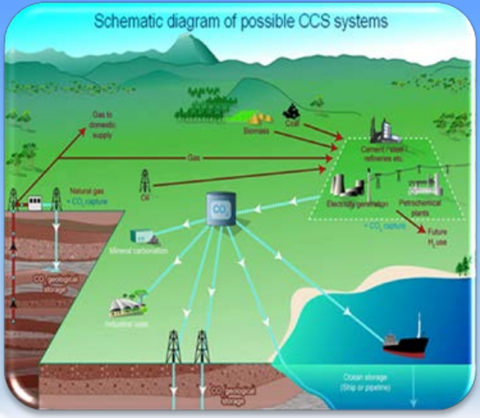
CO_2 Capture Technologies for Power Generation The Challenges Ahead…

Dr. Prachi Singh, IEAGHG R&D Programme, UK

CO_2 Capture and Storage Regional Awareness-Raising Workshop, 13-14th June 2012, Ankara, Turkey

Outline

IEAGHG R&D programme



Overview of CO_2 Capture Technology for Power Plants

Post Combustion

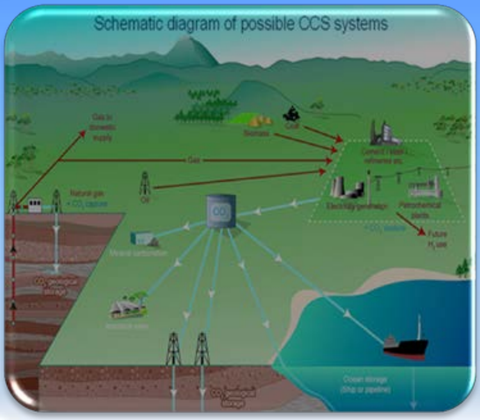
Oxyfuel Combustion

Pre Combustion

Key Issues and Research Direction

Conclusions

IEAGHG R&D programme



Overview of CO_2 Capture Technology for Power Plants

Pre Combustion
Post Combustion
Oxyfuel Combustion

Key Issues and Research Direction

Conclusions

International Energy Agency Greenhouse Gas (IEAGHG) R&D Programme

- ***A collaborative international research programme founded in 1991 from IEA***

  - **Aim:** Provide members with definitive information on the role that technology can play in reducing greenhouse gas emissions

  - **Scope:** All greenhouse gases, all fossil fuels and comparative assessments of technology options.

  - **Focus:** On CCS in recent years

IEA Greenhouse Gas R&D Programme

- ***Producing information that is:***
  - Objective, trustworthy, independent
  - Policy relevant but NOT policy prescriptive
  - Reviewed by external Expert Reviewers
  - Subject to review of policy implications by Members

- ***IEAGHG is an IEA Implementing Agreement in which the participants contribute to a common fund to finance the activities.***

Members and Sponsors

BG GROUP
bp
CEZ GROUP
Chevron
eni
TOTAL
BR PETROBRAS
ALSTOM
CIAB
DOOSAN Doosan Babcock
EnBW
e·on
VATTENFALL
EPRI
ExxonMobil
Schlumberger
SCOTTISHPOWER
REPSOL YPF
INSTITUTO DE INVESTIGACIONES ELECTRICAS
B&W power generation group
Enel L'ENERGIA CHE TI ASCOLTA.
GLOBAL CCS INSTITUTE
JGC
RWE The energy to lead
Statoil

Evaluating technology options to mitigate greenhouse gas emissions
ieaghg

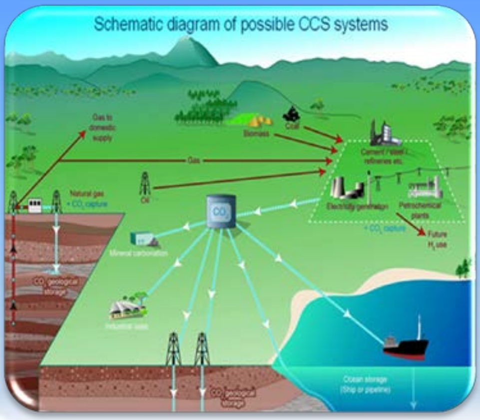
What IEAGHG does

- ***Technical evaluations of mitigation options***
  - ✓ *Comparative analyses with standardised baseline*
- ***Assist international co-operation***
  - ✓ *International research networks*
- ***Assist technology implementation***
  - ✓ *Near market research*
  - ✓ *GCCSI*
- ***Disseminate information***

Specific Focus on CCS

- ***Power Sector***
  - Coal, Natural Gas and Biomass
- ***Industrial sectors***
  - Gas production
  - Oil Refining & Petrochemicals
  - Cement sector
  - Iron & Steel Industry
- ***Cross cutting issues***
  - Policy/Regulations
  - Health & Safety
  - Transport & System Infrastructure

