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Introduction to CO_2 Capture Process

Dr. Jia Li

Sanya, China
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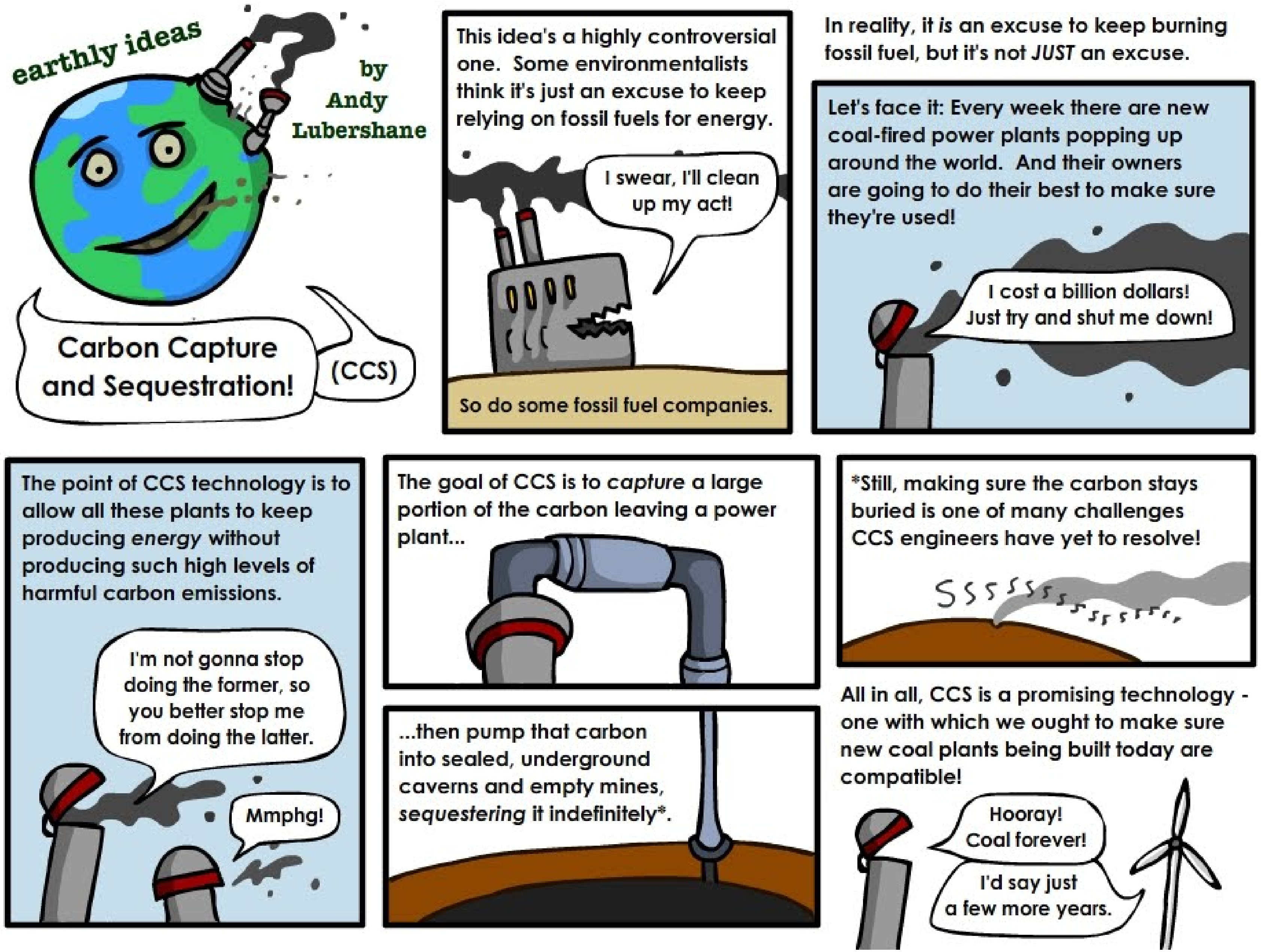
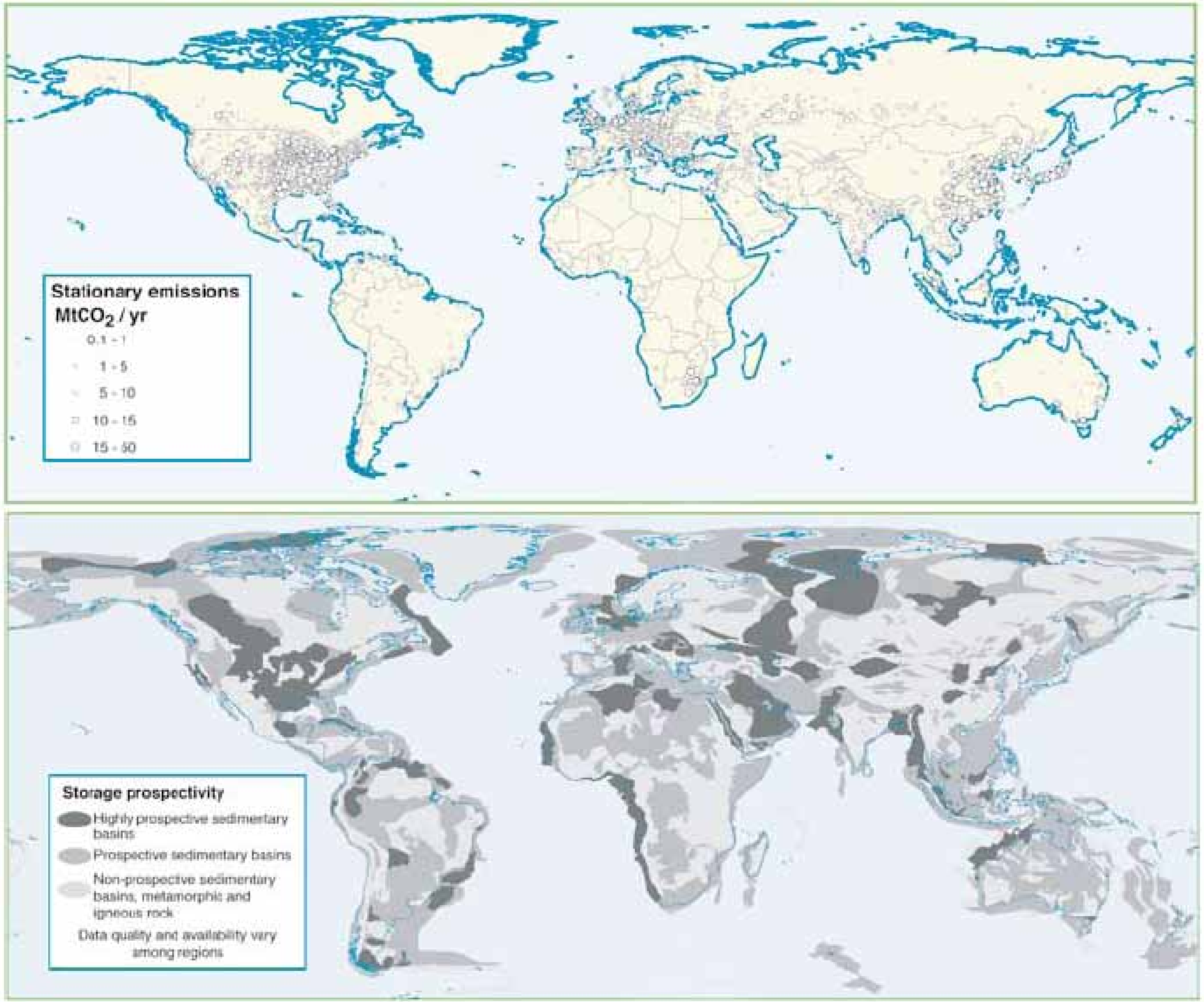
Outline

- Introduction to Carbon Capture and Storage
- Capture Systems
- CO_2 Capture Ready



