*	10.14	9.93	9.77

Mitigation GDP loss with and without CCS



Source: Bauer et al. 2004



NGCC, low price
PC (coal), low price
NGCC, high price
PC (coal), high price
NGCC + CCS, low price
IGCC (coal) + CCS, low price
NGCC + CCS, high price
IGCC (coal) + CCS, high price
wind-offshore
renewable mix
levelized electricity costs ct(EUR) /kWh,el
renewable mix
wind-offshore
including CCS
natural gas
cost jump
caused by CCS
coal
without CCS
two fuel price developments
0
2
4
6
8
10
12
14
2000
2005
2010
2020
2030
2040
2050

Is CCS necessary?

- Aggregate figures can be misleading:
  - Need to know where and when specific challenges arise, e.g. new coal capacity – lock-in.
- Technical potential is not the best indicator of potential
  - Political will
  - Powerful constituencies
  - Public acceptance
  - Financial considerations
- Because there is no hard and fast answer the most important thing to avoid is *failure to act*

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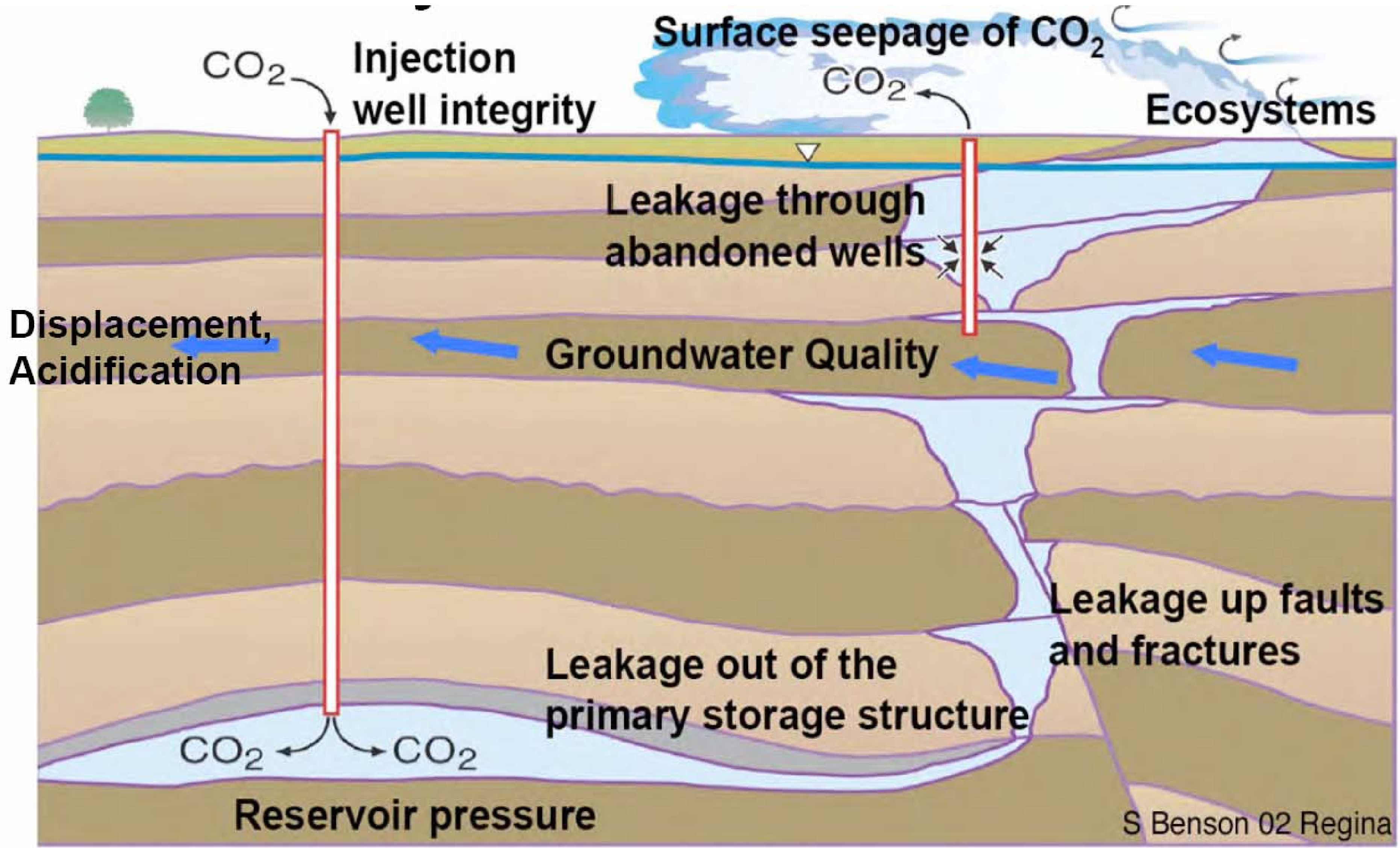
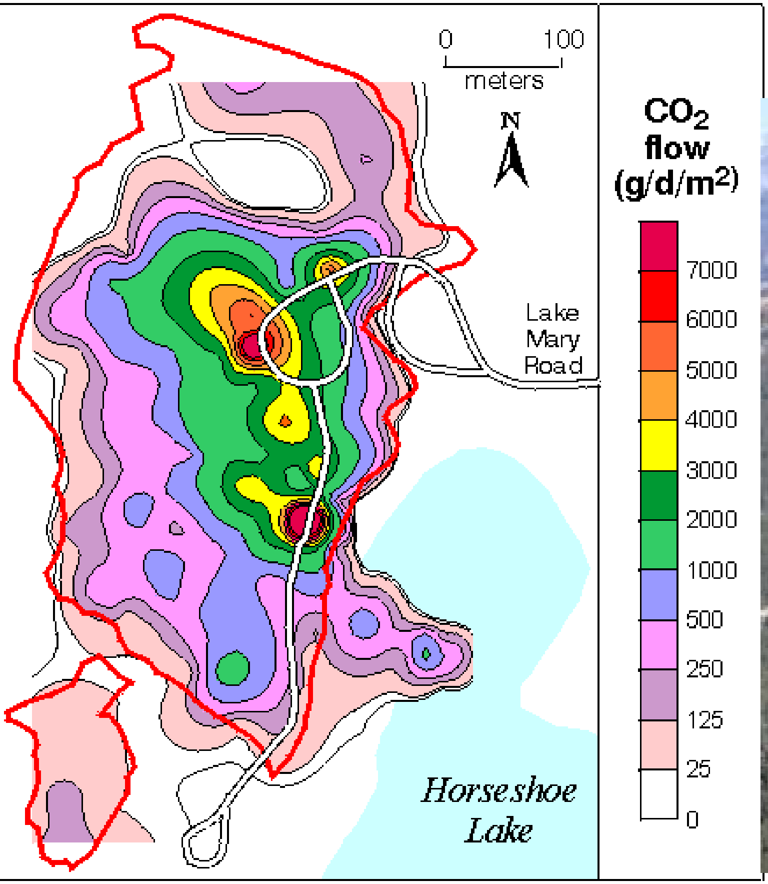
Leakage pathways