IEAGHG R&D programme



Overview of CO_2 Capture Technology for Power Plants

Post Combustion

Oxyfuel Combustion

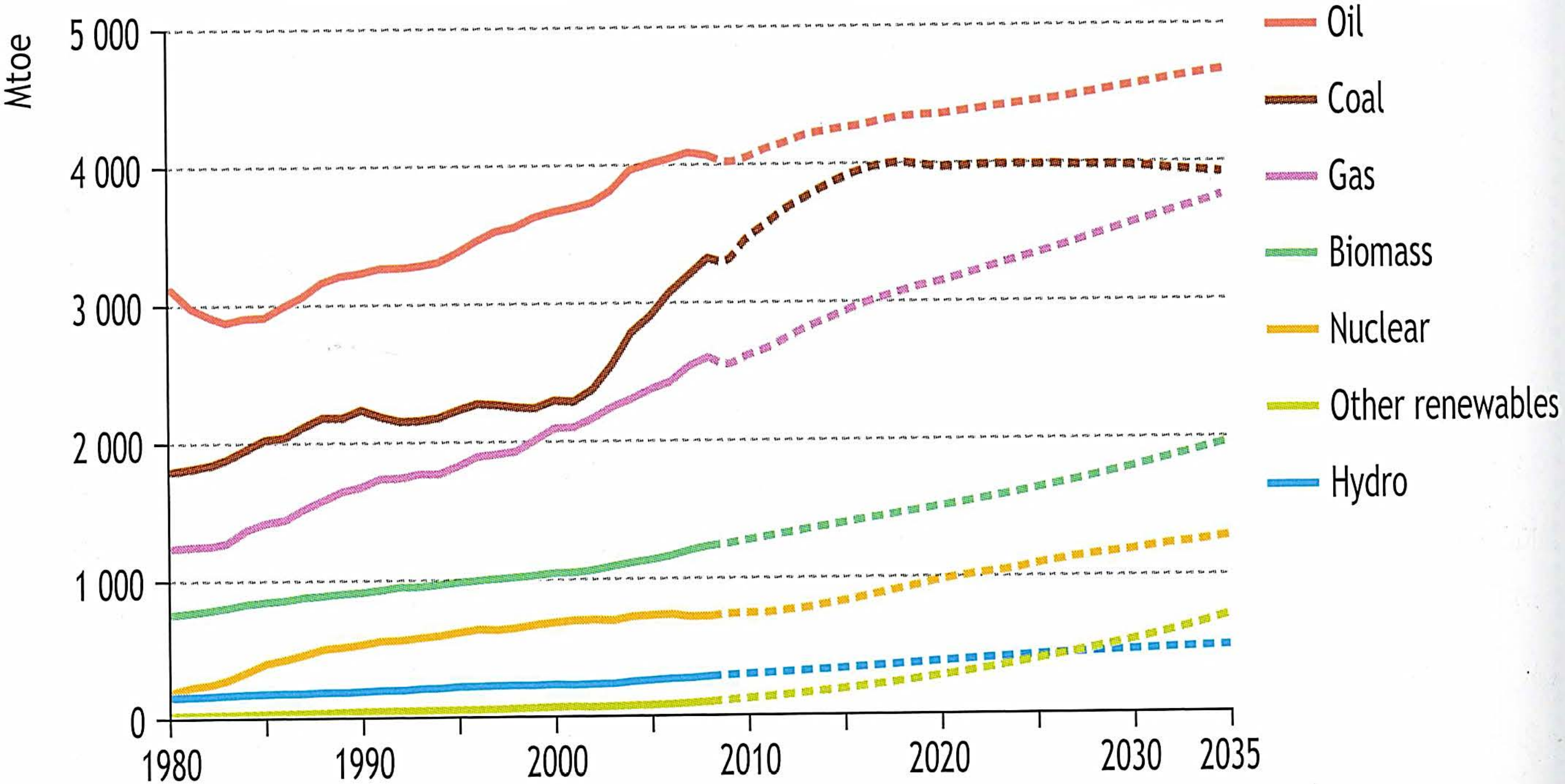
Pre Combustion

Key Issues and Research Direction

Conclusions

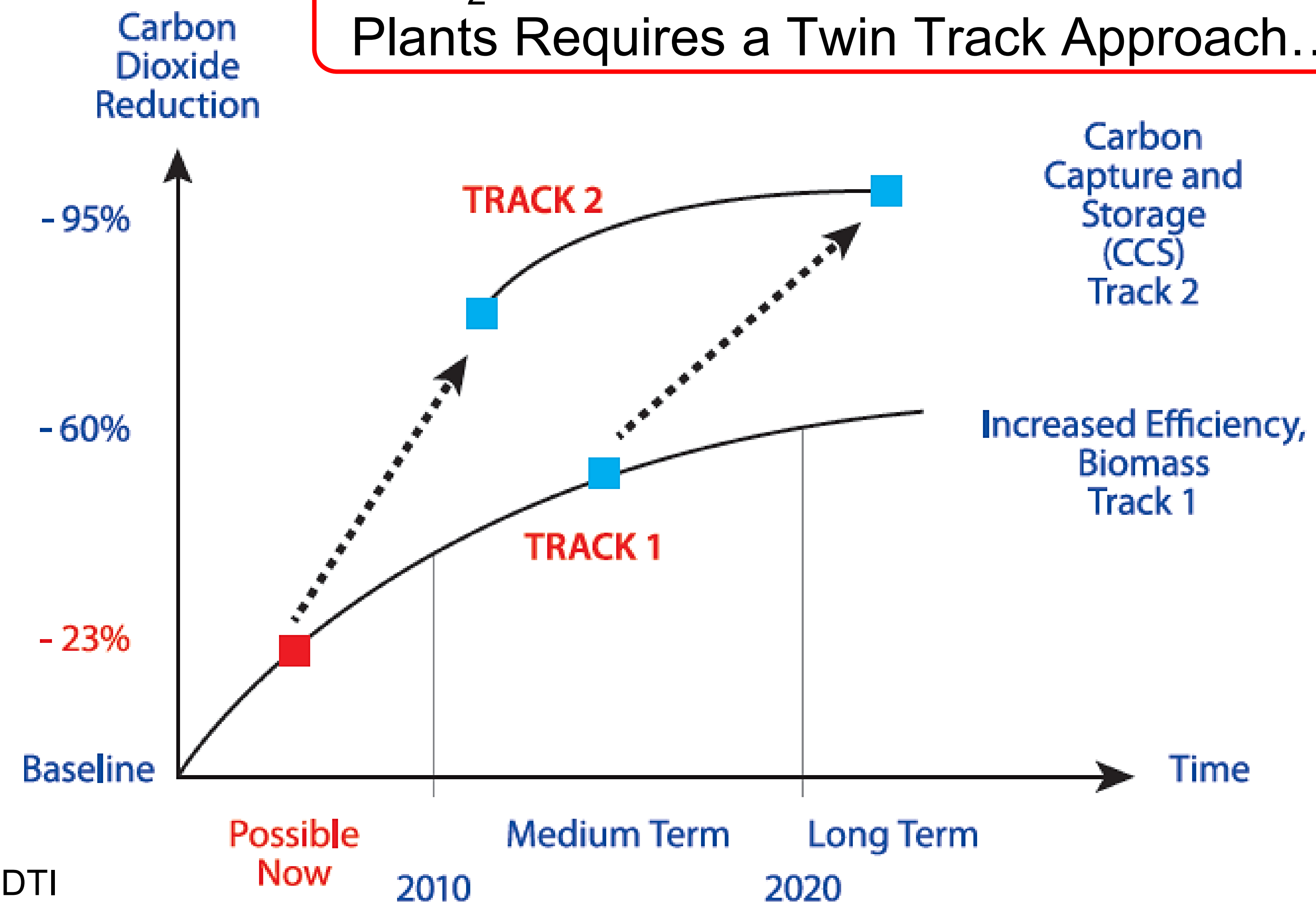
World Primary Energy Demand by Fuel

IEA World Energy Outlook 2010



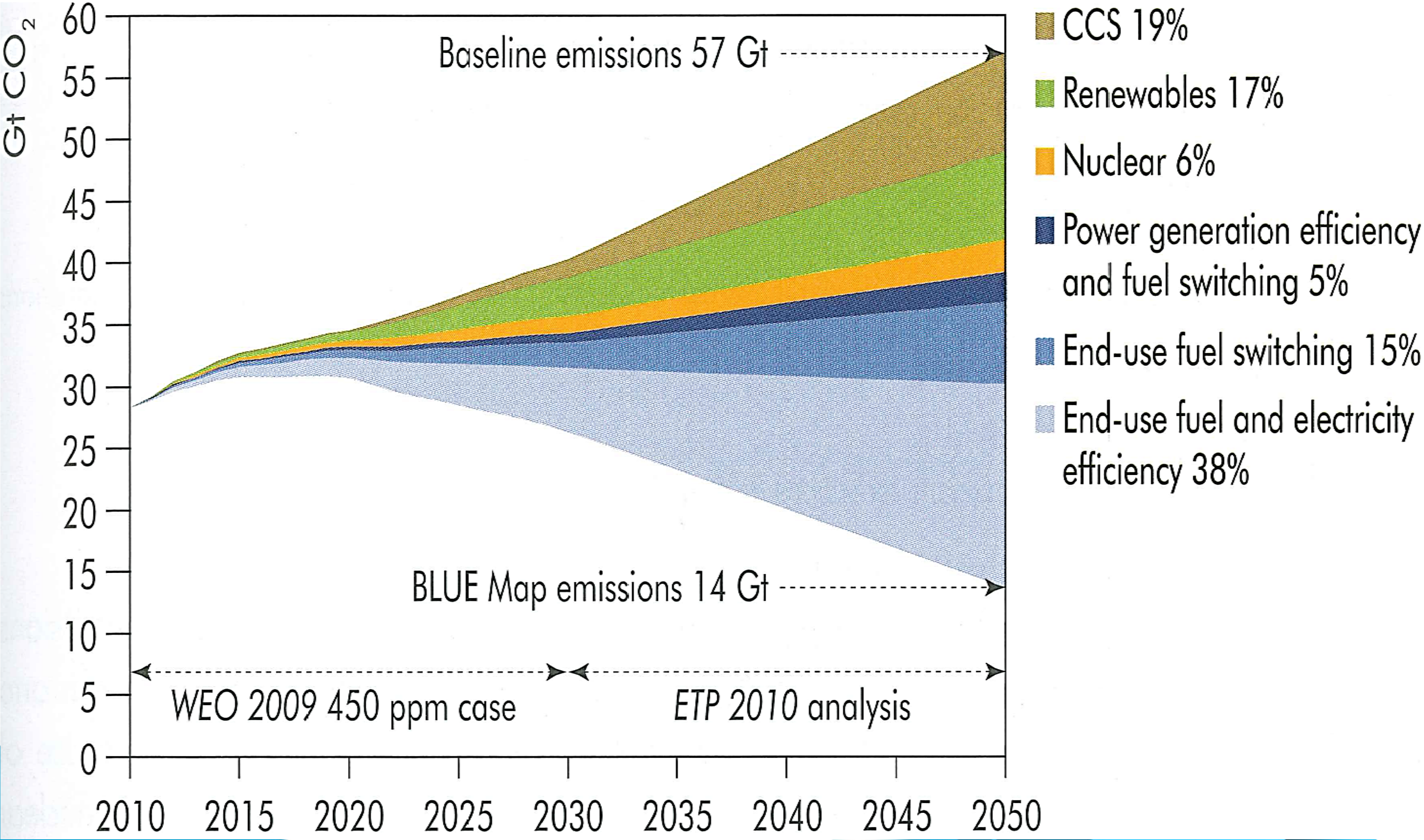
Strategy to Reduce CO_2 Emission

CO_2 Abatement from Coal Fired Power Plants Requires a Twin Track Approach…

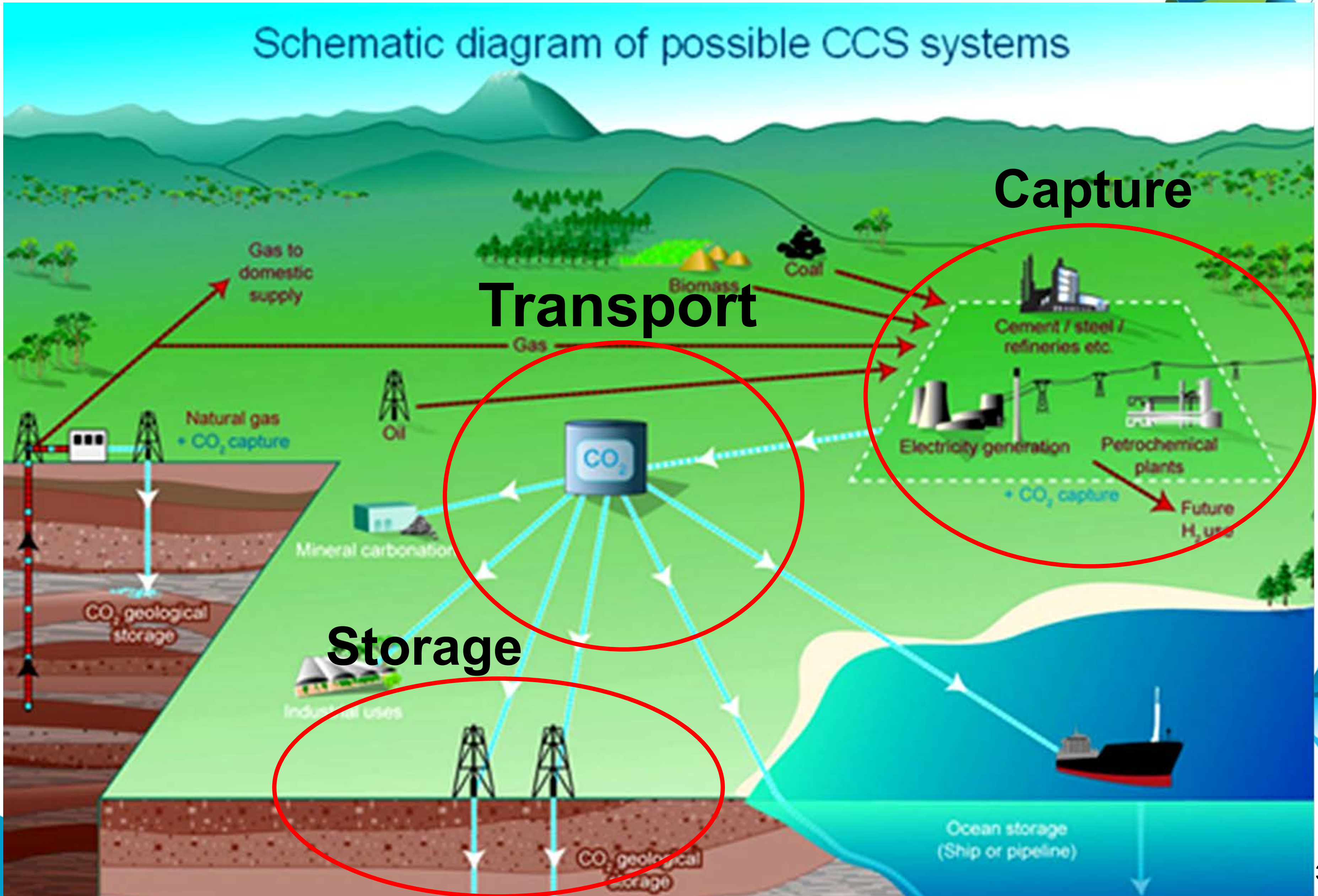


Source: DTI

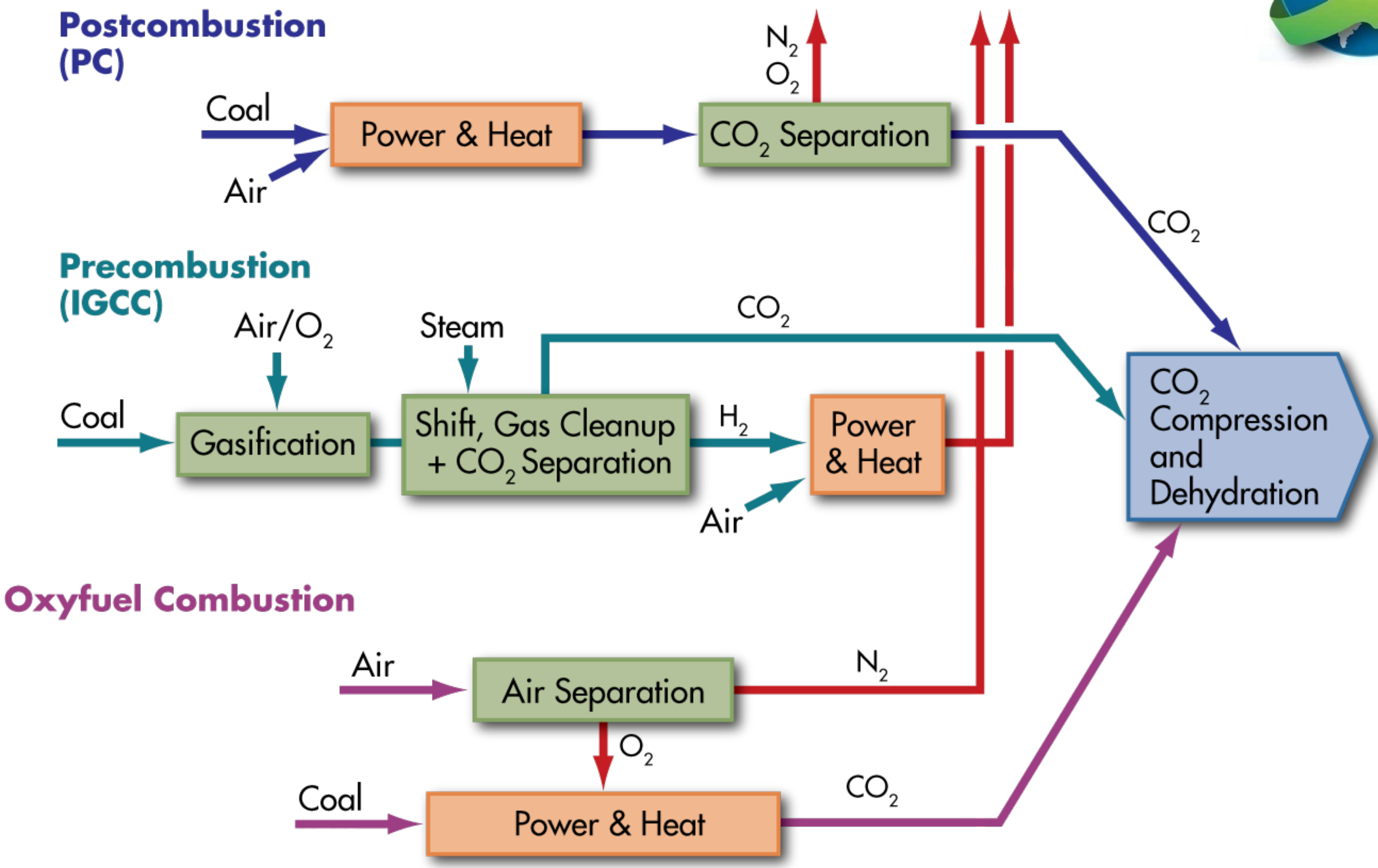
Reducing CO_2 Emission
IEA Energy Technology Prospective 2010



Carbon Capture and Storage (CCS)



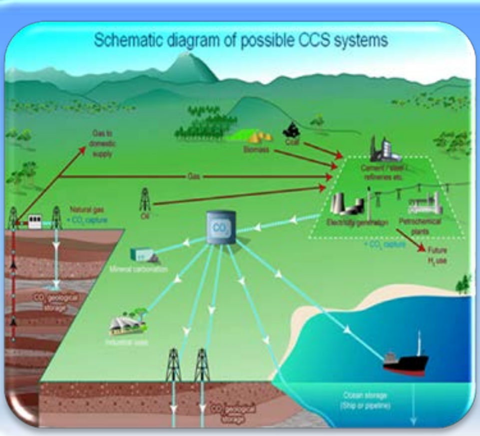
CO_2 Capture Technology Options



Source: EPRI 2007

Outline

IEAGHG R&D programme



Overview of CO_2 Capture Technology for Power Plants

Post Combustion

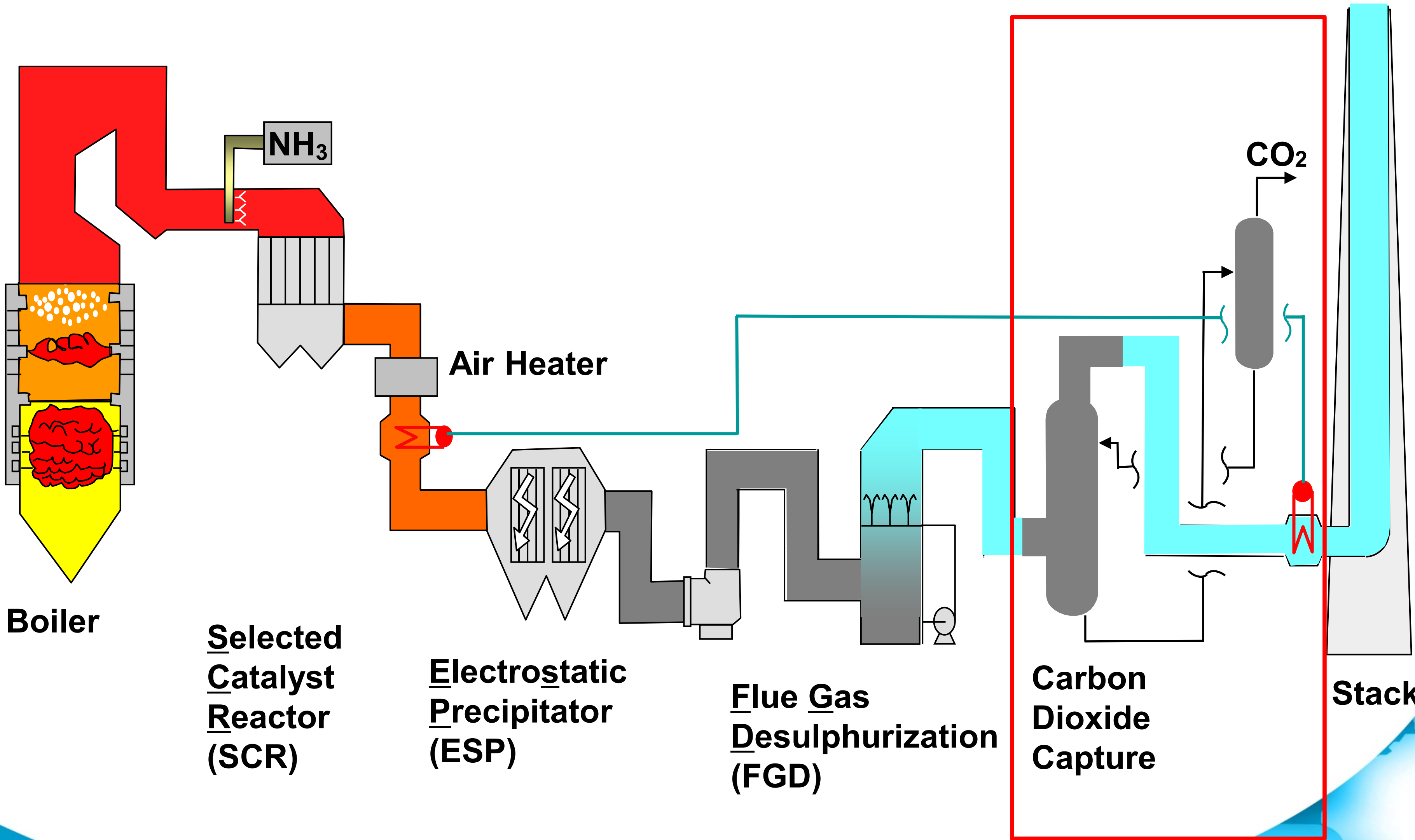
Oxyfuel Combustion

Pre Combustion

Key Issues and Research Direction

Conclusions

Post Combustion Capture



Source: Mitsubishi Heavy Industries

Why Post Combustion Capture?

