Lecture 2: Oxy-Coal Combustion Technology

A Competing Option for Coal Fired Power Plants with CO_2 Capture

Stanley Santos

IEA Greenhouse Gas R&D Programme

2nd APP Oxyfuel Working Group Capacity Building Course

Beijing, China

15th March 2010

第 2讲:煤的富氧燃烧技术

燃煤电站中具有竞争力的二氧化碳捕集技术

Stanley Santos

国际能源署 温室气体研发计划

第二届亚太伙伴计划富氧燃烧能力建设课程

中国, 北京

3月15日，2010年

Overview

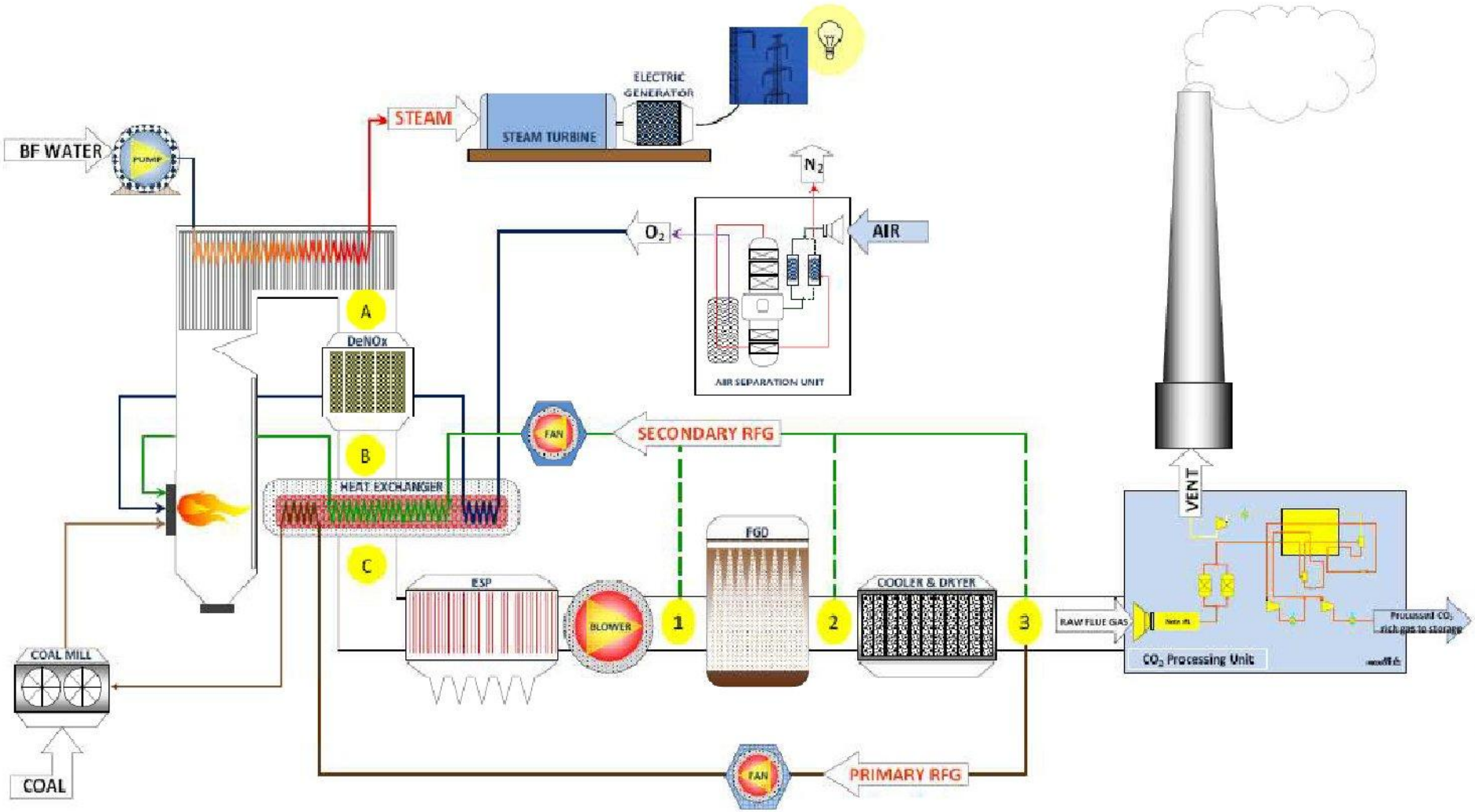
- ***Introduction – Oxyfuel Combustion***
- ***Overview to the Current Status of Large Scale Oxyfuel Combustion Demo Projects***
  - Vattenfall Project
  - CS Energy Project
  - CIUDEN Project
  - Large Scale Burner test facilities worldwide
- ***Overview to the Key Challenges in the Development of this Technology***
  - Boiler and Burner Development
  - Oxygen Supply
  - CO_2 Processing
- ***Concluding Remarks***

目 录

- 引言 – **富氧燃烧**
- **大型富氧燃烧示范项目的现状**
  - Vattenfall 项目
  - CS Energy 项目
  - CIUDEN 项目
  - 世界范围内大型燃烧器测试装置
- **富氧燃烧技术研发中面临的主要挑战**
  - 锅炉和燃烧器的研发
  - 氧气的供给
  - CO_2 处理
- **结论**

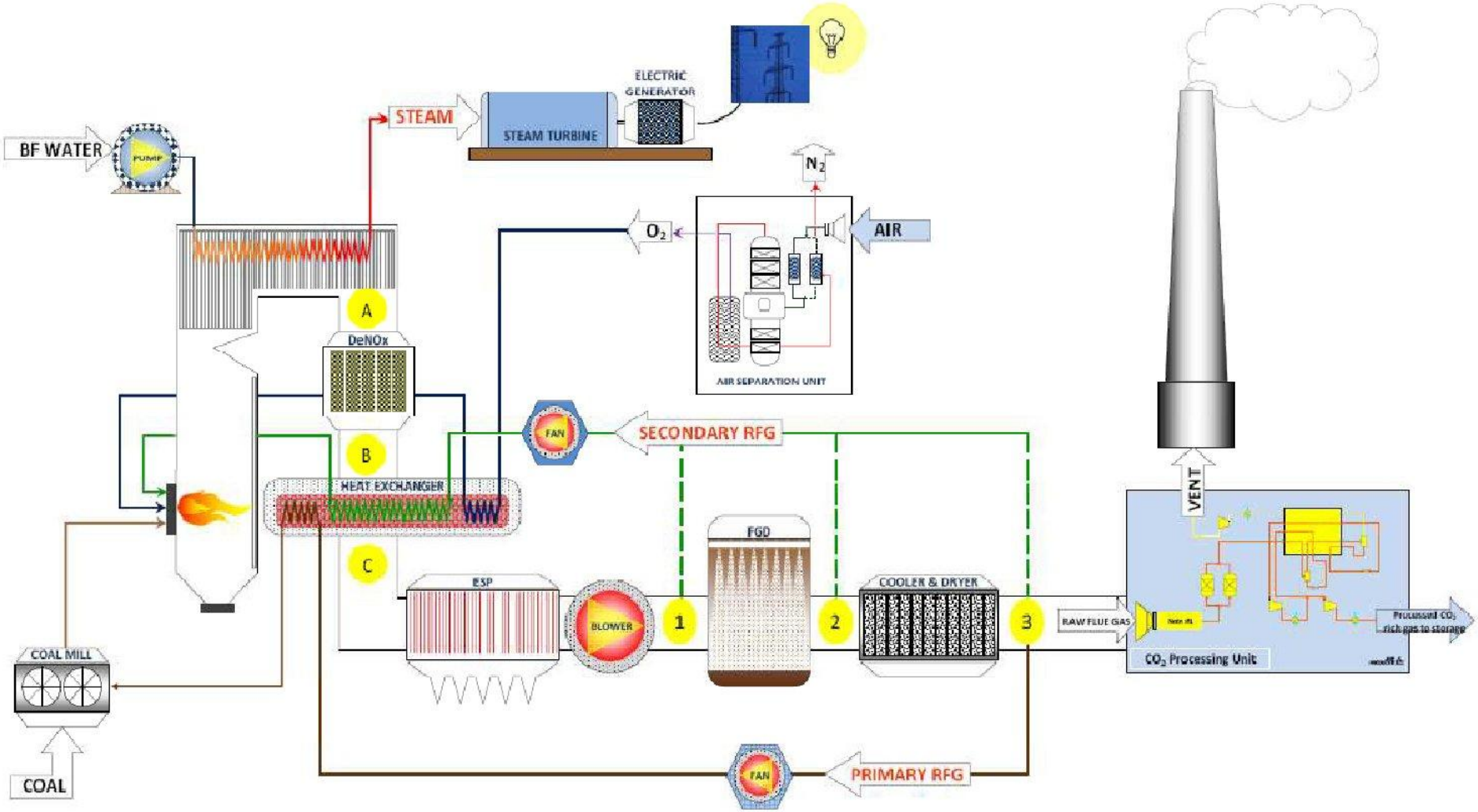
Introduction

Oxyfuel Combustion for Coal Fired Power Plant with CO_2 Capture



引言

燃煤电站富氧燃烧二氧化碳捕集技术



Introduction

- ***Oxyfuel Combustion Technology***
  - This is not a new technology. This has been developed for several decades for various industrial applications.
  - Development of oxyfuel combustion for boiler application started in 1970's.
  - First oxy-coal combustion pilot test was done by ANL during the 1980's
  - First large scale oxy-coal burner test was done by International Combustion in 1990's

引言

- **富氧燃烧技术**
  - 这不是一项新技术；此技术已经在多种工业应用中发展了几十年
  - 富氧燃烧在锅炉上的应用始于20世纪70年代
  - 20世纪80年代美国阿贡国家实验室进行了首次富氧燃煤小型试验
  - 20世纪90年代国际燃烧公司研制了第一个大型富氧燃煤燃烧器

Development of Oxy-Fuel Combustion Application in Industry

1940 – 1950

High Temperature Applications
- Welding
- Metal cutting
- Flame Polishing

1960 – 1970

Productivity Enhancement via O_2 Enrich Combustion (OEC)
- Glass, Aluminium & Cement industries

1980 – 1990

Fuel Savings – Emergence of full Oxy-Fuel Combustion Application
- waste incineration
- steel and copper industries

Idea of using Oxy-Coal Combustion with RFG for Enhanced Oil Recovery (1982)

1990 – 2000

NOx Reduction
- glass melting furnaces
- OEC coal fired boilers

2000 – 2010?

CO_2 Reduction
- Power Generation industry
  - IGCC & OxyFuel boiler applications

Adapted from slide of Sho Kobayashi, Praxair

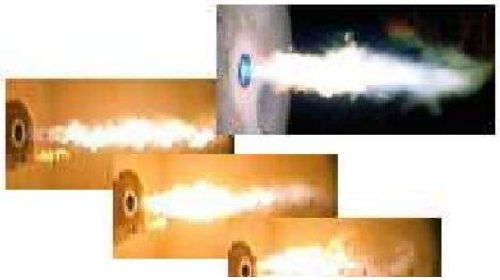
Pictures from IFRF, Air Liqiude, Asahi Glass, Linde Gas

富氧燃烧工业应用的发展

1940 – 1950

高温应用

- 焊接
- 金属切割
- 火焰抛光



1960 – 1970

通过富氧燃烧提高生产率

- 玻璃、铝及水泥工业

1980 – 1990

完全富氧燃烧应用的出现—节约燃料

- 垃圾焚烧
- 钢铁和铜冶炼

利用富氧燃烧加烟气再循环提高原油采收率的理念（1982）

1990 – 2000

NOx减排

- 玻璃熔融炉
- 富氧燃煤锅炉

2000 – 2010?

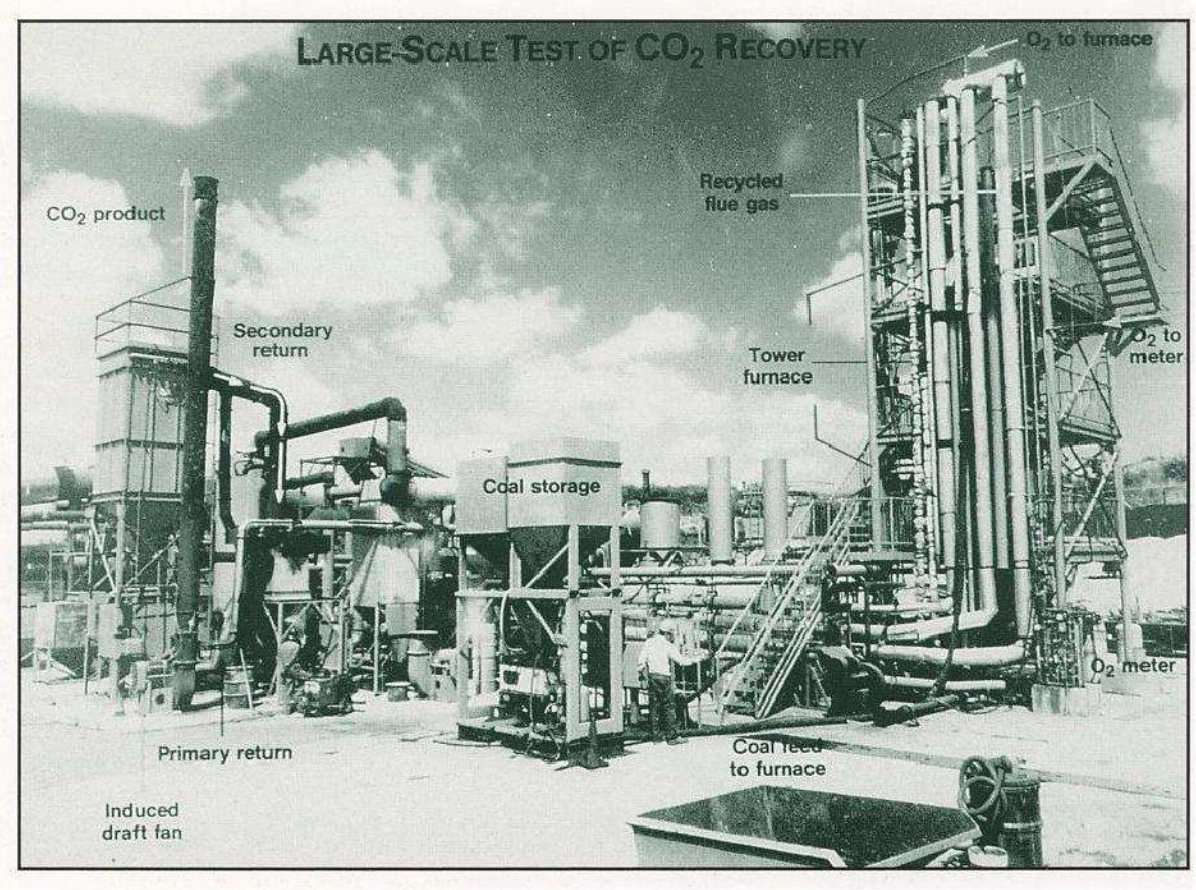
CO_2减排

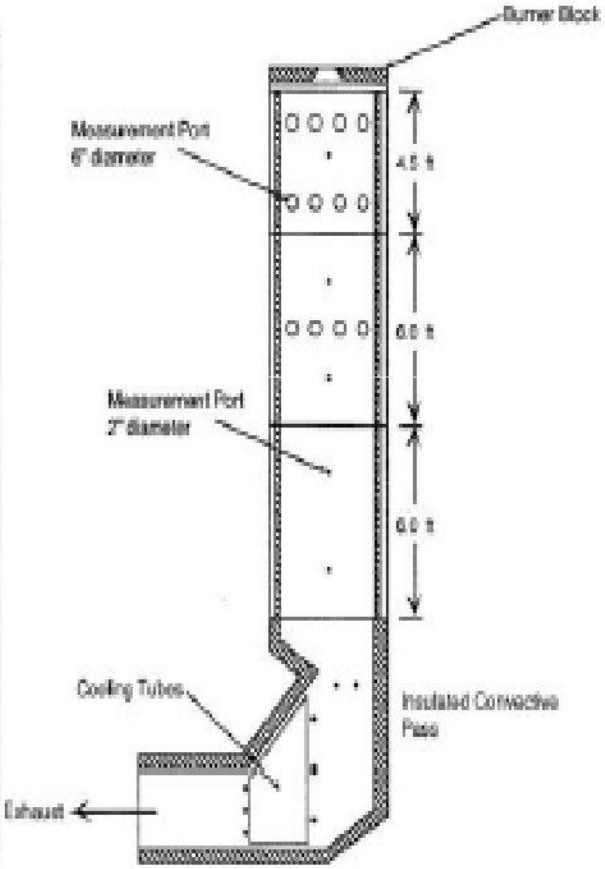
- 电站
- IGCC和富氧燃烧锅炉

Adapted from slide of Sho Kobayashi, Praxair

Pictures from IFRF, Air Liqiude, Asahi Glass, Linde Gas

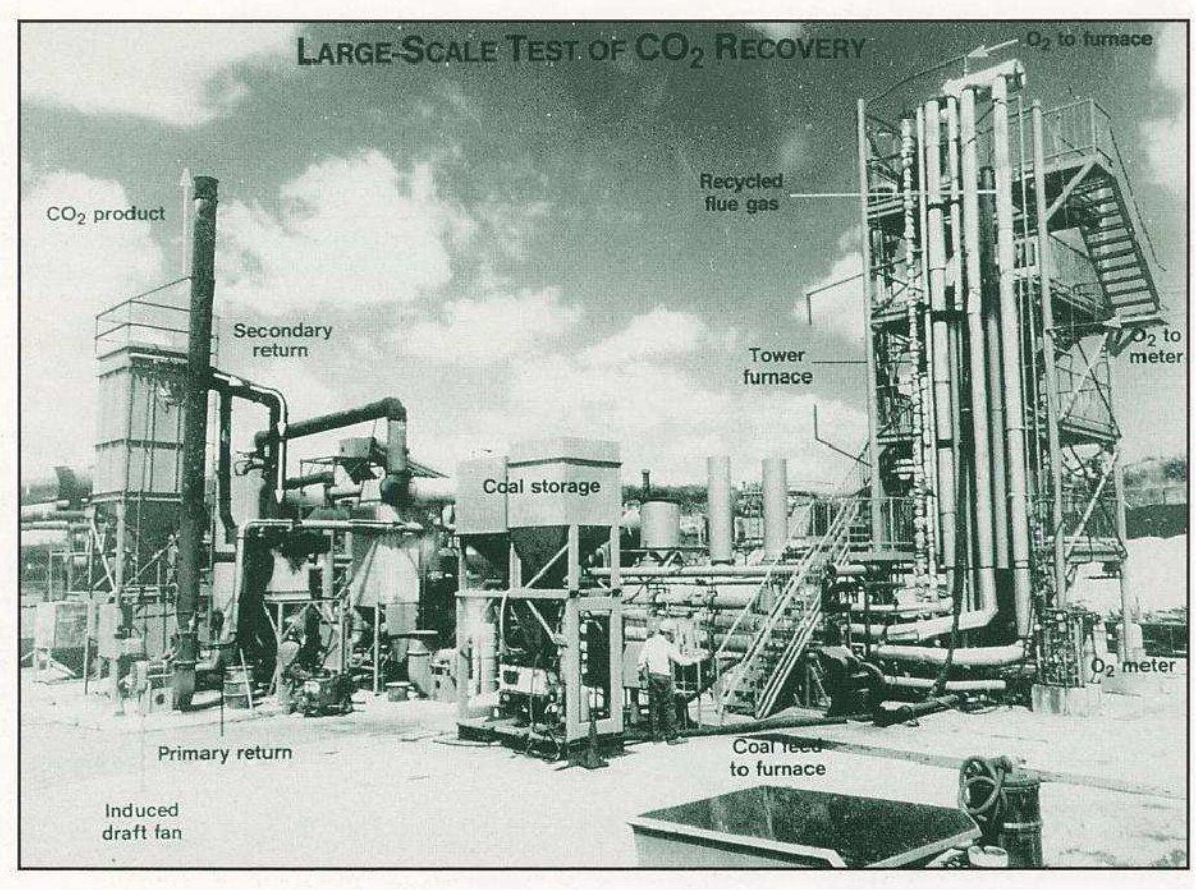
ANL - EERC Study
World's 1st Oxy-Coal Combustion Industrial Pilot Scale Study
Tower Furnace (~ 3MWth)