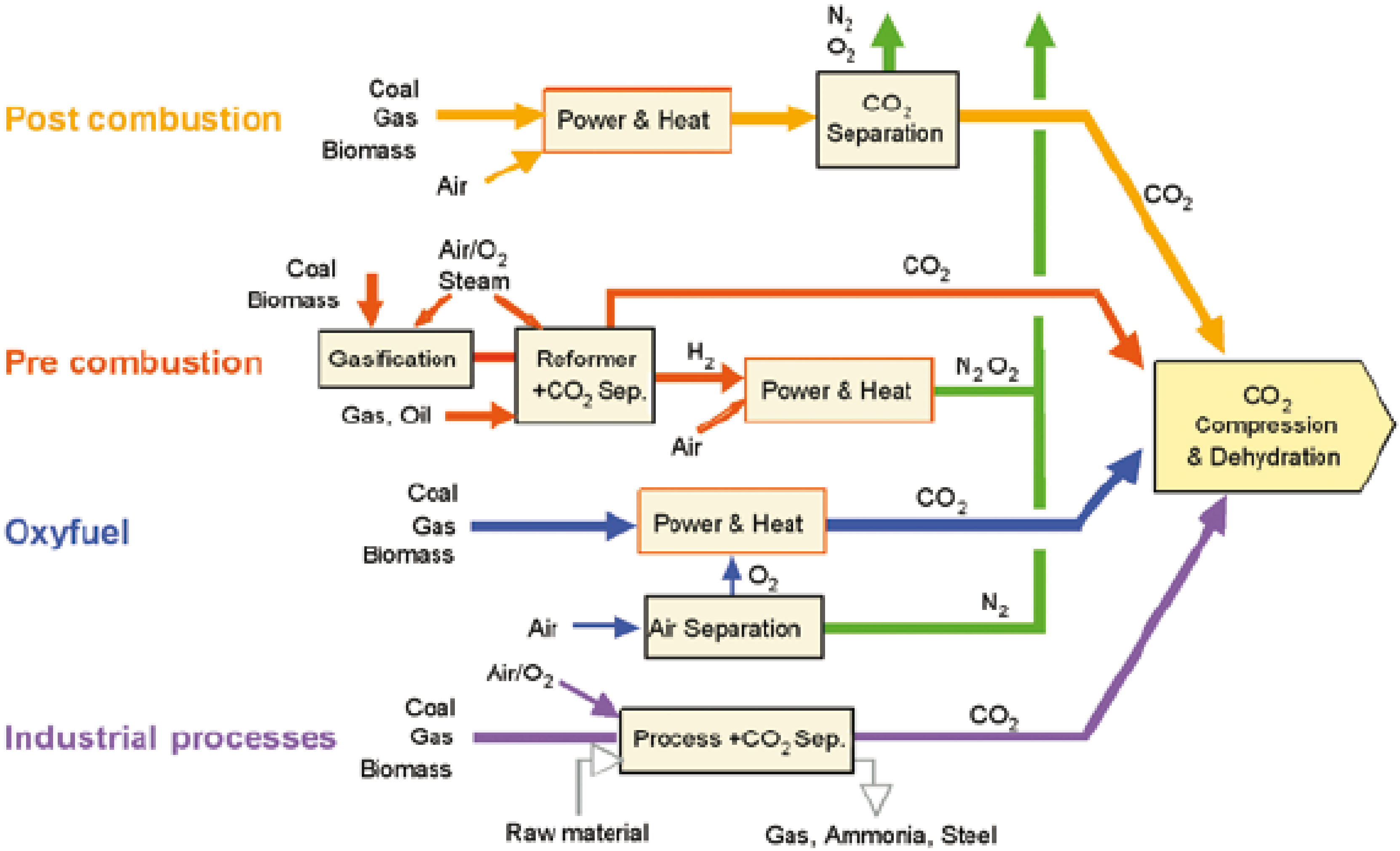
Source: WorldPress.com

CO_2 Stationary Sources and Potential Storage Site



Source: IPCC CCS Special Report, Technical Summary: pp24

Overview of CO_2 Capture Processes and Systems



Source: IPCC CCS Special Report, Technical Summary: pp26

Candidate Gas Stream for CO_2 Capture

Source	CO_2 concentration % vol (dry)	Pressure of gas stream MPa[a]	CO_2 partial pressure MPa
CO_2 from fuel combustion			
• Power station flue gas:			
Natural gas fired boilers	7 - 10	0.1	0.007 - 0.010
Gas turbines	3 - 4	0.1	0.003 - 0.004
Oil fired boilers	11 - 13	0.1	0.011 - 0.013
Coal fired boilers	12 - 14	0.1	0.012 - 0.014
IGCC[b]: after combustion	12 - 14	0.1	0.012 - 0.014
• Oil refinery and petrochemical plant fired heaters	8	0.1	0.008
CO_2 from chemical transformations + fuel combustion			
• Blast furnace gas:			
Before combustion[c]	20	0.2 - 0.3	0.040 - 0.060
After combustion	27	0.1	0.027
• Cement kiln off-gas	14 - 33	0.1	0.014 - 0.033
CO_2 from chemical transformations before combustion			
• IGCC: synthesis gas after gasification	8 - 20	2 - 7	0.16 - 1.4

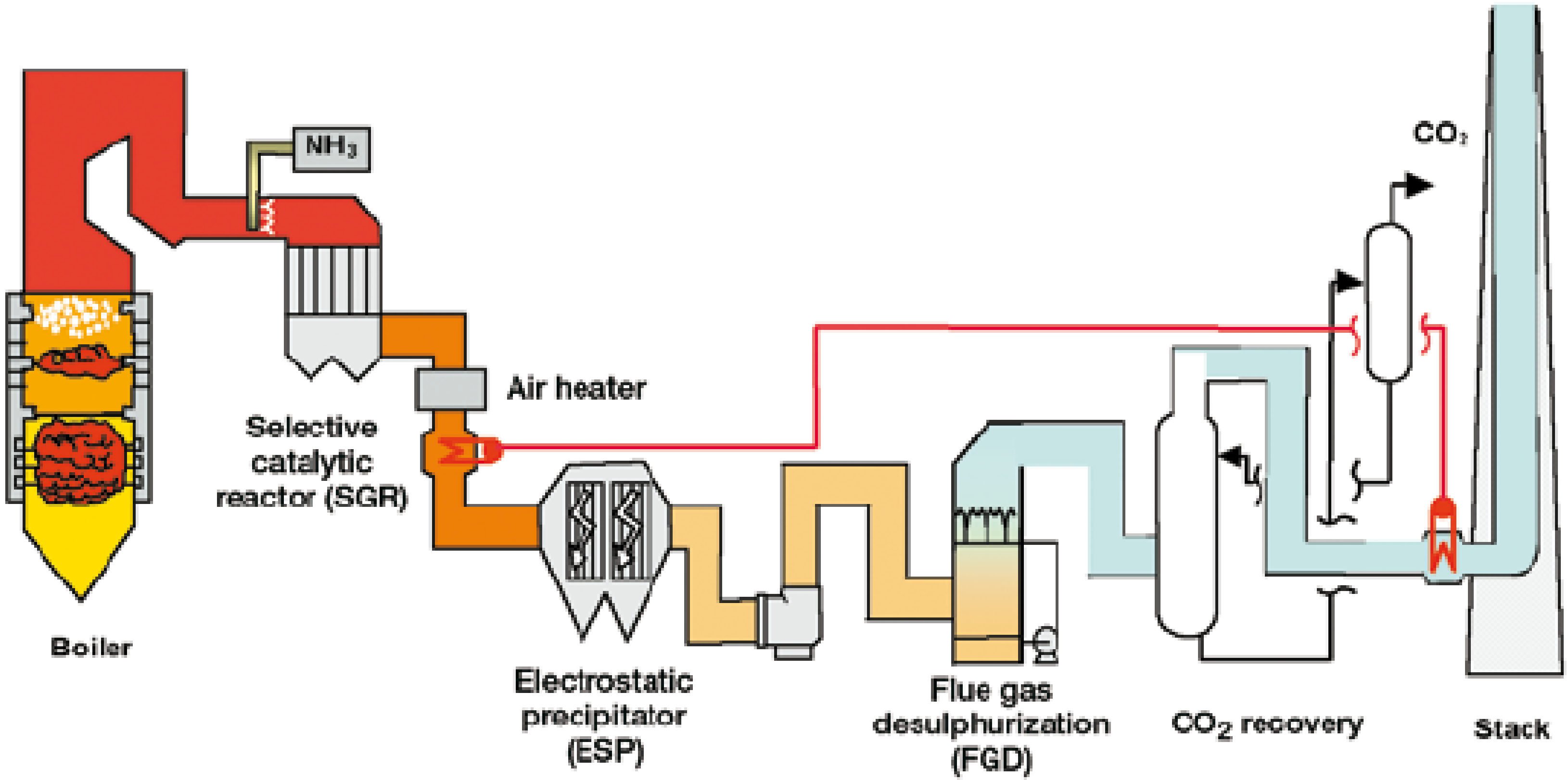
[a] 0.1 MPa = 1 bar.

