Oxy-Coal Combustion Power Plant with CCS

Current Status of Development

Stanley Santos

IEA Greenhouse Gas R&D Programme

Cheltenham, UK

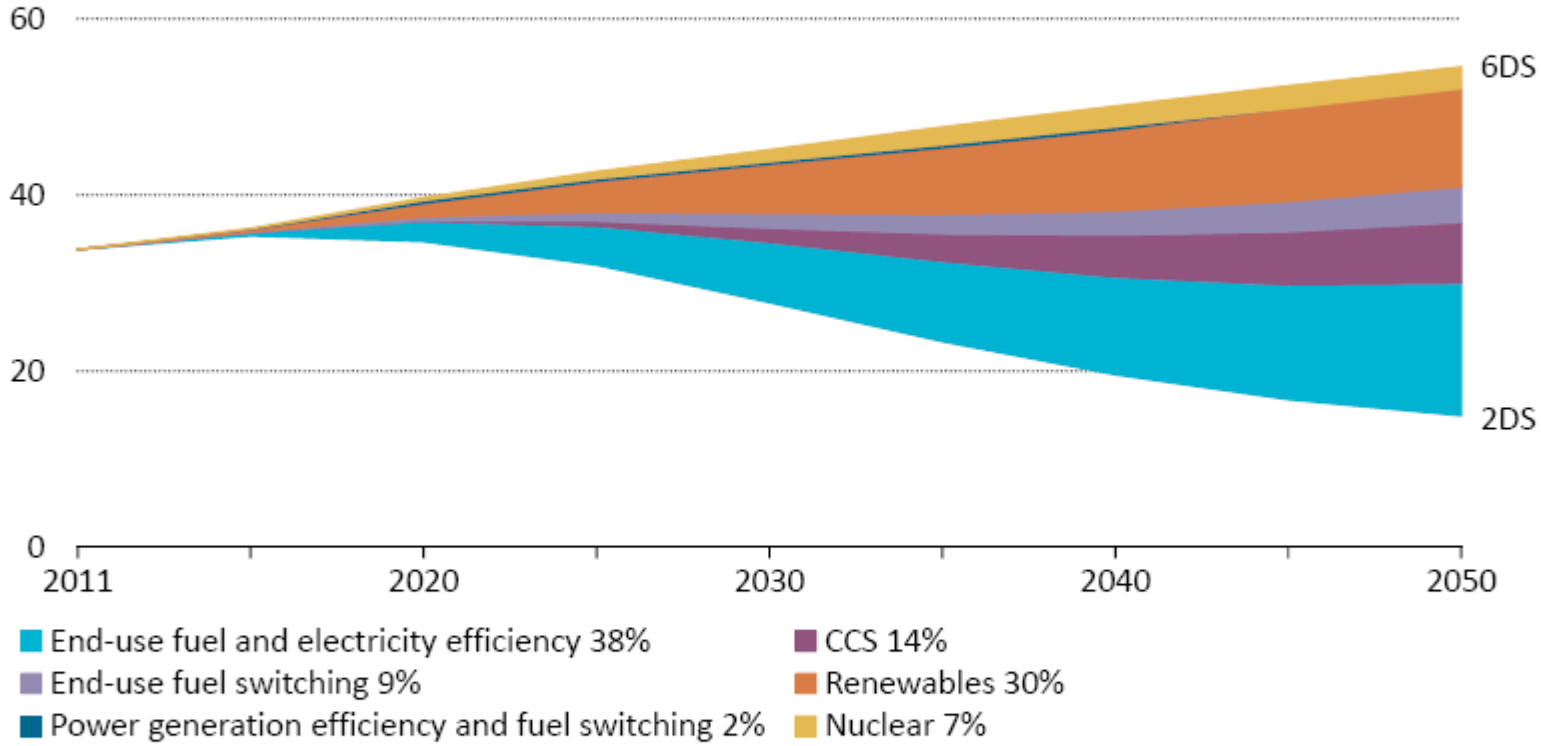
39th Clearwater Conference

Florida, USA

May 2014

A transformation is needed…

ETP 2014



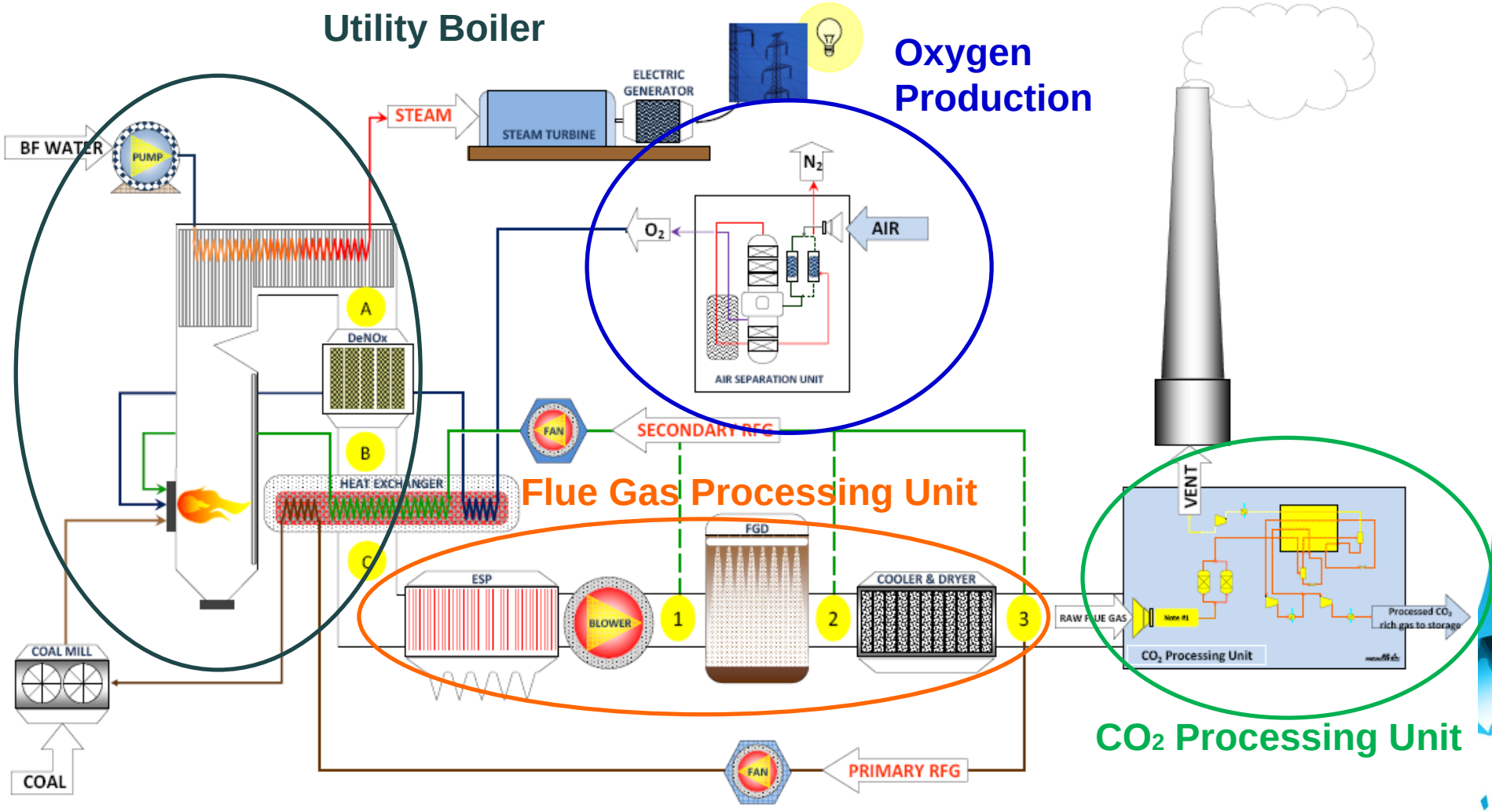
..and we to have the tools to develop a strategy and be proactive.

International Energy Agency

Presentation Objectives

- ***To provide an overview to the current state of development of Oxyfuel Combustion***
  - Burners and boiler development
  - Oxygen production
  - CO_2 processing unit
- ***To provide the highlights of the key developments and identify the critical future direction in R&D***

Oxyfuel Combustion for Coal Fired Power Plant with CCS



ieaghg

FutureGen2 - Illinois (PC - 168MWe)
UK: White Rose Project (PC – 426MWe

China: Shenhua Shenmu Project (PC – 200MWe)

Finish Line

Target : "Commercialised by 2020"

By 2015-2019

Demonstration of 100–300MWe full scale power plant.