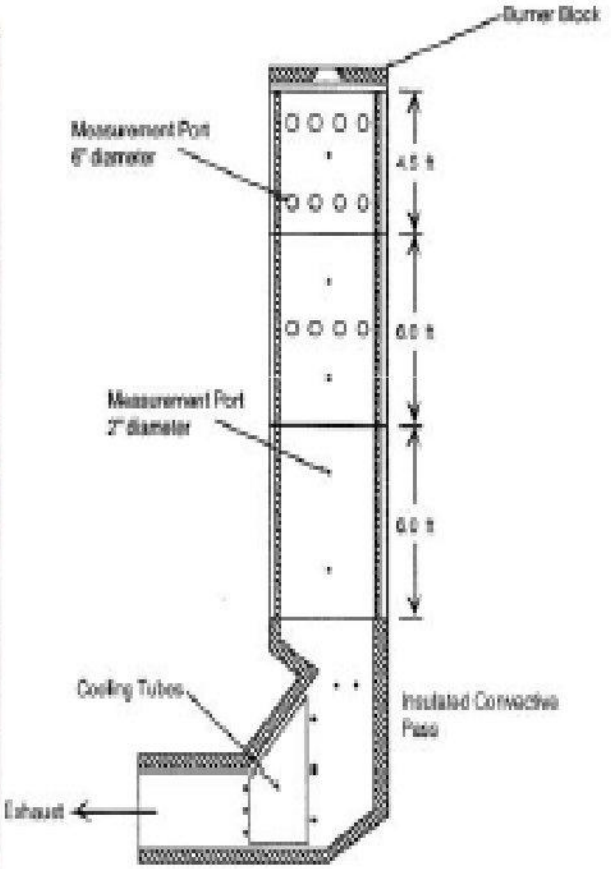




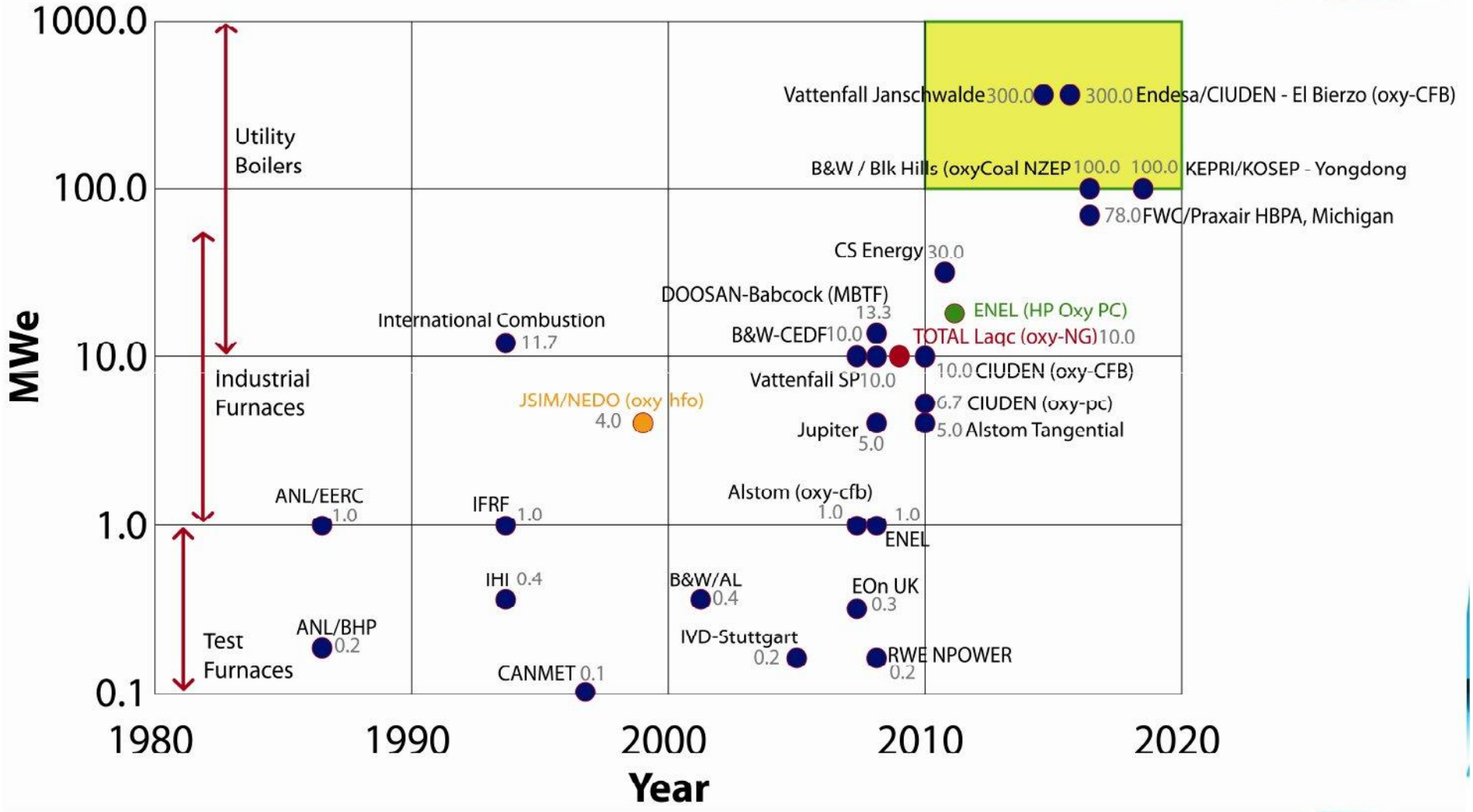
美国阿贡国家实验室 – 能源与环境研究中心

世界第一个富氧燃煤工业小型试验研究
塔式炉(~ 3MWth)

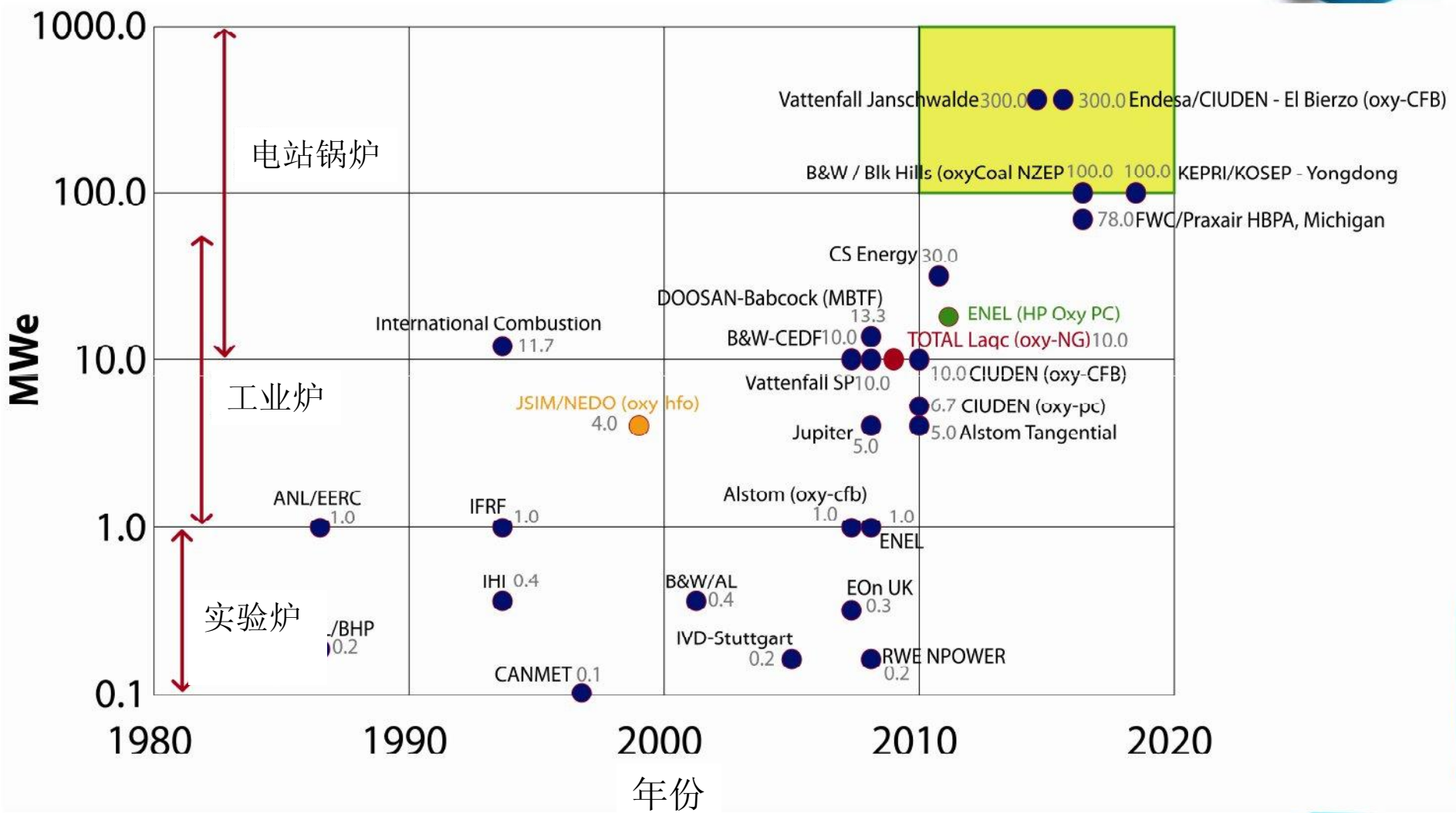




Current Status:
Oxy-Fuel Combustion Boiler Projects



现状：
富氧燃烧锅炉项目


1000.0
100.0
10.0
1.0
0.1
MWe
电站锅炉
工业炉
实验炉
Vattenfall Janschwalde 300.0
300.0 Endesa/CIUDEN - El Bierzo (oxy-CFB)
B&W / Blk Hills (oxyCoal NZEP 100.0
100.0 KEPRI/KOSEP - Yongdong
78.0 FWC/Praxair HBPA, Michigan
CS Energy 30.0
DOOSAN-Babcock (MBTF)
13.3
ENEL (HP Oxy PC)
International Combustion
11.7
B&W-CEDF 10.0
TOTAL Laqc (oxy-NG) 10.0
Vattenfall SP 10.0
10.0 CIUDEN (oxy-CFB)
JSIM/NEDO (oxy hfo)
4.0
6.7 CIUDEN (oxy-pc)
Jupiter
5.0
5.0 Alstom Tangential
ANL/EERC
1.0
IFRF
1.0
Alstom (oxy-cfb)
1.0
1.0
ENEL
IHI 0.4
B&W/AL
0.4
EOn UK
0.3
/BHP
0.2
IVD-Stuttgart
0.2
RWE NPOWER
0.2
CANMET 0.1
1980
1990
2000
2010
2020
年份

Large Scale Pilot and Demo Projects

Updated by S. Santos (06/09/09)

PROJECT	Location	MWth	Start Up Year	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	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**
ENEL HP Oxy	Italy	48	2012	Pilot Plant	Coal	
HBPW – Michigan / Praxair	USA	225	2014?	~75 MWe CFB	Bit.	**With CCS**
Vattenfall (Janschwalde)	Germany	~1000	2014?	~300 MWe PC	Lignite (Bit.)	**With CCS**
Endesa/CIUDEN	Spain	~1000	2015?	~300 MWe CFB?	?	**With CCS**
Black Hills Power/B&W/AL	USA	~400	2015?	~100 MWe PC		**With CCS**
KOSEP/KEPRI Yongdong	Korea	~400	2018?	~100 MWe PC	?	?

大型试验和示范工程

由 S. Santos 更新(06/09/09)

项目名称	地点	MWth	启动年份	锅炉类型	主要燃料	CO2 处理
B & W	美国	30	2007	中试粉煤	烟煤, 次烟煤，褐煤	
Jupiter	美国	20	2007	工业，无烟气再循环	天然气，煤	
Oxy-coal UK	英国	40	2009	中试粉煤	烟煤	
Alstom (Windsor Facility)	美国	15	2009	中试粉煤 (切向)	烟煤, 次烟煤., PRB	
Vattenfall	德国	30	2008	中试粉煤	褐煤 (烟煤）	有CCS
Total, Lacq	法国	30	2009	工业锅炉	天然气	有CCS
Callide	澳大利亚	90	2011	30 MWe 粉煤	烟煤	有CCS
CIUDEN – PC	西班牙	20	2010	中试粉煤	无烟煤. 烟煤,褐煤. 焦	有CCS
CIUDEN – CFB	西班牙	30	2010	中试 CFB	无烟煤. 烟煤,褐煤. 焦	有CCS
ENEL HP Oxy	意大利	48	2012	中试厂	煤	
HBPA – Michigan / Praxair	美国	225	2014?	~75 MWe CFB	烟煤	有CCS
Vattenfall (Janschwalde)	德国	~1000	2014?	~300 MWe 粉煤	褐煤 (烟煤）	有CCS
Endesa/CIUDEN	西班牙	~1000	2015?	~300 MWe CFB?	?	有CCS
Black Hills Power/B&W/AL	美国	~400	2015?	~100 MWe 粉煤		有CCS
KOSEP/KEPRI Yongdong	韩国	~400	2018?	~100 MWe 粉煤	?	?

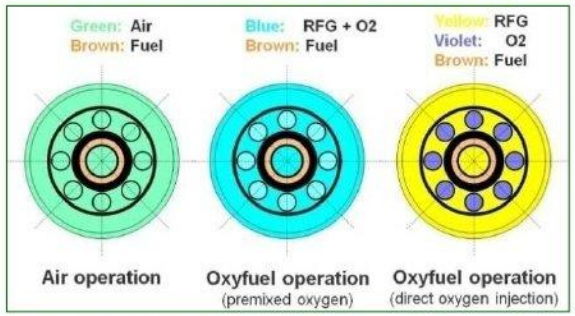
Vattenfall's Schwarze Pumpe Pilot Plant

- ***The World's 1st Pilot Plant – that demonstration a full chain oxyfuel process producing steam.***

- ***As of January 2010 – they have achieved nearly 4500 operating hours.***

- ***A unique testing bed for burner / boiler evaluation.***
  - down fire system

- ***Consists of 3 burner testing periods.***
  - 2 burner testing period to be undertaken using different Alstom's burner for lignite and hard coal
  - 1 burner testing period to be undertaken using Babcock Hitachi's burner for lignite



Courtesy of Vattenfall, Alstom

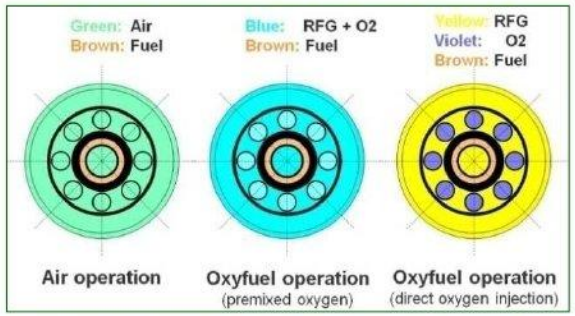
Vattenfall的黑泵中试厂

- 世界第一个中试厂 —— 展示了一个富氧燃烧产生蒸汽的完整工艺流程.

- 截止2010年1月 – 已运行将近4500小时

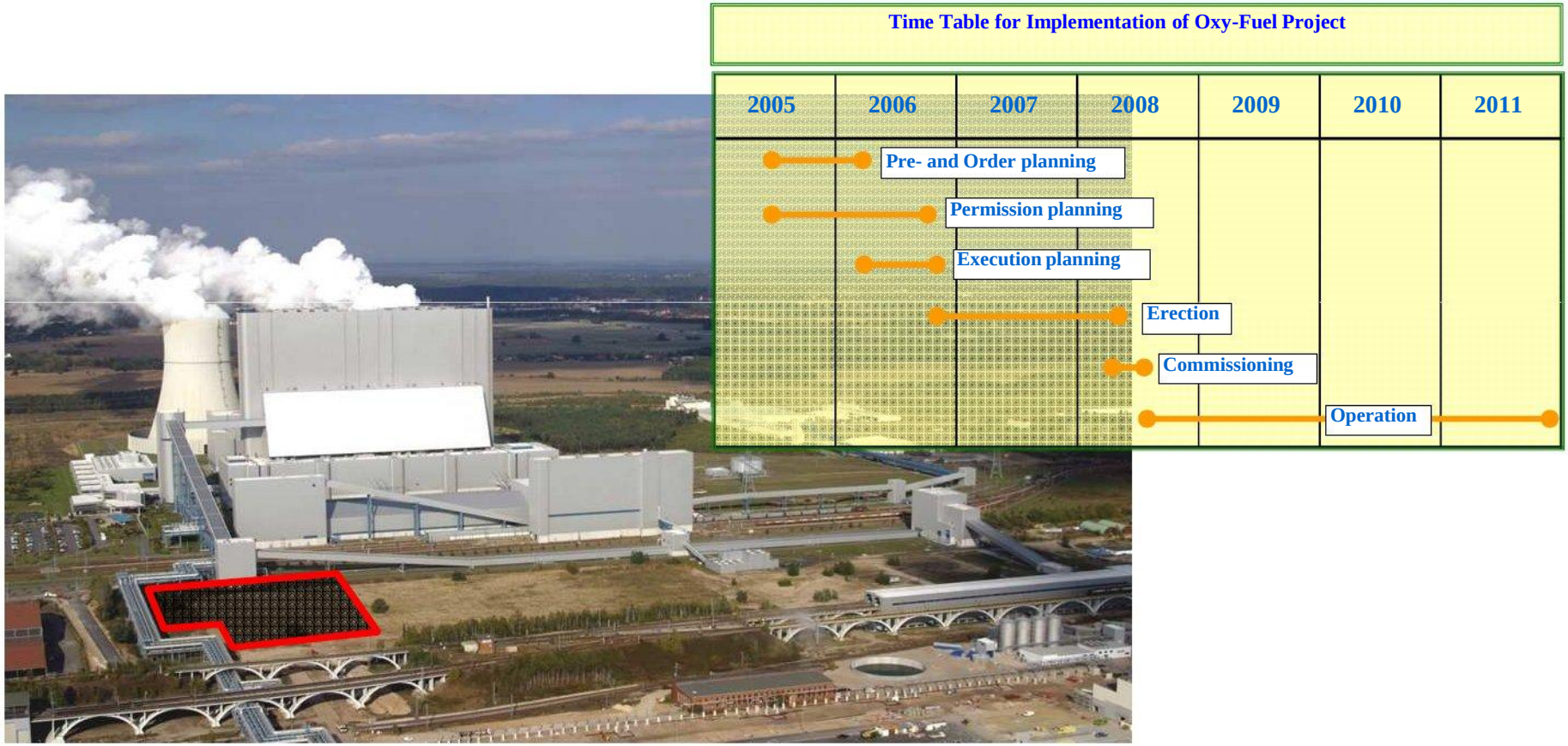
- 是评估测试燃烧器/锅炉的独特试验台
  - 下行火焰燃烧系统

- 由3个燃烧器测试工况组成
  - 2 个燃烧器测试工况采用Alstom的褐煤和硬煤燃烧器
  - 1个燃烧器测试工况采用Babcock Hitachi的褐煤燃烧器