Lake Nyos

Source: S. Haszeldine, U. Edinburgh

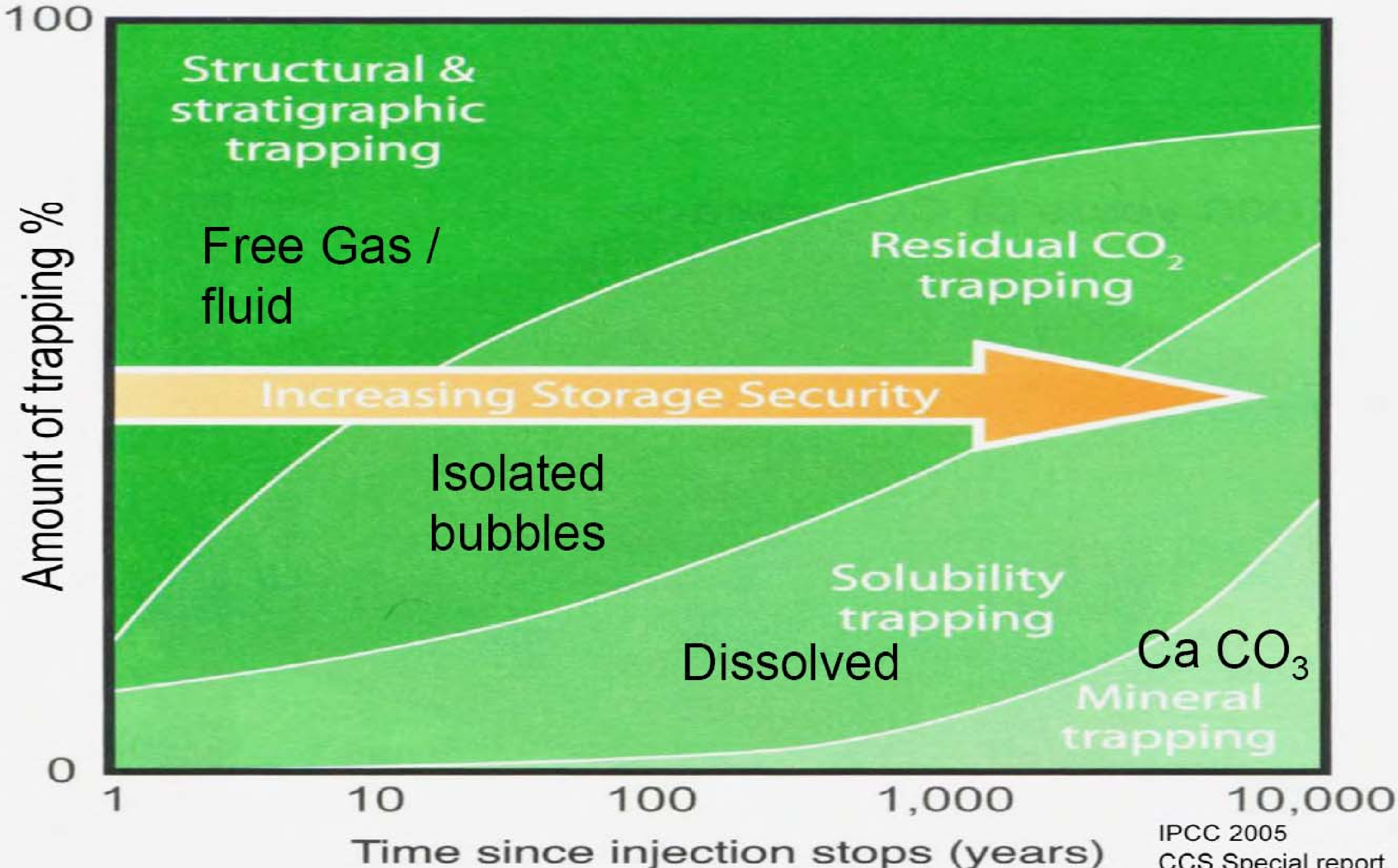
Natural analogue



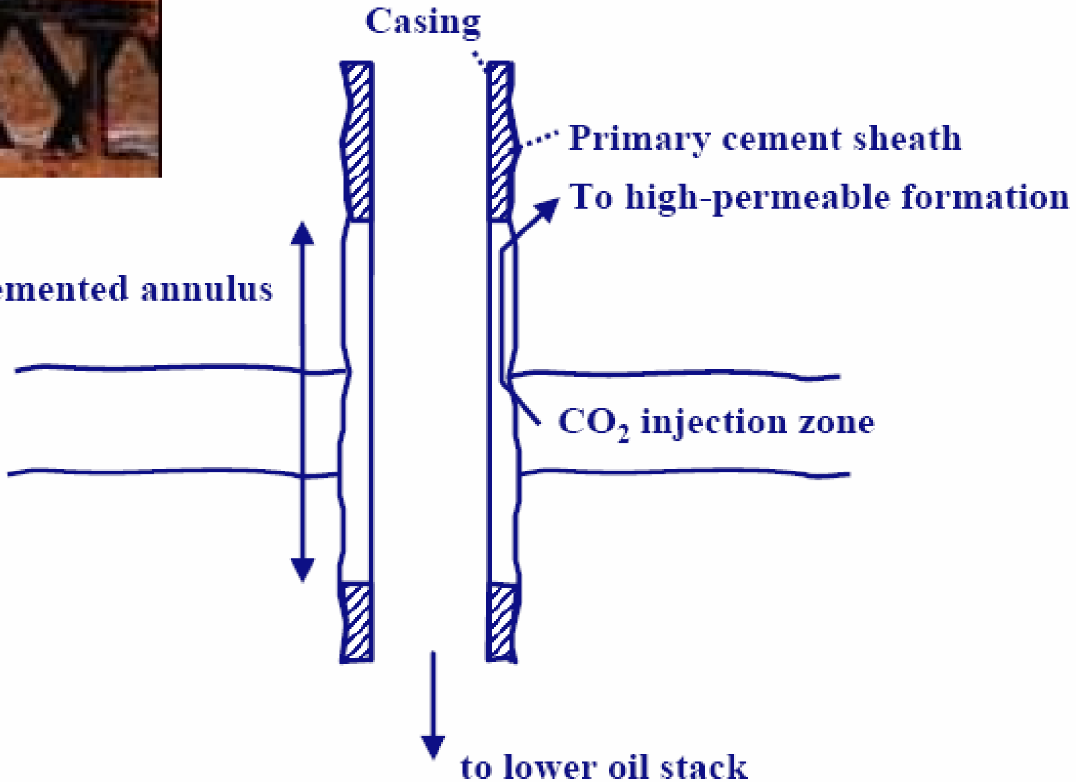
Graphic and photo: USGS

Humans (Healthy adults)	Below 3%	No adverse effects but increased breathing, mild headache and sweating
	4-5% for 'few minutes'	Headache, increased blood pressure and difficulty in breathing
	7-10% up to 1 hour	Headache, dizziness, sweating, rapid breathing and near or full unconsciousness
	15%+	Loss of consciousness in less than one minute. Narcosis, respiratory arrest, convulsions, coma and death
	30%	Death in few minutes
Terrestrial Invertebrates		
insect (Cryptolestes ferrugineus)	15%	Death after ~ 42 days
	100%	Death after ~2 days
soil invertibrates	20%	Majority of any one species have 'behavioural changes'
	11-50%	Lethal for 50% of species
Terrestrial Vertebrates	Rodents 2%	
	Gophers 4%	Observed in burrows and nests
	Birds 9%	
	Fish 1-6%	Significant stress
	Fish >2%	Can be lethal
Plants	>0.2%	Stimulation of C3 photosynthesis plants (includes temperate cereal crops such as wheat)
	>5%	Deleterious effects on plant health and yield.
	5-30%	Severe effects expected.
	>20%	Long-term exposure leads to dead zones with no macroscopic flora.
	>30%	Defined as a lethal concentration.
	20-90%	Trees killed at Mammoth Mountain, CA, USA, probably by suppression of root zone respiration via hypoxia
Fungi	15-20%	Significant inhibition of growth of spores for 2 types of fungi
	30%	No measurable growth of spores
	50%	No germination of spores
Subsurface microbes	None known	Increased concentrations (from injection) are likely to have profound effects as aerobic organisms will be inhibited but anaerobic organisms eg Fe (III) reducers, S reducing reducers and methanogens will respond to rock/water/carbon dioxide interactions and are likely to increase in population size and activity