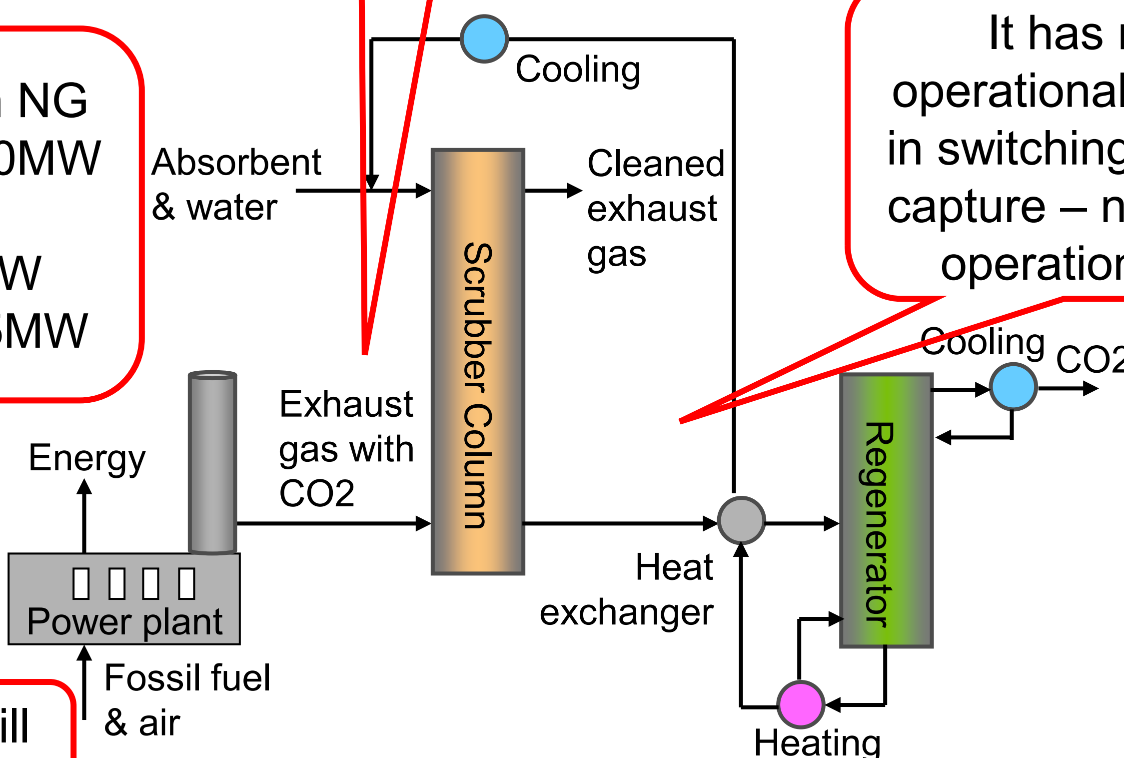
State of Art Technology
Technology is available by pilot demo

Can be easily Retrofitted

Capture readiness makes relatively easy to incorporate Into power plants

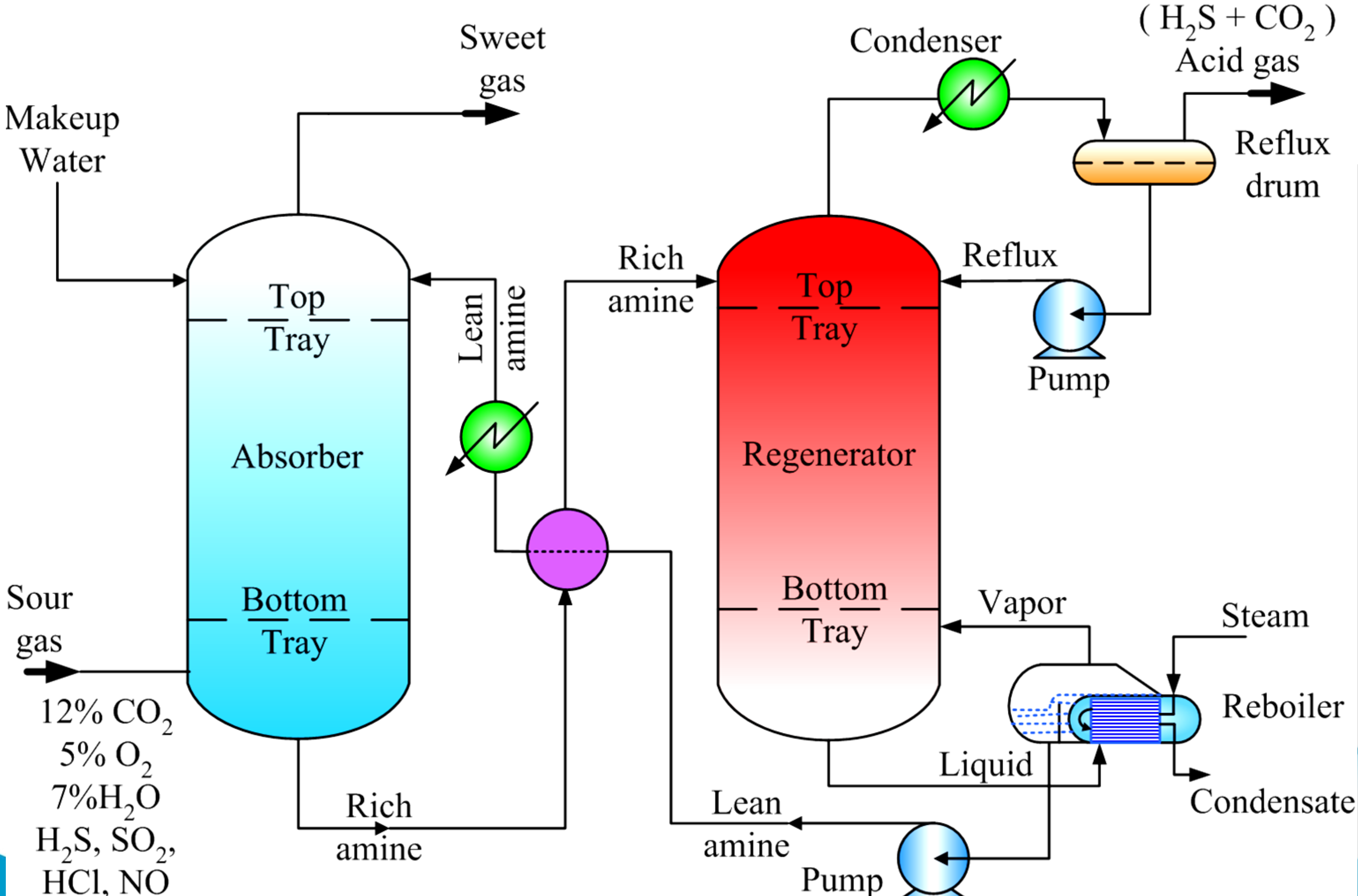
Many Pilot Plant on NG
Flour 80MW, MHI 30MW
Few on Coal
ABBLumus 33 MW
Flour 5MW, MHI 25MW

It has more operational flexibility in switching between capture – no capture operation mode

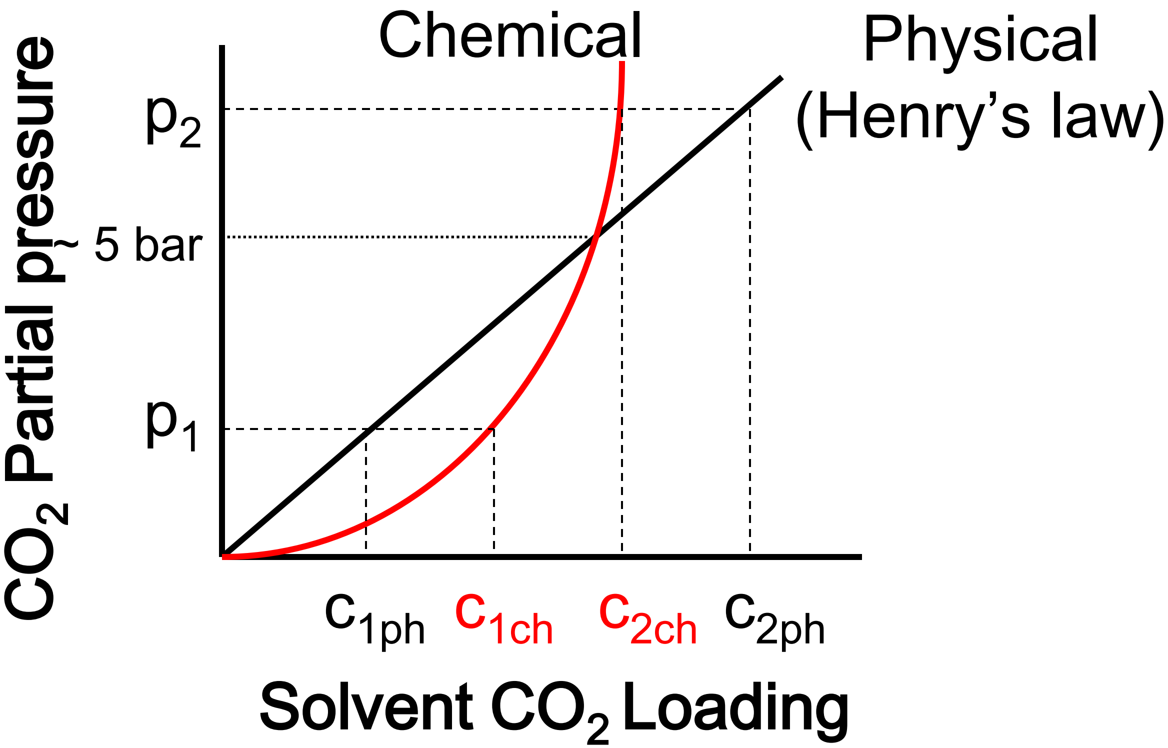


Learning by doing will lead to cost reductions

Post Combustion Capture Unit



Chemical Versus Physical Absorption



Low partial pressure (p_1):

$C_{1ph} < C_{1ch}$

Chemical absorption deserves preference

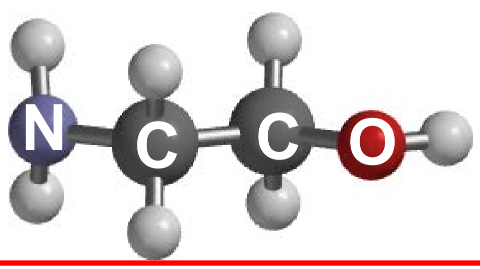
p_2: reverse

Main reaction with CO_2 and amine based solvent

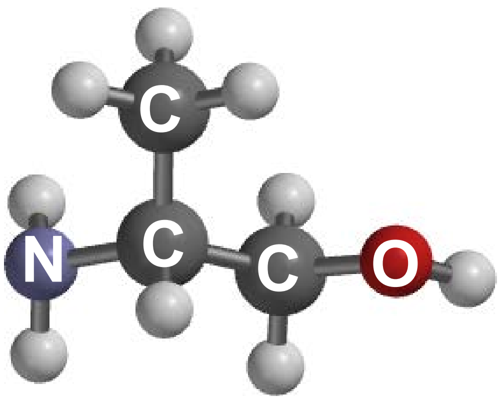
Acid Base Temperature Dependent Reversible Reaction

$$2R_2NH + CO_2 \underset{\text{Fast reaction}}{\overset{\text{Low Temp.}}{\rightleftharpoons}} R_2NCOO^- + R_2NH_2^+$$

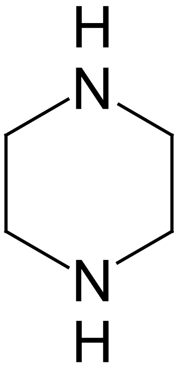
Carbamate



Monoethanolamine (MEA)



Sterically Hindered



Piperazine (Pz)

Commercially available solvents systems

Process Concept	Example	Developers
Conventional MEA	Econamine +	Fluor, ABB
Ammonia	Chilled Ammonia	Alstom
Hindered Amines	KS-1, AMP, …	MHI, EXXON
Tertiary Amines	MDEA	BASF, DOW
Amino Acid Salts	CORAL	TNO, Siemens, BASF
Piperazine		Uni Texas
HiCapt, DMX	Mixture	IFP
Integrated SO_2/CO_2	Amines	Cansolv/Shell
Amine		Aker Clean Carbon
Chemical solvents	DEAB, KoSol, Calcium based,	HTC, Uni Regina, KEPRI, NTNU, SINTEF, CSIRO, KEPRI, EnBW

Challenges in Post Combustion Capture

CO_2 Absorption Capacity & Kinetics

- Degradation
- Corrosion
- Heat stable salt
- Volatile organic compound e.g. Nitrosamine