[b] IGCC: Integrated gasification combined cycle.

[c] Blast furnace gas also contains significant amounts of carbon monoxide that could be converted to CO_2 using the so-called shift reaction.

Source: IPCC CCS Special Report: pp79

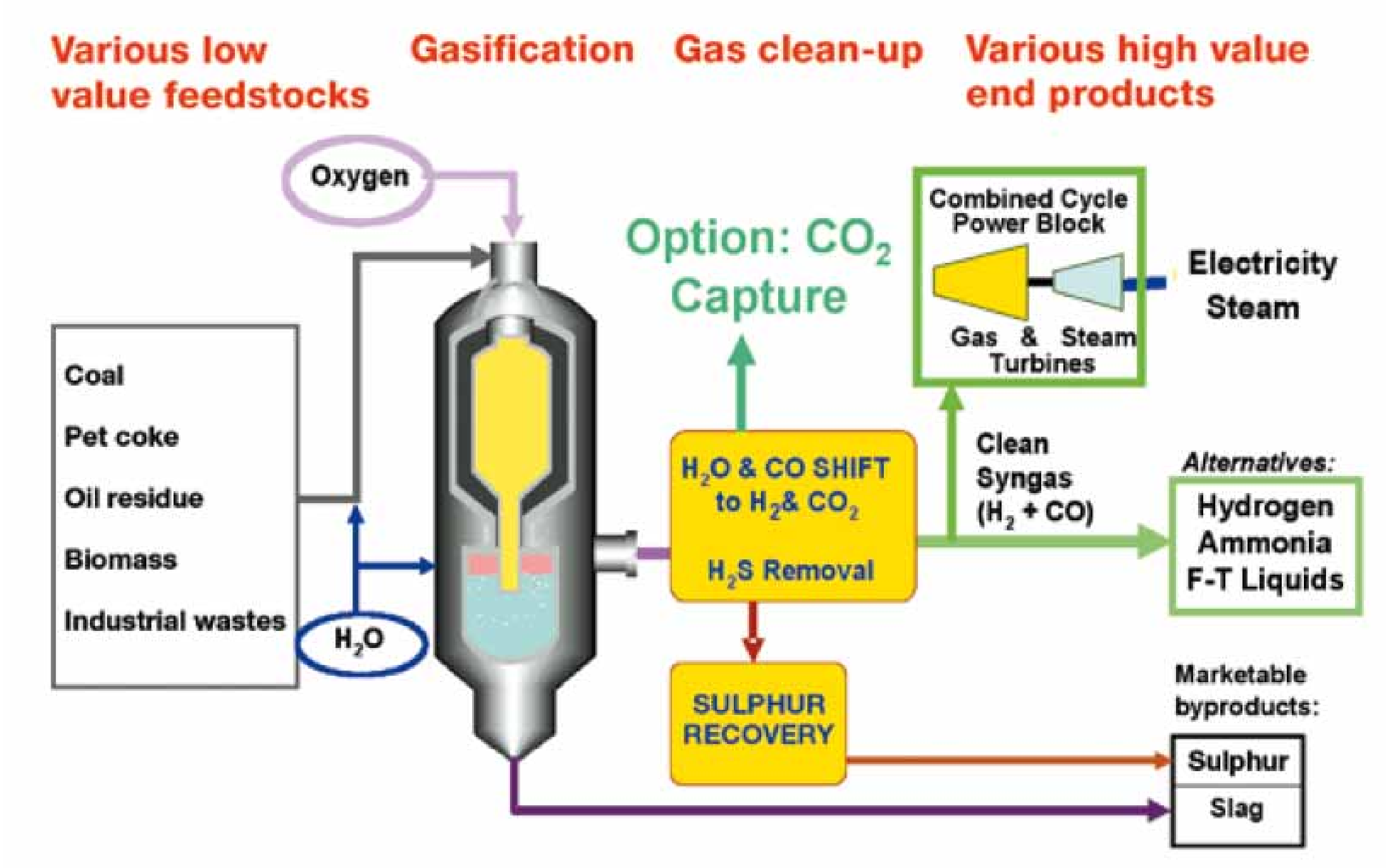
Amine-based Capture System at Pulversied Coal-fired Power Plant



- In post-combustion capture system, CO_2 captured from flue gases produced by combustion of fossil fuels and biomass

Source: IPCC CCS Special Report: pp114

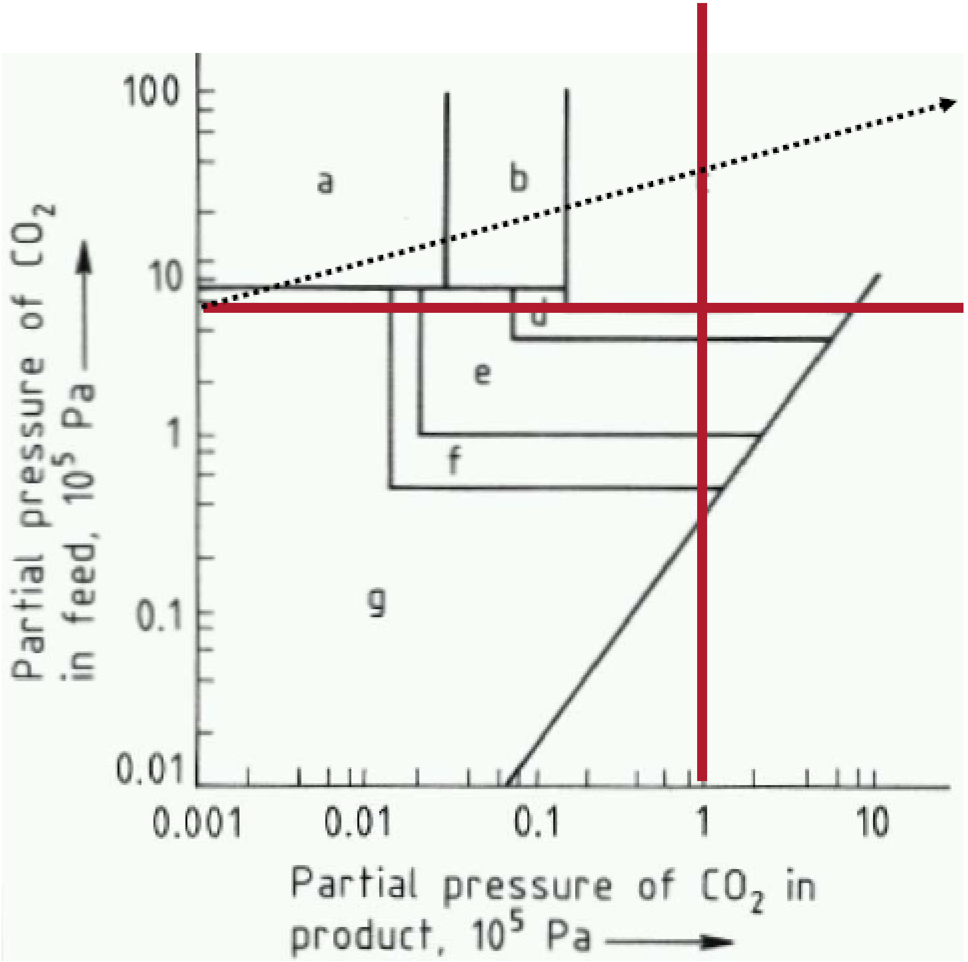
Conventional Pre-combustion CO_2 Capture