Trapping types over time

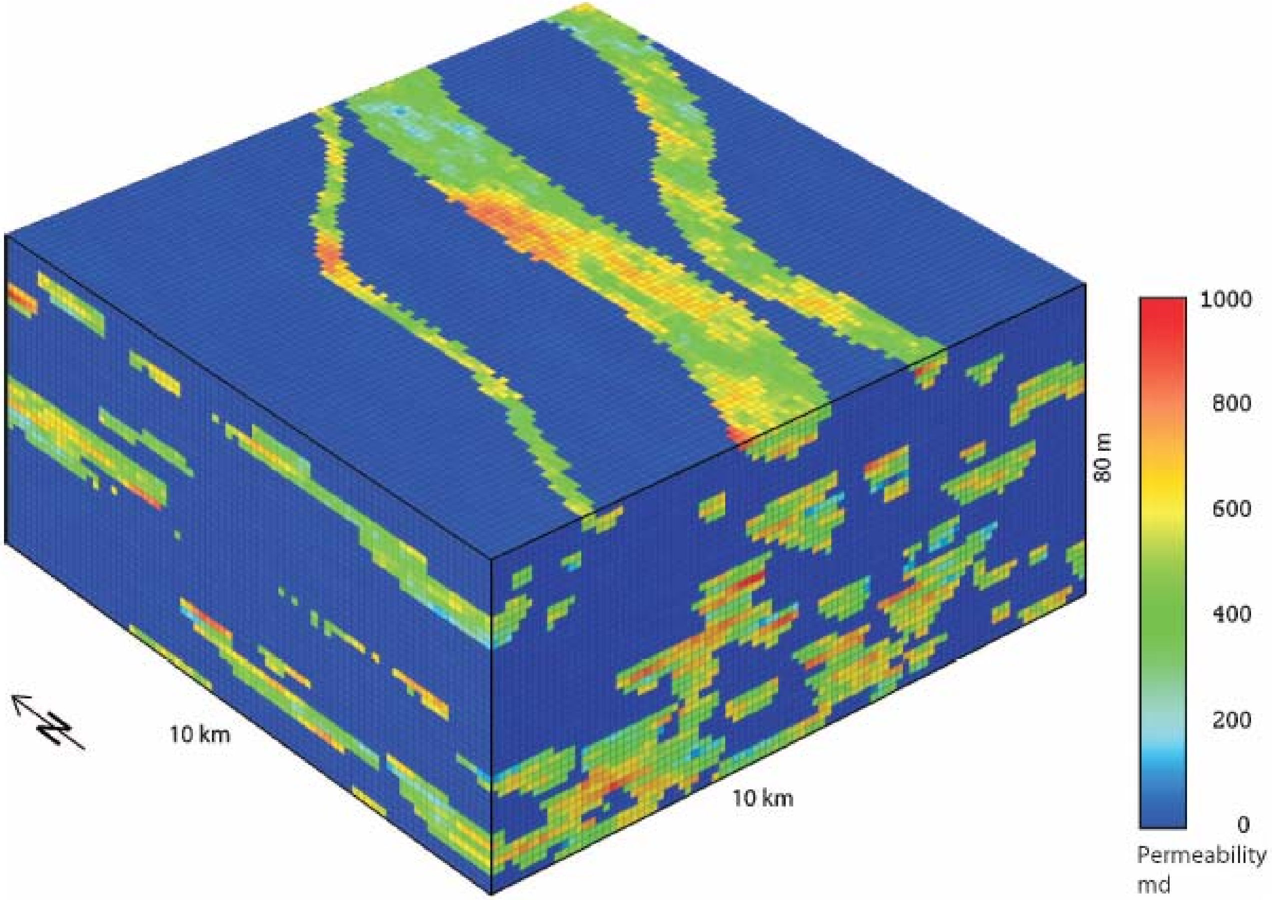


IPCC 2005
CCS Special report

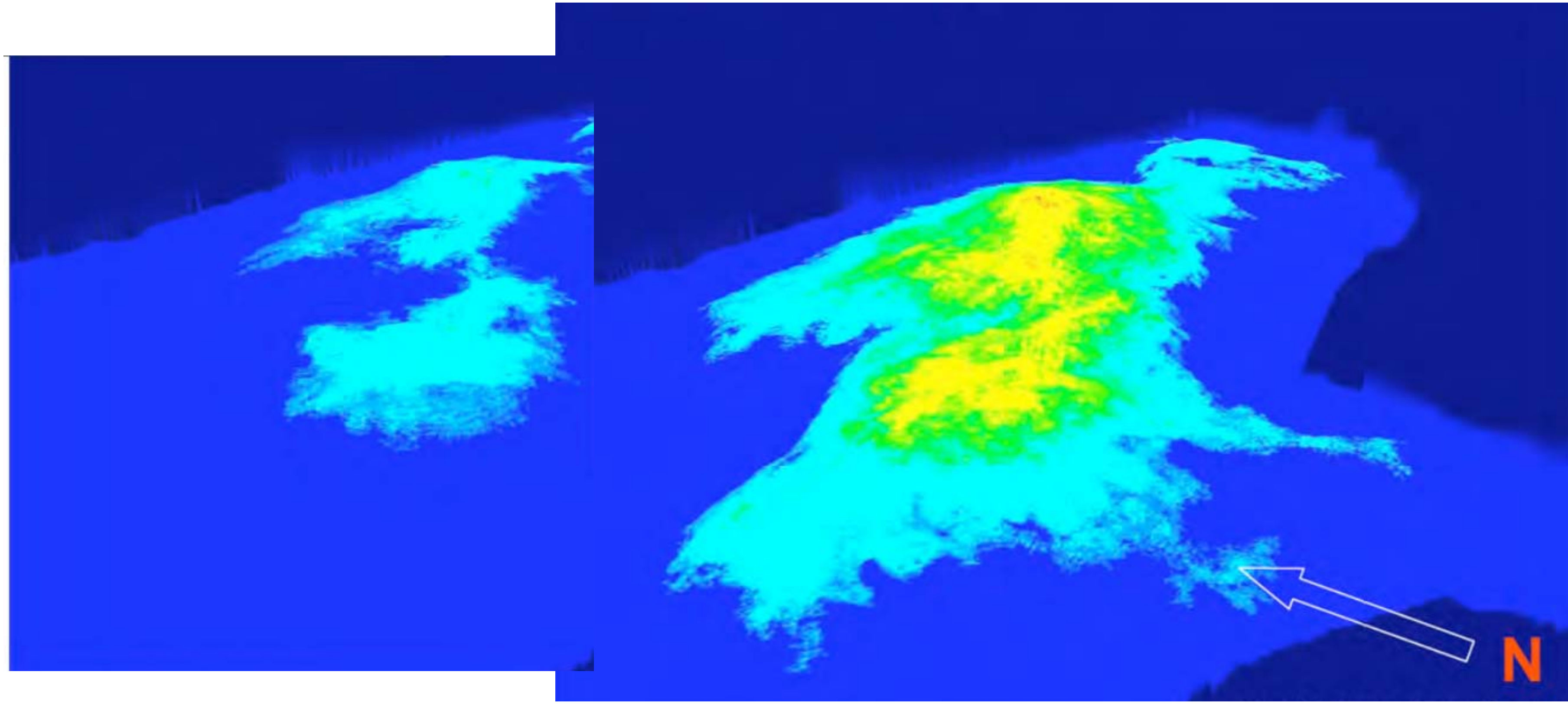


Casing
Primary cement sheath
To high-permeable formation
Uncemented annulus
CO_2 injection zone
to lower oil stack

Baseline characterisation



Numerical monitoring



Source: S. Haszeldine, U. Edinburgh

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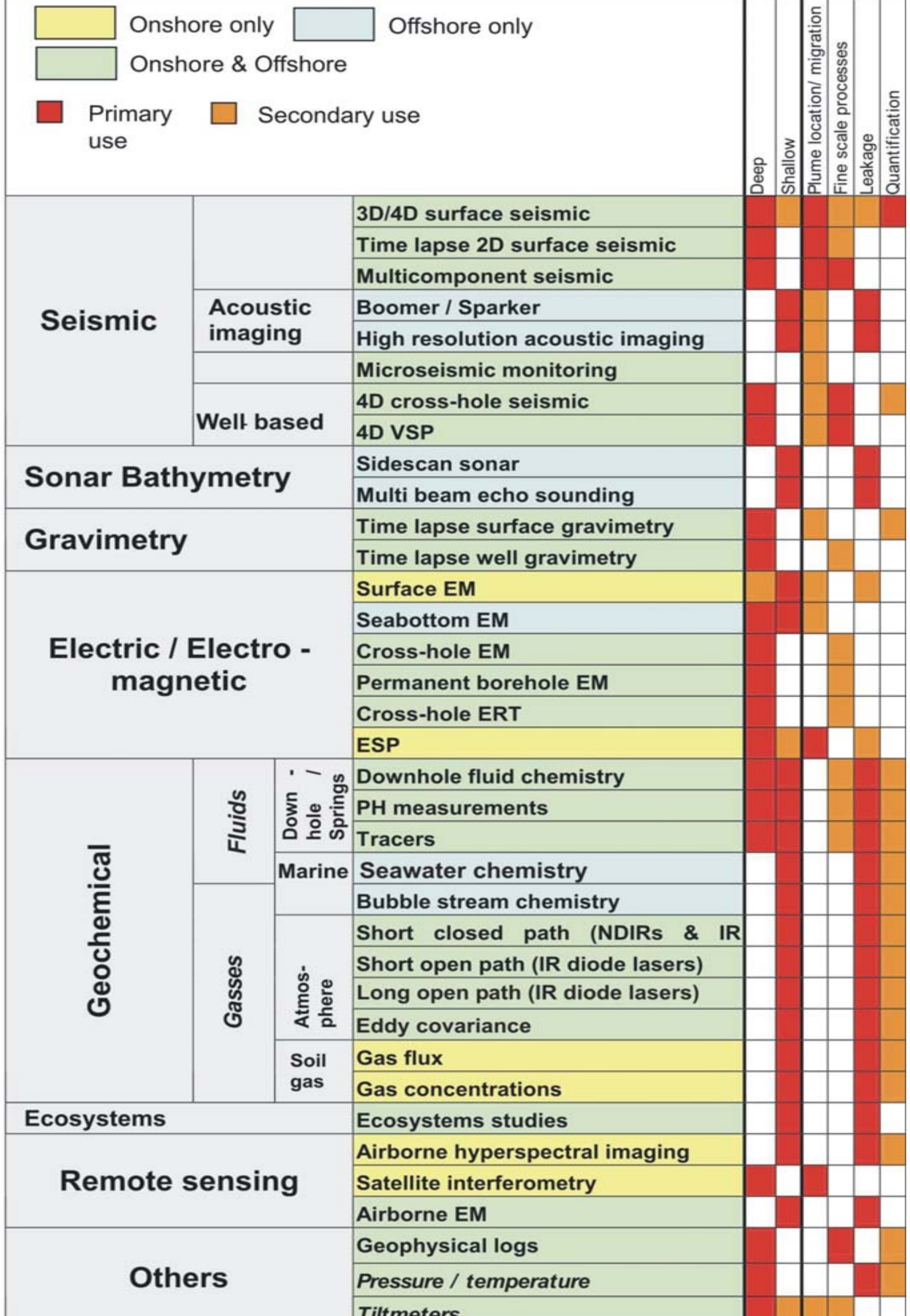
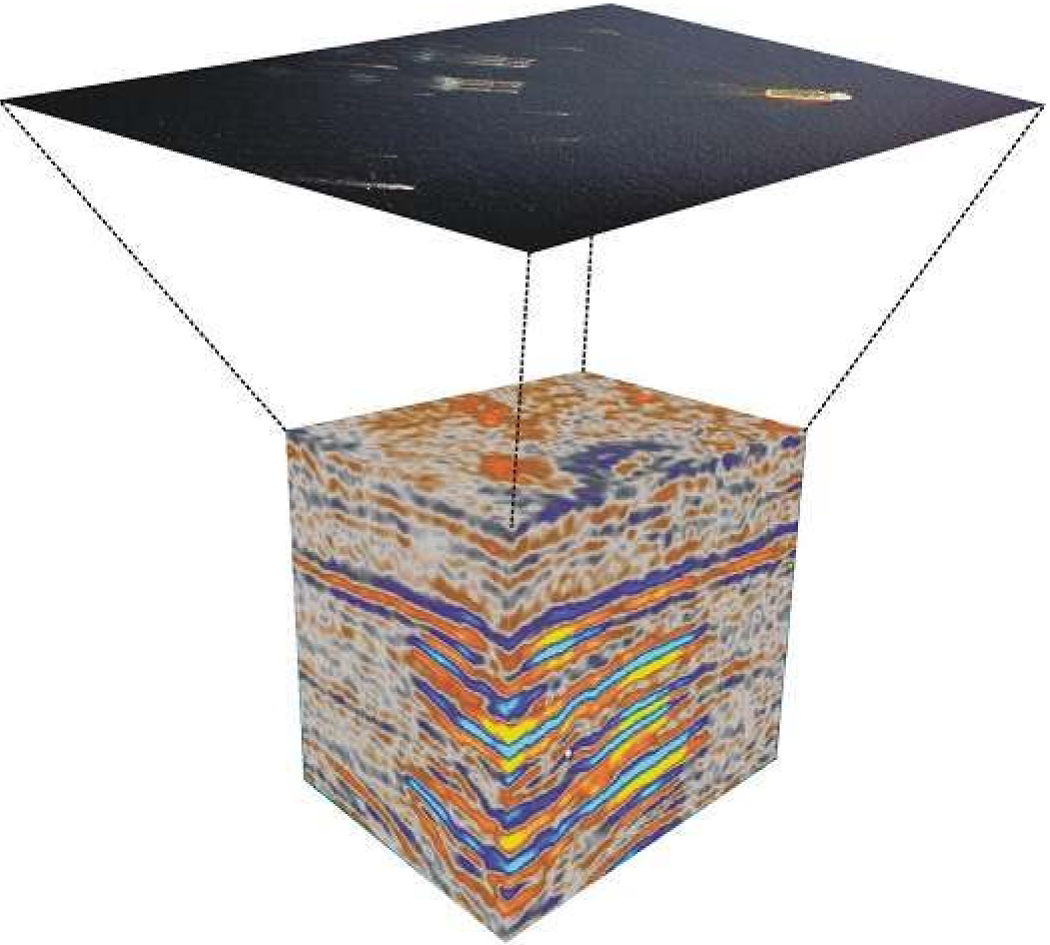
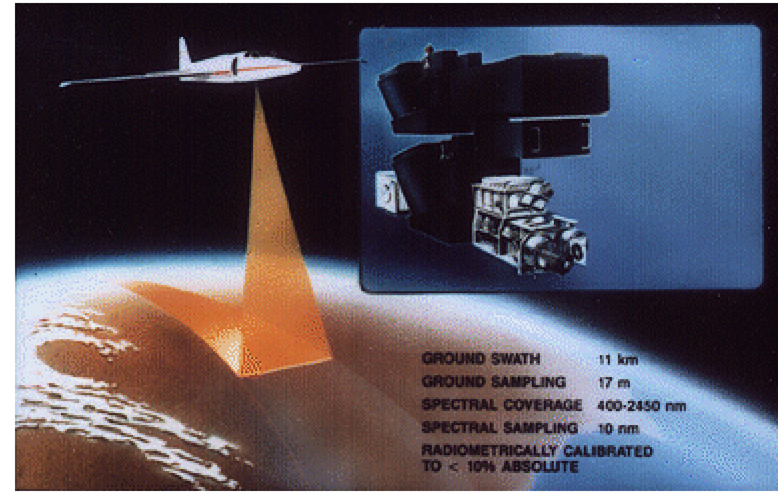
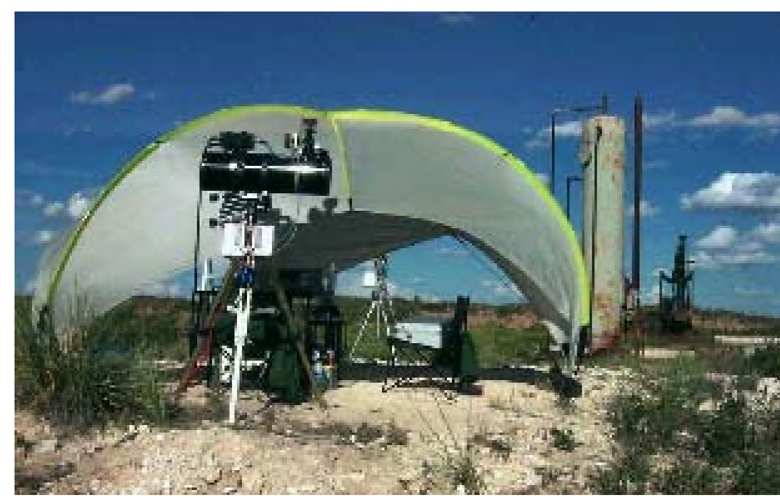
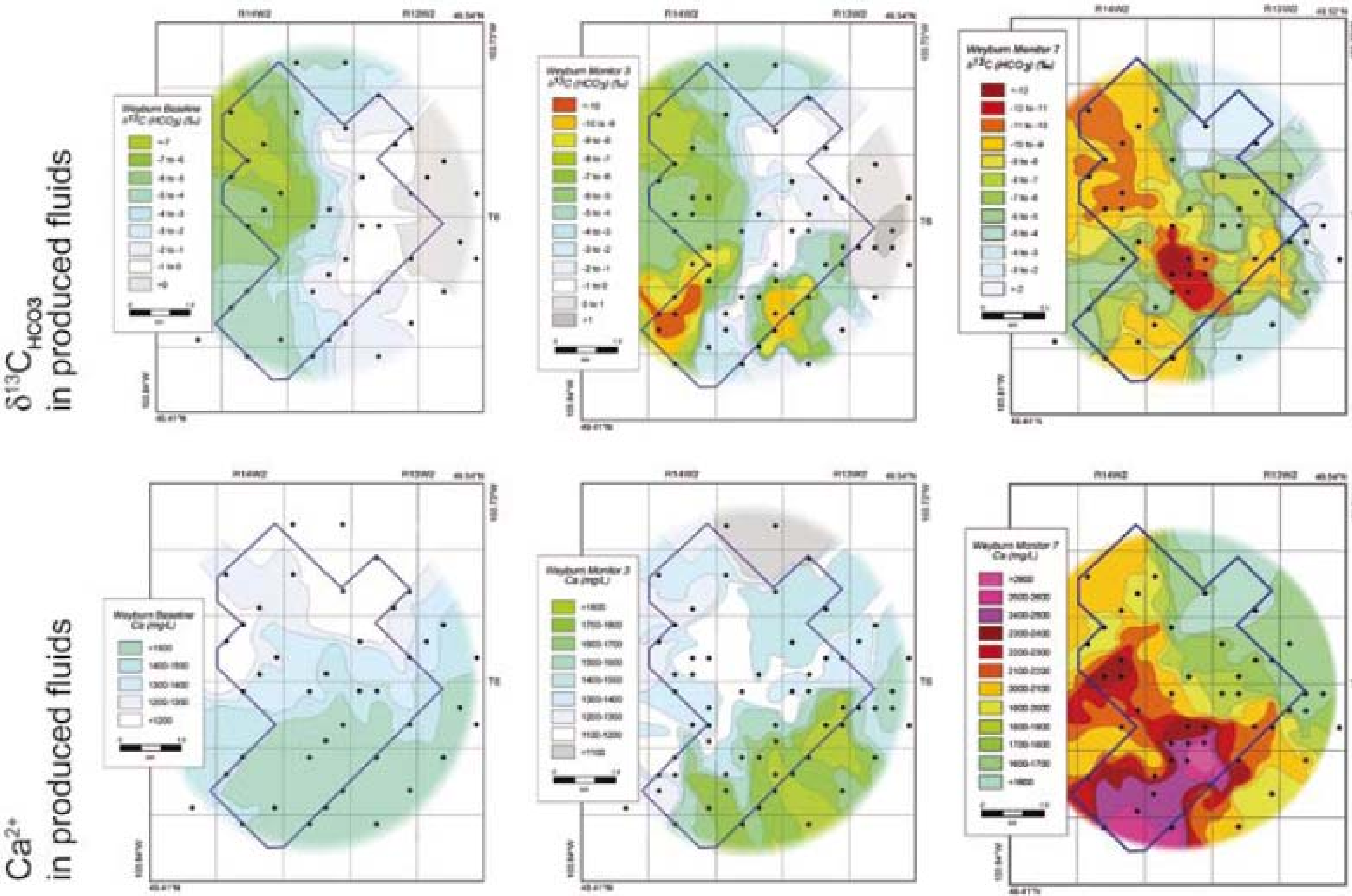


