CO_2 Capture for Power Generation
The Challenges Ahead...

Stanley Santos

IEA Greenhouse Gas R&D Programme

Cheltenham, UK

Regional Workshop for
the Baltic Sea and Central & Eastern European Countries

Vilnius, Lithuania

13th April 2011

IEA Greenhouse Gas R&D Programme

- ***A collaborative research programme founded in 1991***
- ***Aim: Provide members with definitive information on the role that technology can play in reducing greenhouse gas emissions.***
- ***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
- ***IEA GHG is an IEA Implementing Agreement in which the Participants contribute to a common fund to finance the activities.***
- ***Activities: Studies and Reports (>120); International Research Networks : Wells, Risk, Monitoring, Modelling, Oxyfuel, Capture, Social Research, Solid Looping; Communications (GHGT conferences, IJGGC, etc); facilitating and focusing R&D and demonstration activities e.g. Weyburn***

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***

Members and Sponsors

Global Policy Context

International Policy Setting

Implementation actions

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

Technical Evaluations

- ***Recently reported***
  - Water Usage and Analysis from Power Plants with CO_2 capture
  - Safety in capture and transport
  - Site characterisation criteria
  - Storage capacity coefficients
  - Well integrity
  - Biomass CCS
  - Operating flexibility of power plants with CCS

- ***Underway***
  - Removal of impurities from CO_2
  - CCS Life cycle analysis
  - Best practice guidelines for site characterisation
  - Pipeline infrastructure
  - Injection strategies for CO_2 storage sites
  - Prospects for storage of CO_2 in EOR
  - Iron and Steel – Techno Economic Study

International Cooperation

One of our objectives is to provide an avenue for discussion on specific issues toward development of CCS and support any confidence building activities

Research Networks

- Post Combustion CO2 Capture
- Oxyfuel Combustion
- Solid Looping
- Monitoring and modelling of CO_2 injection
- Well bore integrity
- Risk Assessment
- Communications research

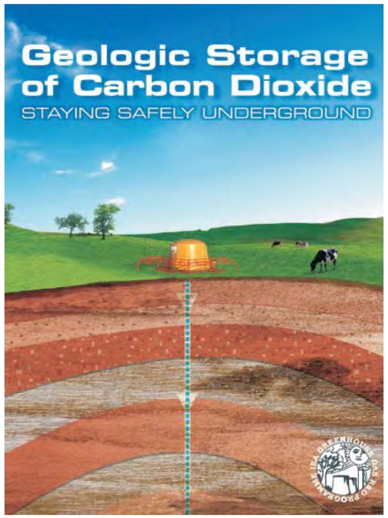
Practical R,D & D

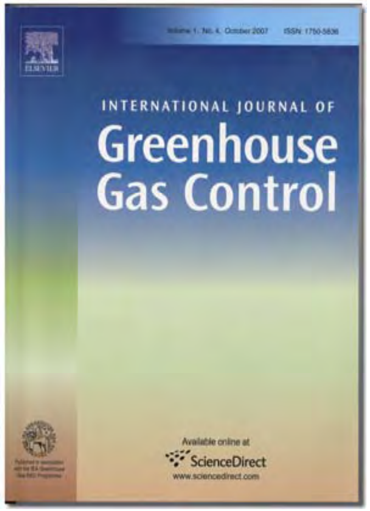
- Weyburn-Midale Canada
- TSB Project on OxySOx
- CO2SINK, Germany
- CO2Remove
- Dynamis
- MOVECBM, Poland

Implementation

- ***International Bodies***
  - EU ZEP
  - London Convention/OSPAR
  - UNFCCC/SBSTA
  - CSLF Technical Group
  - FENCO-ERA
  - UNIDO
  - IEA/CSLF/GCCSI G8
- ***Direct activities***
  - GCCSI
  - IEA Regulators network
  - International Summer School series
    - Mentored programmes at GHGT conferences

Dissemination





GHGT-11
Kyoto, Japan
www.ghgt.info

Oxyfuel Combustion Conference 2

Callide Oxyfuel Project

ieaghg

THE UNIVERSITY OF NEWCASTLE AUSTRALIA

xstrata coal

VATTENFALL

AIR LIQUIDE

HITACHI Inspire the Next

GOBIERNO DE ESPAÑA

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Overview

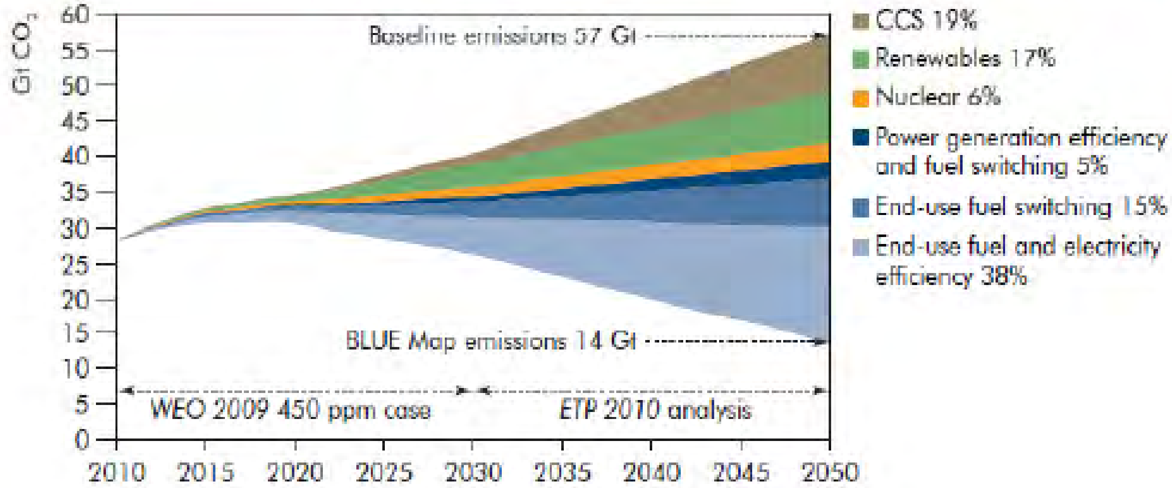
- ***Why we need CO_2 capture and storage?***
- ***An Overview to CO_2 CaptureTechnologies***
  - Post Combustion CO_2 Capture
  - Oxyfuel Combustion with CO_2 Capture
  - Pre-Combustion CO_2 Capture
- ***Some of the Challenges, Key Issues and Direction of Research***
- ***Concluding Remarks***

Introduction

WHY WE NEED CO2 CAPTURE AND STORAGE

CCS in ETP-2010: Contribution to Emissions Savings

- CCS has the 2nd largest share (19%) of CO_2 reductions in 2050 (9.4 $GtCO_2$, or 120 $GtCO_2$ from 2010-2050)

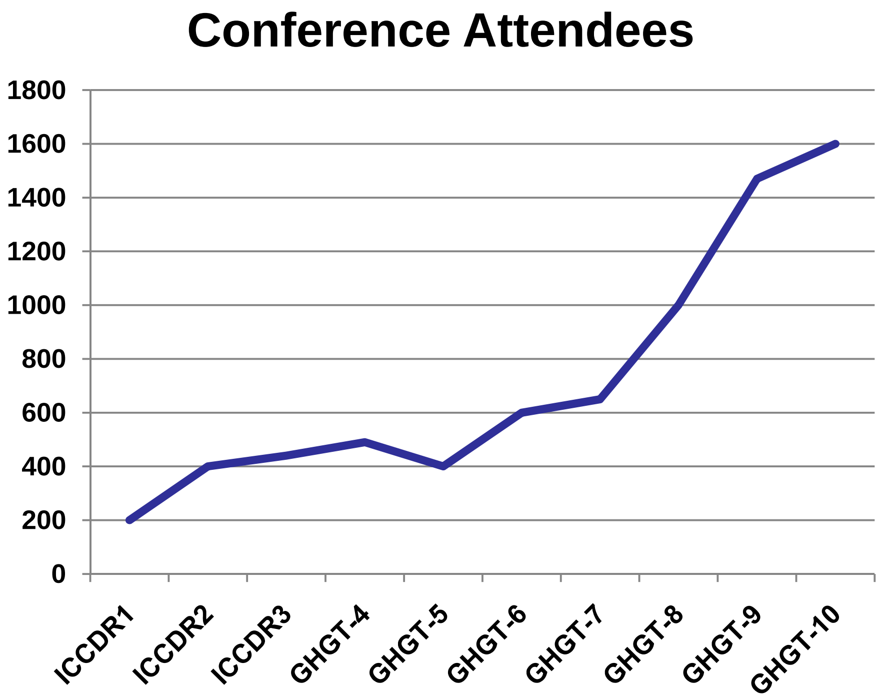


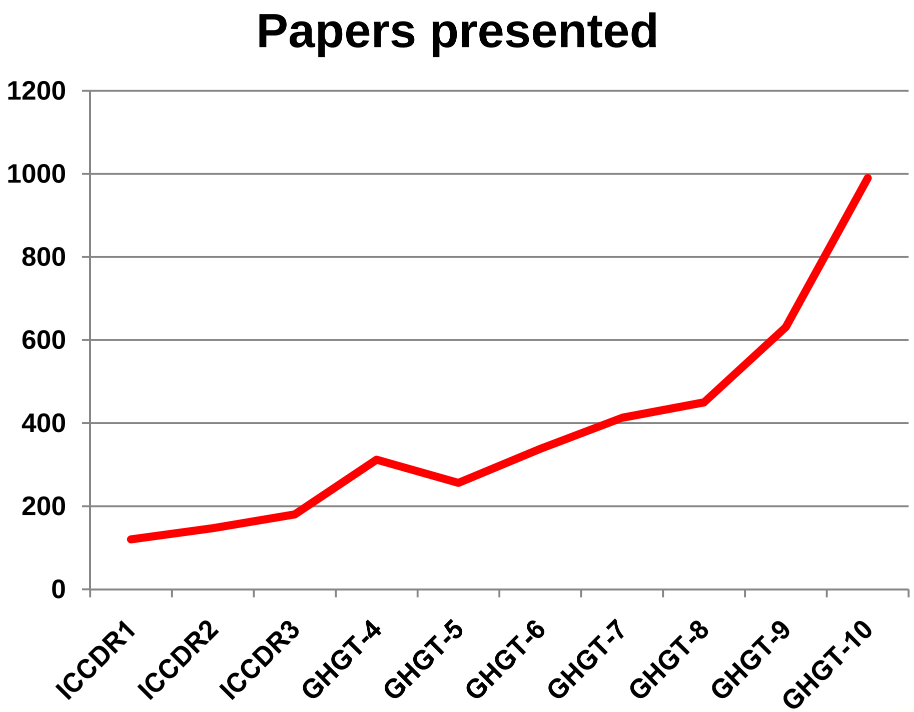
- CCS contributes to 31% of emissions reductions in the power sector by 2050, comparable to renewables
- In 2050, 90% of electricity generated from coal comes from plants with CCS (plus 30% of NG plants use CCS)
- In industry & fuel transformation, CCS has the 2nd largest share (33%) of direct emissions reductions

ETP 2010 BLUE Map Scenario

Over the past 20 years...

Growth in Interest in CCS has been significant

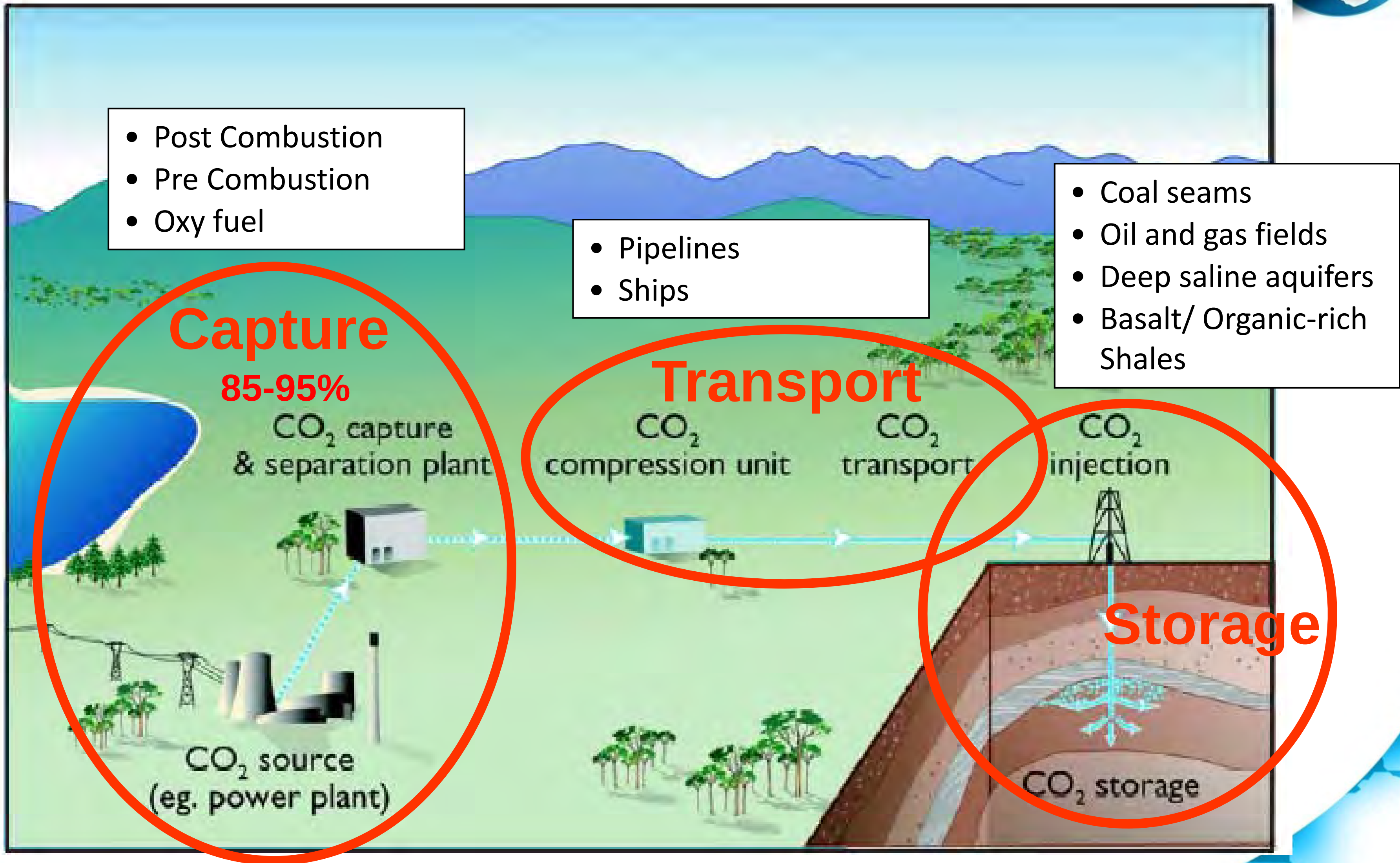




Introduction

CO_2 CAPTURE TECHNOLOGY FOR POWER GENERATION - AN OVERVIEW

What is CCS?