2012 – Callide – World's first 30MWe retrofitted Oxy-coal power plant

2015 – HUST Industrial Project for 35 MWt Oxyfuel Pilot Plant

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

2012 – CIUDEN – World's first 30MWt Oxy-CFB Pilot Plant

2008

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

Alstom	Schwarze Pumpe	2008	30MWth	Lignite
Hitachi Babcock	Schwarze Pumpe	2010	30MWth	Lignite
Doosan Babcock	Schwarze Pumpe	2012	30MWth	Lignite
IHI	Callide	2011	90MWth	Coal
Alstom / AL	Lacq	2009	30MWth	Gas/Oil?
CIUDEN	El Bierzo CFB Facility	2012	30MWth	Coal
CIUDEN	El Bierzo PC Facility	2012	20MWth	Coal

2007

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

2003 - 2005

Vattenfall (ENCAP ++)
CS Energy / IHI Callide Project

1998 – 2001

CANMET
US DOE Project / B&W / Air Liquide

1990 - 1995

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

1980's

ANL/Battelle/EERC completed the first industrial scale pilot plant

Can we still achieve our goal to commercialise the technology by 2020???

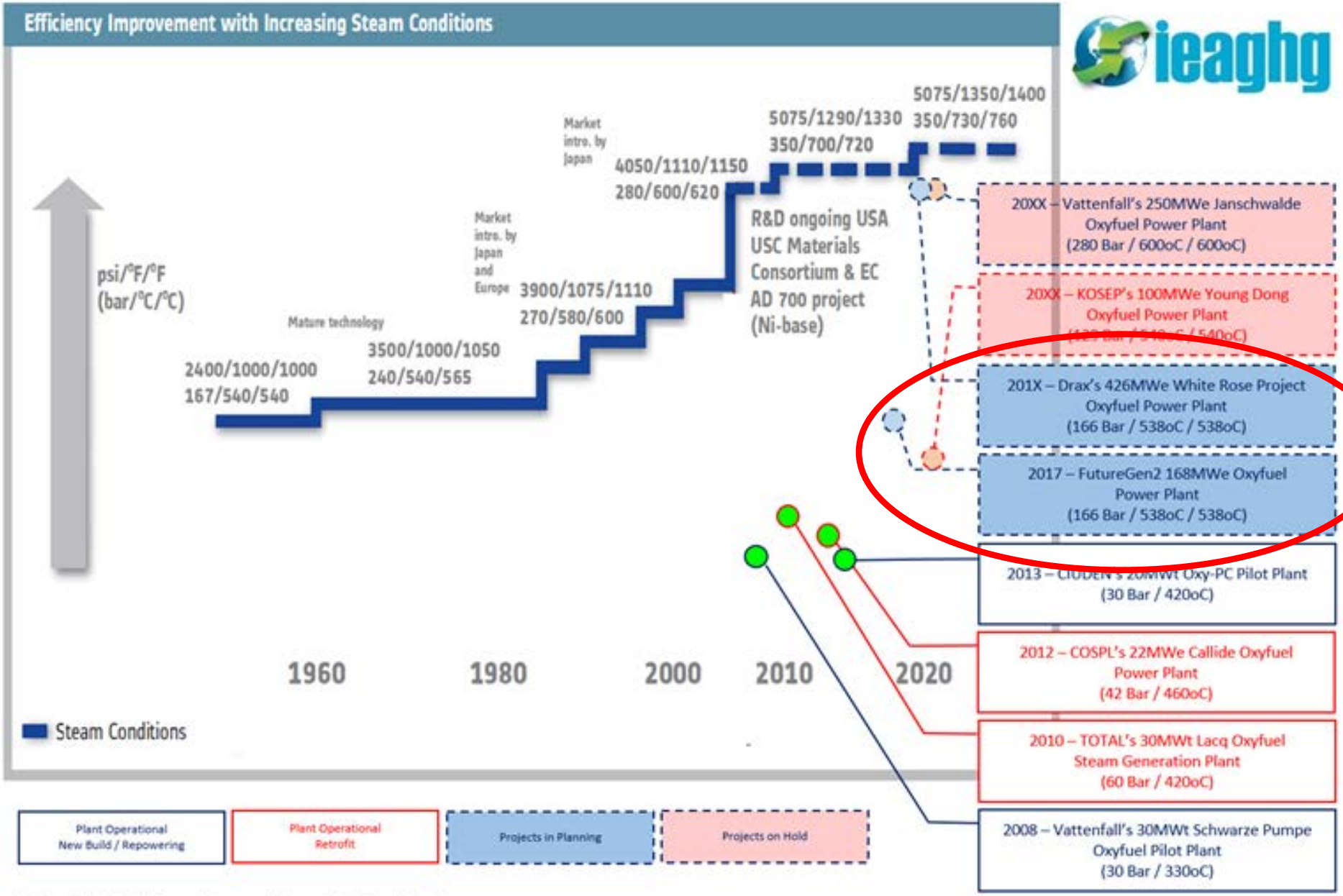
First large scale 35MWt Oxy-Coal Burner Retrofit Test done by International Combustion

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

Updated by S. Santos (02/06/14)

Developments in Burners & Boilers

- ***We have seen the rapid development of Oxyfuel Combustion in the last 10 years***
  - Vattenfall's Oxyfuel Projects
    - Covering the work from Schwarze Pumpe Large Scale Pilot Plant to Janschwalde's FEED.
  - Callide Oxyfuel Project
    - Largest mini-demonstration project in the world
  - TOTAL's Lacq Project
    - First pilot demonstration of CO2 injection from oxyfuel boiler
  - CIUDEN's Oxyfuel Projects
    - World largest pilot plant for oxy-CFB



S. Santos (16/04/2014) - figure of steam conditions adapted from Alstom's paper

Large Scale Demo – Progressing

FutureGen™ ALLIANCE

FutureGen 2.0

- Repower Meredosia Energy Center with oxy-combustion and CCS technology
  - Repowered gross: 168 MWe
  - Near-zero emissions
  - CO_2 capture rate: 98%
  - CO_2 capture volume: 1.1 MMT/yr
  - Pipeline transport: ~30 miles
  - Deep geologic storage

Design	Construction	Power Production w/CCS	Post-closure monitoring

2010 2014 2017 2037 2087

2

www.FutureGenAlliance.org

Investment decision to be made before the end of 2014

Large Scale Demo – Progressing

What is making it work? – Delivery

Partner Roles, bringing depth of know-how and resources

OXY-POWER PLANT

CAPTURE POWER

- Full-Chain Integration

Alstom

- Delivery of Oxy-Power Plant
- Integration of Oxy-Power Plant

Drax

- O&M of Oxy-PP
- Trading Services
- Site Services
- Fuel Supply
- Electrical Connection

BOC-Linde

- Delivery of ASU
- O&M of ASU

CO_2 TRANSPORT & STORAGE

nationalgrid Carbon Ltd

- Delivery of Transport & Storage network
- O&M of Transport & Storage network

CAPTURE POWER

18/19 Feb 2014 White Rose 8th European CCS Conference Brussels

Investment decision to be made before the end of 2015

What's the future landscape of Oxyfuel R&D for boilers & burner development

- ***We have learned a lot in the last 10 years***
  - It could be concluded that oxyfuel combustion is ready for demonstration
  - It could be operated very similar to the conventional utility boilers
- ***Work in both Oxy-PC and Oxy-CFB will continue.***
  - The pace of development will depend on the market
- ***Different fundamental R&D activities will not stop – it is expected to follow the development path of conventional utility boilers.***
  - Fuel characterisation
  - Pollutant formation and reduction
  - Materials development
  - Modelling development
- ***Work in opportunity fuels – expected to grow (how fast?)***
  - Biomass, petcoke, and others

Oxygen Production

- ***Facts:***
  - Today, only the Cryogenic Air Separation Unit or ASU is capable of delivering the oxygen demand of a large oxyfuel combustion boiler for power plant with CO_2 capture…
  - For every 500MWe net output you will require ~10,000 t/d O_2
    - Low Purity (95-97%)*
    - Low Pressure (nearly atmospheric)

