CO_2 Capture for Coal Fired Power Plant
The Challenges Ahead...

Stanley Santos

IEA Greenhouse Gas R&D Programme

Cheltenham, UK

CCS Opportunities in CCOP Region

CCOP-EPPM Workshop (Indonesia)

September 2012

IEA GHG Introduction

- ***IEA Greenhouse Gas R&D Programme (IEA GHG)***
  - What is programme's relation to the International Energy Agency (IEA)?
  - What the Programme does?
  - Who are the members?
  - What role do we play in a global CCS context?

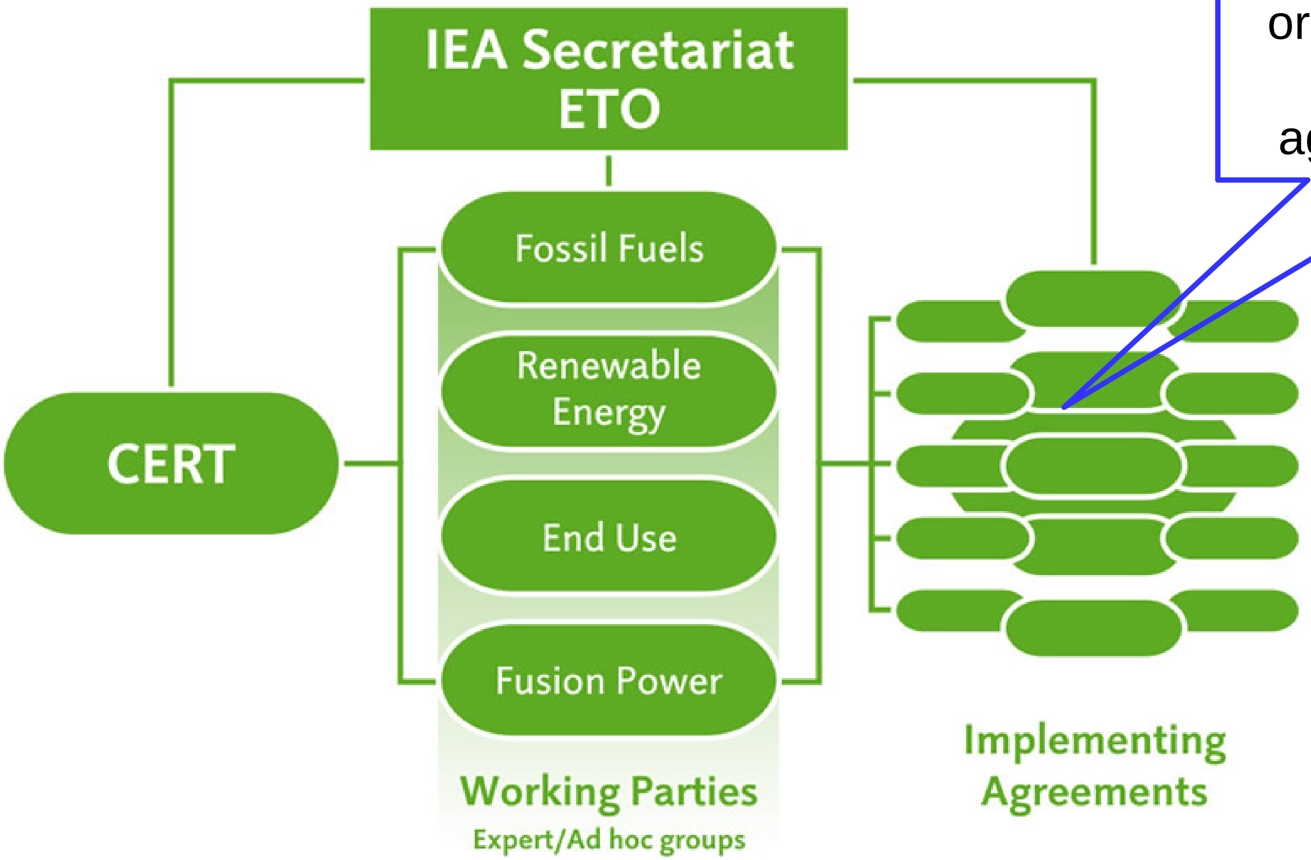
International Energy Agency

- ***The International Energy Agency (IEA) is an intergovernmental organisation which acts as energy policy advisor to 28 member countries in their effort to ensure reliable, affordable and clean energy for their citizens.***

- ***Founded during the oil crisis of 1973-74, the IEA's initial role was to co-ordinate measures in times of oil supply emergencies.***
  - 1st Implementing Agreement under IEA is the IEA Clean Coal Centre

IEA Greenhouse Gas R&D Programme

Our Relation to the International Energy Agency



IEA GHG is one of 40 organisations having an implementing agreement with IEA

IEA Greenhouse Gas R&D Programme

- ***A collaborative research programme founded in 1991 as an IEA Implementing Agreement fully financed by its members***
  - 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
- ***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

Members and Sponsors

IEAGHG Activities

- ***Task 1: Evaluation of technology options***
  - Based on a standard methodology to allow direct comparisons and are peer reviewed
- ***Task 2: Facilitating implementation***
  - Provision of “evidence based information”
- ***Task 3: Facilitating international cooperation***
  - Knowledge transfer from existing, laboratory, pilot and commercial scale CCS projects globally
- ***Task 4:To disseminate the results as widely as possible.***

Specific Area of Focus for CO_2 Capture Technology

- ***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

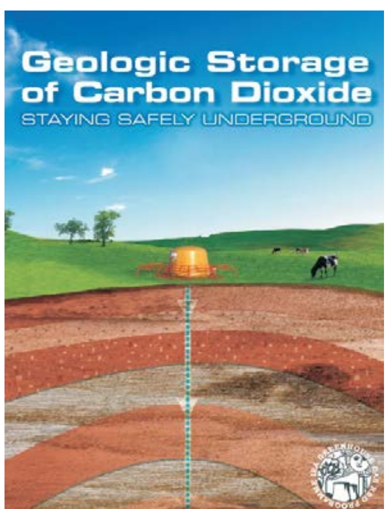
Global Policy Context

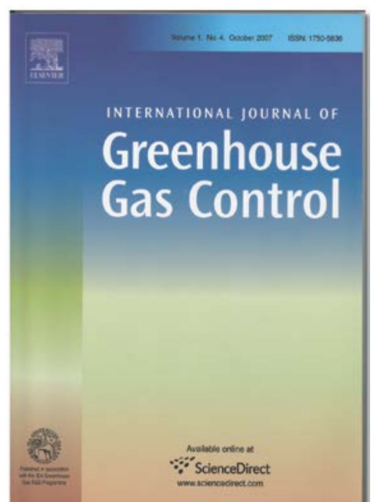
International Policy Setting

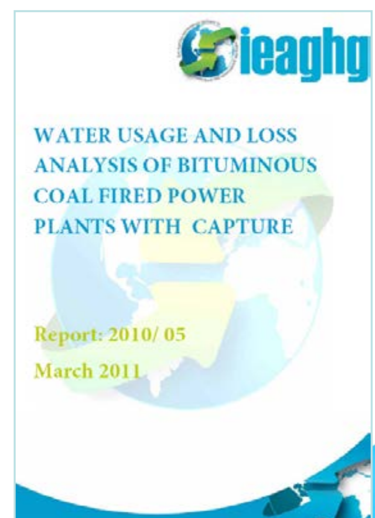
Implementation actions

- National/Corporate policy setting
- National/Corporate research programmes

Dissemination







Over the past 20 years...

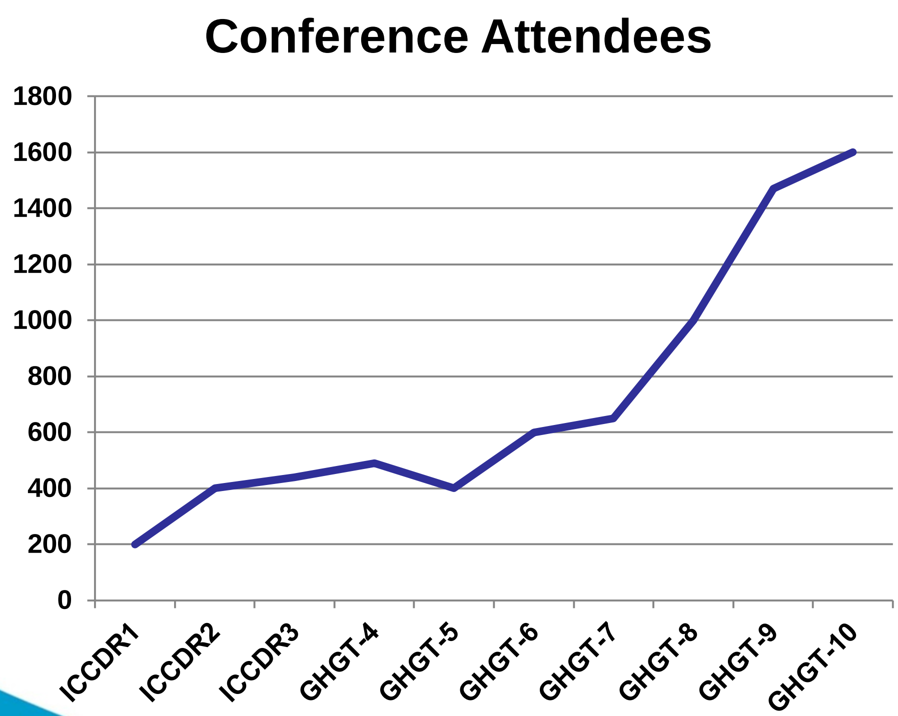
Growth in Interest in CCS has been significant

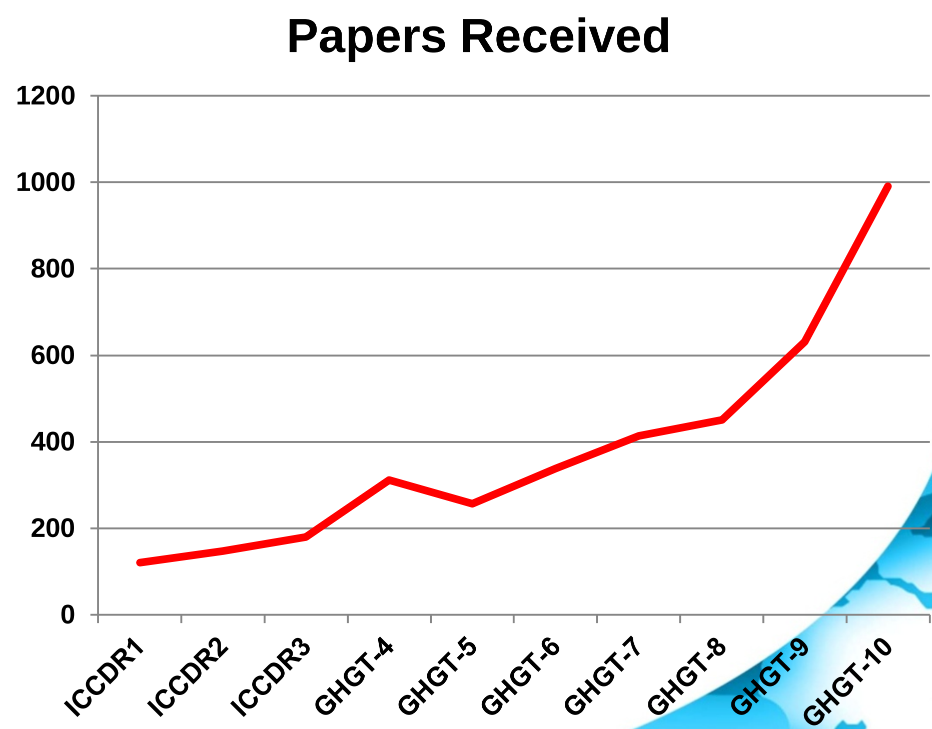
GHGT-11
18th-22nd Nov. 2012
Kyoto, Japan
www.ghgt.info

1220 Abstracts submitted

- a new record

Registration now open…





Overview

- ***Why we need CO_2 capture and storage?***
- ***An Overview to CO_2 CaptureTechnologies***
  - Post Combustion CO_2 Capture
  - Oxyfuel Combustion with CO_2 Capture
  - Pre-Combustion CO_2 Capture
- ***Some of the Challenges, Key Issues and Direction of Research***
- ***Concluding Remarks***

Introduction

WHY WE NEED CO_2 CAPTURE AND STORAGE

ETP 2012 – Choice of 3 Futures

ETP 2012

2DS

a vision of a **sustainable** energy system of reduced Greenhouse Gas (GHG) and CO_2 emissions

The 2°C Scenario

4DS

reflecting pledges by countries to cut emissions and boost energy efficiency

The 4°C Scenario

6DS

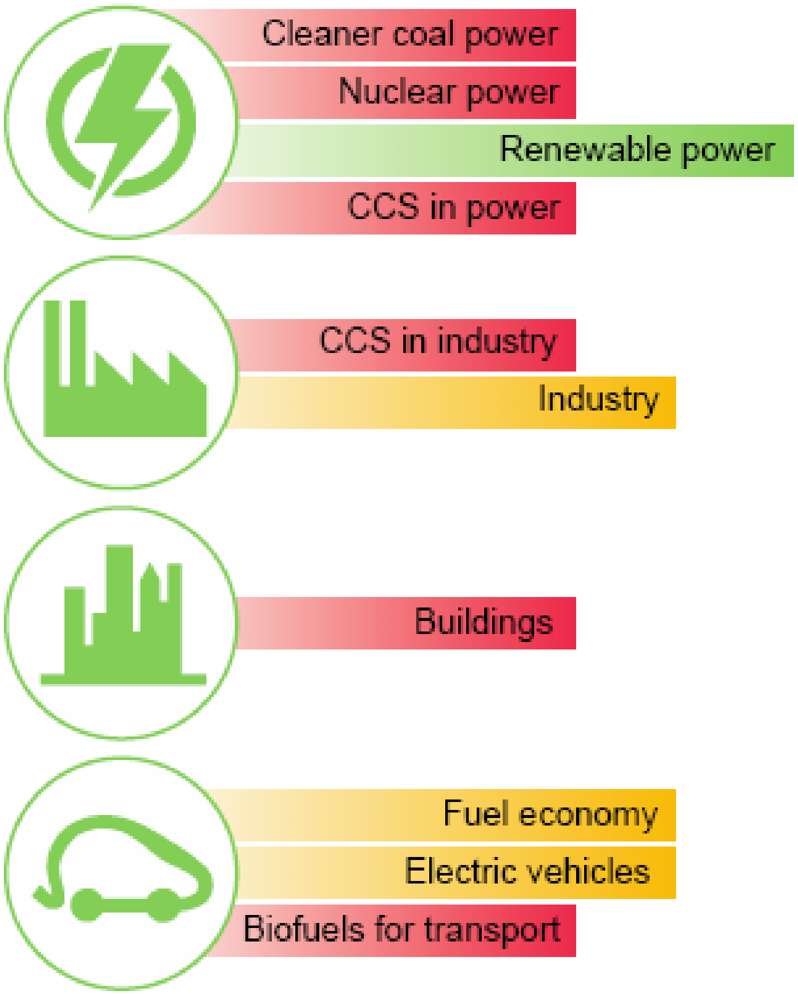
where the world is now heading with potentially **devastating** results