- Pre-combustion capture involves reacting a fuel with oxygen or air and/or steam to give mainly a ‘synthesis gas (syngas)’ or fuel gas’ composed of carbon monoxide and hydrogen.
- Hydrogen rich gas at lower temperature before entering gas turbine

Source: ECN

Choosing Absorption Methods for Pre-combustion Capture



Trade-off at P_{CO2} ~ 5 bara between solvent loading/recirculation (lean vs. rich) and equipment sizing

Selection of suitable CO_2 absorption process:

a) Physical solvent + amine

b) Physical solvent, physical solvent + amine or activated hot K_2CO_3

c) Physical solvent

d) Physical solvent or activated hot K_2CO_3

e) Activated hot K_2CO_3 or concentrated amine

f) Activated hot K_2CO_3 or amine

g) Amine

Source: ECN

Common solvents for CO_2 Removal at pre-combustion Capture Process

Solvent name	Type	Chemical name	Vendors
Rectisol	Physical	Methanol	Lurgi and Linde, Germany Lotepro Corporation, USA
Purisol	Physical	N-methyl-2-pyrolidone (NMP)	Lurgi, Germany
Selexol	Physical	Dimethyl ethers of polyethylene glycol (DMPEG)	Union Carbide, USA
Benfield	Chemical	Potassium carbonate	UOP
MEA	Chemical	Monoethanolamine	Various
MDEA	Chemical	Methyldiethylamine	BASF and others
Sulfinol	Chemical	Tetrahydrothiophene 1,1-dioxide (Sulfolane), an alkaloamine and water	Shell

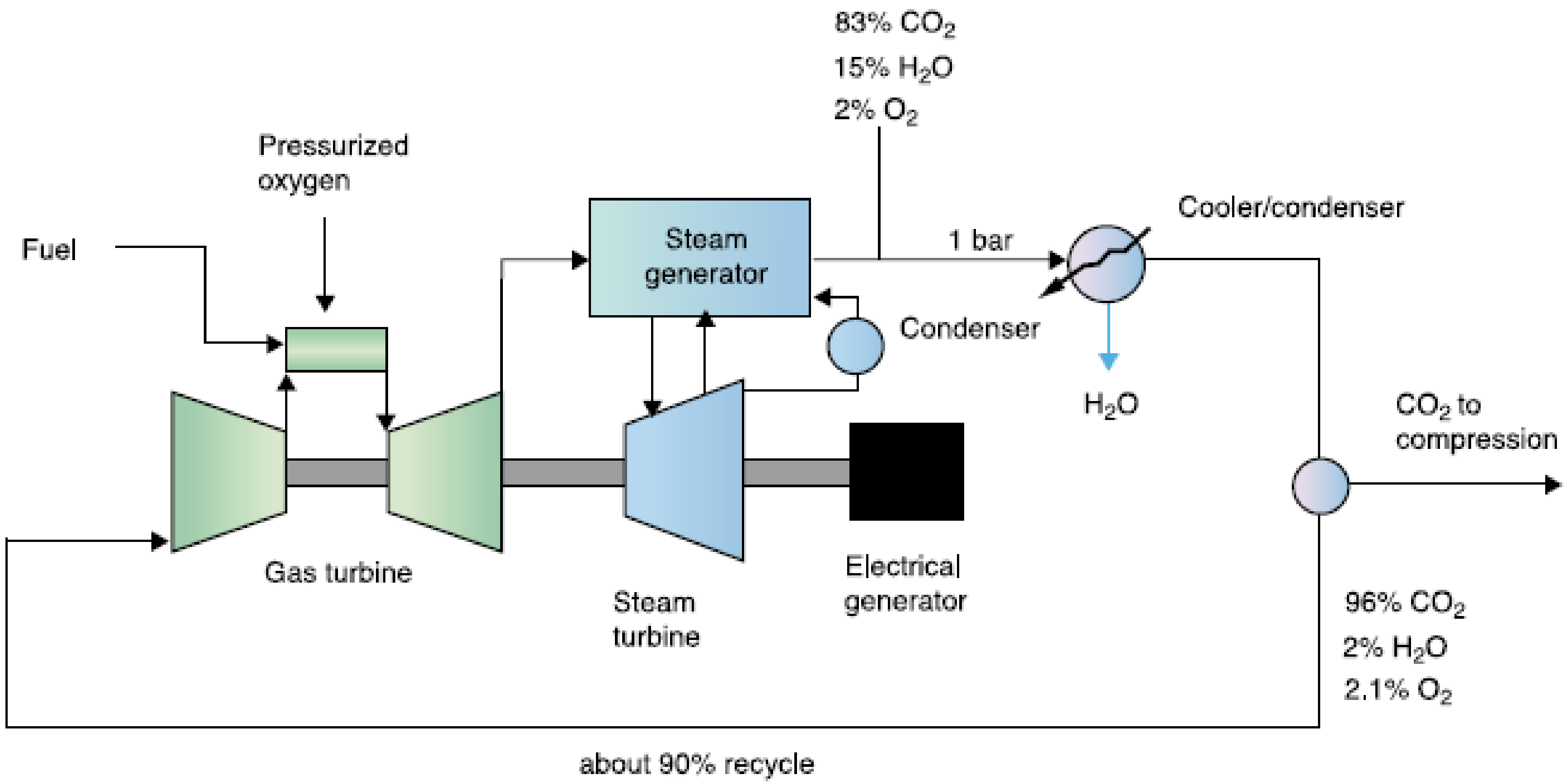
- Low partial CO_2 pressure: chemical solvents,

  e.g. MEA, MDEA

- High partial CO_2 pressure: physical solvents,

  e.g. Rectisol, Selexol

Principle of Oxy-fuel Gas Turbine Combined Cycle



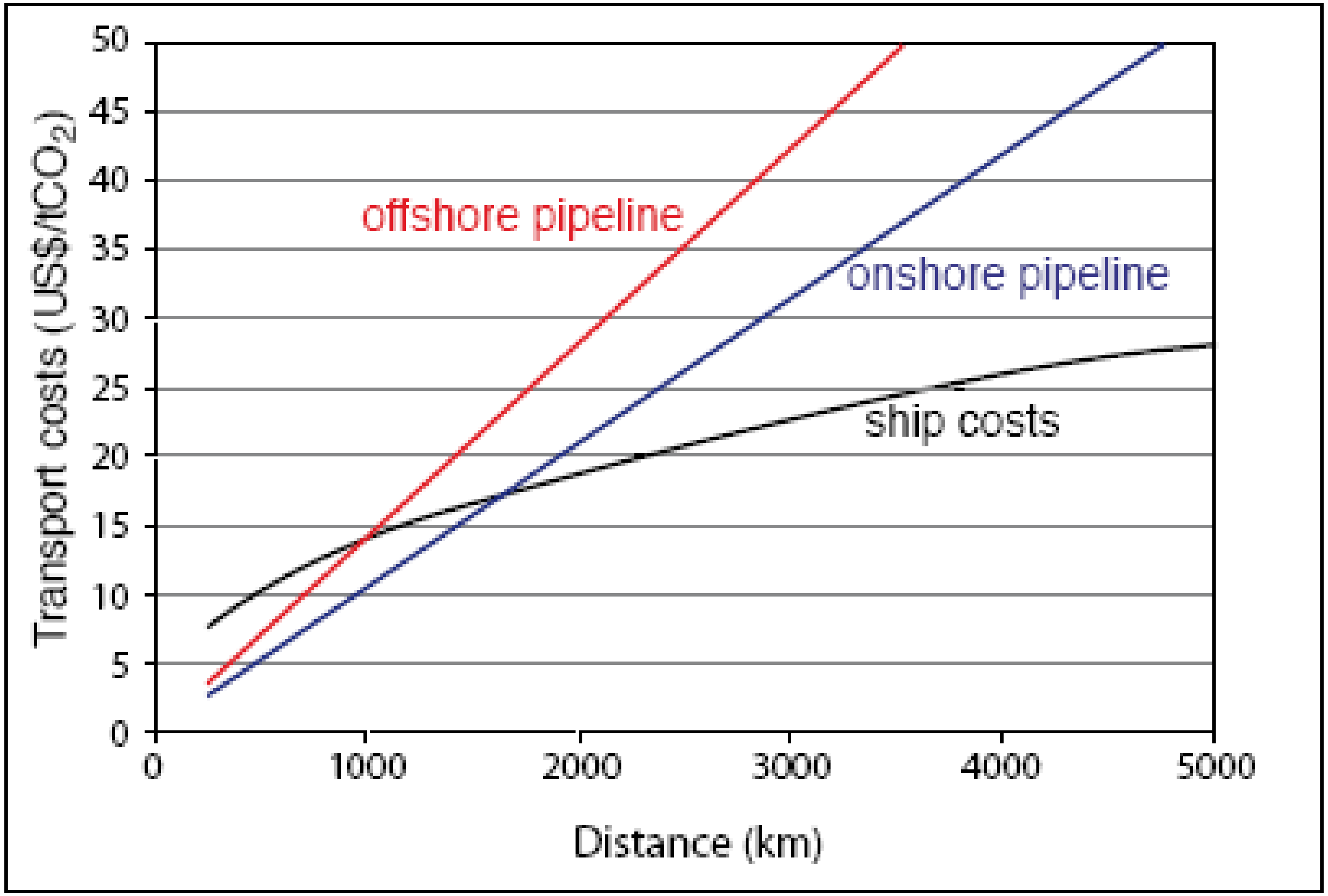
In oxy-fuel combustion, nearly pure oxygen is used for combustion instead of air, resulting in a flue gas that is mainly CO_2 and H_2O.