Onshore only
Offshore only
Onshore & Offshore
Primary use
Secondary use
Deep
Shallow
Plume location/ migration
Fine scale processes
Leakage
Quantification
Seismic
Acoustic imaging
Well based
3D/4D surface seismic
Time lapse 2D surface seismic
Multicomponent seismic
Boomer / Sparker
High resolution acoustic imaging
Microseismic monitoring
4D cross-hole seismic
4D VSP
Sonar Bathymetry
Sidescan sonar
Multi beam echo sounding
Gravimetry
Time lapse surface gravimetry
Time lapse well gravimetry
Electric / Electro - magnetic
Surface EM
Seabottom EM
Cross-hole EM
Permanent borehole EM
Cross-hole ERT
ESP
Geochemical
Fluids
Down - hole / Springs
Downhole fluid chemistry
PH measurements
Tracers
Marine
Seawater chemistry
Bubble stream chemistry
Gasses
Atmos- phere
Short closed path (NDIRs & IR
Short open path (IR diode lasers)
Long open path (IR diode lasers)
Eddy covariance
Soil gas
Gas flux
Gas concentrations
Ecosystems
Ecosystems studies
Remote sensing
Airborne hyperspectral imaging
Satellite interferometry
Airborne EM
Others
Geophysical logs
Pressure / temperature
Tiltmeters




GROUND SWATH 11 km
GROUND SAMPLING 17 m
SPECTRAL COVERAGE 400-2450 nm
SPECTRAL SAMPLING 10 nm
RADIOMETRICALLY CALIBRATED
TO < 10% ABSOLUTE





δ13C HCO3 in produced fluids
Ca2+ in produced fluids
Weyburn Baseline δ13C (HCO3) (‰)
Weyburn Monitor 3 δ13C (HCO3) (‰)
Weyburn Monitor 7 δ13C (HCO3) (‰)
Weyburn Baseline Ca (mg/L)
Weyburn Monitor 3 Ca (mg/L)
Weyburn Monitor 7 Ca (mg/L)
R14W2
R13W2
T6