At 95% purity will have 2% N2 and 3% Ar

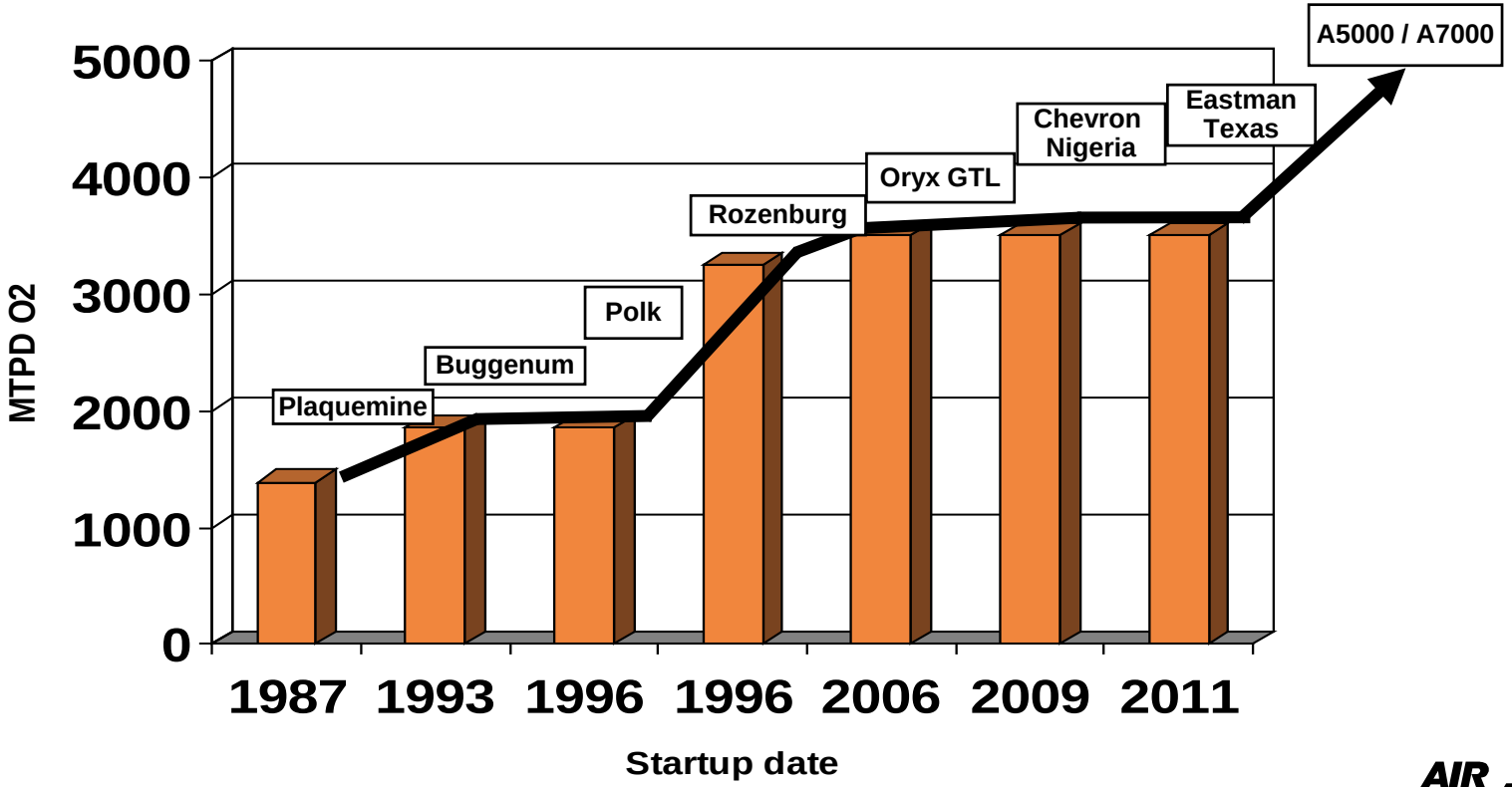
Cryogenic Air Separation – Capacity Increase

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

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

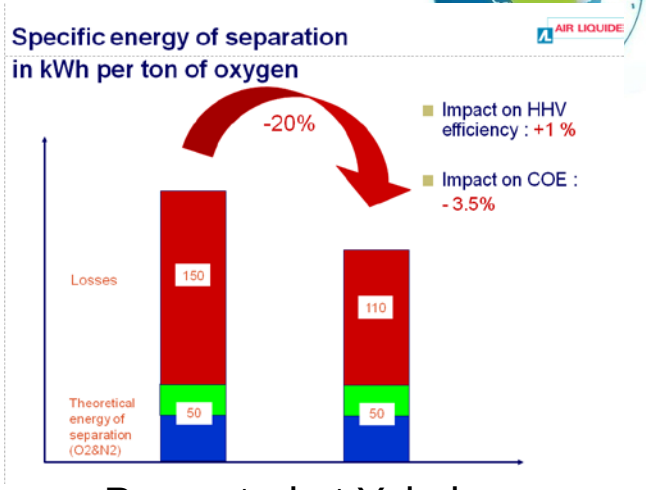
Experience - Large ASU Projects and Train Scale-up

- **Market drives ASU scale-up**
- **Proven 70% scale-up**
- **Quoting 5,000+ MTPD today**

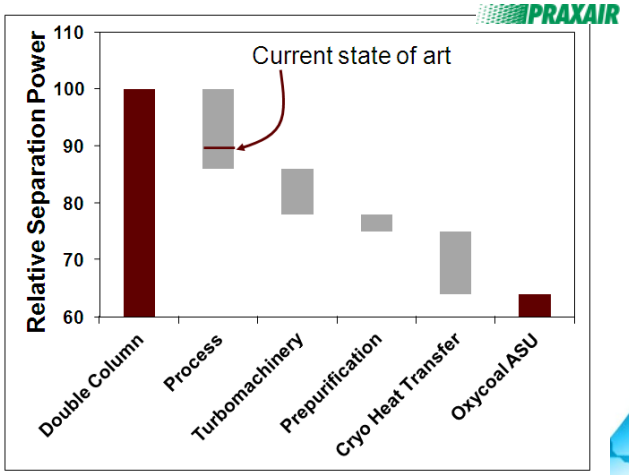


Current Status - Cryogenic ASU for Oxyfuel Combustion

- *Advances and Development in ASU could result to 25-35% less energy consumption than what could be delivered by the current state of the art ASU today.*
  - A target of 140 kWh/t O_2 (at ISO condition) is achievable
  - These ASU would not be based on the conventional 2 column ASU – but it could be hybrid based on 3 columns design or dual reboiler design.