Source: IPCC CCS Special Report: pp126

Transportation Options

- Pipeline (viable for transporting above 1 million tonne pa)
- Ship (only at certain condition)
- Tanker Vehicle (only for moving small amount of CO_2, e.g. 50,000 tonnes CO_2 from capture pilot pa)

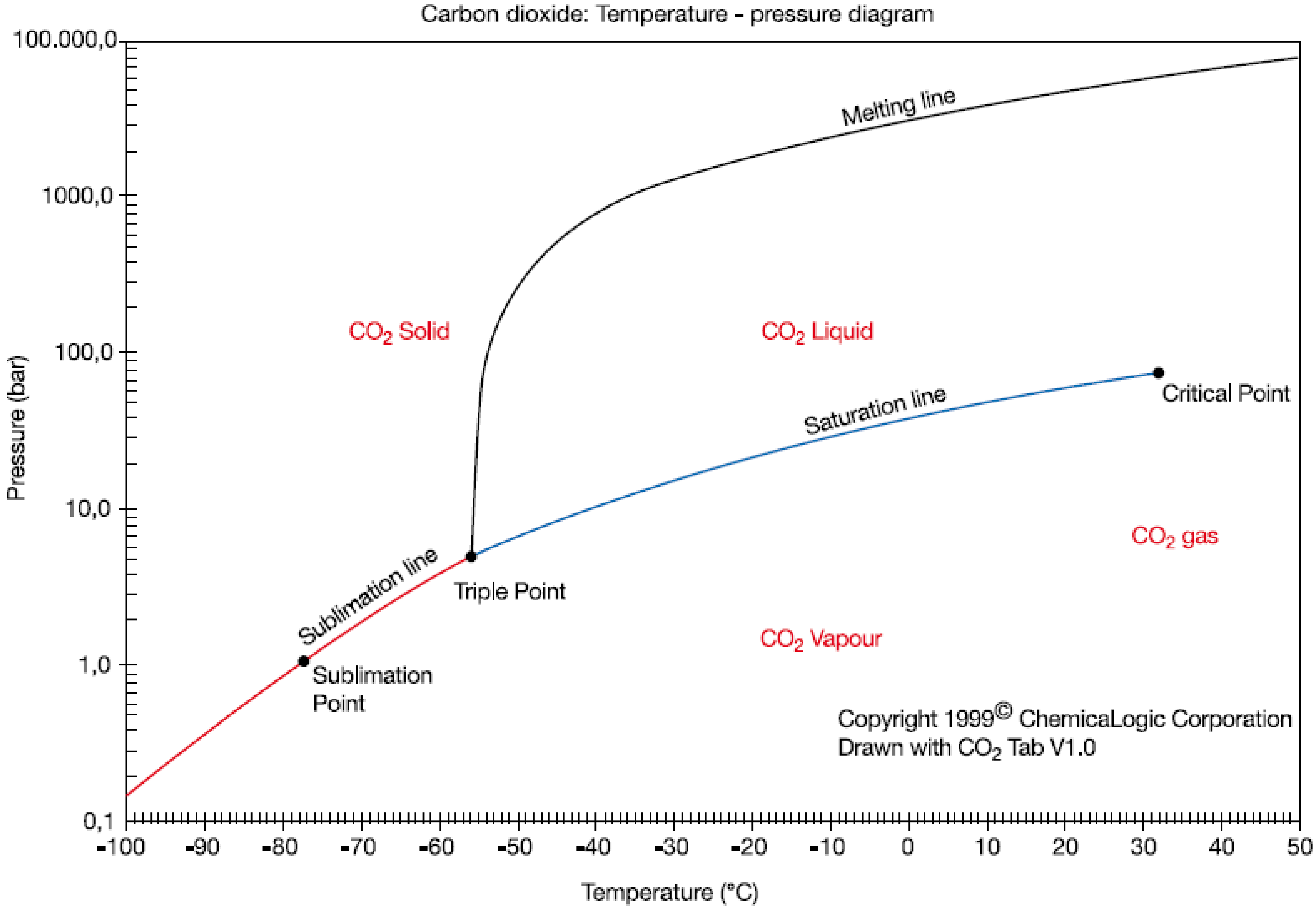
Costs of CO_2 Transportation Options



Source: IPCC CCS Special Report, Technical Summary, pp31

CO_2 Pipeline in North America

Source: European Energy Forum



Source: ChemicaLogic Corporation

Dated back 1977

ON GEOENGINEERING AND THE CO_2 PROBLEM

MARCHETTI-24

CESARE MARCHETTI

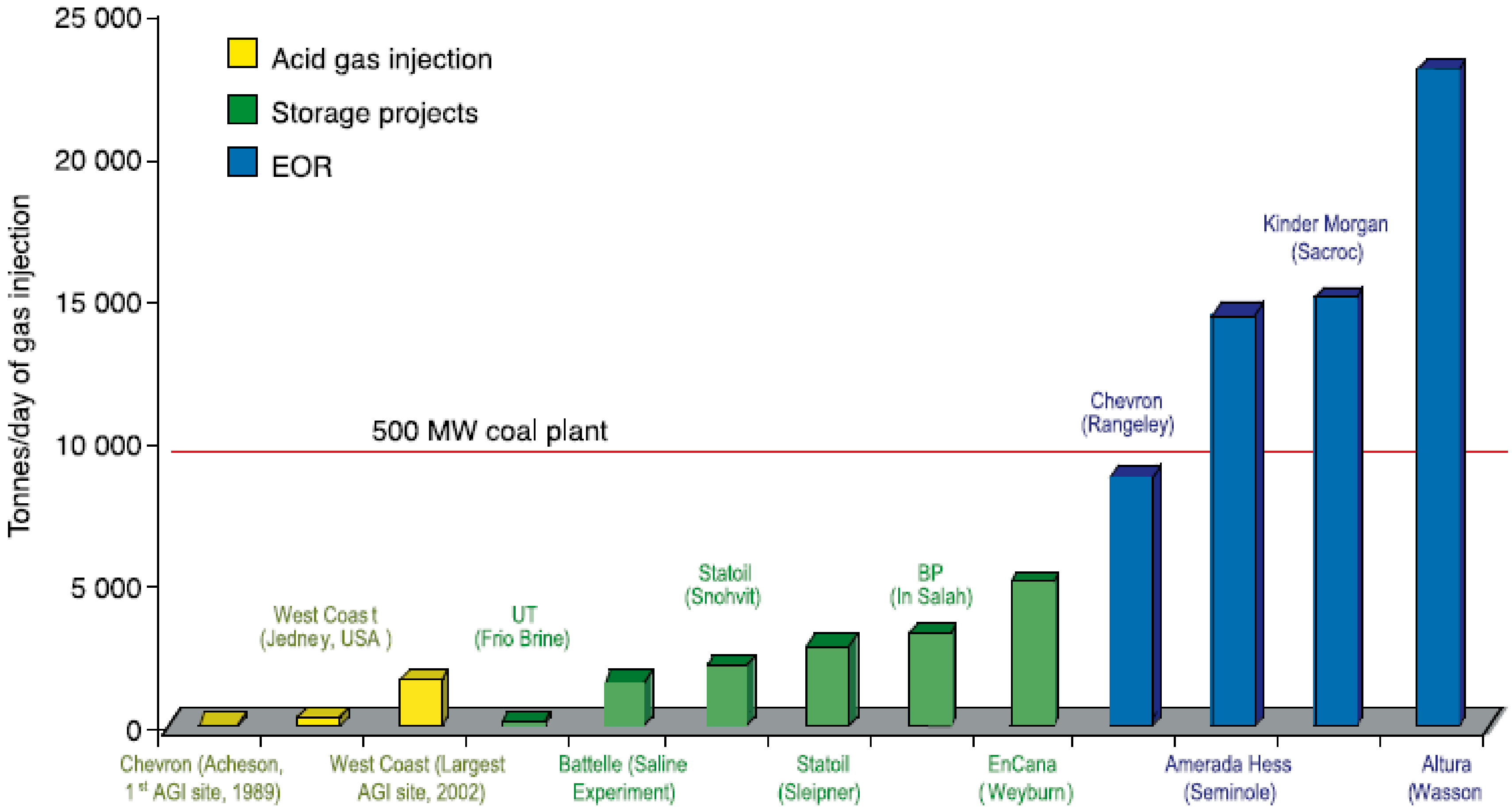
International Institute for Applied Systems Analysis, Laxenburg, Austria

