IEA Greenhouse Gas R&D Programme

Current Status and Developments in CO_2 Capture Technologies for Power Generation (What are the Challenges Ahead)

by:

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IEA Greenhouse Gas R&D Programme

Presented at:

CO_2 Capture and Storage – Response to Climate Change
2nd Regional Workshop for CE and EE Countries

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Presentation Outline

- Introduction to IEA Greenhouse Gas R&D Programme (IEA GHG)
- Overview to Carbon Capture Technologies and current R&D Activities
  - Post-Combustion Capture
  - Oxy-Combustion Capture
  - Pre Combustion Capture
- Some of the key issues looking onto the different capture technologies
- Concluding Remarks

IEA Greenhouse Gas R&D Programme

Brief Introduction to

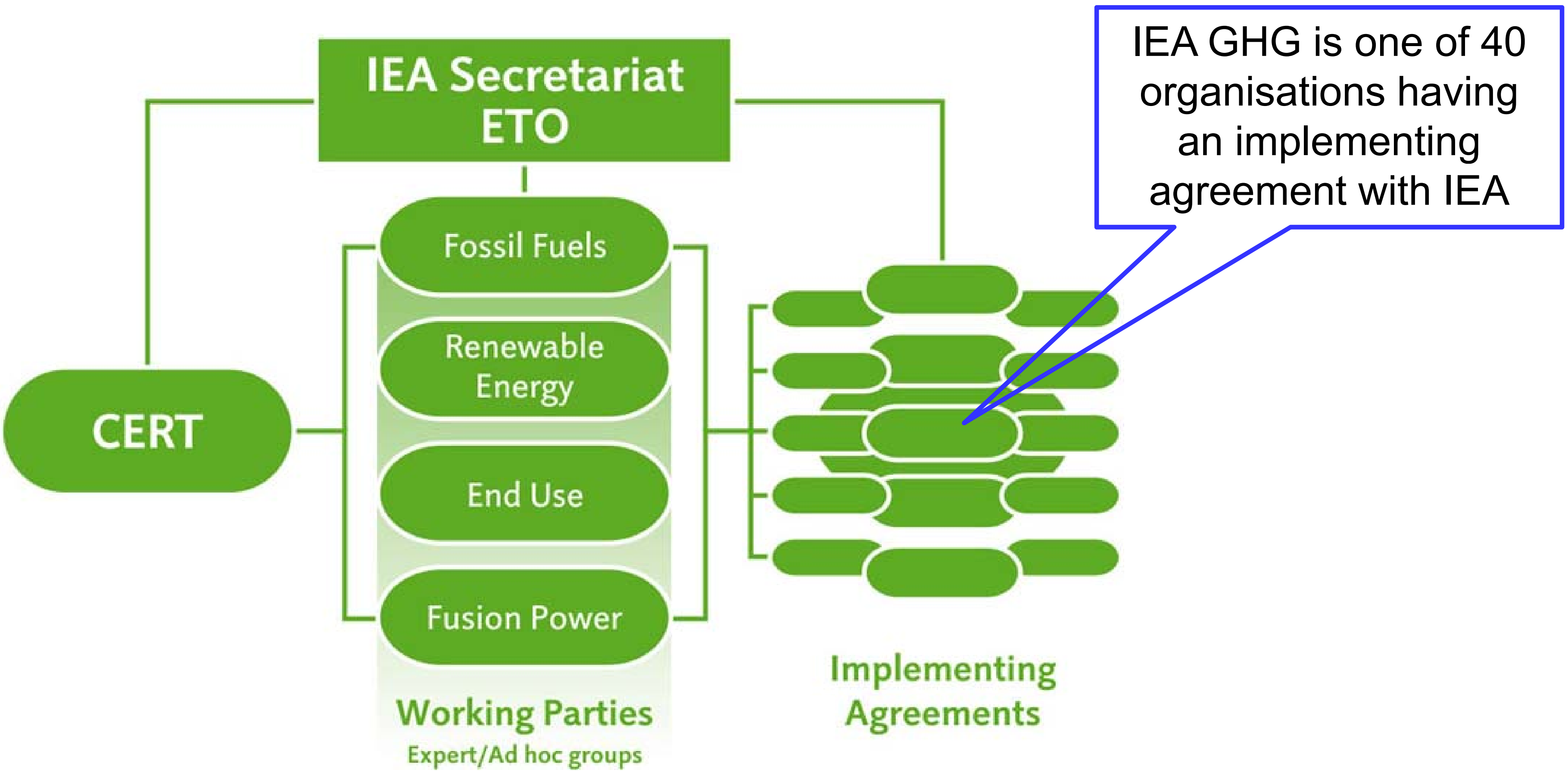
IEA Greenhouse Gas R&D Programme (IEAGHG)

Introduction to IEAGHG

- IEA Greenhouse Gas R&D Programme (IEAGHG)
  - An organisation having an implementing agreement with the International Energy Agency.
  - A collaborative research programme that started in 1991.
- Our main role is to evaluate (without any bias) technologies that could provide significant reduction to the greenhouse gas emissions.
- **Our main aim is to provide our members with an up to date information on the role that technology can play in reducing greenhouse gas emissions**

IEA Greenhouse Gas R&D Programme

Our Relation to the International Energy Agency



Current Membership

The Programme is supported by 19 governments, EC, OPEC, CIAB and 20 industrial sponsors

What do we do?

- New phase (5) started at end of 2004:
  - 3 Main activities:
    - A1: Technology and Market information
    - A2: Confidence building
    - A3: Information dissemination
  - Aimed at answering:
    - How do different technology options compare?
    - Can the option be done safely and legally?
    - What needs to be done to introduce the technology and be confident it will work?

Technology and Market Information

Implementation Support

- Methodology for CCS projects under CDM
- Guidelines for CCS site characterisation
- CCS Project Financing
- Regional capacity for CO_2 storage in India

Regulatory Support

- Risk assessment and regulatory needs
- Environmental impact assessment for CCS
- Capture-ready power plant
- Monitoring Selection Tool

Technical Assessments

- Improved solvent scrubbing processes for CO_2 capture
- Capture of CO_2 from medium scale installations
- Improved Oxygen production processes
- Collection of CO_2 from distributed sources
- CO_2 Capture in the cement industry
- Co-production of hydrogen and electricity
- Remediation of leakage from geological storage
- Fuel Cells for CHP
- CO_2 Pipeline transmission costs

IEAGHG Research Network

- Objectives
  - To provide an avenue for discussion on specific issues toward development of CCS and support any confidence building activities
  - http://www.co2captureandstorage.info/networks/networks.htm

- IEAGHG manages 6 Research Networks
  - International CO_2 Capture Network
  - International Oxy-Combustion Network
  - Monitoring Network
  - Risk Assessment Network
  - Well Bore Integrity Network

Participants from 2nd Oxy-Combustion Workshop (CT, USA – Jan. 2007)

1st Int'l Oxyfuel Combustion Conference

1st IEA GHG International Oxyfuel Combustion Conference

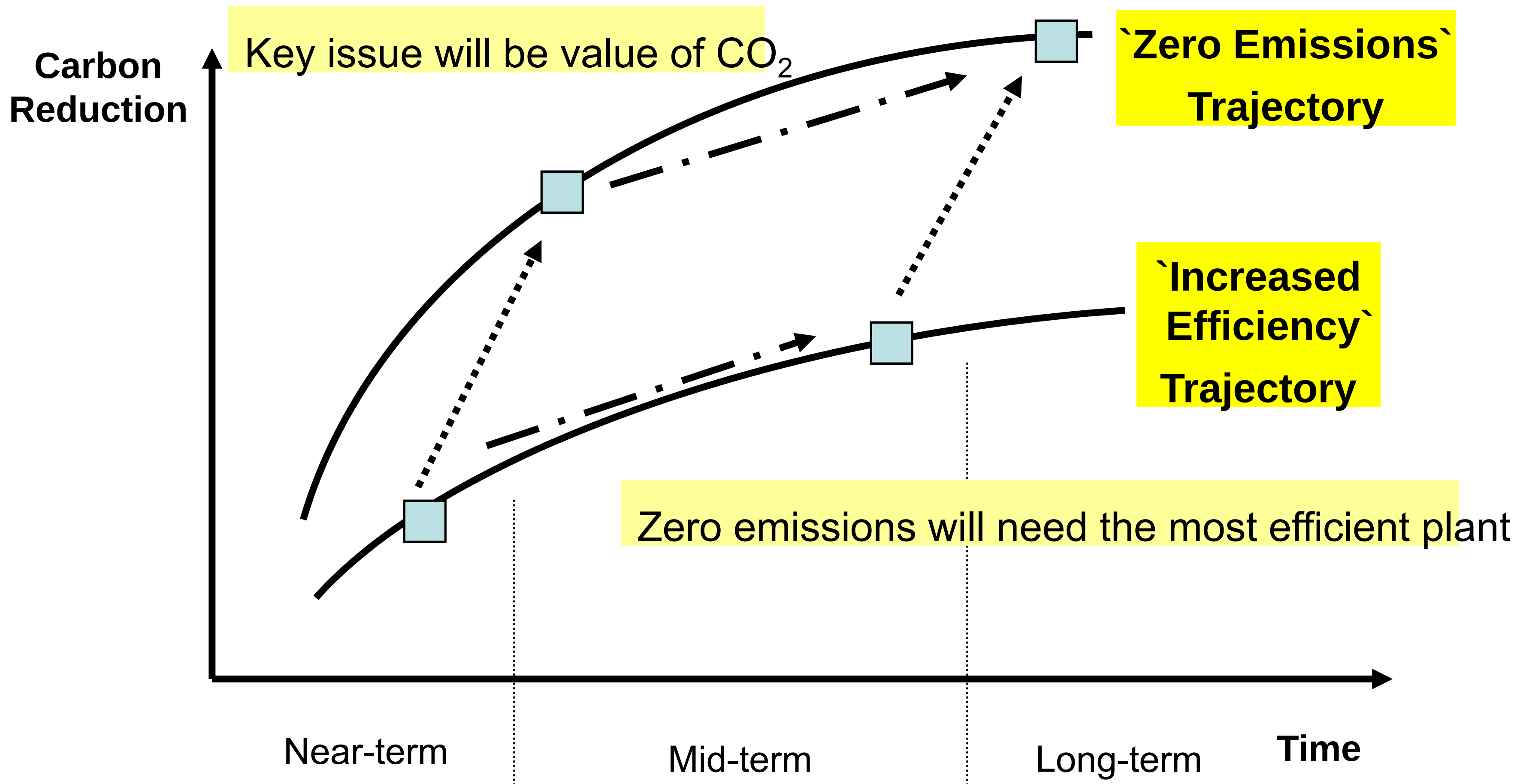
8th-11th September 2009

Radisson Hotel, Cottbus, Germany

- As of the deadline (today), ~ 85 abstracts submitted to be considered for oral and poster presentations.
  - ~ 40 oral and 40 poster presentations are expected.
- Participation of all major players in the field of oxyfuel combustion technology.
- **An Opportunity to Discuss and Learn!**