Overview of issues

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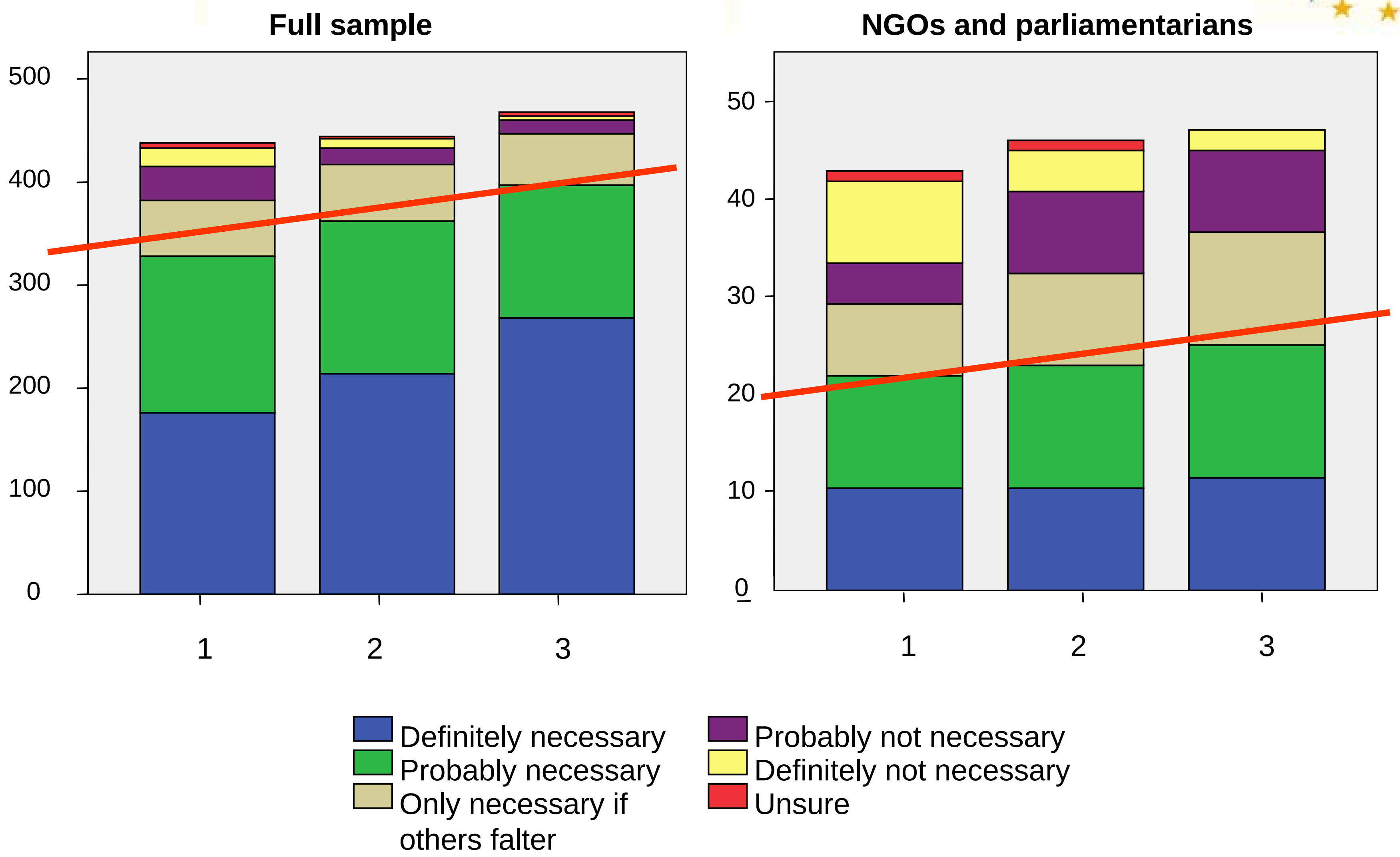
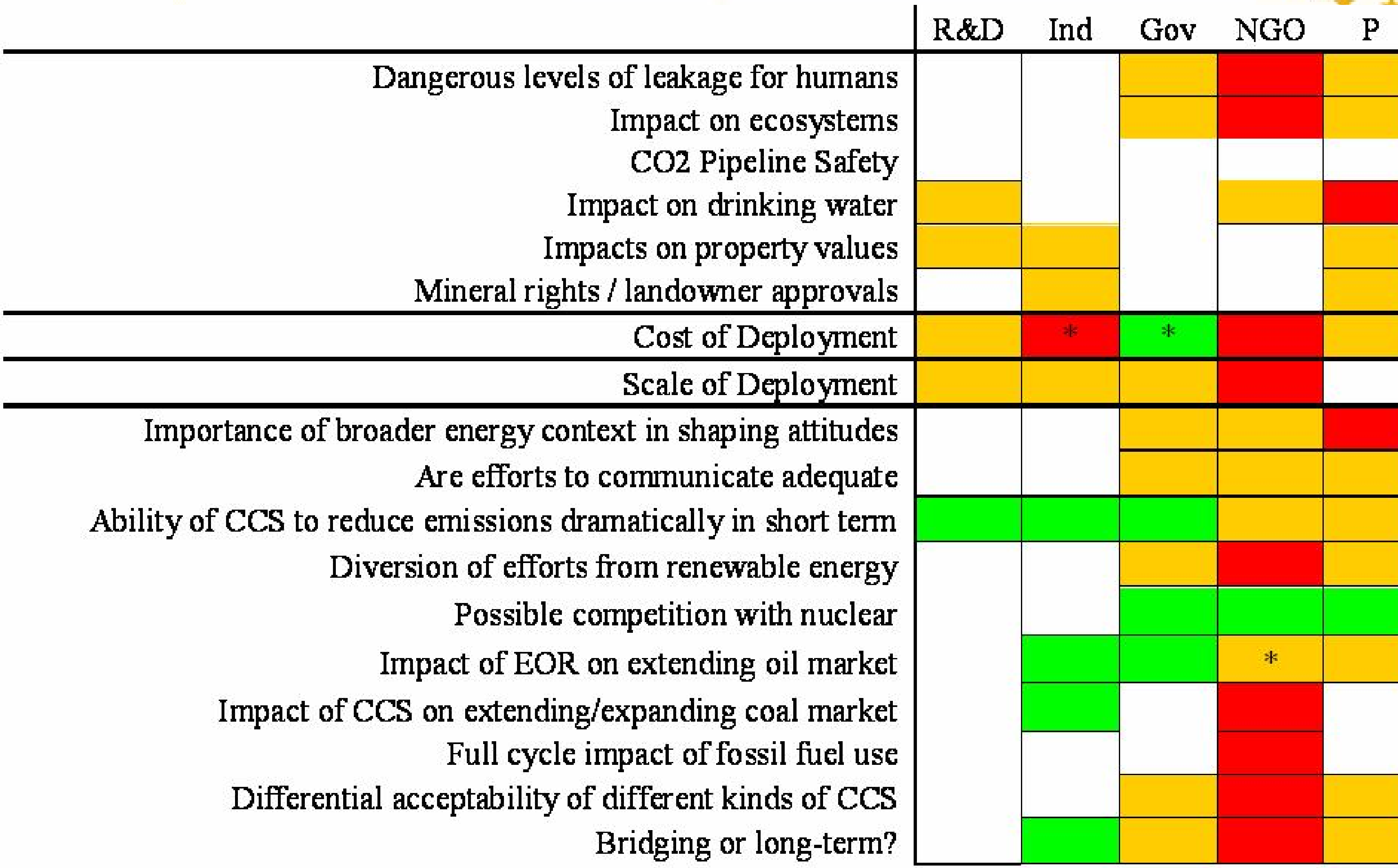
ACCSEPT survey:
Perceived need for CCS in own country (1), EU (2) and globally (3)



Prioritised stakeholder concerns



Source: IEEP

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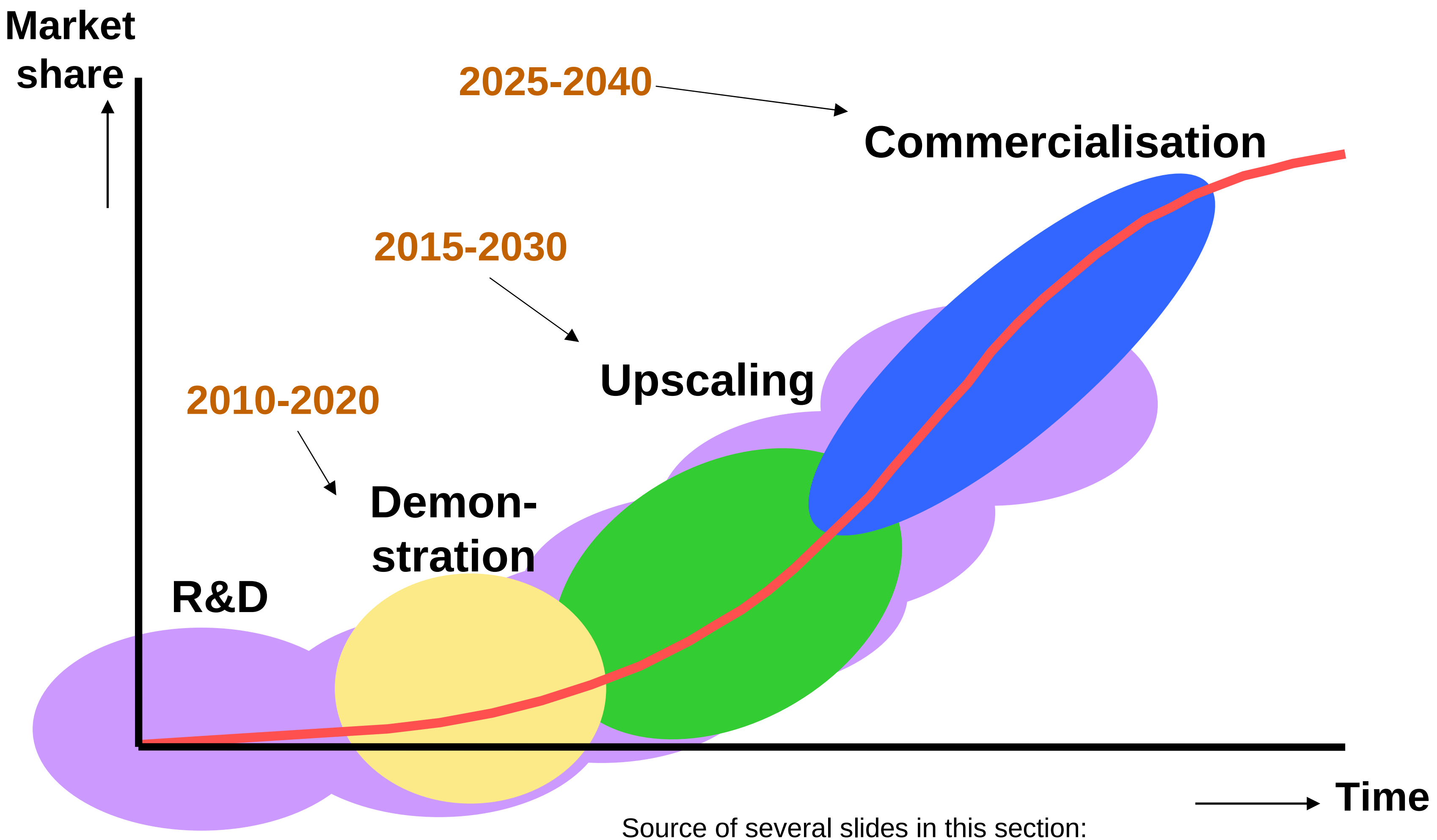
CCS deployment curve



Source of several slides in this section:
Heleen de Coninck, ECN

Current EU discussion

- Directive on CCS proposed by the Commission, under consideration by Parliament now
- Regulates approaches to risk assessment, licensing
- Includes CCS in emissions trading

→Doesn't do anything about commitment to demonstration plants

→Doesn't ensure CCS is part of a defined end to coal pollution

EU Emissions Trading Scheme

- The basic option already on the table
- Cost-effective instrument, if strong incentive given
- However, if EUA prices remain low:
  - Preference for low-cost abatement options
  - Innovation market failure
  - ETS unlikely to lead to CCS deployment

→ Need for complementary policies

Complementary policies

- Public financial support (most likely MS level)
  - Investment support
  - Feed-in subsidies
  - CO_2 price guarantee
- Low-carbon portfolio standard with tradable certificates (most likely EU level)
- CCS obligation (EU level)

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Our view…

- Don't allow CCS to be promoted as hype – it should either contribute or get out of the way. The failure of CCS is entirely likely if not forced in; the failure of low carbon alternatives is entirely likely if CCS is not forced out – it is currently as much a delaying tactic as a solution.
- If it is to be an option you can't sit on the fence: make it prove itself by devoting public funding (which leverages private money).
- Subject demonstrations to defined timetables and goals.
- Create required emissions standards or mandatory CCS rather than leaving it to the ETS market alone – price uncertainty and future political will are too uncertain.
- A requirement will make alternatives to CCS even more attractive because the counterfactual probably isn't solar energy but coal pollution.