The 6°C Scenario

International Energy Agency

Clean energy: slow lane to fast track

ETP 2012

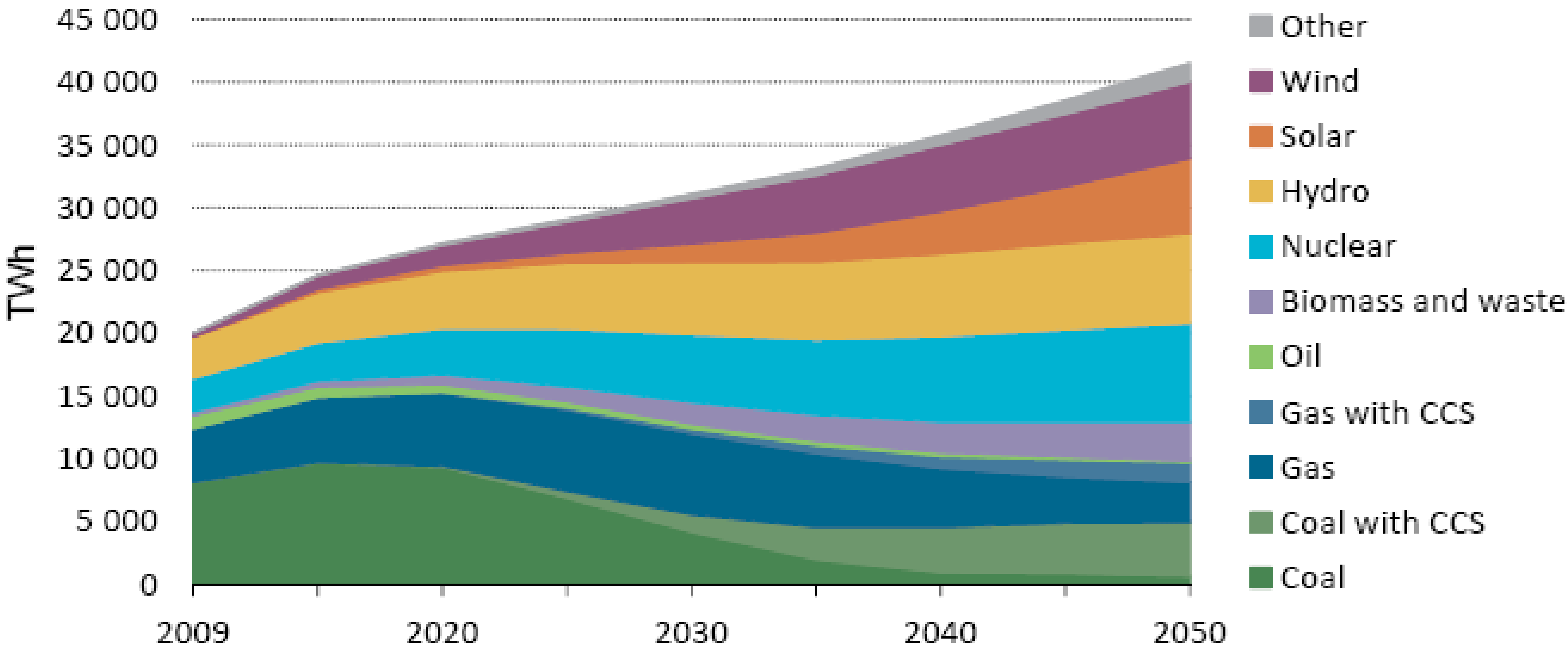


Progress is too slow in almost all technology areas

Significant action is required to get back on track

Low-carbon electricity: a clean core

ETP 2012

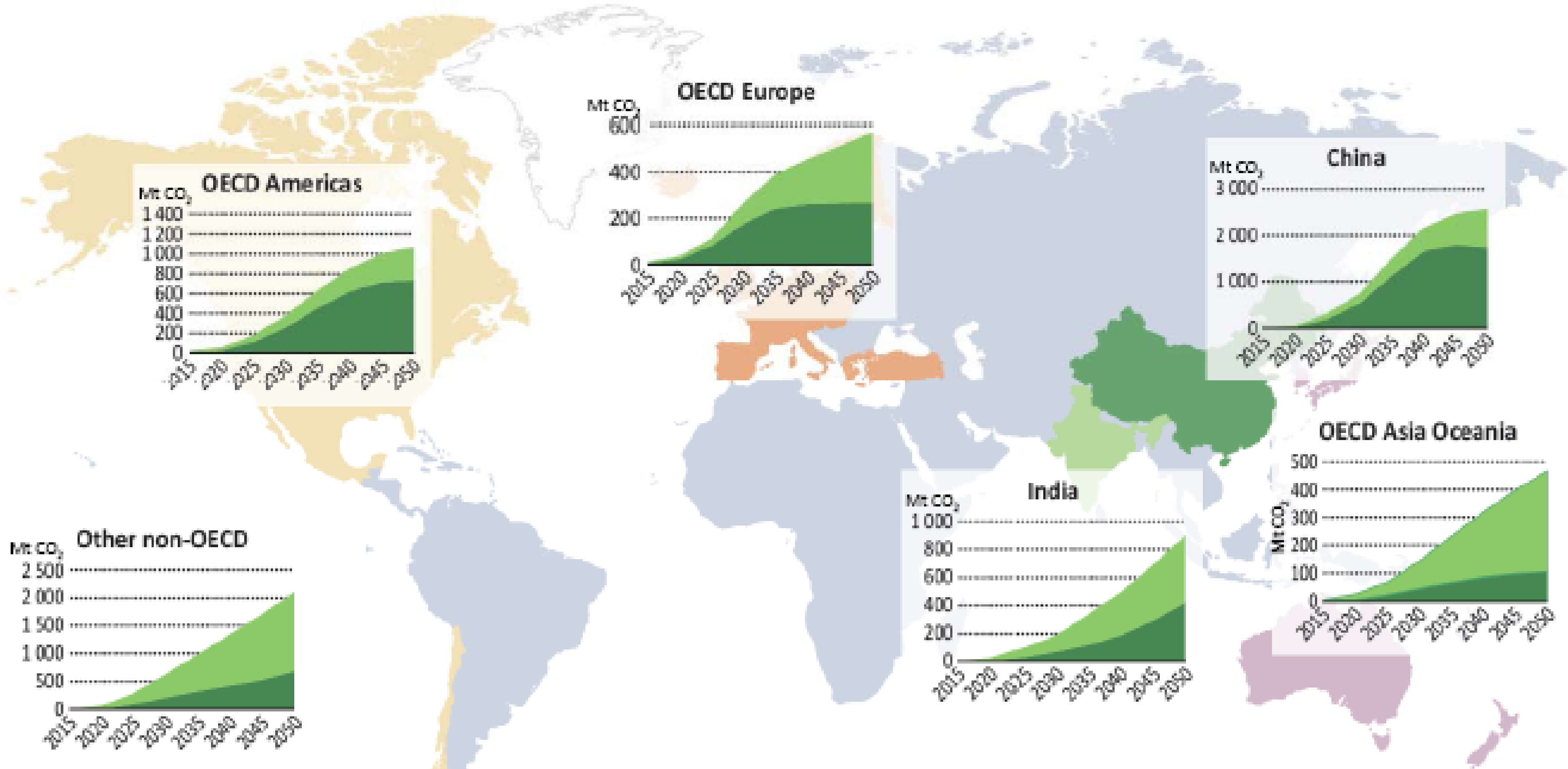


Renewables will generate more than half the world's electricity in the 2DS

International Energy Agency

The CCS infant must grow quickly

ETP 2012



Note: Capture rates in $MtCO_2$ /year

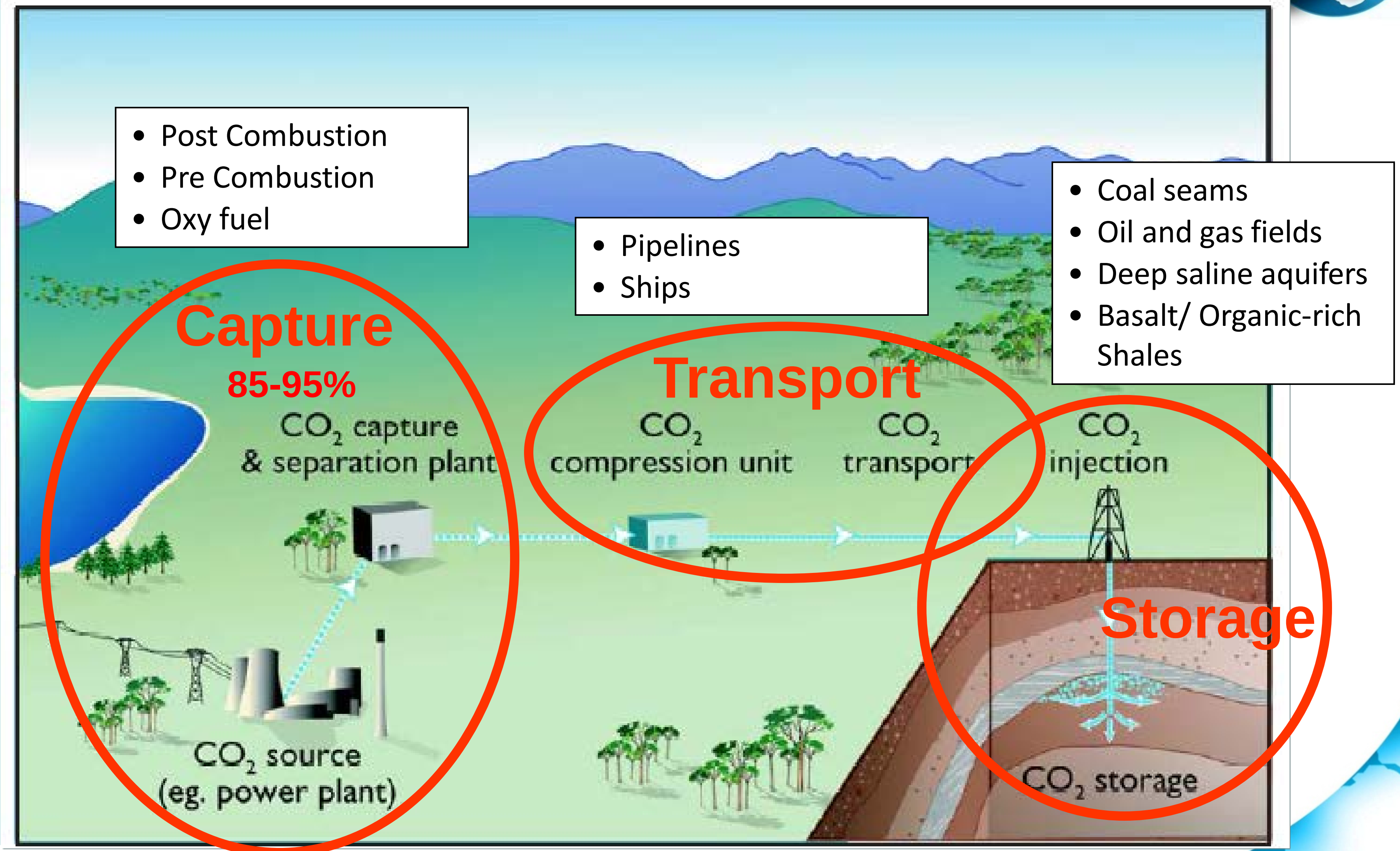
Power generation   Industrial applications

International Energy Agency

Introduction

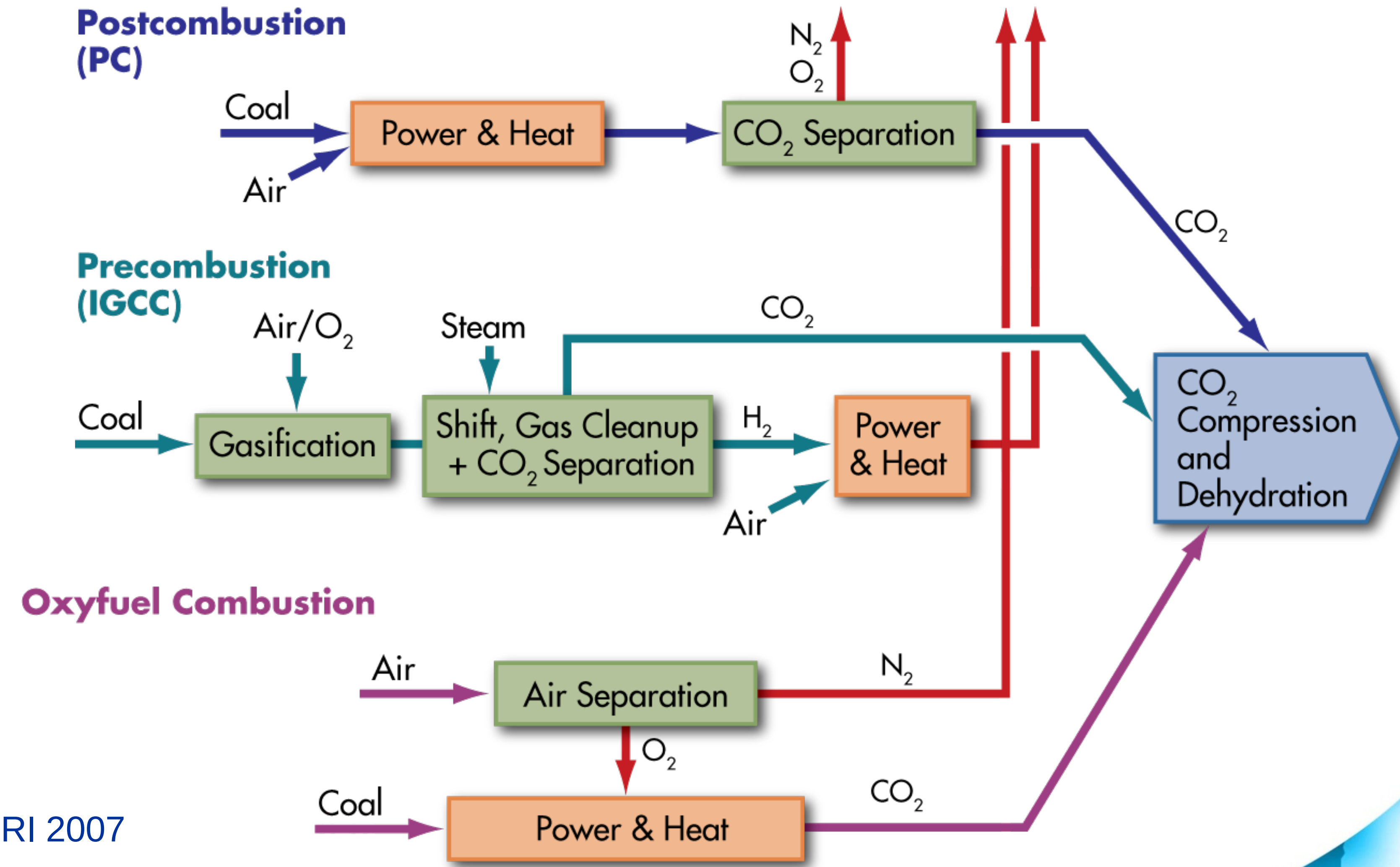
CO_2 CAPTURE TECHNOLOGY FOR POWER GENERATION - AN OVERVIEW

What is CCS?



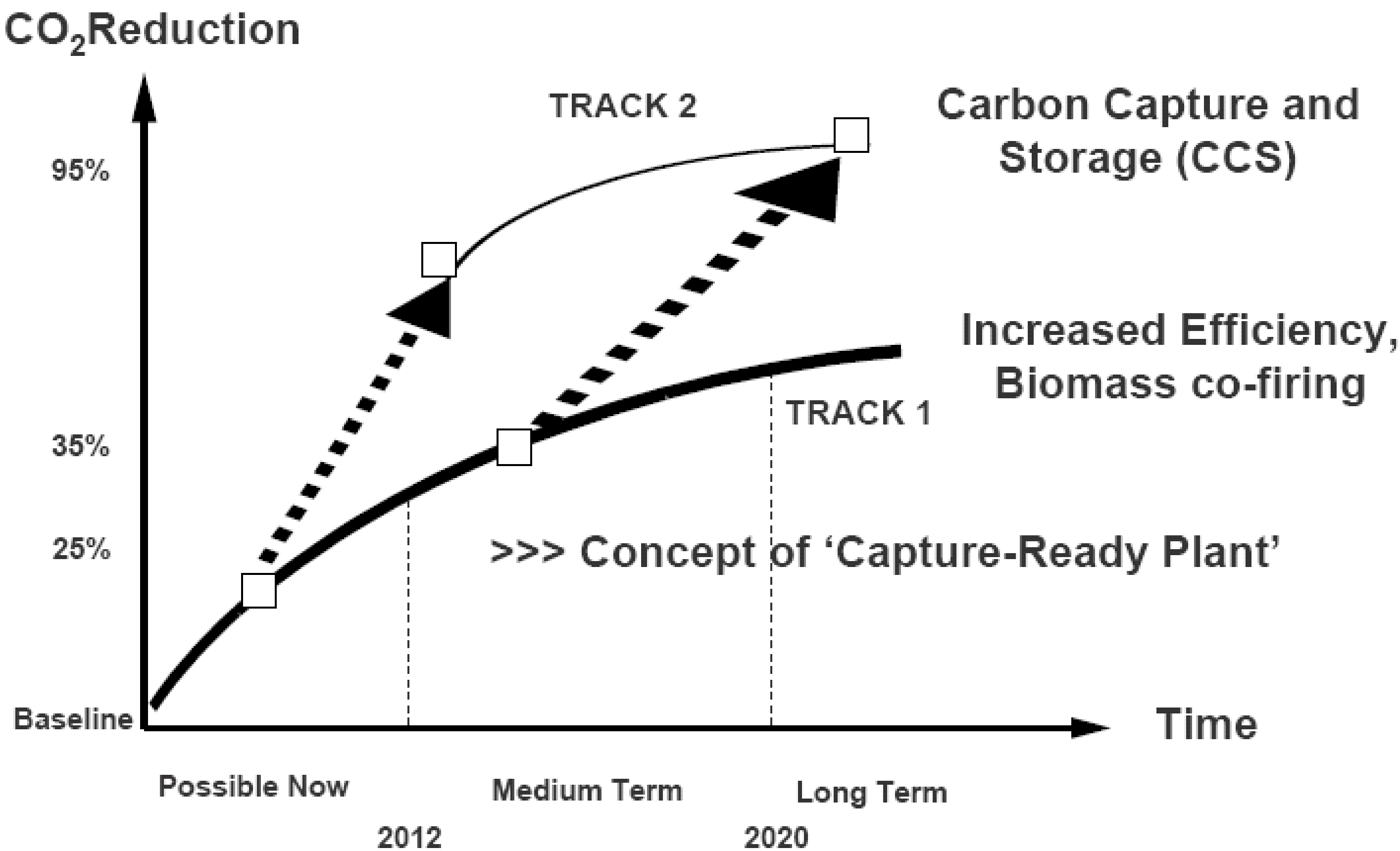
Post Combustion
Pre Combustion
Oxy fuel
Pipelines
Ships
Coal seams
Oil and gas fields
Deep saline aquifers
Basalt/ Organic-rich Shales
Capture
85-95%
CO_2 capture & separation plant
CO_2 source (eg. power plant)
Transport
CO_2 compression unit
CO_2 transport
CO_2 injection
Storage
CO_2 storage

