Lecture 1: Pulverised coal combustion carbon capture and storage, GHG reduction and oxyfuel technology

APP OFWG Capacity Building Course, Monday/Tuesday 15/16 March, 2010
Xijiao Hotel, Beijing, China

Professor Terry Wall

OFWG Project Leader and
University of Newcastle, Australia

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Asia-Pacific Partnership on Clean Development & Climate

第1讲：煤粉燃烧的二氧化碳捕集和储存, 温室气体减排以及富氧燃烧技术

亚太伙伴计划富氧燃烧能力建设课程
西郊宾馆，北京，中国
2010年**3**月**15/16**（星期一**/**星期二）

Terry Wall 教授
OFWG项目负责人

澳大利亚纽卡斯尔大学

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Content and references

Lecture content:

1. CCS technology comparisons
2. Carbon avoidance costs
3. Oxyfuel technology status

References:

B.J.P. Buhre, L.K. Elliott, C.D. Sheng, R.P. Gupta, and T.F. Wall, Oxy-Fuel Combustion Technology For Coal-Fired Power Generation, Progress in Energy and Combustion Science, 31, 283-307, 2005.

T. F. Wall, Combustion processes for carbon capture, Invited plenary lecture and review, 31st International Symposium on Combustion, University of Heidelberg, Proceedings of The Combustion Institute, 31, 31-47, 2007.

Terry Wall, Yinghui Liu, Chris Spero, Liza Elliott, Sameer Khare, Renu Rathnam, Farida Zeenathal, Behdad Moghtaderi, Bart Buhre, Changdong Scheng, Raj Gupta, Toshihiko Yamada, Keiji Makino, Jianglong Yu, An overview on oxyfuel coal combustion—state of the art research and technology development, Chemical Engineering Research and Design (ChERD), Volume 87, Issue 8, Pages 1003-1016, 2009.

… and web links on OFWG site http://www.newcastle.edu.au/project/oxy-fuel-working-group/links.html

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内容和参考文献

讲座内容:

1. CCS的技术比较
2. 碳减排成本
3. 富氧燃烧技术现状

参考文献:

B.J.P. Buhre, L.K. Elliott, C.D. Sheng, R.P. Gupta, and T.F. Wall, Oxy-Fuel Combustion Technology For Coal-Fired Power Generation, Progress in Energy and Combustion Science, 31, 283-307, 2005.

T. F. Wall, Combustion processes for carbon capture, Invited plenary lecture and review, 31st International Symposium on Combustion, University of Heidelberg, Proceedings of The Combustion Institute, 31, 31-47, 2007.

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…另外参考**OFWG**网站**http://www.newcastle.edu.au/project/oxy-fuel-working-group/links.html**

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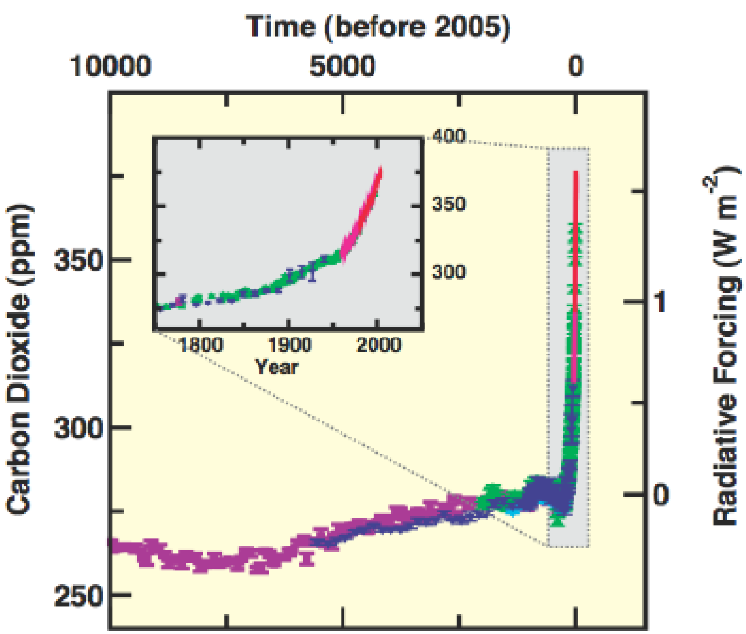
IPCC report on "Climate Change 2007: The Physical Science Basis", released Feb 2, 2007

Changes in Greenhouse Gases from ice-Core and Modern Data



Most of the observed increase in globally averaged temperatures since the mid-20th century is *very likely* due to the observed increase in anthropogenic greenhouse gas concentrations.