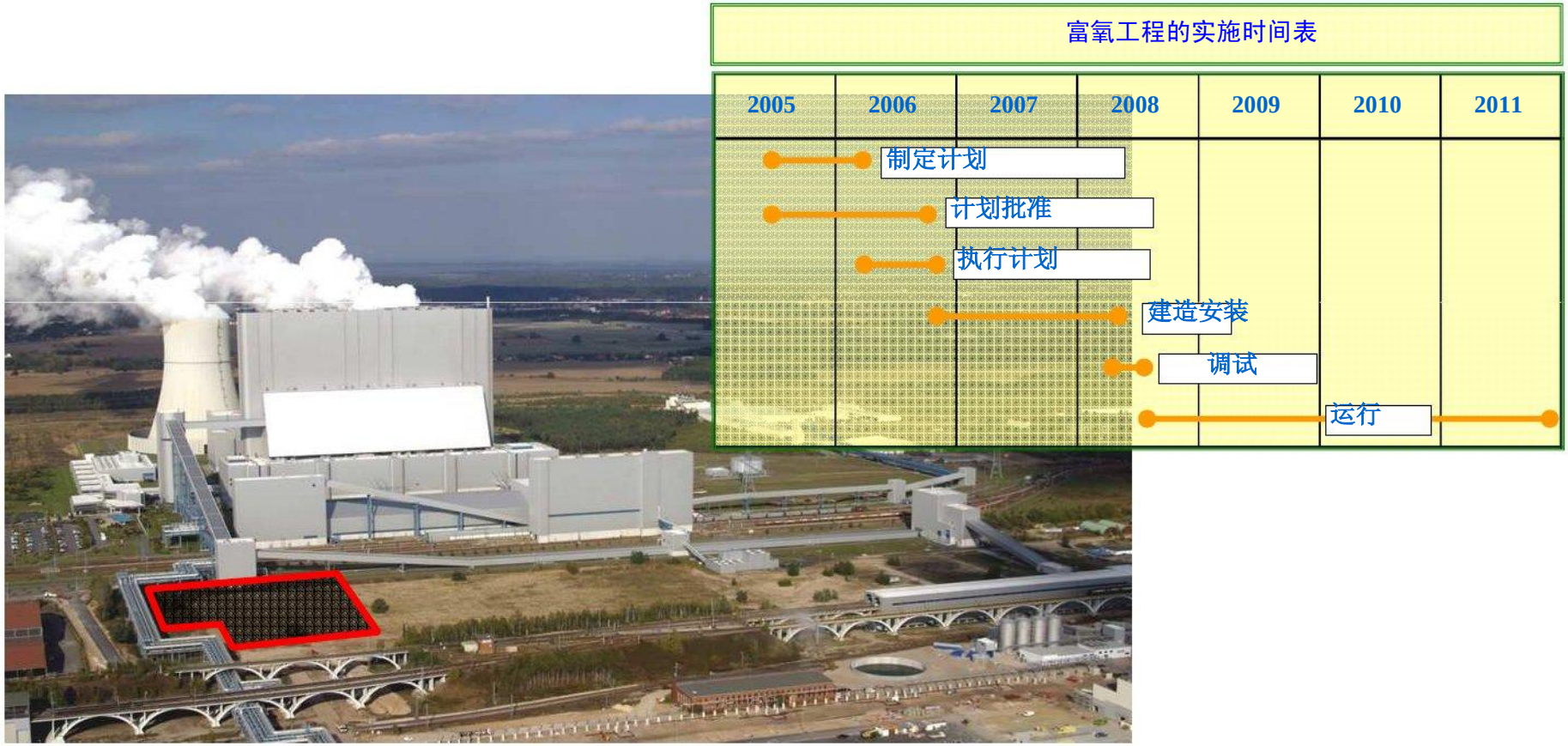
Courtesy of Vattenfall, Alstom

Vattenfall's Effort in Leading Oxyfuel Development



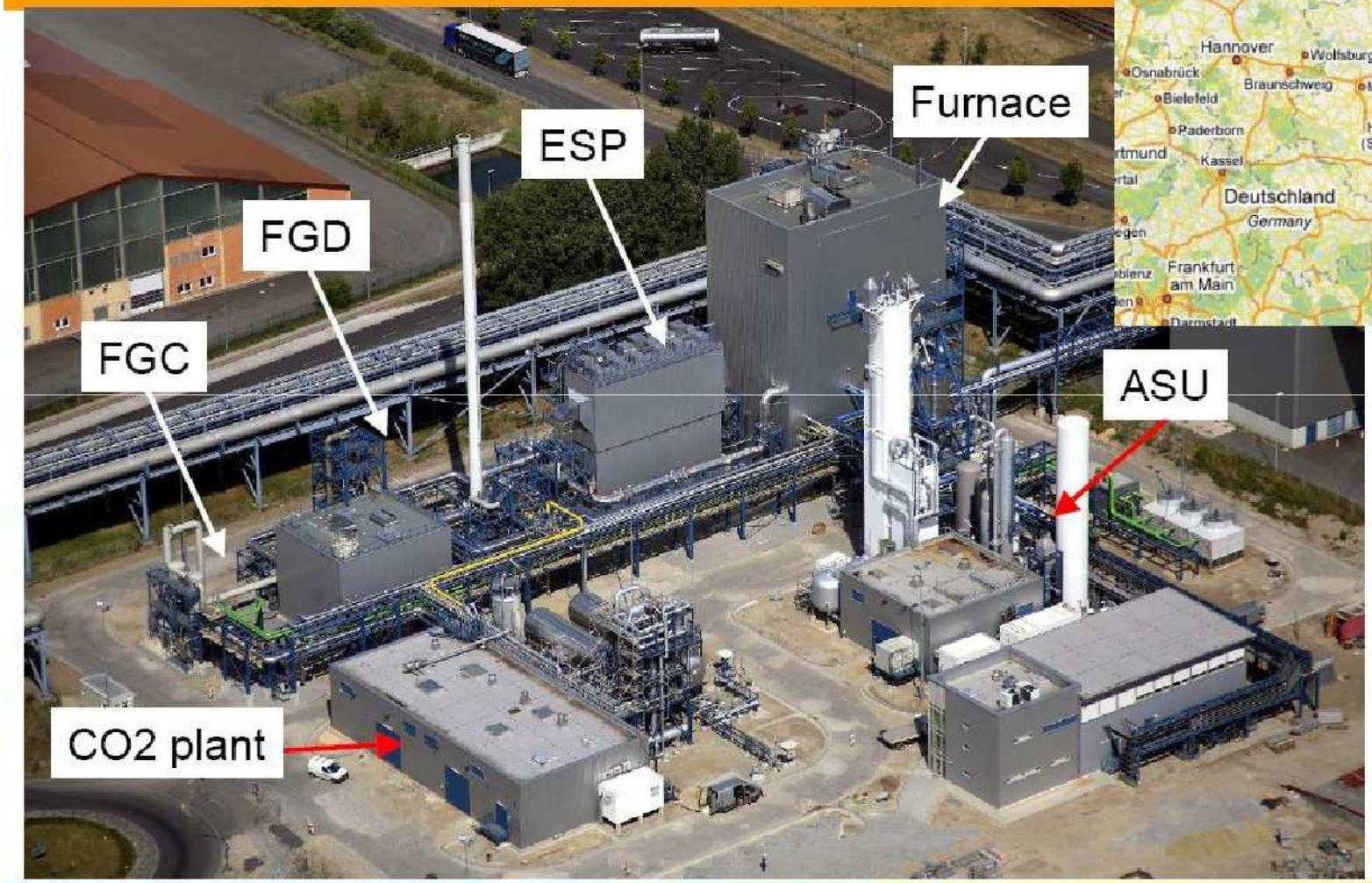
Courtesy of Vattenfall

Vattenfall在引领富氧燃烧技术发展中的努力



由Vattenfall提供

The Oxyfuel pilot plant



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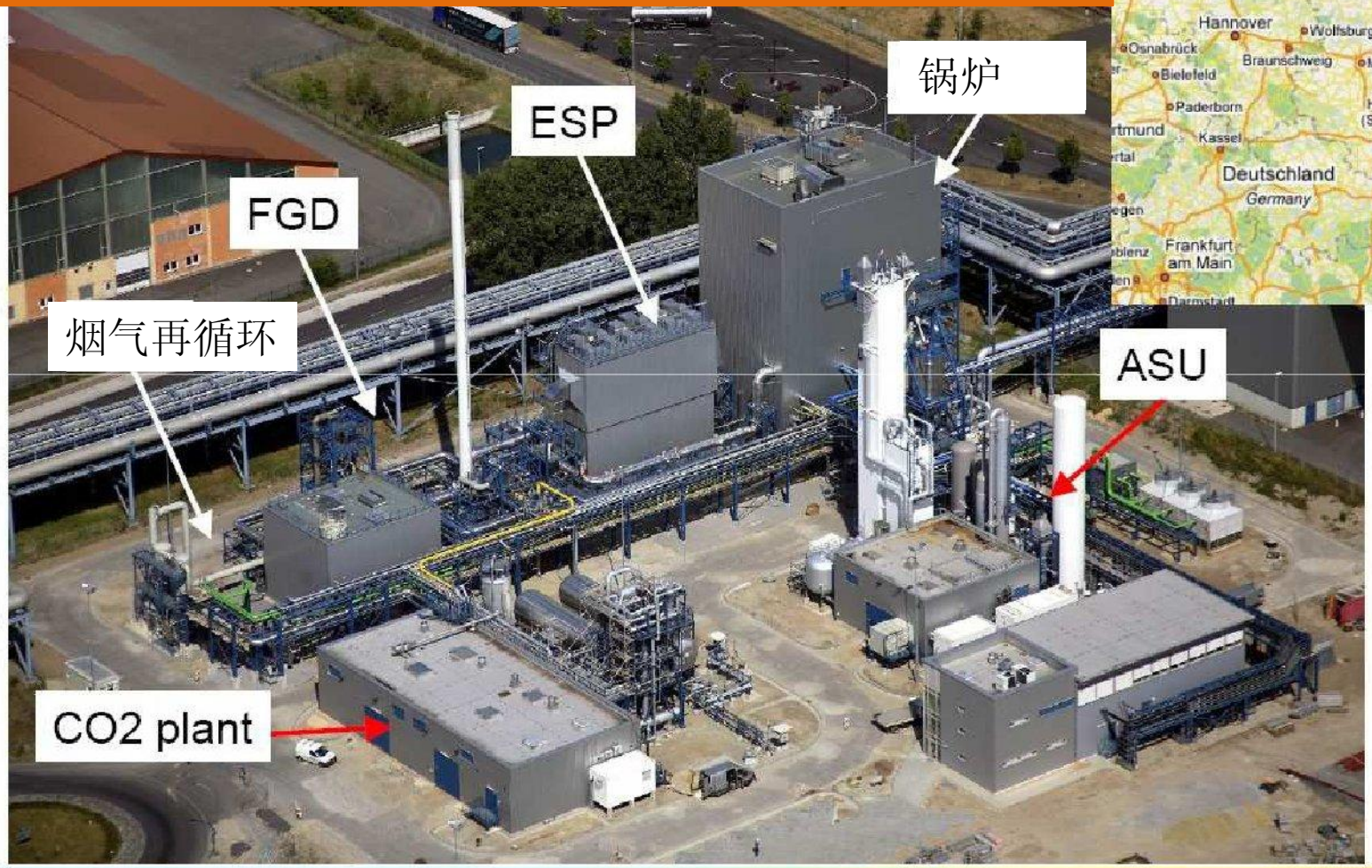
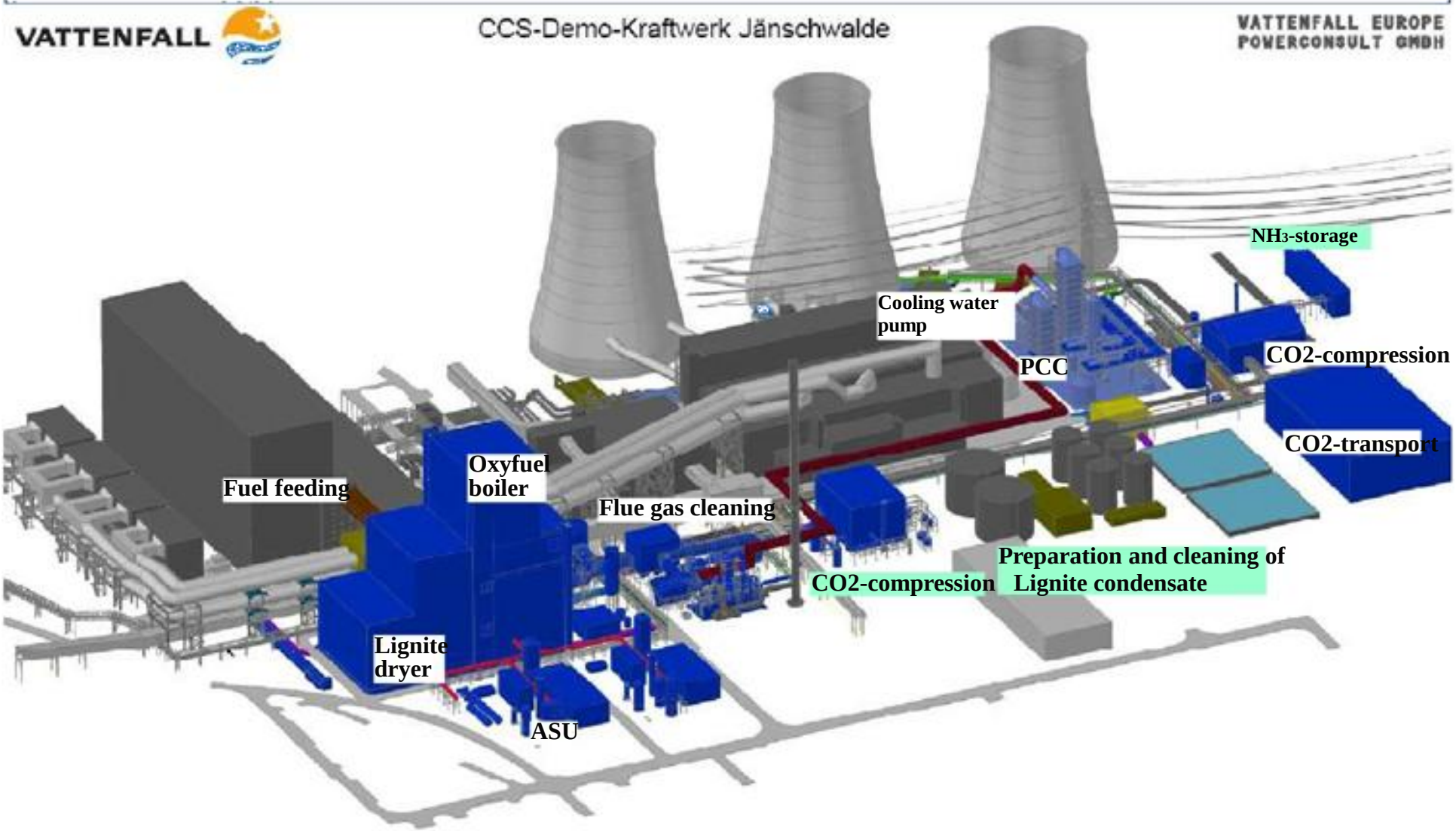
富氧燃烧锅炉中试厂


锅炉
ESP
FGD
烟气再循环
ASU
CO2 plant

Kiel
Lübeck
Rostock
Hamburg
Szczecin
Bremen
Gorzów Wielkopolski
Berlin
Hannover
Wolfsburg
Potsdam
Osnabrück
Braunschweig
Magdeburg
Bielefeld
Paderborn
Halle (Saale)
Kassel
Leipzig
Dresden
Deutschland
Germany
Chemnitz
Frankfurt am Main
Praha

Jänschwalde demonstration plant – view from south east



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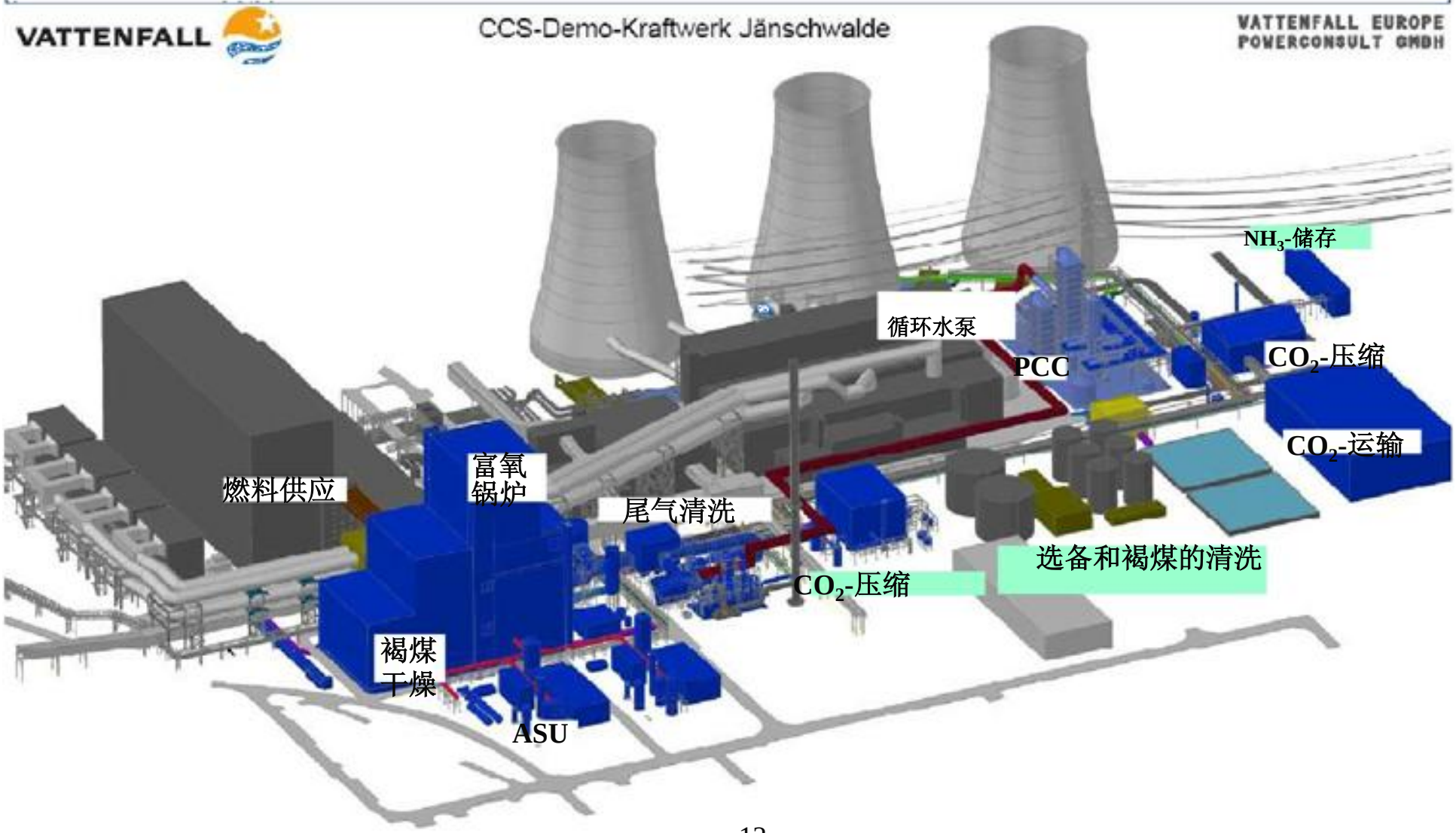
Jänschwalde 示范电站 – 东南视角



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

© Vattenfall AB

VATTENFALL

Jänschwalde 示范电站
500 MW，富氧燃烧+燃烧后捕集

© Vattenfall AB

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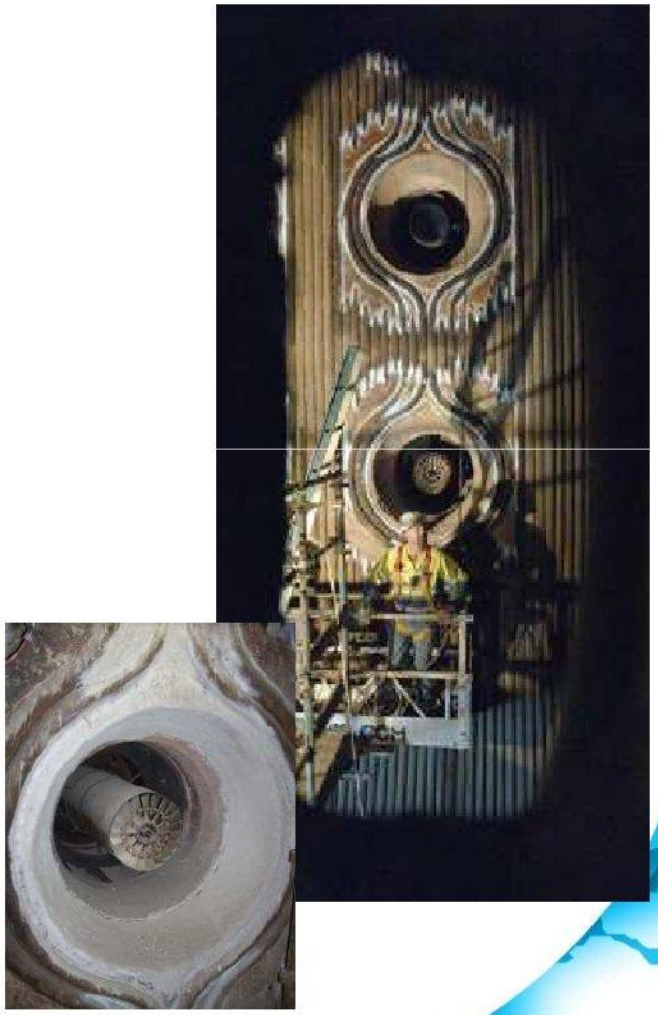
CS Energy/IHI Burner Testing Programme at Callide A Power Station

- ***Callide A Project – would be the world's 1st oxyfuel retrofitted power station.***
  - First oxyfuel pilot plant that will actually produce electricity.
  - Installation of 2x ~45MW_{th} Wall Fired Burners
  - A unique position to provide information related to the burner – burner interaction
  - Project Scope (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)