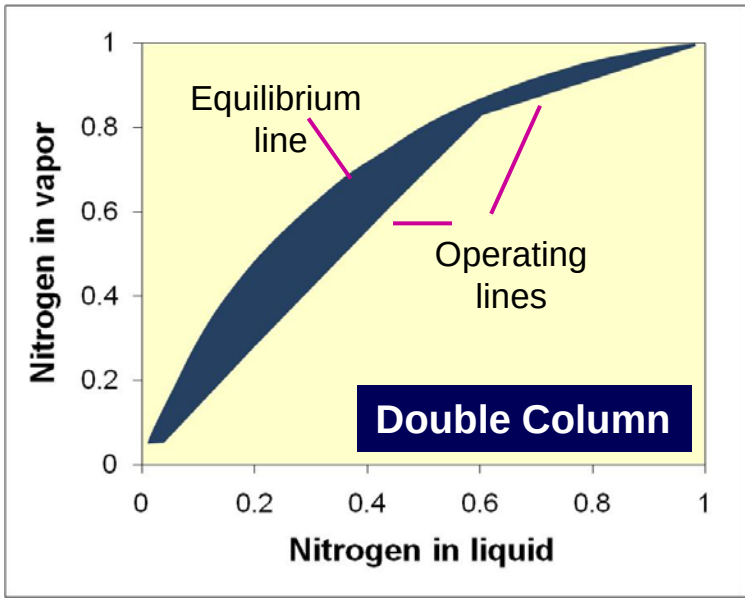


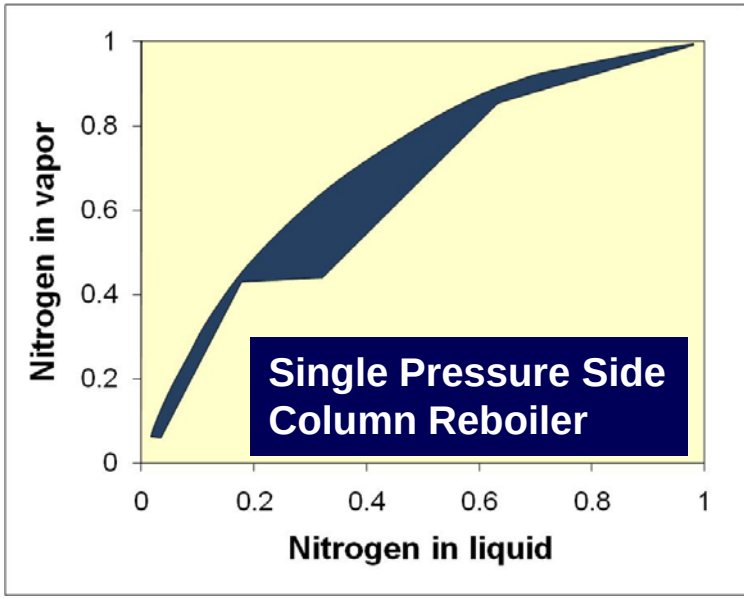
Presented at Yokohama Workshop, March 2008

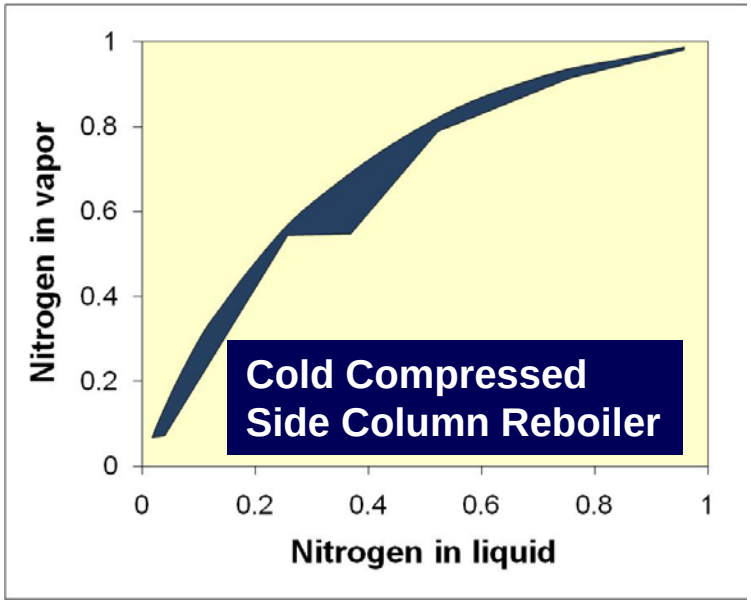


Presented at OCC2 - Yeppoon , Australia September 2011

McCabe Thiele Diagrams

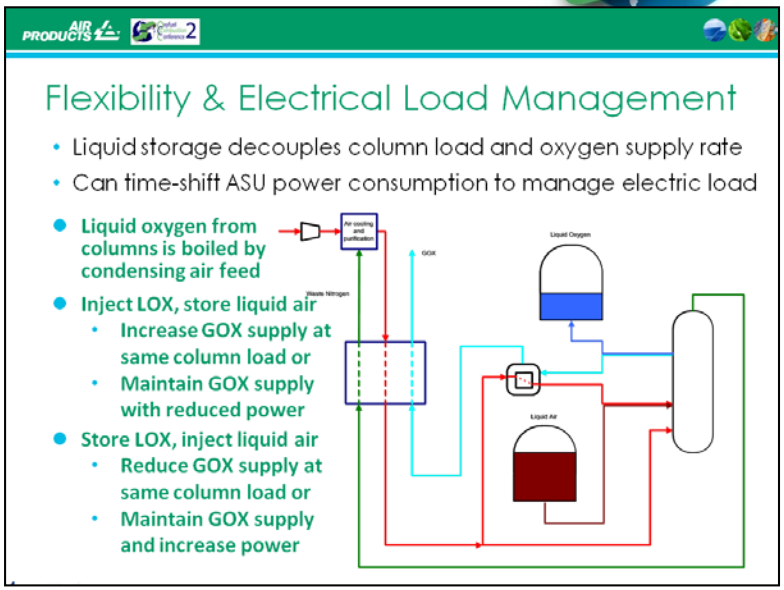


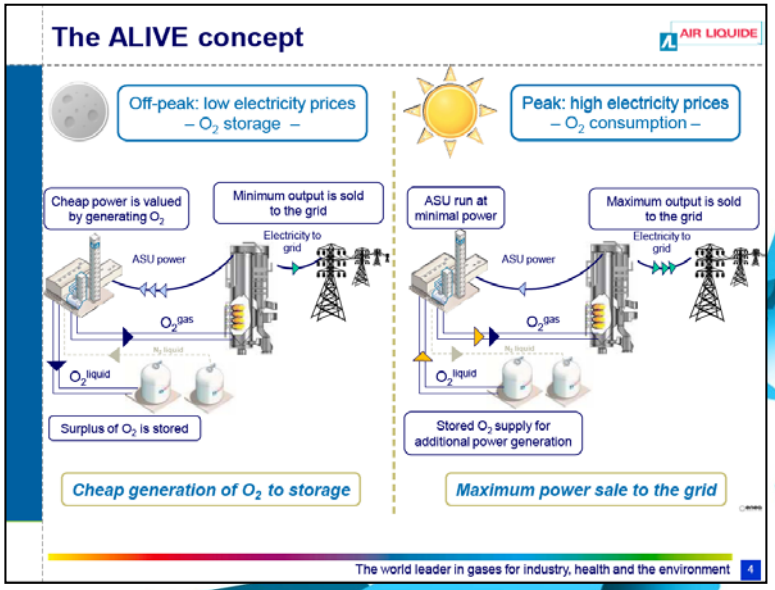




ASU's Flexibility & Energy Storage

- *Ramping between 1-3%/min the ASU could be designed and adapted without co-production of liquid gases (i.e. air, O_2, N_2)*
  - Design of such plant would be strongly dependent on the arrangements of the main air compressors
- *With co-production of liquid gases*
  - wide ranging flexibility could be achieved.
  - Additionally, the manner on how the ASU will be operated could have a good potential for Energy Storage with CCS.
- *Current challenge will be on how to balance between CAPEX and OPEX to achieve the optimised flexible ASU that meets the demand of the power plant*





Reliance Petcoke Gasification

World's largest ASU's: 5 units each with 5250 tpd O2

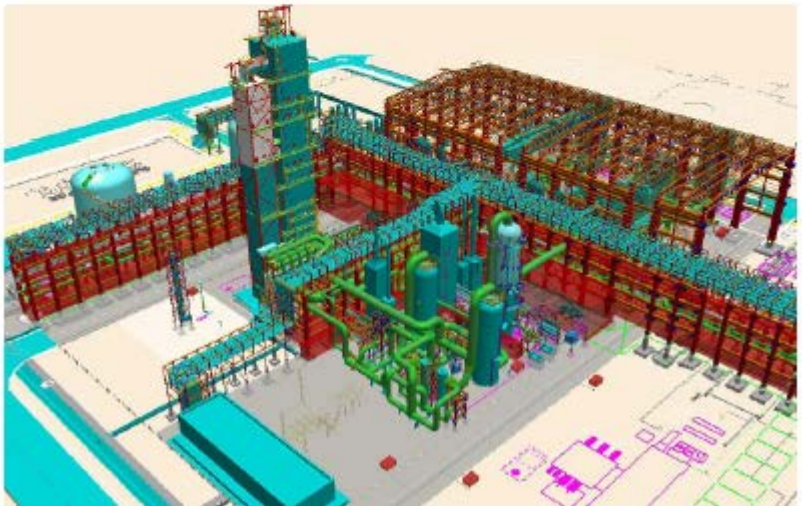
THE LINDE GROUP

The Target

- Supply O2 at the lowest life cycle cost
- Assure highest plant reliability

The Solution for Oxygen Supply

- Install five identical ASU units
- Capacity of one unit is 5250 tpd O2 (largest plant size worldwide)
- Highest power efficiency



Although the design of the ASUs for Gasification and Oxyfuel Combustion have a lot of differences…

Nonetheless, by building and operating the world's largest single train ASUs will benefit the Oxyfuel Combustion Technology – i.e. **Demonstrating ASUs of the size needed for Oxyfuel Combustion could be build today.**

What's the future landscape of Oxyfuel R&D for oxygen production

- ***Once the world's largest single train ASUs starts its operation – this will provide a very good basis as a "Reference" to application of oxyfuel combustion.***

- ***Crucial to the improvement of cryogenic ASUs for future oxyfuel combustion applications are:***
  - Flexibility of the Main Air Compressor
  - Development of process controls
  - Integration with the boiler island and the CPU.