Overview to Different Leading CO_2 Capture Technologies for Power Generation

Current View on CCS and Efficiency Increase



CO_2 Capture technologies

General Overview

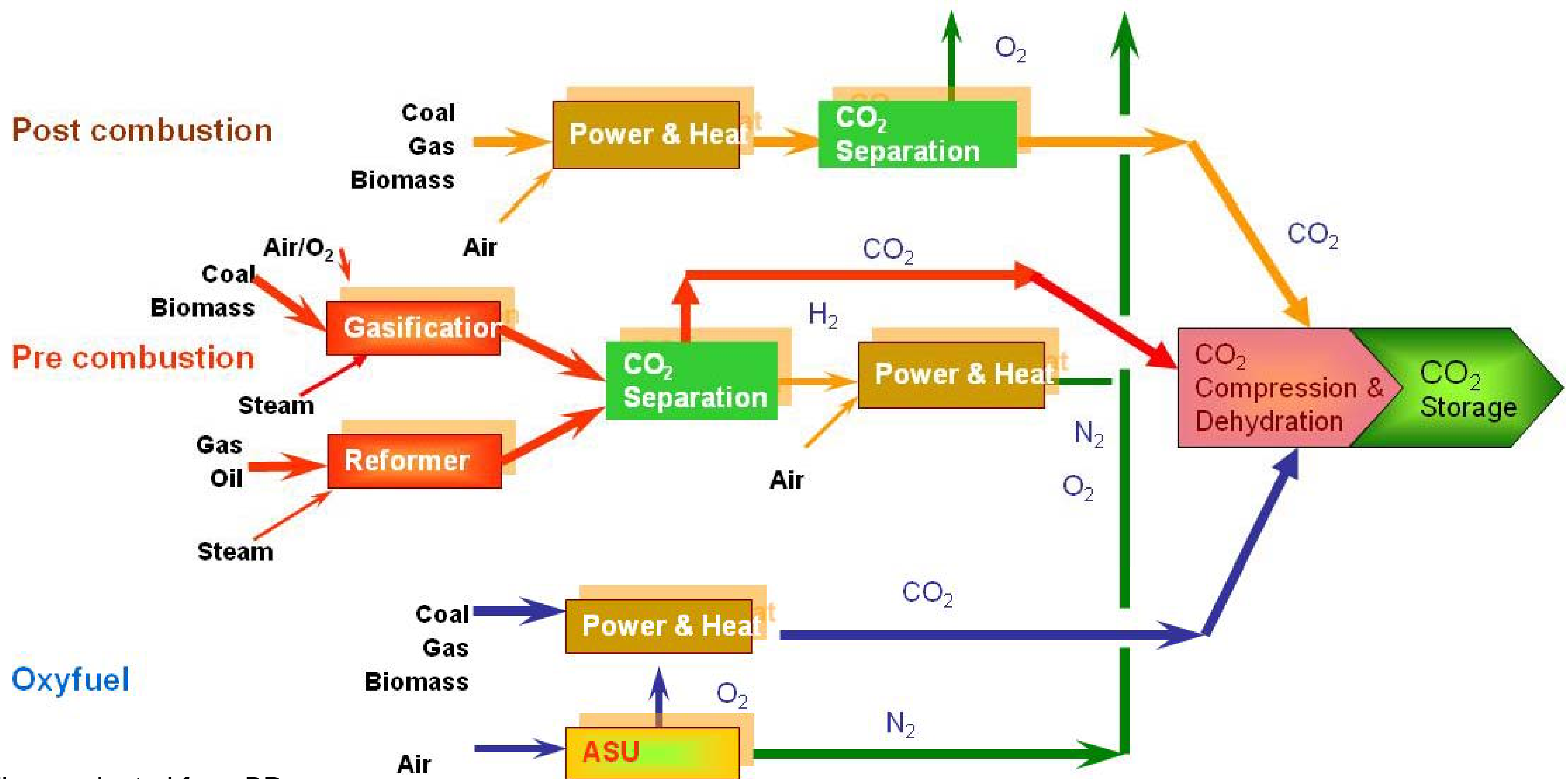
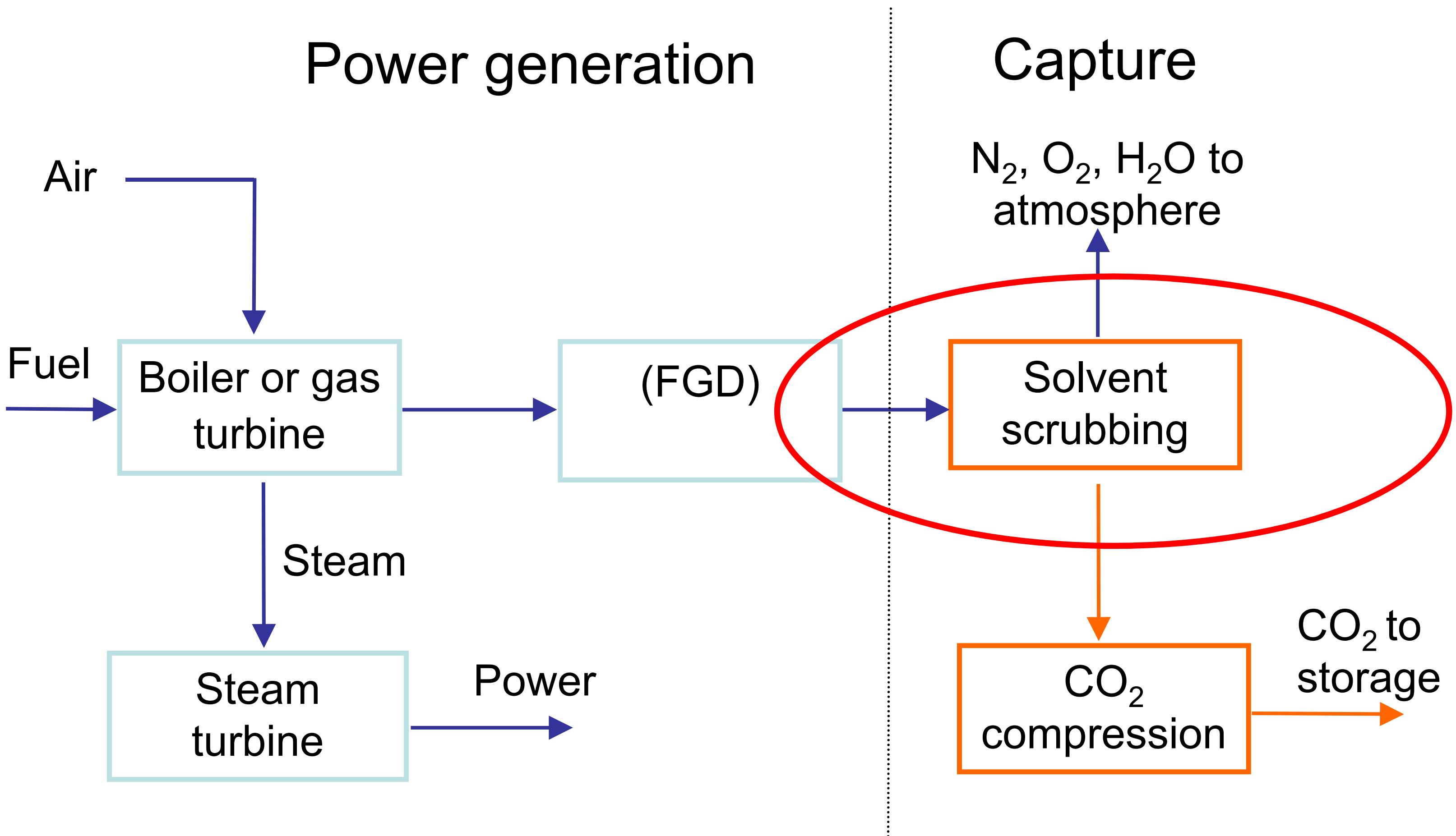


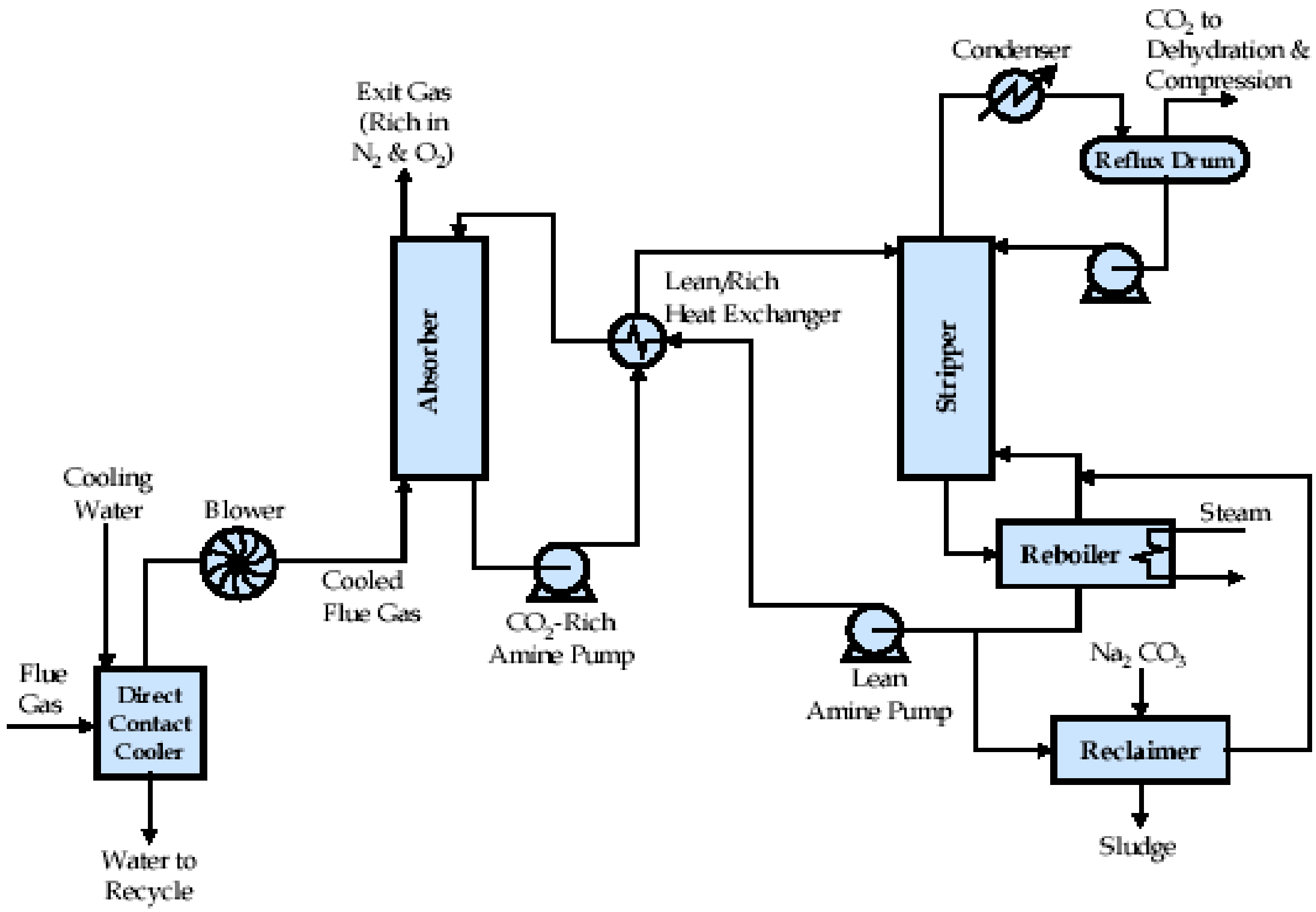
Figure adapted from BP

Post-Combustion Capture

Post-Combustion Capture



Chemical Absorption Process



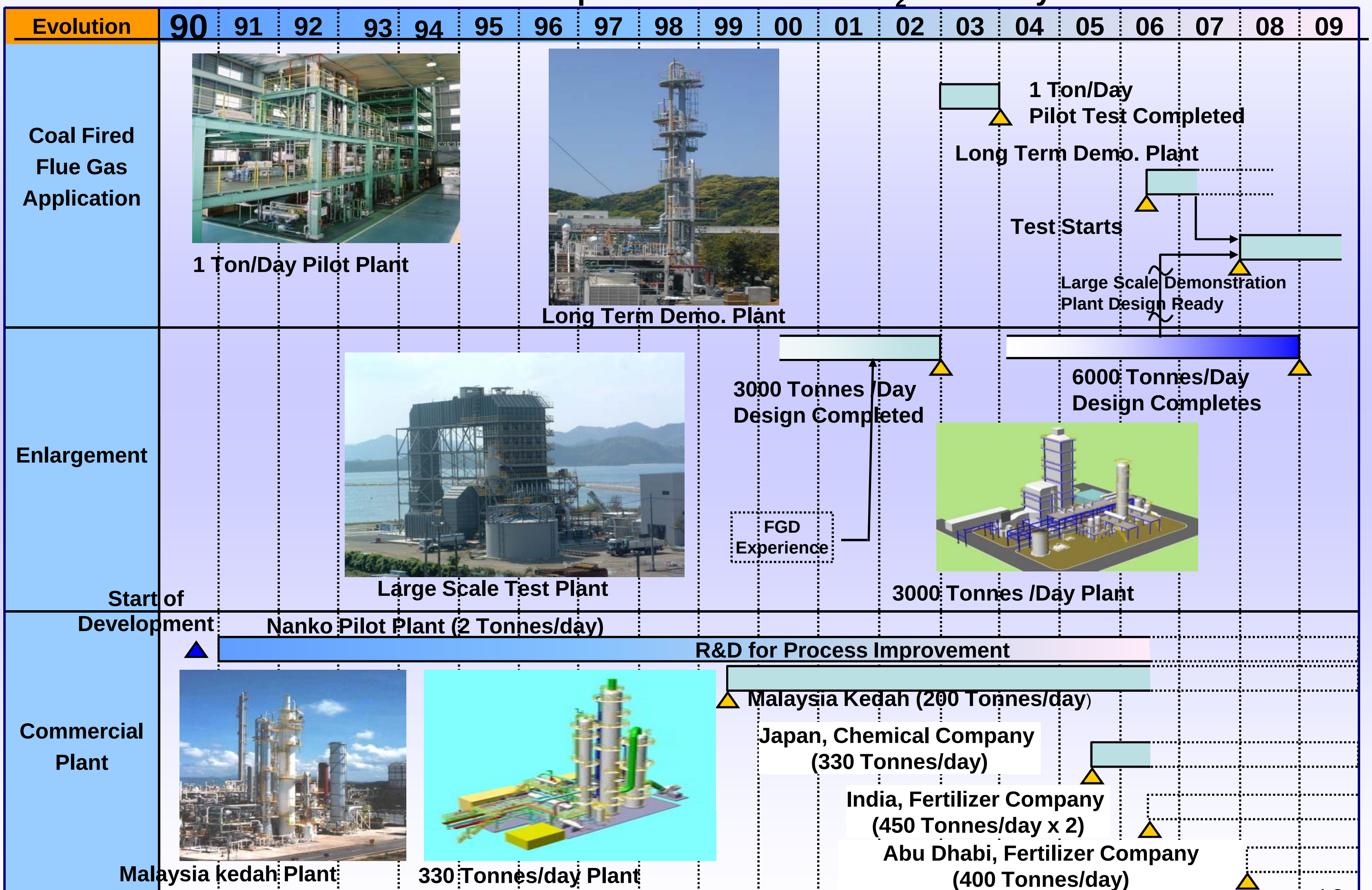
CO_2 Based Solvent Scrubbing

- 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
- Current R&D Focus
  - Development of new type of solvents
  - Development is also on-going for application to coal fired power plant

MITSUBISHI CO_2 Recovery Technology from Flue Gas

<Experience and R&D Facilities>

MHI's Evolution Development of Flue Gas CO_2 Recovery Plant



R&D Effort in Europe

- Castor / Caesar Post-Combustion Pilot Plant Project
  - Installed at the Esbjerg Power Station
- Pilot Capacity: 1000 kg CO_2 per hour (25 TPD)
- 5000 Nm^3/h flue gas (coal combustion)
- Now in operation
  - started in March 2006
  - both MEA and 2 types of "Castor" Solvents were evaluated