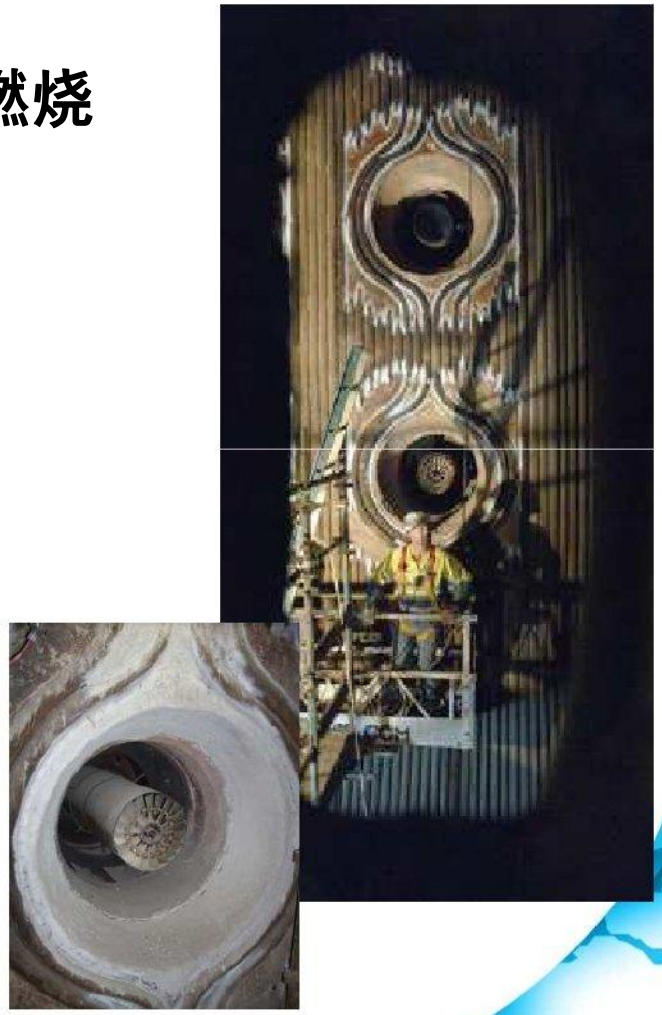


Courtesy of CS Energy, IHI

Callide A电站CS Energy/IHI 燃烧器测试项目

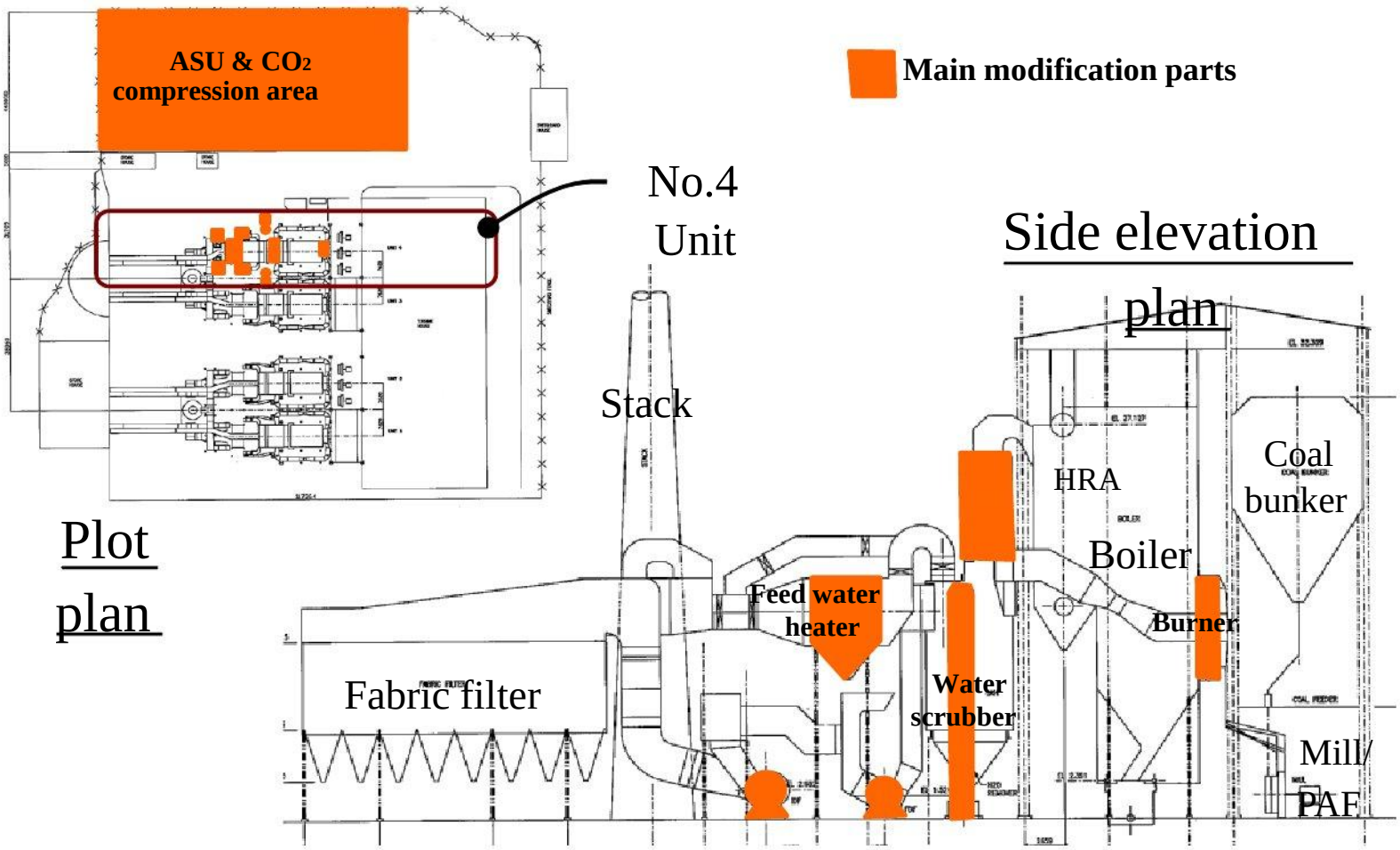
- **Callide A项目 – 将成为世界第一个富氧燃烧改造电站**
  - 将是第一个发电的富氧燃烧电站
  - 安装了2个 ~45MW_{th} 墙式燃烧器
  - 提供了炉内燃烧器的独特测试平台

    ——燃烧器相互影响
  - 项目规划 (运行4 年):
    - 制氧厂 (额定 2 x 330 t/d ASUs)
    - 锅炉翻新和富氧改造 (1 x 30 MWe 机组)
    - CO_2 压缩和提纯 (抽取20%的烟气至75 t/d CO_2处理厂)
    - 公路运输，地质埋存 (~ 30 t/d 液态CO_2)



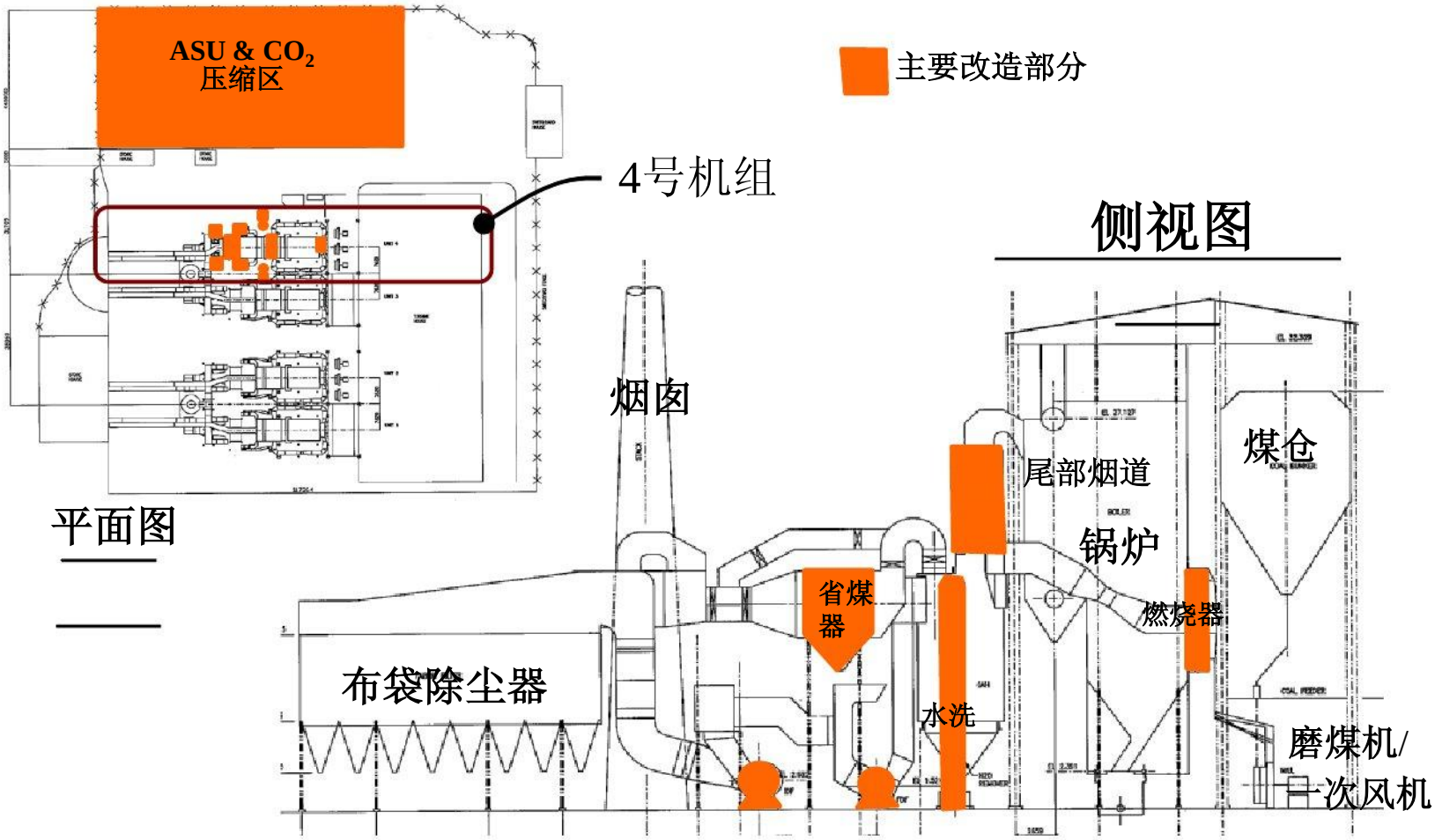
Courtesy of CS Energy, IHI

COP Design Studies – Oxyfuel boiler modifications



Callide Oxyfuel Project

COP项目设计研究 – 富氧燃烧锅炉改造



Callide Oxyfuel Project

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.*

CIUDEN CO_2 捕集项目

- 第一个富氧燃烧循环流化床锅炉大型示范电站

- 粉煤富氧燃烧锅炉与Vattenfall和Callide项目类似

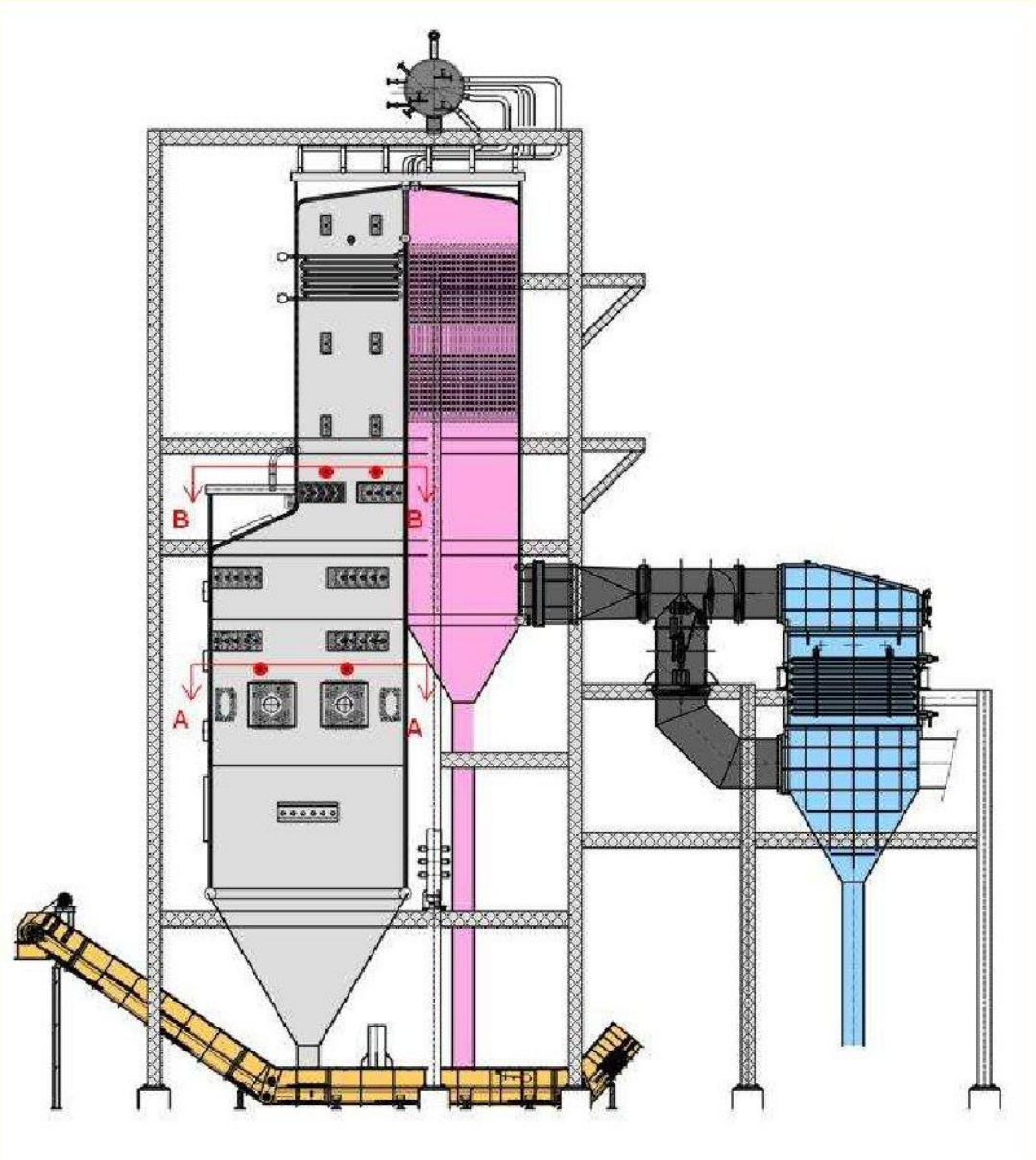
- 提供了炉内燃烧器的独特测试平台
  ——燃烧器相互影响（更小规模）

- 第一个研究燃烧无烟煤（可能是世界上第一个），石油焦和生物质的富氧燃烧装置

CIUDEN: CO_2 Capture TDP main characteristics

PC Boiler

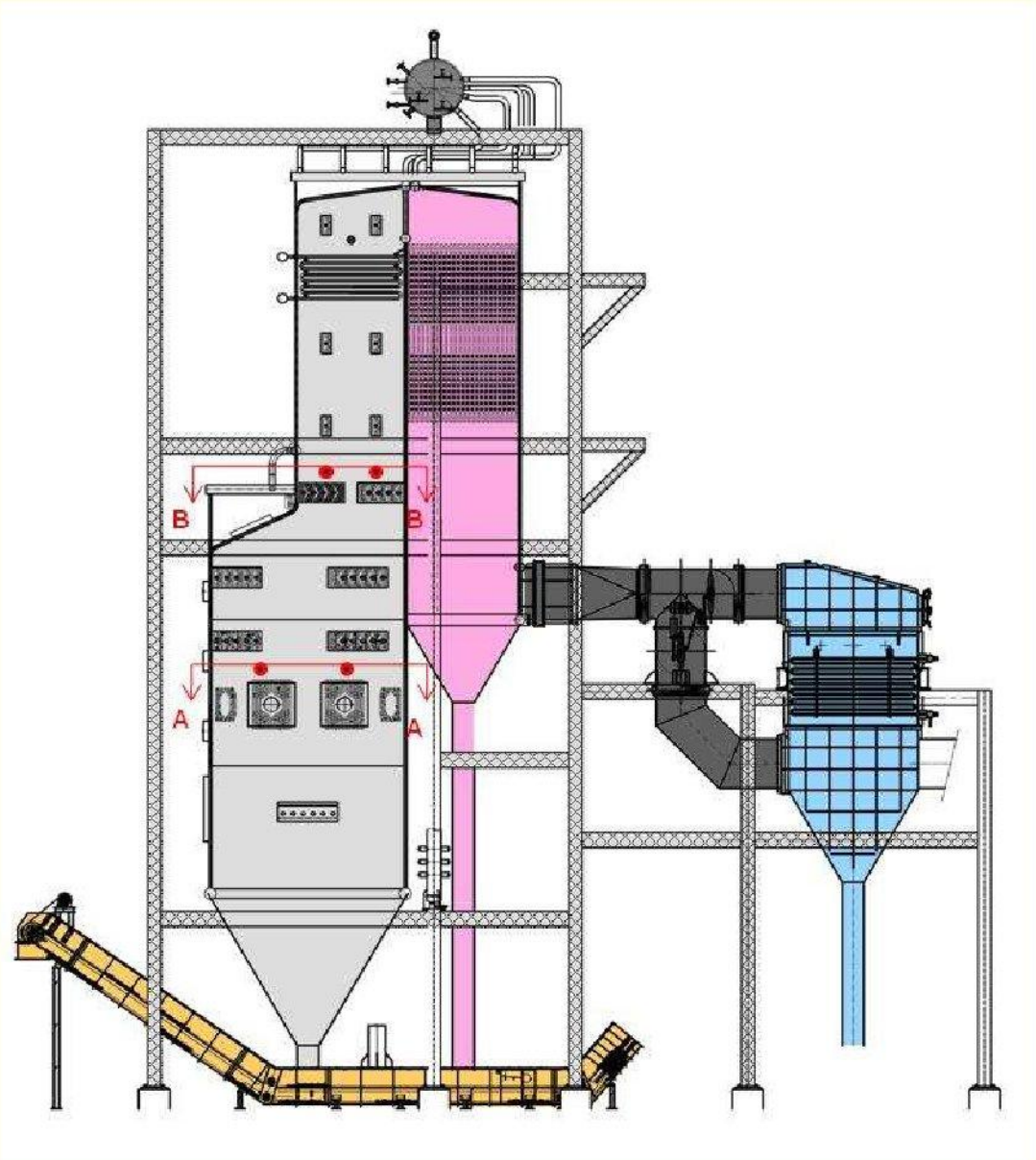
Size (m)	24 x 7,6 x 4,5
Burners	4 horizontal burners 2 vertical burners
MWt PCS max oxycombustion mode	20
O_2 (kg/h)	6600
Recirculation gas flow (kg/h)	17900
Flue gas flow (kg/h)	26400
Coal flow rate (kg/h)	3350
Steam (t/h)	25
P(bar) / T (° C)	30 / 420



CIUDEN: CO_2 捕集技术开发项目主要参数

煤粉锅炉

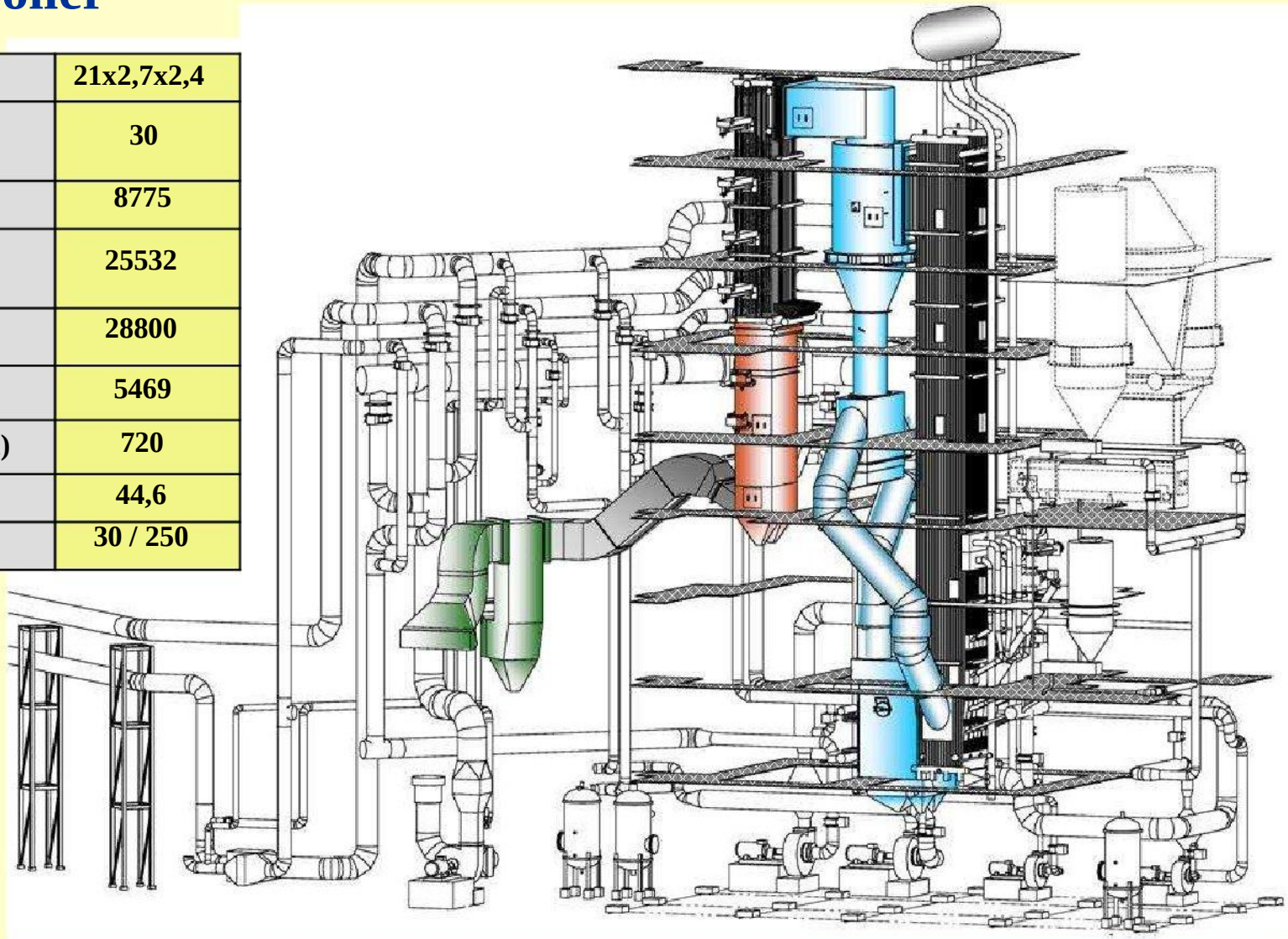
尺寸 (m)	24 x 7,6 x 4,5
燃烧器	4 水平燃烧器 2 垂直燃烧器
富氧燃烧模式下最大的出力 MWt	20
O_2 (kg/h)	6600
再循环烟气量 (kg/h)	17900
烟气流量 (kg/h)	26400
给煤量 (kg/h)	3350
蒸汽 (t/h)	25
P(bar) / T (° C)	30 / 420