Abstract. The problem of CO_2 control in the atmosphere is tackled by proposing a kind of 'fuel cycle' for fossil fuels where CO_2 is partially or totally collected at certain transformation points and properly disposed of.

CO_2 is disposed of by injection into suitable sinking thermohaline currents that carry and spread it into the deep ocean that has a very large equilibrium capacity.

The Mediterranean undercurrent entering the Atlantic at Gibraltar has been identified as one such current; it would have sufficient capacity to deal with all CO_2 produced in Europe even in the year 2100.

Comparison of the magnitude of CO_2 injection activities illustrating that the storage operations from a typical 500-MW coal plant will be the same order of magnitude as existing CO_2 injection operations



Source: Heinrich et al, 2003

Capture Cost based on State-of-art Technology in 2005

	Pulverized Coal Power Plant	Natural Gas Combined Cycle Power Plant	Integrated Coal Gasification Combined Cycle Power Plant
Cost of electricity without CCS (US$ MWh^{-1})	43-52	31-50	41-61
Power plant with capture			
Increased Fuel Requirement (%)	24-40	11-22	14-25
CO_2 captured (kg MWh^{-1})	820-970	360-410	670-940
CO_2 avoided (kg MWh^{-1})	620-700	300-320	590-730
% CO_2 avoided	81-88	83-88	81-91
Power plant with capture and geological storage[6]			
Cost of electricity (US$ MWh^{-1})	63-99	43-77	55-91
Electricity cost increase (US$ MWh^{-1})	19-47	12-29	10-32
% increase	43-91	37-85	21-78
Mitigation cost (US$/t$CO_2$ avoided)	30-71	38-91	14-53
Mitigation cost (US$/tC avoided)	110-260	140-330	51-200
Power plant with capture and enhanced oil recovery[7]			
Cost of electricity (US$ MWh^{-1})	49-81	37-70	40-75
Electricity cost increase (US$ MWh^{-1})	5-29	6-22	(-5)-19
% increase	12-57	19-63	(-10)-46
Mitigation cost (US$/t$CO_2$ avoided)	9-44	19-68	(-7)-31
Mitigation cost (US$/tC avoided)	31-160	71-250	(-25)-120

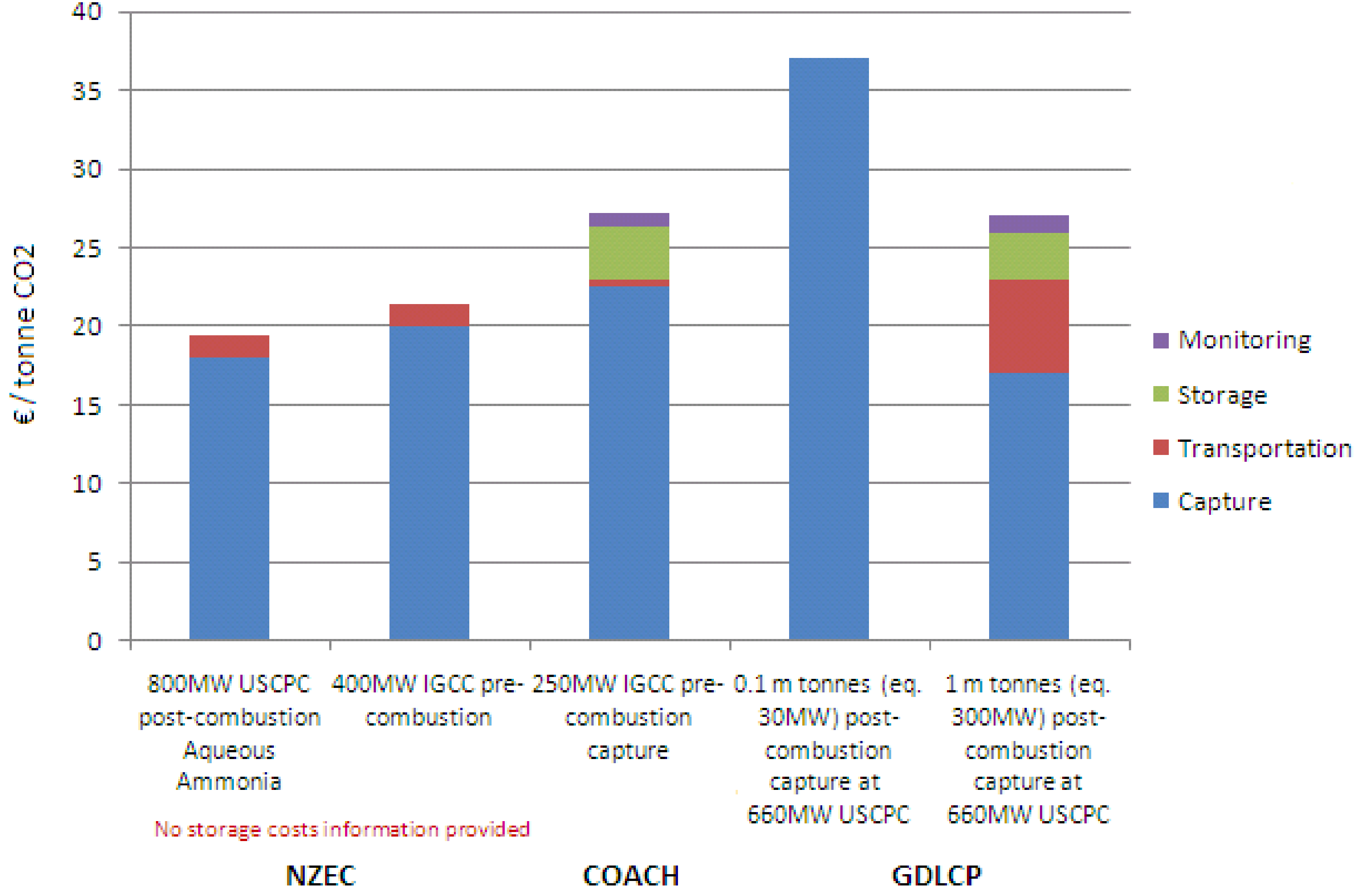
Source: IPCC CCS Special Report, pp347

Mitigation cost for different combination of CCS technologies

	NGCC Reference Plant		PC Reference Plant	
	US$/t$CO_2$ avoided	US$/tC avoided	US$/t$CO_2$ avoided	US$/tC avoided
Power plant with capture and geological storage				
NGCC	40-90	140-330	20-60	80-220
PC	70-270	260-980	30-70	110-260
IGCC	40-220	150-790	20-70	80-260
Power plant with capture and EOR				
NGCC	20-70	70-250	1-30	4-130
PC	50-240	180-890	10-40	30-160
IGCC	20 – 190	80 – 710	1 – 40	4 – 160