Regeneration temperature
Reaction enthalpy

- Detailed Model development
- Process Integration

Source : AkerClean Carbon Pilot TCM, Mongstad, Norway

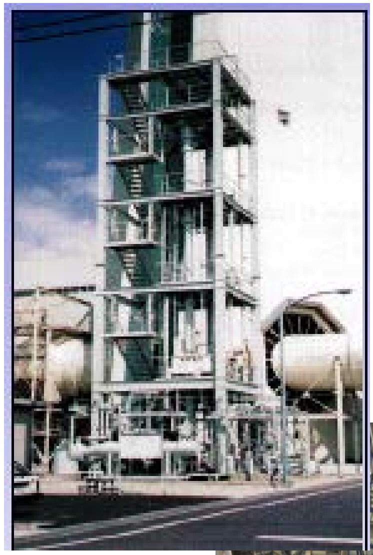
Post Combustion Pilot Projects

Project	Plant & Fuel Type	Year of Start-up	Plant Size	CO_2 Captured (Mtonne/year)
American Electric Power Mountaineer Plant, Chilled Ammonia, **USA**	Coal-fired Power Plant	2009	20 MW	0.1
Matsushima Coal Plant, Amine (MHI), **Japan**	Coal-fired Power Plant	2006	0.8 MW	0.004
Munmorah Pilot Plant, Ammonia Delta, CSIRO, **Australia**	Coal-fired Power Plant	2008	1 MW	0.005
CASTOR CO2 Capture to Storage Amine (Multiple) **Denmark**	Coal-fired Power Plant	2008	3 MW	0.008
Eni and Enel Federico II Brindisi Power Plant, Amine Enel, **Italy**	Coal-fired Power Plant	2009	1.5 MW	0.008
CATO-2 CO2 Catcher, Amine (Multiple), **Netherlands**	Coal-fired Power Plant	2008	0.4 MW	0.002
CaOling project, Carbonate looping **Spain**	Coal-fired Power Plant	2011	~0.6 MW	0.007
Statoil Mongstad Cogeneration Pilot Chilled Ammonia Alstom; Amine, AkerClean Carbon, **Norway**	Natural gas-fired Power Plant	2012	15 MW 7MW	0.080 0.020
PGE Bechatów Power Station, Amine Alstom & Dow Chem. **Poland**	Coal-fired Power Plant	2014	20 MW	0.1

What's Next

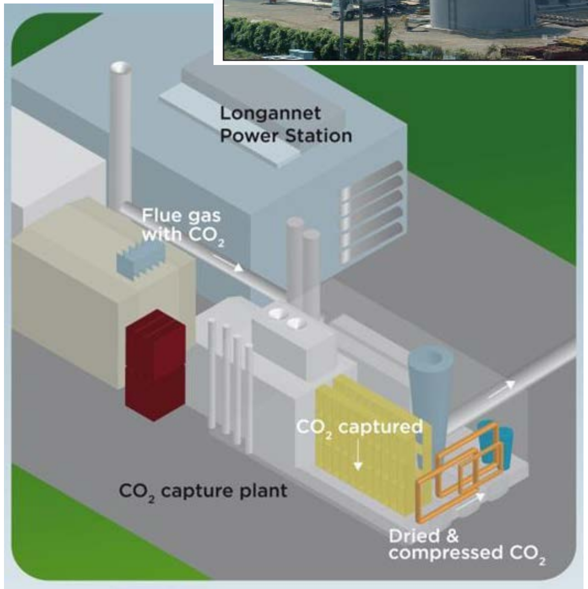
MHI Large Scale Demo Unit

Pilot Plants



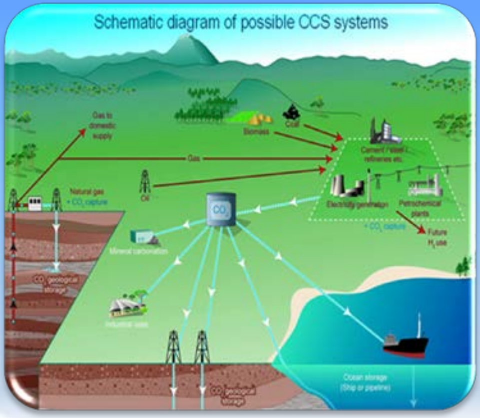
Nanko Pilot Plant (2t/d)

Castor Pilot Plant (2t/d)



Commercial Scale Demonstration

IEAGHG R&D programme



Overview of CO_2 Capture Technology for Power Plants

Post Combustion

Oxyfuel Combustion

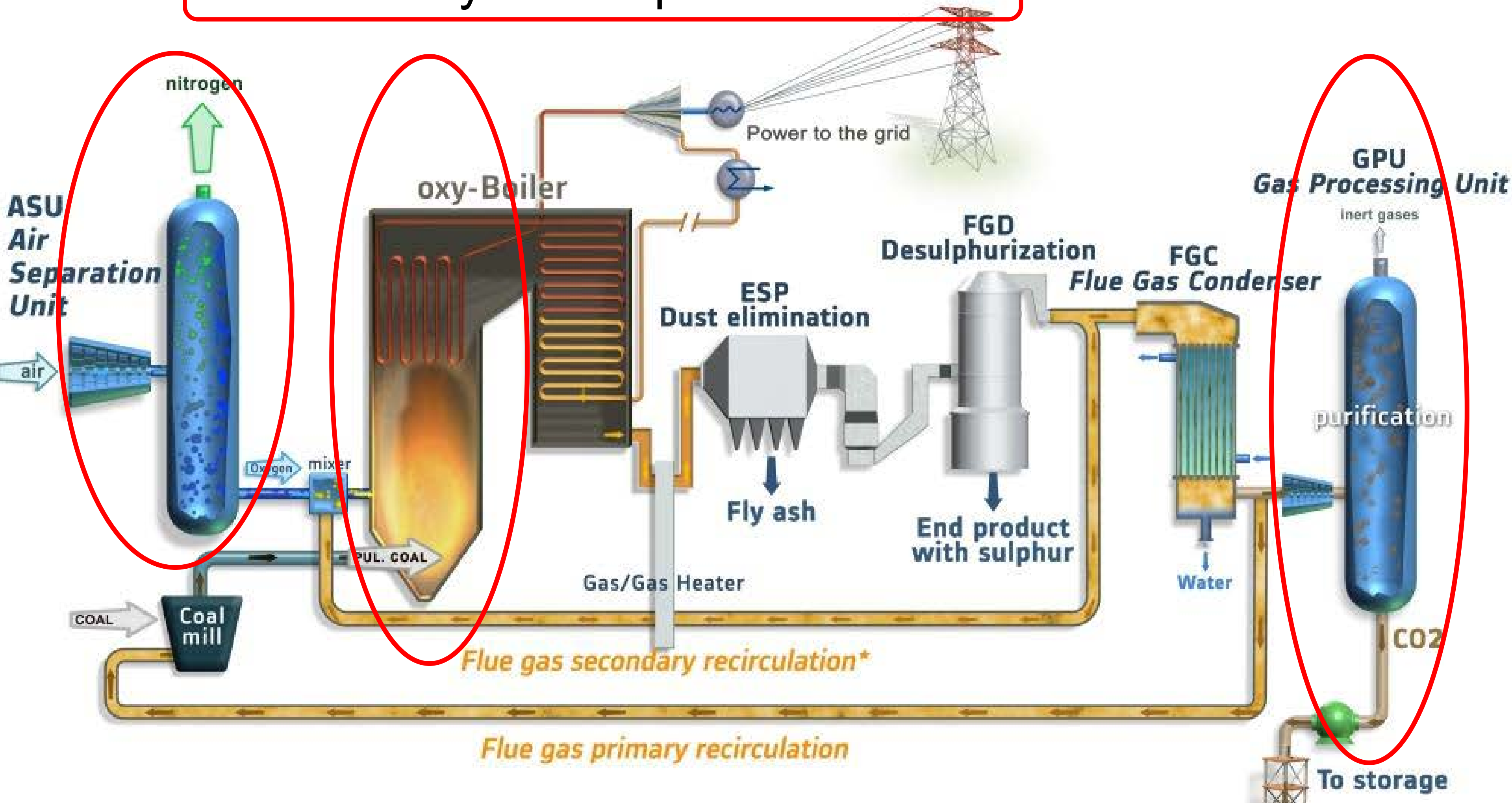
Pre Combustion

Key Issues and Research Direction

Conclusions

Oxyfuel Combustion Technology

Three Key Development Issues



Source: Alstom

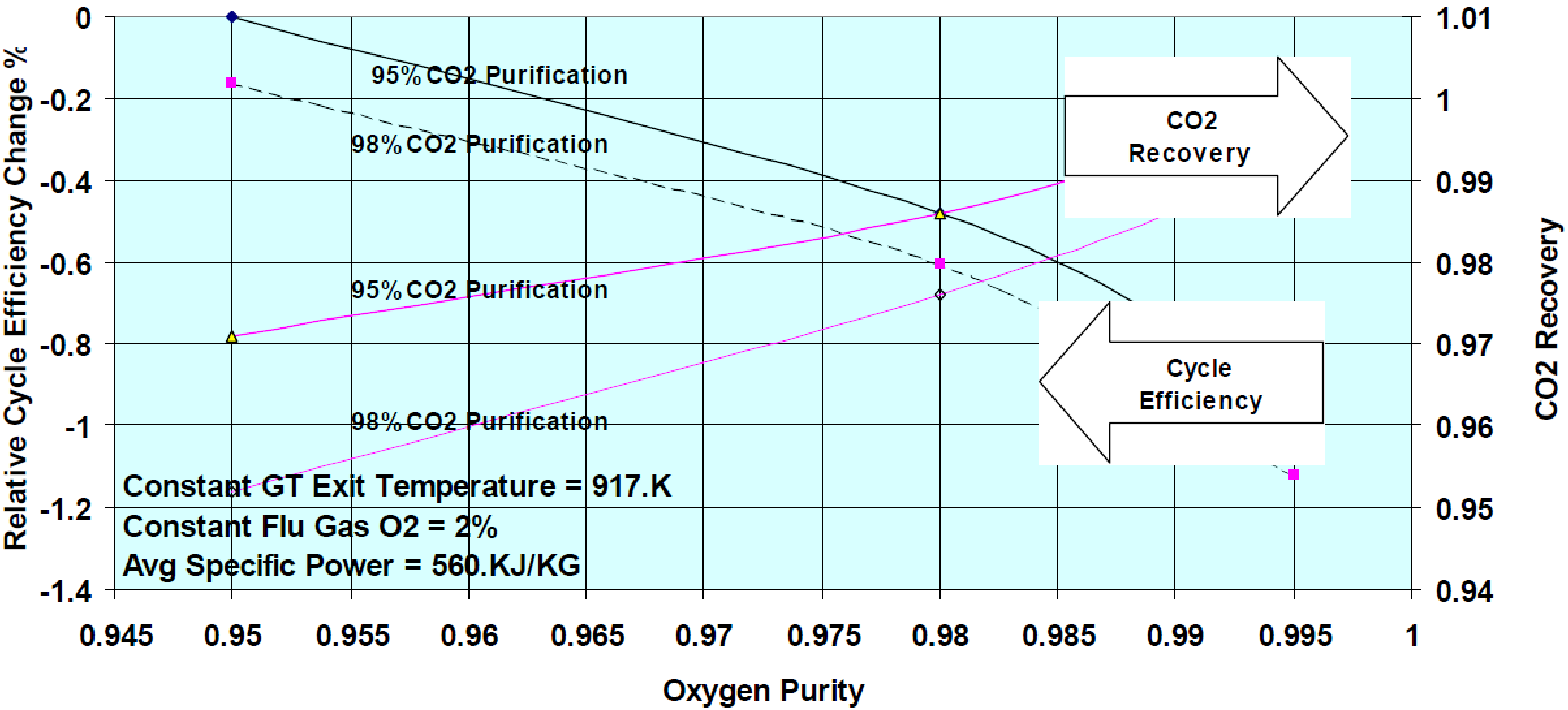
Cryogenic Air Separation Capacity Increase

1902
5 kg/h
(0,1 ton/day)

2006
1,250 Million kg/h
(30,000 ton/day)