CIUDEN: CO_2 Capture TDP main characteristics

CFB Boiler

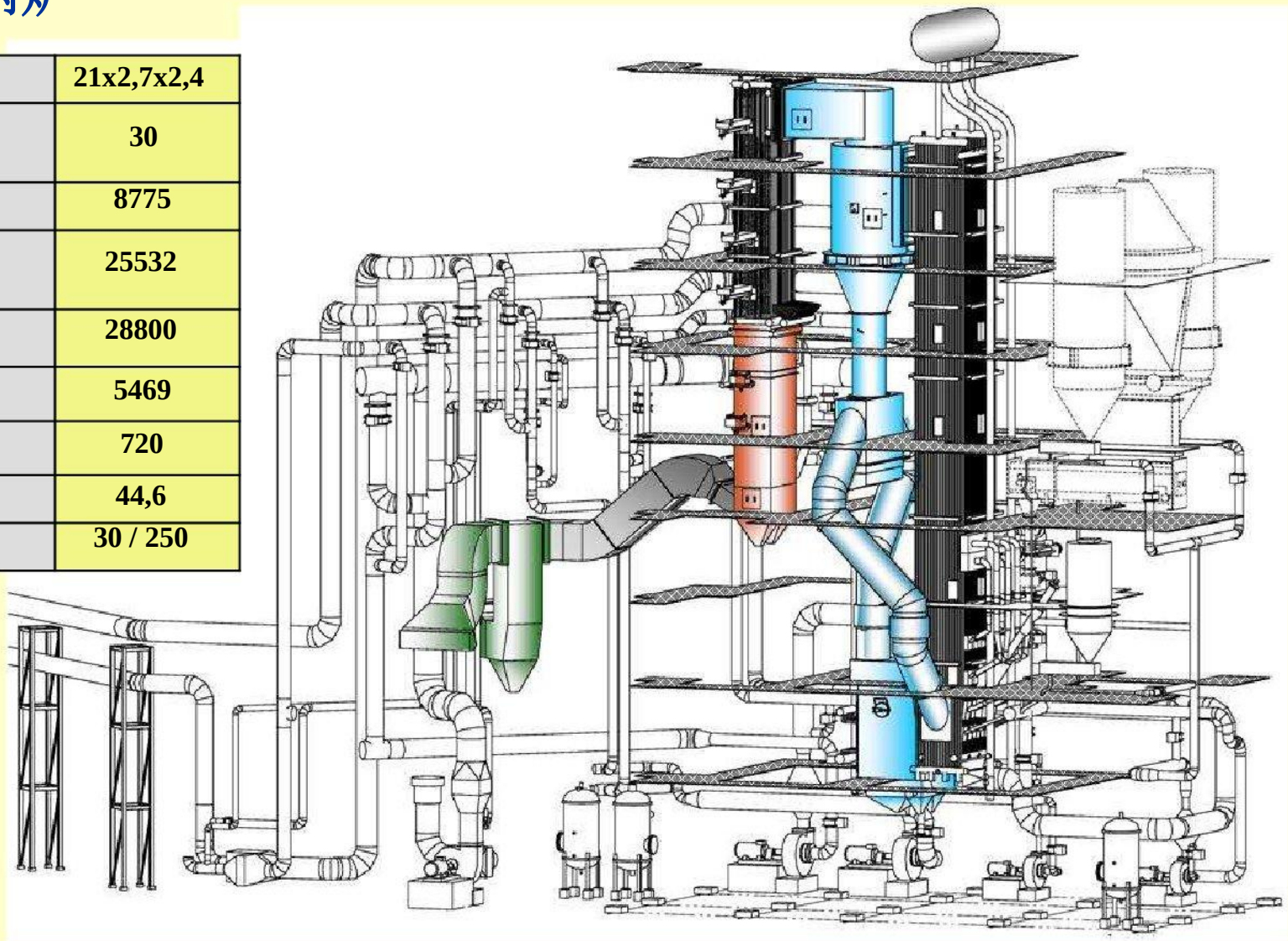
Dimensions (m)	21x2,7x2,4
MWt SCP max oxy-combustion	30
O_2 (kg/h)	8775
Flue gas recycle (kg/h)	25532
Flue gas (kg/h)	28800
Coal feed (kg/h)	5469
Limestone feed (kg/h)	720
Steam (t/h)	44,6
P(bar) / T (° C)	30 / 250



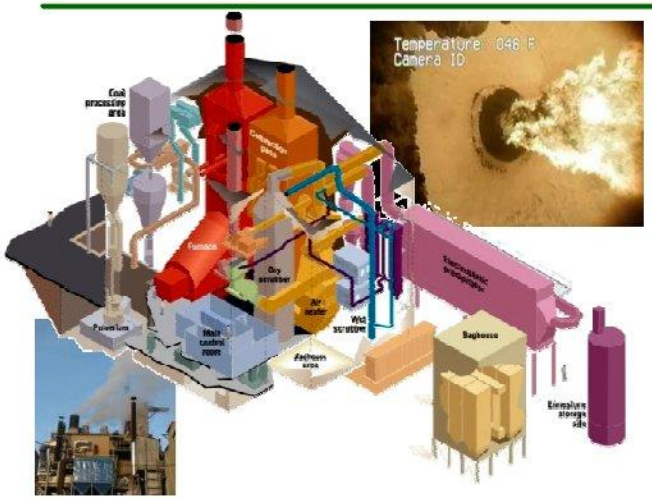
CIUDEN: CO_2 捕集技术开发项目主要参数

CFB 锅炉

规模 (m)	21x2,7x2,4
富氧燃烧模式下最大出力 MWt	30
O_2 (kg/h)	8775
再循环烟气量 (kg/h)	25532
烟气量 (kg/h)	28800
给煤量(kg/h)	5469
石灰石量(kg/h)	720
蒸汽 (t/h)	44,6
P(bar) / T (° C)	30 / 250

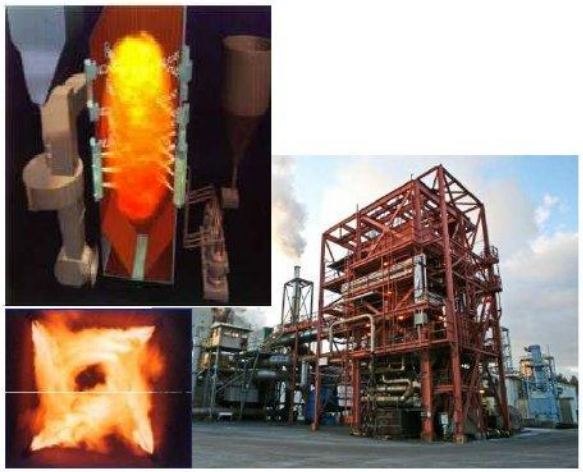


Today... There are 3 Major Full Scale PC Burner Testing Facilities Worldwide Retrofitted for Oxyfuel



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

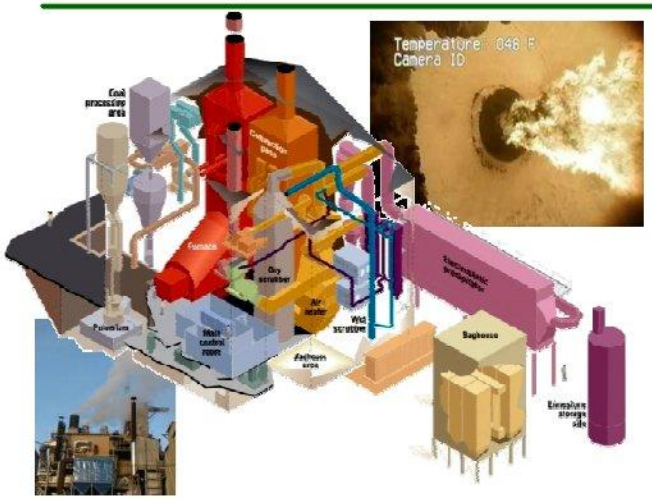
- Doosan Babcock – 40MW$_{th}$ in 90MW$_{th}$ MBTF
- Renfrew, Scotland, UK
- Start of Operation: Jun. 2009
- Wall Fired Burner Development



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

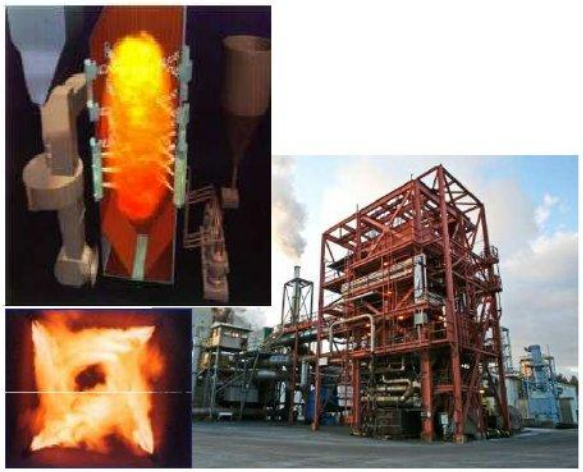
Courtesy of Alstom, B&W and Doosan Babcock

今天... 世界范围内主要有3个被改造用于富氧燃烧的全尺寸粉煤燃烧器测试设备



- *Babcock and Wilcox (B&W) 30MW$_{th}$ CEDF*
- *Barberton*, 俄亥俄州, 美国
- 运行开始时间: *2008年10月*
- 墙式燃烧器

- Doosan Babcock – 40MW$_{th}$ in 90MW$_{th}$ MBTF
- Renfrew, 苏格兰, 英国
- 运行开始时间: *2009年6月*
- 墙式燃烧器



- Alstom Power Plant Lab. – 15MW$_{th}$ in 30MW$_{th}$ BSF
- Windsor,康乃迪克州, 美国
- 运行开始时间: *2009年11月*
- T型燃烧器

Courtesy of Alstom, B&W and Doosan Babcock

Burner Development for Oxyfuel Combustion

- ***Burners are critical to combustion, emissions, and thermal efficiency / capacity of the utility boilers***

- ***Critical importance to burner development is a full scale testing***
  - This is an important exercise to establish reference data that could be used in the development and validation of different modeling tools.
  - This is also to gain experience in operating full scale burner. (i.e. start up/shut down, flame stability, efficiency, heat transfer, fouling and slagging, etc…).

20

富氧燃烧的燃烧器开发

- 燃烧器对电站锅炉的燃烧、污染物排放、热效率以及负荷是至关重要的

- 全尺寸实验对燃烧器研发至关重要
  - 这是获取实验数据的重要手段，以用来开发和验证不同建模工具。

  - 获得全尺寸燃烧器的运行经验。
    (例如：开/停机、 火焰稳定性、效率、传热、积灰和结焦等等…).

Burner Development for Oxyfuel Combustion

- ***Development of Full Scale Burner Testing Programme could either be accomplished by:***

  - Retrofitting of Full Scale Burner Test Rigs
    - B&W's 30MW$_{th}$ CEDF Facility (Ohio, USA)
    - Doosan Babcock's 40MW$_{th}$ MBTF Facility (Renfrew, Scotland)
    - Alstom 's 15MW$_{th}$ BSF Facility (Connecticut, USA)

  - Testing in a Full Chain Oxyfuel CCS Pilot / Demo Plant
    - Vattenfall's Schwarze Pumpe Pilot Plant (Cottbus, Germany)
    - CS Energy's Callide Power Plant (Queensland, Australia)
    - TOTAL's Lacq Facility (Lacq, France)
    - CIUDEN Demo Facility (El Bierzo, Spain)

富氧燃烧器开发

- 全尺寸富氧燃烧器测试平台的其他解决方案
  - 对已有全尺寸燃烧器测试系统的改造
    - B&W的 30MW_{th} CEDF 装置(Ohio, USA)
    - Doosan Babcock的 40MW_{th} MBTF 装置 (Renfrew, Scotland)
    - Alstom 的 15MW_{th} BSF 装置 (Connecticut, USA)
  - 在带有CCS和发电的富氧中试 / 示范电厂中的测试
    - Vattenfall的黑泵中试厂 (Cottbus, 德国)
    - CS Energy的Callide 电站 (Queensland, 澳大利亚)
    - TOTAL的 Lacq 装置 (Lacq, 法国)
    - CIUDEN 示范装置(El Bierzo, 西班牙)

Challenges to Boiler and Burner Development

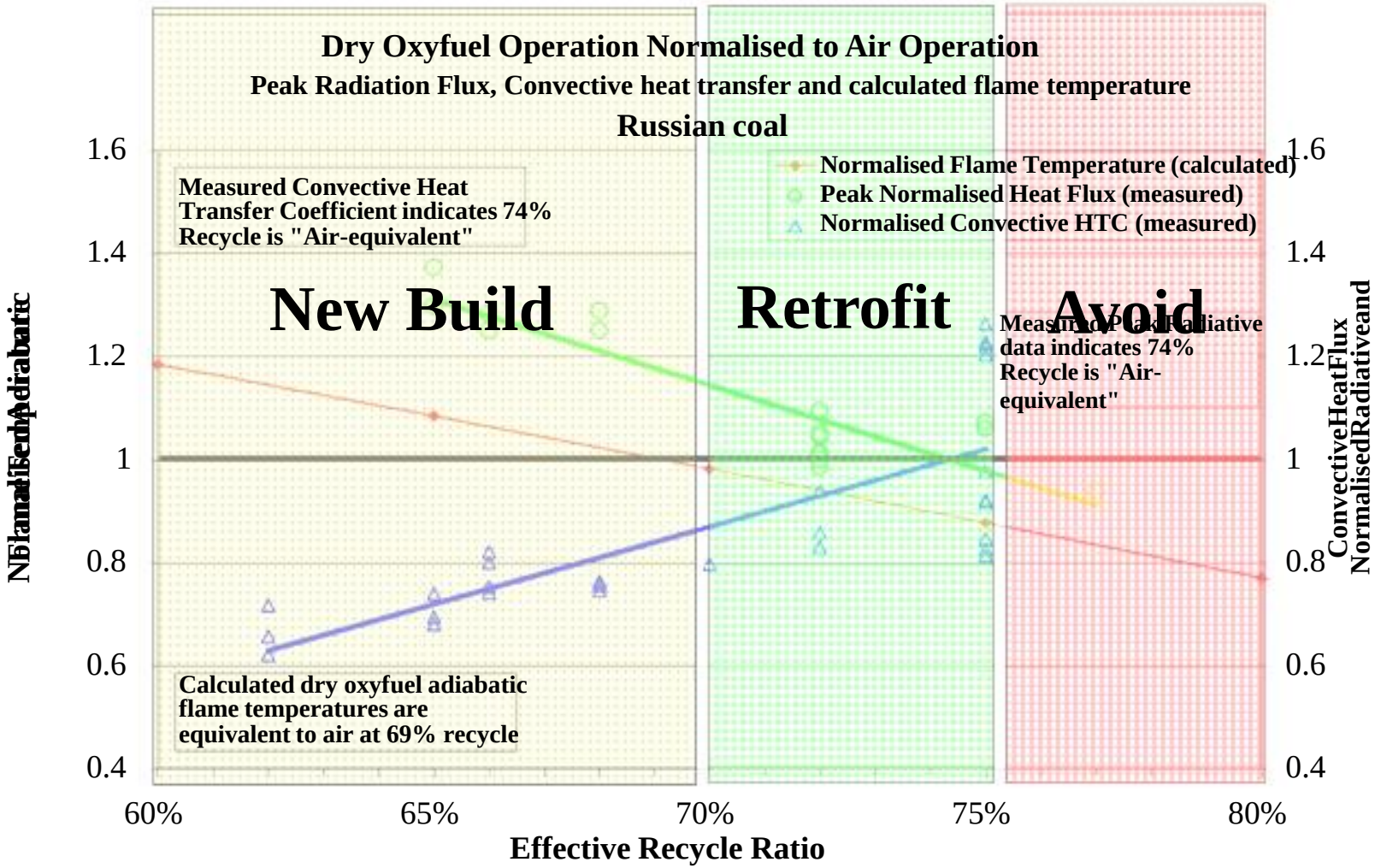
- ***Recycling of the Flue Gas***
  - What are parameters that we should consider in the burner design? (Flame stability, Heat Transfer, Carbon in Ash, Pollutant Formation - especially CO, O_2 injection point, etc...)
- ***Air ingress issue***
  - What is the maximum allowed that would not affect the design of the CO_2 processing unit?
- ***Other Combustion Issues***
  - Corrosion
  - Slagging and Fouling
  - Emissions

对锅炉和燃烧器开发的挑战

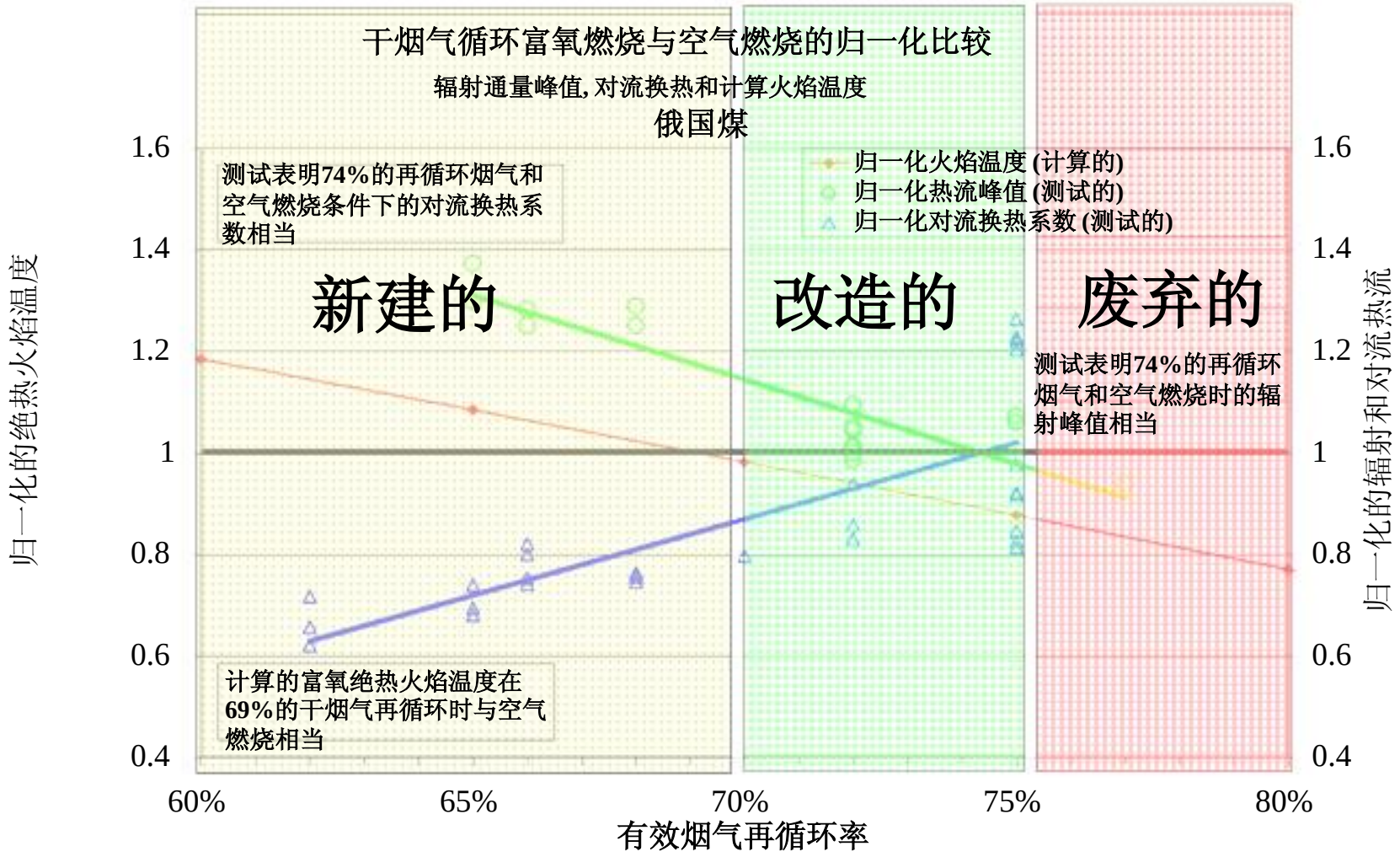
- 烟气再循环量
  - 在燃烧器设计中我们应该考虑哪些参数？

    (火焰稳定性，传热，飞灰含碳量，污染物的生成（特别是CO），O_2 加入点等等...)
- 漏风问题
  - 在保证不影响CO_2 压缩机组设计的情况下，所能允许的最大漏风量是多少？
- 其他燃烧问题
  - 腐蚀
  - 积灰和结焦
  - 污染物排放

Normalised Convective & Radiative heat flux – Russian Coal - Dry Recycle

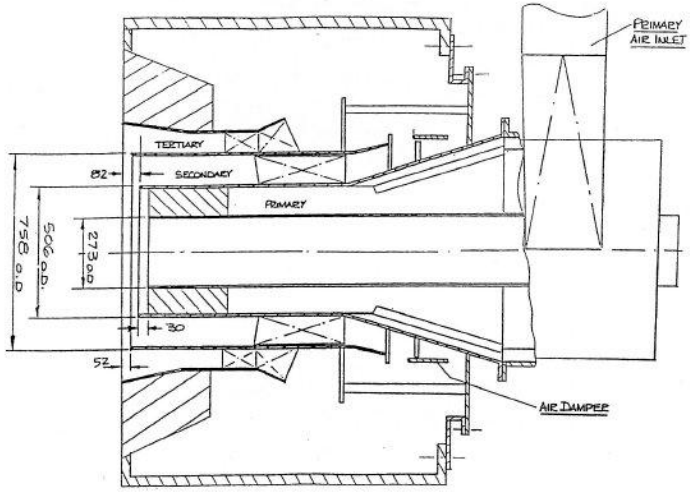


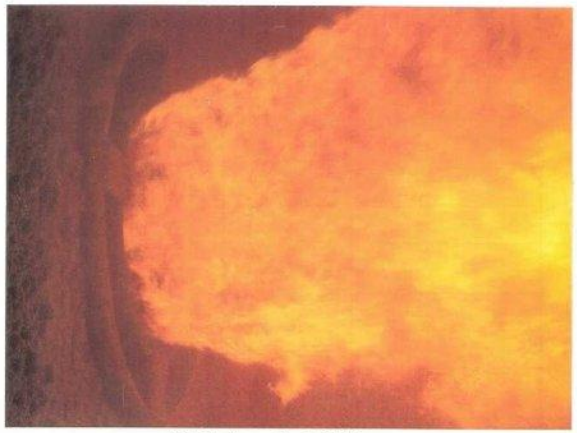
归一化对流、辐射热通量
– 俄国煤 – 干烟气循环



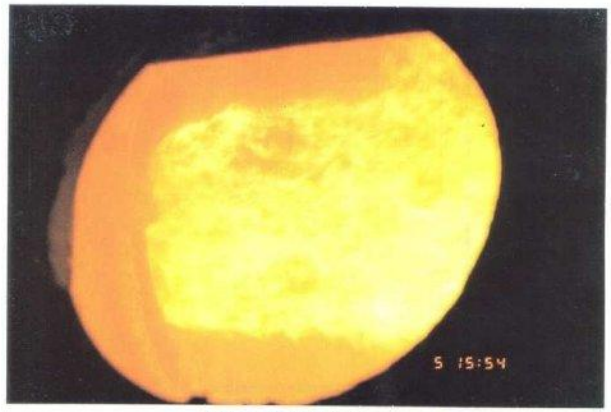
Problem with Air Ingress

1st Large Scale Oxy-Coal Combustion Burner Test Experience - International Combustion Ltd.