For the next two decades a warming of about 0.2° C per decade is projected for a range of emission scenarios. Even if the concentrations of all greenhouse gases and aerosols had been kept constant at year 2000 levels, a further warming of about 0.1° C per decade would be expected.

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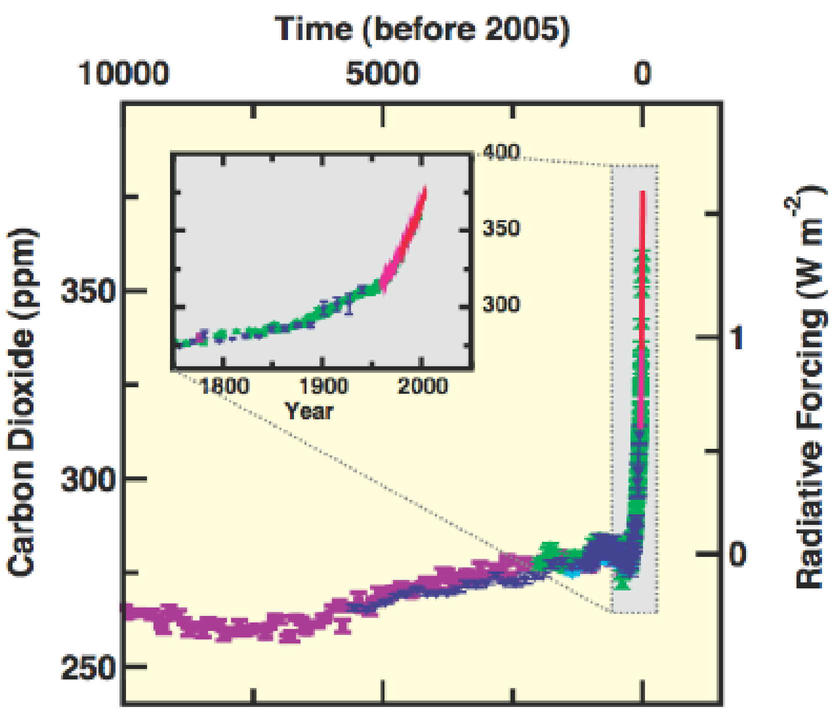
IPCC 报告“气候变化2007：自然科学基础”
2007年2月2日发表

来自冰芯及现代数据中
温室气体的变化



20世纪中期以来观察到的全球平均气温升高，几乎可以确信主要是由于人类活动导致的温室气体浓度升高引起的。

未来20年内，气温平均每10年气候上升0.2℃。即使将所有温室气体和气溶胶的浓度控制在2000年的水平，仍然可以预期到未来气温每10年会上升0.1℃左右。

Reports other than IPCC

IEA CCS technology costs, 2003-5

Stern Report, 2007 – act now or costs greater later

MIT coal report, 2007 – coal needs CCS

McKinsey Report, 2007 – CCS costs in context

GCCI Report, 2009 – status of CCS

IPCC以外的报告

国际能源署 CCS 技术成本, 2003-5

Stern 报告, 2007 – 现在行动或者留着更大的代价

MIT 煤报告, 2007 – 煤需要CCS

McKinsey 报告, 2007 – CCS 的成本

GCCI 报告, 2009 – CCS的现状

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Course focus: Why power generation? Why coal? Why CCS?

Thambimuthu, GHCT-8 Conference Opening Session, June, 2006. “ Need to focus on

- Power generation, the main source of emissions
- Coal, the main fuel for power generation
- Saline aquifers, the largest potential store ”

Coal emits more CO_2 per energy than other fuels, but is a relatively secure energy source

CCS R&D emphasis on coal technology

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课程重点：为什么是发电？为什么是煤？为什么要CCS？

Thambimuthu在2006年GHCT-8 会议开幕式上指出，" 需要把重点放在：

- 发电系统，排放的主要来源
- 煤炭，发电的主要燃料
- 含盐蓄水层，最具潜力的存储区"

与同等单位热值的其他燃料相比，煤炭排放的CO_2更多，但它是一个相对安全的能源资源。

CCS的研发重点是煤炭利用技术。

CO_2 storage capacity

Capacity

- In highly prospective and prospective areas, suitable saline aquifer formations, oil or gas fields, or coal beds, at least