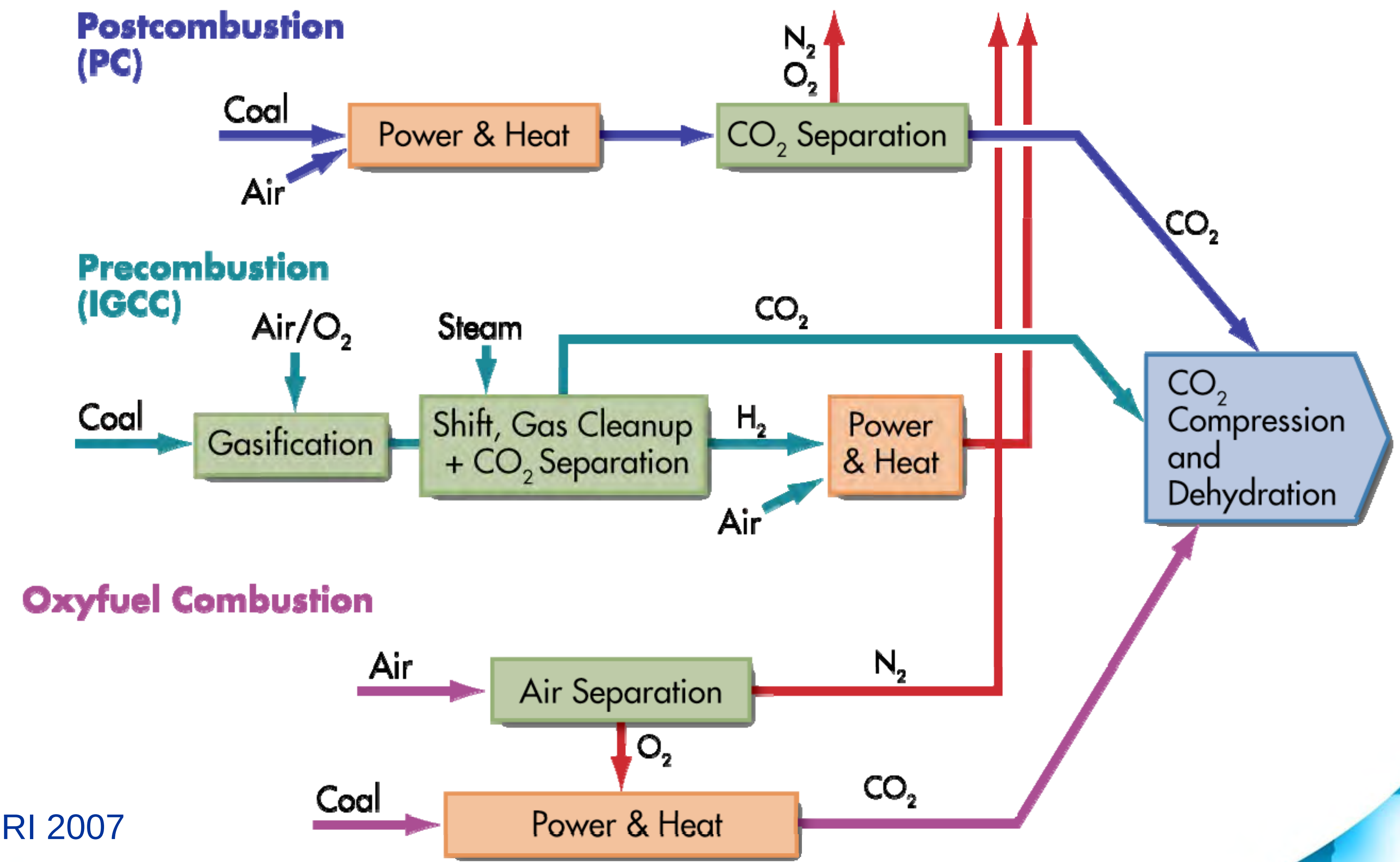
- Post Combustion
- Pre Combustion
- Oxy fuel

- Pipelines
- Ships

- Coal seams
- Oil and gas fields
- Deep saline aquifers
- Basalt/ Organic-rich Shales

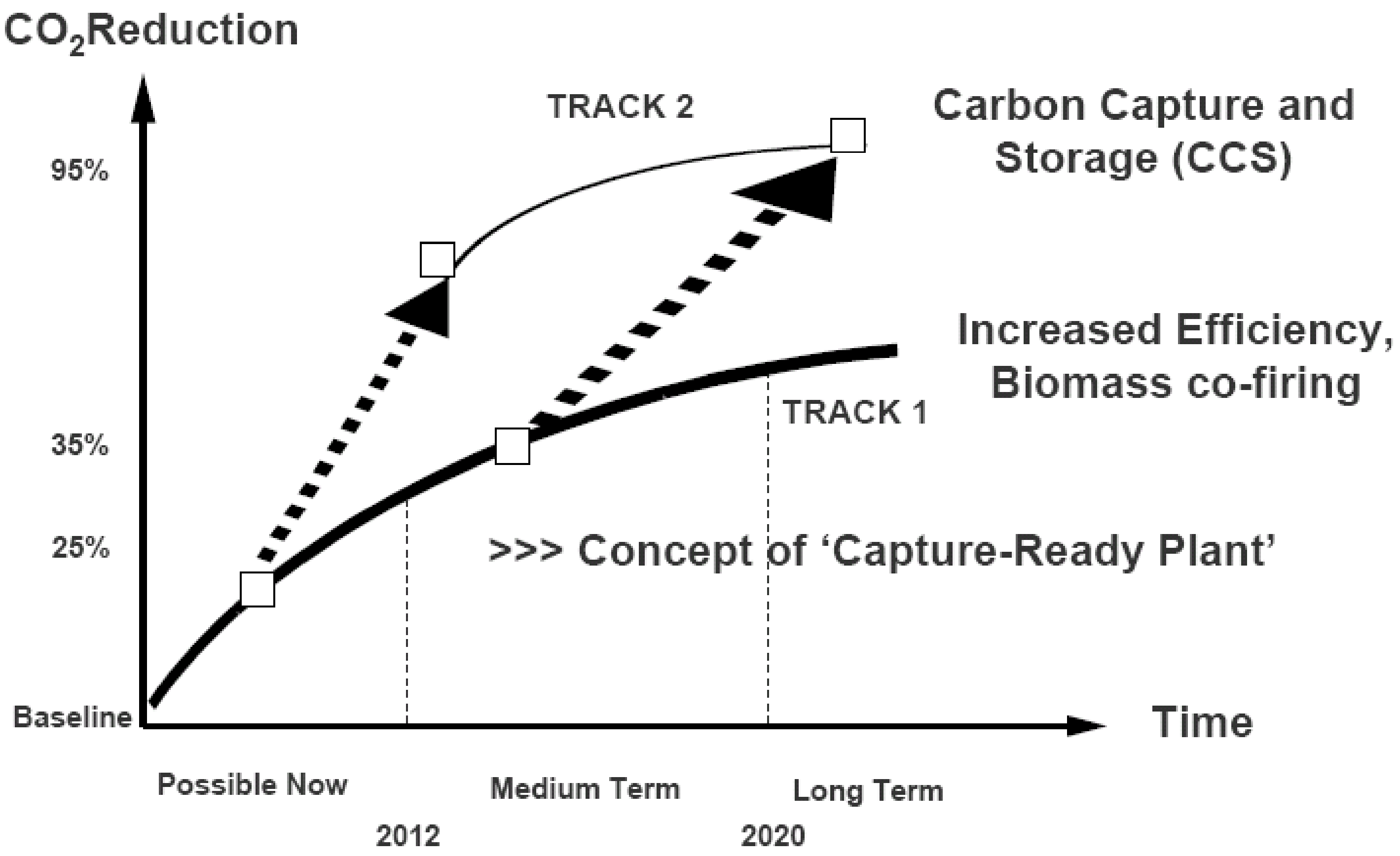
Capture
85-95%
CO_2 capture & separation plant
CO_2 source (eg. power plant)
Transport
CO_2 compression unit
CO_2 transport
CO_2 injection
Storage
CO_2 storage