- ***Development for alternative oxygen production should continue.***
  - It is not expected to dislodge the cryogenic ASU for some time.

CO_2 Processing Unit

- ***Key Areas of Development in CO_2 Processing Unit or CPU***
  - Compression and Removal of minor impurities (NOx, SOx and Other Trace elements
  - Dehydration Unit
  - Cryogenic Separation of Inerts (Cold Box development)
  - Additional capture of CO_2 from the CPU

- ***Other key driver to the development is the specification of the CO_2.***
  - Management of CO_2 purity requires good interaction between boiler, flue gas processing and CPU

Overview of Development of CPU over the last 10 years...

- ***Recognition of the NOx and SOx reaction by Air Products (presented during GHGT Conference – June 2006)***
  - This has led to the rapid technology development among the industrial gas producers.
- ***Identification of potential impact of Hg to the operation of the CPU.***
- ***Development of the use of impure CO_2 as refrigerant driven mostly by reducing energy penalty.***
- ***Work on further recovery of CO_2 in the vent of CPU.***

NOx SO_2 Reactions in the CO_2 Compression System

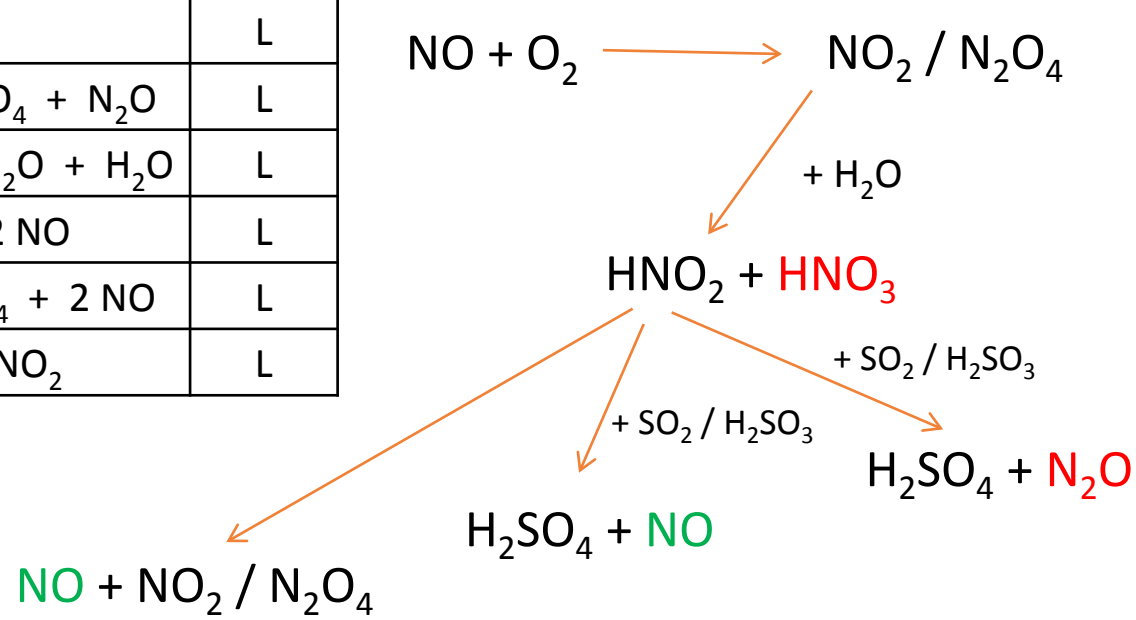
- **We realised that SO_2, NOx and Hg can be removed in the CO_2 compression process, in the presence of water and oxygen.**
- **SO_2 is converted to Sulphuric Acid, NO_2 converted to Nitric Acid:**
  - $NO + ½ O_2 = NO_2$ (1) Slow
  - $2 NO_2 = N_2O_4$ (2) Fast
  - $2 NO_2 + H_2O = HNO_2 + HNO_3$ (3) Slow
  - $3 HNO_2 = HNO_3 + 2 NO + H_2O$ (4) Fast
  - $NO_2 + SO_2 = NO + SO_3$ (5) Fast
  - $SO_3 + H_2O = H_2SO_4$ (6) Fast
- **Rate increases with Pressure to the 3rd power**
  - **only feasible at elevated pressure**
- **No Nitric Acid is formed until all the SO_2 is converted**
- **Pressure, reactor design and residence times, are important.**

AIR PRODUCTS

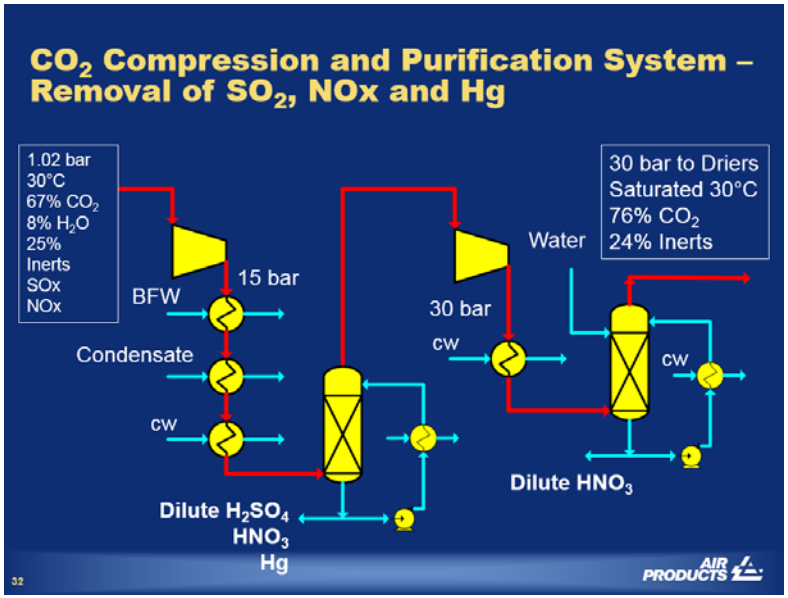
Updated NO_x - SO_x Reaction Network

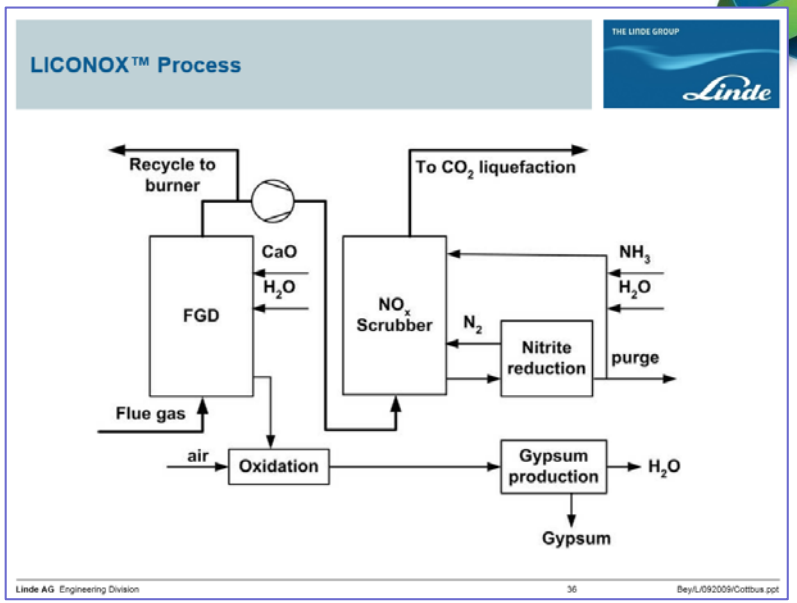
Stoichiometry	Phase
$2\ NO + O_2 \rightarrow 2\ NO_2$	V
$2\ NO_2 \rightleftharpoons N_2O_4$	V
$N_2O_4 + H_2O \rightarrow HNO_3 + HNO_2$	L
$2\ HNO_2 \rightleftharpoons NO + NO_2 + H_2O$	L
$4\ HNO_2 \rightleftharpoons 2\ NO + N_2O_4 + 2\ H_2O$	L
$SO_2 + H_2O \rightleftharpoons H_2SO_3$	L
$2\ HNO_2 + 2\ SO_2 + H_2O \rightleftharpoons 2\ H_2SO_4 + N_2O$	L
$2\ HNO_2 + 2\ H_2SO_3 \rightarrow 2\ H_2SO_4 + N_2O + H_2O$	L
$2\ HNO_2 + SO_2 \rightarrow H_2SO_4 + 2\ NO$	L
$2\ HNO_2 + H_2SO_3 \rightarrow H_2O + H_2SO_4 + 2\ NO$	L
$2\ NO_2 + H_2O \rightarrow HNO_3 + HNO_2$	L