Thank you

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IEEP is a not-for-profit institute dedicated to the analysis, understanding and promotion of policies for a sustainable environment in Europe

Extras slides follow

Uncertainties in Risk Assessment

Benchmarking exercise where 7 organizations using own methods and tools made independent risk assessment of the same Chemical Installation.

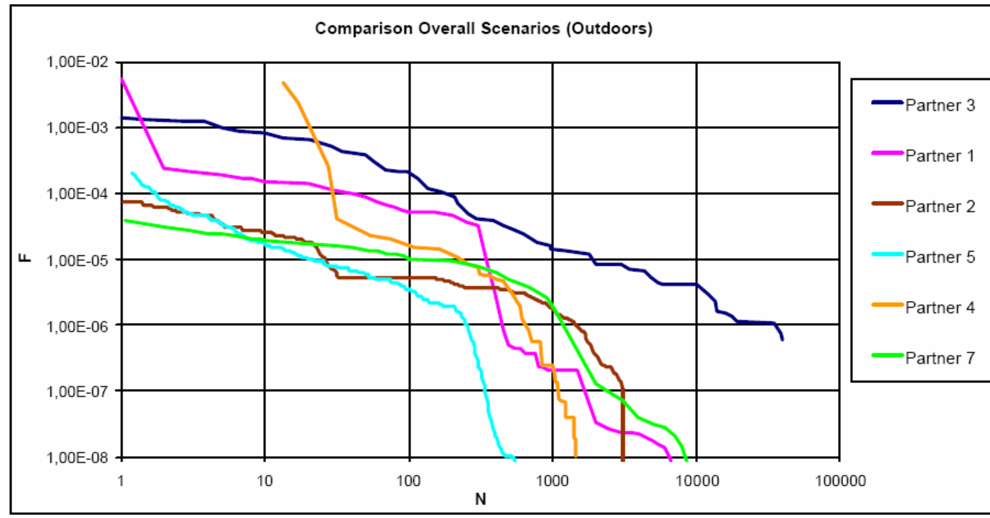


Figure 2. Discrepancy in societal risk calculations (based on fictitious population data)

Variations in individual societal risk calculations (based on fictitious population data).

Variations in individual safety distance calculations: Maximum and minimum distances for the isorisk curve 10-5 yr-1.

Source: Det Norske Veritas (DNV)

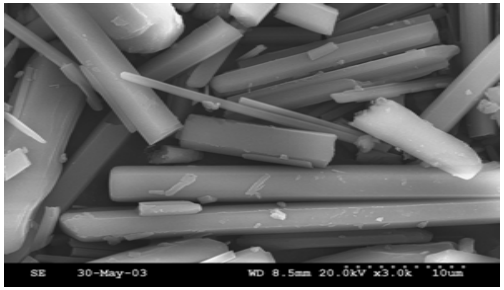
Mineral Carbonation

Mineral Carbonation – the chemical fixation of CO_2 in minerals to form geologically stable mineral carbonates

(1) Olivine

(2) Serpentine

+ CO_2 →



		△G
(1)	$Mg_2SiO_4 + 2CO_2 \rightarrow 2MgCO_3 + SiO_2$	-209 kJ/mol
(2)	$Mg_3Si_2O_5(OH)_4 + 3CO_2 \rightarrow 3MgCO_3 + 2SiO_2 + 2H_2O$	-67 kJ/mol

Characteristics

- Thermodynamically favored
- Mimic natural weathering
- Slow reaction kinetics

Which is appropriate when?

	Demonstration 2010-2020	Up-scaling 2015-2030	Commercialisation 2025-2040
ETS (weak)	Yes	Yes	Yes
ETS (strong)	Yes	Yes	Yes
Investment support	Yes	No	No
Feed-in subsidy	Yes	Yes	No
CO_2 price guarantee	Yes	Yes	No
Portfolio + certificates	No	Yes	Yes
Obligation	No	Yes	Yes

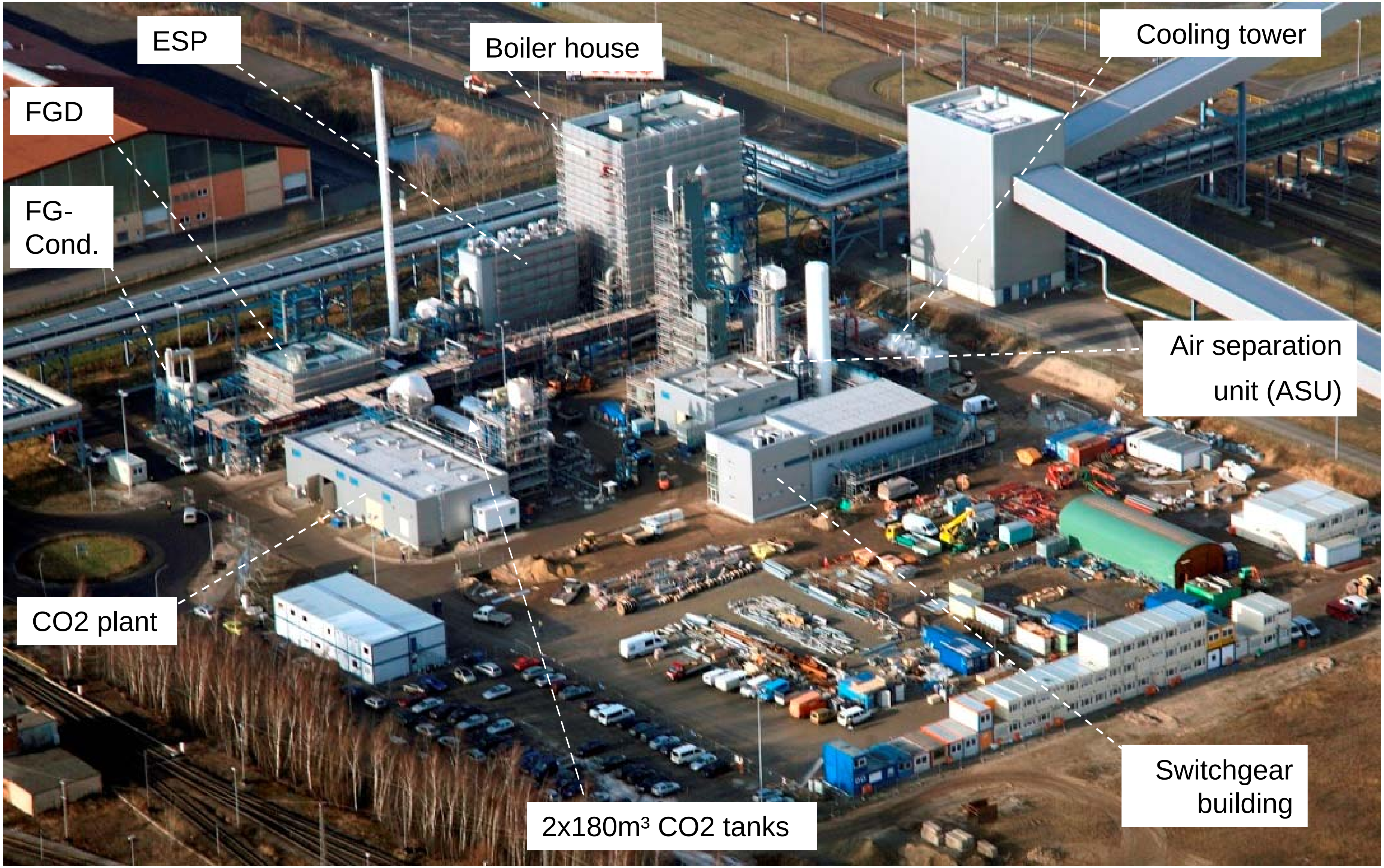
Multicriteria analysis

	Effectiveness	Risk + cost burden	Consistency	Feasibility
ETS (low price)	-	0	+	+
ETS (high price)	+	+	+	+/-
Investment support	+	-	0	-
Feed-in subsidy	+	-	0	-
CO_2 price guarantee	+	-	0	-
Portfolio + certificates	+	+	0/-	+/-
Obligation	+	+	0/-	+