CO_2 Capture Options



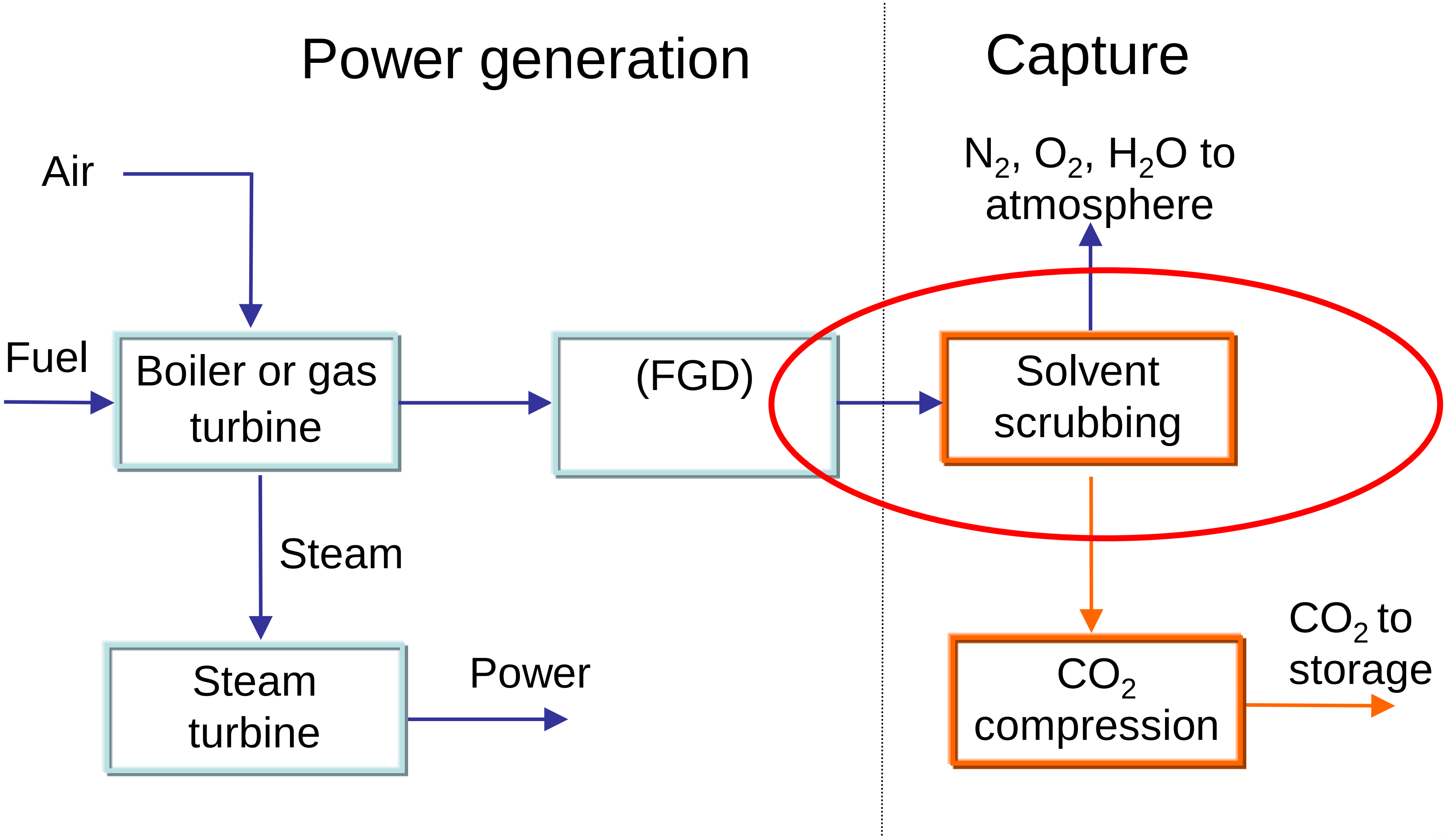
EPRI 2007

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



POST COMBUSTION CO_2 CAPTURE TECHNOLOGY FOR COAL FIRED POWER GENERATION

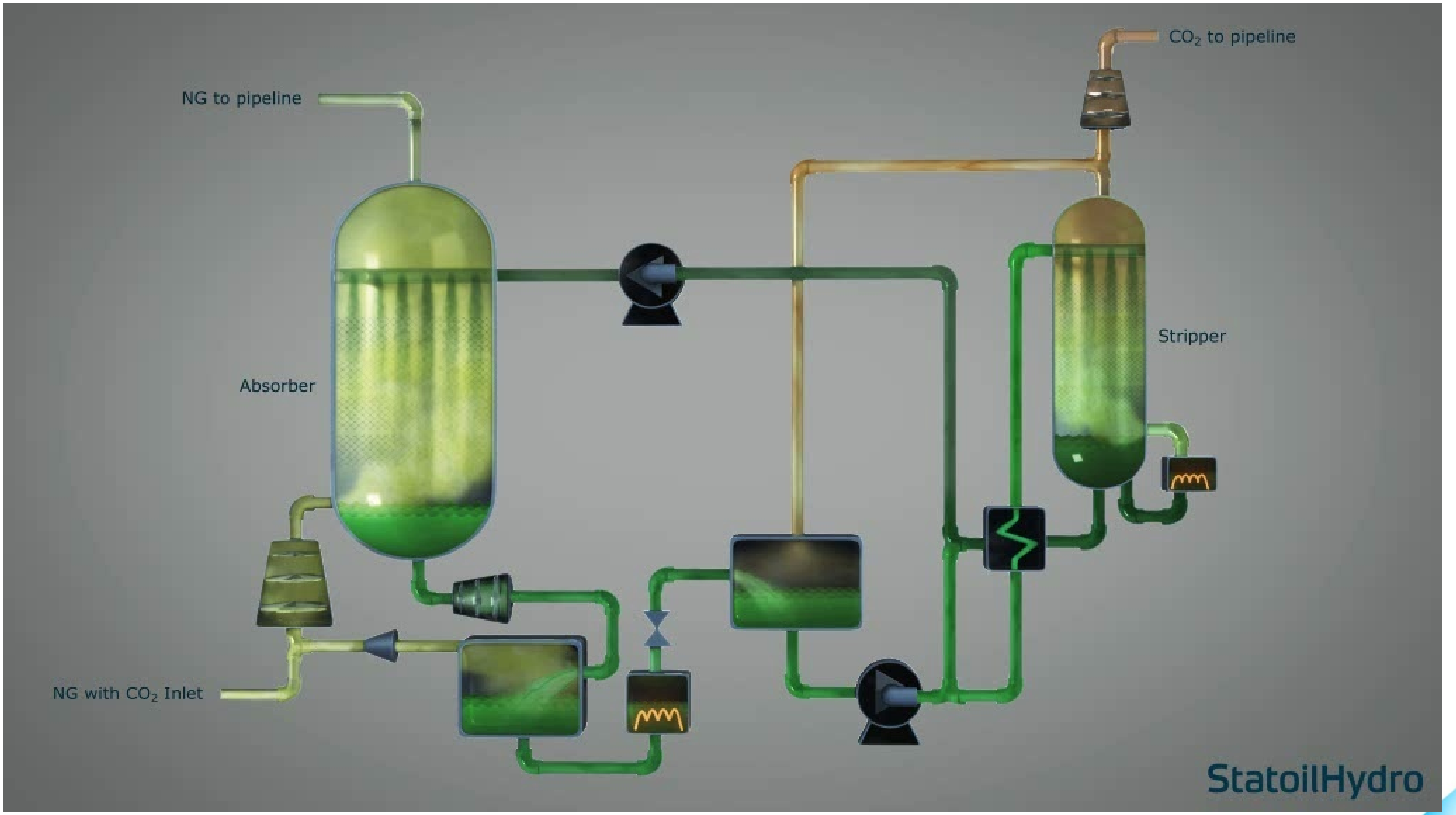
Post-Combustion Capture



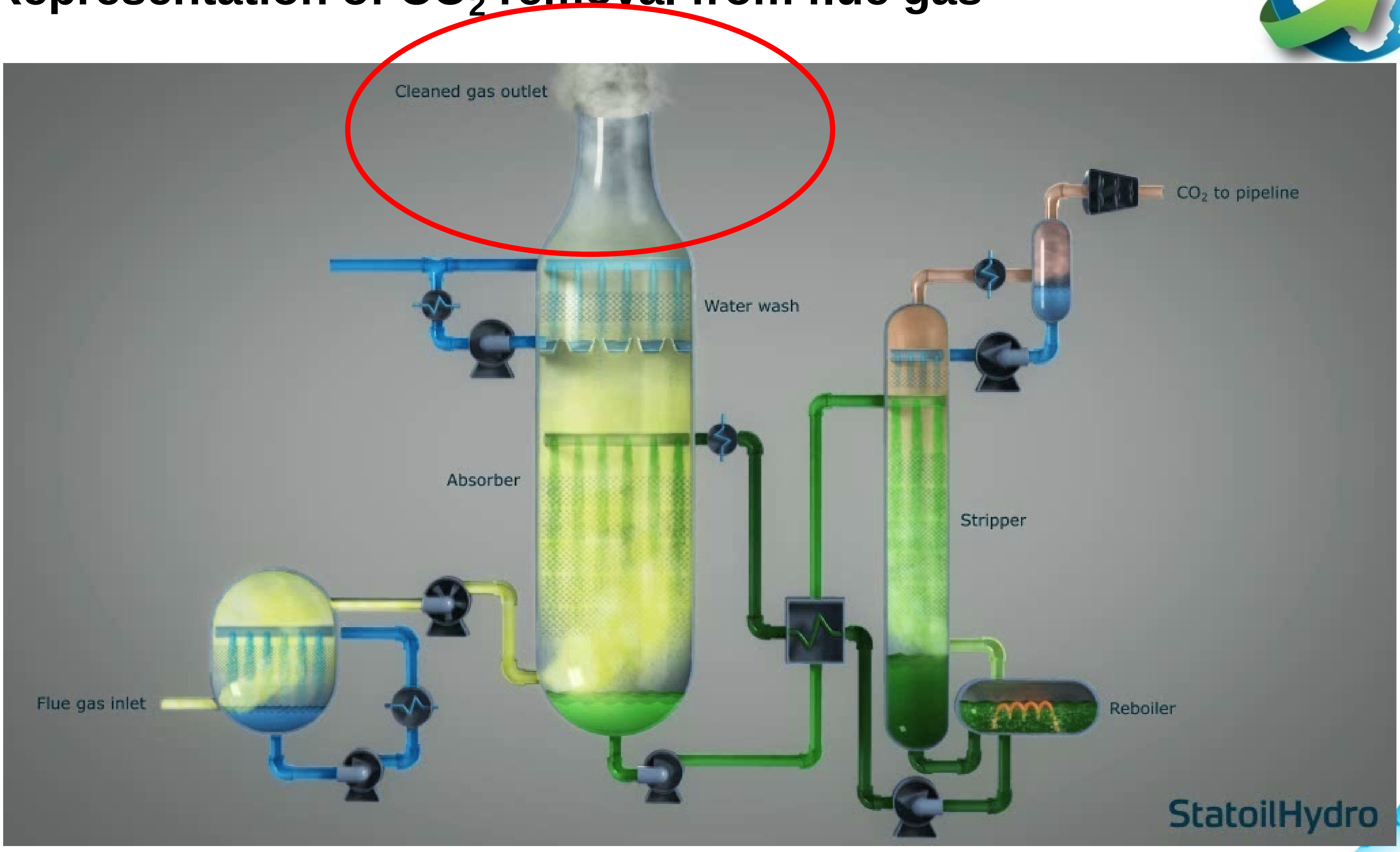
CO_2 Based Solvent Scrubbing

- ***Use of Amine scrubbing to capture CO_2 is the most mature among the 3 mostly considered capture technology options for the power generation.***
- ***Amine based solvent is currently the commonly used for CO_2 capture***
  - widely used in food processing (ie. carbonated drinks) and chemical industries (ie. Urea plant)
  - Large scale demonstration (> 1 MT/yr of scale) – mostly in oil and gas fields applications
  - For example in Sleipner and In Salah
  - New projects such as Gorgon (~ 3 MT/yr in scale) using parallel train of post-capture gas treatment plant

Representation of CO_2 removal from natural gas processing



Representation of CO_2 removal from flue gas



Challenges to Post CO_2 Combustion Capture

- **Low total flue gas pressure**
- **Low CO_2 concentrations**
- **Very high flow rates (Huge columns)**
- **High energy demand in the reboiler (25-35% of power plant output)**
- **Impurities cause solvent degradation, loss of performance and equipment corrosion**
- **Solvent losses and waste products**
- **Emissions from CO_2 capture plant**

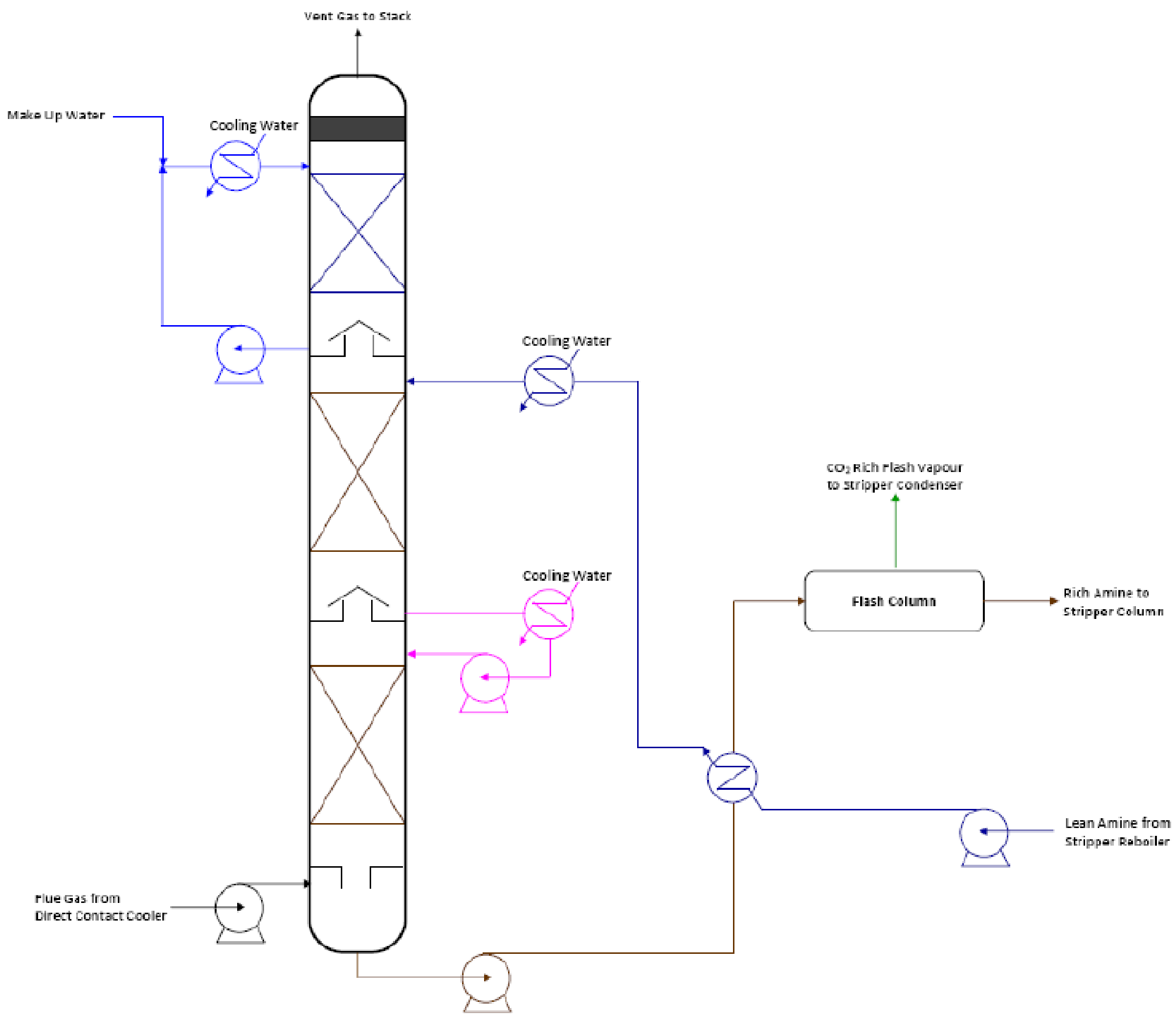
Picture: Mongstad Large Scale Pilot (TCM)

Issues for Post Combustion Capture

- **Issues to be addressed in the development of Post Combustion Technologies:**
  - Increase in cost of electricity
  - Reduction in Power Plant Efficiency
- **Solvent Process break-through required**
  - Energy requirements
  - Reaction rates
  - Contactor improvements
  - Liquid capacities
  - Chemical stability/corrosion
  - Desorption process improvements
- **Integration with power plant**
  - Heat integration with other process plant
  - Concepts for “capture readiness”

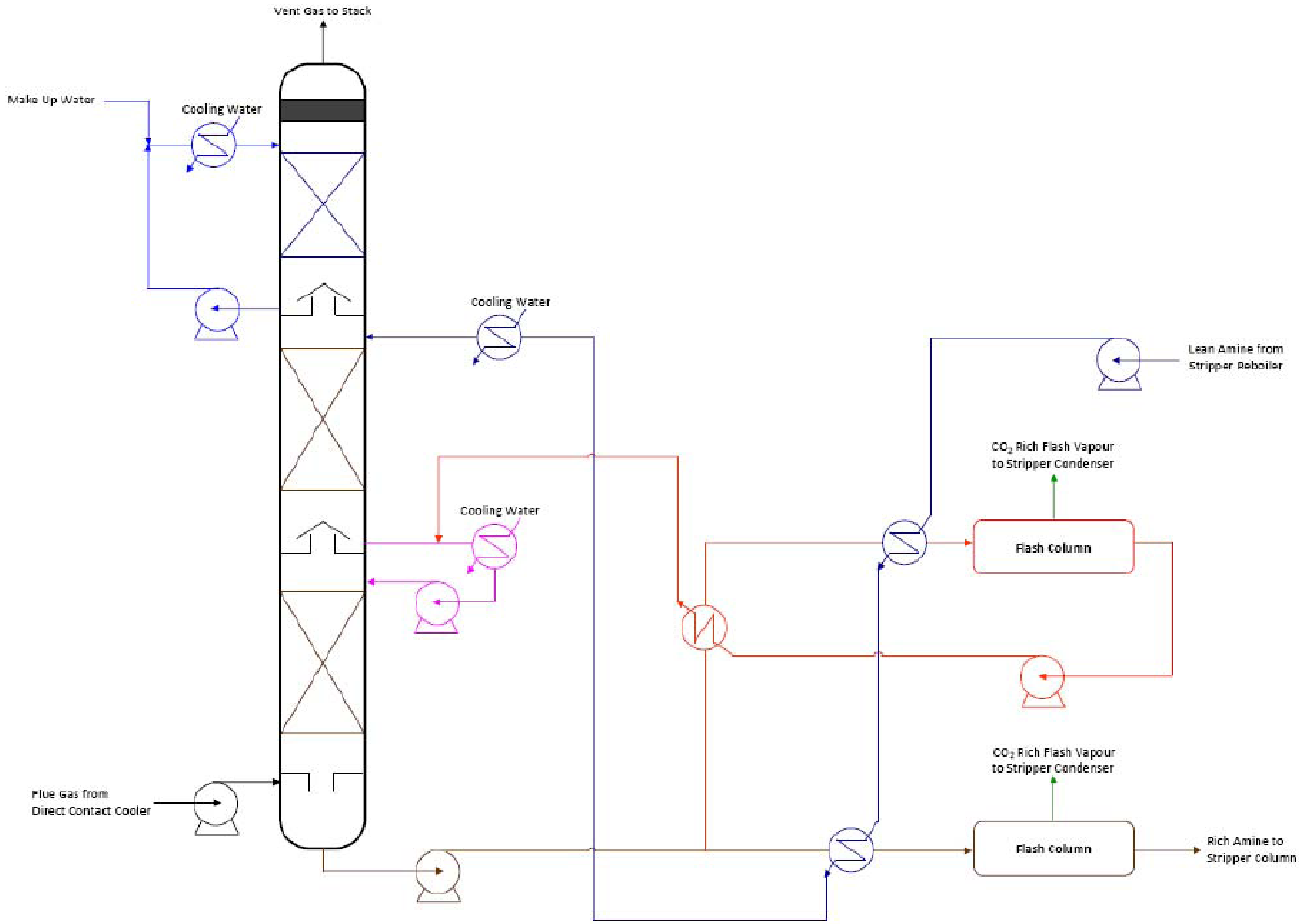
CO2 Capture Plant

(Conventional Absorber Column Configuration)



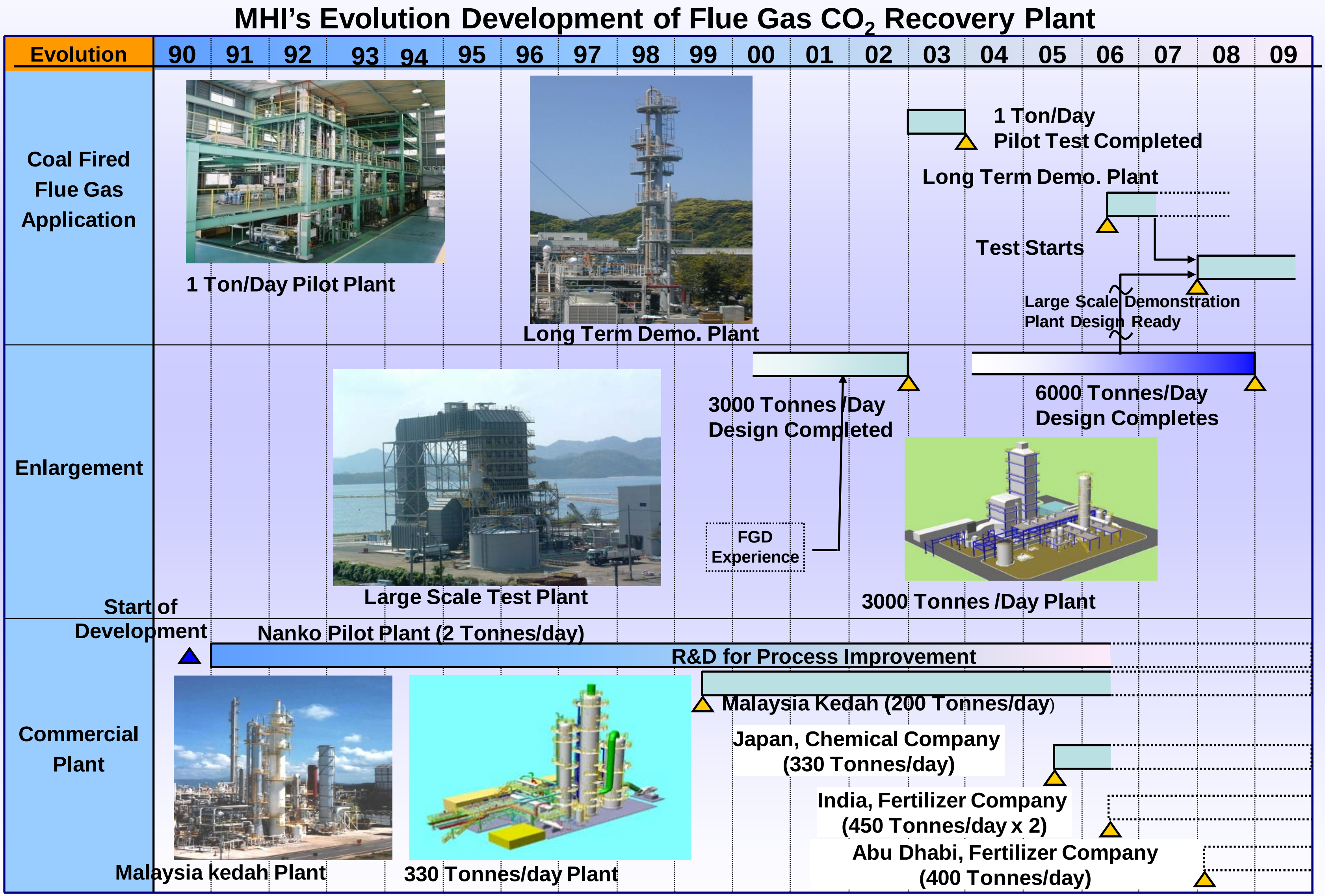
CO_2 Capture Plant

(Split Flow and Inter-cooling Configuration)