Source: Linde

Oxygen Production : Cryogenic Air Separation

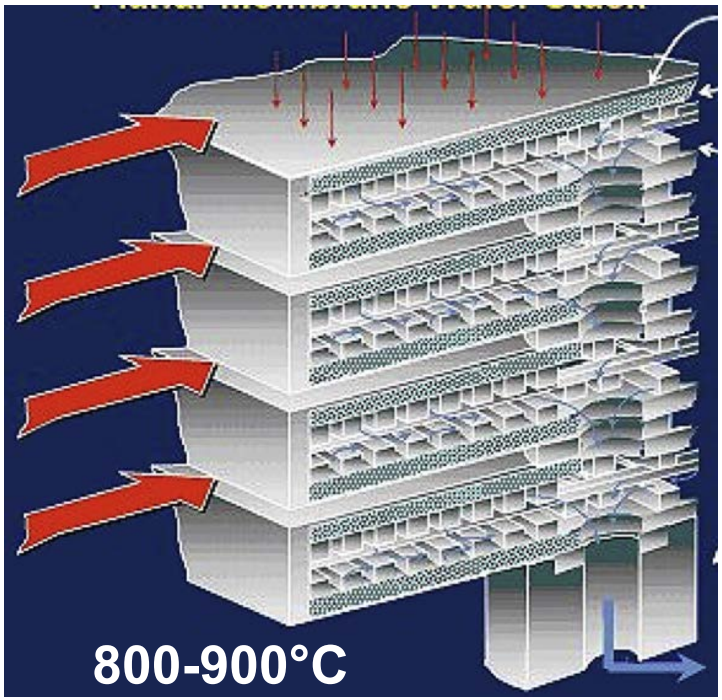


Source: IEAGHG 2010/07

Oxygen Production Cost Reduction Options

Ion Transport Membrane

Air



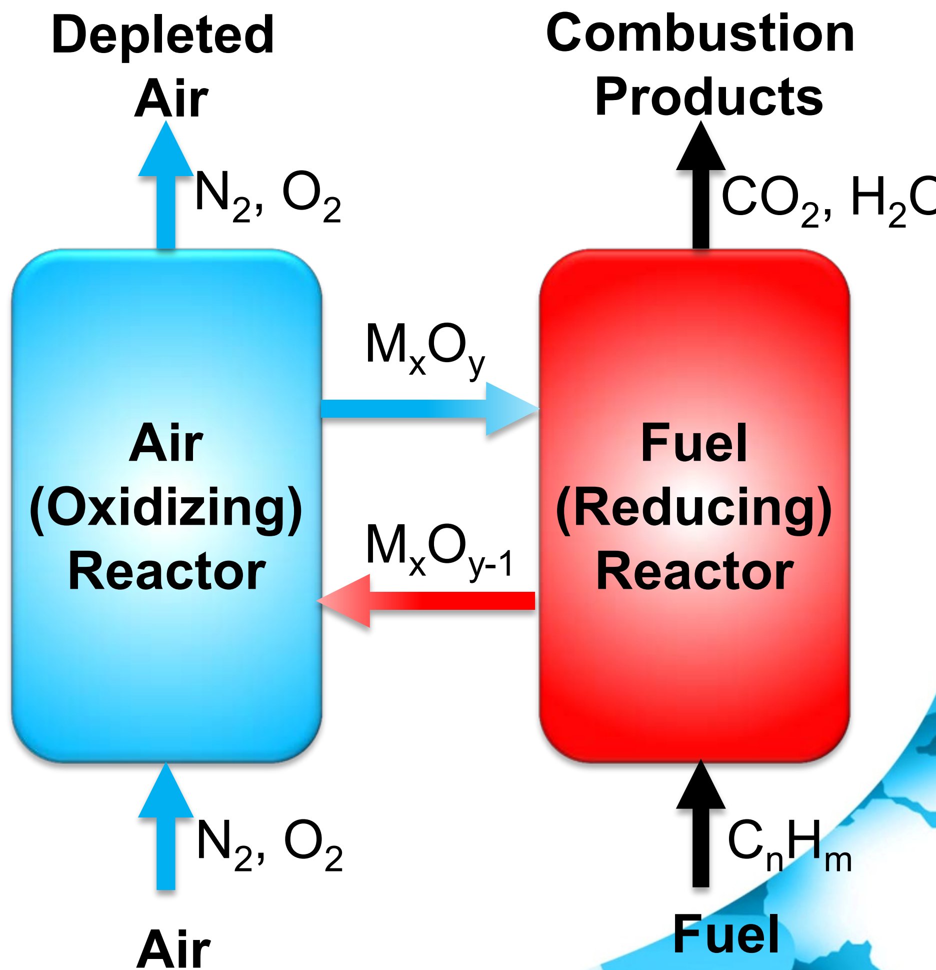
14 to 21 Bar

Pure Oxygen

Integration to IGCC

Source: Air Products

Chemical looping Combustion



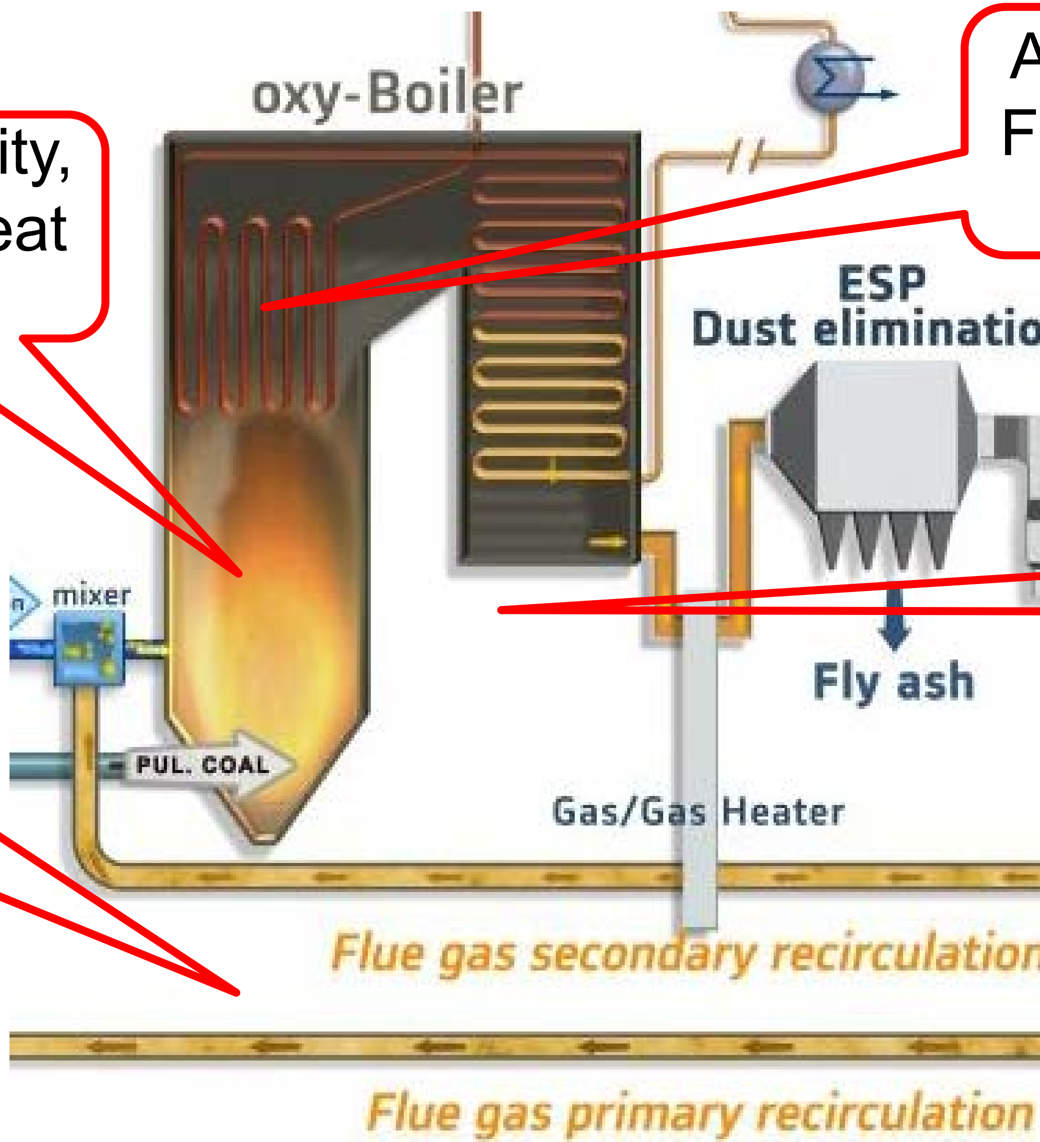
Oxyfuel Boiler

Flame Stability, Radiative Heat Transfer

Ash Slagging, Fouling &Tube Corrosion

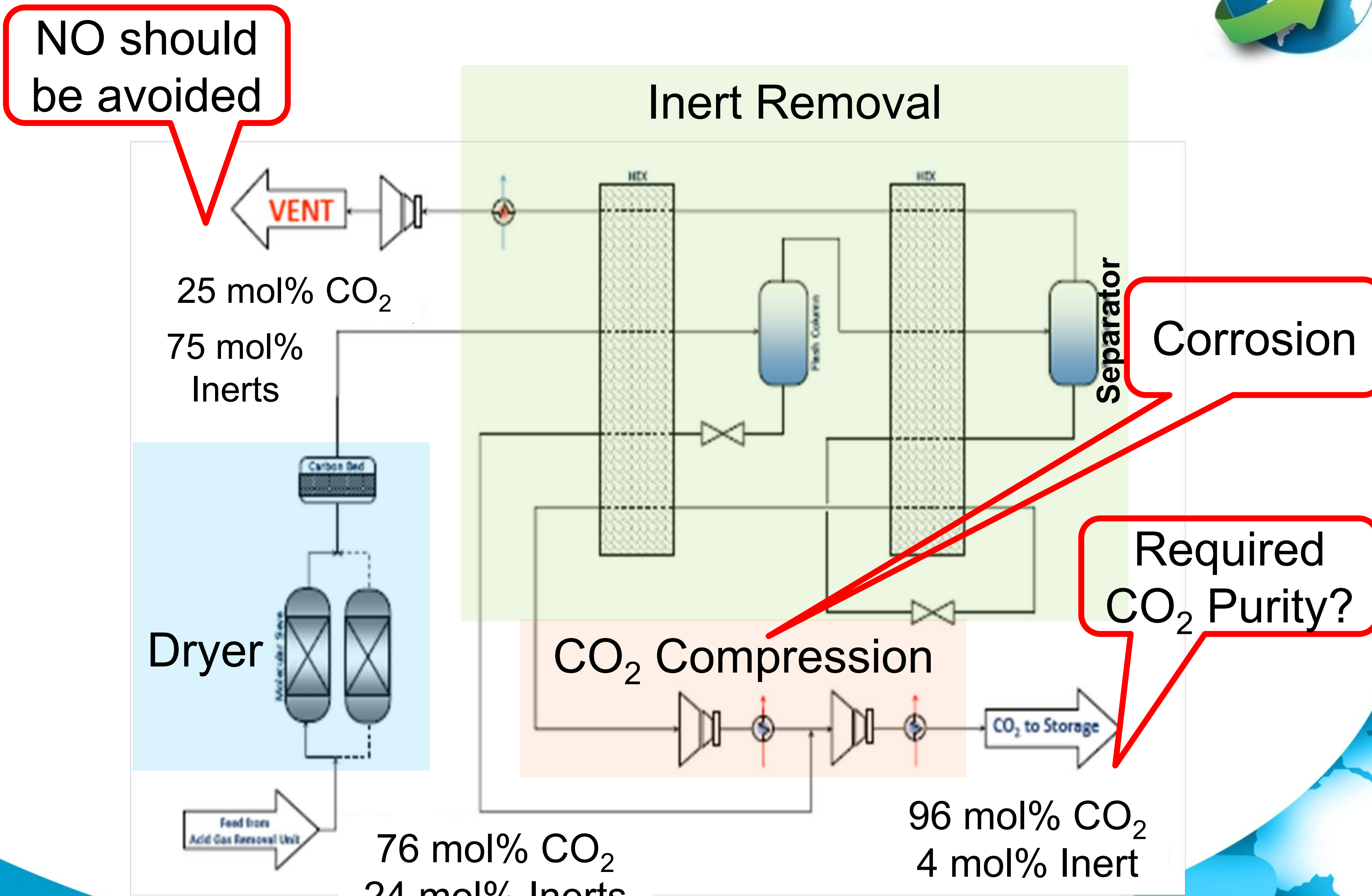
Material Selection

Reduction of Recycled Flue gas



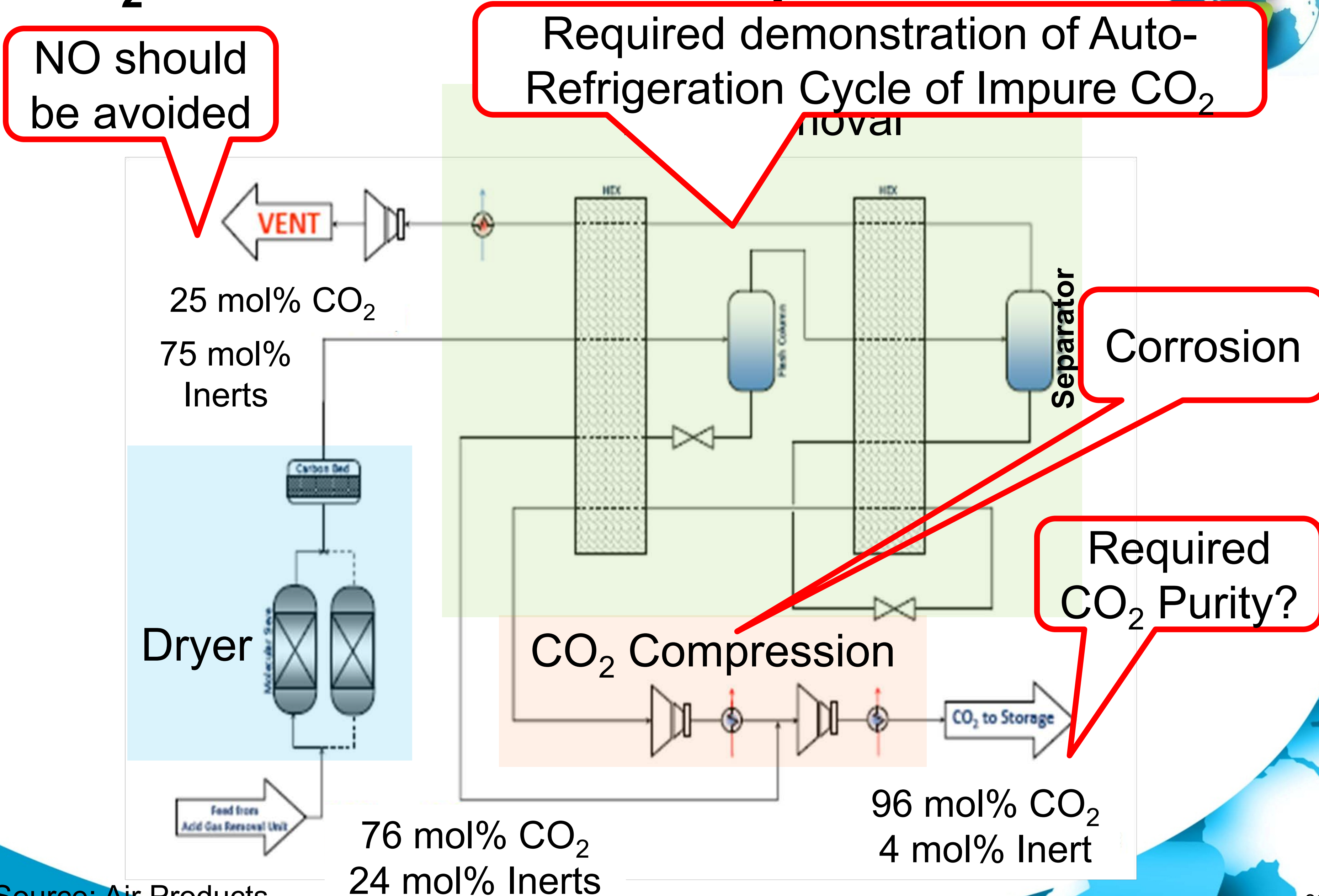
Source: Alstom

CO_2 Purification and Compression

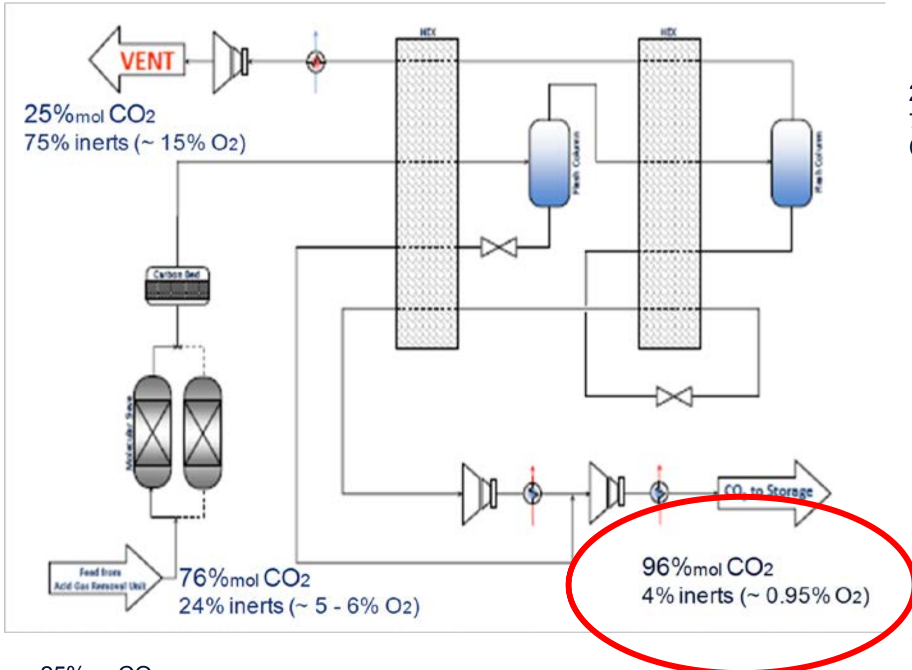


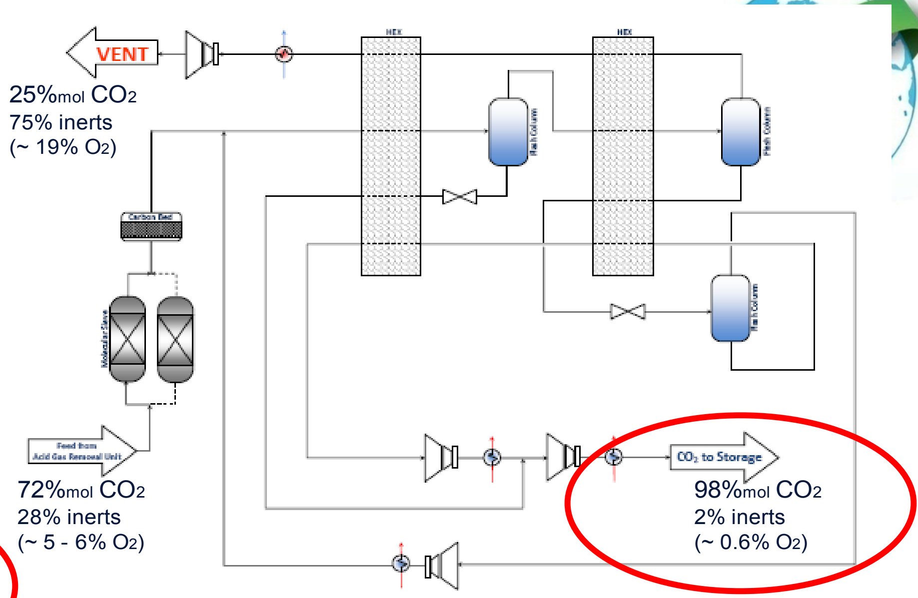
Source: Air Products

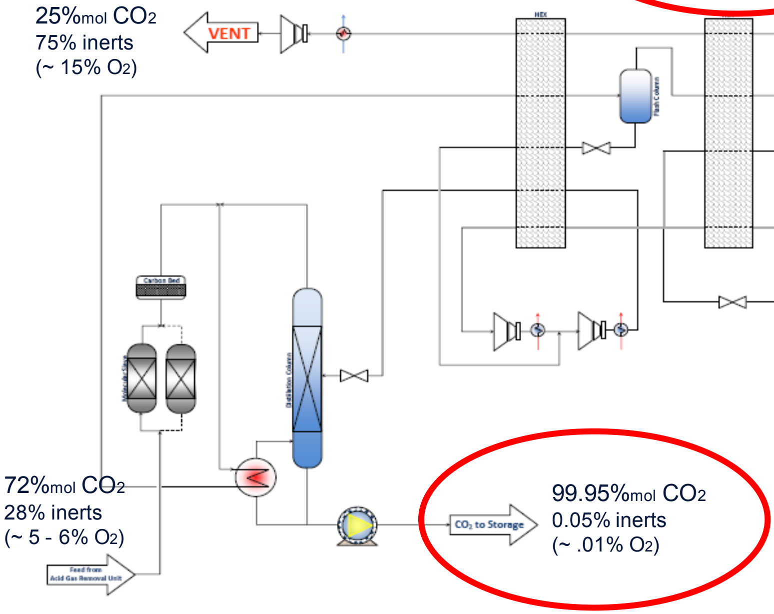
CO_2 Purification and Compression

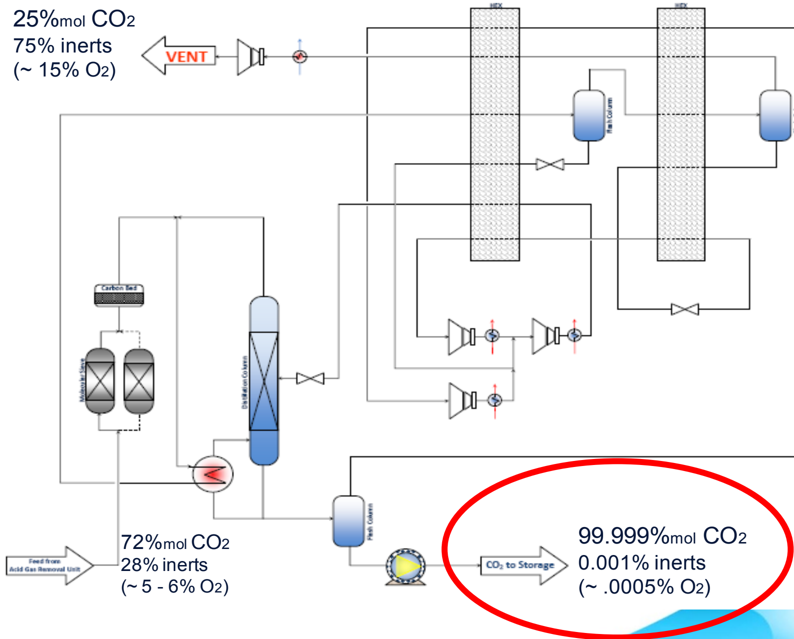


Source: Air Products


VENT
25%mol CO2
75% inerts (~ 15% O2)
HEX
HEX
Carbon Bed
Feed from Acid Gas Removal Unit
76%mol CO2
24% inerts (~ 5 - 6% O2)
CO2 to Storage
96%mol CO2
4% inerts (~ 0.95% O2)

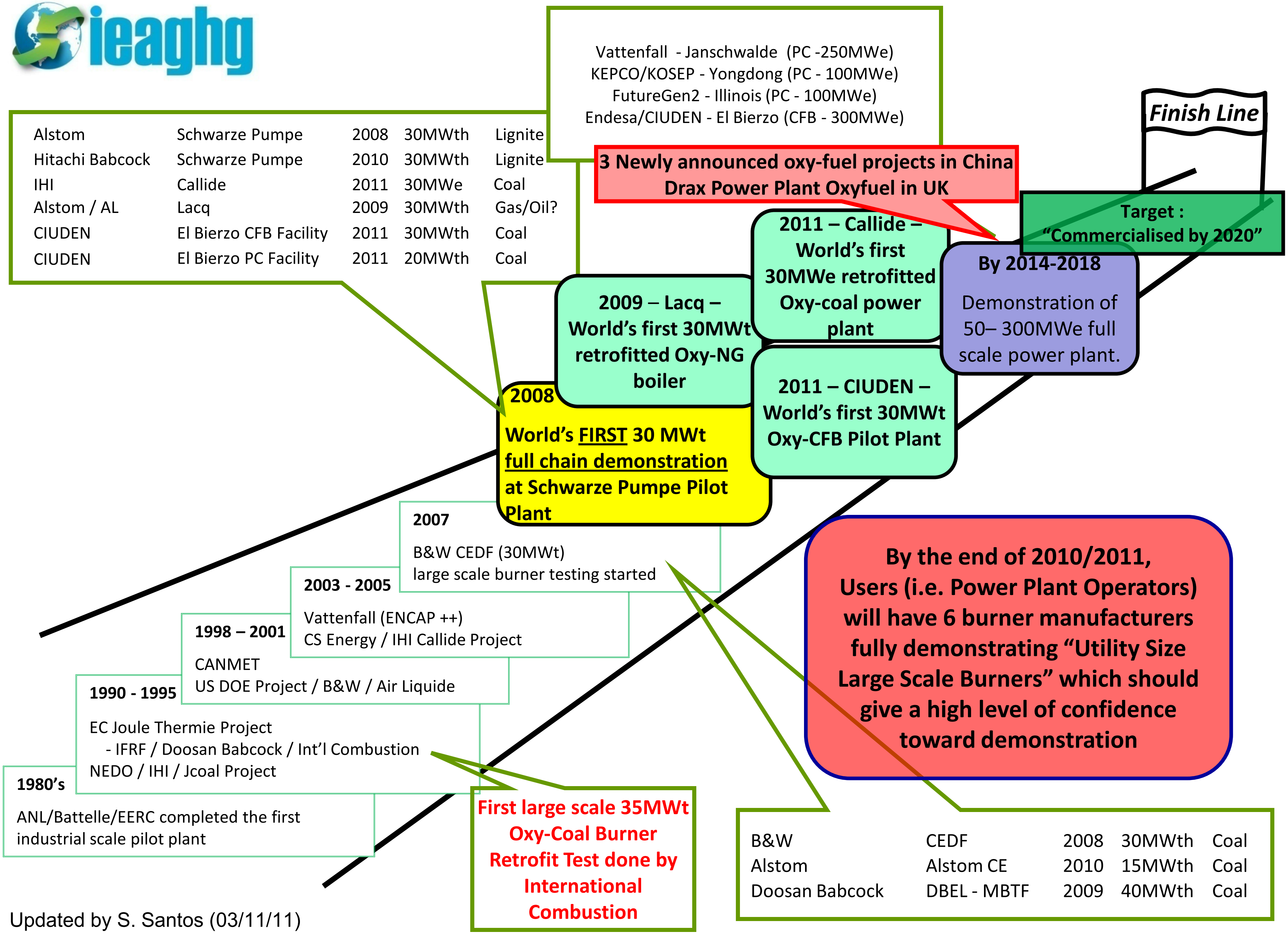

VENT
25%mol CO2
75% inerts
(~ 19% O2)
HEX
HEX
Carbon Bed
Feed from Acid Gas Removal Unit
72%mol CO2
28% inerts
(~ 5 - 6% O2)