CO_2 Capture Options



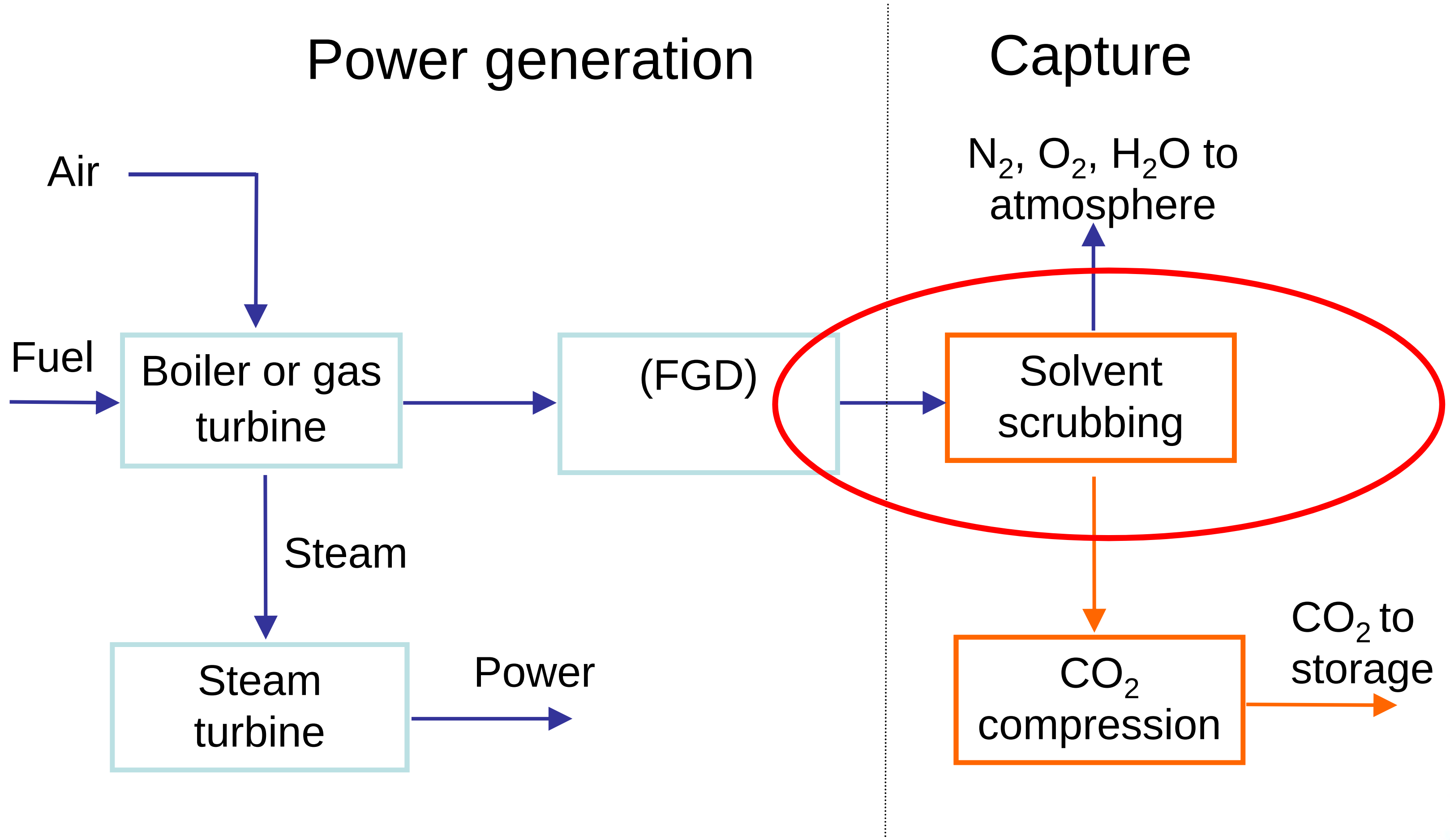
EPRI 2007

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



POST COMBUSTION CO_2 CAPTURE TECHNOLOGY FOR COAL FIRED POWER GENERATION

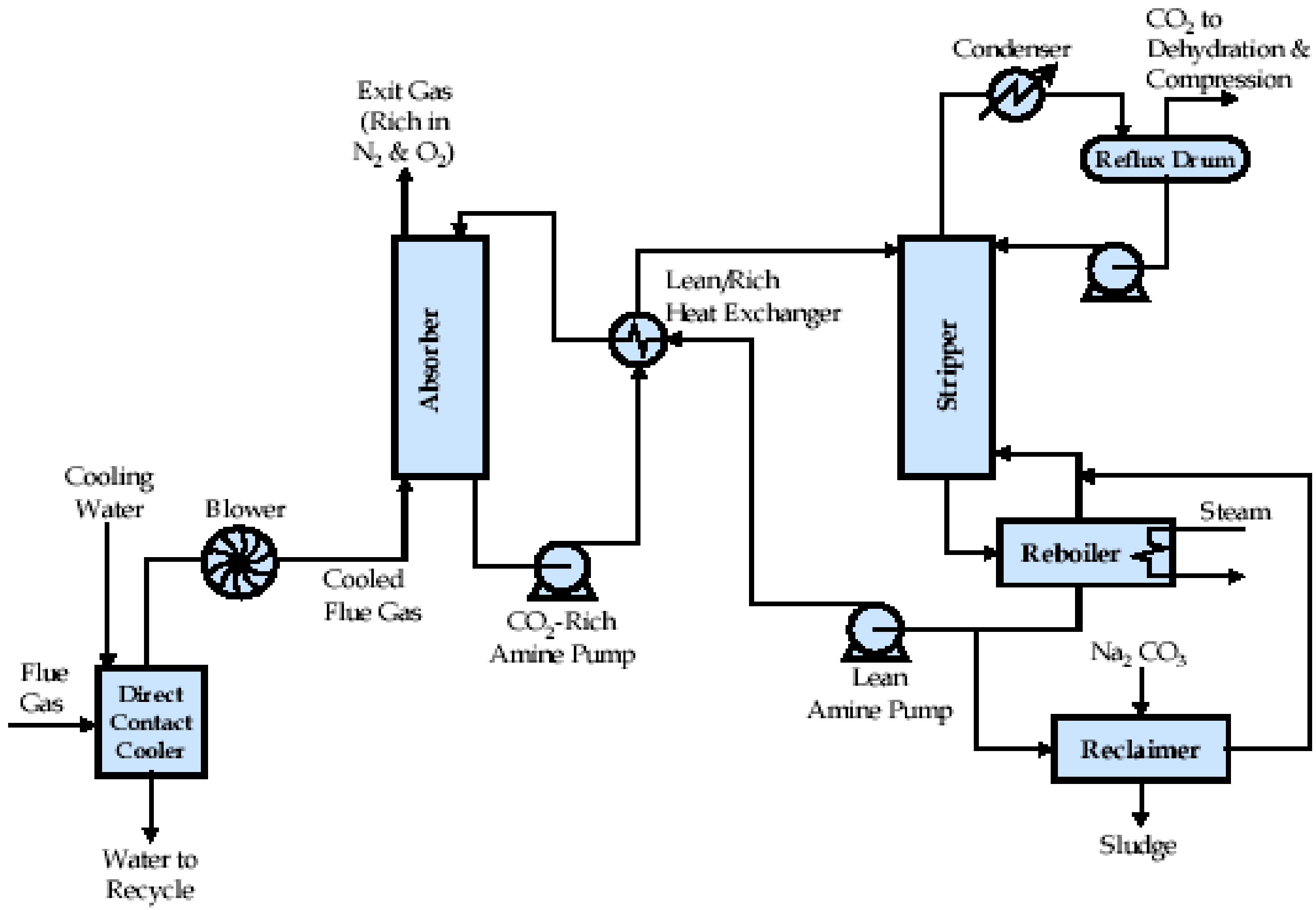
Post-Combustion Capture



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

Chemical Absorption Process



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 CO2 capture plant**

Picture: CASTOR pilot plant -Esbjerg

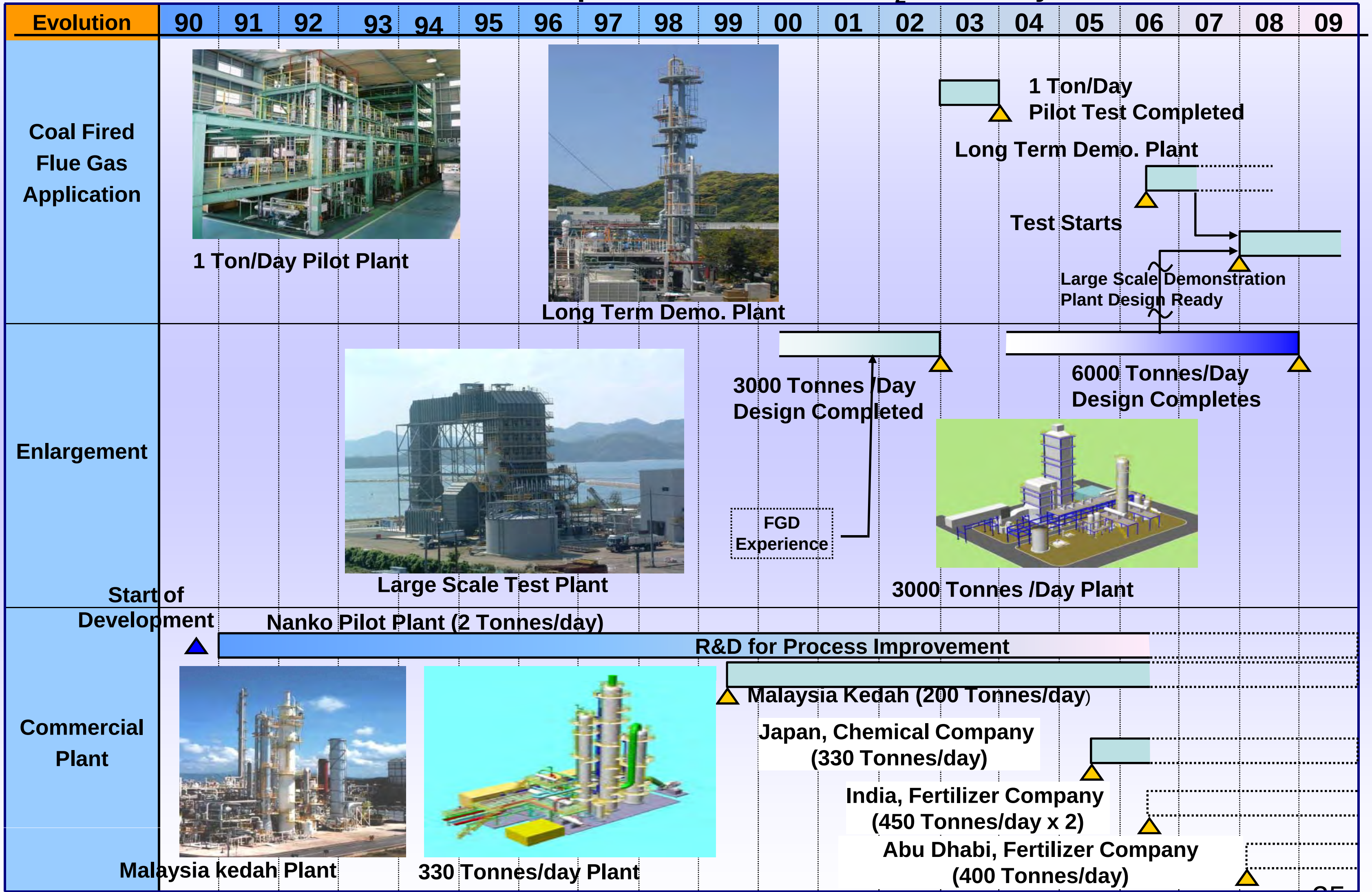
Issues for Post Combustion Capture

- **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”

MITSUBISHI CO_2 Recovery Technology from Flue Gas

<Experience and R&D Facilities>

MHI's Evolution Development of Flue Gas CO_2 Recovery Plant



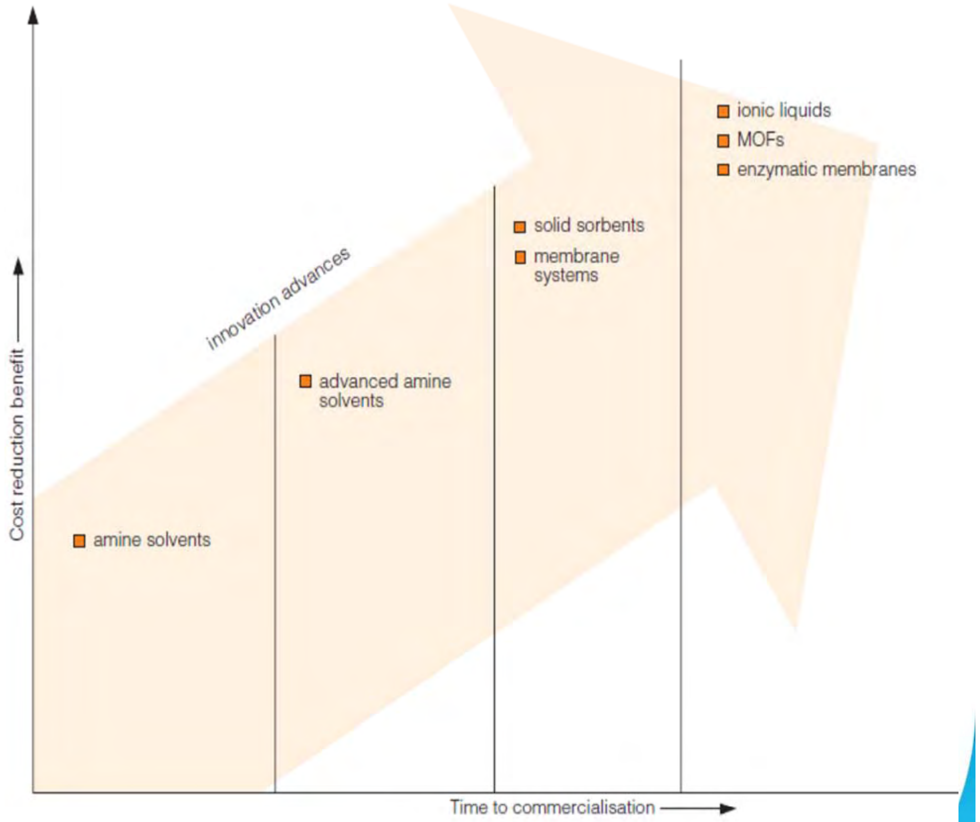
MITSUBISHI HEAVY INDUSTRIES, LTD.

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

Post Combustion: Where to Focus

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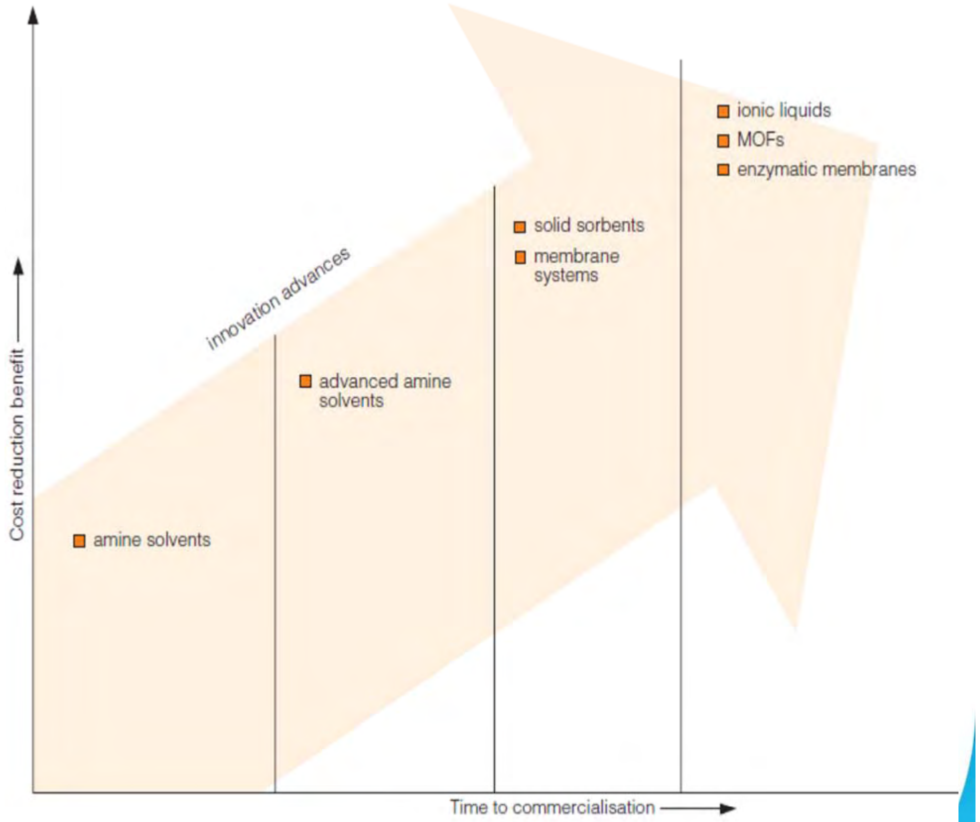


Source: Figueroa et al., 2008

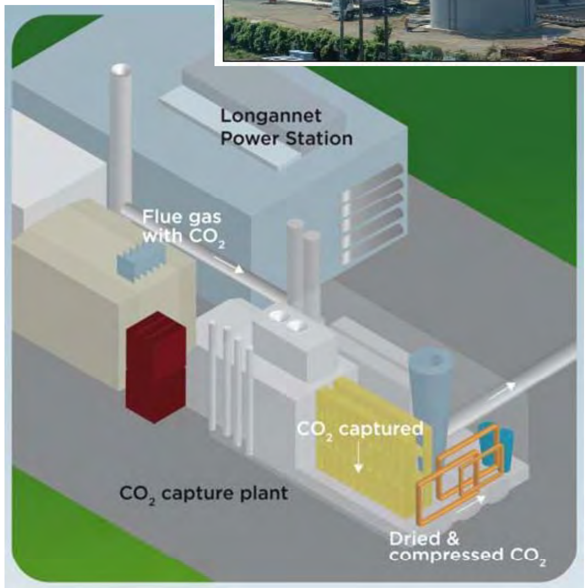
What's Next

Nanko Pilot Plant (2t/d)

Castor Pilot Plant (2t/d)