MITSUBISHI CO_2 Recovery Technology from Flue Gas

<Experience and R&D Facilities>

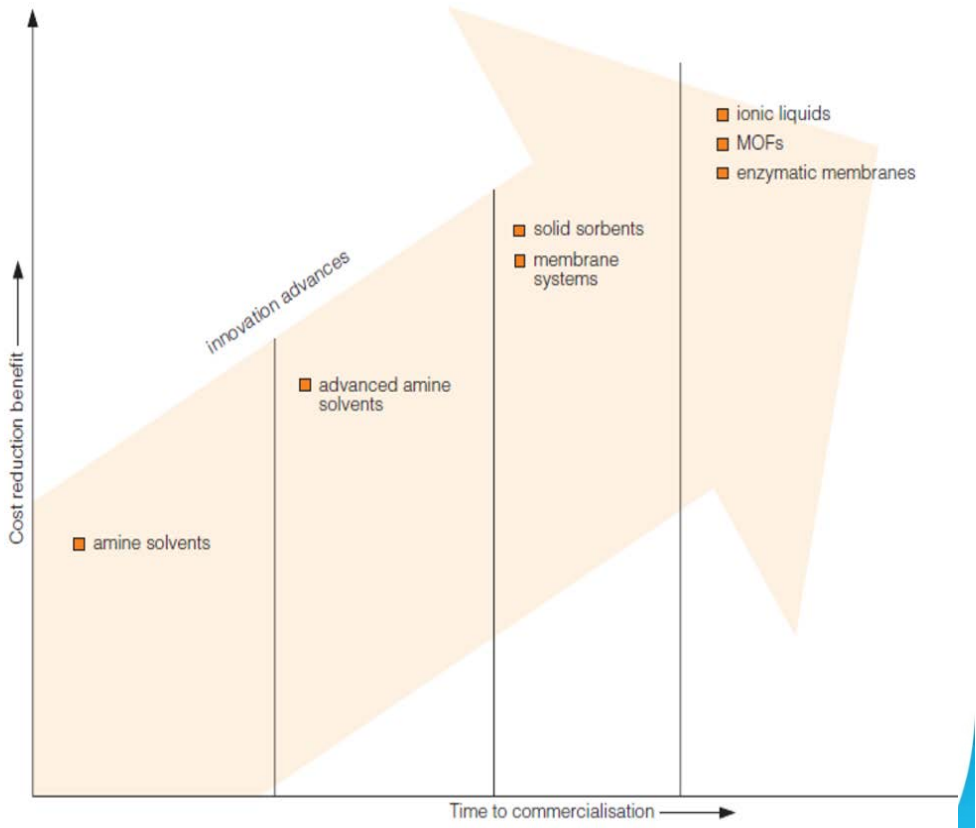


Post Combustion Capture Development

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
Potassium Carbonate	K_2CO_3	CO2CRC, Uni Texas
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
Ionic liquids		Univ of Leoben
Adsorbents	MOFs, Immobilized amine sorbents, HMS, regenerable sorbents	NETL
Membrane	Selective, FTM, Module	TPS, TNO, NETL,

Post Combustion:
Where to Focus

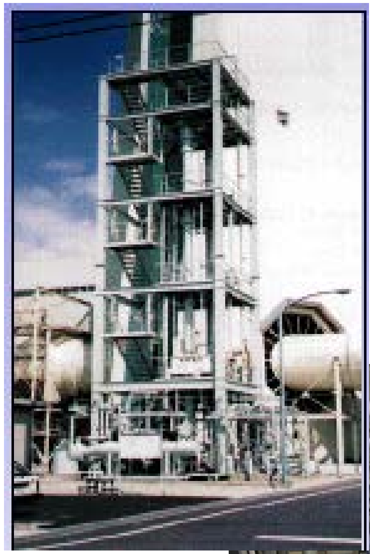
- **Novel solvents: Higher capacity, lower reaction enthalpy, stable and cheaper**
- **Smart process concepts and heat integration**
- **Capture environmental impact**
- **Cheaper equipments (absorber > 45% of CAPEX)**
- **Membranes, adsorbents and other processes have the potential as 2nd/3rd generation**



Source: Figueroa et al., 2008

What’s Next

Pilot Plants



Nanko Pilot Plant
(2t/d)

Castor Pilot Plant
(2t/d)

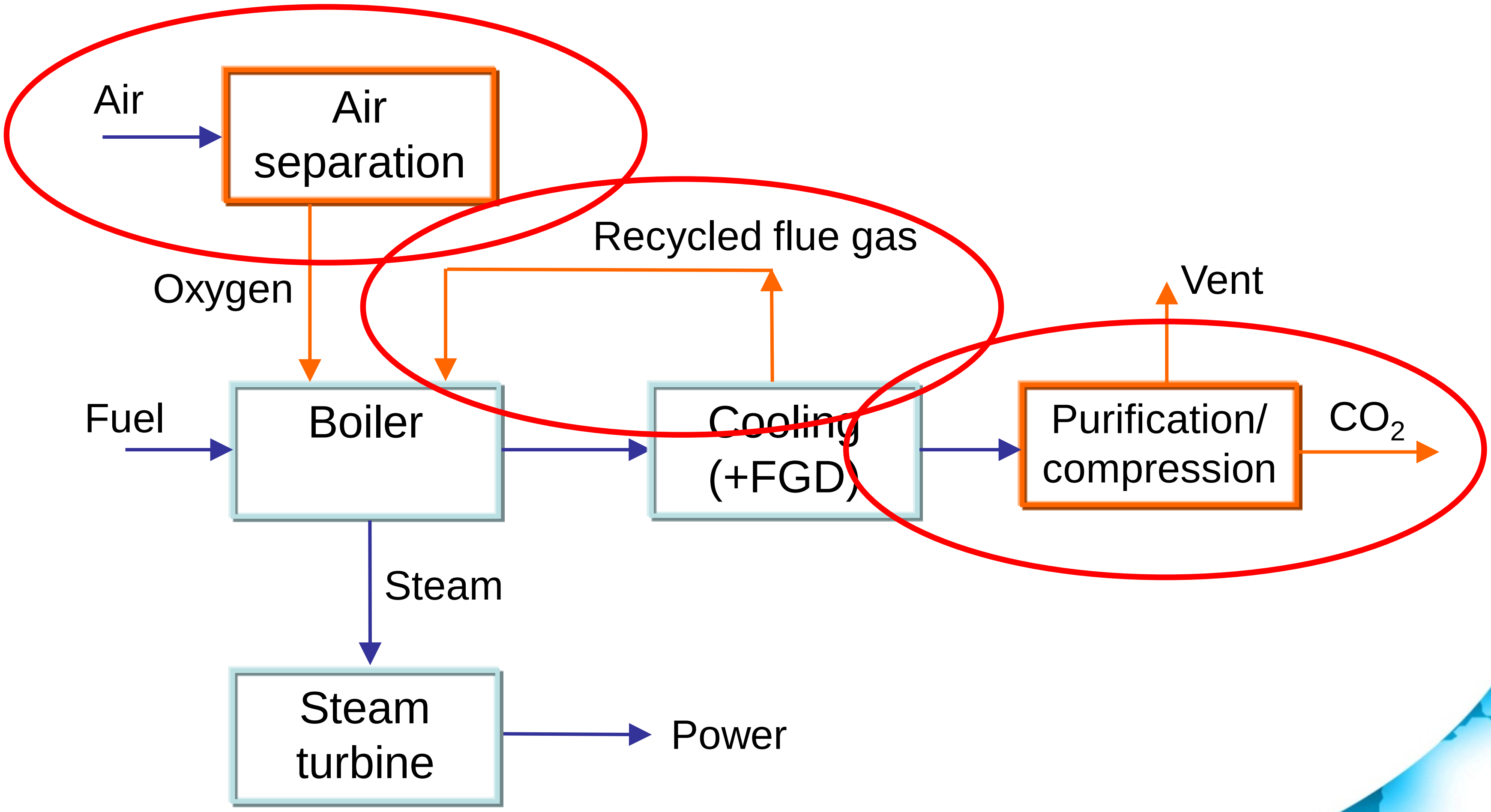
MHI Large Scale Demo Unit

Boundary Dam – Under Construction

Commercial Scale Demonstration

OXYFUEL COMBUSTION CO_2 CAPTURE TECHNOLOGY FOR COAL FIRED POWER GENERATION

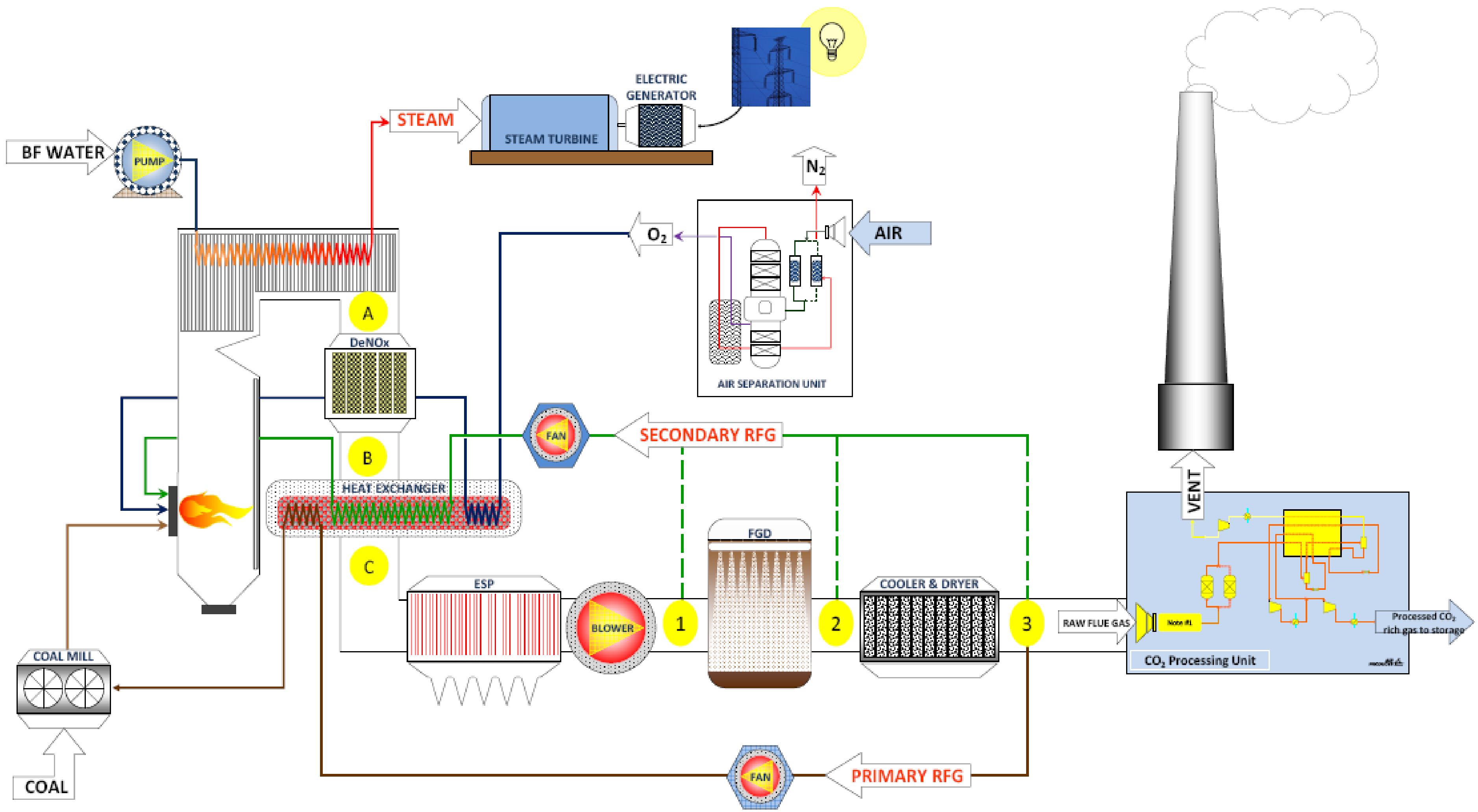
Oxy-Coal Combustion Technology

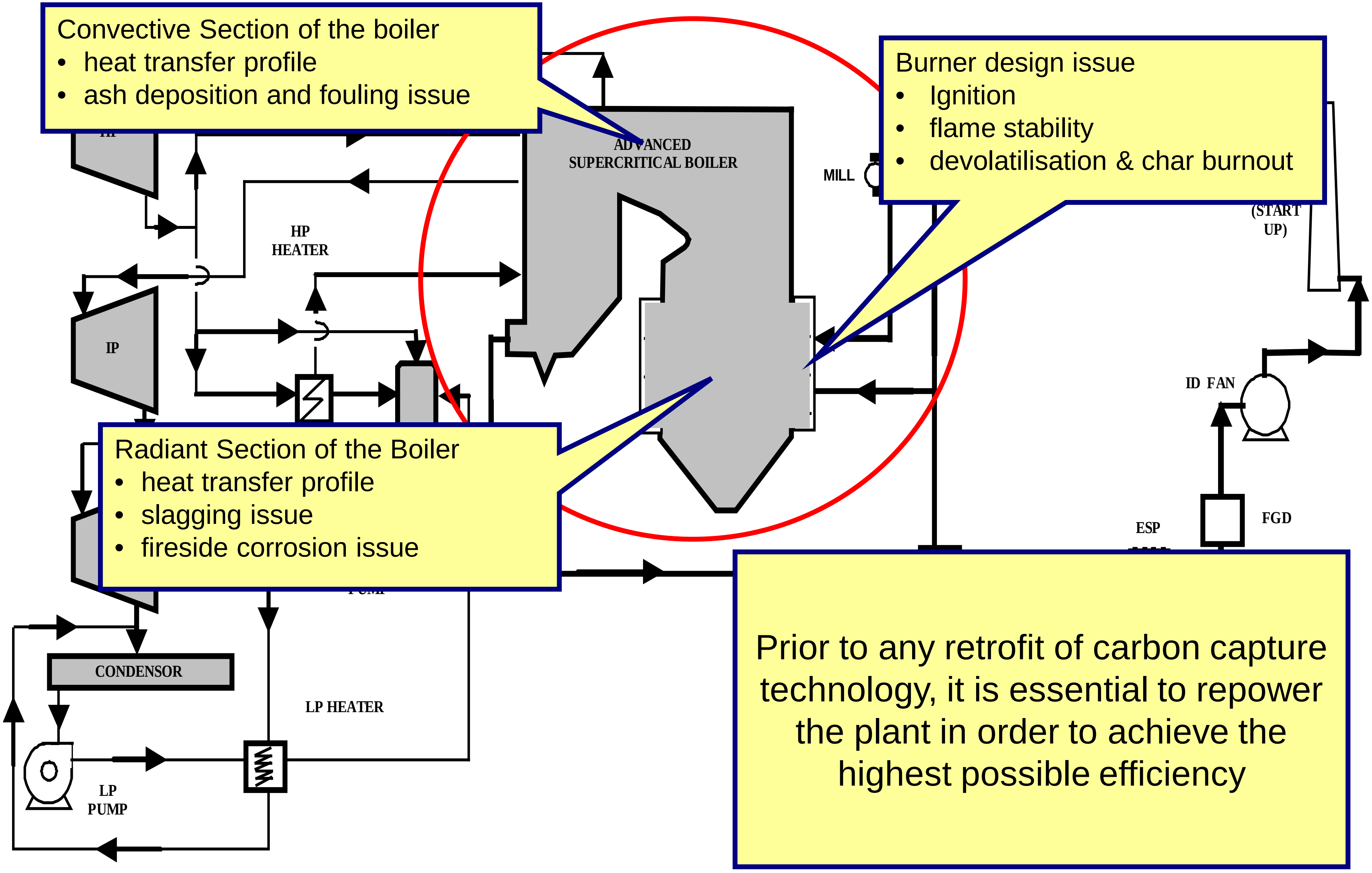


Oxy-Combustion Technology

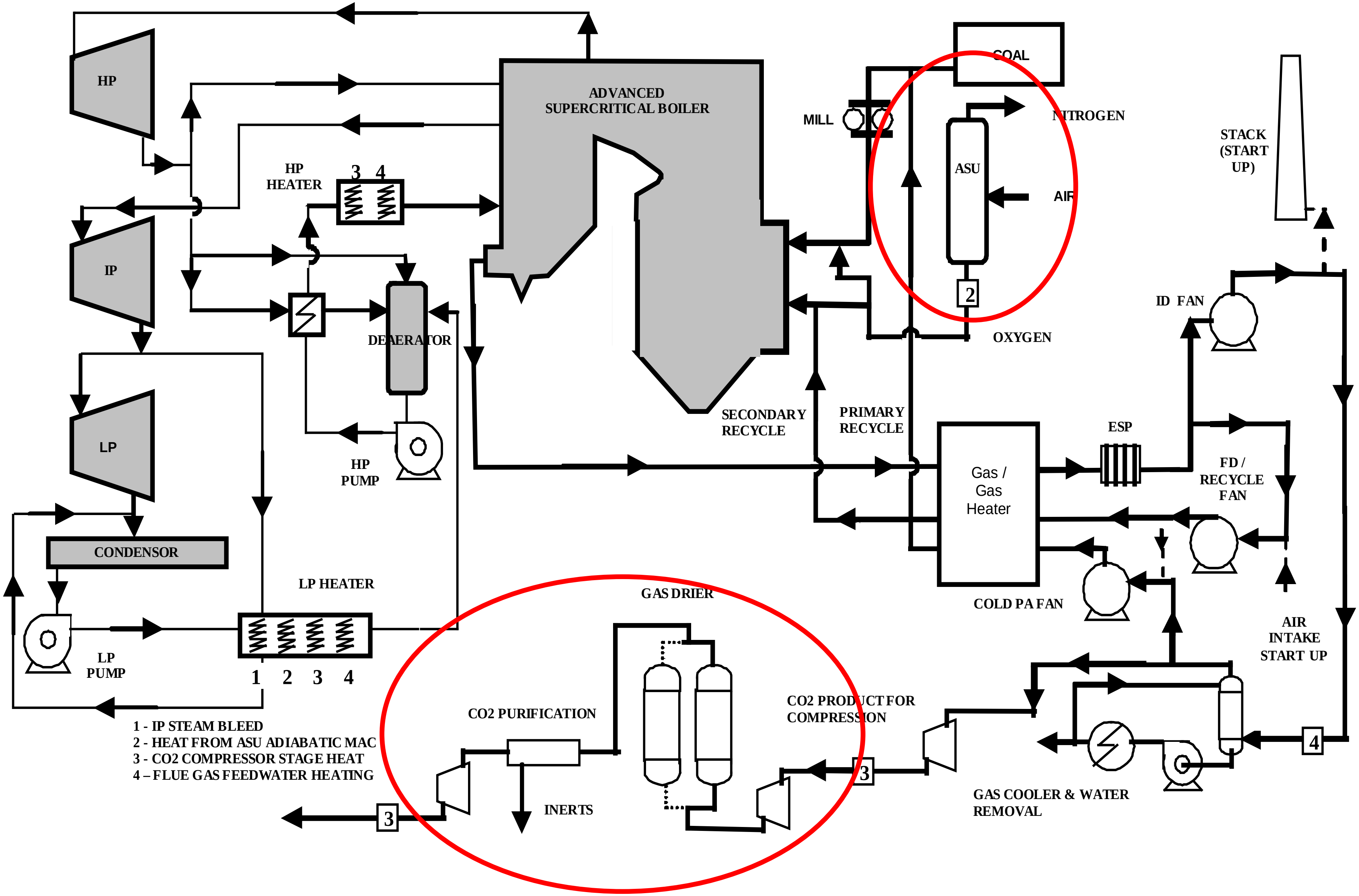
- ***Use of oxygen instead of air in a boiler – "Oxy-Combustion" is a feasible option for power plant with CO_2 capture. With continuous demonstration of this technology... It is catching up!!!***
- ***3 key development issues***
  - Boiler and burner development
  - Air Separation Unit – "Cost of Oxygen production"
  - CO_2 processing – What could be a viable purity for storage ???