Vattenfall's CCS demo project at Nordjyllandsværket

On February 6, 2008 Vattenfall Nordic Thermal Power Generation announced the intention to develop a full-scale Carbon Capture & Storage (CCS) demonstration project

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Some Other Current Activities

- UK (2014) – investment decision by next year.
  - BERR CCS Competition (3 of 9 bidders remain in contention as candidate to received funding from UK government)
    - EOn UK (Kingsnorth Project) – Arup, MHI, Flour, EPRI, Tullow oil
    - RWENpower / Peel Power (Peel Holding, Dong Energy, Mott MacDonald)
    - Scottish Power (Longannet Project) – Aker Kavaerner, Marathon oil
- Germany (2012) – investment decision by next year
  - Vattenfall's Janschwalde Project includes the retrofit of 250MWe power plant
- Doosan Babcock partnership with HTC Purenergy / EESTech
  - China Project in the pipeline: 330 MWe of Tainjin DaGang Huashi Power Generation Co. Ltd.
- … (many more) …

Post-combustion capture: KEY ISSUES

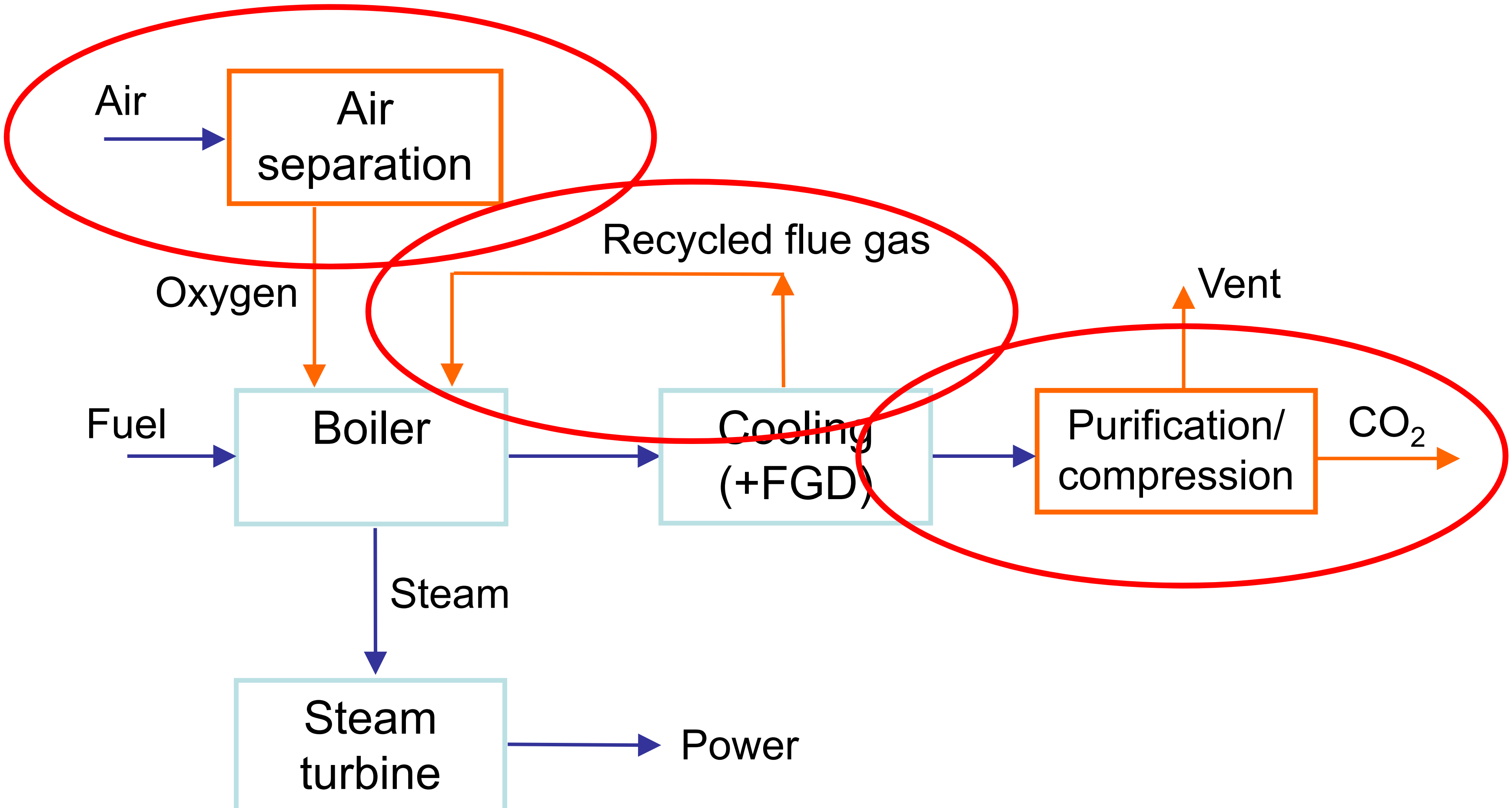
- Solvent life
  - Requires very low SOx (< 10 ppm) and NO_2 (< 20 ppm)
  - Solvent could be very expensive – target: lower solvent losses
- Corrosion
  - Stainless steel v carbon steel
  - Inhibitors can contain V, Sn, Sb (antimony)
- Energy consumption
  - Regeneration of solvent
- Environmental impacts
  - Some degradation products known and regulated; others are not.

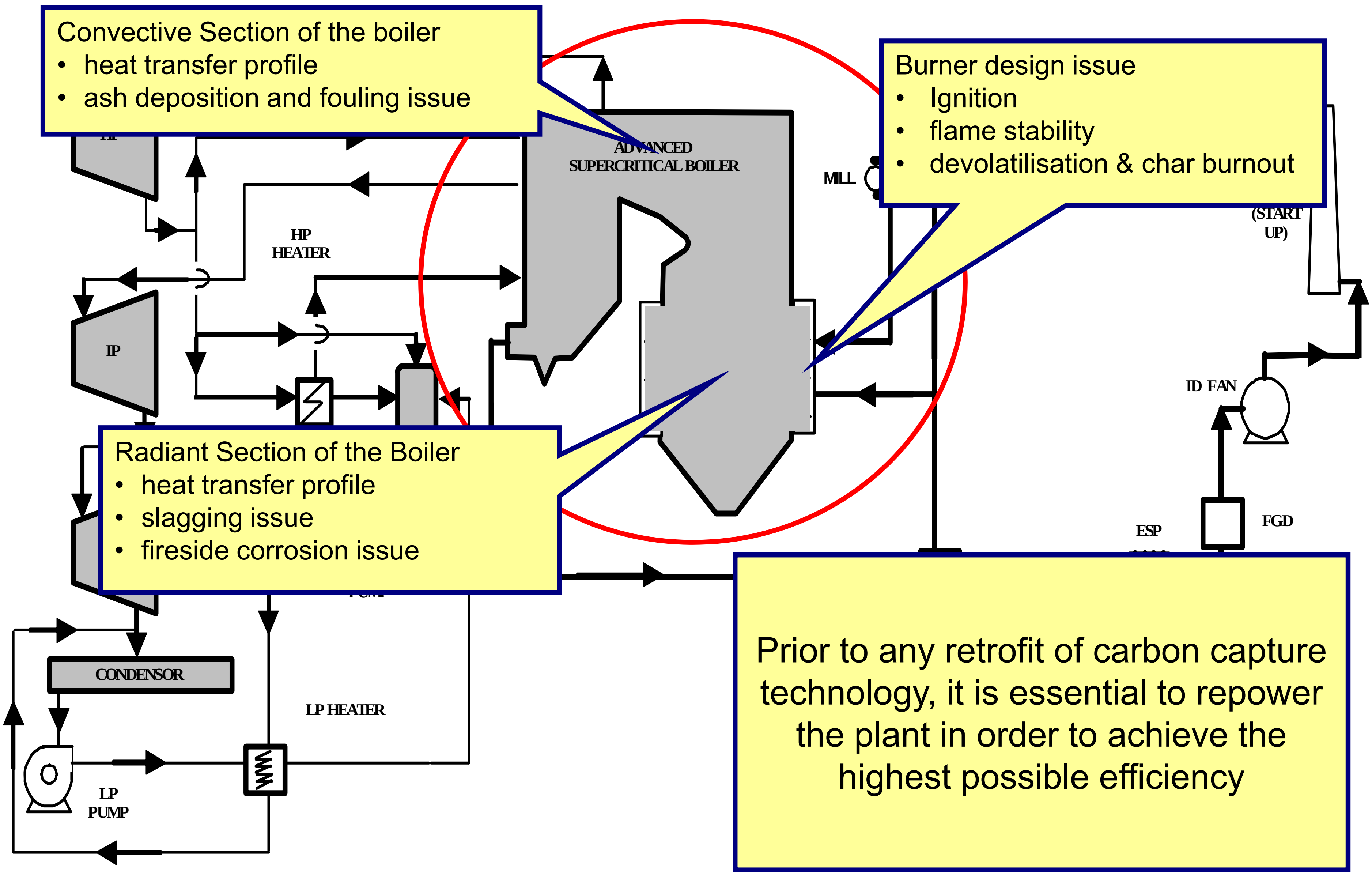
Future Direction of Research

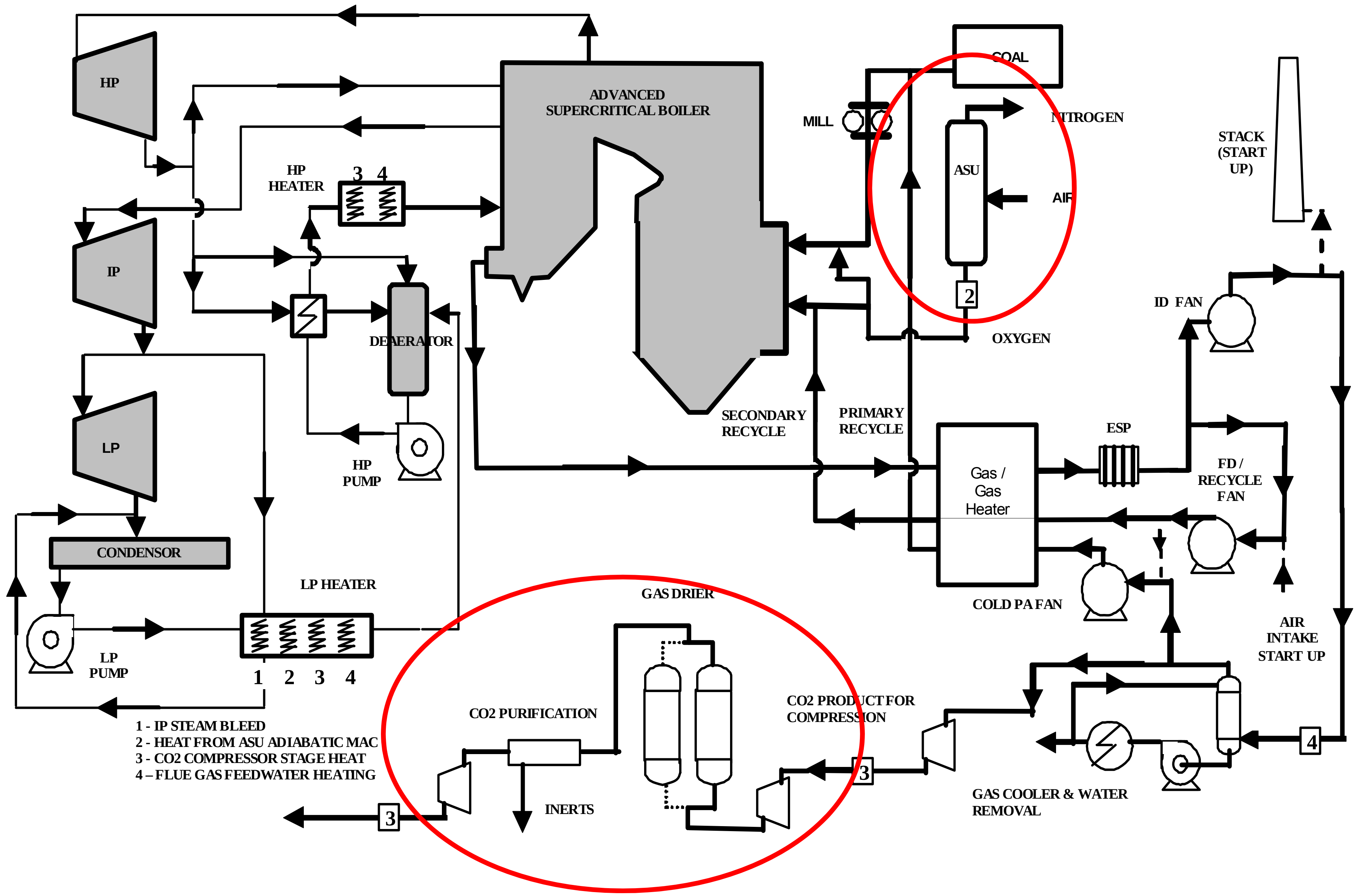
- Cost and Process Optimisation of the current MEA based Technologies
  - Design of the Absorption column
  - Reduction of Energy consumption of the regenerative column
- Improvement of Current solvents
  - Improving kinetics
  - Improving additives to reduce degradation
- Development of new solvents
  - For Examples: Chilled Ammonia process, Cansolv solvent, KS2, etc...
- Environmental Impact Assessment
  - Impact assessment due solvent degradation
  - Fugitive emissions (especially NH3 as one of the by-product of degradation)