Test 1 - Conventional Air firing



Test 3 - O_2/RFG Firing

30 MWth Low NOx burner

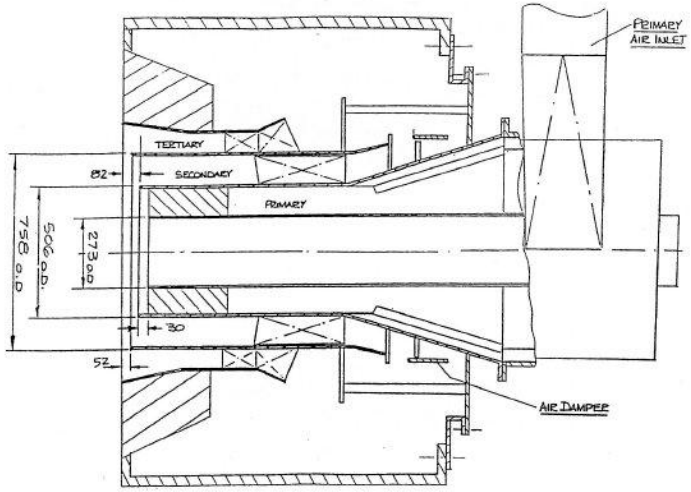
Because of Air Ingress the desired CO_2 composition (only ~ 28% dry basis).

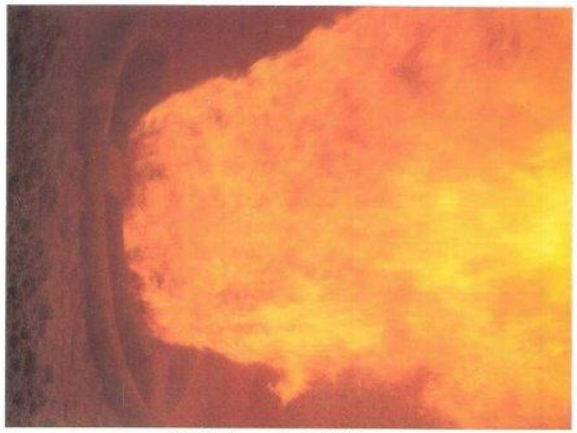
Air Ingress in boilers

- approx. 3 % of flue gas flow for a new conventional power plant
- up to 10 % over the years for power plants in use

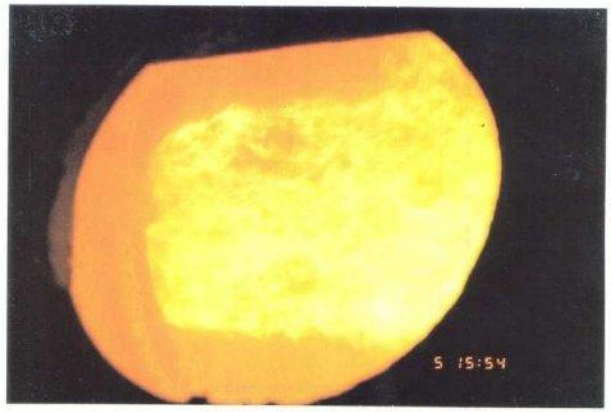
漏风问题

第一个大型富氧燃煤燃烧器测试
- 国际燃烧公司





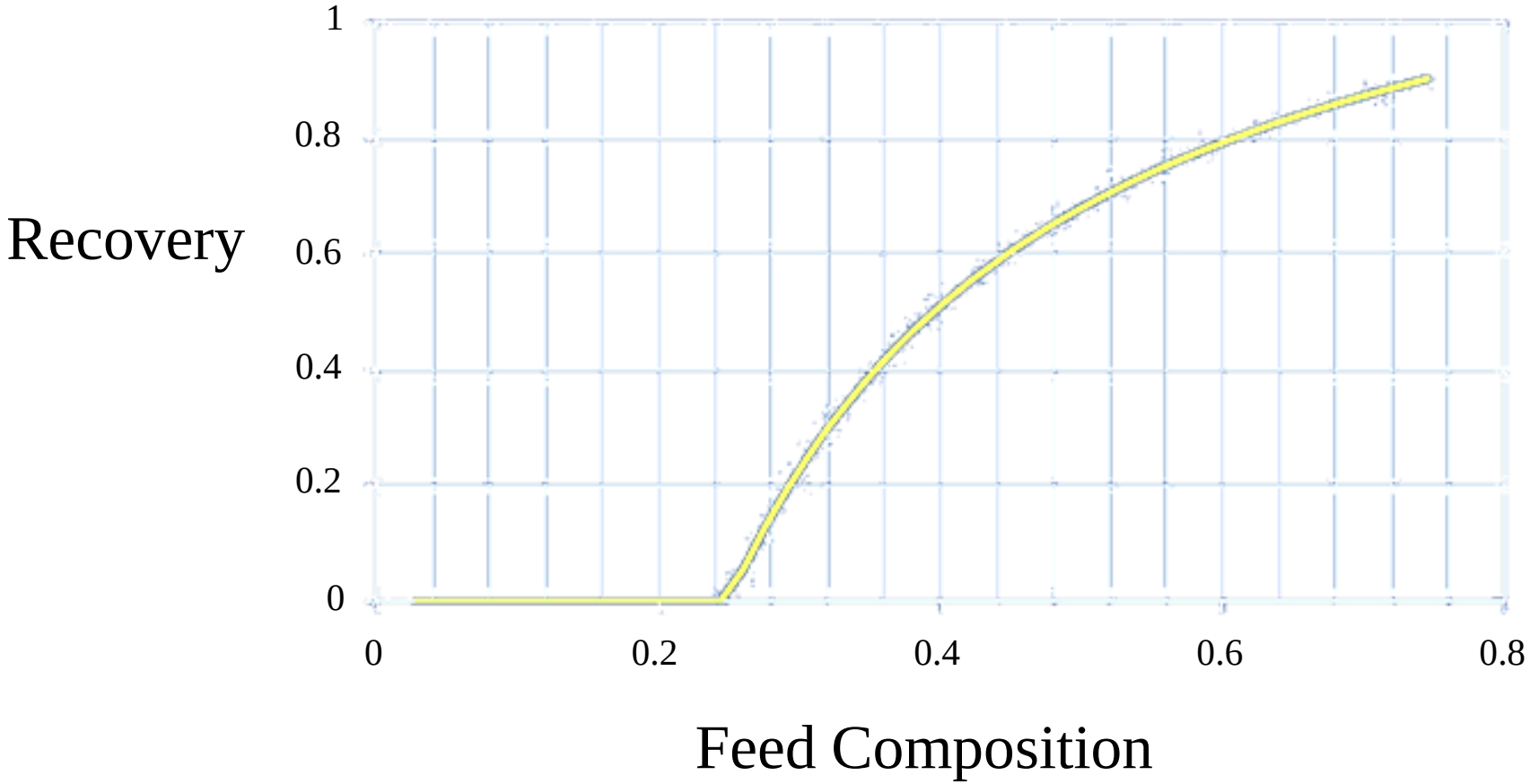
Test 1 - Conventional Air firing



Test 3 - O_2/RFG Firing

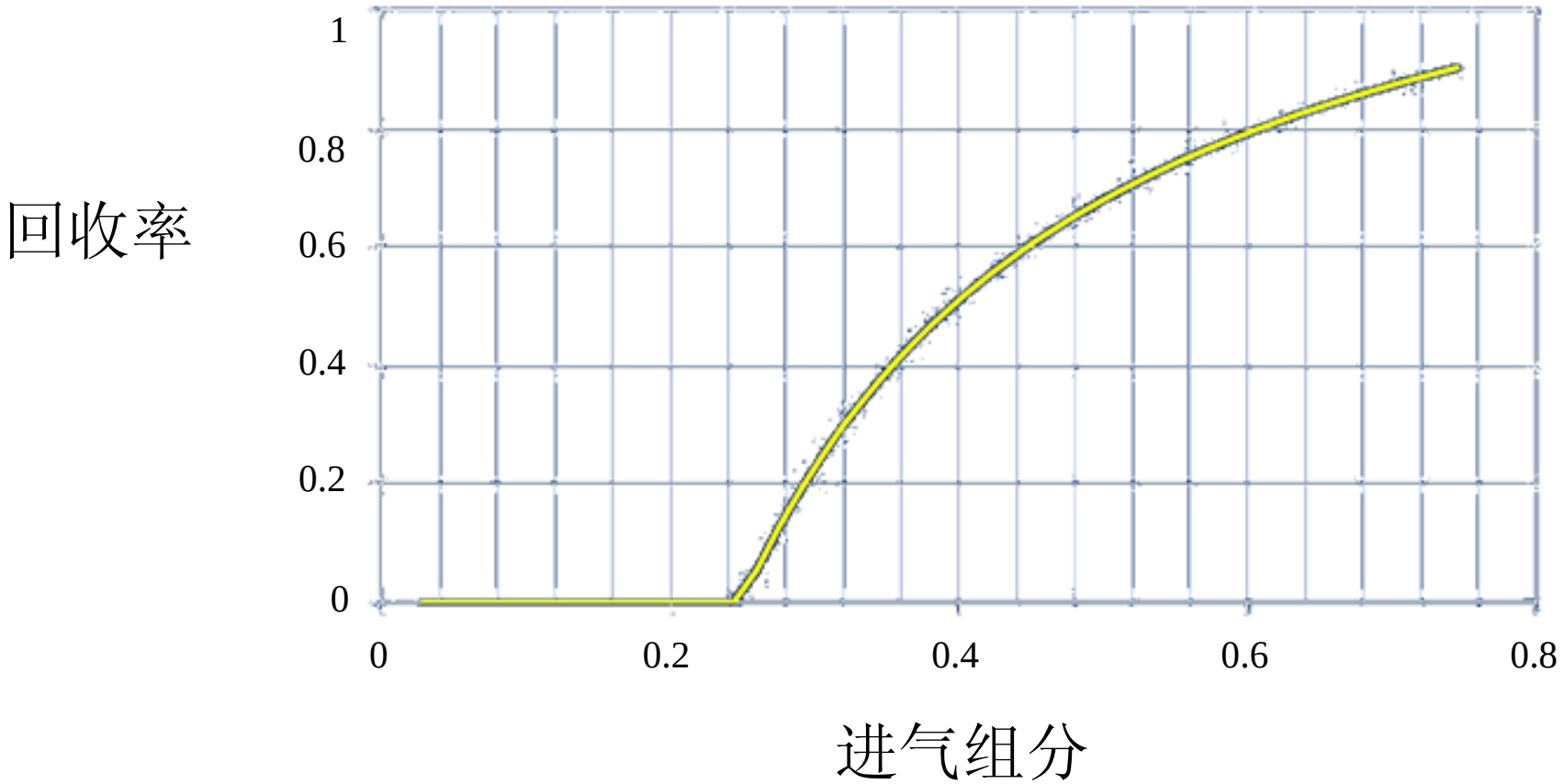
- ✓ 30 MWth 低 NOx 燃烧器
- ✓ 由于漏风，预期的CO_2含量(只有 ~ 28%，干燥基)
- ✓ 锅炉中的漏风
  - ✓ 新建传统电站大约 3 % 烟气量的漏风量
  - ✓ 对已运行多年的电厂高达10 %烟气量的漏风量

CO_2 Recovery Depends On Feed Composition



At -55° C, 30 bar

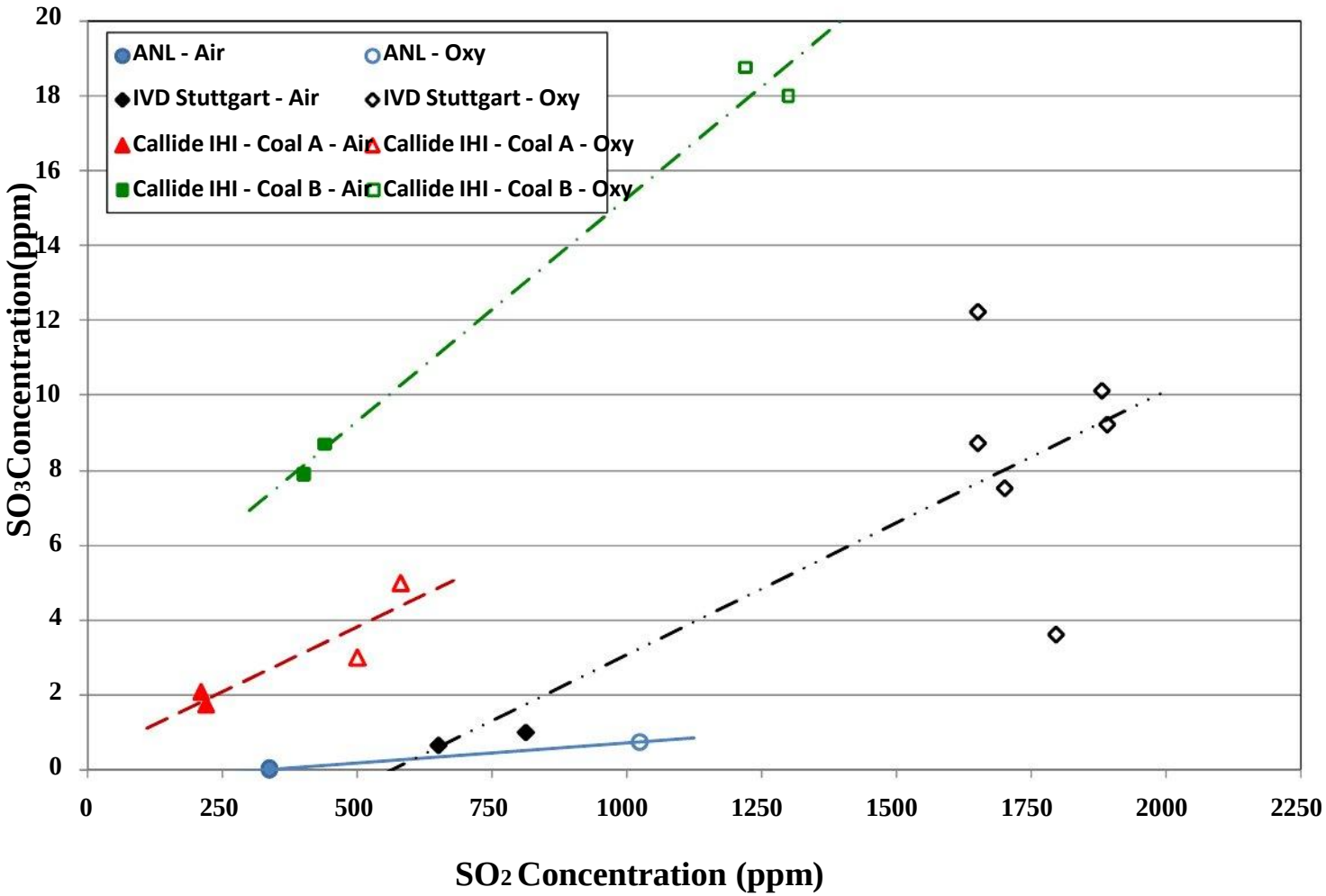
CO_2 回收率取决于进气组分



温度-55℃，压力- 30 bar

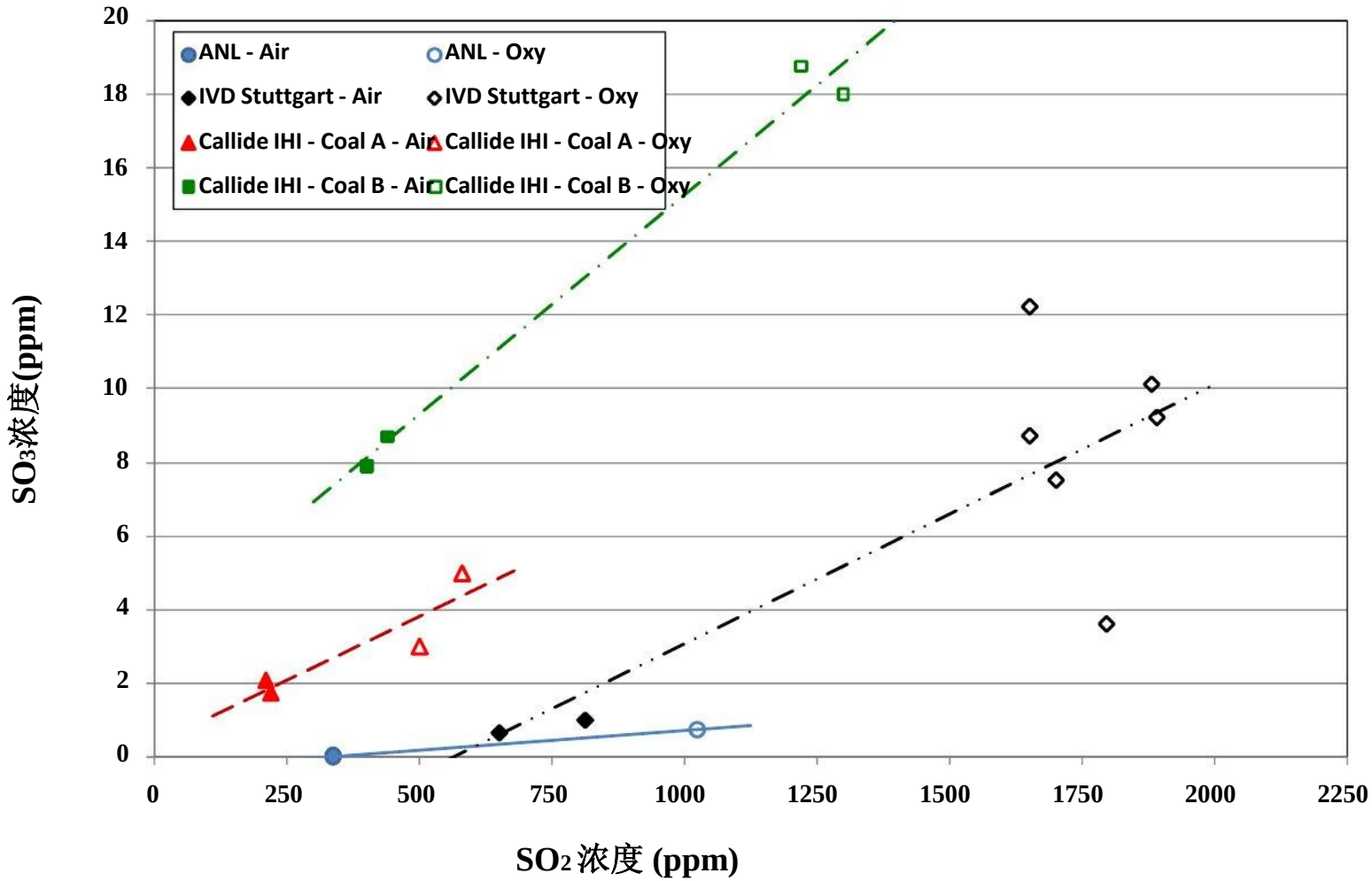
SO_3 Emissions

(Results from ANL-EERC, IVD Stuttgart, Callide/IHI)