Oxyfuel Combustion Overall Schematic Diagram

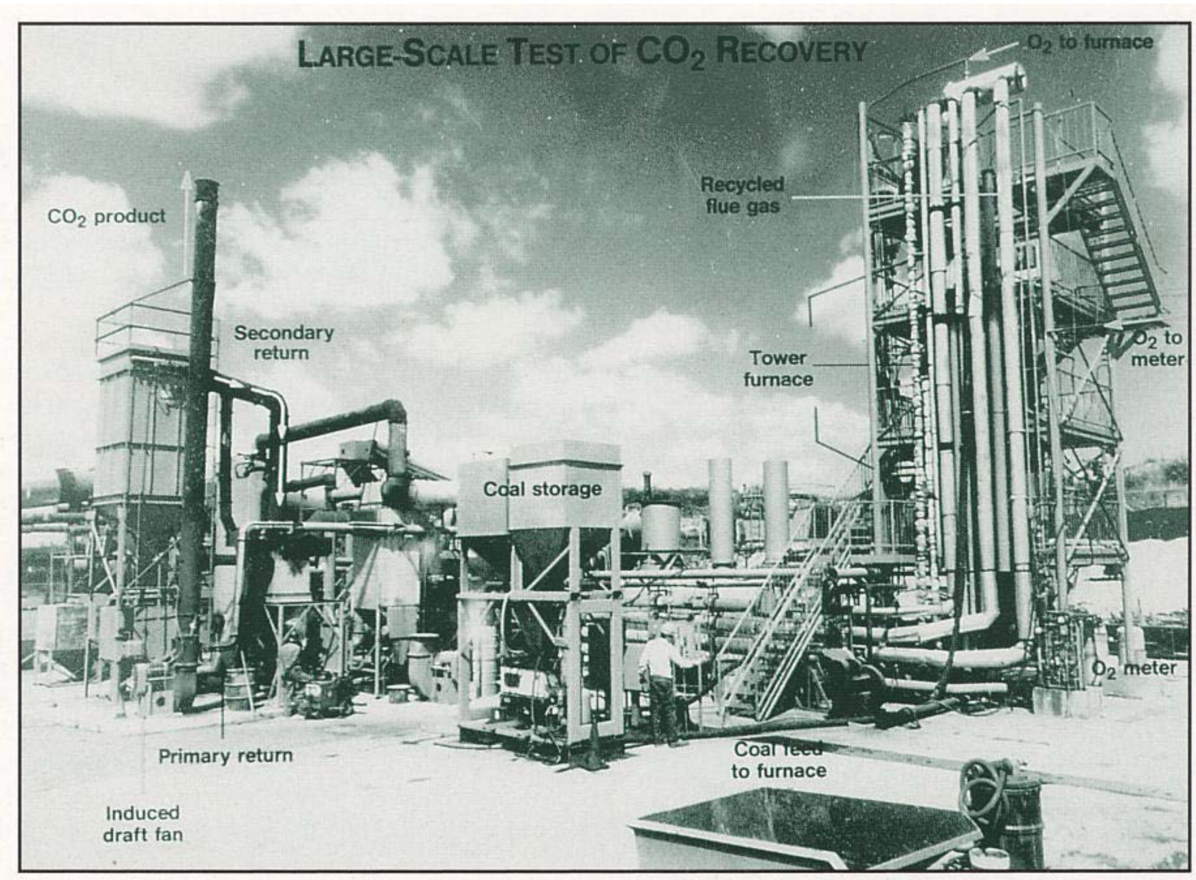


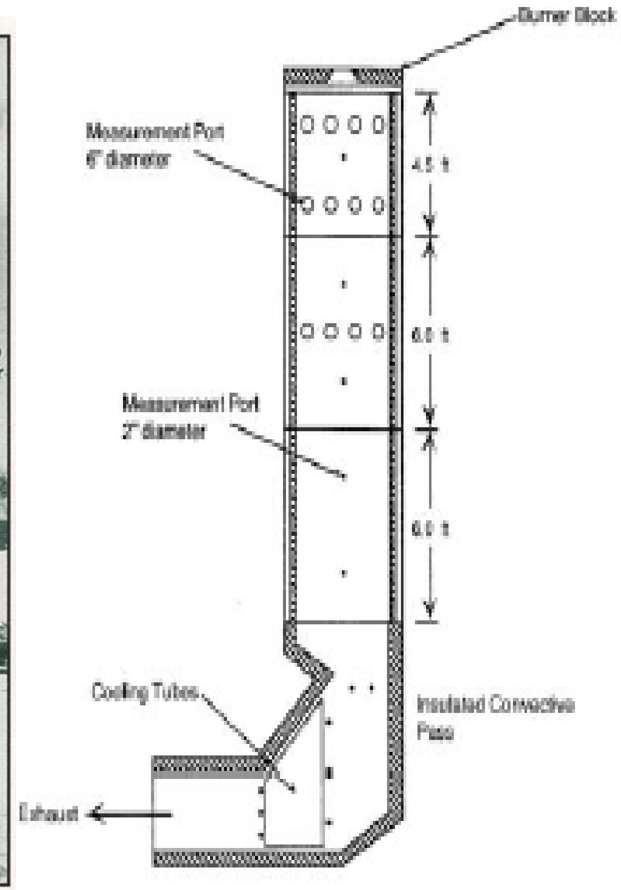


Prior to any retrofit of carbon capture technology, it is essential to repower the plant in order to achieve the highest possible efficiency

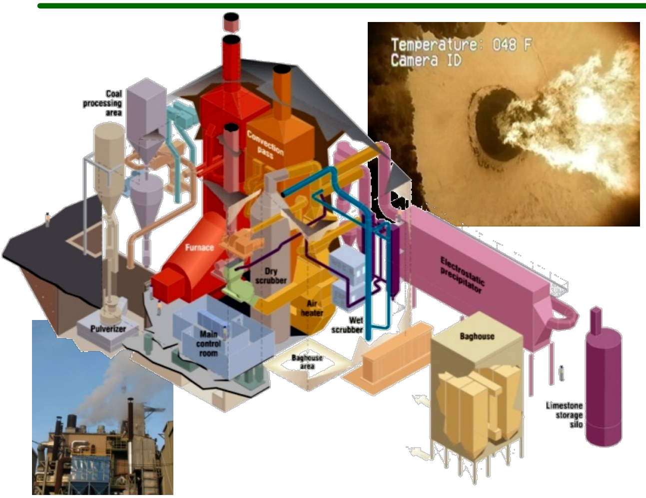

HP
IP
LP
CONDENSOR
LP PUMP
LP HEATER
1 2 3 4
HP HEATER
3 4
DEAERATOR
HP PUMP
ADVANCED SUPERCRITICAL BOILER
MILL
COAL
NITROGEN
ASU
AIR
2
OXYGEN
STACK (START UP)
ID FAN
SECONDARY RECYCLE
PRIMARY RECYCLE
Gas / Gas Heater
ESP
FD / RECYCLE FAN
COLD PA FAN
AIR INTAKE START UP
4
GAS DRIER
CO2 PURIFICATION
CO2 PRODUCT FOR COMPRESSION
INERTS
3
GAS COOLER & WATER REMOVAL
1 - IP STEAM BLEED
2 - HEAT FROM ASU ADIABATIC MAC
3 - CO2 COMPRESSOR STAGE HEAT
4 – FLUE GAS FEEDWATER HEATING

ANL - EERC Study
World's 1st Oxy-Coal Combustion Industrial Pilot Scale Study
Tower Furnace (~ 3MWth)



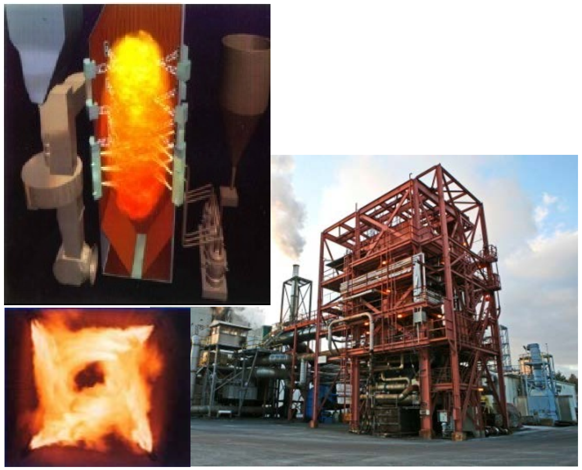


Today... There are 3 Major Full Scale PC Burner Testing Facilities Worldwide Retrofitted for Oxyfuel



- *Babcock and Wilcox (B&W) 30MW$_{th}$ CEDF*
- *Barberton, Ohio, USA*
- *Start of Operation: Oct. 2008*
- *Wall Fired Burner Development*

- Doosan Babcock – 40MW$_{th}$ in 90MW$_{th}$ MBTF
- Renfrew, Scotland, UK
- Start of Operation: Jun. 2009
- Wall Fired Burner Development



- Alstom Power Plant Lab. – 15MW$_{th}$ in 30MW$_{th}$ BSF
- Windsor, Connecticut, USA
- Start of Operation: Nov. 2009
- T-Fired Burner Development

Courtesy of Alstom, B&W and Doosan Babcock

Oxygen Production

- *As of today, the only available technology for oxygen production in large quantities is **cryogenic air separation**.*

- *Advances and Development in ASU could result to 25% less energy consumption.*
    - These design would be based on either a 3 column design or dual reboiler design.

Cryogenic Air Separation – Capacity Increase

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

2006 :
1,250 Mio kg/h
(30.000 ton/day)

Points for Discussion…

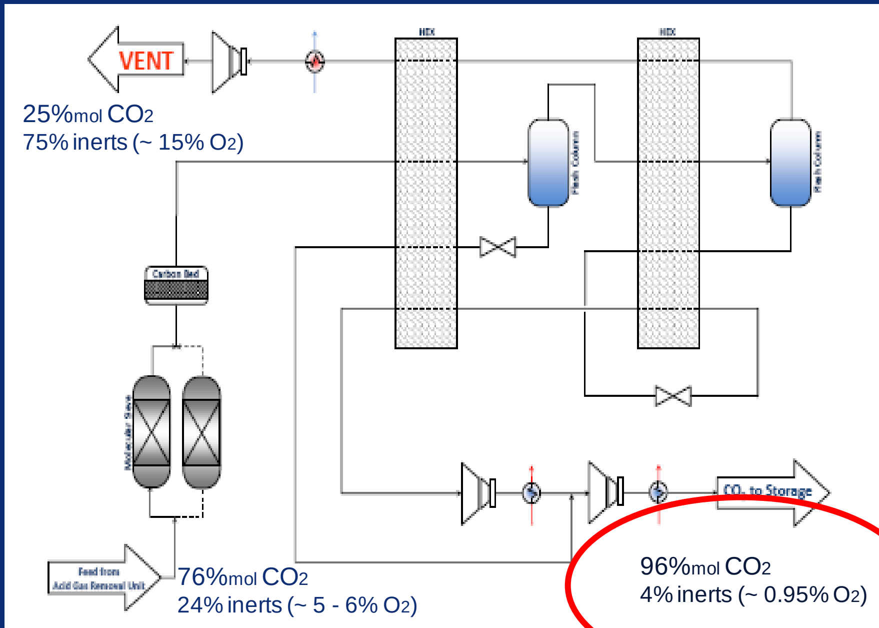
- ***~10,000 TPD of O_2 is required for a 500MWe (net) oxy-coal power plant with CCS.***
  - This means that you will need 2 single trains of 5000 TPD O_2
  - Largest operating ASU today (single train) ~4000 TPD O_2.

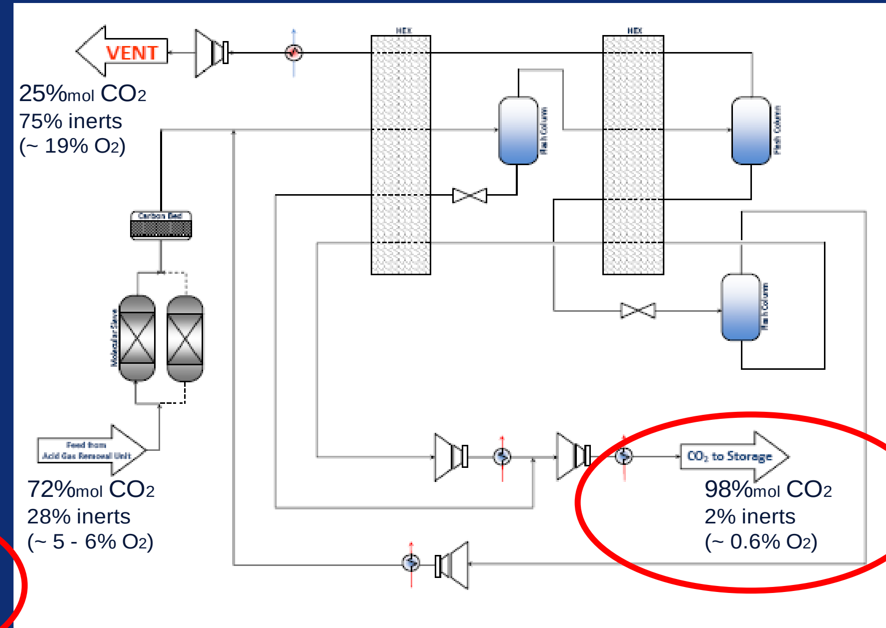
- ***Some of the Engineering Considerations***
  - What could be the maximum capacity of oxygen production per train?
  - Operation flexibility (i.e. load following, etc…)
  - What will you do about the large volume of Nitrogen produced from this ASU?

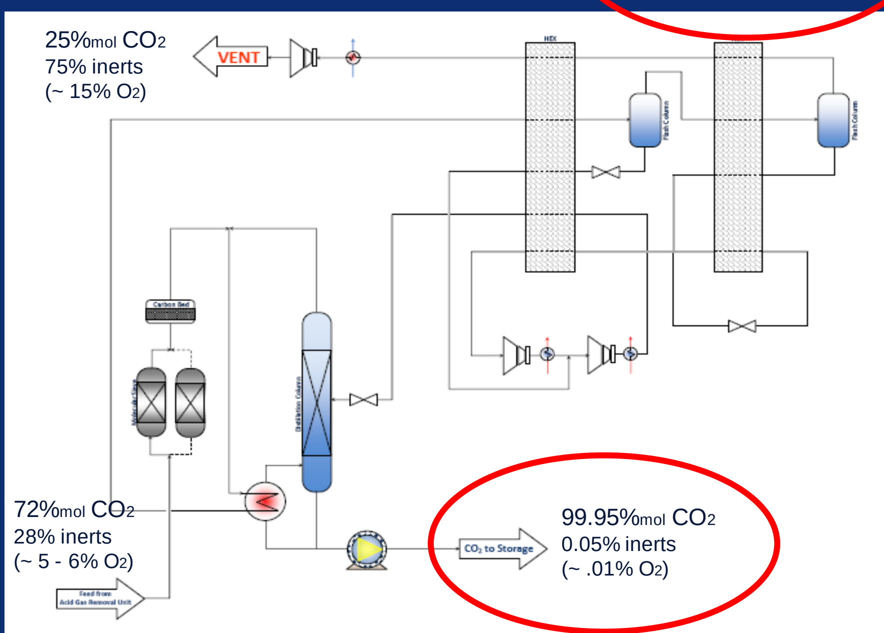
Challenges to CO_2 Processing Unit

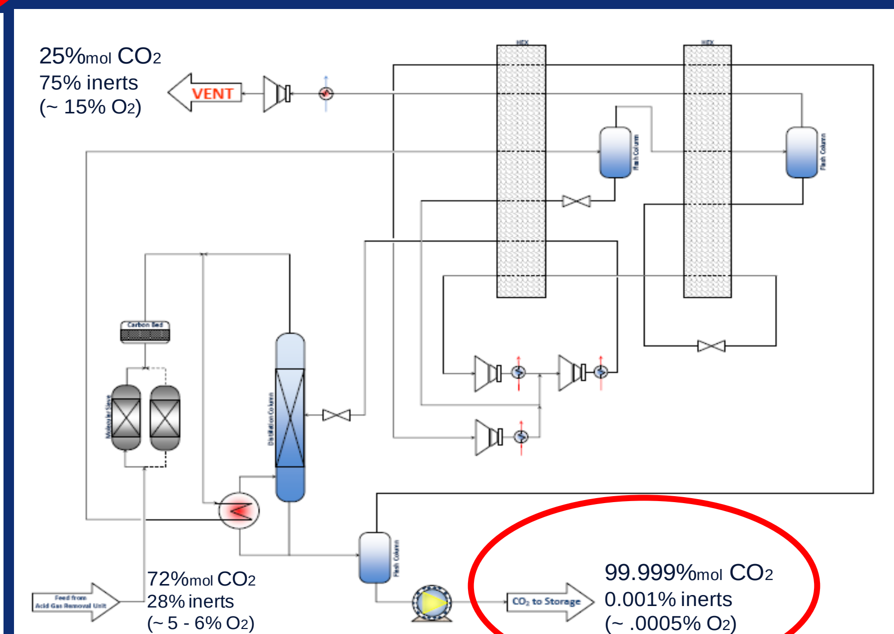
- ***The CO_2 processing unit could be very competitive business (an important growth area) for industrial gas companies.***

- ***Challenges are:***
  - Demand of the quality requirements of the CO_2 from the power plant for transport and storage. **What are the Required Specification?**
  - Further recovery of CO_2 from the vent will make oxyfuel more competitive if high recovery of CO_2 is required!
  - **Need a large scale demonstration of the CO_2 processing unit using impure CO_2 as refrigerant.**