Pilot Plants

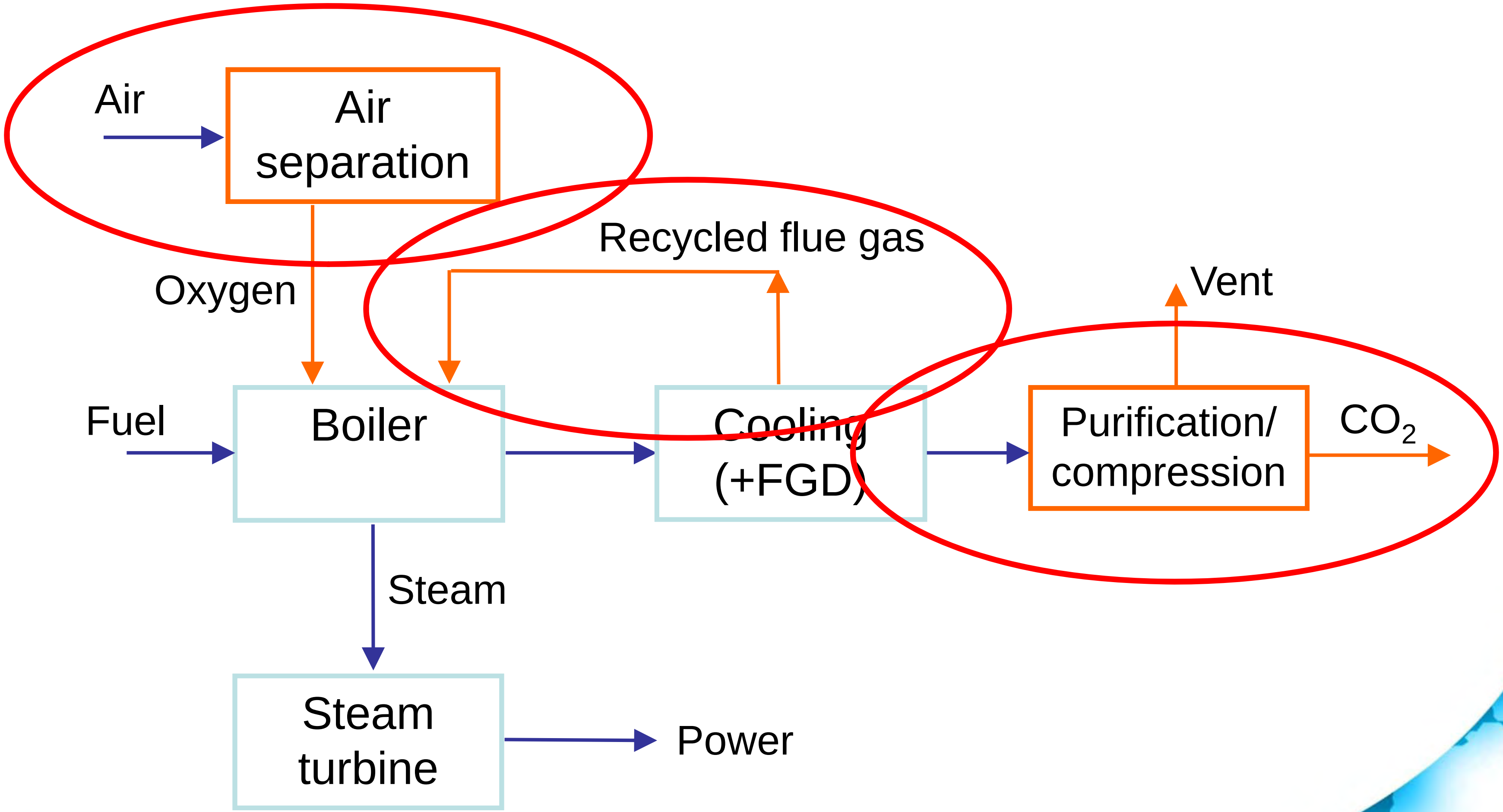
MHI Large Scale Demo Unit



Commercial Scale Demonstration

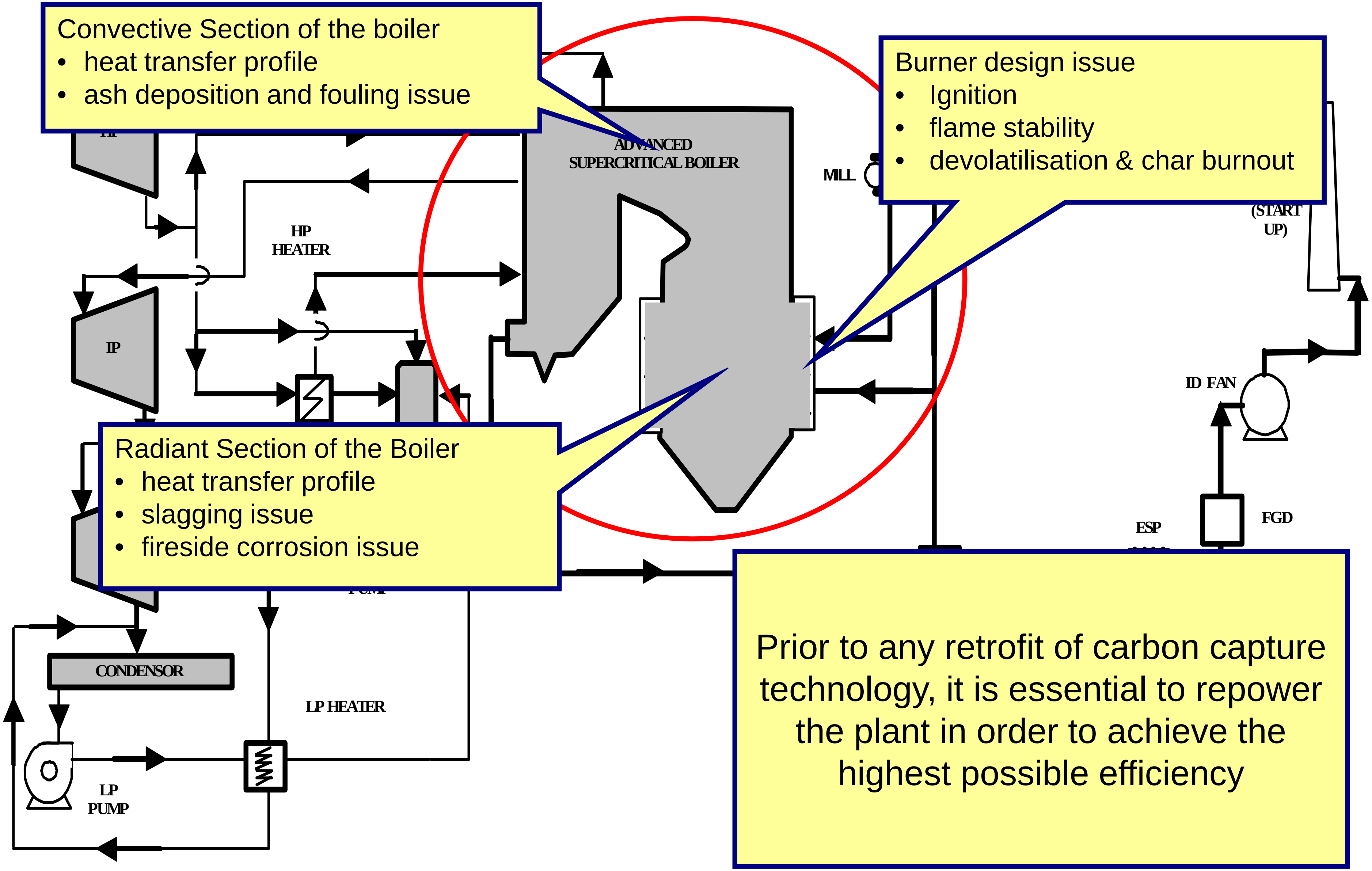
OXYFUEL COMBUSTION CO_2 CAPTURE TECHNOLOGY FOR COAL FIRED POWER GENERATION

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 CO2 capture. With continuous demonstration of this technology... It is catching up!!!***
- ***3 key development issues***
  - Boiler and burner development
  - Air Separation Unit – "Cost and capacity of oxygen production"
  - CO_2 processing – "Removal of impurities"

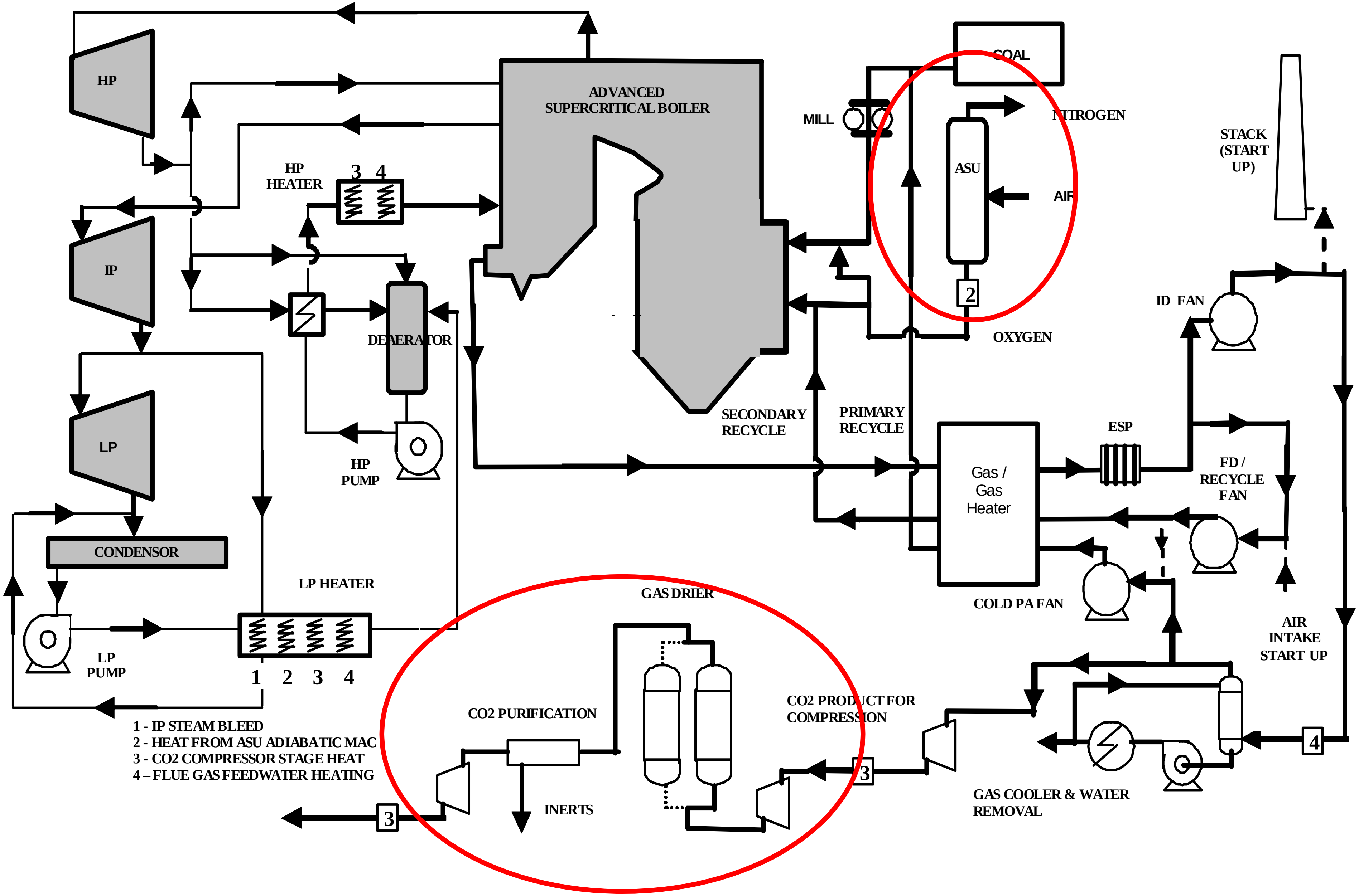


Convective Section of the boiler
- heat transfer profile
- ash deposition and fouling issue

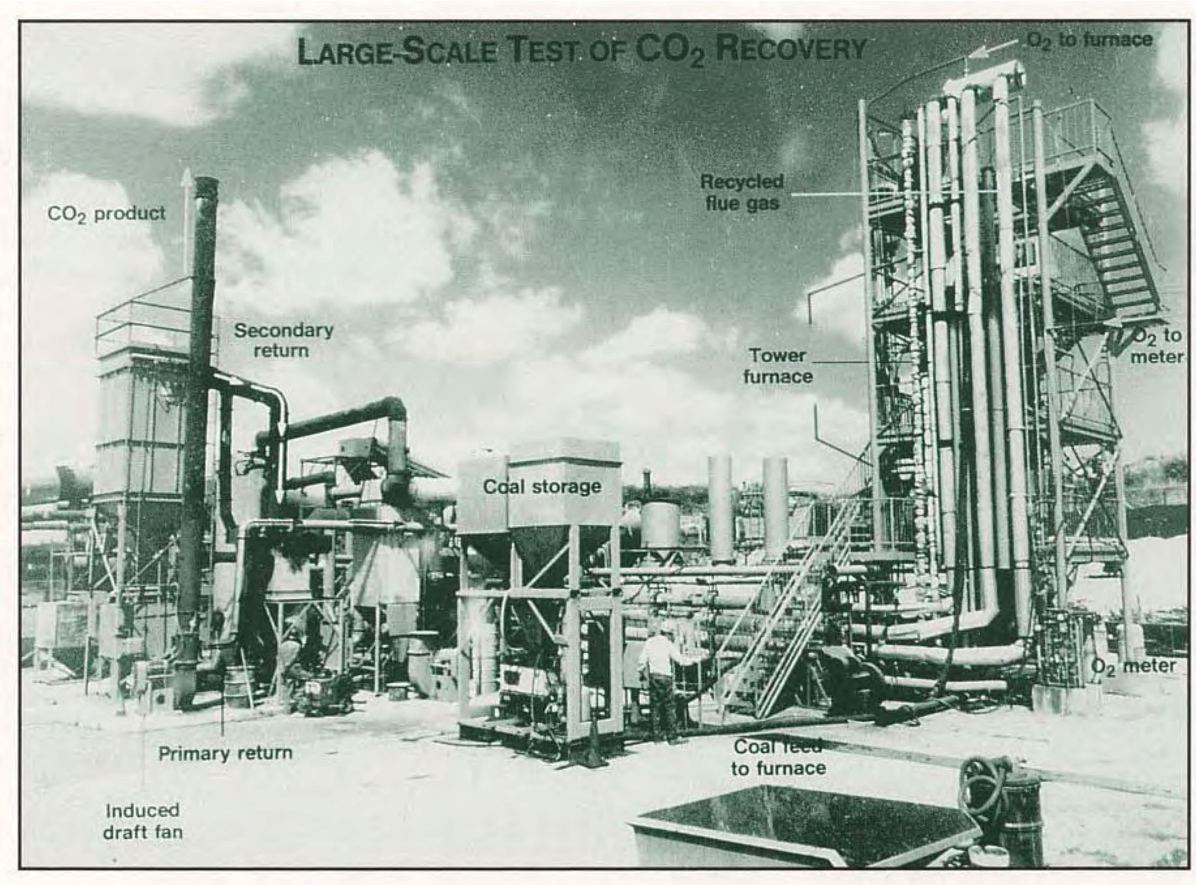
Burner design issue
- Ignition
- flame stability
- devolatilisation & char burnout

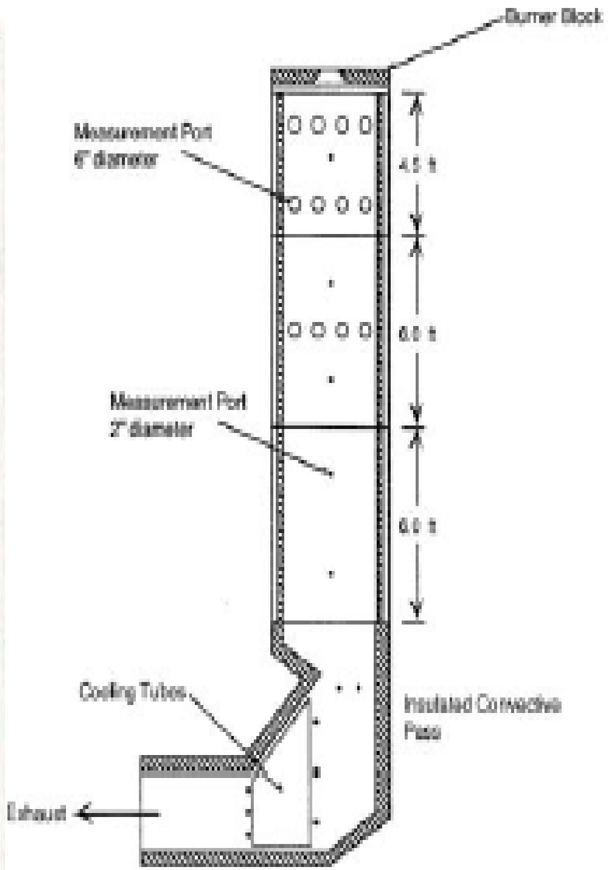
Radiant Section of the Boiler
- heat transfer profile
- slagging issue
- fireside corrosion issue