CO2 to Storage
98%mol CO2
2% inerts
(~ 0.6% O2)


25%mol CO2
75% inerts
(~ 15% O2)
VENT
72%mol CO2
28% inerts
(~ 5 - 6% O2)
CO2 to Storage
99.95%mol CO2
0.05% inerts
(~ .01% O2)


25%mol CO2
75% inerts
(~ 15% O2)
VENT
72%mol CO2
28% inerts
(~ 5 - 6% O2)
CO2 to Storage
99.999%mol CO2
0.001% inerts
(~ .0005% O2)

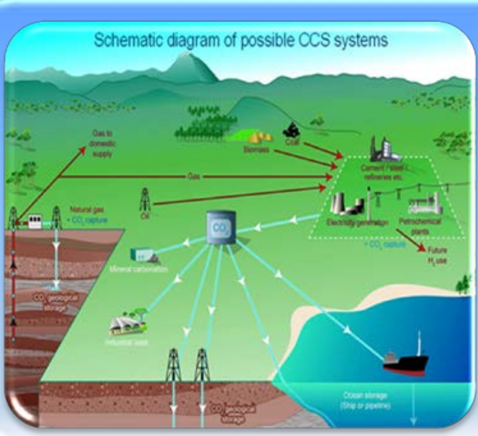
Oxyfuel Large Scale Pilot and Demo Projects

Project	Plant & Fuel Type	Year of Start-up	Plant Size	CO_2 Captured (Mtonne/year)
Schwarze Pumpe (Spremberg, **Germany**)	Coal-fired boiler	2008	30 MW_{th} (~10 MW)	0.075
Total Lacq (Lacq, **France**)	Natural gas-fired boiler	2009	30 MW_{th} (~10 MW)	0.075
OxyCoal UK (Renfrew, **Scotland**)	Coal-fired boiler	2009	40 MW_{th} (~13 MW)	N/A
CIUDEN (Cubillos del Sil, **Spain**)	Coal-fired boiler	2011	20 MW_{th} (~7 MW)	<0.092
CS Energy Callide A (Biloela, **Australia**)	Coal-fired boiler	2012	30 MW_{th}	0.3
FutureGen 2.0 (Meredosia, **Illinois, USA**)	Coal-fired boiler	2015	200 MW	1.3
Datang Daqing (Heilongjiang, **China**)	Coal-fired boiler	2015	350 MW	~1.0
OXYCFB300 (Cubillos del Sil, **Spain**)	Coal-fired boiler	2015	300 MW	N/A
Oxy CCS Demonstration (North Yorkshire, **UK**)	Coal-fired boiler	2016	426 MW_g	~2.0



Updated by S. Santos (03/11/11)