Oxy-Coal Combustion Technology

Oxy-Coal Combustion Technology



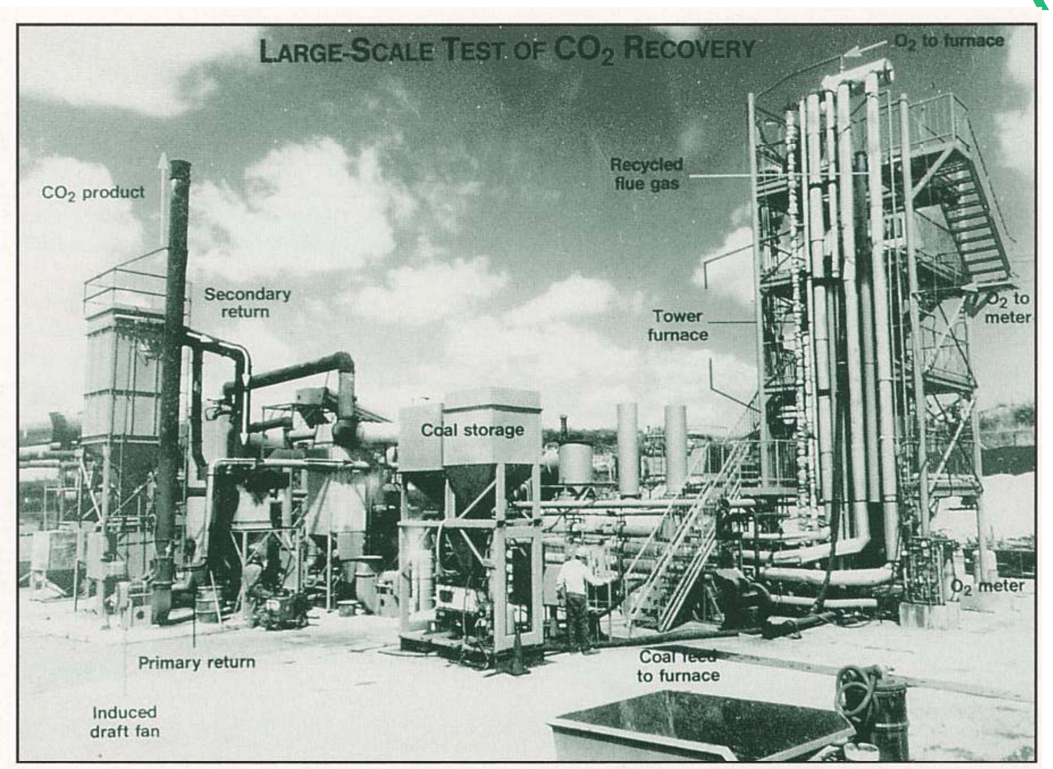

Convective Section of the boiler
• heat transfer profile
• ash deposition and fouling issue
Burner design issue
• Ignition
• flame stability
• devolatilisation & char burnout
ADVANCED SUPERCRITICAL BOILER
MILL
HP HEATER
IP
(START UP)
ID FAN
Radiant Section of the Boiler
• heat transfer profile
• slagging issue
• fireside corrosion issue
ESP
FGD
CONDENSOR
LP HEATER
LP PUMP
Prior to any retrofit of carbon capture technology, it is essential to repower the plant in order to achieve the highest possible efficiency

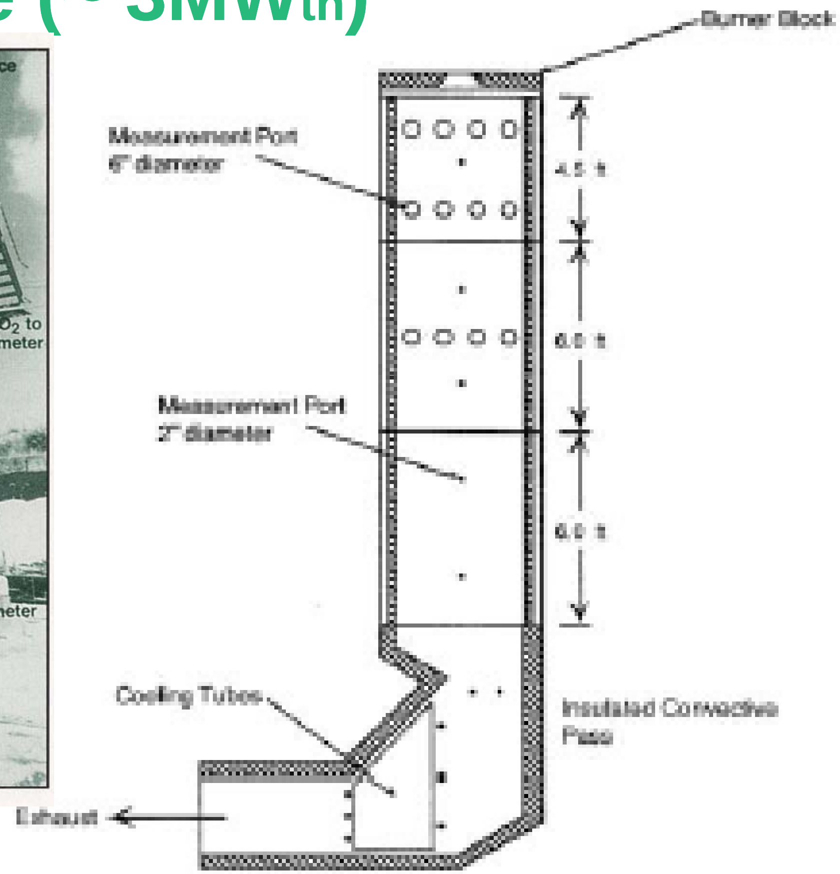

HP
IP
LP
ADVANCED SUPERCRITICAL BOILER
COAL
MILL
NITROGEN
ASU
AIR
OXYGEN
2
STACK (START UP)
HP HEATER
3 4
DEAERATOR
HP PUMP
SECONDARY RECYCLE
PRIMARY RECYCLE
Gas / Gas Heater
ESP
ID FAN
FD / RECYCLE FAN
COLD PA FAN
AIR INTAKE START UP
CONDENSOR
LP HEATER
LP PUMP
1 2 3 4
1 - IP STEAM BLEED
2 - HEAT FROM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

Oxy-Combustion Technology

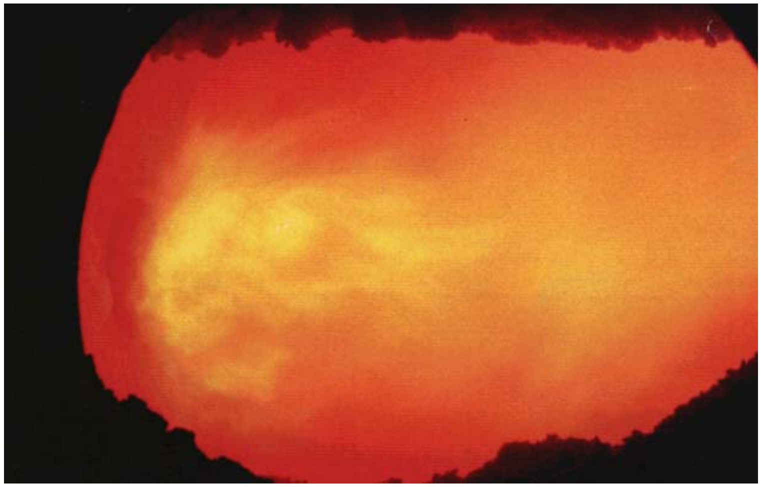
- Use of oxygen instead of air in a boiler – “Oxy-Combustion” is the least mature among the 3 mostly considered capture technology options for the power generation.
- 3 key development issues
  - Boiler and burner development
  - Air Separation Unit – “Cost and capacity of oxygen production”
  - CO_2 processing – “Removal of impurities”

ANL - EERC Study
World's 1st Oxy-Coal Pilot Scale Study
Tower Furnace (~ $3MW_{th}$)



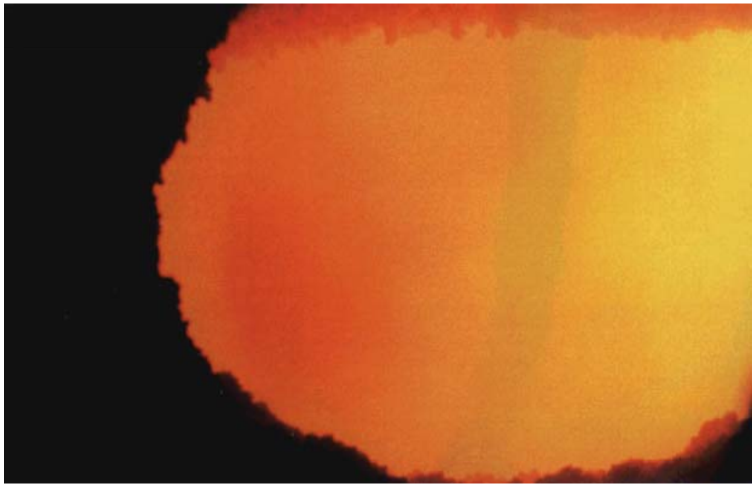


Coal Flame Photos: Air Fired vs Oxy-Fired (Courtesy of IHI)

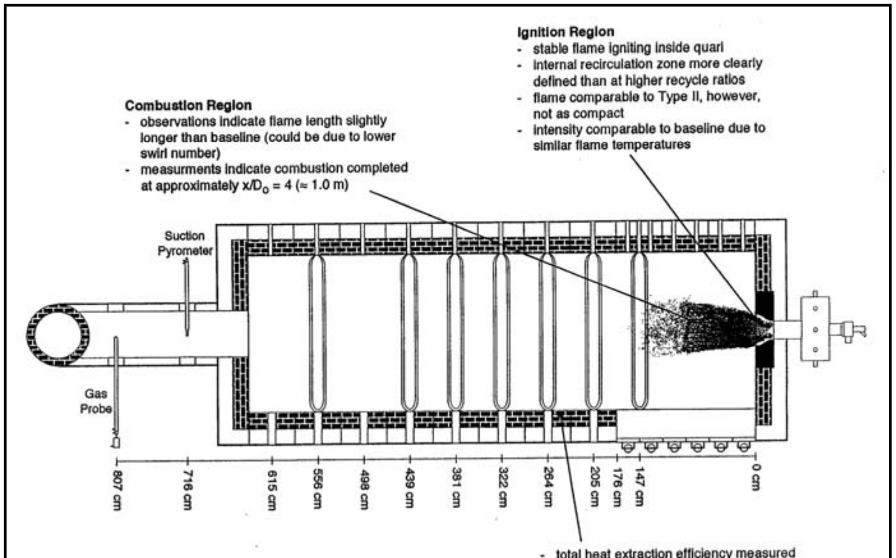


Air mode (O_2 : 21%)

Oxy mode (O_2 : 21%)

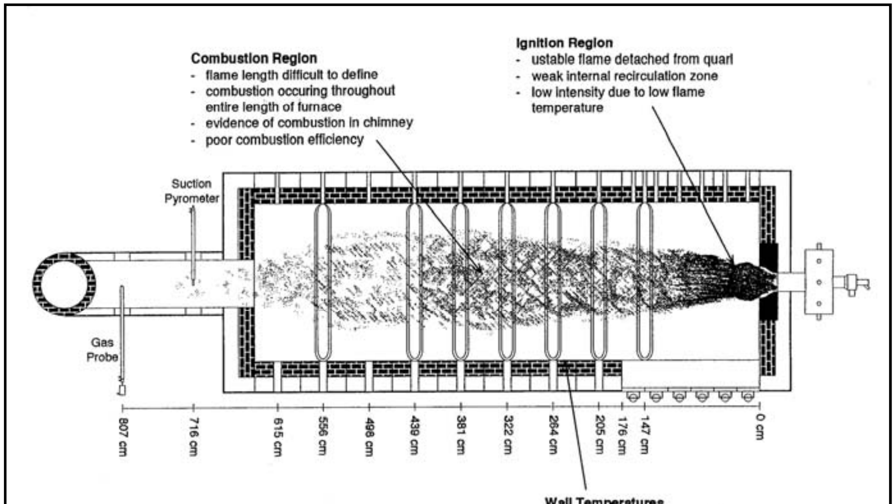


Oxy mode (O_2 : 30%)



O_2-RFG flame with recycle ratio = 0.58

Recycle Ratio = 0.58
(~ 0.61 include the CO_2 to transport coal)

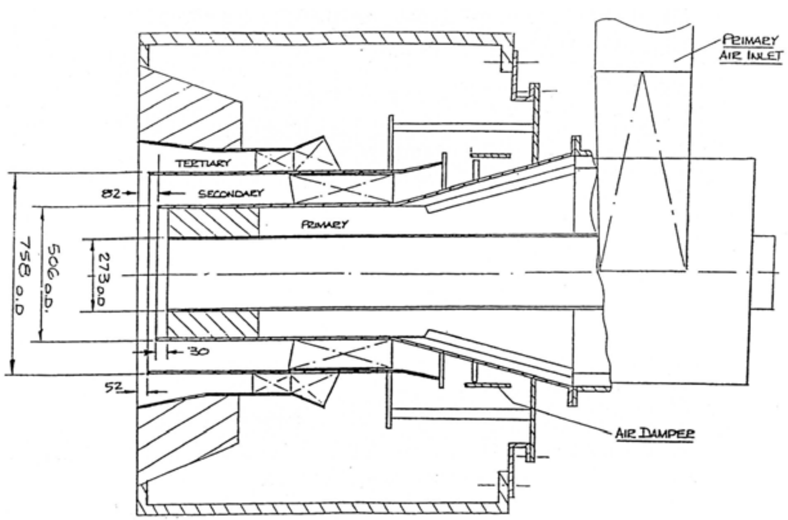


O_2-RFG flame with recycle ratio = 0.76

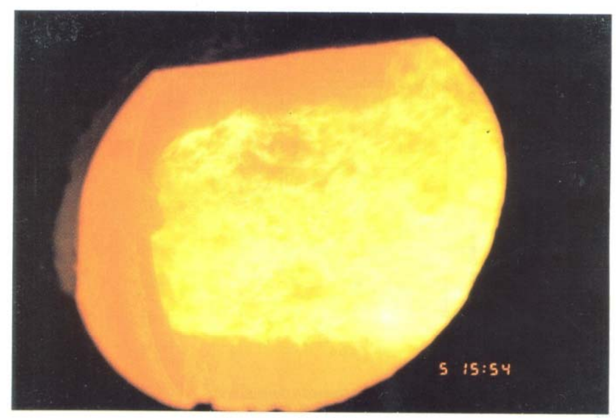
Recycle Ratio = 0.76

Courtesy of IFRF

1st Large Scale Oxy-Coal Combustion Experience (International Combustion Ltd.)