SO_3 排放

(来自ANL-EERC, IVD Stuttgart, Callide/IHI的实验结果)



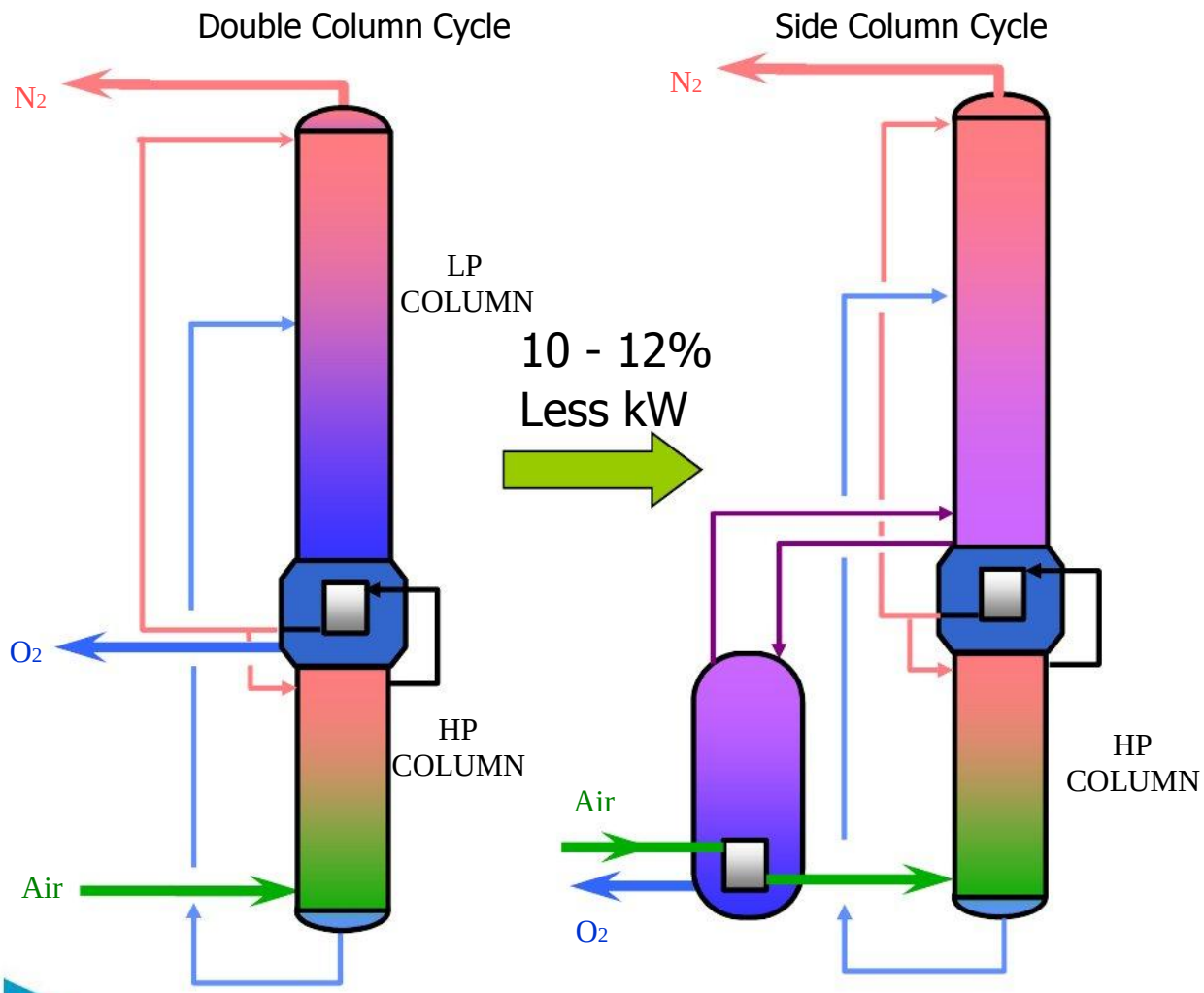
Challenges to Oxygen Production

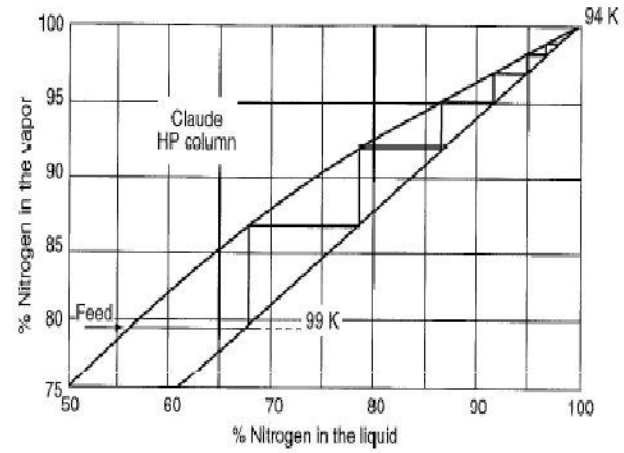
- *As of today, the only available technology for oxygen production in large quantities is* ***cryogenic air separation.***
- *Advances and Development in ASU could result to 25% less energy consumption.*
  - These design would be based on either a 3 column design or dual reboiler design.
- *Challenges are:*
  - Cost of production of oxygen (energy consumption)
  - Utilisation of nitrogen within power plant.

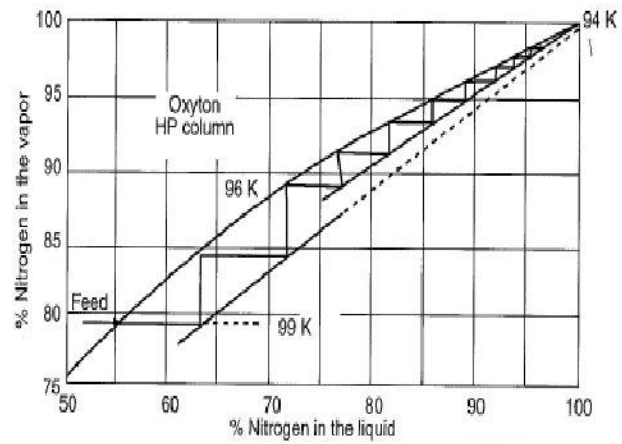
制氧的挑战

- 目前，**低温空气分离**是唯一可行的大规模制氧技术
- ASU的进步和发展能够节约25%的能量消耗
  - 以3 塔或双再热锅炉设计为基础
- 面临的挑战是:
  - 制氧成本 (能耗)
  - 电站中氮气的利用

ASU Distillation Process

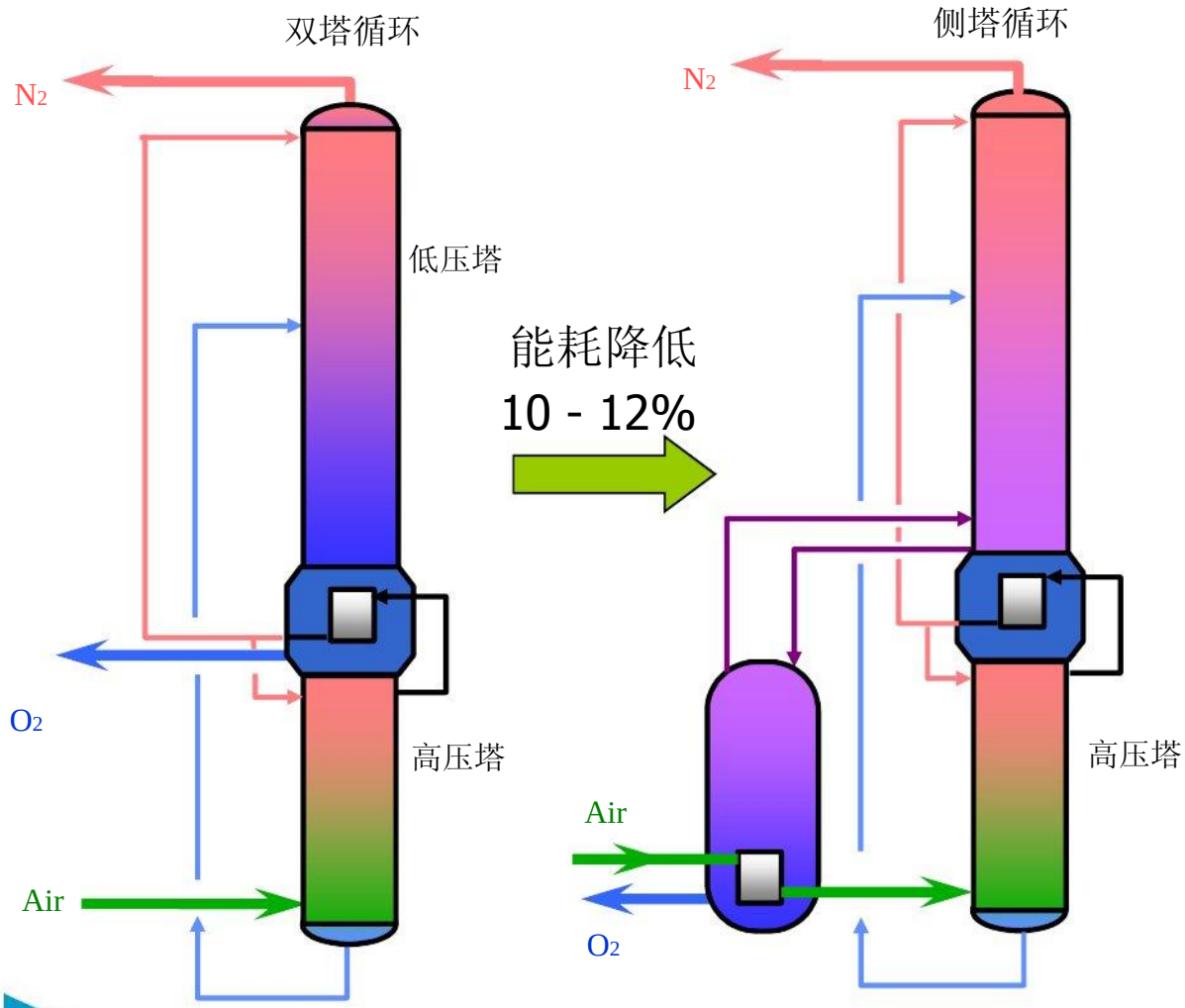


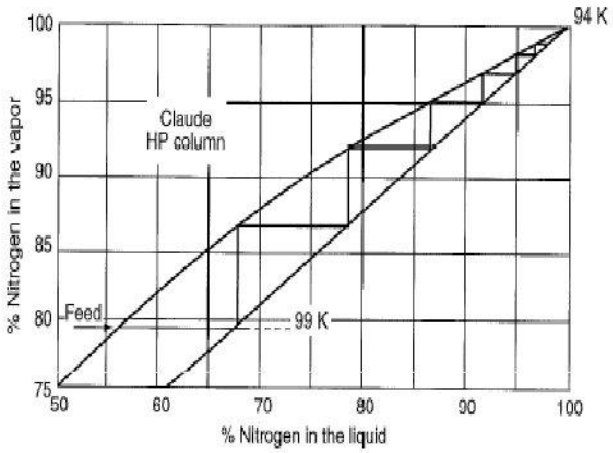


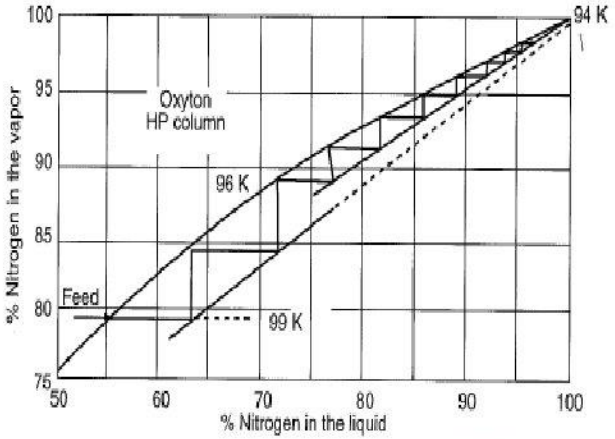


Liquid Vapor Equilibria Figure from F. Kerry (2007)

ASU 精馏过程







相平衡图 来自F. Kerry (2007)

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.**

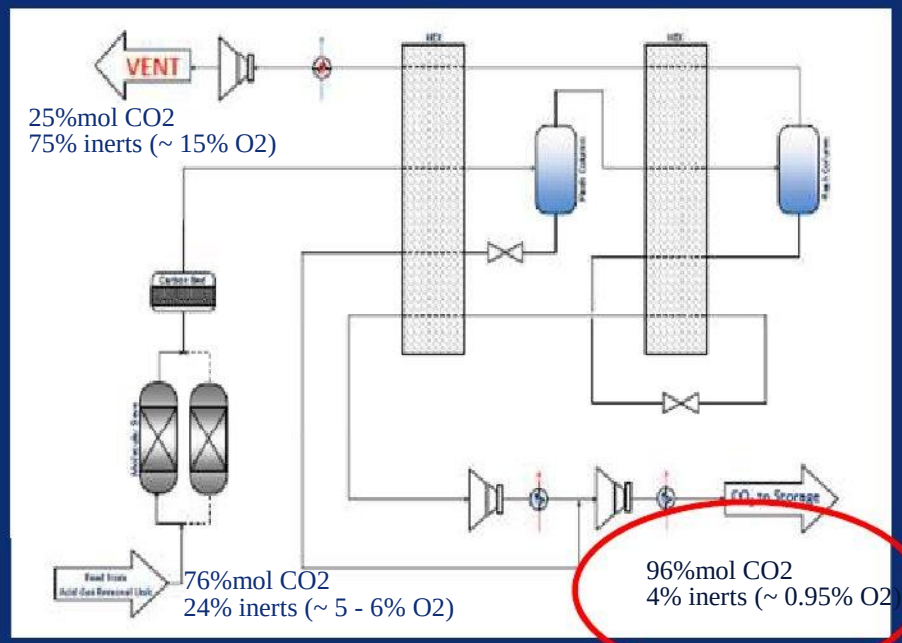
CO_2 处理单元的挑战

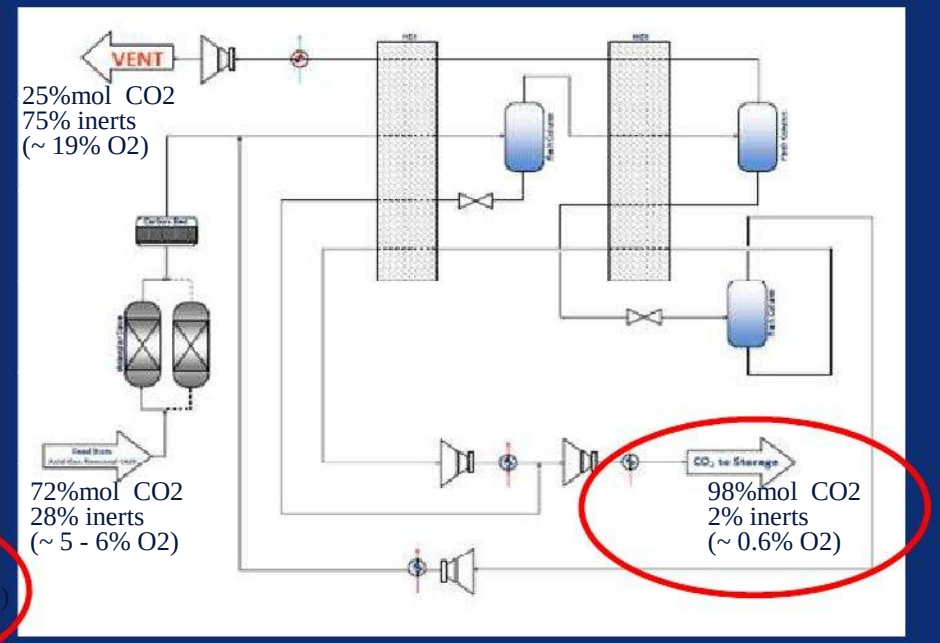
- **CO_2 处理单元对工业气体公司可能成为一项非常有竞争力的业务 (非常重要的增长点)**

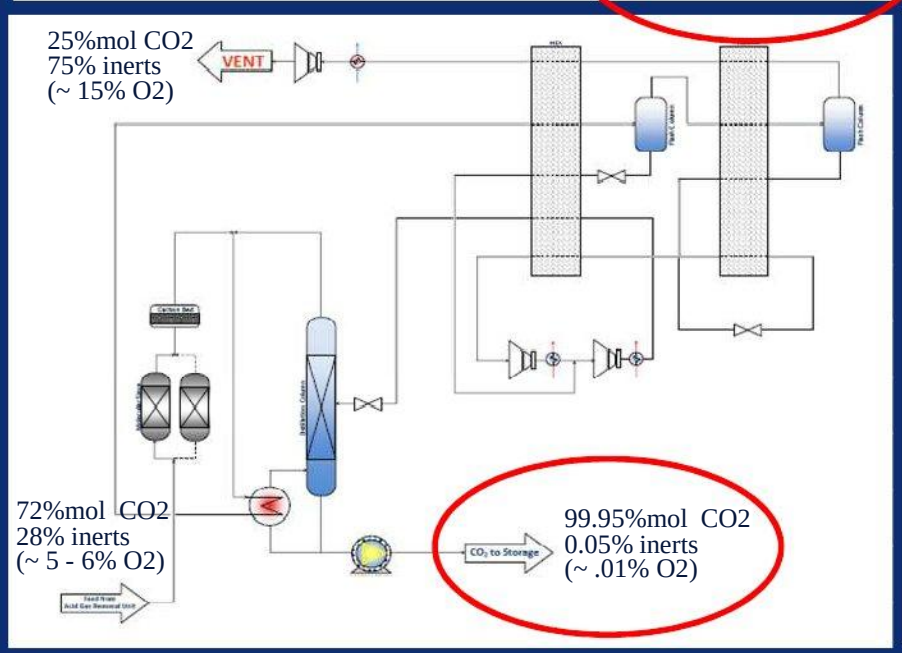
- **面临的挑战是:**
  - 运输和储存过程中对于电厂CO_2的质量要求

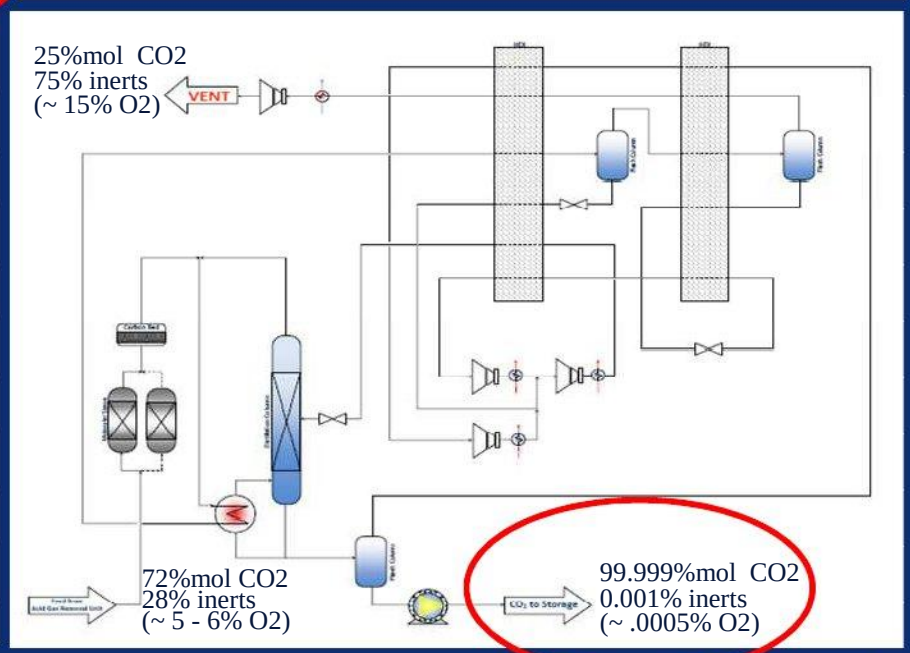
    具体的要求？

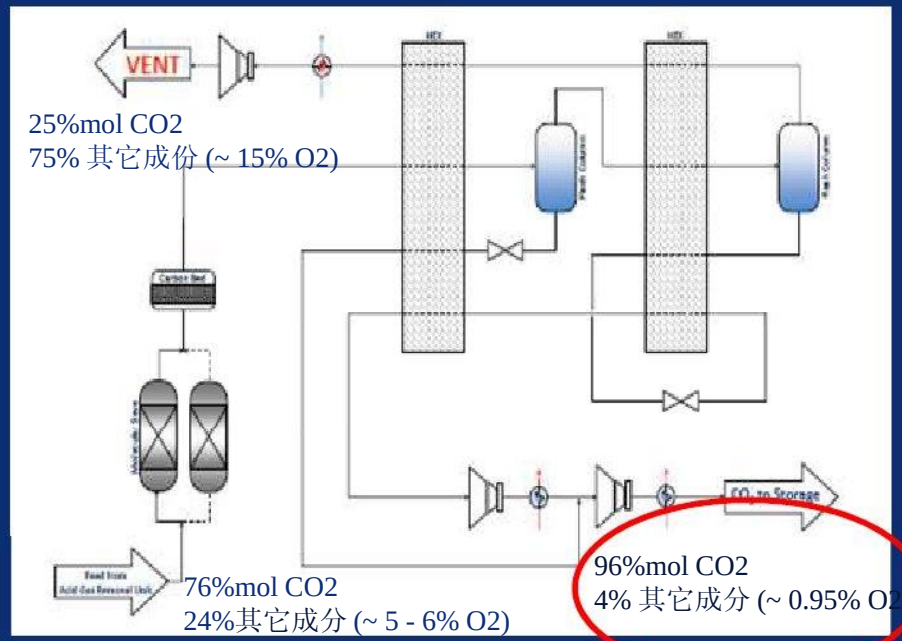
  - 如果要求高的CO_2 回收率，出口CO_2的进一步回收将使得富氧燃烧技术更有竞争力
  - **需要大型CO_2处理单元示范装置，能够处理不纯的 CO_2**