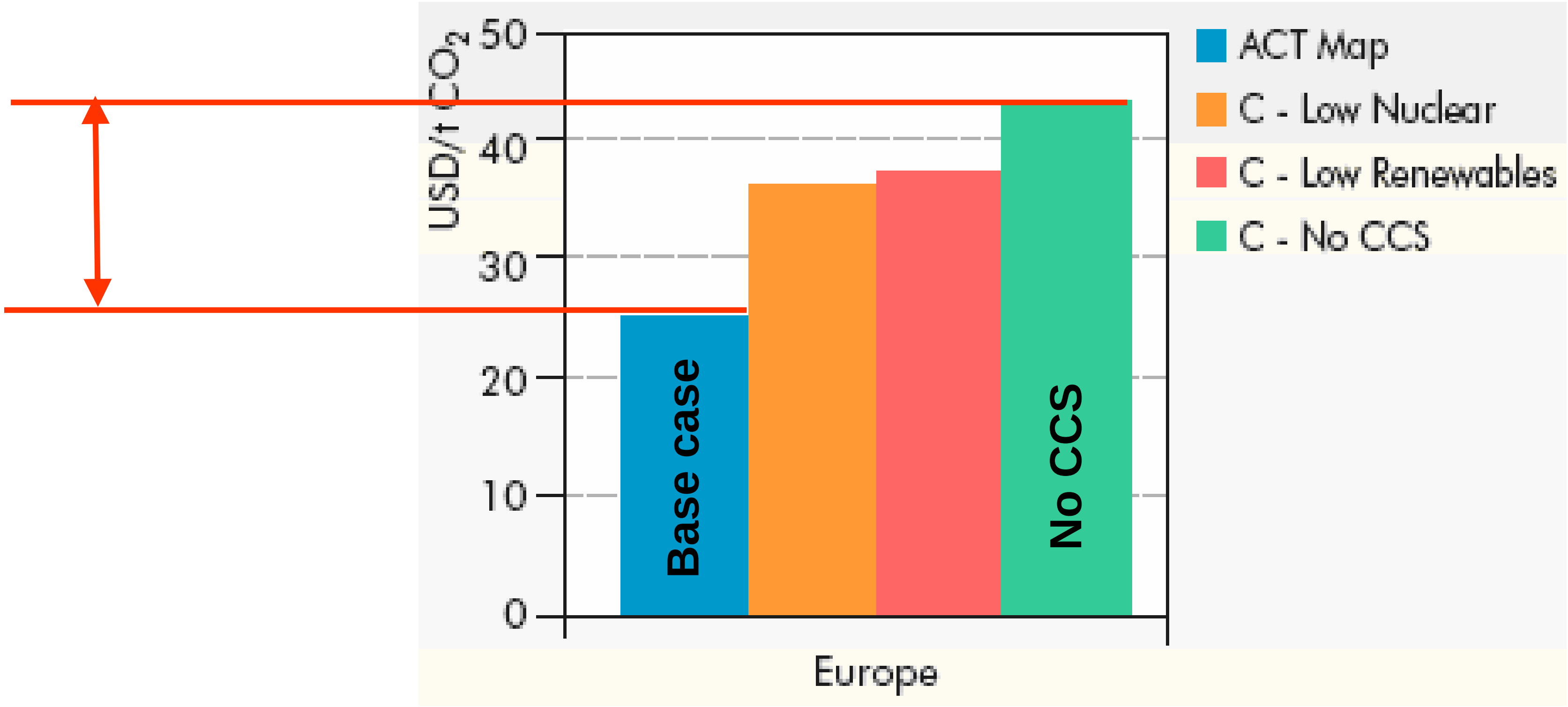
Main message on support

- Current approach is to use the ETS as an incentive – IA shows that a strong price signal is the best across the board
- However, a weak price signal is not as effective as a mandatory requirement
- Question: do we run the risk of relying on the creation of a strong price signal?
- In either case, need to push early movement:
  - ETS only post-2012
  - A future mandate runs the risk of industry doing insufficient development and forcing a push-back on the requirement later.

Oxyfuel pilot plant at Schwarze Pumpe



CCS modelled to reduce costs

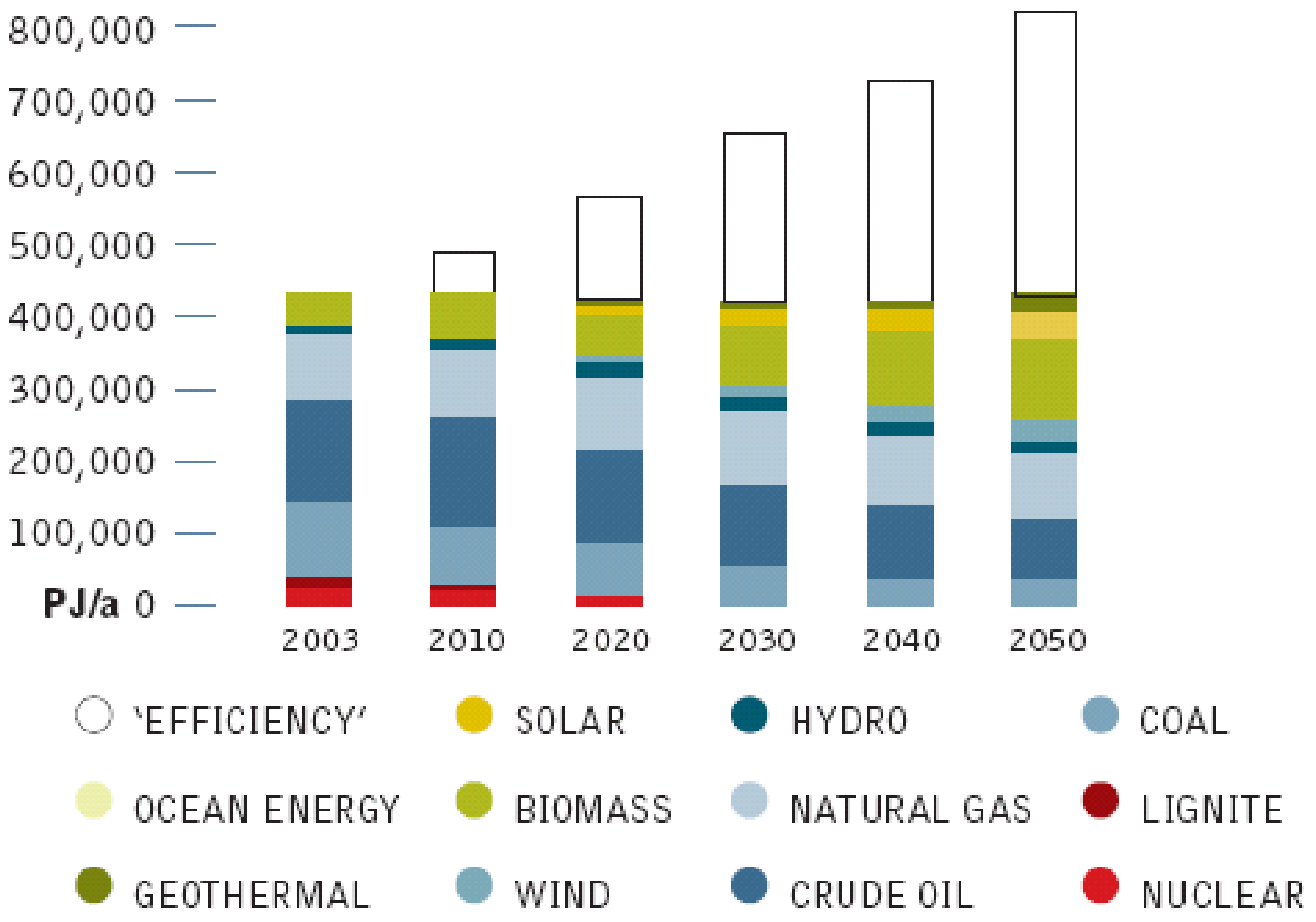


IEA 2006

Shares of CO_2 emission reductions in 2050 by contributing factor (%)						
Scenarios	Map	Low Nuclear	Low Renewables	No CCS	Low Efficiency	TECH Plus
Fossil fuel mix in power generation	5.1	4.6	5.2	5.9	6.7	5.3
Fossil fuel generation efficiency	0.8	0.9	1.0	2.9	1.4	0.7
Nuclear	6.0	1.9	6.8	10.3	7.3	7.2
Hydropower	1.6	1.6	0.1	2.1	1.4	1.2
Biomass power generation	1.7	1.8	0.3	2.6	2.1	1.5
Other renewables power generation	6.1	6.6	4.5	11.3	7.2	7.2
CCS power generation	12.4	14.3	14.3	0.0	17.9	11.7
CCS coal-to-liquids	3.3	3.4	3.3	0.0	4.2	4.6
CCS industry	4.6	4.7	4.7	0.0	5.5	3.9
Fuel mix buildings and industry	7.7	7.5	7.4	5.5	9.6	7.3
Increased use of biofuels in transport	5.6	5.8	5.7	6.4	6.0	6.2
Hydrogen and fuel cells in transport	0.0	0.0	0.0	0.0	0.0	4.1
End-use efficiency	45.2	46.9	46.6	53.1	30.7	39.2
Total	**100**	**100**	**100**	**100**	**100**	**100**