Test 1 - Conventional Air firing



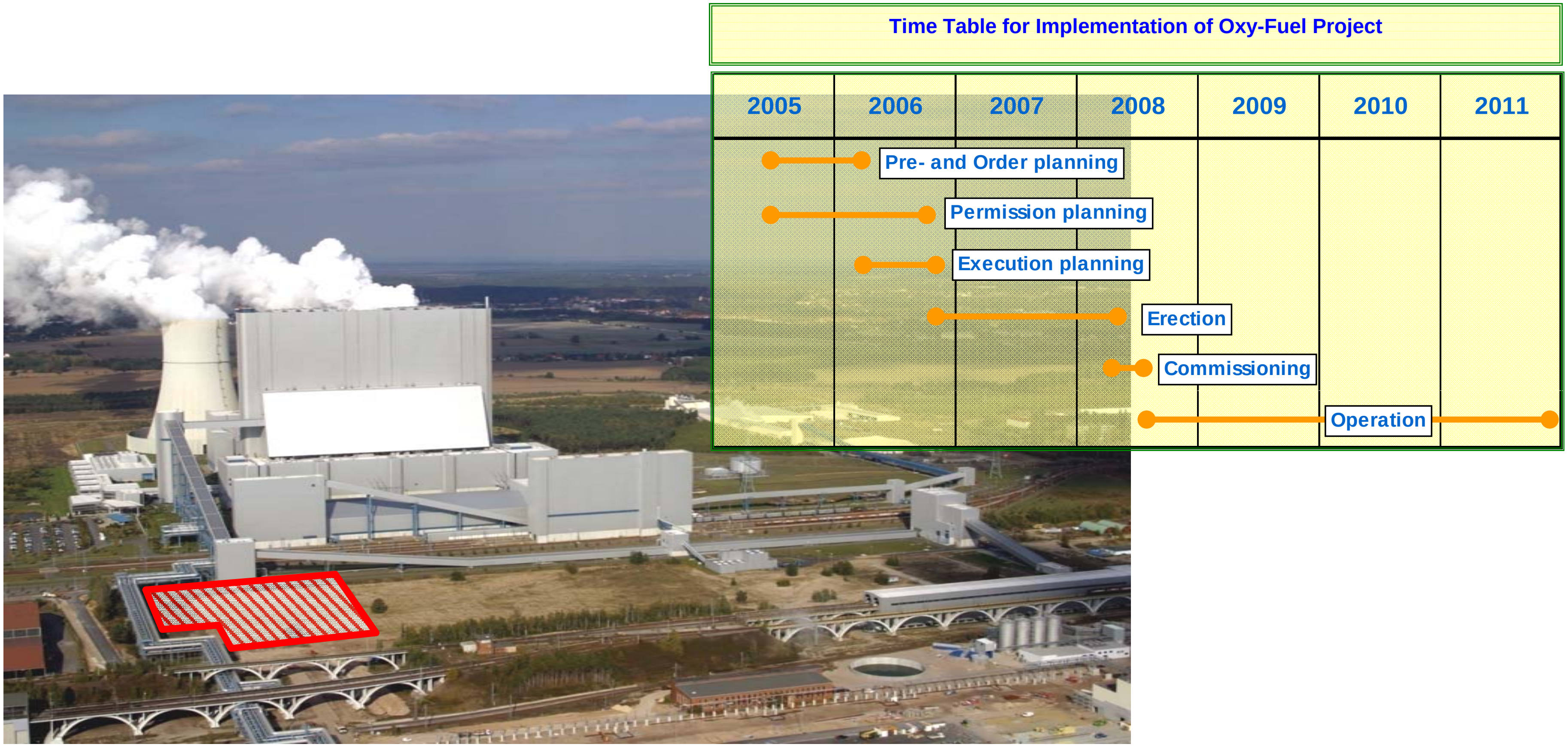
Test 3 - O_2/RFG Firing

- ✓ 35 MWth Low NOx burner
- ✓ Although it was not able to achieve the desirable CO_2 composition – the first combustion trial gained significant experience in burner start up

Oxy-Combustion Technology

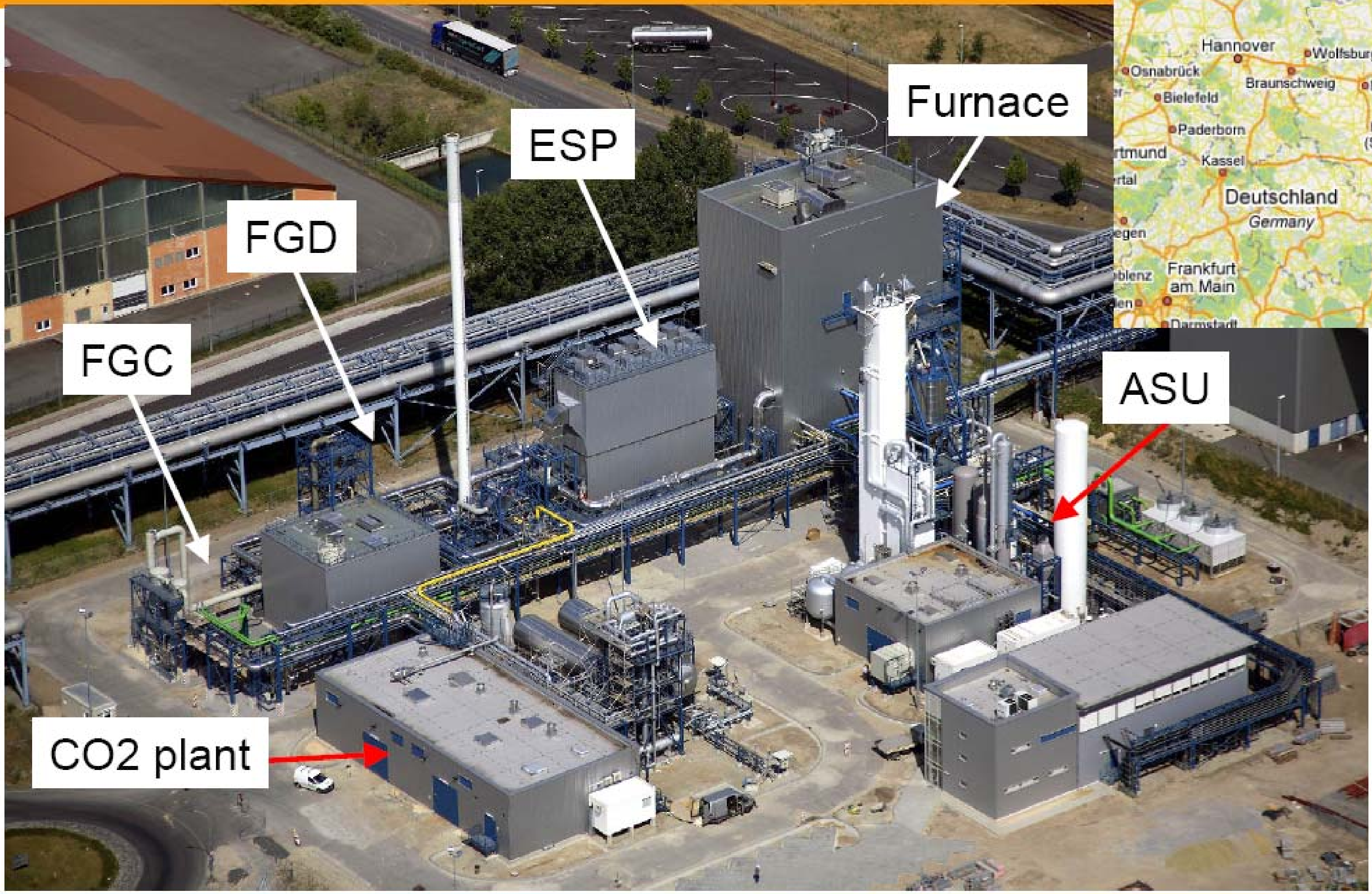
What are the Enabling Studies in the near future that will provide a big step forward for Oxy-Coal Combustion…

Vattenfall Schwarze Pumpe Pilot Project



Courtesy of Vattenfall

The Oxyfuel pilot plant



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First experience from implementation of oxyfuel operation

- Extensive safety measures for handling of CO_2-rich flue gases and O_2
  - Gas warning systems have been installed
  - Personal gas alarms
  - CO_2 detectors are mounted on the floor levels
  - Gas ventilation of boiler house
- Implementation of different flue gas paths and requires bypass systems and as well as a new control system.
  - complex control and instrumentation system to handle flexibility
  - Implementation of the control systems for the ASU and the CO_2 plant into the control system of the steam generator presented a challenge
- Due to the varying compositions in the flue gas, the flow measurements have to be modified with additional density correction
- Corrosion in flue gas ducts due to increased H_2O, CO_2 and SO_2 content and frequent start-ups and shut downs

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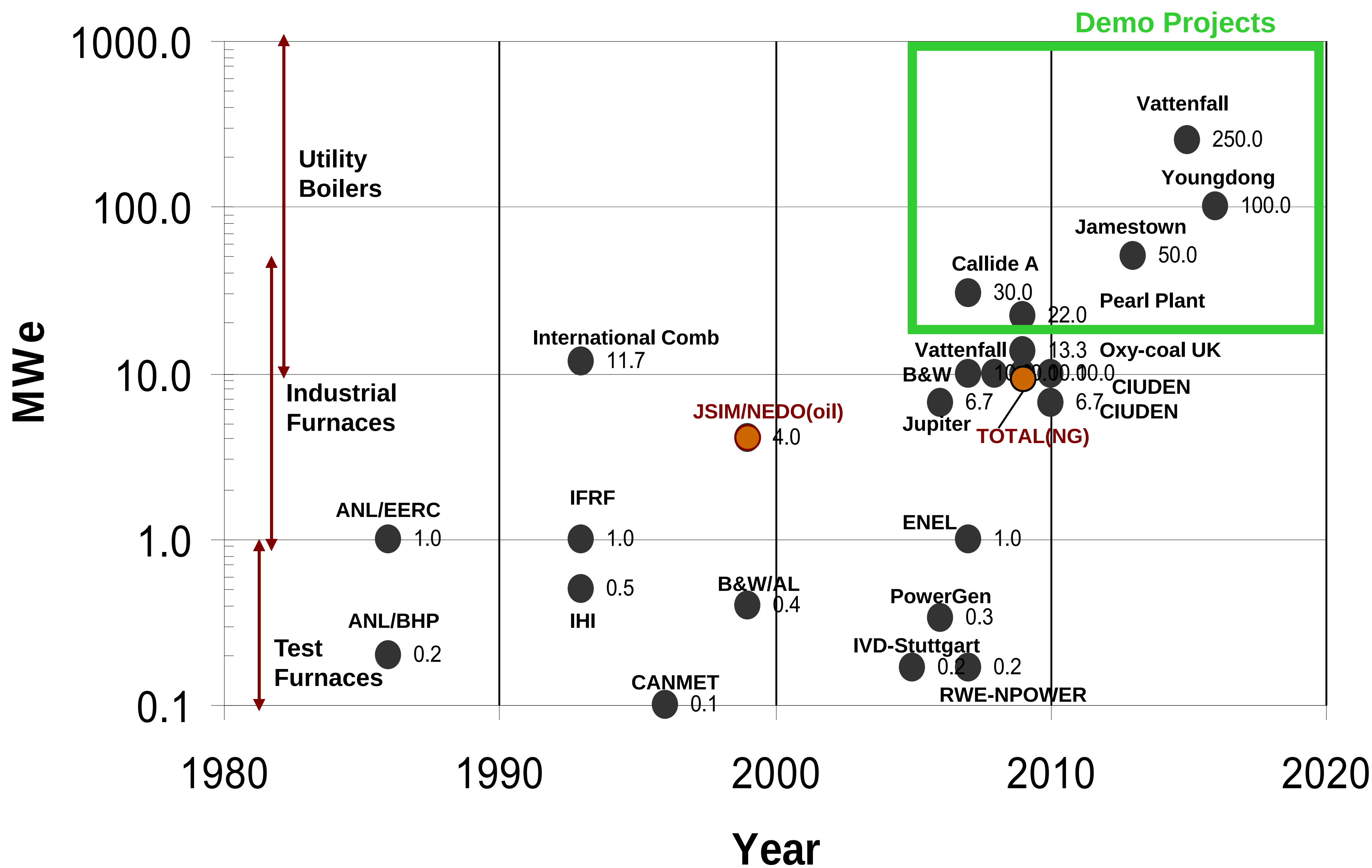
Oxy-Fuel Combustion Boiler Projects

(Conversion @ 1 MWe = 3 MWt = 10 MMBtu/hr)