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


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


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


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

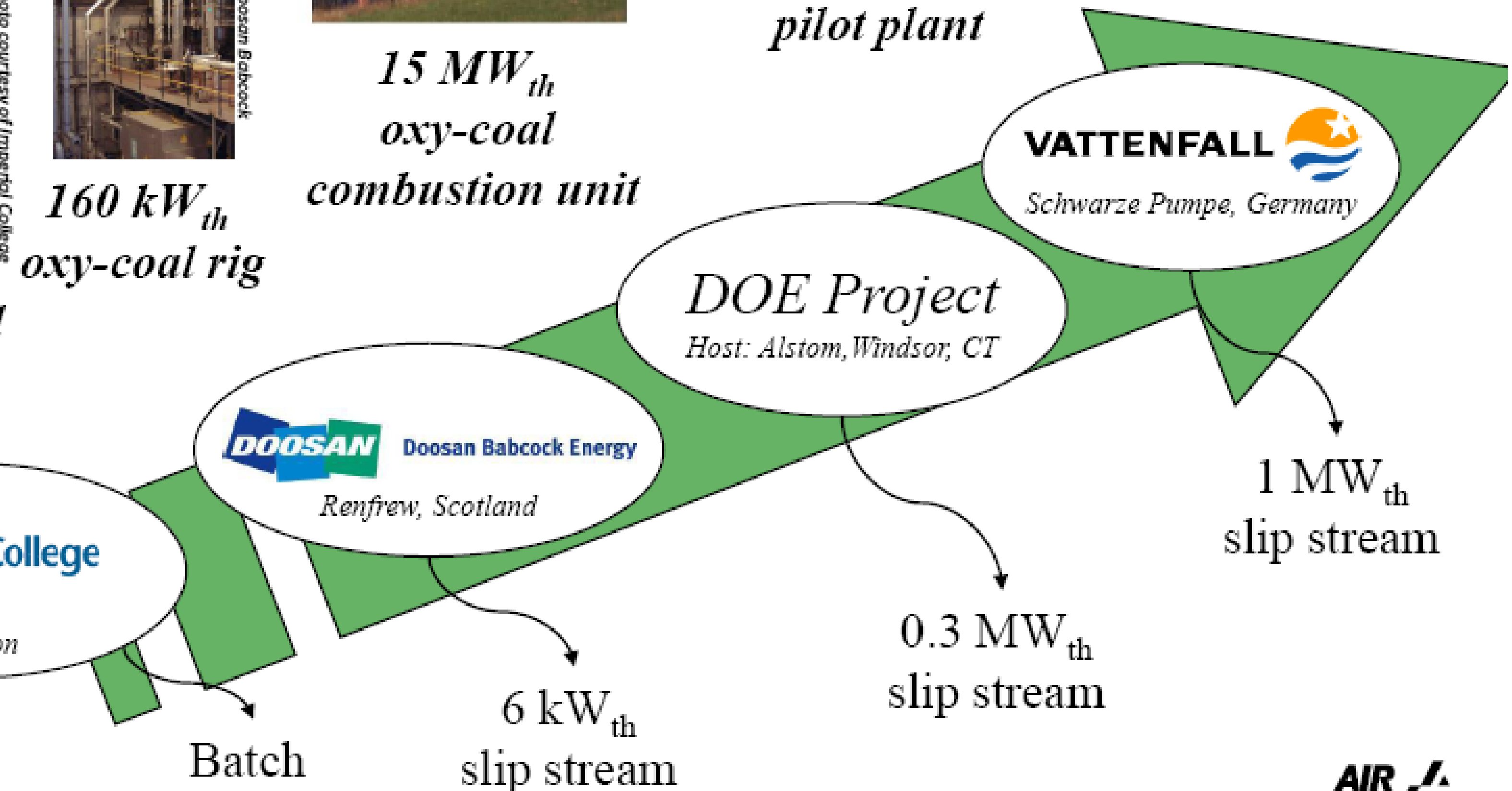
Path to from Lab to Demo

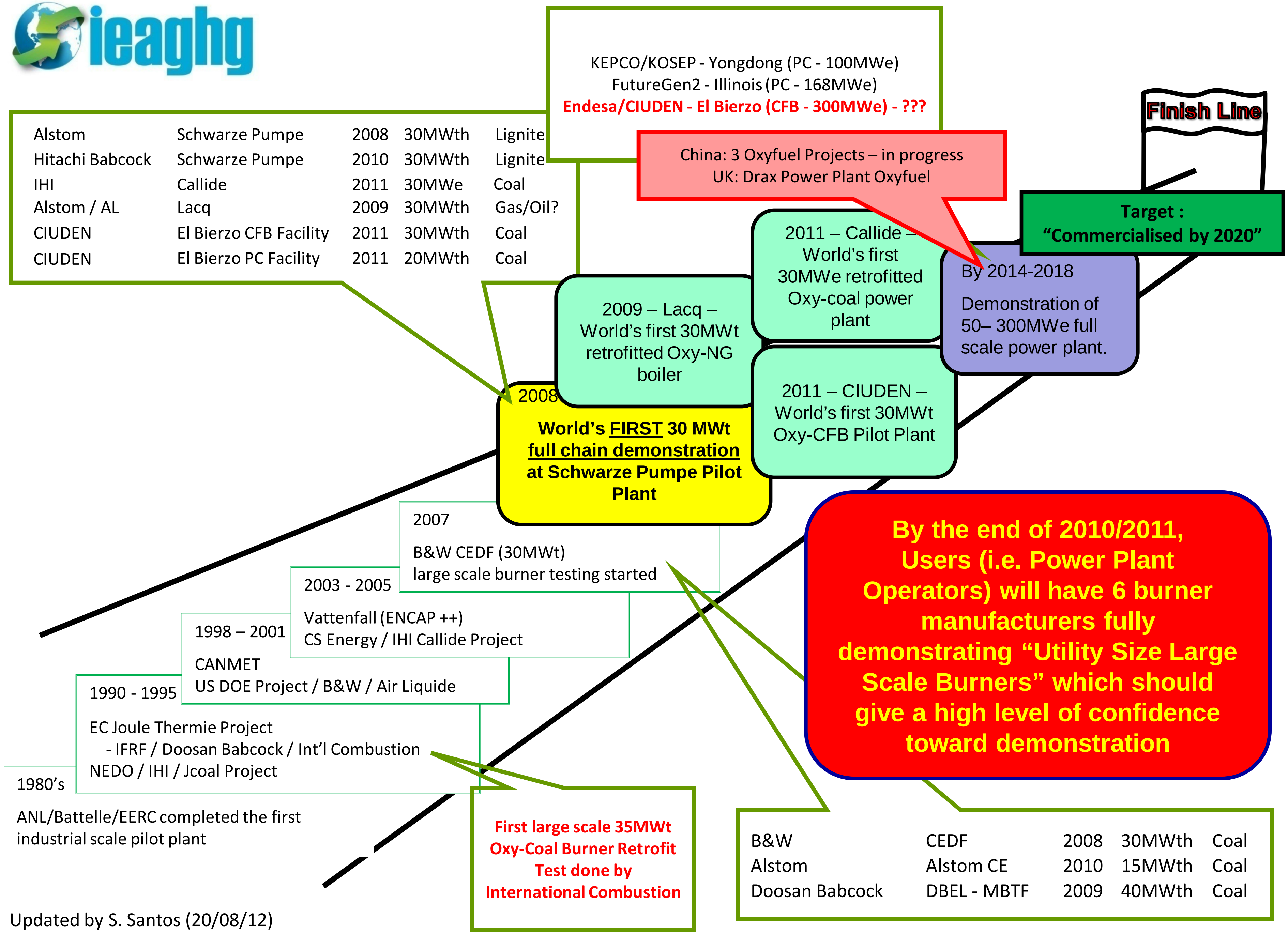
Cylinder fed bench rig

160 kW_{th} oxy-coal rig

15 MW_{th} oxy-coal combustion unit

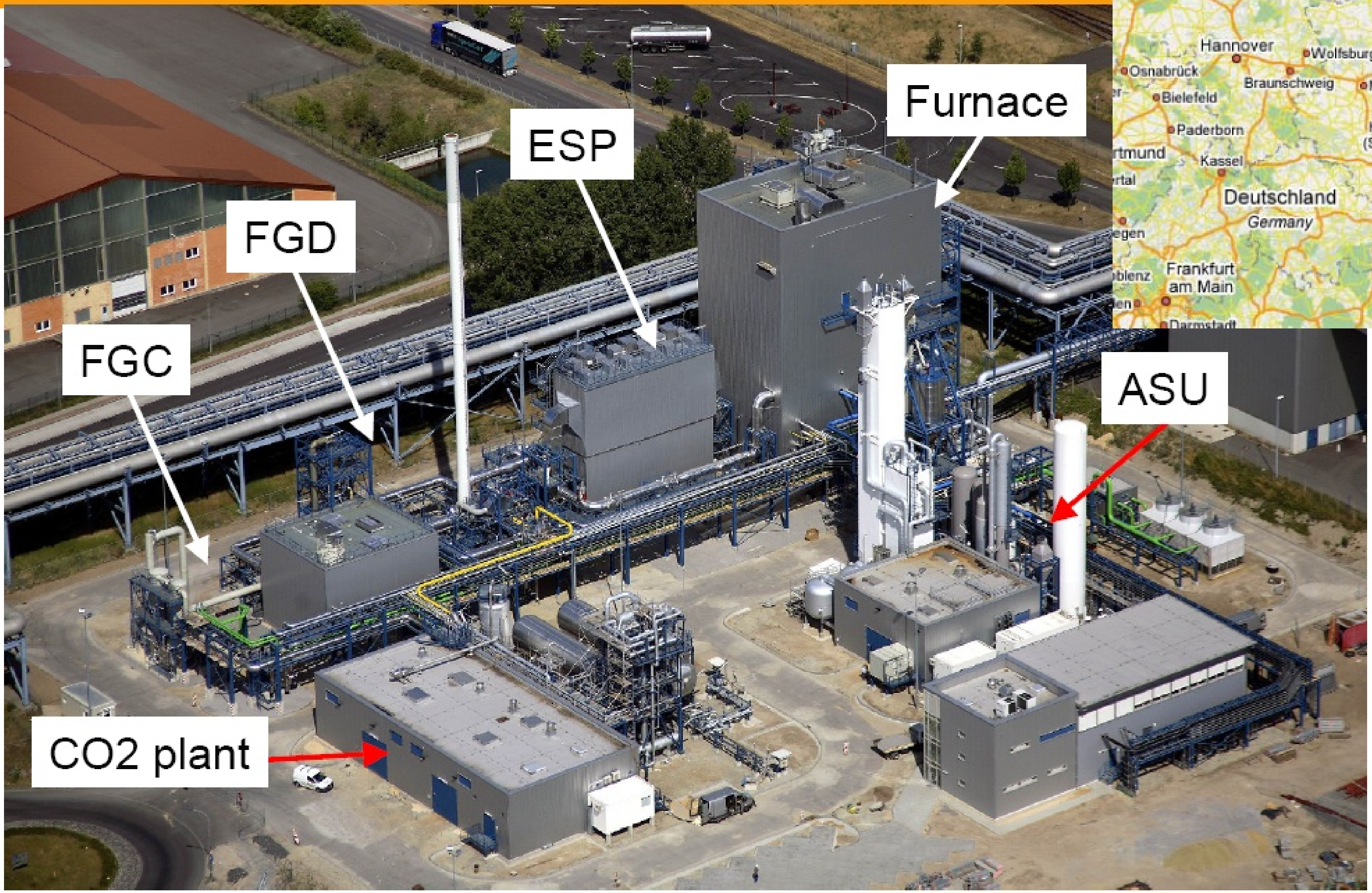
30 MW_{th} oxy-coal pilot plant





Updated by S. Santos (20/08/12)

The Oxyfuel pilot plant



CIUDEN CO_2 Capture Programme.

- *First oxyfuel pilot plant that will demonstrate in large scale the Oxy-CFB technology.*

- *Oxy-PC facility is very complimentary to Vattenfall's and Callide's facilities.*

- *Could be in a unique position to provide information related to the burner – burner interaction (in smaller scale).*

- *1st facility to investigate Anthracite (this would be first in the world), Petcoke and Biomass.*

CS Energy/IHI Burner Testing Programme at Callide A Power Station

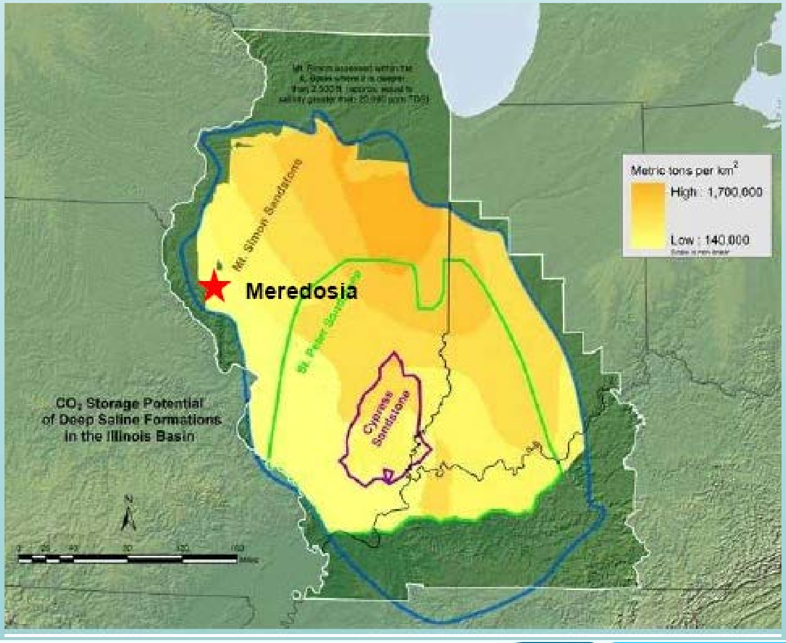
- ***Callide A Project – would be the world's 1st oxyfuel retrofitted power station.***
  - First oxyfuel pilot plant that will actually produce electricity.
  - Installation of 2 new Wall Fired Burners
  - A unique position to provide information related to the burner – burner interaction
  - Project Scope (2-4 years operation):
    - Oxygen plant (nominal 2 x 330 tpd ASUs)
    - Boiler refurbishment and oxy-fuel retrofit (1 x 30 MWe Unit)
    - CO_2 compression & purification (75 tpd process plant from a 20% side stream)
    - Road transport and geological storage (~ 30 tpd liquid CO_2)


Courtesy of CS Energy, IHI

FUTUREGEN2 Project

(Pictures from B&W)

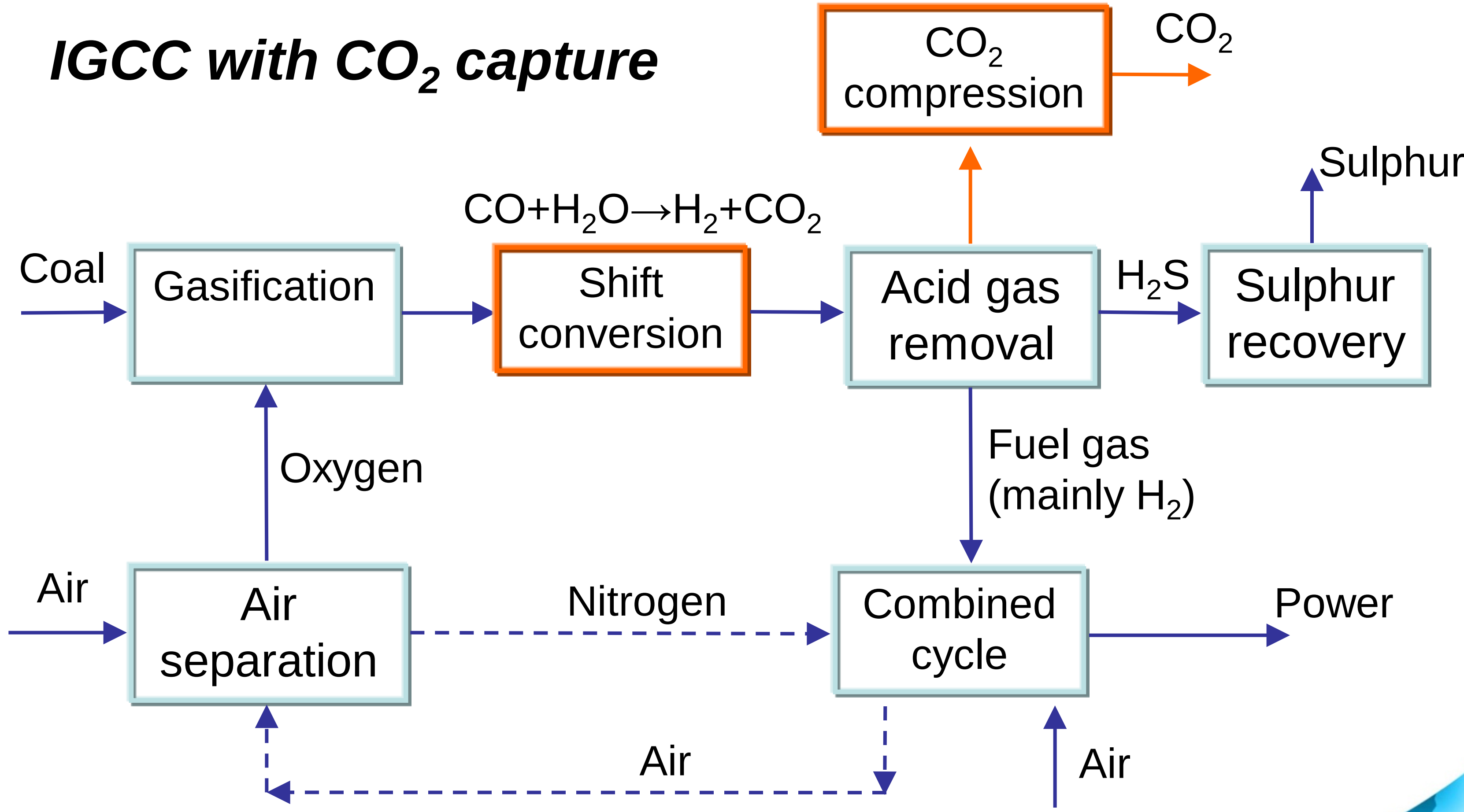
- ***Awarded US$ 1 billion AARA funding (September 2010)***
- ***Meredosia Power Plant (Originally owned by Ameren)***
  - Oil fired power plant (200MWe) – build in 1975
  - Boiler will be replaced to fire Illinois Coal (3.2% S)
- ***Morgan County for Storage Site***
  - 32 miles from the Meredosia
  - Deep Saline Formation at a depth of 4500 ft (~1,375 m)



PRE COMBUSTION CO_2 CAPTURE TECHNOLOGY FOR COAL FIRED POWER GENERATION

Pre-Combustion Capture

IGCC with CO_2 capture



55

IGCC without Capture

5 coal-based IGCC demonstration plant in the USA, Netherlands, Spain and Japan

IGCC is not at present the preferred technology for new coal-fired power plants

Main commercial interest in IGCC is for use of petroleum residues

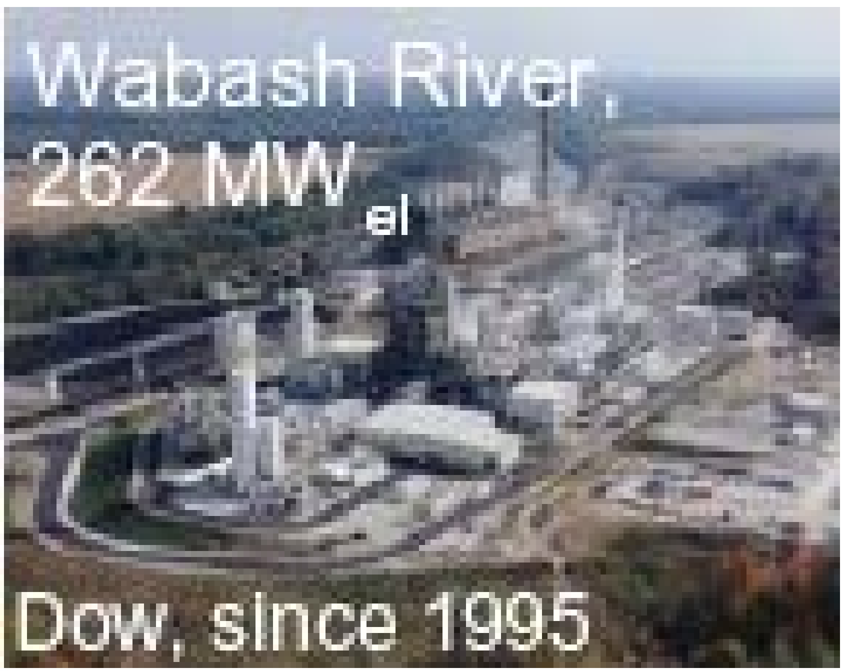
Several plants built and planned at refineries

IGCC has a small advantage over PC plant when CCS is added

Coal IGCC in Operation Worldwide

Projects Site	Buggenum Netherland	Puertollano Spain	Wabash River USA	Tampa USA	Nakoso Japan
Gasifier type	O_2-blown Dry-feed Shell	O_2-blown Dry-feed Plenflo	O_2-blown Slurry-feed E-Gas™	O_2-blown Slurry-feed GE	Air-blown Dry-feed MHI
Coal consumption (metric t/d)	2,000 t/d	2,600 t/d	2,500 t/d	2,500 t/d	1,700 t/d
Gross output (GT)	284 MW 1,100˚C-class	335 MW 1,300˚C-class	297 MW 1,300˚C-class	315 MW 1,300˚C-class	250MW 1,200˚C-class
Demonstration test start	Jan. 1994	Dec. 1997	Oct. 1995	Sep. 1996	Sep. 2007

IGCC – Currently in Operation



GREENGEN IGCC Laboratory

(Under Commission and Fully Operational by 2012)

- Power: 265MW
- Net eff. 41%
- SO_2 : <1.4mg/Nm3
- NO_X: 52mg/Nm3
- PM: <1mg/Nm3
- Start to operate in Dec. 2011

- Gasifier: HCERI
- GT: SIEMENS
- ASU: Kai Feng Air Separation
- ST: Shanghai Electric
- HRSG: Hangzhou Boiler
- Engineering: HCERI,SINOPEC,NWEPDI

Data and Information from China Huaneng Group (2011)

Overview of Pre-Combustion Technology

Pre-combustion capture process is not a new concept

- Primarily based on production of synthetic gas, separating the CO_2 and using the decarbonised syngas as fuel for the gas turbine