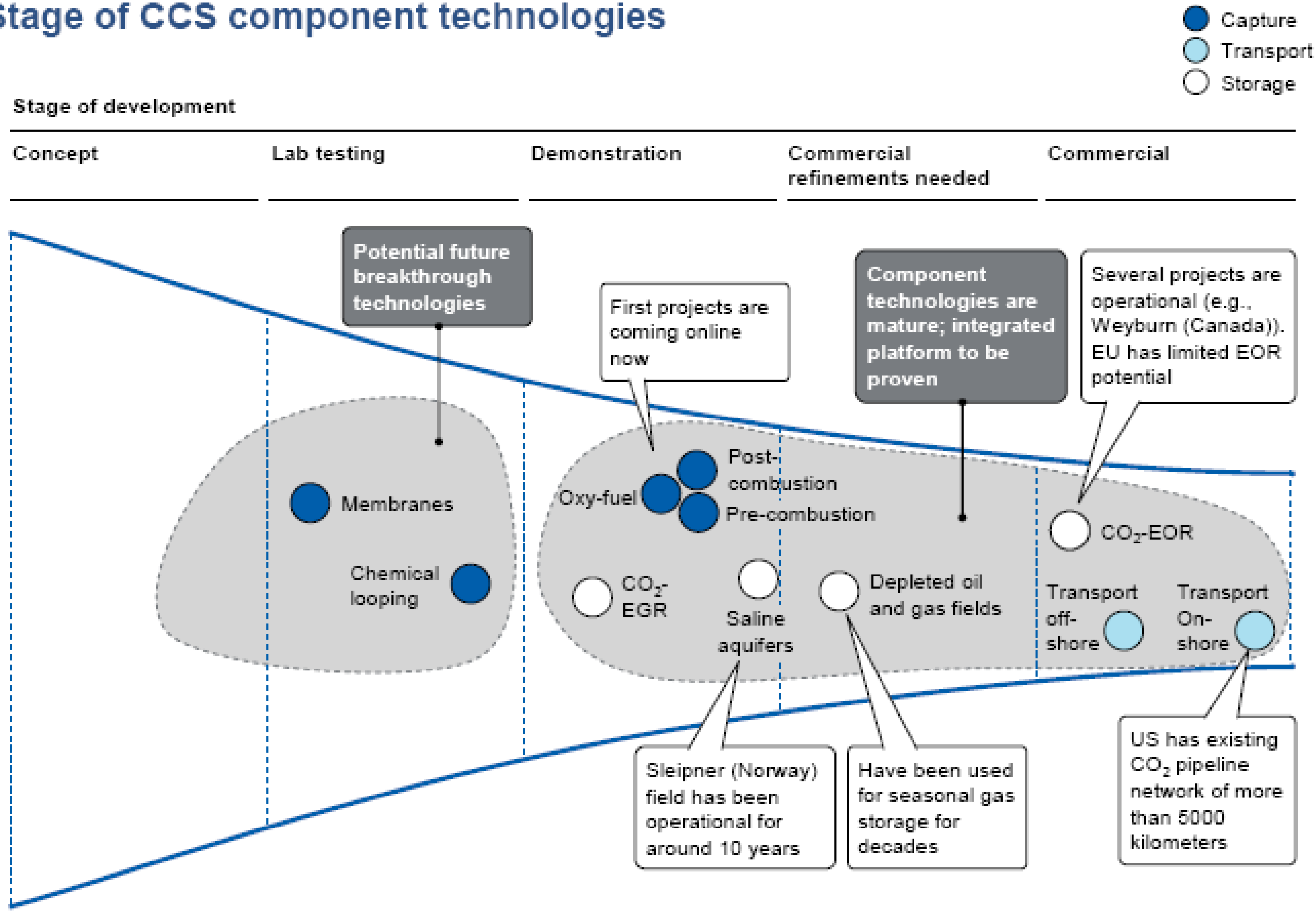
Source: IPCC CCS Special Report, pp347

Estimates for CCS Costs in China



Source: NZEC, COACH, LINKSCHINA Research

Stage of CCS component technologies



Source: Interviews; Team analysis

Source: Mckinsey and Corporation, 2008

Capture Ready

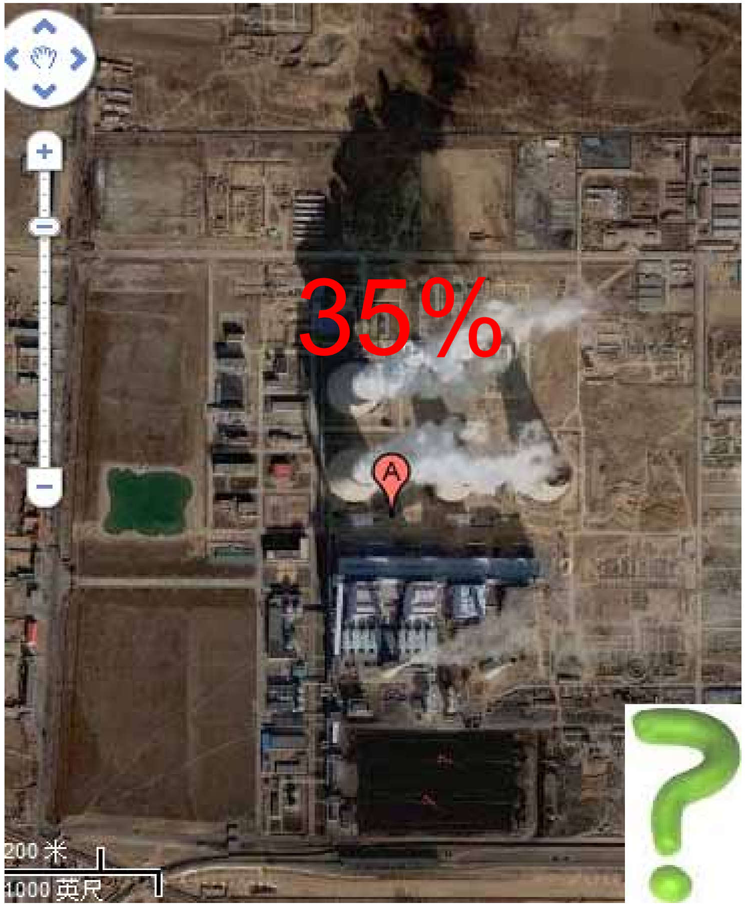
Typical Layout of Chinese Power Plants

Source: LinksChina 2009

Capture Ready

Existing Plants Retrofitting potential
- A survey of 103 power plants in China

Source: LinksChina, 2009



The Gleneagles Communiqué, July 2005

14. We will work to accelerate the development and commercialization of Carbon Capture and Storage technology by:

(a) endorsing the objectives and activities of the Carbon Sequestration Leadership Forum (CSLF), and encouraging the Forum to work with broader civil society and to address the barriers to the public acceptability of CCS technology;

(b) inviting the IEA to work with the CSLF to hold a workshop on short-term opportunities for CCS in the fossil fuel sector, including from Enhanced Oil Recovery and CO_2 removal from natural gas production;

(c) inviting the IEA to work with the CSLF to study definitions, costs, and scope for 'capture ready' plant and consider economic incentives;

(d) collaborating with key developing countries to research options for geological CO_2 storage; and

(e) working with industry and with national and international research programmes and partnerships to explore the potential of CCS technologies, including with developing countries.

At the request of the Gleneagles G8 summit, the IEA Greenhouse Gas Programme published a study which identified the following key elements for CCR power plants:

► A CO_2 capture ready power plant is a plant which can include CO_2 capture when the necessary regulatory or economic drivers are in place. The aim of building plants that are capturing ready is to reduce the risk of stranded assets and carbon lock-in.