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

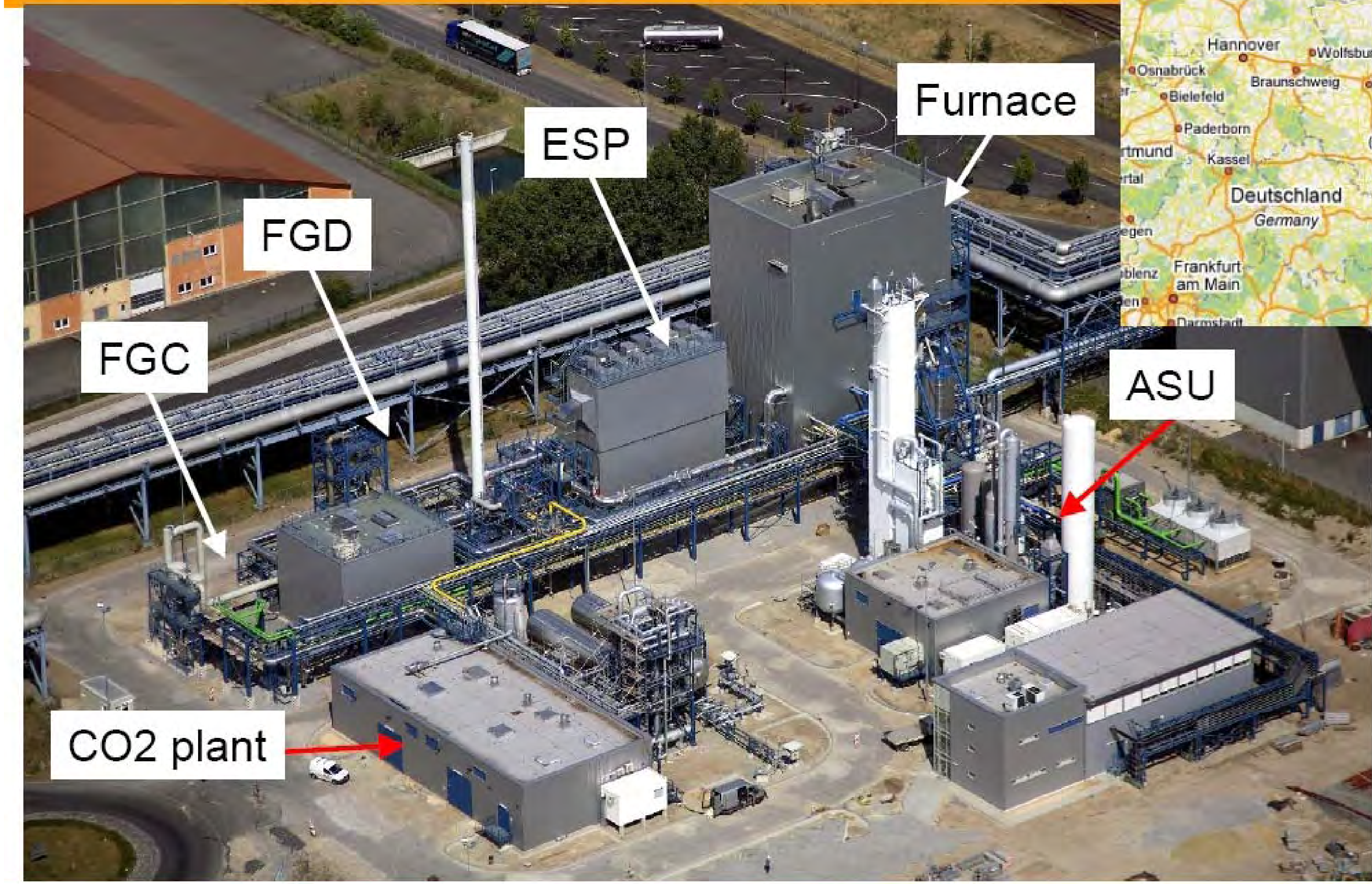

HP
IP
LP
CONDENSOR
LP PUMP
LP HEATER
1 2 3 4
HP HEATER
3 4
DEAERATOR
HP PUMP
ADVANCED SUPERCRITICAL BOILER
MILL
COAL
NITROGEN
ASU
AIR
2
OXYGEN
STACK (START UP)
ID FAN
SECONDARY RECYCLE
PRIMARY RECYCLE
Gas / Gas Heater
ESP
FD / RECYCLE FAN
COLD PA FAN
AIR INTAKE START UP
GAS DRIER
CO2 PURIFICATION
INERTS
CO2 PRODUCT FOR COMPRESSION
GAS COOLER & WATER REMOVAL
3
4
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)



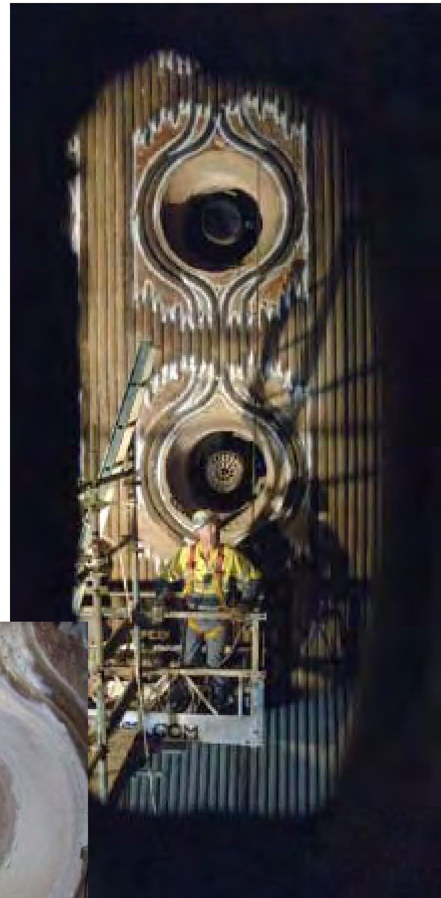


The Oxyfuel pilot plant



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)

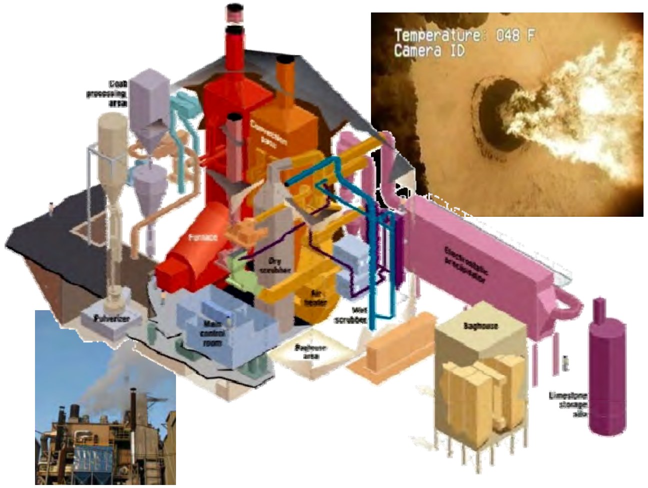


Courtesy of CS Energy, IHI

CIUDEN CO_2 Capture Programme.

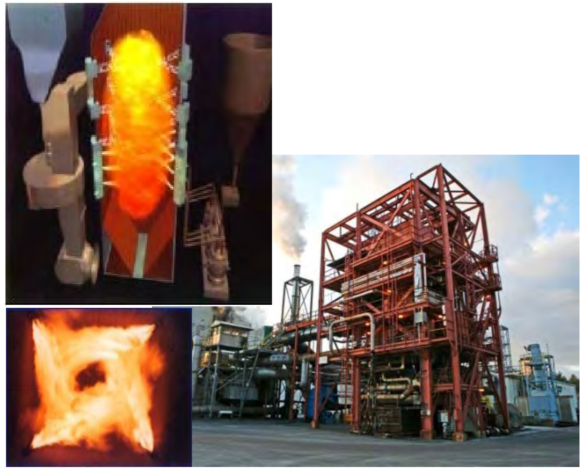
- *First oxyfuel pilot plant that will demonstrate in large scale the Oxy-CFB technology.*
- *Oxy-PC facility is very complimentary to Vattenfall's and Callide's facilities.*
- *Could be in a unique position to provide information related to the burner – burner interaction (in smaller scale).*
- *1st facility to investigate Anthracite (this would be first in the world), Petcoke and Biomass.*

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

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Jänschwalde demonstration plant.
500 MW with oxyfuel and post combustion capture

VATTENFALL

Key Areas of Development

- ***Areas of Development***
  - Burner and Boiler Development
  - Oxygen Production
  - CO2 Processing Unit
- ***Some of the Challenges...***
  - Are we ready to demonstrate in large scale...?
  - Reducing the Cost of Oxygen Production – an important aspect to the demonstration and commericialisation of oxyfuel.
  - How will the regulations define the CO2 purity???

Cryogenic Air Separation – Capacity Increase

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

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

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.

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 O2
    - Largest operating ASU today (single train) ~4000 TPD O2.
- ***Remaining Issues***
    - 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.**

Air Products' CO_2 Purification and Compression Technology for Oxyfuel

Sour Compression
SOx, NOx, Hg
Removal

- SO_x/NO_x removed in compression system
  - NO is oxidised to NO_2 which oxidises SO_2 to SO_3
  - The Lead Chamber Process
- FGD and $DeNO_x$ systems
  - Optimisation
  - Elimination
- Low NOx burners are not required for oxyfuel combustion
- Hg will also be removed, reacting with the nitric acid that is formed

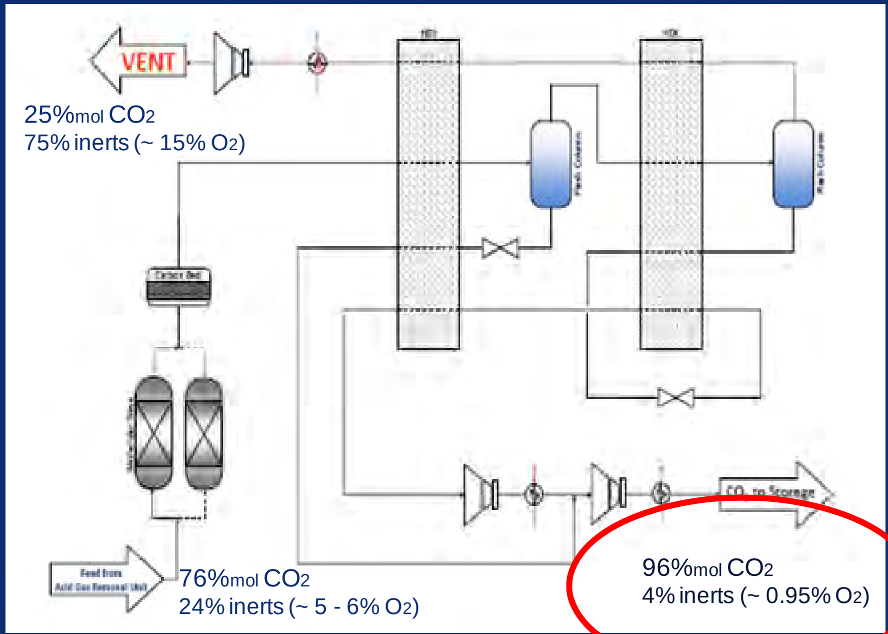
Auto-Refrigerated
Inerts Removal
Ar, N_2, O_2

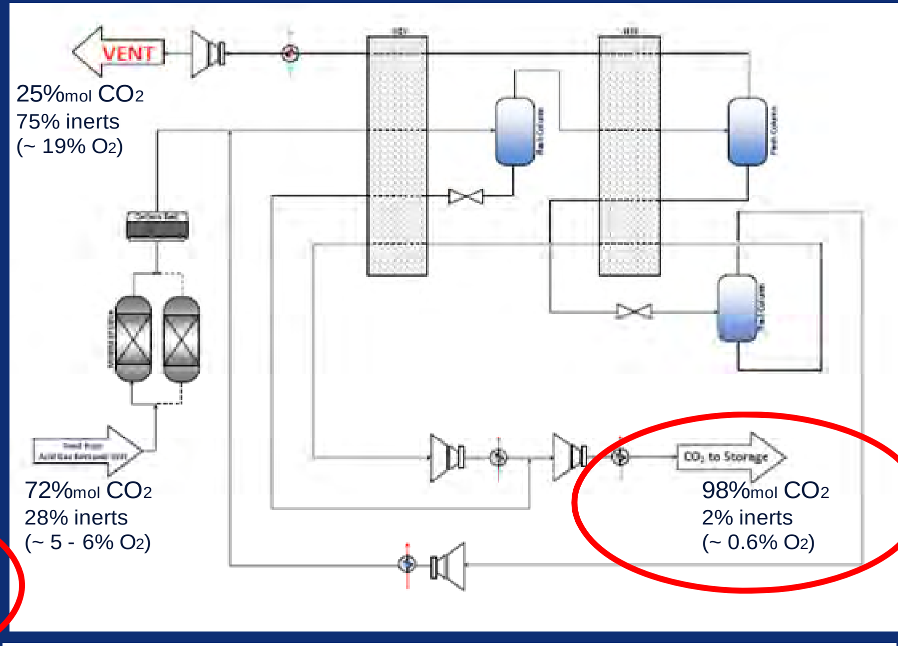
- Removal minimises compression and transportation costs.
- Optional O_2 removal for EOR-grade CO_2
- CO_2 capture rate of 90% with CO_2 purity >95%
- CO_2 capture rate depends on raw CO_2 purity which depends on air ingress

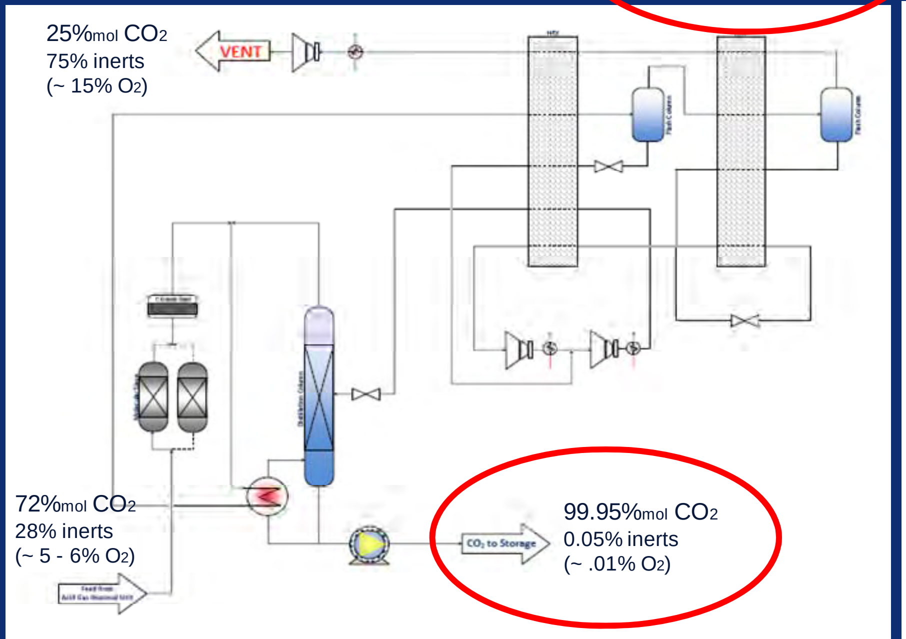
Air Products'
PRISM® Membrane
For enhanced
CO_2 + O_2 Recovery