Large Scale Pilot and Demo Projects

PROJECT	Location	MW_{th}	Start up	Boiler Type	Main Fuel	CO2 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	2008	Pilot PC		
Vattenfall	Germany	30	2008	Pilot PC	Lignite (Bit.)	**With CCS**
Total, Lacq	France	30	2009	Industrial	Nat gas	**With CCS**
Pearl Plant	USA	66	2009	22 MWe PC	Bit	Side stream
Callide	Australia	90	2010	30 MWe PC	Bit.	**With CCS**
Ciuden - PC	Spain	20	2010	Pilot PC	Anthra.(Pet ck)	?
Ciuden - CFB	Spain	30	2010	Pilot CFB	Anthra.(Pet ck)	?
Jamestown	USA	150	2013	50 MWe CFB	Bit.	**With CCS**
Vattenfall (Janschwalde)	Germany	~1000	2015	~250 MWe PC	Lignite (Bit.)	**With CCS**
Youngdong	Korea	~400	2016?	~100 MWe PC?	?	?
Endessa	Spain	~1500	2015?	~500 MWe CFB?	?	**With CCS**

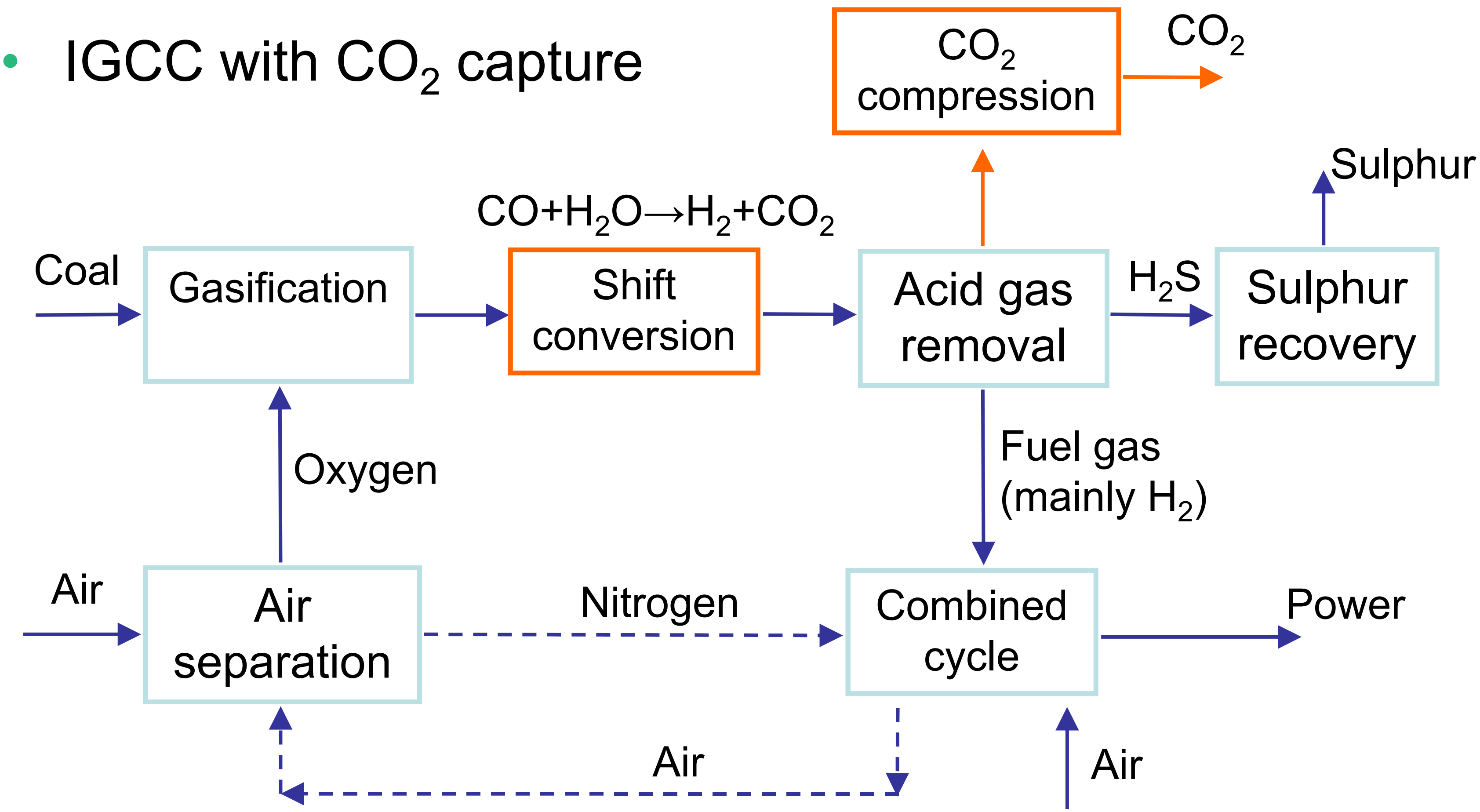
Oxy-Combustion: KEY ISSUES

- Air Ingress
  - Estimated that every 1% of air ingress should result to about 3-5% reduction of the CO_2 concentration in the flue gas.
  - Several failures have been noted from previous experiences of not reaching the desired concentration of CO_2 due to air ingress.
  - This is a big challenge especially retrofitting a power plant.
- Boiler and Burner Development
  - We need to build our confidence in running an oxy-fired burner/boiler especially at the same scale of our current PC boiler.
  - Various technical issues elucidated - these include heat transfer aspect, ash and slagging, equipment scaling up, emissions control, etc…
  - Largest burner test as of today operated with oxy-firing mode for coal was done by International Combustion during the 1990's - what have we learned from this test?
- Cost and capacity of producing your oxygen

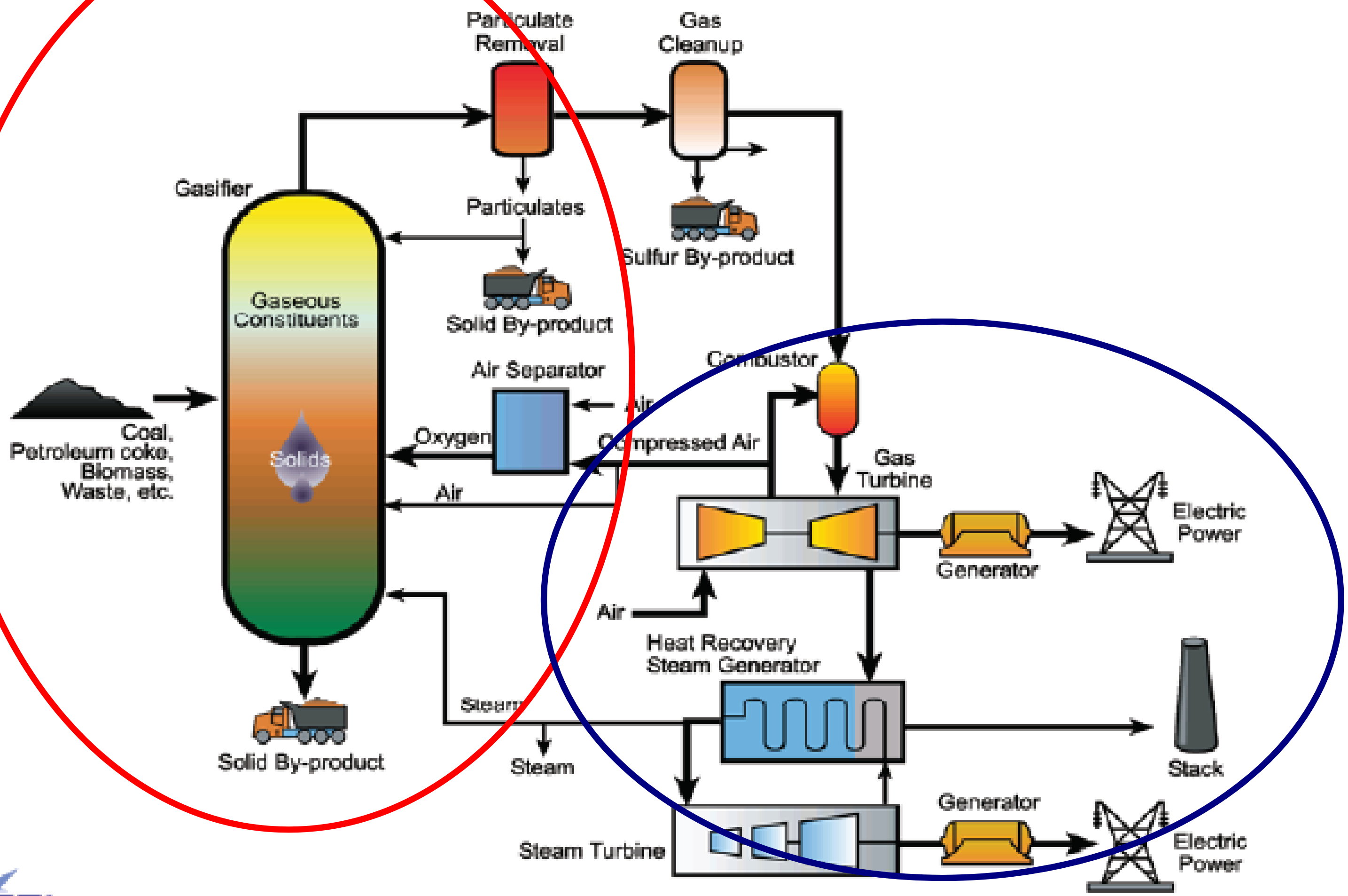
Pre-Combustion Capture
(Considering only Coal Power Plant)

Pre-Combustion Capture

- IGCC with CO_2 capture



Integrated Gasification Combined Cycle (IGCC)



IGCC without Capture

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

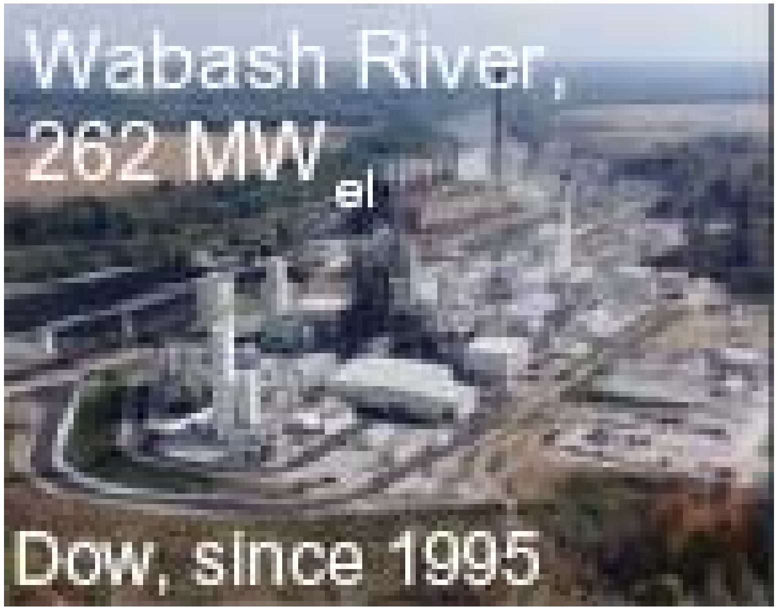
- IGCC is not at present the preferred technology for new coal-fired power plants
- Main commercial interest in IGCC is for use of petroleum residues
- Several plants built and planned at refineries

- IGCC has some intrinsic advantage over PC plant when CCS is to retrofitted or 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



250MWe Air Blown IGCC (Fukushima, Japan)

CO_2 Capture in IGCC

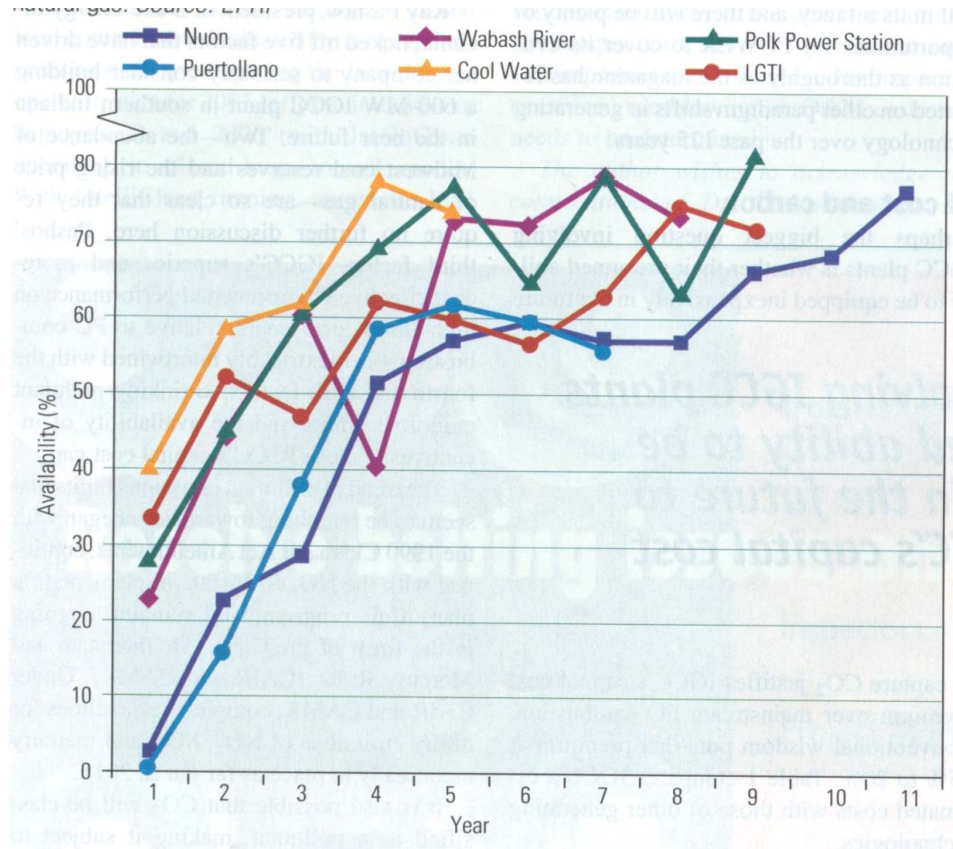
- Advantages of IGCC for CO_2 capture
  - High CO_2 concentration and high overall pressure
    - Lower energy consumption for CO_2 separation
    - Compact equipment
  - Proven CO_2 separation technology can be used
  - Possibility of co-production of hydrogen
- Disadvantages
  - IGCC is unfamiliar technology for power generators
  - Existing coal fired plants have low availability
  - IGCC without CO_2 capture has generally higher costs than pulverised coal combustion