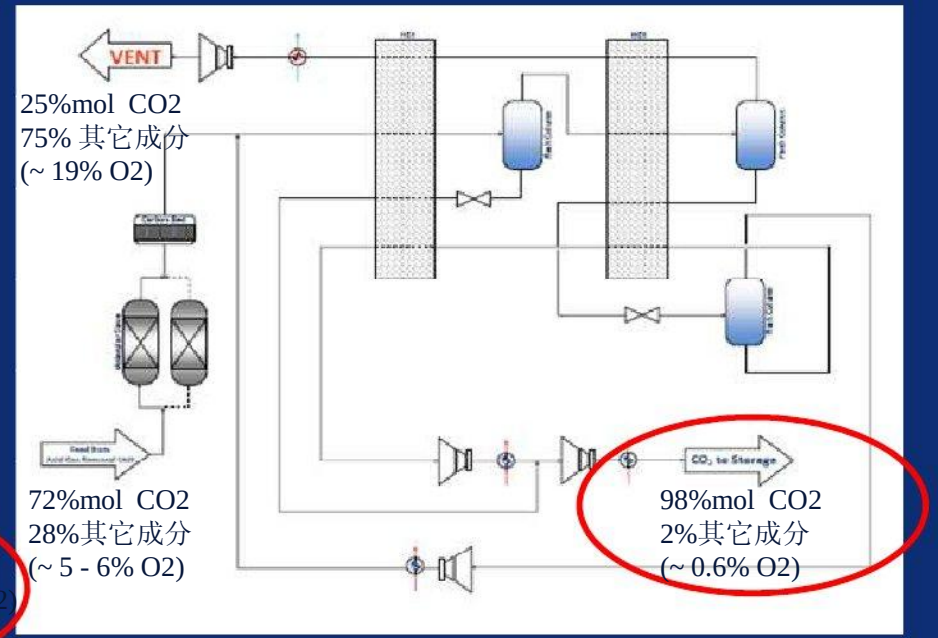

VENT
25%mol CO2
75% inerts (~ 15% O2)
76%mol CO2
24% inerts (~ 5 - 6% O2)
96%mol CO2
4% inerts (~ 0.95% O2)

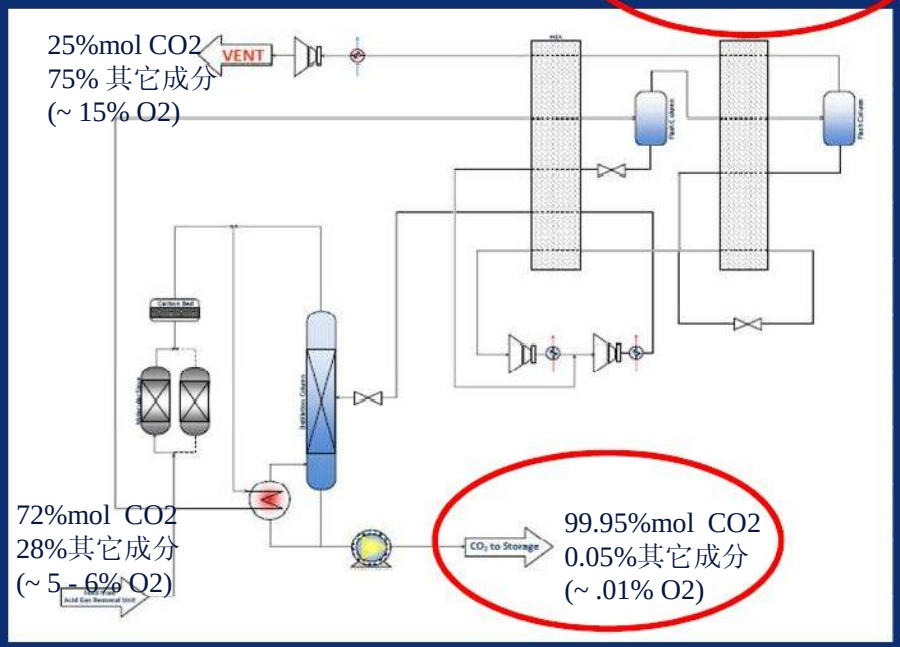

VENT
25%mol CO2
75% inerts
(~ 19% O2)
72%mol CO2
28% inerts
(~ 5 - 6% O2)
98%mol CO2
2% inerts
(~ 0.6% O2)

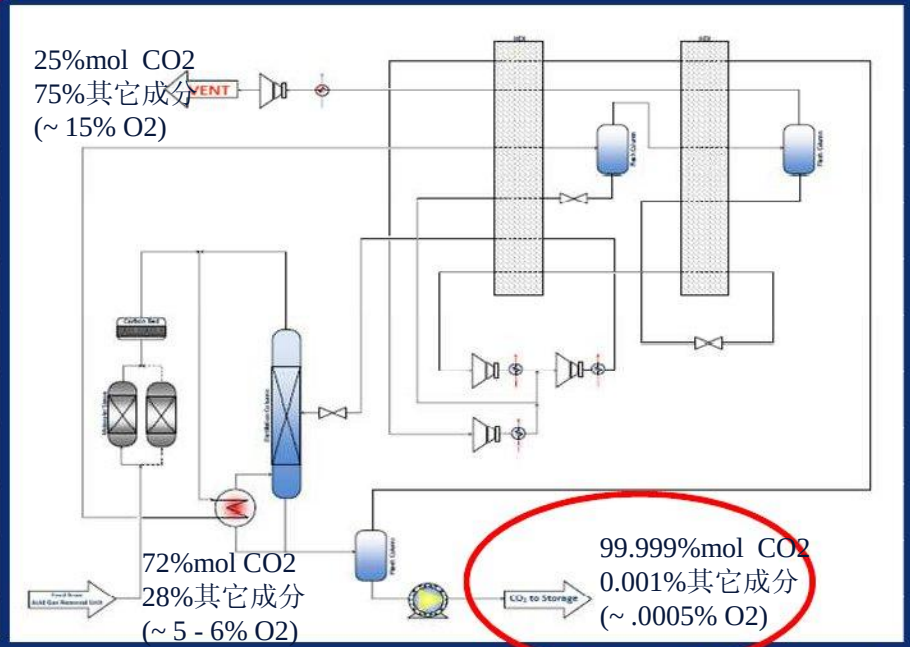

25%mol CO2
75% inerts
(~ 15% O2)
VENT
72%mol CO2
28% inerts
(~ 5 - 6% O2)
99.95%mol CO2
0.05% inerts
(~ .01% O2)


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


VENT
25%mol CO2
75% 其它成份 (~ 15% O2)
76%mol CO2
24%其它成分 (~ 5 - 6% O2)
96%mol CO2
4% 其它成分 (~ 0.95% O2)


VENT
25%mol CO2
75% 其它成分
(~ 19% O2)
72%mol CO2
28%其它成分
(~ 5 - 6% O2)
98%mol CO2
2%其它成分
(~ 0.6% O2)

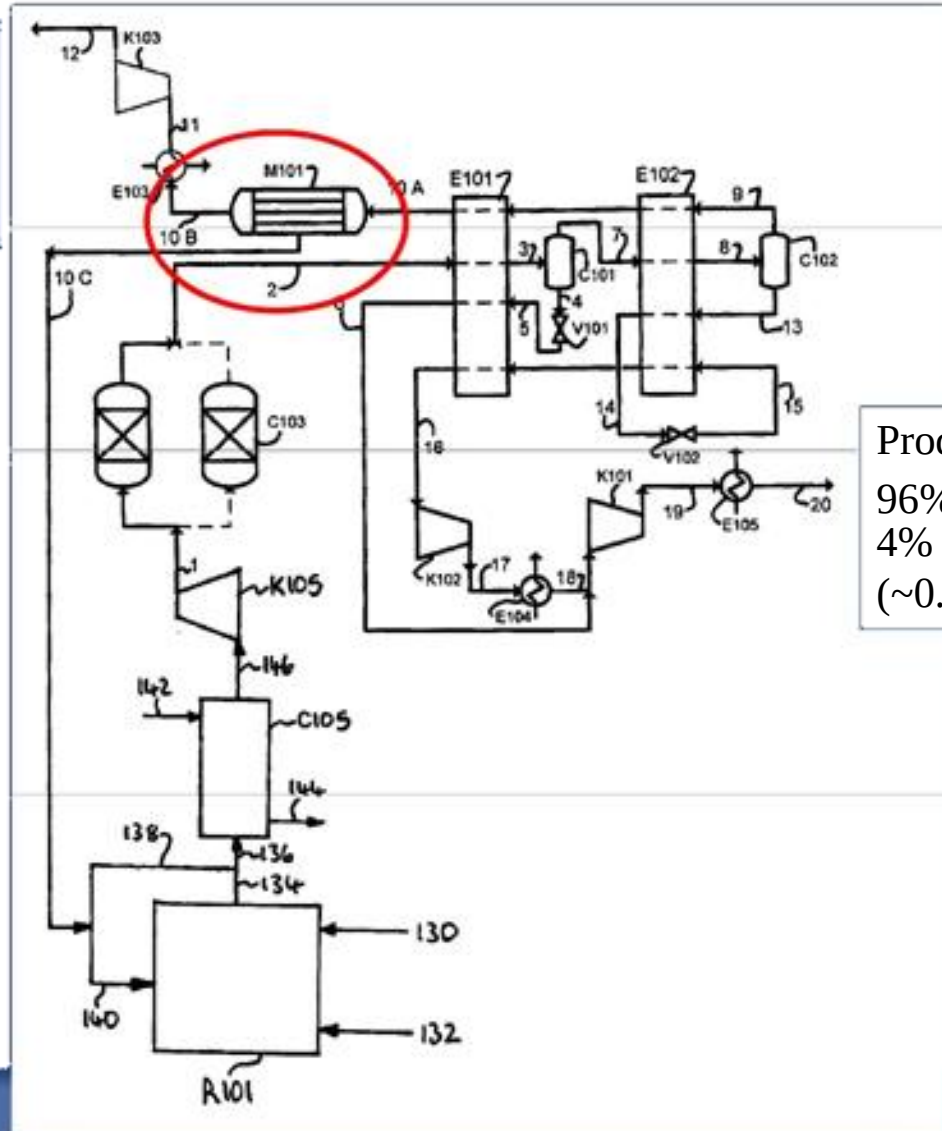

25%mol CO2
75% 其它成分
(~ 15% O2)
VENT
72%mol CO2
28%其它成分
(~ 5 - 6% O2)
99.95%mol CO2
0.05%其它成分
(~ .01% O2)


25%mol CO2
75%其它成分
(~ 15% O2)
VENT
72%mol CO2
28%其它成分
(~ 5 - 6% O2)
99.999%mol CO2
0.001%其它成分
(~ .0005% O2)

Use of Membrane to recover CO_2 and O_2 at the vent

Vent:

7% CO_2
93% inerts
(~10% O_2)



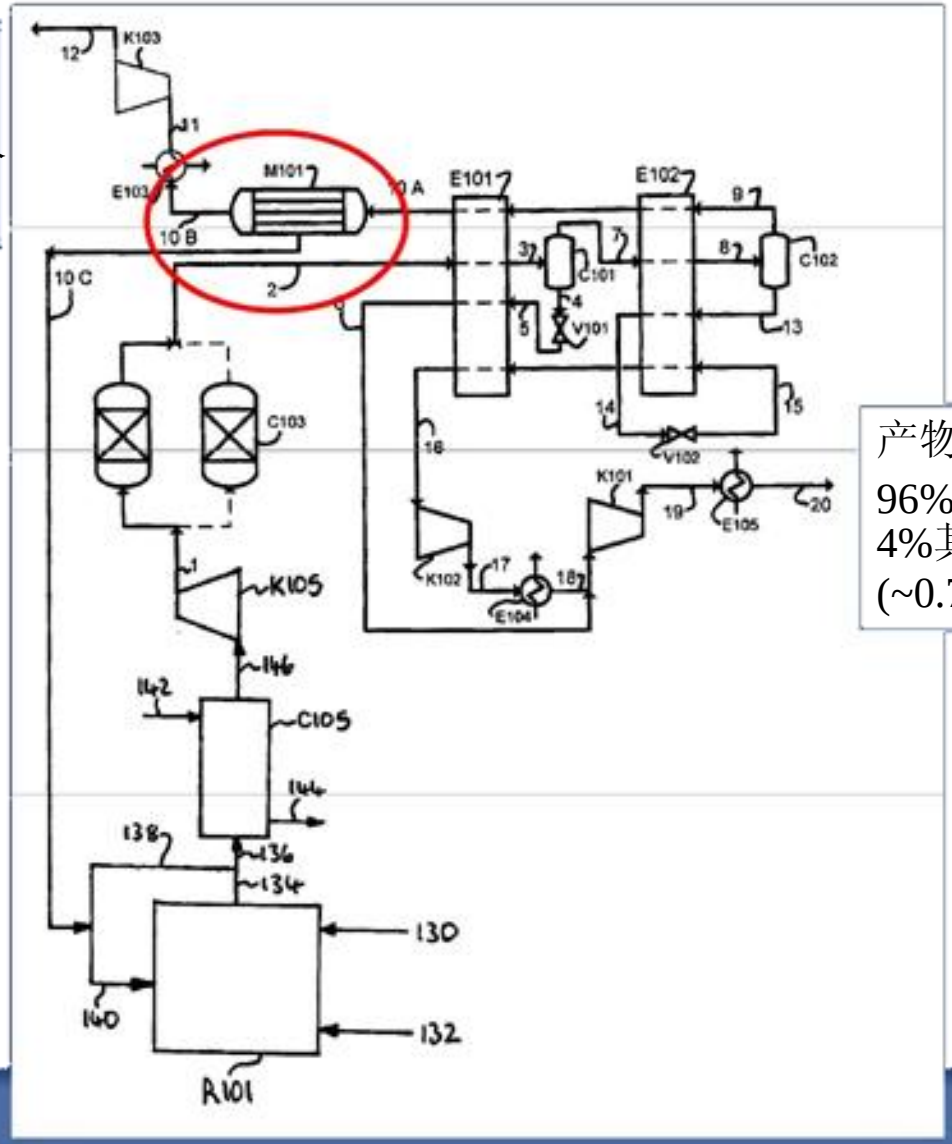
Product

96% CO_2
4% inerts
(~0.75% O_2)

采用膜分离技术回收出口CO_2和O_2

Vent:

7% CO_2
93%其它成分
(~10% O_2)



产物

96% CO_2
4%其它成分
(~0.75% O_2)

Concluding Remarks

- *Oxyfuel Combustion Technology is a viable option for any coal fired power plant with CO_2 Capture.*
- *Oxyfuel Combustion Technology is an option for new build or retrofit cases.*
- ***We need to demonstrate Oxyfuel Combustion Technology to build our confidence.***
- *Business sense, it could have a simple business model for power generation companies wherein the operation of the ASU and CO_2 processing could be outsourced with a long term supply contract from the industrial gas companies.*

结论

- 对任何进行CO_2捕集的燃煤电站来说，富氧燃烧技术是一种可行的选择
- 富氧燃烧技术是新建或改造电站的一种选择
- **需要建设示范工程来建立对富氧燃烧技术的信心**
- 商业意识：对于发电公司，这里有一种简单的商业模式就是能够将ASU和CO_2处理系统的运行转包给工业气体公司，签订长期供应合同。

ieaghg

Vattenfall - Janschwalde (PC -250MWe)
KEPCO/KOSEP - Yongdong (PC - 100MWe)
Black Hills Power - Wyoming (PC - 100MWe)
FW/Praxair – HBPW Michigan (CFB - 78MWe)
Endesa/CIUDEN - El Bierzo (CFB - 300MWe)

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
ENEL HP Oxyfuel	Brindisi Test Facility	2012	48MWth	Coal

Target : "Commercialised by 2020"

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

By 2014-2018

Demonstration of 50– 300MWe full scale power plant.

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

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

2008

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

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

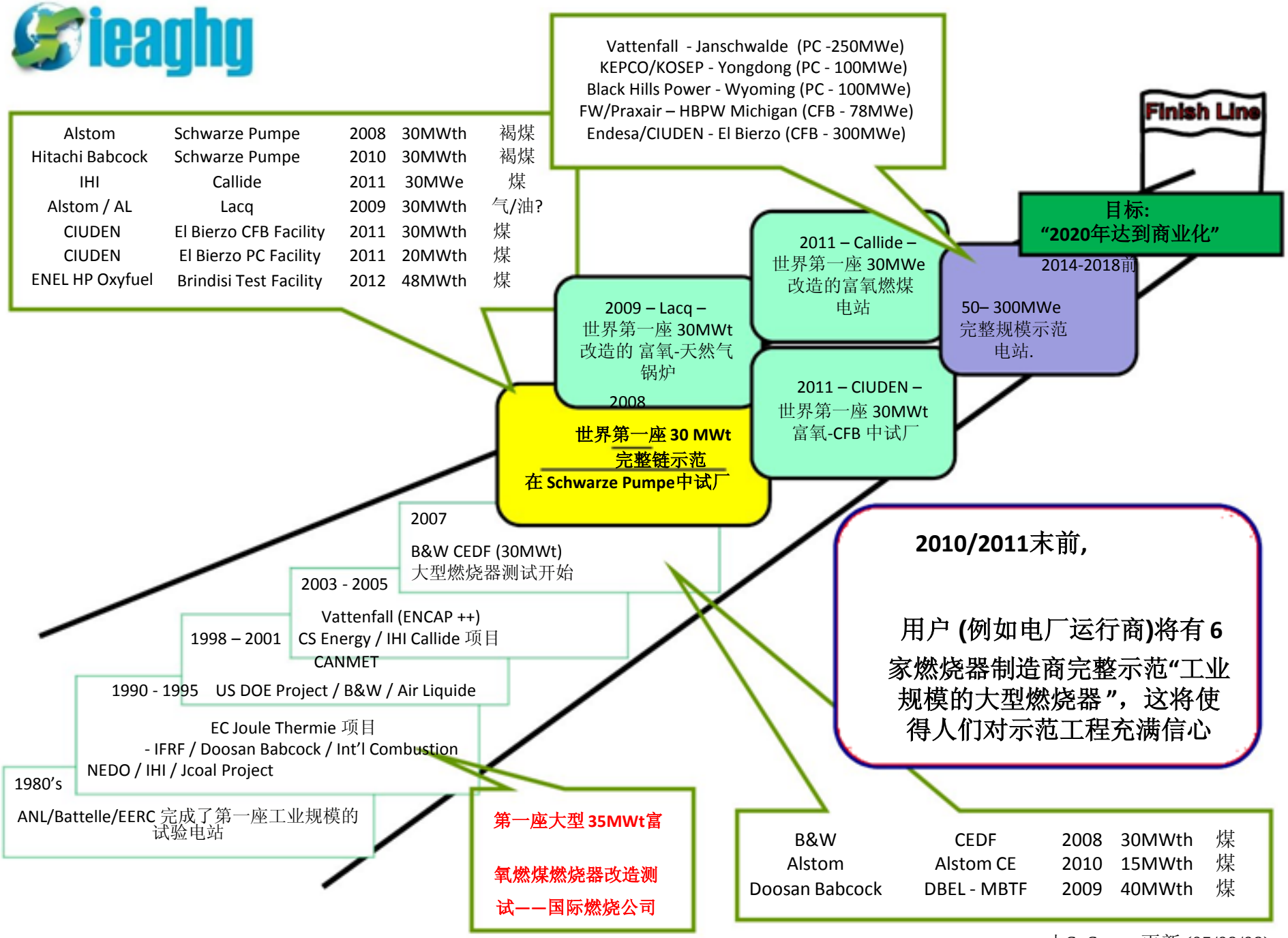
ANL/Battelle/EERC completed the first industrial scale pilot plant

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

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 (05/09/09)



由S. Santos更新 (05/09/09)

Concluding Remarks

- ***China could be in a unique position to demonstrate the three leading technology for CO_2 capture.***
  - GreenGen provided the platform to demonstrate pre-combustion capture.
  - Post-Combustion capture is now being demonstrated in China in slip stream scale.
  - Oxyfuel Combustion technology is the only missing link.

结论

- **中国在以下三种CO_2捕集领先技术的示范中可能处于重要地位**
  - 绿色煤电为燃烧前捕集的示范提供了平台
  - 中国正在以部分尾气进行燃烧后捕集的示范
  - 目前尚缺富氧燃烧技术的示范项目

Thank you

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Thank you

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