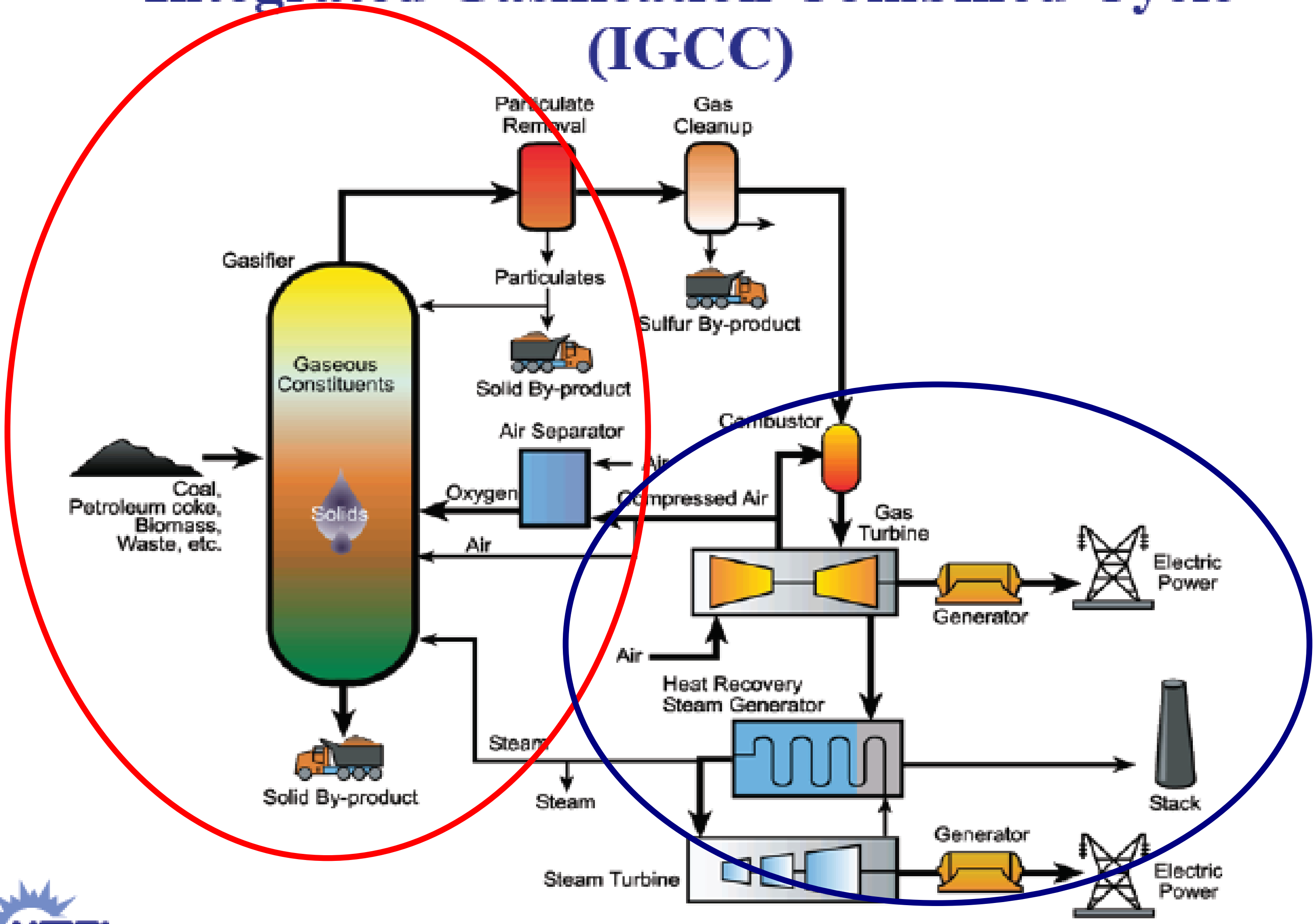
One of the main elements is the gasification of the fuel feedstock to produce syngas

Gasification technologies could produce a waste gas stream, which has high concentration of CO_2

- This offers an opportunity to capture CO_2 at low cost

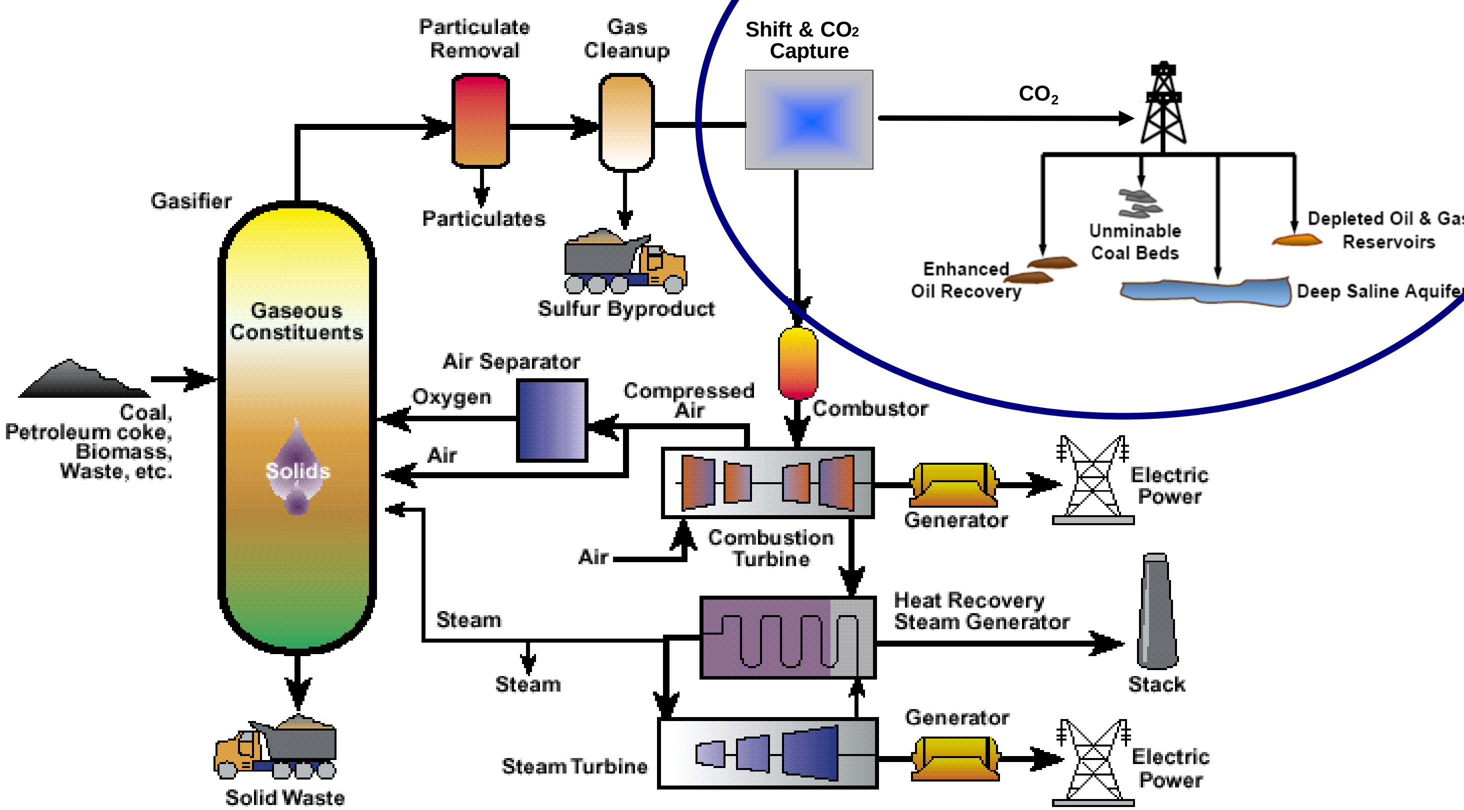
It should be noted that CO_2 capture is not a process requirement, but could be easily implemented if warranted

Integrated Gasification Combined Cycle (IGCC)



Descriptor - include initials, /org#/date

Integrated Gasification Combine Cycle with CO_2 Capture



NETL

Shift Reactor

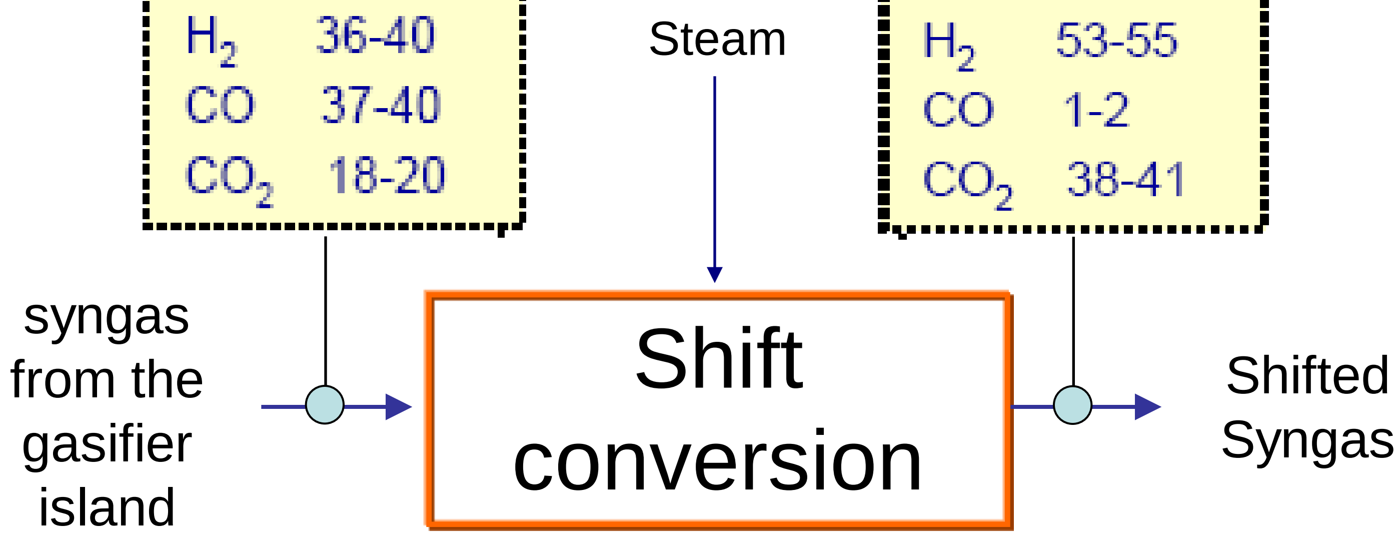
CO_2 Capture Advantages:

1. High P_{CO2}
2. Low Volume Syngas Stream
3. CO_2 Produced at Pressure

Most Important Operating Parameter: Catalyst will determine the type of syngas processing required!

Mole % (Dry)	
H_2	36-40
CO	37-40
CO_2	18-20

Mole % (Dry)	
H_2	53-55
CO	1-2
CO_2	38-41



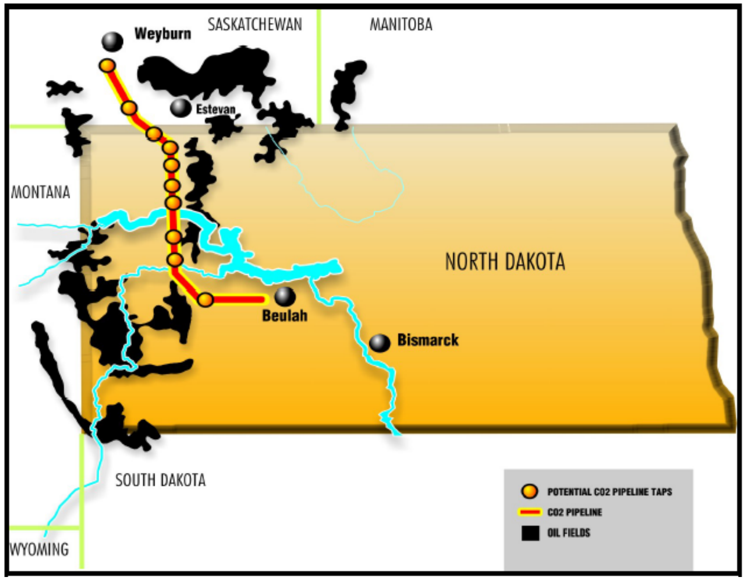
$CO + H_2O \rightarrow H_2 + CO_2$

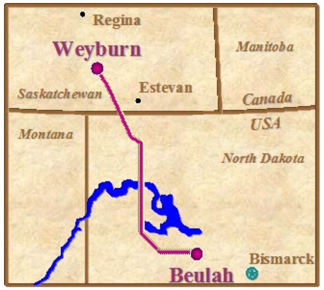
CO_2 Capture via Physical Absorption

- ***Separation is primarily based on Henry's Law***
- ***Due to high partial pressure of CO_2***
  - The absorption capacity of organic or inorganic solvents for CO_2 increases with increasing pressure and decreasing temperature.
- ***Absorption of CO_2 occurs at high partial pressures of CO_2 and low temperatures. The solvents are then regenerated by either heating or pressure reduction.***
- ***Most well known commercial processes/solvents***
  - Selexol (dimethylether of polyethylene glycol)
  - Rectisol (cold methanol)

Rectisol Units of Dakota Gasification Plant

Picture courtesy of DGC





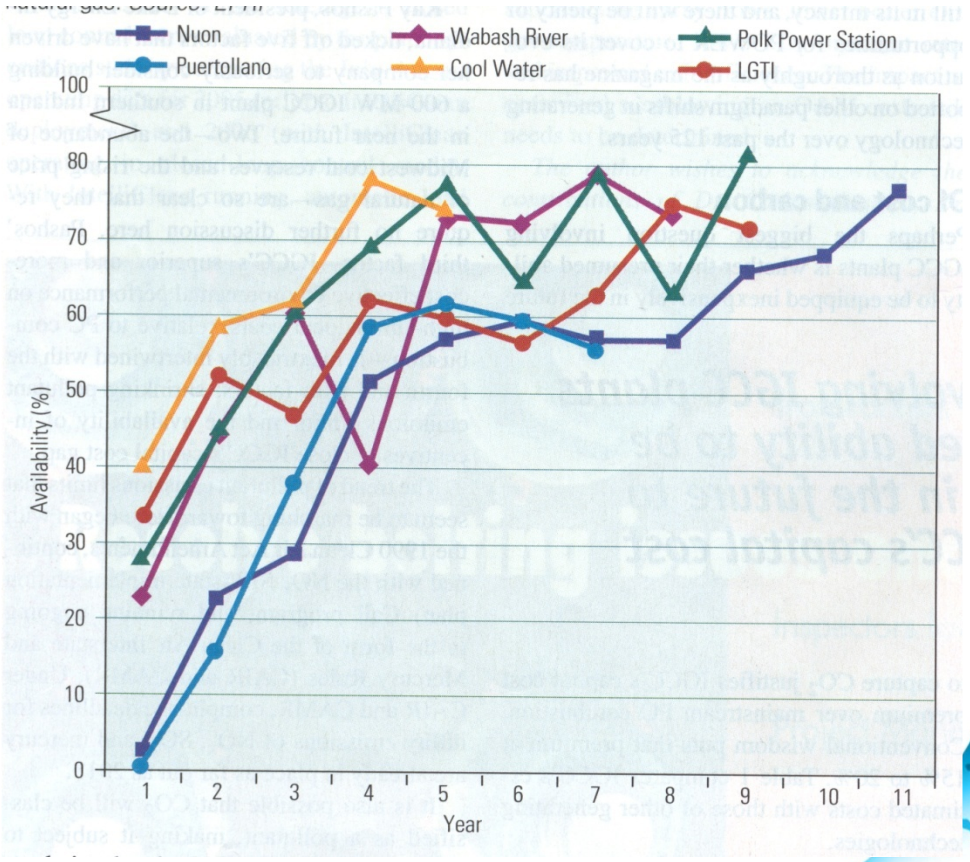
Pre-Combustion Capture: Key Barrier

Will reliability hinders the deployment of IGCC?

Record for IGCC's availability has been poor but improving.

Complexity of the plant could be a turn off to prospective investors or power generation company

Cost is another issue



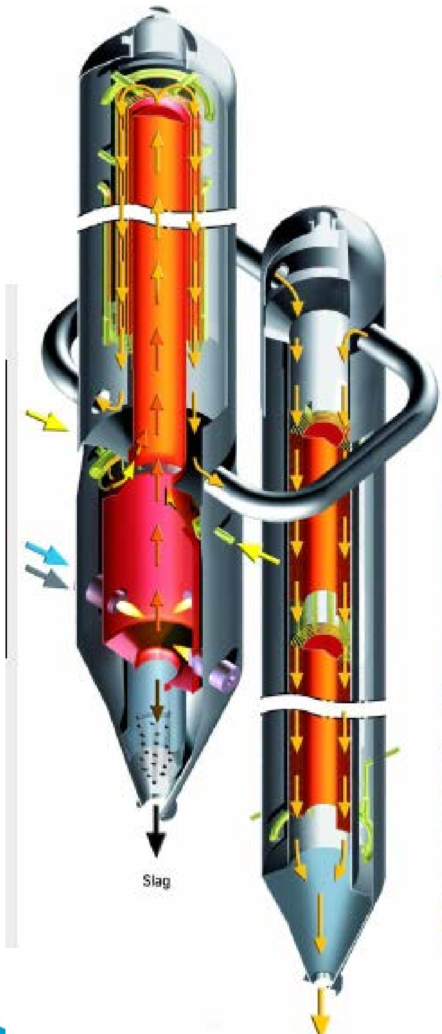
Source: EPRI

66

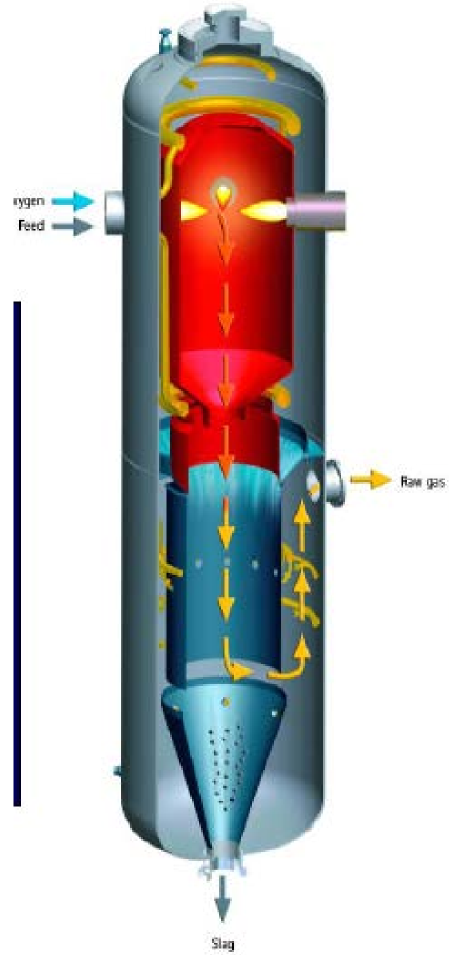
Pre-Combustion Capture: Key Development Area

- ***Development in Gasifier Technology***
  - Adaptation of the Gasifier for CO2 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***

Uhde Prenflo Design Modification for CO2 capture application...