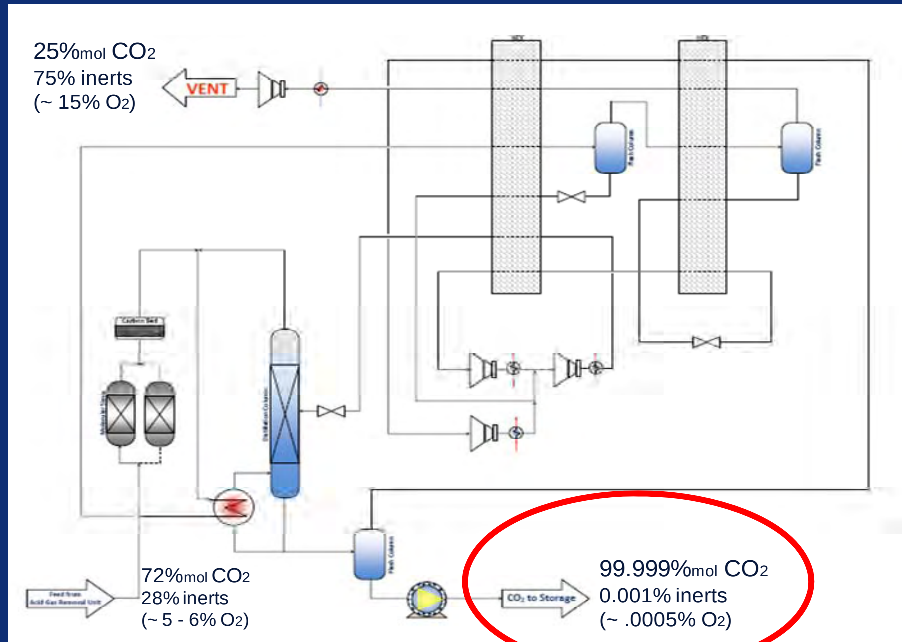
- Inerts vent stream is clean, at pressure and rich in CO_2 (~25%) and O_2 (~20%)
- Polymeric membrane unit – selective for CO_2 and O_2 – in vent stream will recycle CO_2 and O_2 rich permeate stream to the boiler.
- CO_2 capture rate increases to >97% and ASU size/power reduced by ~5%

AIR PRODUCTS


VENT
25%mol CO_2
75% inerts (~ 15% O_2)
Carbon Bed
CO₂ to Storage
Feed from Acid Gas Removal Unit
76%mol CO_2
24% inerts (~ 5 - 6% O_2)
96%mol CO_2
4% inerts (~ 0.95% O_2)


VENT
25%mol CO_2
75% inerts
(~ 19% O_2)
CO₂ to Storage
72%mol CO_2
28% inerts
(~ 5 - 6% O_2)
98%mol CO_2
2% inerts
(~ 0.6% O_2)


25%mol CO_2
75% inerts
(~ 15% O_2)
VENT
72%mol CO_2
28% inerts
(~ 5 - 6% O_2)
CO₂ to Storage
99.95%mol CO_2
0.05% inerts
(~ .01% O_2)


25%mol CO_2
75% inerts
(~ 15% O_2)
VENT
72%mol CO_2
28% inerts
(~ 5 - 6% O_2)
CO₂ to Storage
99.999%mol CO_2
0.001% inerts
(~ .0005% O_2)

Path to from Lab to Demo

Photo courtesy of Imperial College

Cylinder fed bench rig

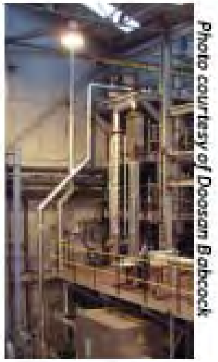


Photo courtesy of Doosan Babcock

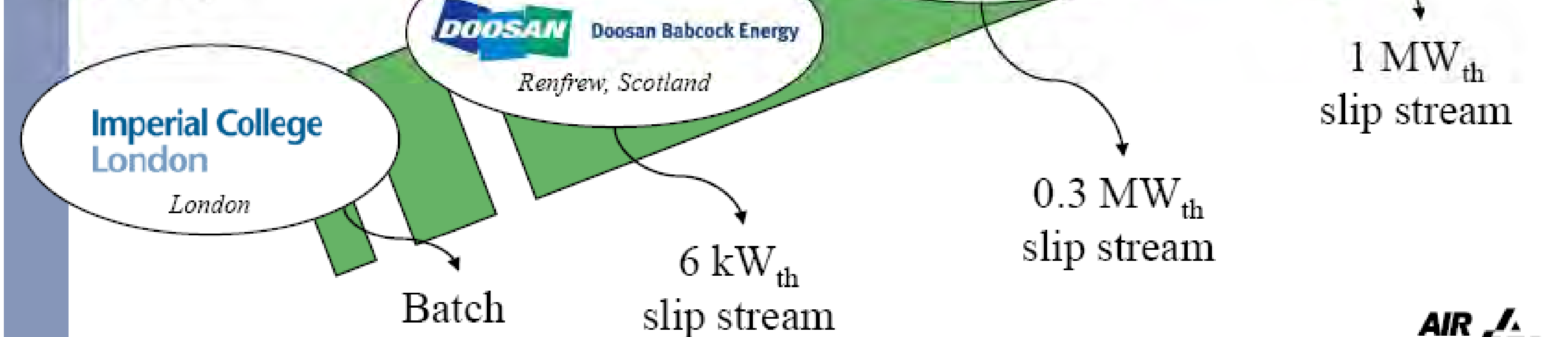
160 kW$_{th}$ oxy-coal rig

Photo courtesy of Alstom Power

15 MW$_{th}$ oxy-coal combustion unit

Photo courtesy of Vattenfall

30 MW$_{th}$ oxy-coal pilot plant



Large Scale Pilot and Demo Projects

Updated by S. Santos (01/12/10)

PROJECT	Location	MWth	Start Up Year	Boiler Type	Main Fuel	CO_2 Train
B & W	USA	30	2007	Pilot PC	Bit, Sub B., Lig.	
Jupiter	USA	20	2007	Industr. No FGR	NG, Coal	
Oxy-coal UK	UK	40	2009	Pilot PC	Bituminous	
Alstom (Windsor Facility)	USA	15	2009	Pilot PC (Tangential)	Bit., Sub B., PRB	
Vattenfall	Germany	30	2008	Pilot PC	Lignite (Bit.)	**With CCS**
Total, Lacq	France	30	2009	Industrial boiler	NG	**With CCS**
Callide	Australia	90	2010	30 MWe PC	Bituminous	**With CCS**
CIUDEN – PC	Spain	20	2010	Pilot PC	Anthra. Bit, Lig. Coke	**With CCS**
CIUDEN – CFB	Spain	30	2010	Pilot CFB	Anthra. Bit, Lig. Coke	**With CCS**
Vattenfall (Janschwalde)	Germany	~1000	2014?	~300 MWe PC	Lignite (Bit.)	**With CCS**
Endesa/CIUDEN	Spain	~1000	2015?	~300 MWe CFB?	?	**With CCS**
FutureGen2	USA	~600	2015?	~200 MWe PC	Bituminous Coal	**With CCS**
KOSEP/KEPRI Yongdong	Korea	~400	2018?	~100 MWe PC	?	?

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Alstom	Schwarze Pumpe	2008	30MWth	Lignite
Hitachi Babcock	Schwarze Pumpe	2010	30MWth	Lignite
IHI	Callide	2011	30MWe	Coal
Alstom / AL	Lacq	2009	30MWth	Gas/Oil?
CIUDEN	El Bierzo CFB Facility	2011	30MWth	Coal
CIUDEN	El Bierzo PC Facility	2011	20MWth	Coal

Vattenfall - Janschwalde (PC -250MWe)
KEPCO/KOSEP - Yongdong (PC - 100MWe)
FutureGen2 - Illinois (PC - 100MWe)
Endesa/CIUDEN - El Bierzo (CFB - 300MWe)

Finish Line

Target :
"Commercialised by 2020"

1980's
ANL/Battelle/EERC completed the first industrial scale pilot plant

1990 - 1995
EC Joule Thermie Project
- IFRF / Doosan Babcock / Int'l Combustion
NEDO / IHI / Jcoal Project

First large scale 35MWt Oxy-Coal Burner Retrofit Test done by International Combustion

1998 – 2001
CANMET
US DOE Project / B&W / Air Liquide

2003 - 2005
Vattenfall (ENCAP ++)
CS Energy / IHI Callide Project

2007
B&W CEDF (30MWt)
large scale burner testing started

2008
World's FIRST 30 MWt full chain demonstration at Schwarze Pumpe Pilot Plant

2009 – Lacq – World's first 30MWt retrofitted Oxy-NG boiler

2011 – Callide – World's first 30MWe retrofitted Oxy-coal power plant

2011 – CIUDEN – World's first 30MWt Oxy-CFB Pilot Plant

By 2014-2018

Demonstration of 50– 300MWe full scale power plant.

By the end of 2010/2011, Users (i.e. Power Plant Operators) will have 6 burner manufacturers fully demonstrating "Utility Size Large Scale Burners" which should give a high level of confidence toward demonstration

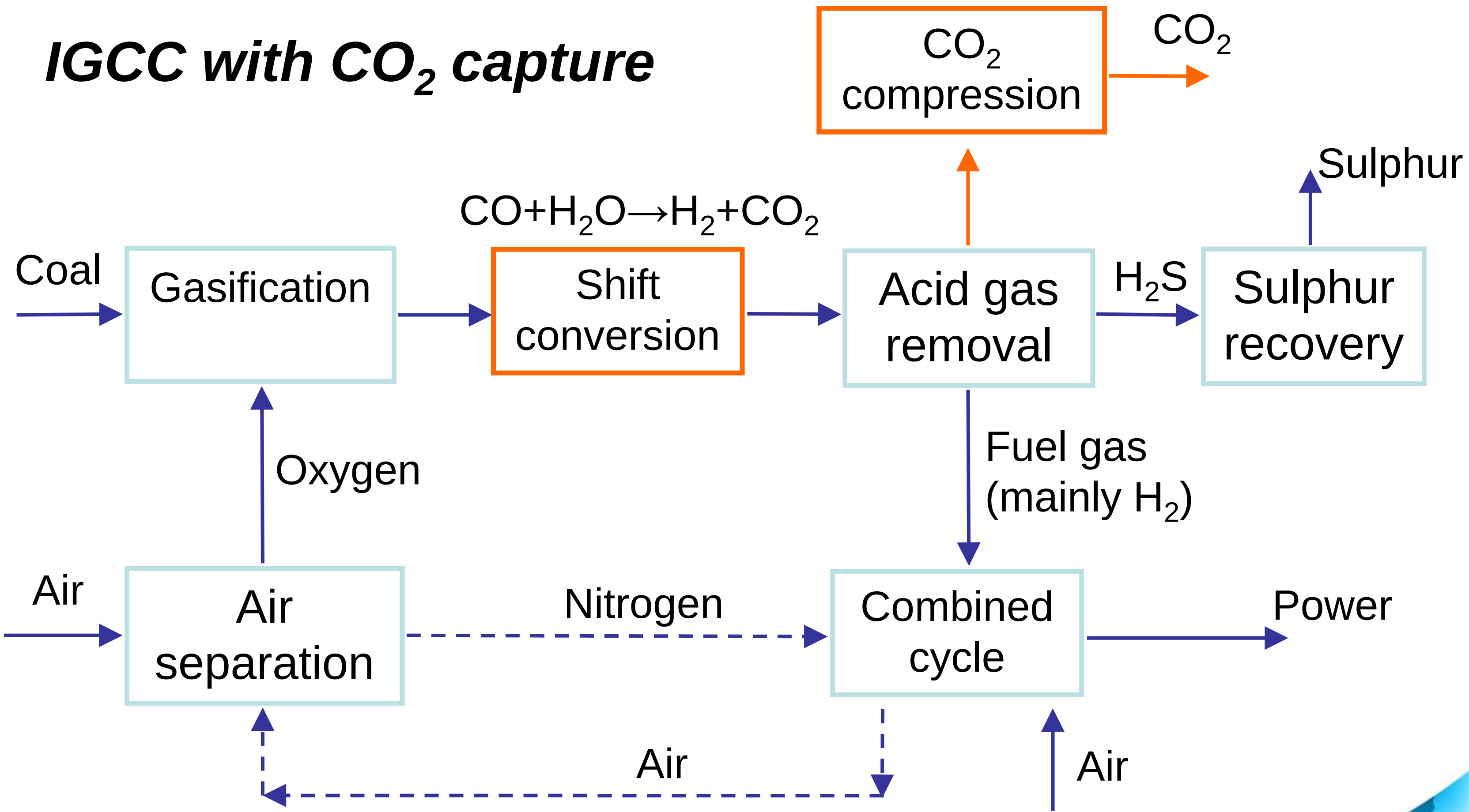
B&W	CEDF	2008	30MWth	Coal
Alstom	Alstom CE	2010	15MWth	Coal
Doosan Babcock	DBEL - MBTF	2009	40MWth	Coal

Updated by S. Santos (01/12/10)