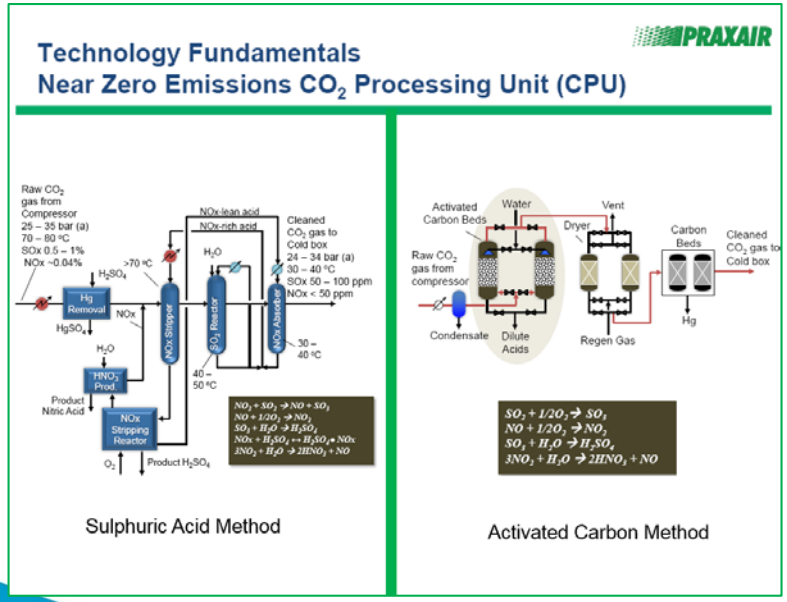
Green – propagates NO_x redox cycle
Red – terminates NO_x redox cycle