IEAGHG R&D programme



Overview of CO_2 Capture Technology for Power Plants

Post Combustion

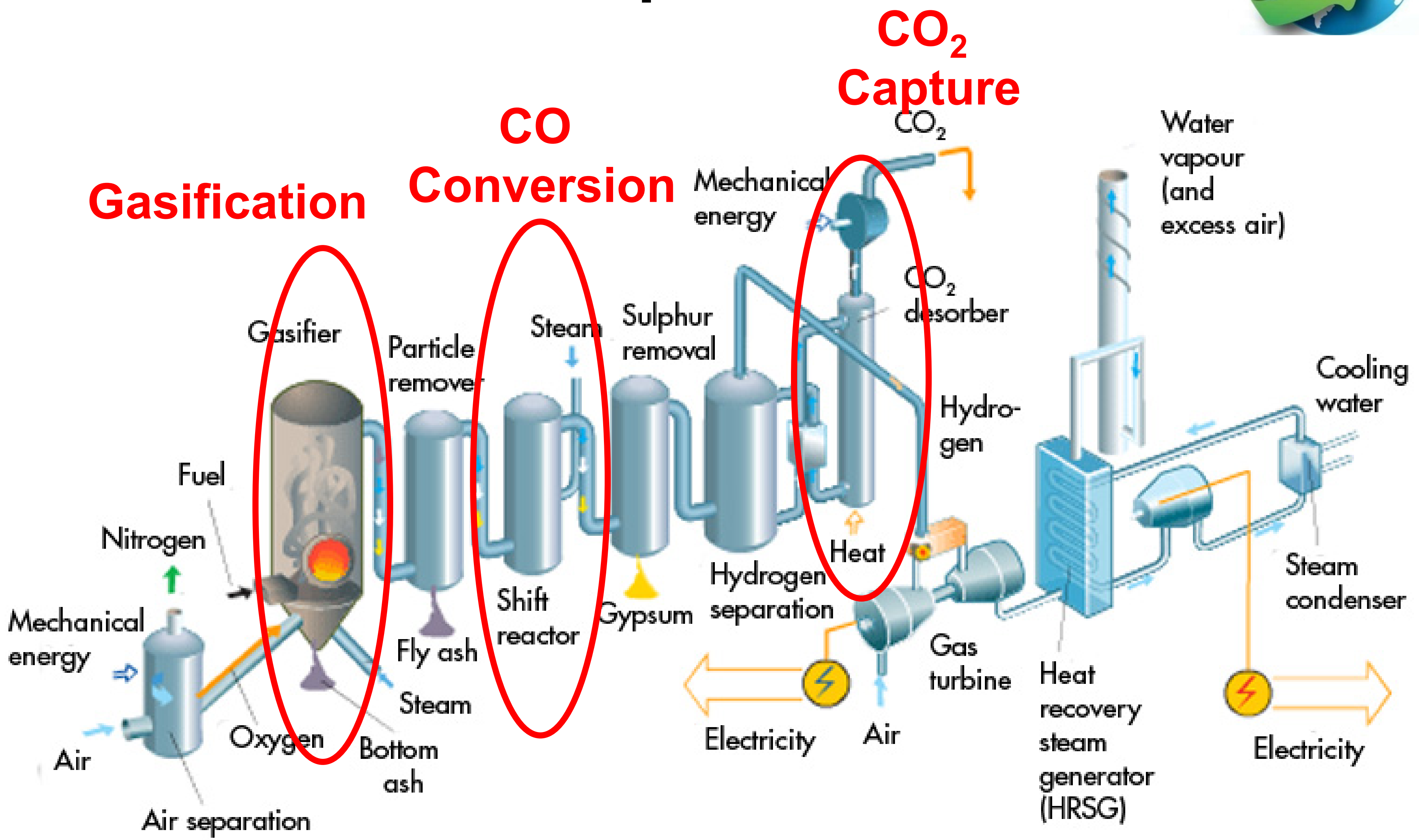
Oxyfuel Combustion

Pre Combustion

Key Issues and Research Direction

Conclusions

Pre-Combustion Capture



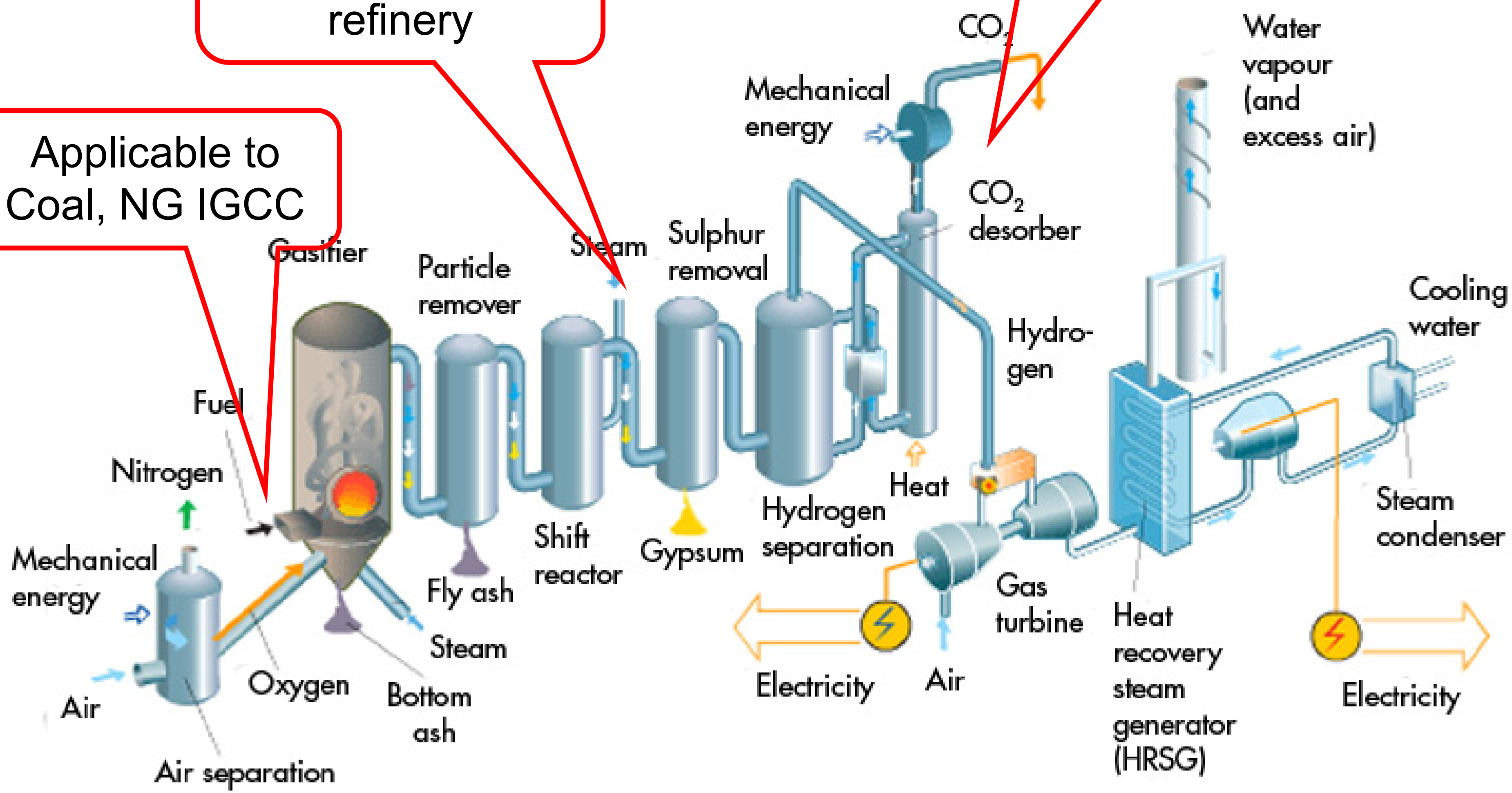
Source: Vattenfall

Why Pre-Combustion Capture ?

Proven Industrial Technology in Oil refinery

90-95% CO_2 is captured

Applicable to Coal, NG IGCC



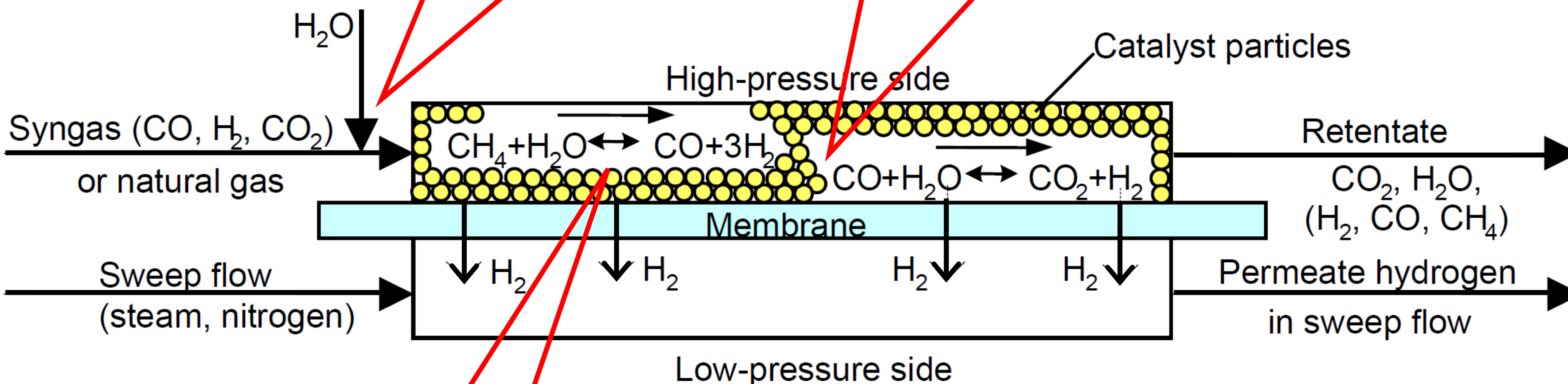
Source: Vattenfall

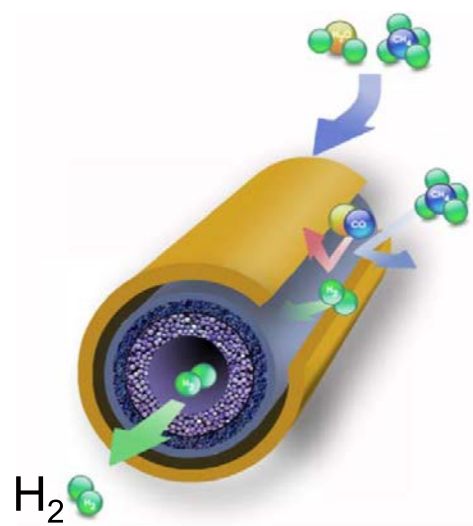
CO Shift Reactor: H_2 Selective Membrane Reactor