IGCC

- IGCC with pre-combustion capture has been the fundamental building blocks in various programme for co-generation of electricity and hydrogen
- Some examples
  - Europe: HYPOGEN Programme
  - Japan: EAGLE Project
  - China: GreenGen Project

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 both prospective investors and power plant operator
- Cost is another issue



Source: EPRI

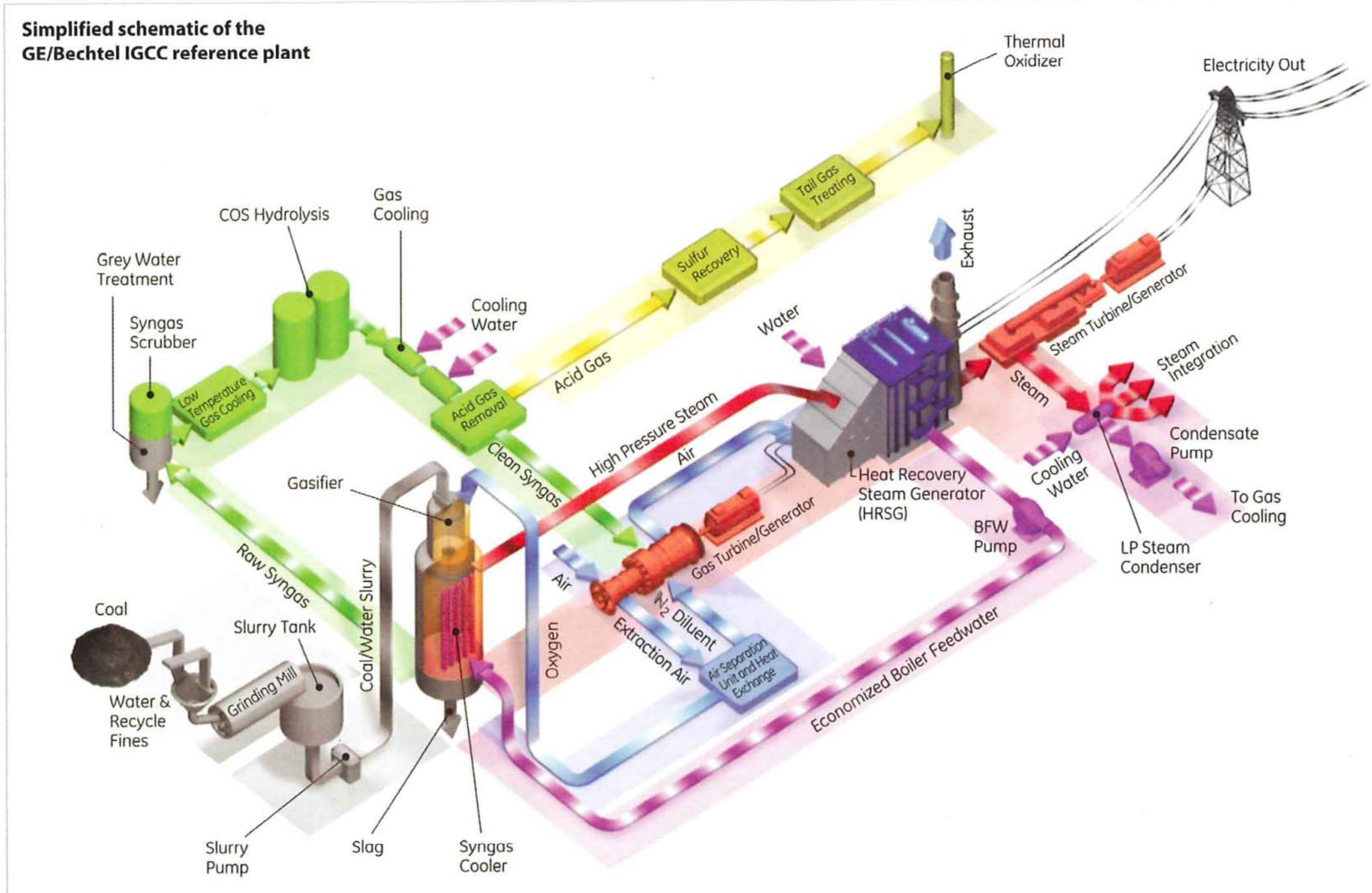
Pre-Combustion Capture: Key Development Area

- Development in Gasifier Technology
- Development in Shift Reactor
  - Choice of Sour vs Sweet Shift Reaction
- Development in Separation of CO_2 using Physical Absorption technology
- Development in the Gas Turbine technology
  - Development of gas turbine firing H2 rich fuel using the current DLN technology

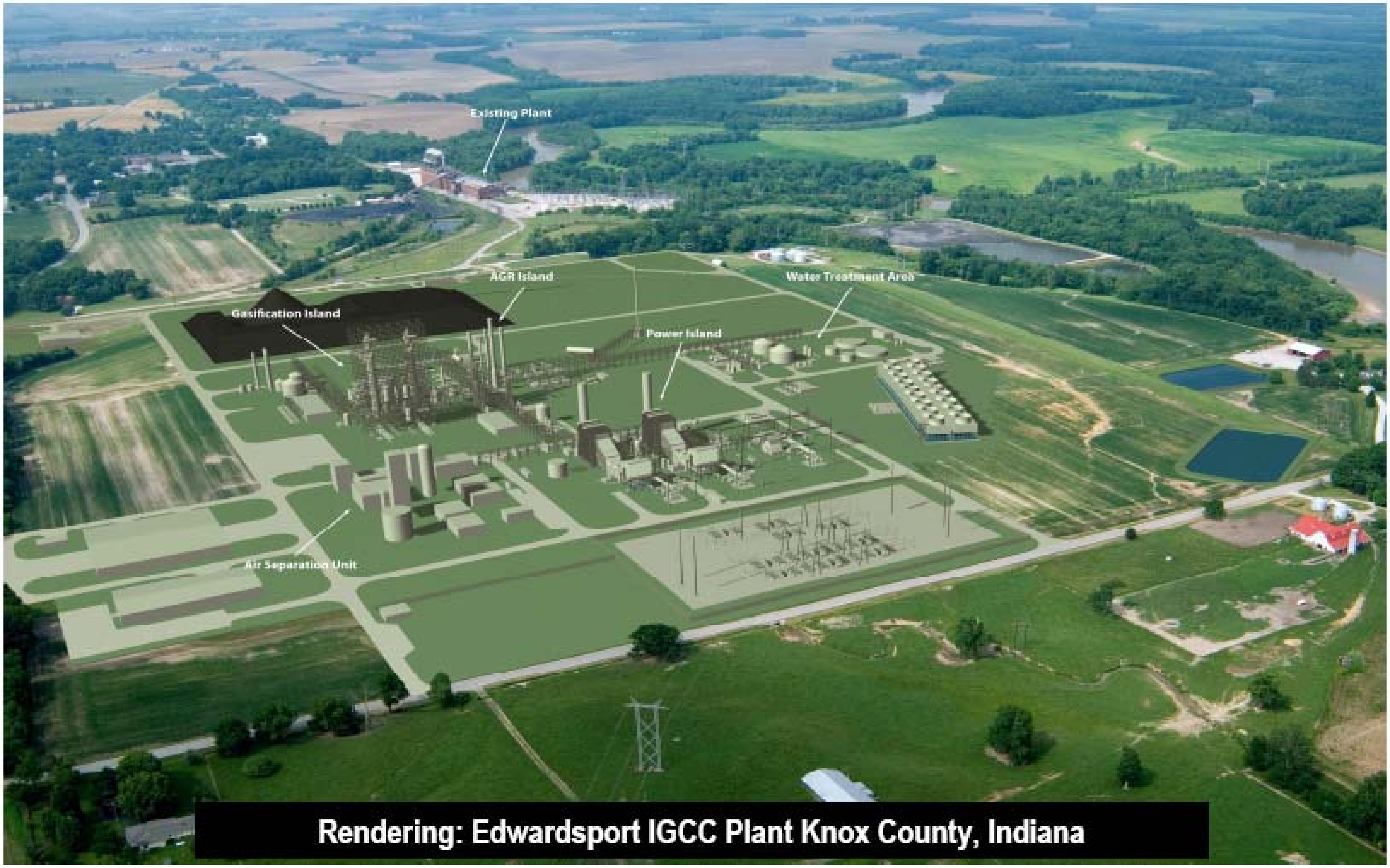
What are the current trend of development in IGCC Based Technology…

- New fleet taking advantage of 10+ years of operation in the U.S. and Europe
  - Materials of construction
  - Spare equipment
  - Gasifier refractory / membrane wall
  - Burner design
- Range of suppliers to choose from, for a wide variety of coals and other feedstocks
- EPC alliances can provide important guarantees

GE Bechtel Reference Plant



Duke Energy Edwardsport IGCC Layout



Rendering: Edwardsport IGCC Plant Knox County, Indiana

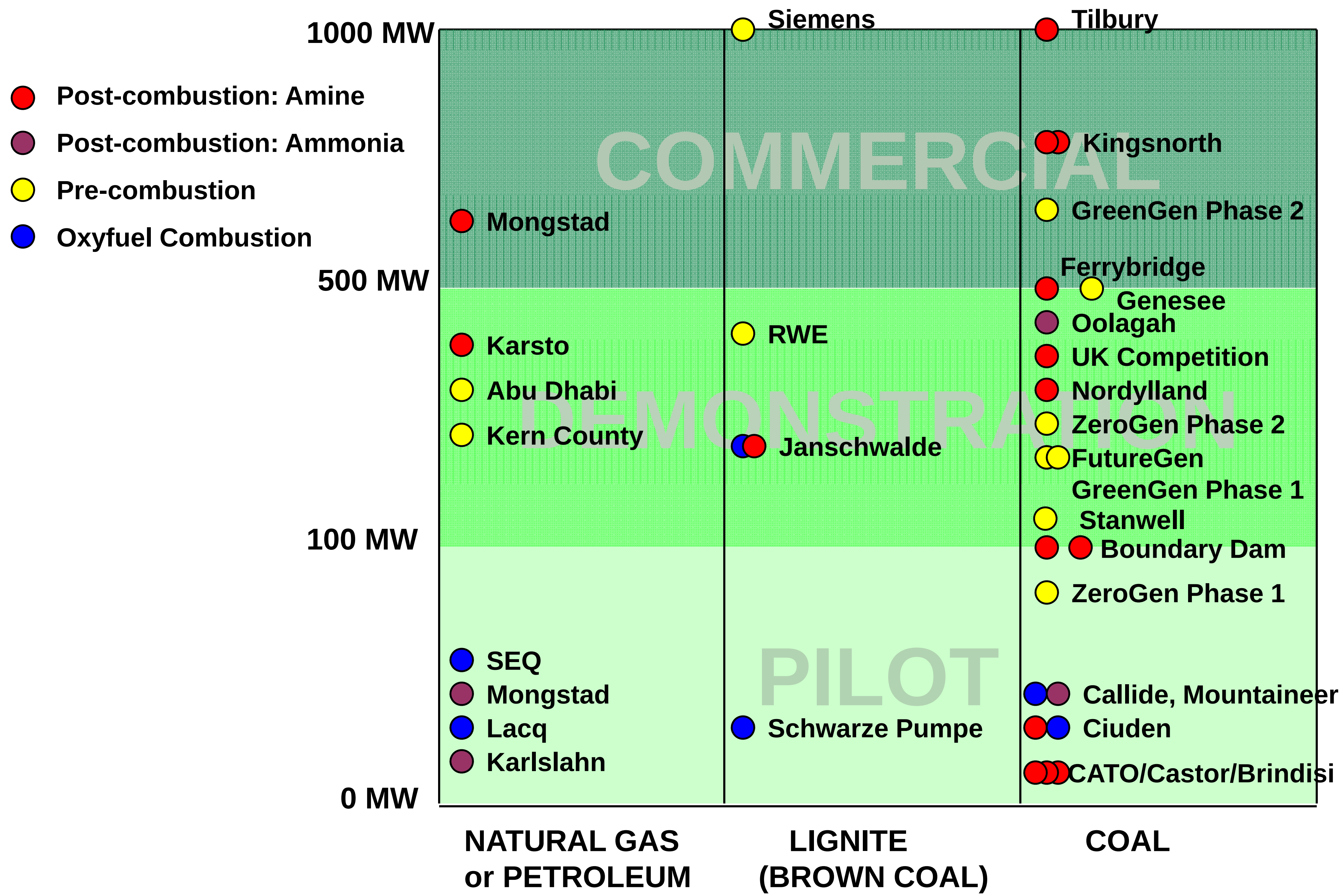
New Product Introduction (NPI)

- GE New Product Introduction
  - Reference Plant
  - Radiant Syngas Cooler
  - Advanced Feed Injector
  - 7FBJ
  - Refractory
  - Distributed Control System – Mark VIe
- GE continuing to progress thru NPI toll gate process
  - Track and Manage to ensure Delivery by GE
- Extended Startup period (13 months) to accommodate NPI Testing and Validations

Concluding Remarks

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.