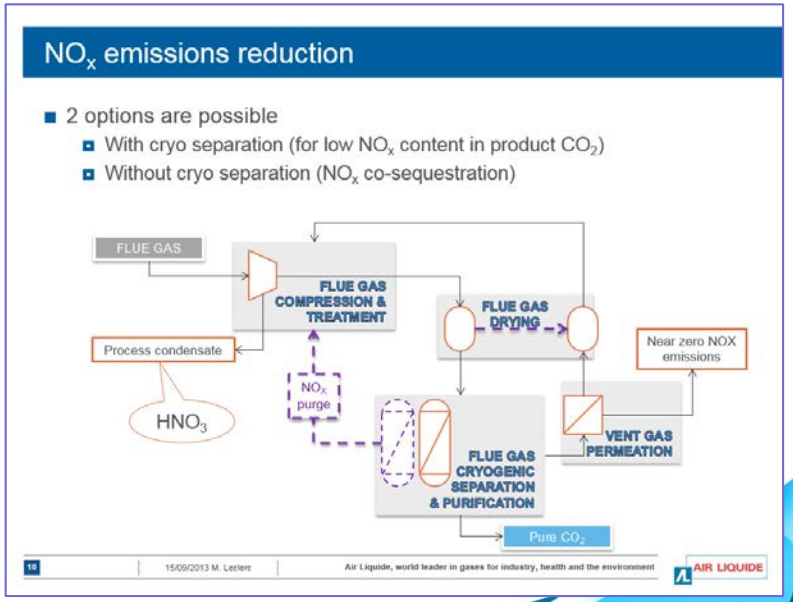


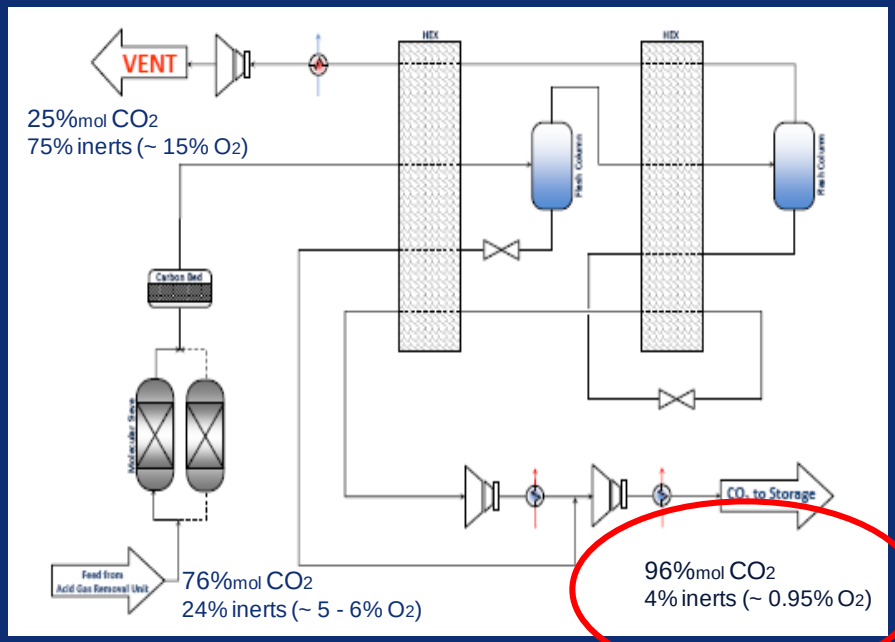
Removal of NOx, SOx and others…

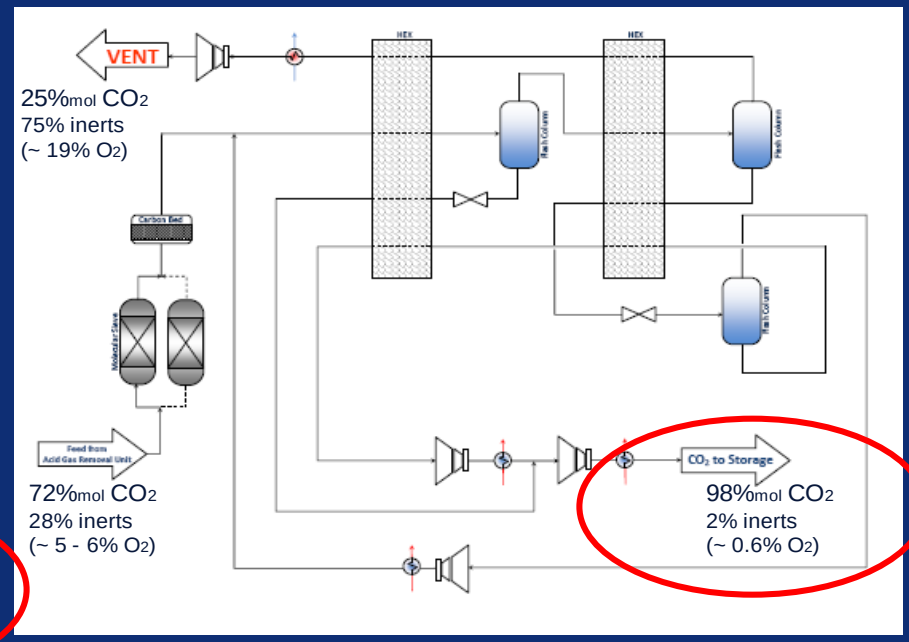


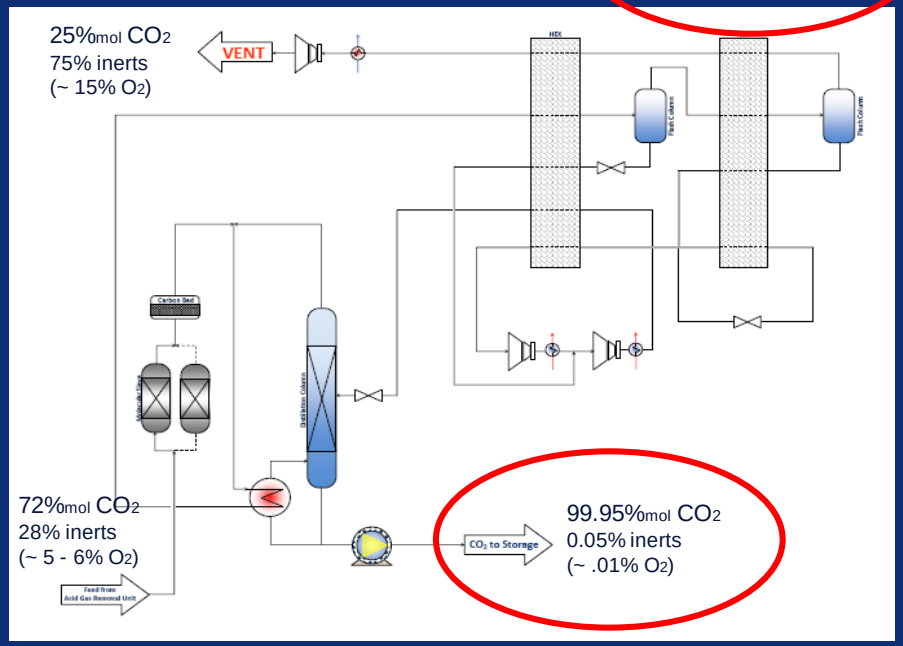


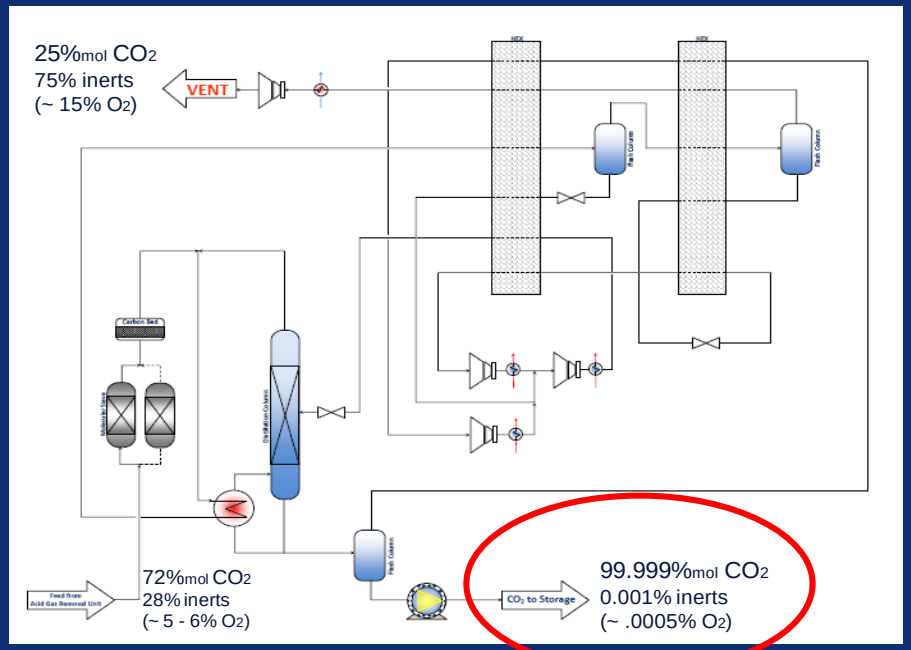






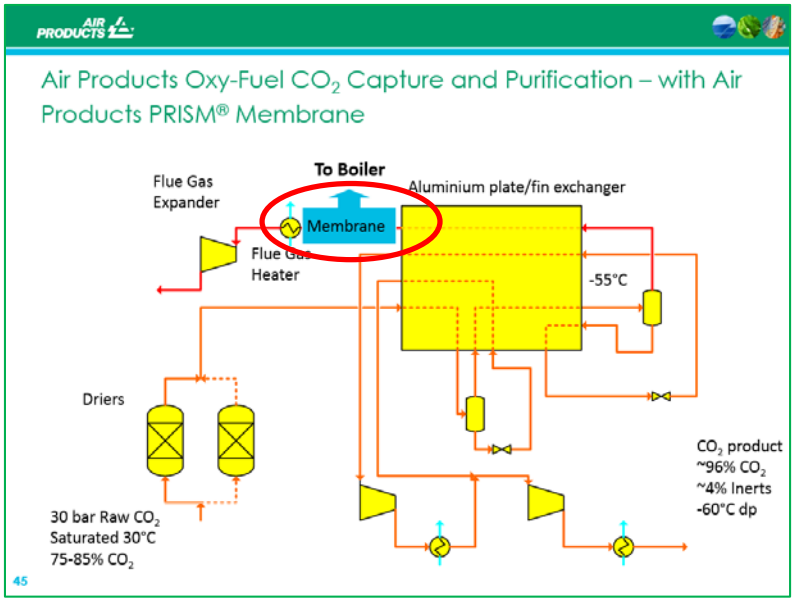


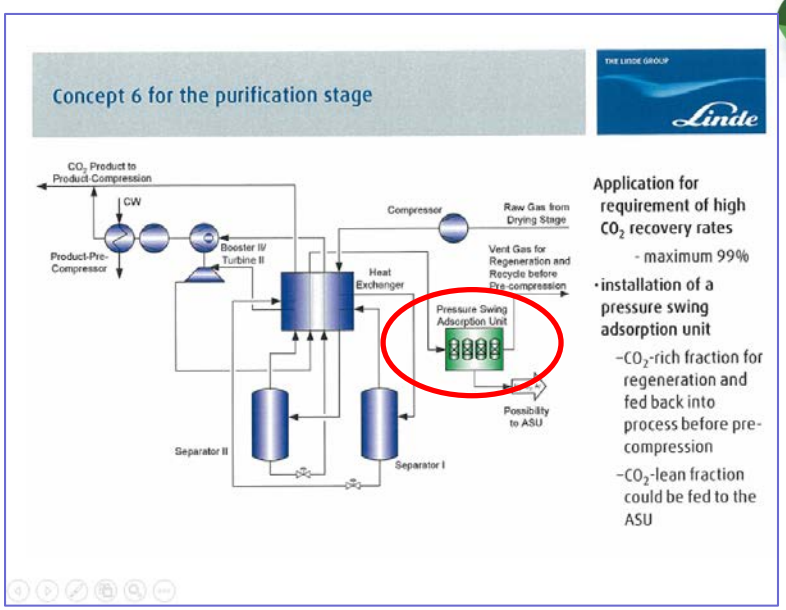


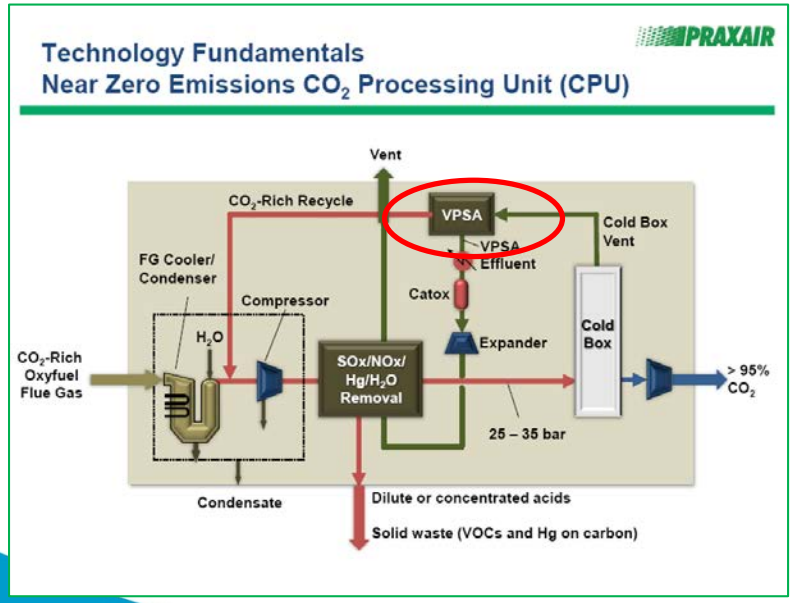


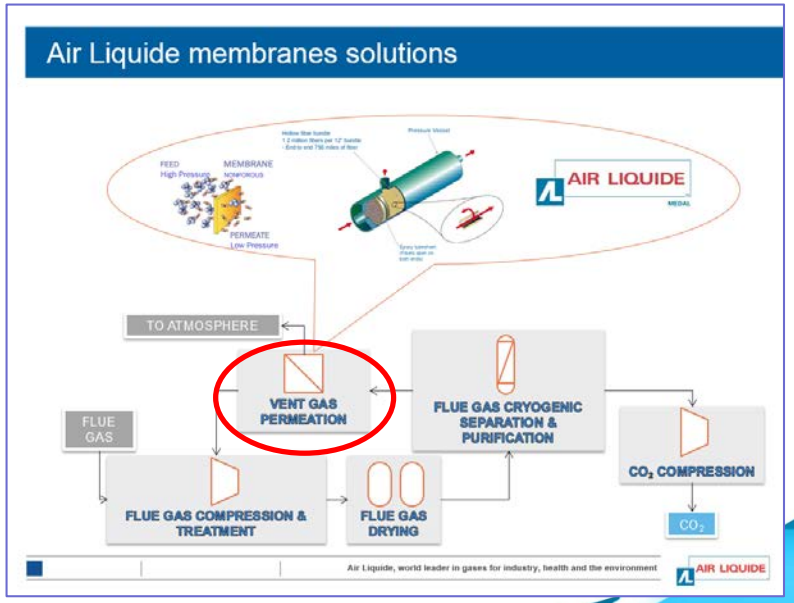
AIR PRODUCTS

Capture Rate: Greater than 98% CO_2…









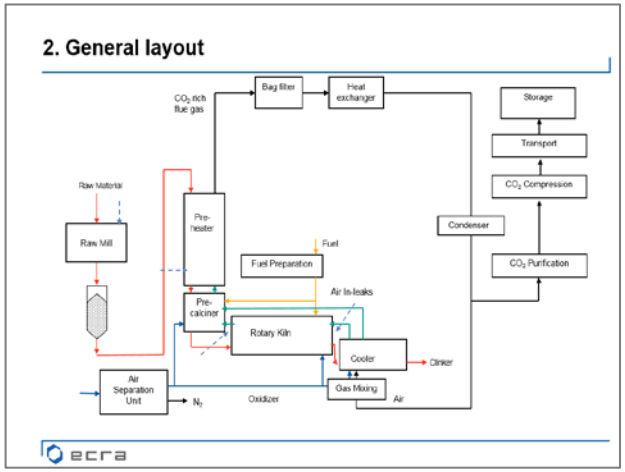
What's the future landscape of Oxyfuel R&D for CO_2 Processing Unit

- ***Specification of CO_2 is crucial to the engineering and design of the CPU***

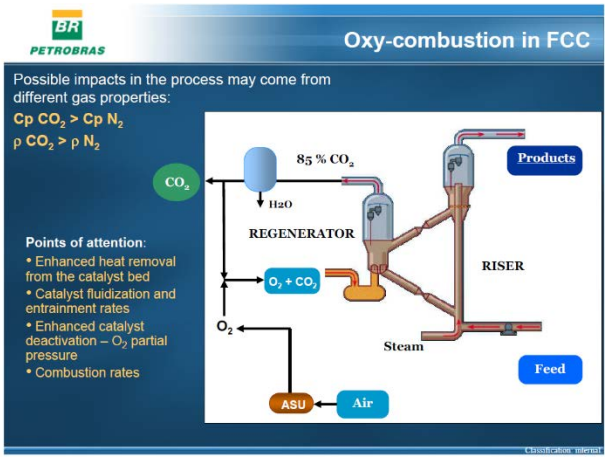
- ***We need large scale demonstration – to validate the key results obtained from various pilot plant experience.***