Reduction in Steam

Issues related to Catalyst e.g. Sulphur

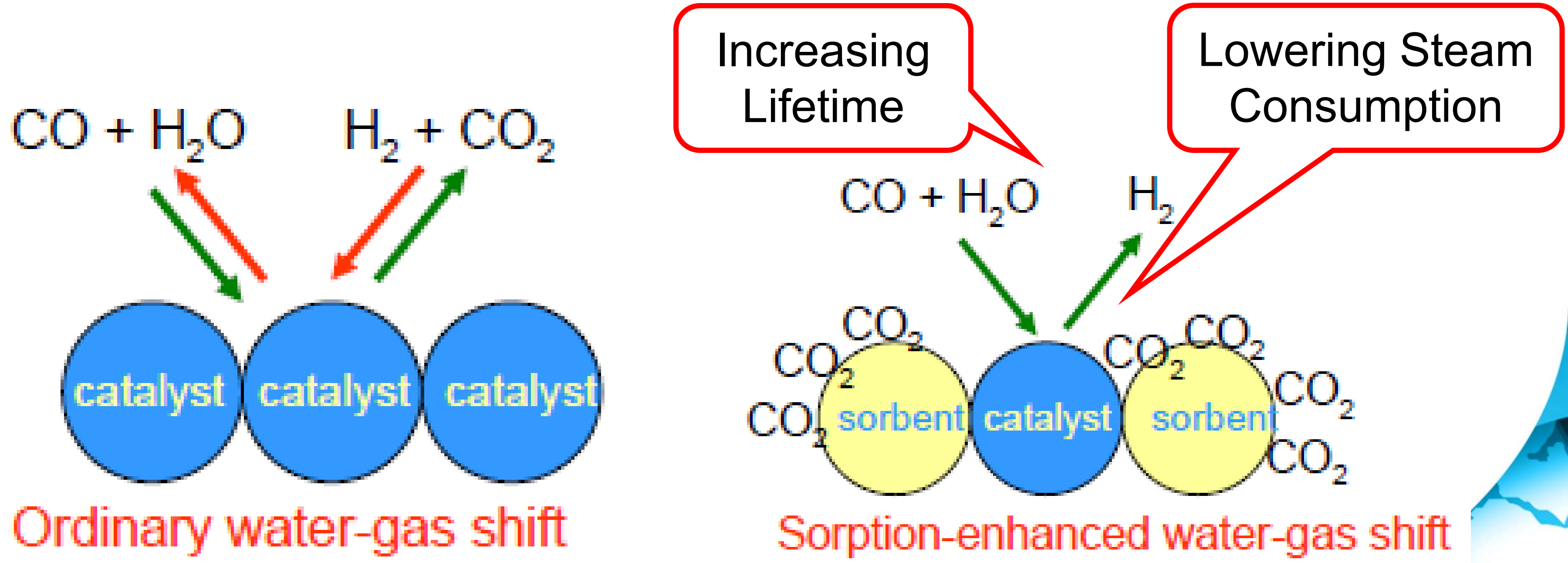
Heat Management



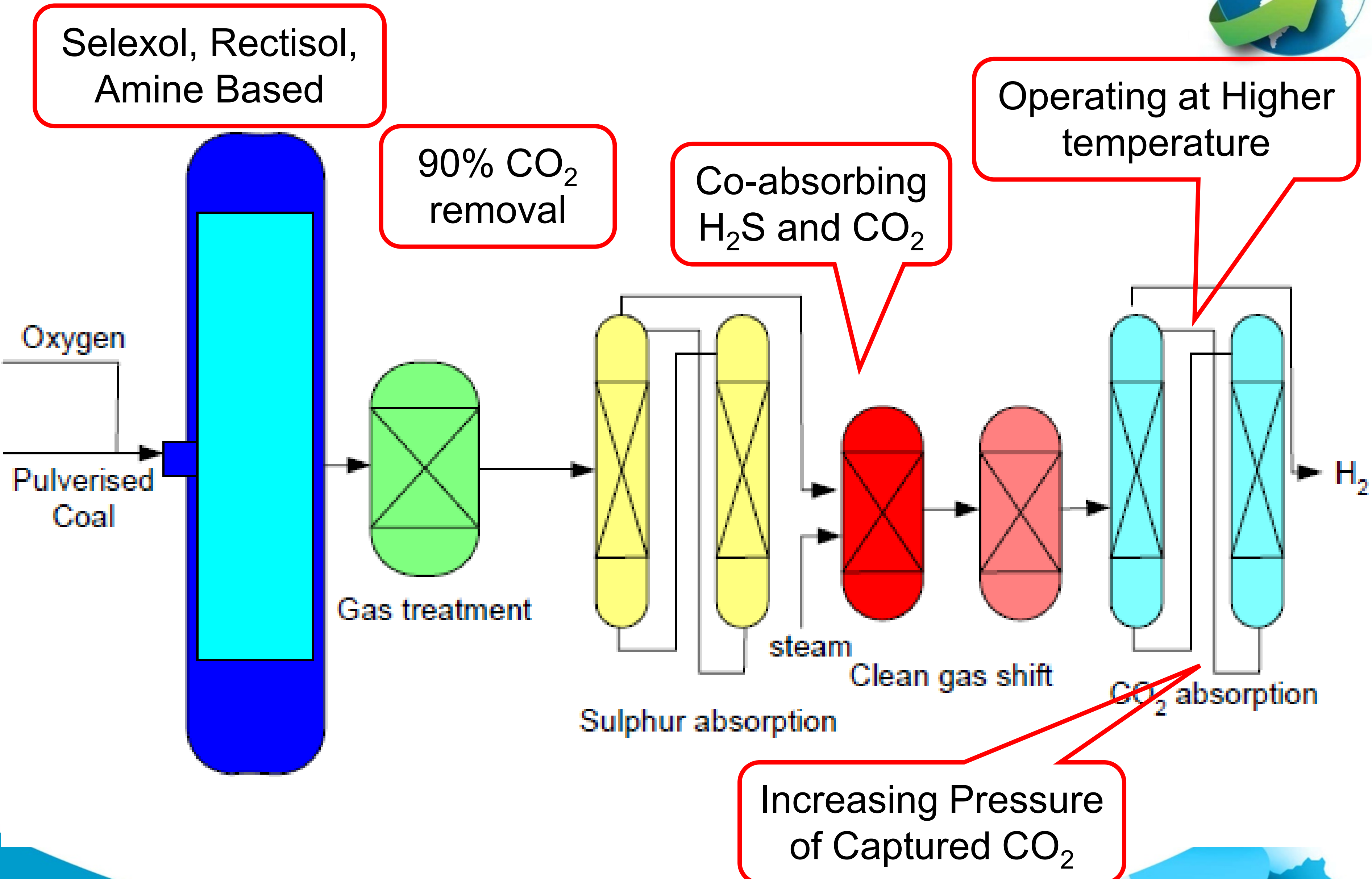


Sorption Enhanced Water Gas Shift Reactor (SEWGS)

- Catalyst is combined with CO_2 sorbent
- When sorbent is saturated with CO_2, it is regenerated with steam
- H_2 is produced at higher temperature and pressure.



Conventional CO_2 Scrubbing



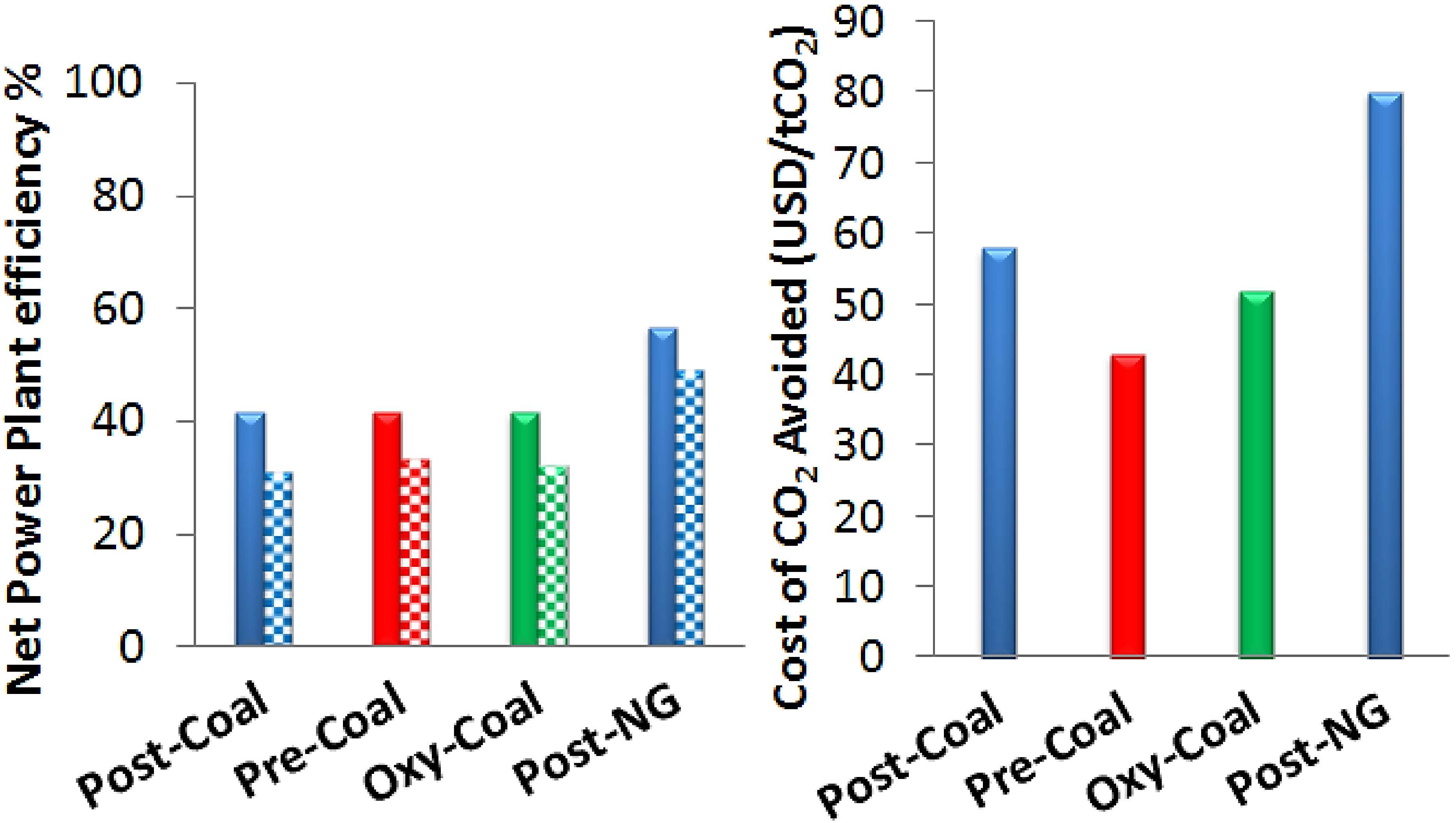
Key Development Area for Pre-Combustion

- ***Development in Gasifier Technology***
  - ✓Adaptation of the Gasifier for CO_2 capture...
- ***Development in Air Separation Units***
  - ✓Membrane Technology???
- ***Development in Shift Reactor***
  - ✓Choice of Sour Vs. Sweet Shift Reaction
- ***Development in Separation of CO_2 using Physical Absorption technology***

Pre Combustion Full Scale Demo. Projects

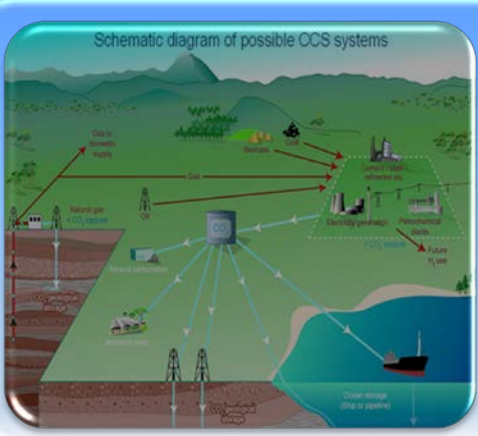
Project	Plant & Fuel Type	Year of Start-up	Plant Size	CO_2 Captured (Mtonne/year)
GreenGen, Tianji Binhai, **China**	Coal IGCC and poly-generation	2011	250 MW	N/A
Don Valley IGCC, Selexol, Stainforth, **UK**	Coal-IGCC	2014	900 MW	4.5
SummitPower, Rectisol, Penwell, **Texas**	Coal IGCC and polygen (urea)	2014	400 MW_g	3.0
Hydrogen Energy, Kern County, **California**	Petcoke IGCC	2016	250 MW	2
RWE Goldenbergwerk, Hurth, **Germany**	Lignite-IGCC	2015	360 MW	2.3
Belle Plaine , Saskatchewan, **Canada**	Coal & PetCoke	N/A	500 MW	>1
Kedzierzyn Zero Emission Power and Chemicals, Opole, **Poland**	Coal-biomass IGCC and polygen	2015	309 MW 500 ktons /yr methanol	2.4
Nuon Magnum, Eeemshaven, **Netherlands**	Multi-fuel IGCC	2015	1200 MW_g	N/A

Performance and Cost of CO_2 Capture



Source: IEA 2011

IEAGHG R&D programme



Overview of CO_2 Capture Technology for Power Plants

Post Combustion

Oxyfuel Combustion

Pre Combustion

Key Issues and Research Direction

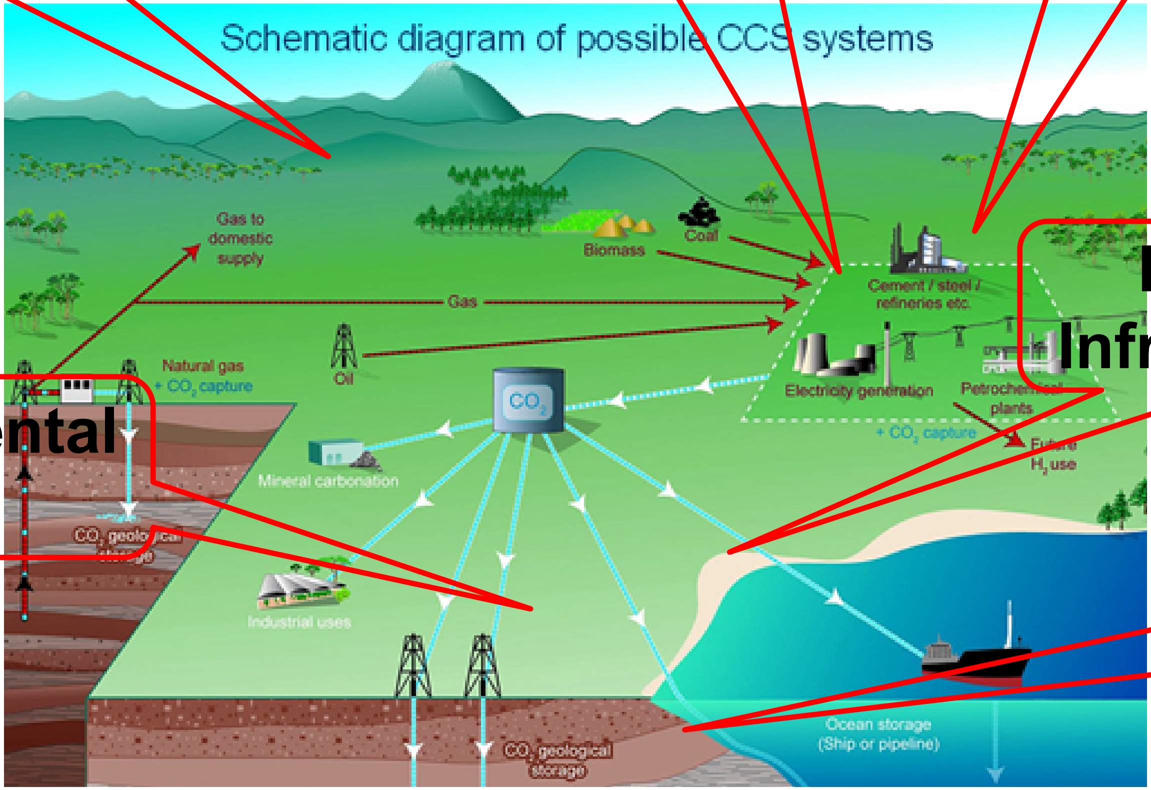
Conclusions

Challenges for CCS in Power Generation

Large Scale Demonstration

Reducing CO_2 Capture Cost

Reducing Energy Penalty



Building Infrastructure

Environmental Impact

Safe CO_2 Storage

Non-technological Issues

Concluding Remarks

- ***<u>CCS will play an important role</u>*** in reducing greenhouse gas emissions from the power generation sector.
- ***<u>Several activities have been initiated worldwide</u>*** in the development of Carbon Capture for Power Generation industry.
- There are two set of horse race among the three options for newly build and retrofit plant. ***<u>There is no leader at the moment!</u>***
- We ***<u>need large scale demonstration</u>*** of the carbon capture technology to build the confidence necessary for a rapid deployment.
- We ***<u>need to overcome the challenges that CCS</u>*** should face toward its path to commercialisation.

Thank you

E-mail:
prachi.singh@ieaghg.org

Website: *www.ieaghg.org*

GHGT-11
Kyoto, Japan
www.ghgt.info
18th - 22nd Nov. 2012