► Developers of capture ready plants should take responsibility for ensuring that all known factors in their control that would prevent installation and operation of CO_2 capture have been identified and eliminated. This might include:

⊙ A study of options for CO_2 captures retrofit and potential pre-investments

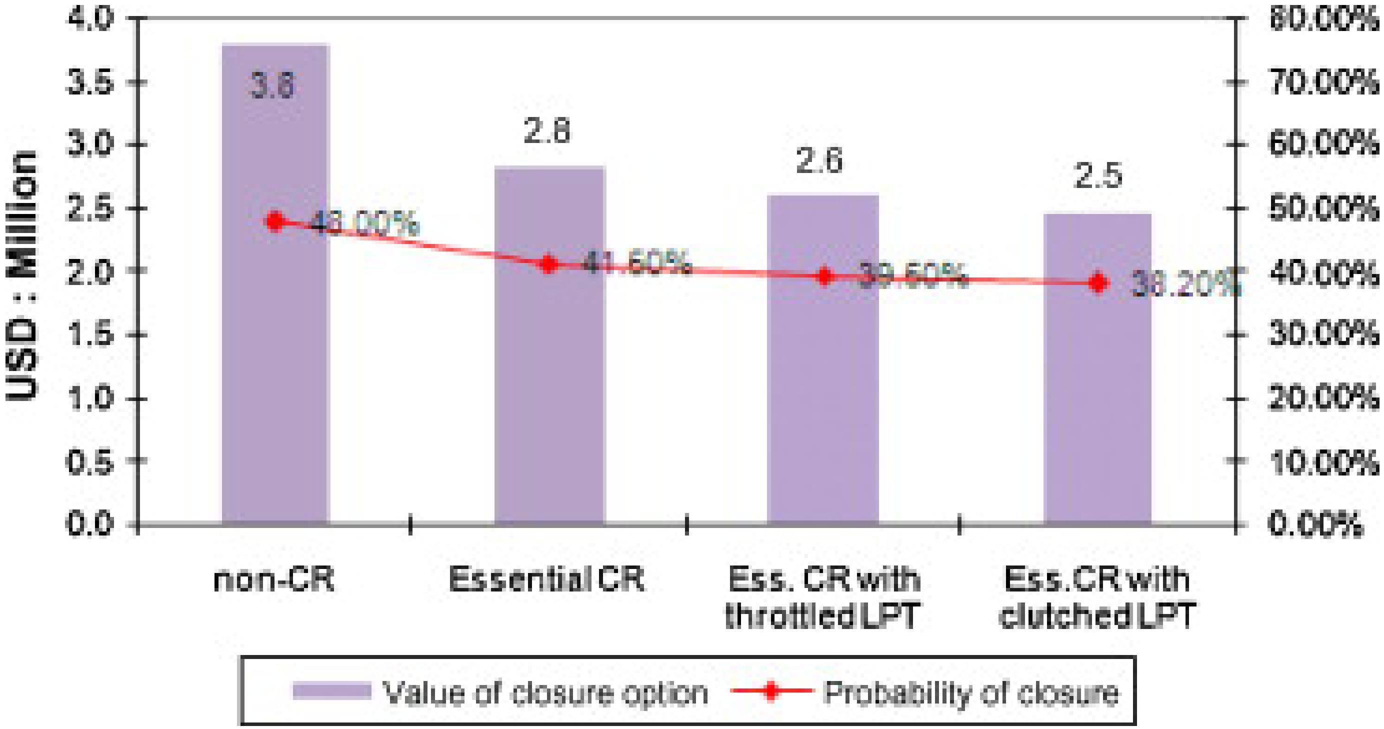
⊙ Inclusion of sufficient space and access for the additional facilities

⊙ Identification of reasonable routes to storage of CO_2 Competent authorities involved in permitting power plants should be provided with sufficient information to be able to judge whether the developer has met these criteria.

Source: IEA GHG, 2008

Capture Ready investment reduces closure possibility

- A study of CO_2 capture ready at Chinese coal-fired power plant



Source: Liang et al, 2009

All new power plants above 300MW must be capture ready

DEPARTMENT OF ENERGY & CLIMATE CHANGE

URN 09D/810

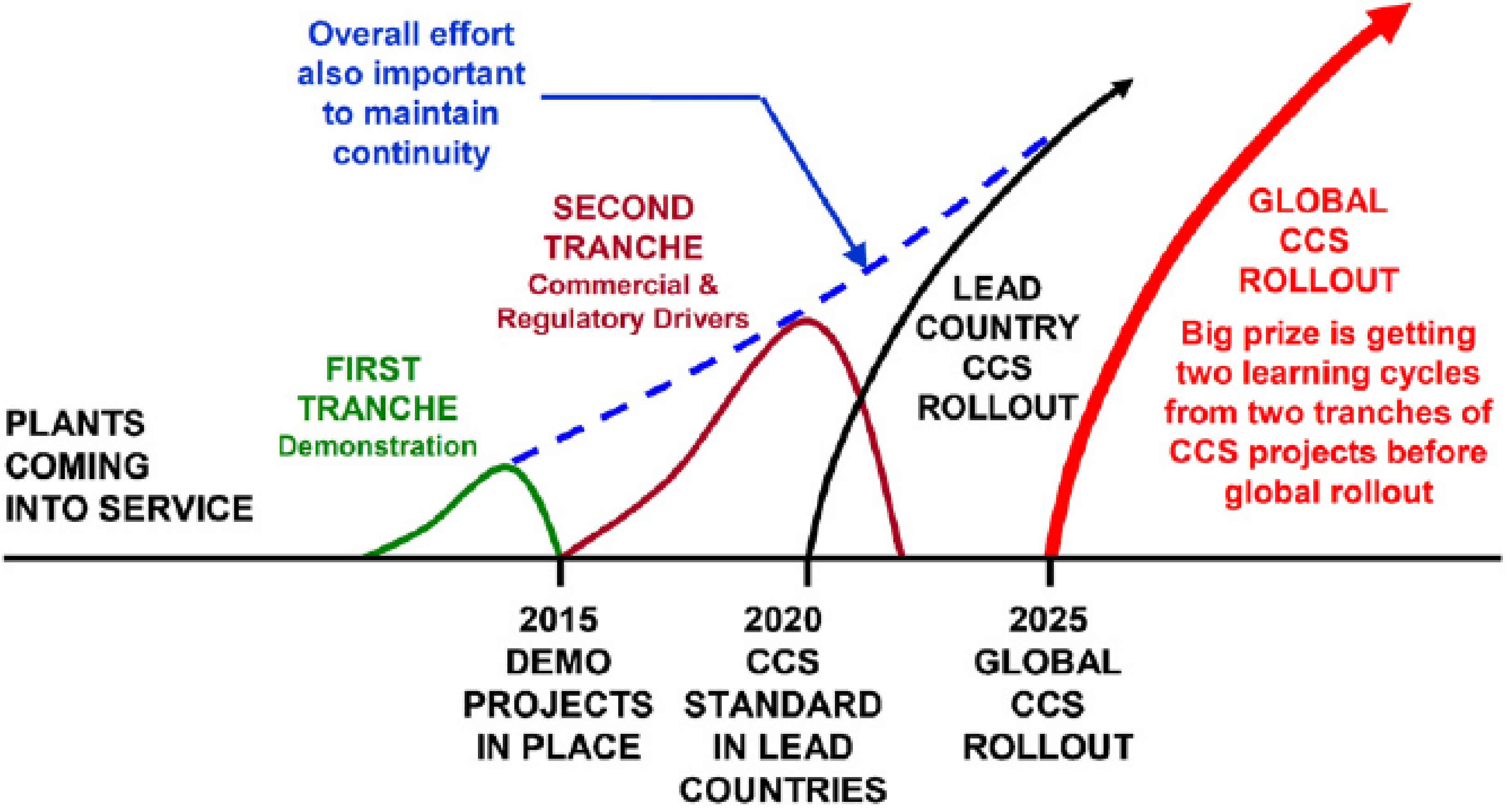
November 2009

Carbon Capture Readiness (CCR)

A guidance note for Section 36 Electricity Act 1989 consent applications

http://www.decc.gov.uk/en/content/cms/what_we_do/uk_supply/energy_mix/ccs/ccs.aspx

Schematic of two-tranche model for demonstration and deployment



Source: Gibbins and Hannah, 2008