  - Selection of process configurations have several options

- ***Also for future R&D will require focus on:***
  - Flexibility of the CPU - this hinged on the CO_2 compressors and pumps performance.
  - Development of process controls
  - Integration with the boiler island and the CPU.

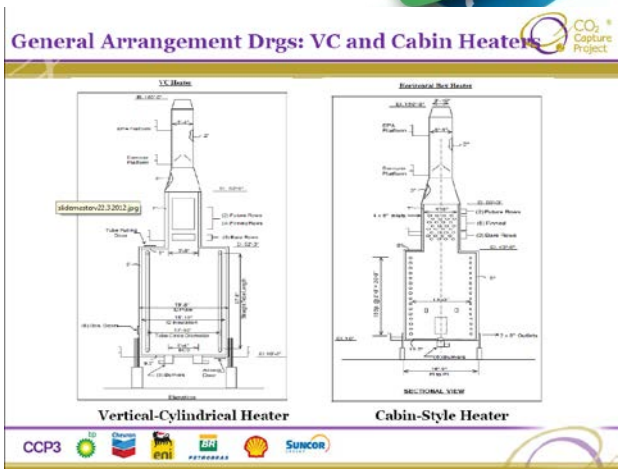
Oxyfuel Combustion with CCS is not only for Power Generation…



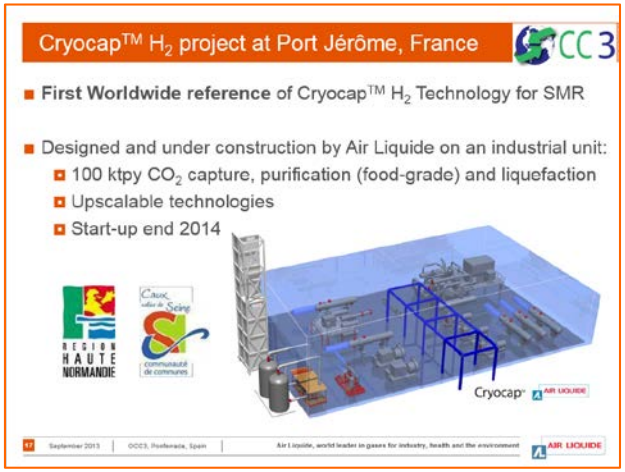
Cement Industry



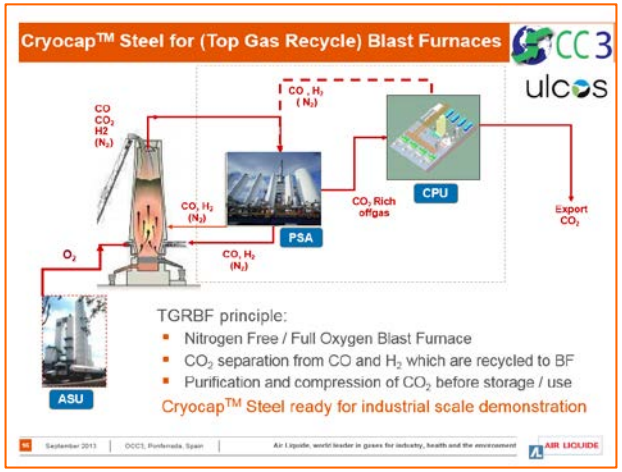
Oil Refining Industry



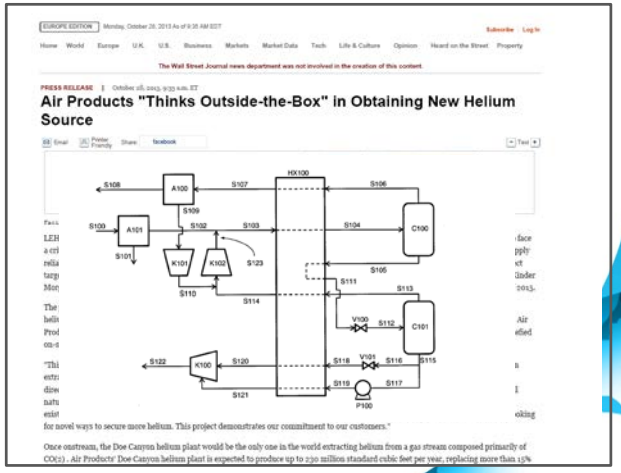
Oil Refining Industry



H2 Production



Steel Industry



Helium recovery from natural CO_2 source

Thank You

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IEA Greenhouse Gas R&D Programme

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