PRE COMBUSTION CO_2 CAPTURE TECHNOLOGY FOR COAL FIRED POWER GENERATION

Pre-Combustion Capture

- ***IGCC with CO_2 capture***



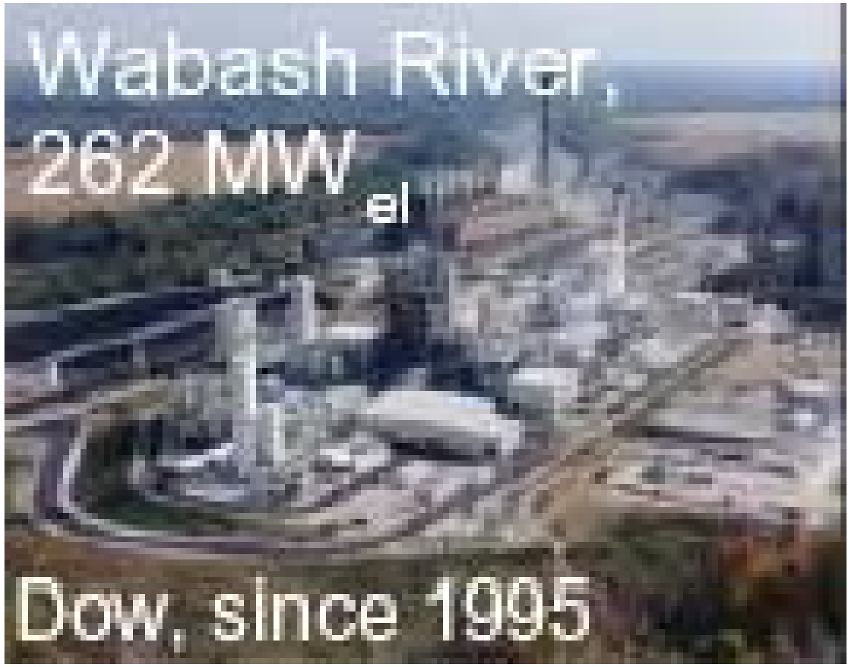
IGCC without Capture

- *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



Overview of Pre-Combustion Technology

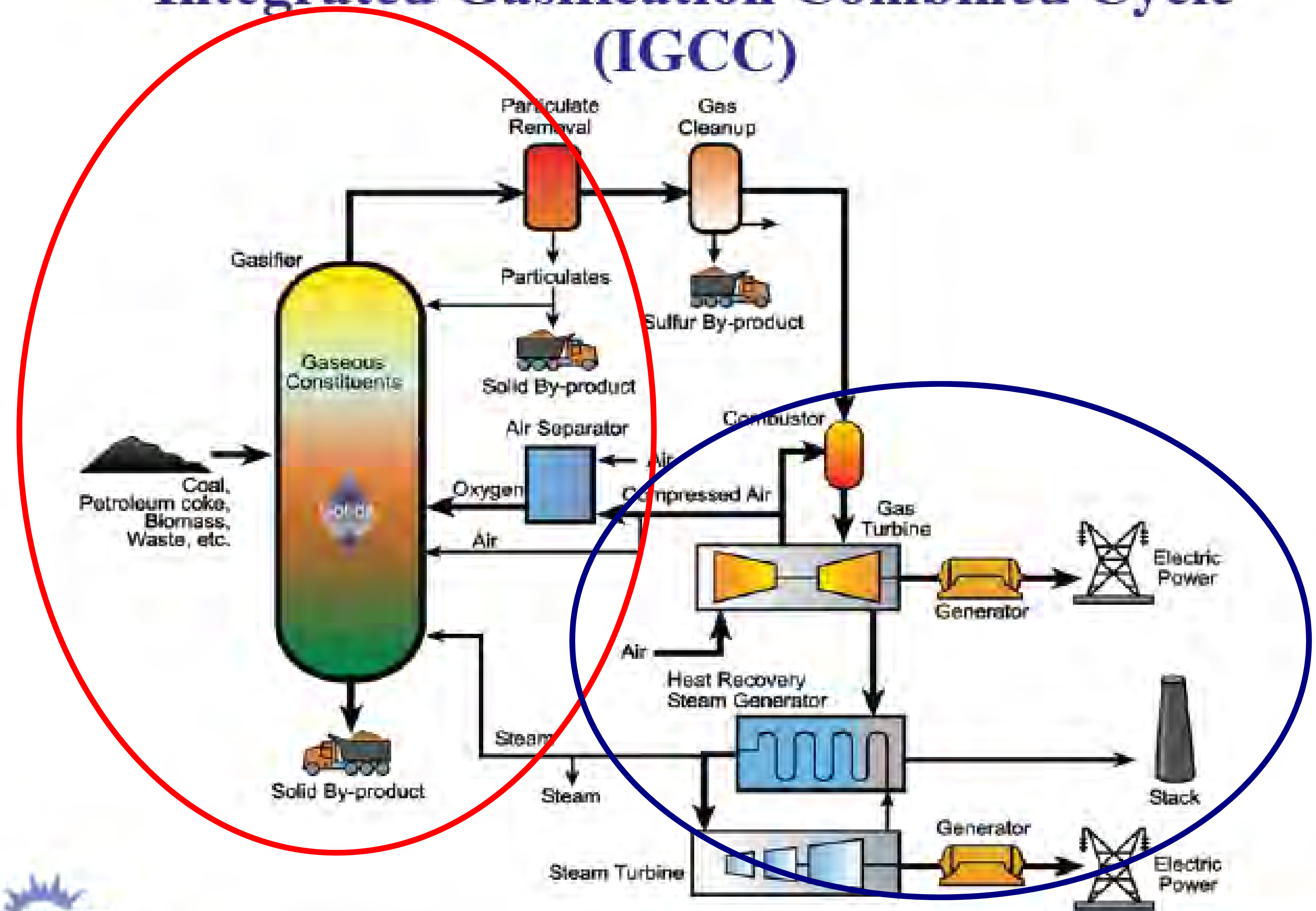
- ***Pre-combustion capture process is not a new concept***
  - Primarily based on production of synthetic gas, separating the CO_2 and using the decarbonised syngas as fuel for the gas turbine

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

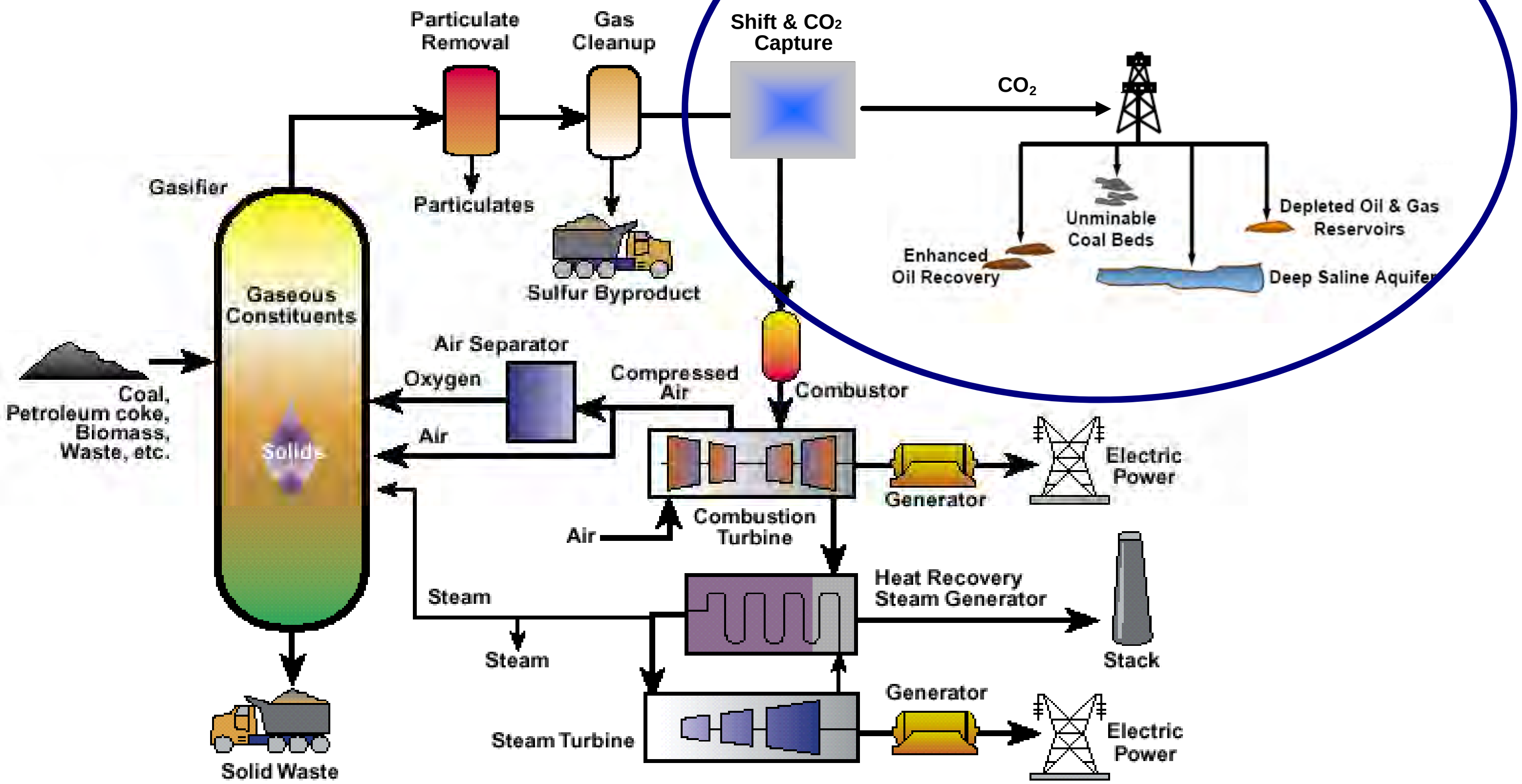
- ***Gasification technologies could produce a waste gas stream, which has high concentration of CO_2***
  - This offers an opportunity to capture CO_2 at low cost

- ***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)



Integrated Gasification Combine Cycle with CO_2 Capture



Shift Reactor

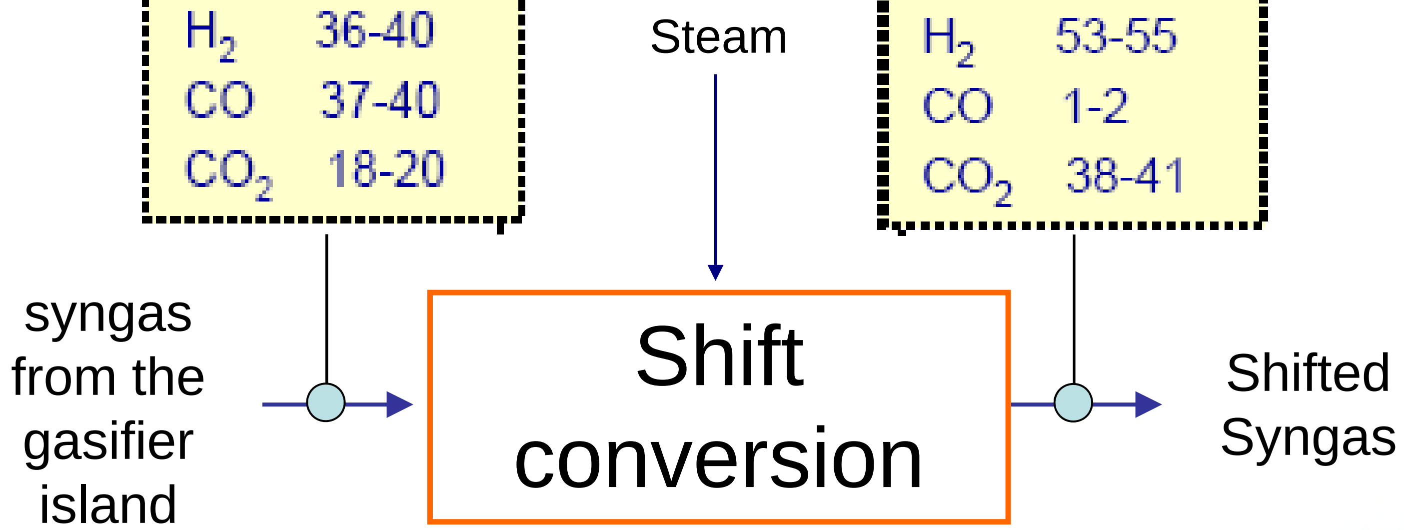
CO_2 Capture Advantages:

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)