PSG

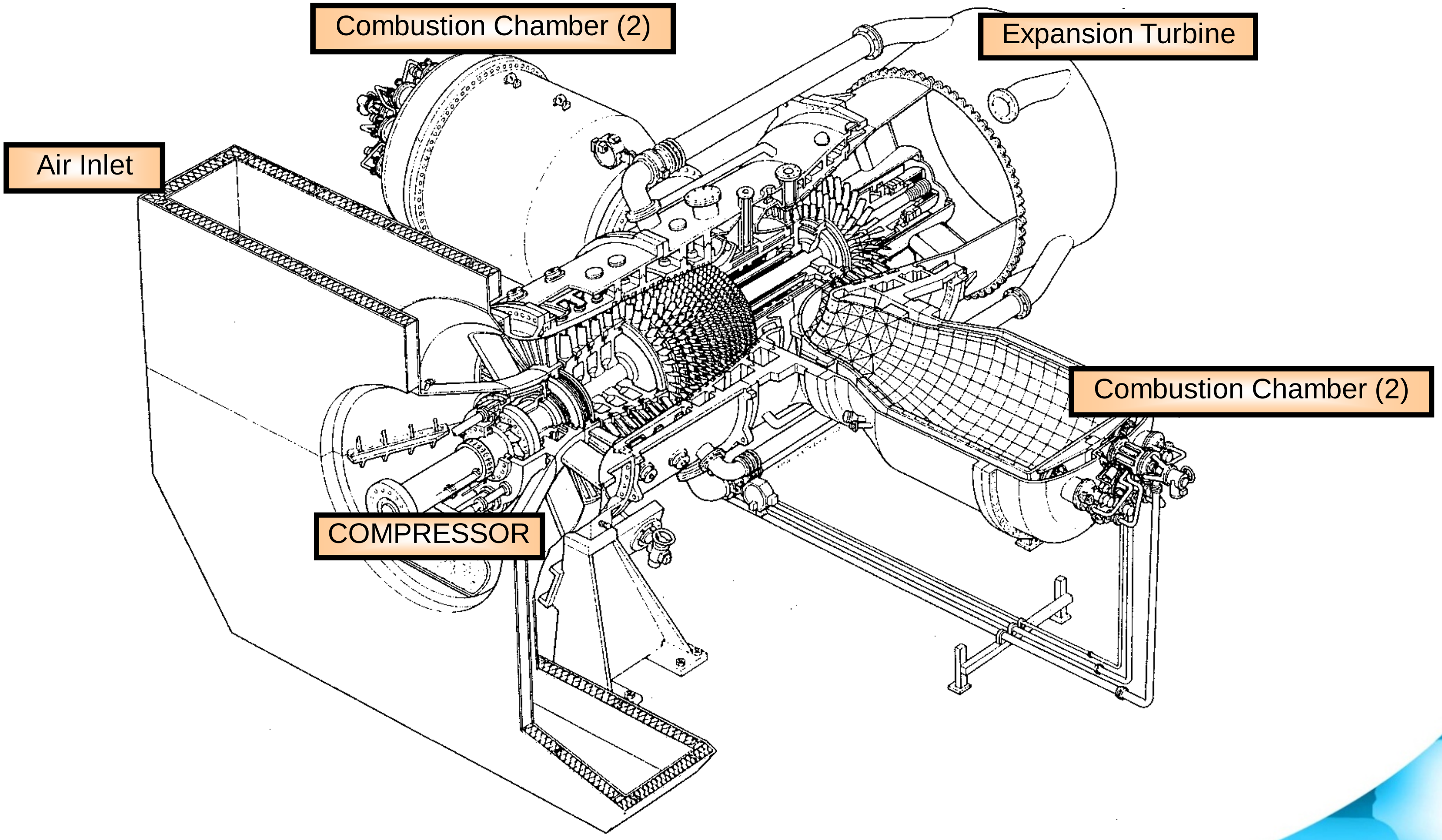


PDQ

11

ThyssenKrupp

Development in Gas Turbine Technology: Horizontal Silo

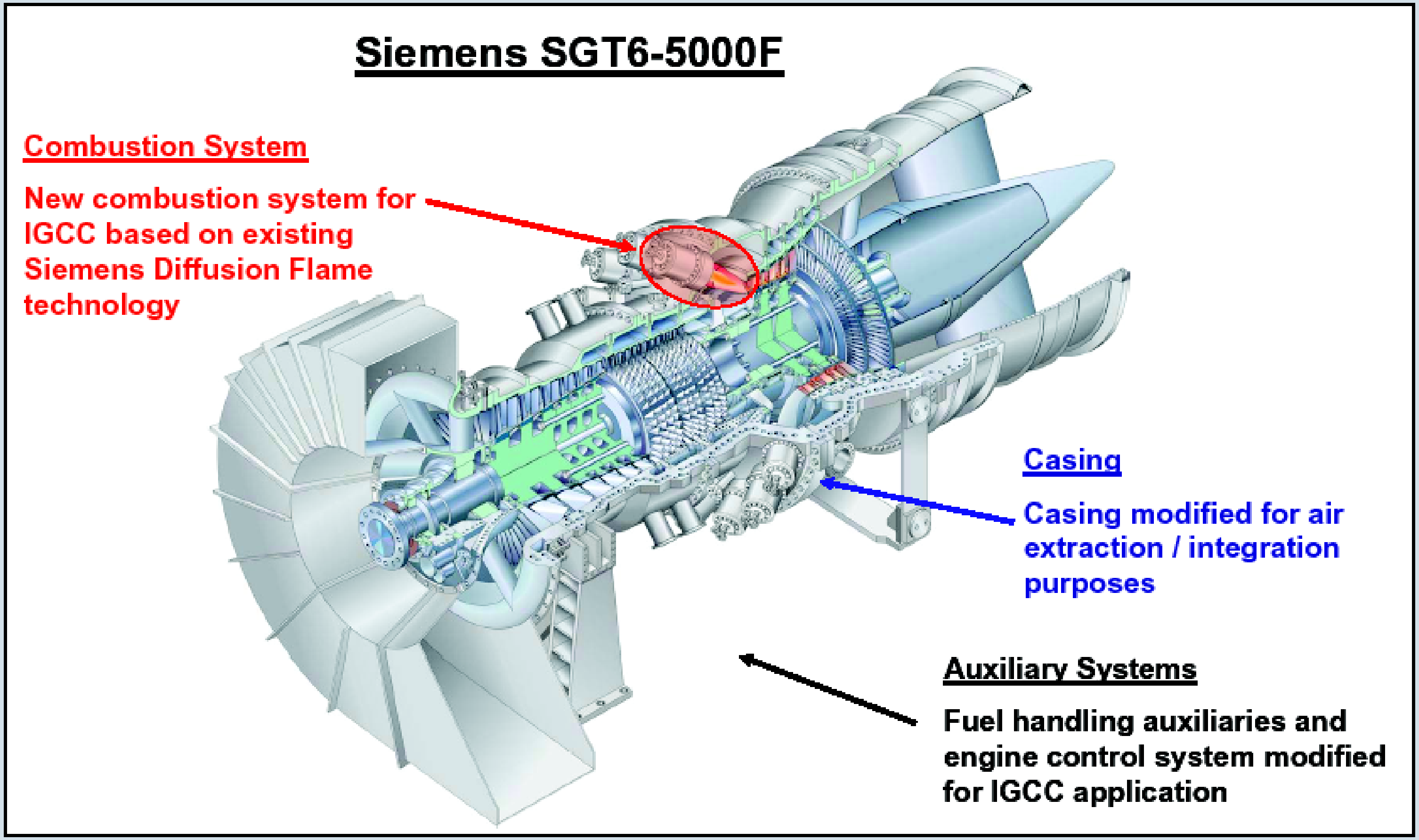


Development in Gas Turbine Technology: Annular Combustor

IGCC Gas Turbines

Typical Gas Turbine Changes for IGCC Applications

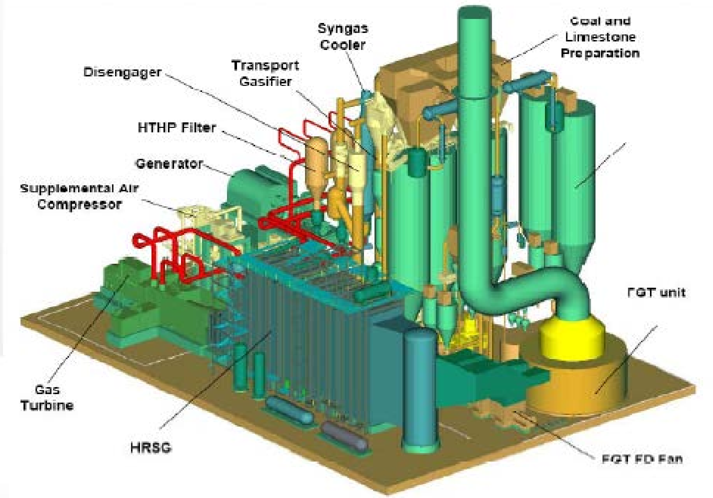
SIEMENS



Kemper County IGCC Project

(Data and Pictures from SECARB Review Presentation)

- **Plant**: 582MW electric power plant
- **Technology**: Advanced coal-gasification technology, developed in partnership with DOE
- **Fuel**: Mississippi lignite
- **MPC Investment**: $2.4B
- **CO_2 Capture:** 65% equivalent to natural gas
- **In-service**: May 2014



Concluding Remarks

SUMMARY AND KEY MESSAGES

Concluding Remarks

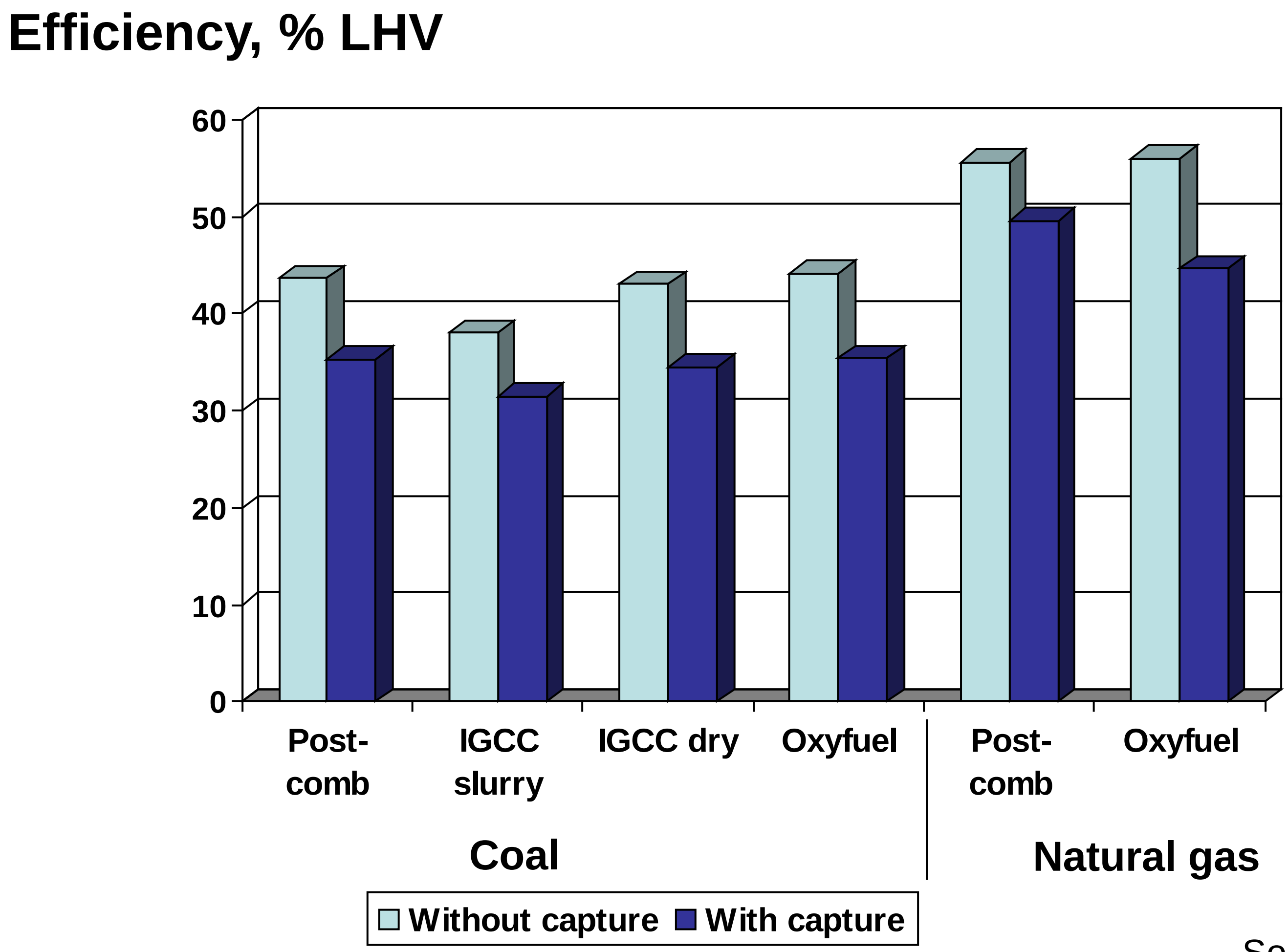
- ***CCS will play an important role in reducing greenhouse gas emissions from the power generation sector.***
- ***Several activities have been initiated worldwide in the development of Carbon Capture for Power Generation industry.***
- ***There are two set of horse race among the three options for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

 73

Thank you

Email: *stanley.santos@ieaghg.org*
Website: *http://www.ieaghg.org*

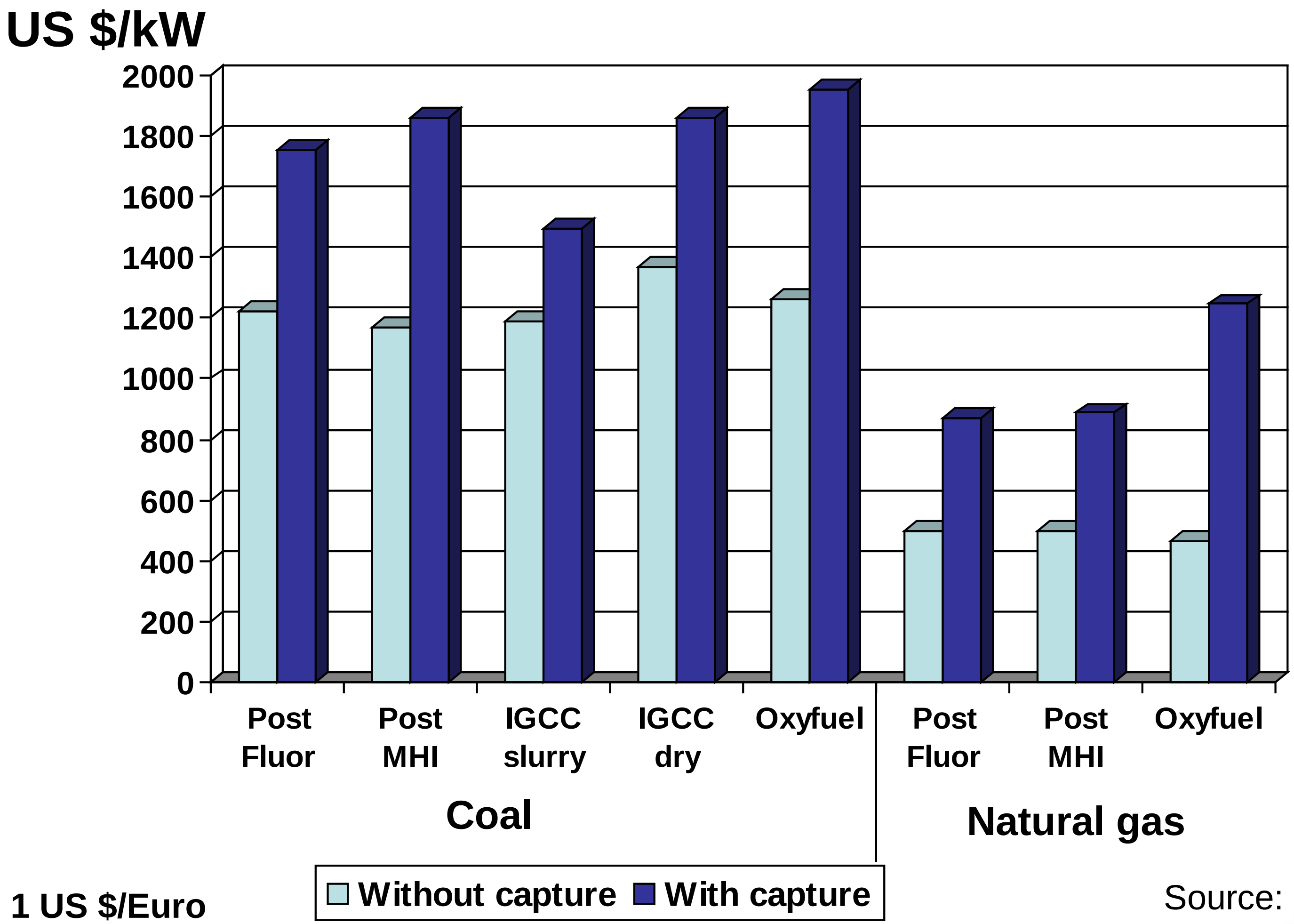
Power Generation Efficiency



Source: IEA GHG studies

75

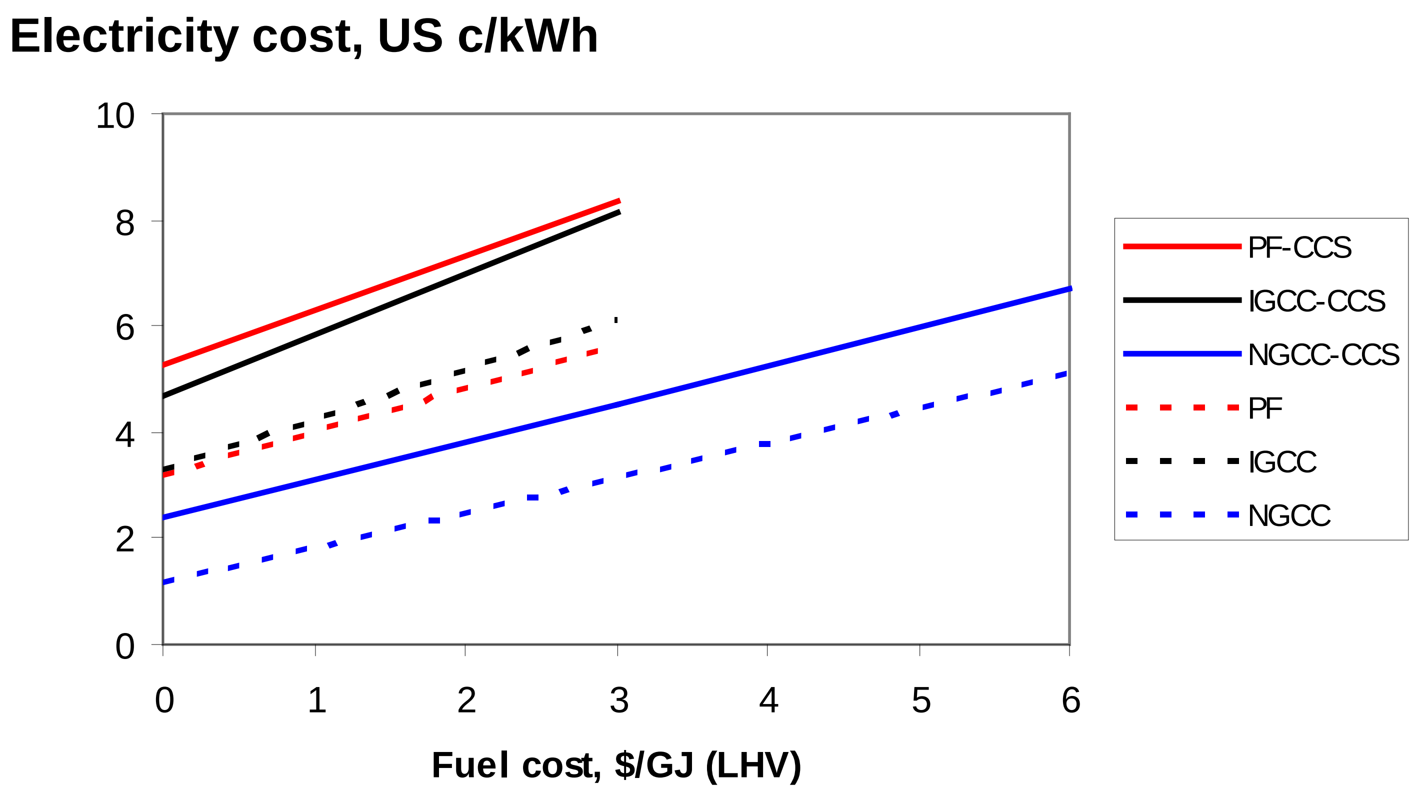
Capital Cost



Based on 1 US $/Euro

Source: IEA GHG studies

Cost of Capture and Storage



Basis: 10% DCF, 25 year life, 85% load factor, \$8/t CO_2 stored