Post-combustion: Amine
Post-combustion: Ammonia
Pre-combustion
Oxyfuel Combustion
1000 MW
500 MW
100 MW
0 MW
COMMERCIAL
DEMONSTRATION
PILOT
Siemens
Tilbury
Kingsnorth
GreenGen Phase 2
Mongstad
Ferrybridge
Genesee
Oolagah
UK Competition
Nordylland
ZeroGen Phase 2
FutureGen
GreenGen Phase 1
Stanwell
Boundary Dam
ZeroGen Phase 1
RWE
Karsto
Abu Dhabi
Kern County
Janschwalde
SEQ
Mongstad
Lacq
Karlslahn
Schwarze Pumpe
Callide, Mountaineer
Ciuden
CATO/Castor/Brindisi
NATURAL GAS
or PETROLEUM
LIGNITE
(BROWN COAL)
COAL

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

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

2008

World's <u>FIRST</u> 30 MWt full chain demonstration at Schwarze Pumpe – started operation

Alstom	Schwarze Pumpe	2008	30MWth	Lignite
Hitachi Babcock	Schwarze Pumpe	2010	30MWth	Lignite
IHI	Callide	2010	30MWe	Coal
Alstom / AL	Lacq	2009	30MWth	Gas/Oil?
FW - CIUDEN	Ibierza Facitity	2010	15Mwth	Coal
FW - CIUDEN	Ibierza facility	2010	20MWth	Coal

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

By 2014-2016

Demonstration of 50– 500MWe full scale power plant.

Vattenfall's Janschwalde (250MWe)
KEPCO/KOSEP - Yongdong (100MWe)
FW/Praxair - Jamestown (50MWe)
Endessa (500MWe)

Target :
"Commercialised by 2020"

Thank You!!!

For Any Questions...

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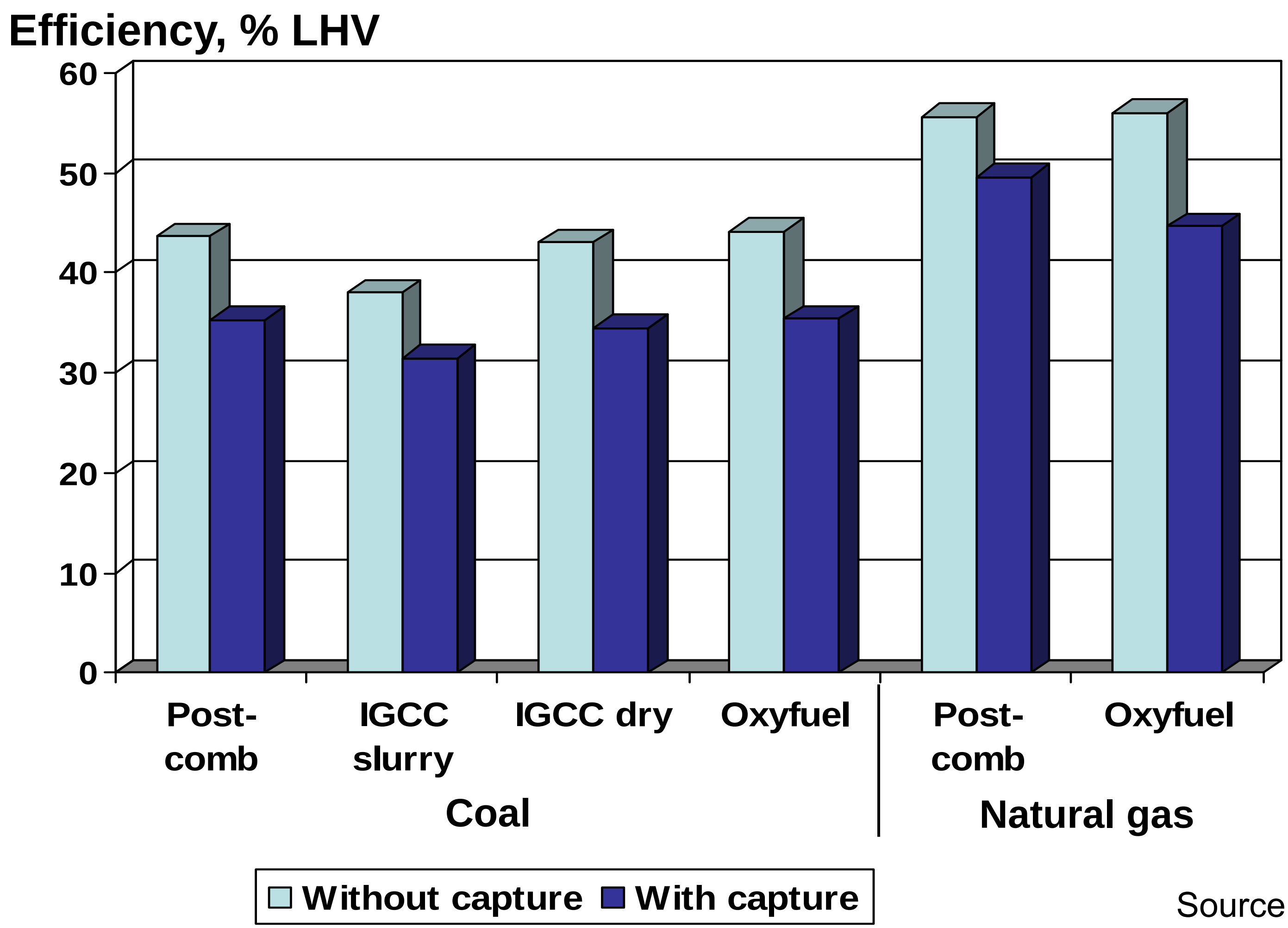
General Website: http://www.ieagreen.org.uk

CCS Website: http://www.co2captureandstorage.info

Back Up Slides

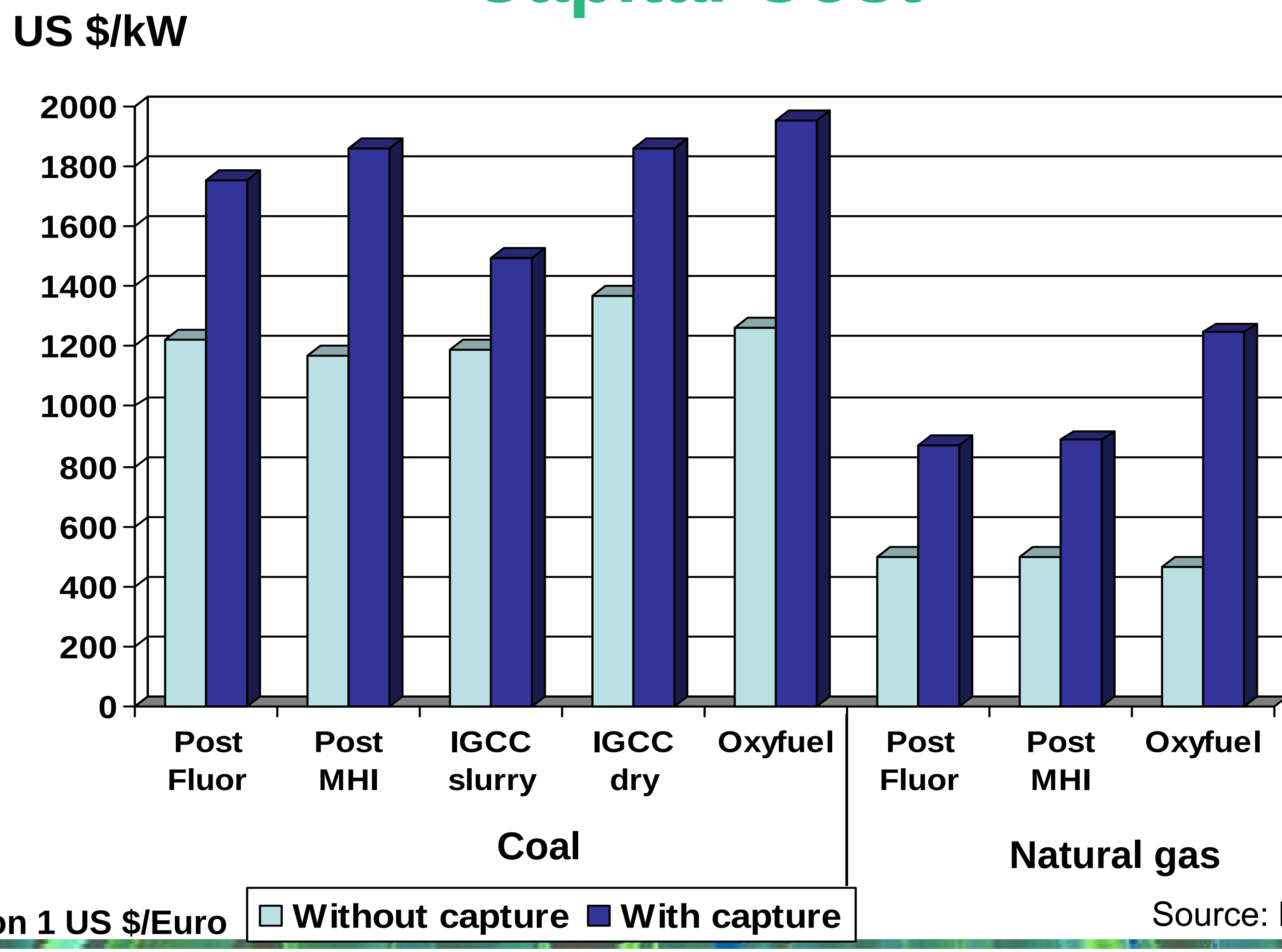
CO_2 Capture – Overview to the Performance and Economics

Power Generation Efficiency



Source: IEA GHG studies

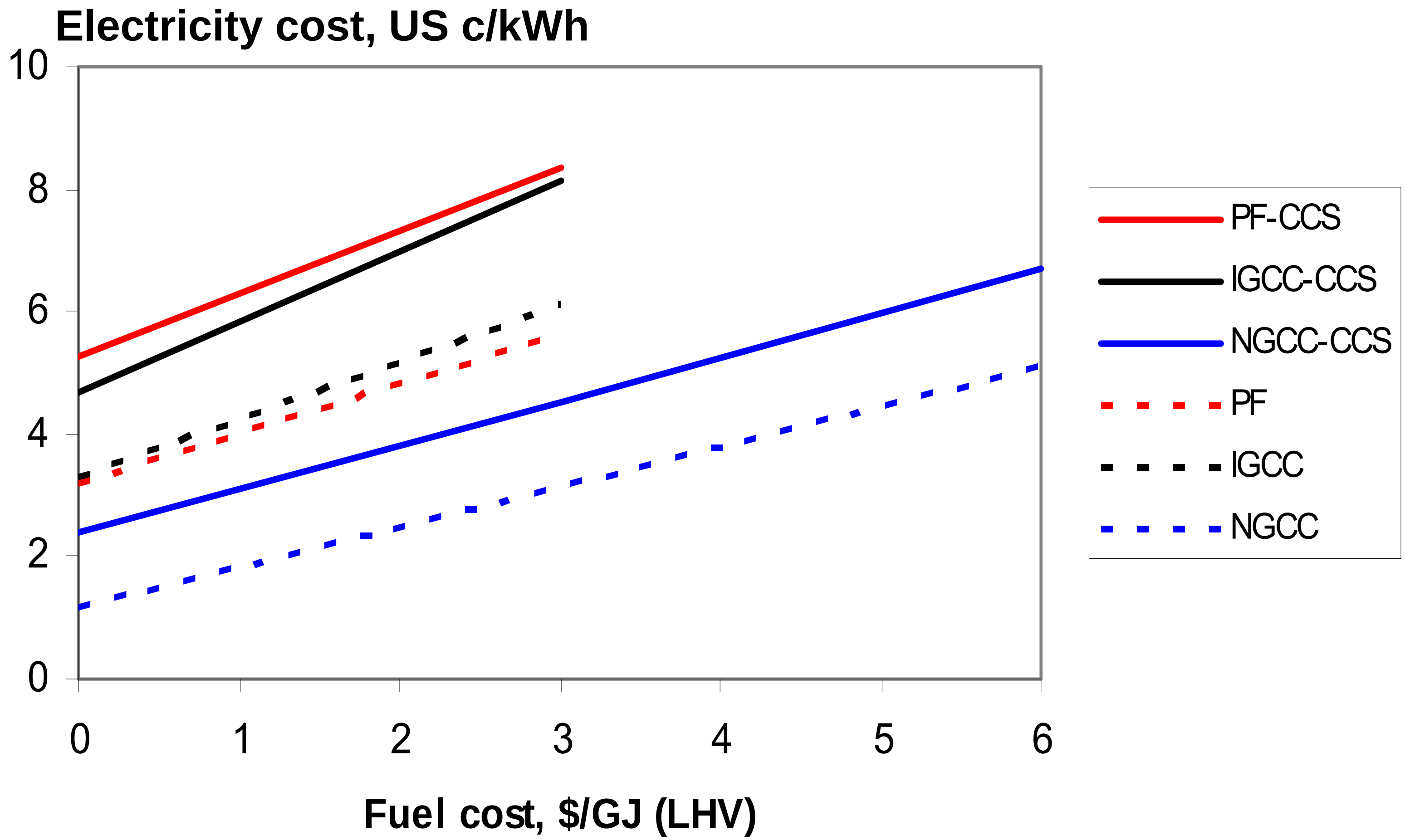
Capital Cost



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