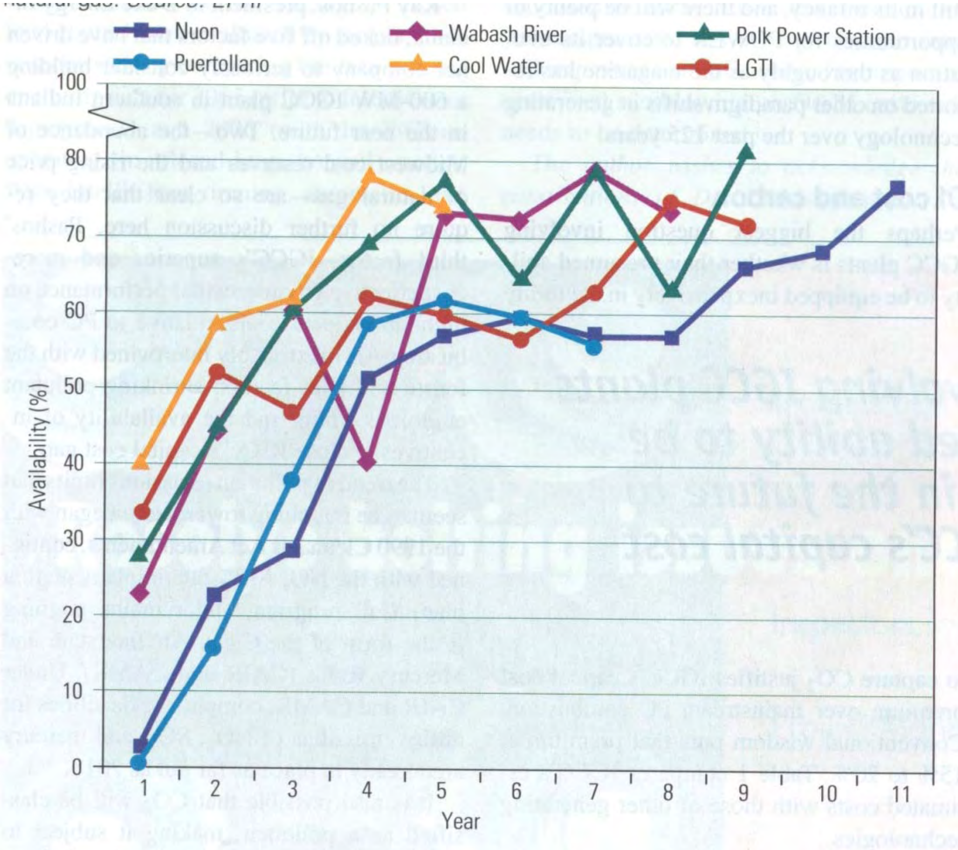
Pre-Combustion Capture: Key Barrier

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

Pre-Combustion Capture:
Key Development Area

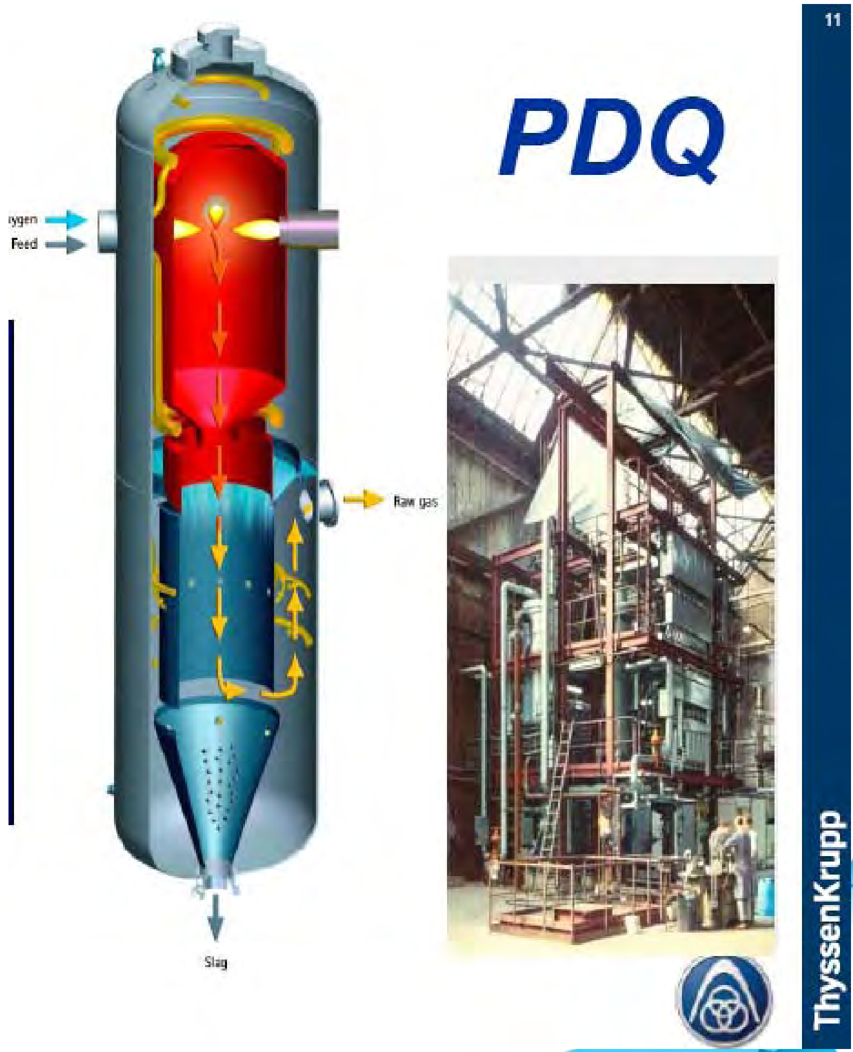
- ***Development in Gasifier Technology***
  - Adaptation of the Gasifier for CO2 capture...

- ***Development in Air Separation Units***
  - Membrane Technology???

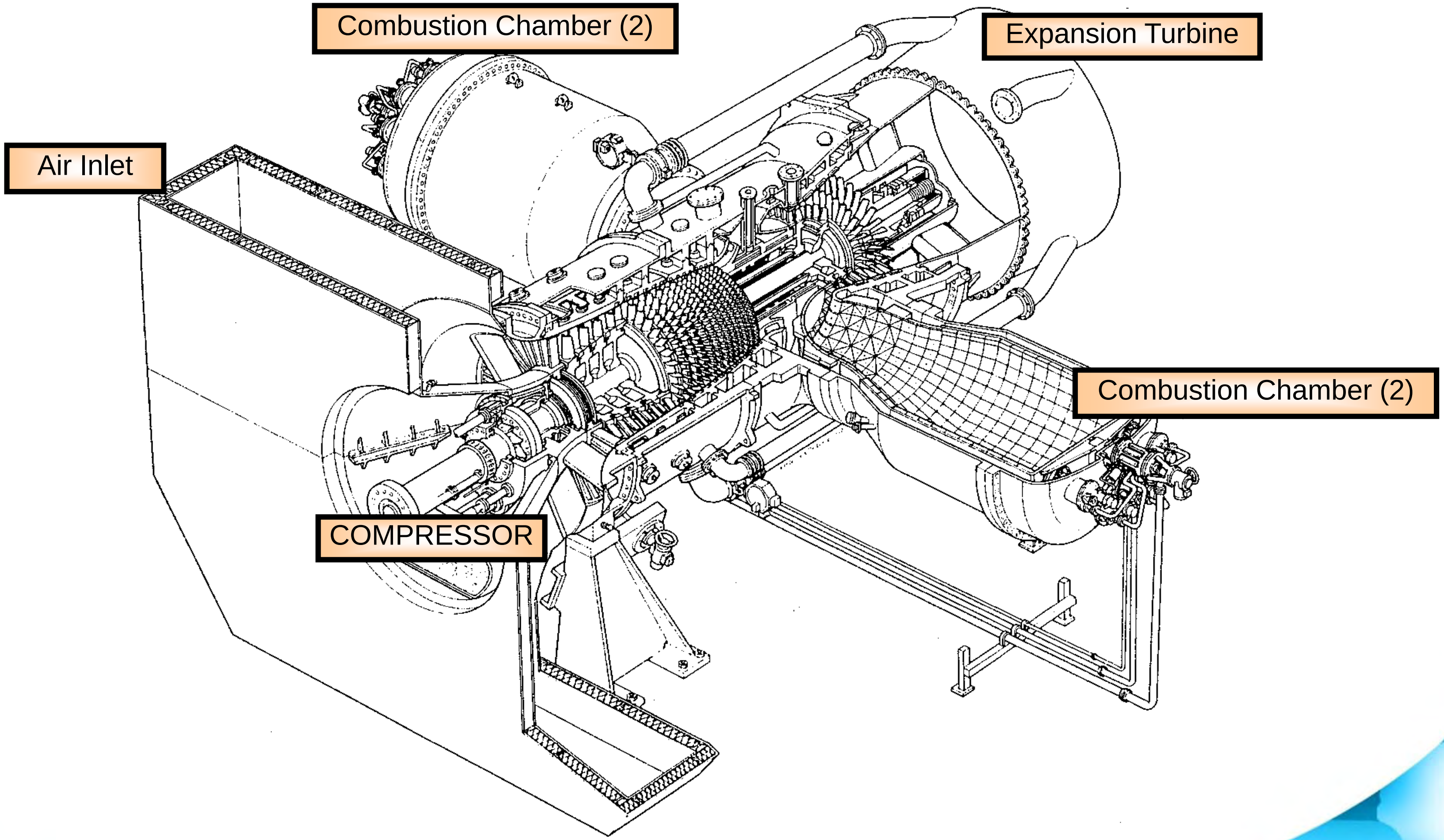
- ***Development in Shift Reactor***
  - Choice of Sour vs Sweet Shift Reaction

- ***Development in Separation of CO_2 using Physical Absorption technology***

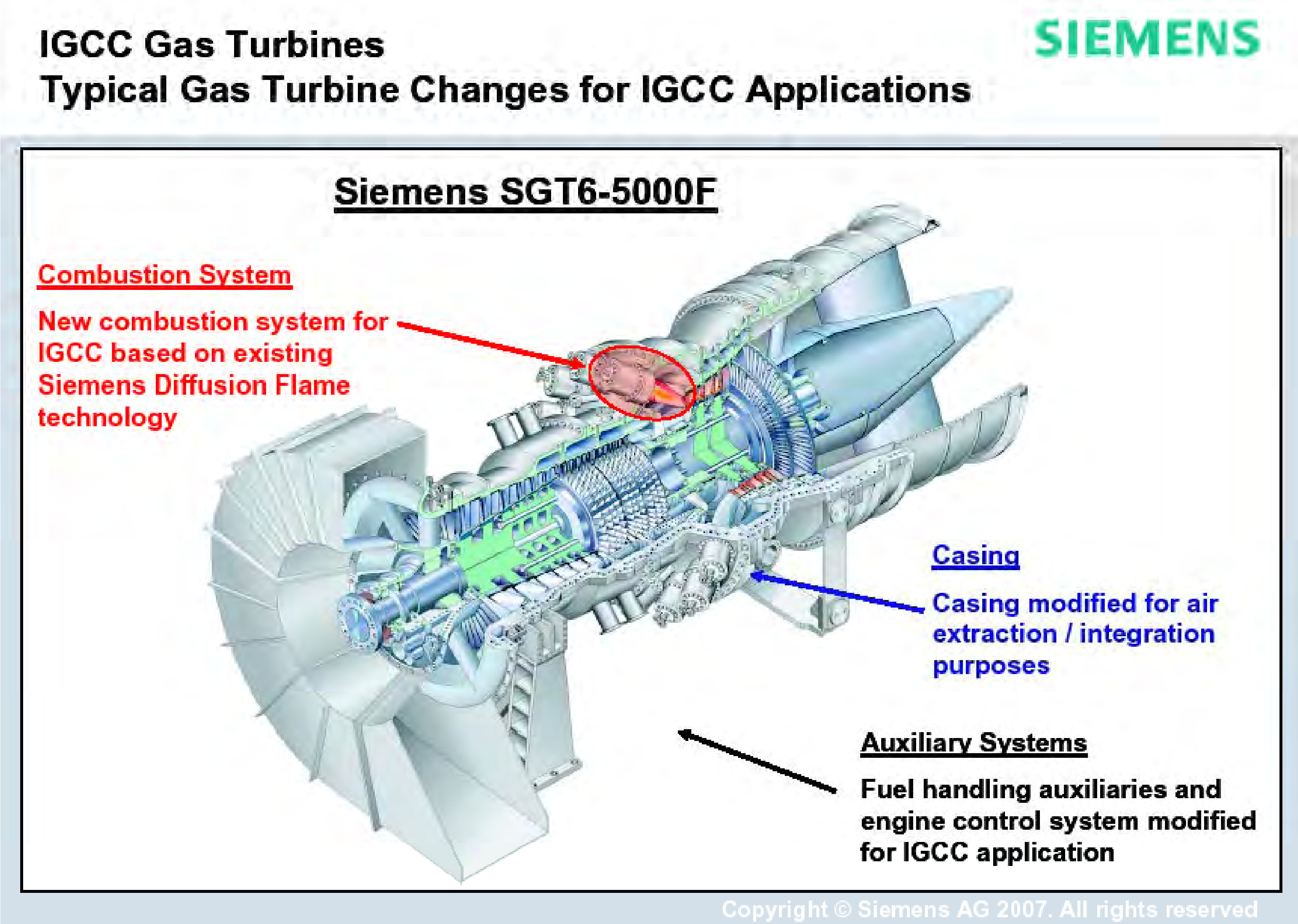
Uhde Prenflo Design Modification for CO2 capture application...



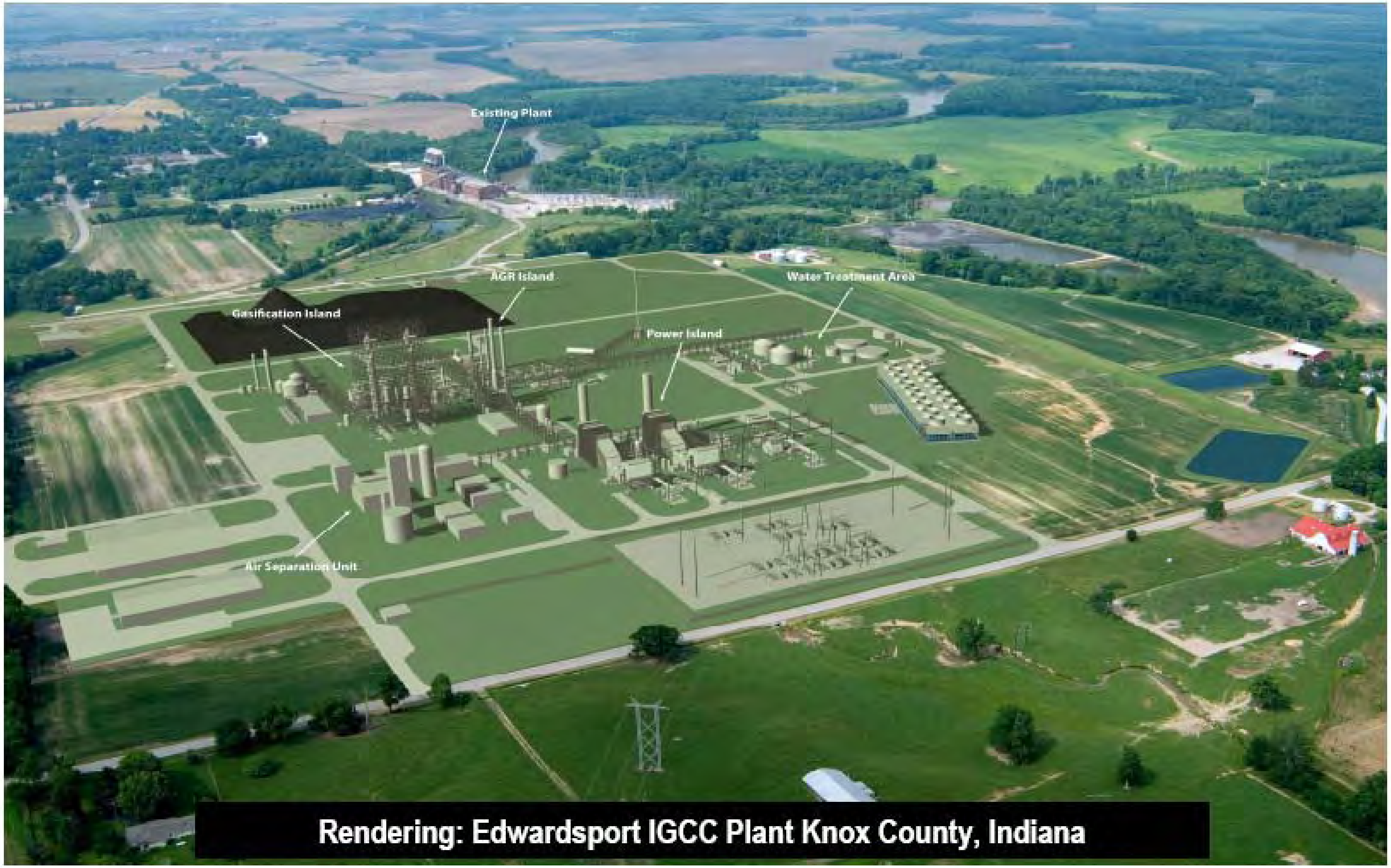
Development in Gas Turbine Technology: Horizontal Silo



Development in Gas Turbine Technology: Annular Combustor



Duke Energy Edwardsport IGCC Layout



Rendering: Edwardsport IGCC Plant Knox County, Indiana

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.***

Thank you

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