IEA Energy technology perspectives, 2006

No CCS, no nuclear

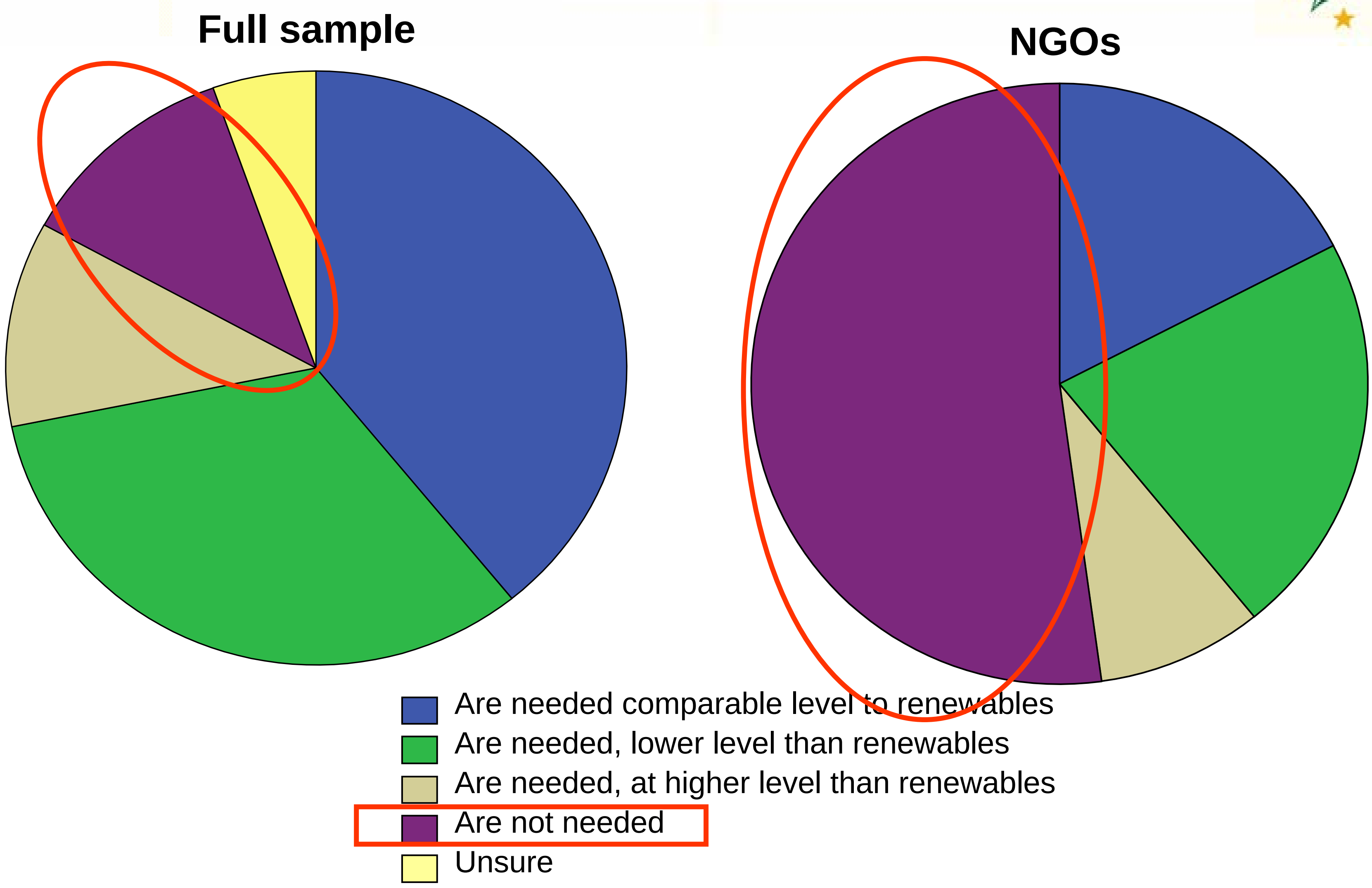


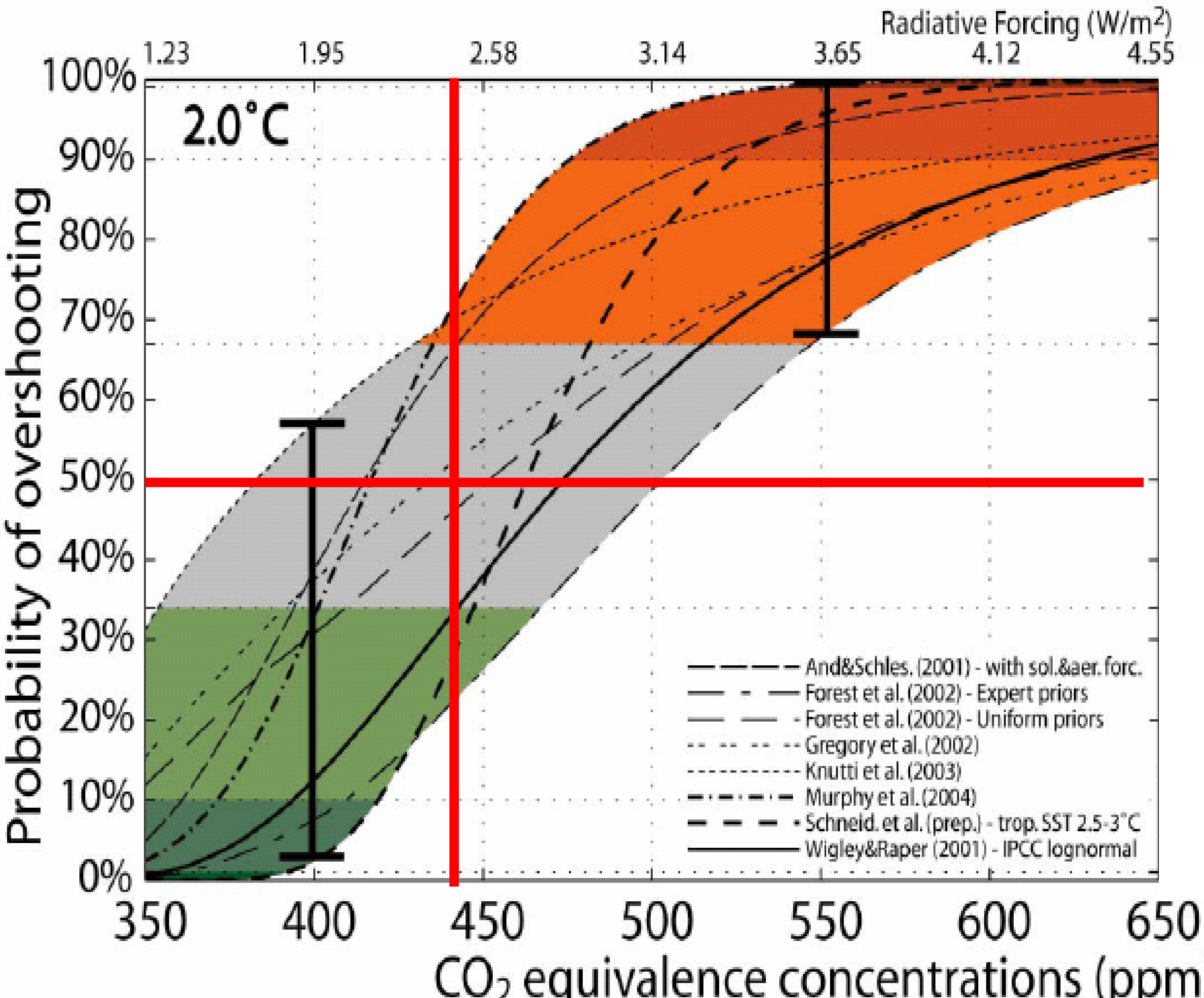
Greenpeace energy [R}evolution, 2007

Is CCS safe?

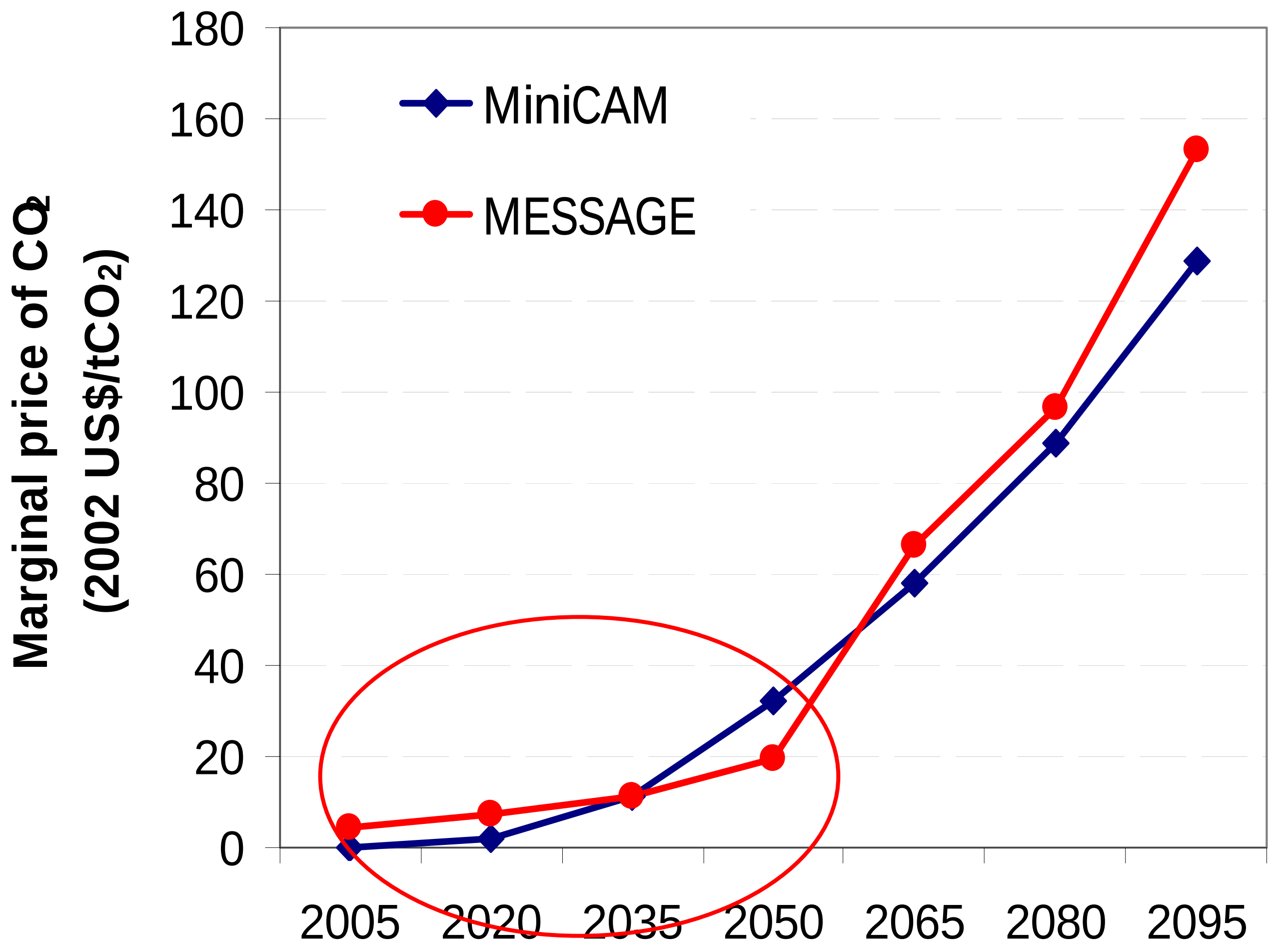
- Short answer: probably
  - *Technically*: likely to be well within industry capabilities to control leakage.
  - *Main possible problem:* management failures, poor decision making.
- Compared to what?
  - Current coal emissions already a killer
  - Power industry, natural gas transport and storage are good analogues
- How can we prove it?
  - Experience with CO_2 to date, natural analogues, natural gas
  - An element of uncertainty remains with storage
  - A barrier towards the public: communicating risk

Survey: financial incentives for CCS





Radiative Forcing (W/m2)
1.23
1.95
2.58
3.14
3.65
4.12
4.55
2.0°C
Probability of overshooting
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
350
400
450
500
550
600
650
CO2 equivalence concentrations (ppm)
And&Schles. (2001) - with sol.&aer. forc.
Forest et al. (2002) - Expert priors
Forest et al. (2002) - Uniform priors
Gregory et al. (2002)
Knutti et al. (2003)
Murphy et al. (2004)
Schneid. et al. (prep.) - trop. SST 2.5-3°C
Wigley&Raper (2001) - IPCC lognormal



Marginal price of CO_2
(2002 US$/t$CO_2$)
MiniCAM
MESSAGE
180
160
140
120
100
80
60
40
20
0
2005
2020
2035
2050
2065
2080
2095

Is CCS acceptable?

- To most stakeholders it is, although often as a second-best necessity
- Everyone is concerned about costs – they must show signs of being manageable
- Risk perception is as yet not fully formed and needs to be carefully managed
- Projects on the ground may mobilise new interest groups