- 2,000 $GtCO_2$ ~ 150 years of worldwide CO_2 from large stationary sources

Matching CO_2 sources and storage sinks

- 30-60% of CO_2 emissions from electricity generation and 30-40% of those from industry would be suitable for capture in the future

- IPCC study uses 1-8 US$/$tCO_2$ for 250 km transport

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CO_2的存储容量

容量

- 具有埋存CO_2的预期前景和高预期前景的地区至少包括：合适的盐水层，石油、天然气田和煤层
- 150年内，全球大型固定源排放的二氧化碳为2,000 GtCO_2

匹配CO_2排放源和CO_2埋存点

- CO_2排放量中，电力行业的30-60%和工业界的30-40%在未来将适合于捕捉。
- IPCC报告中，每吨CO_2运输250公里的花费为1-8美元。

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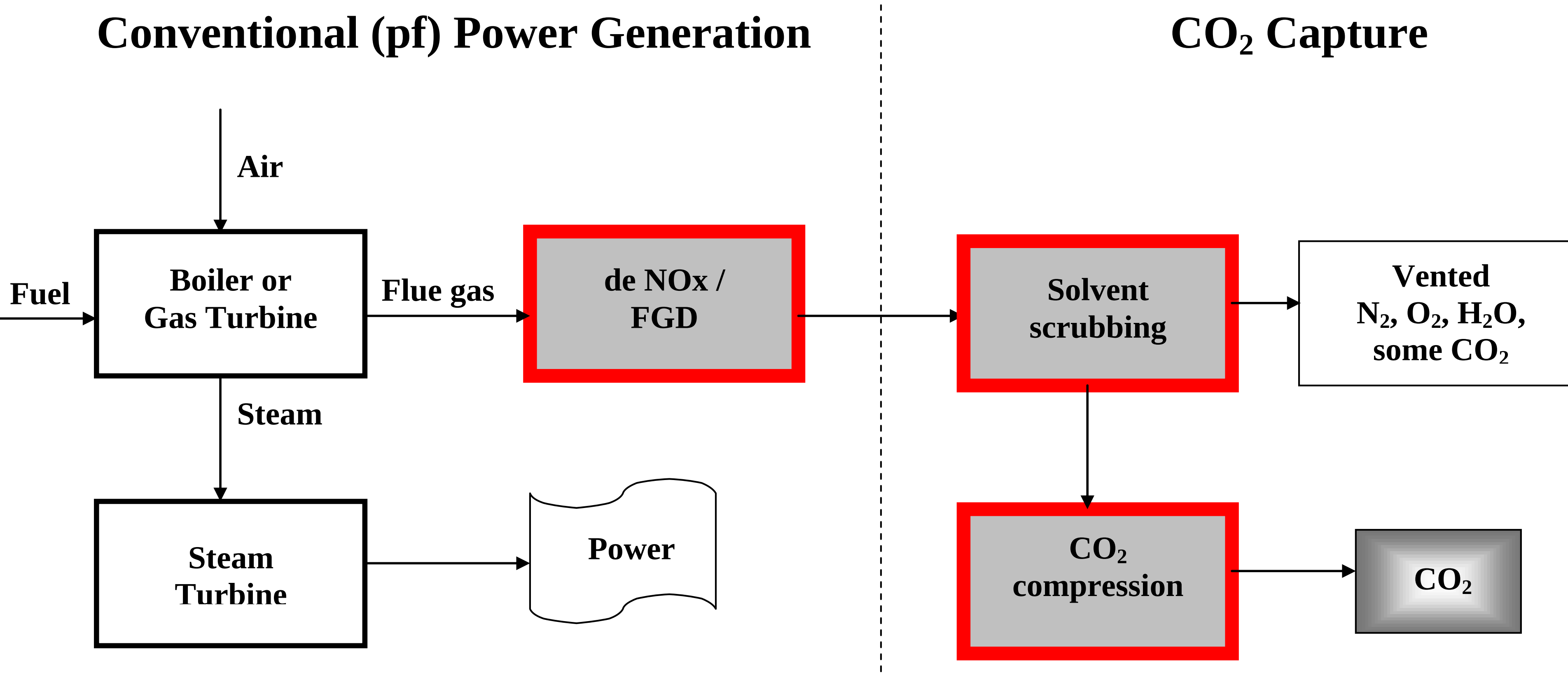
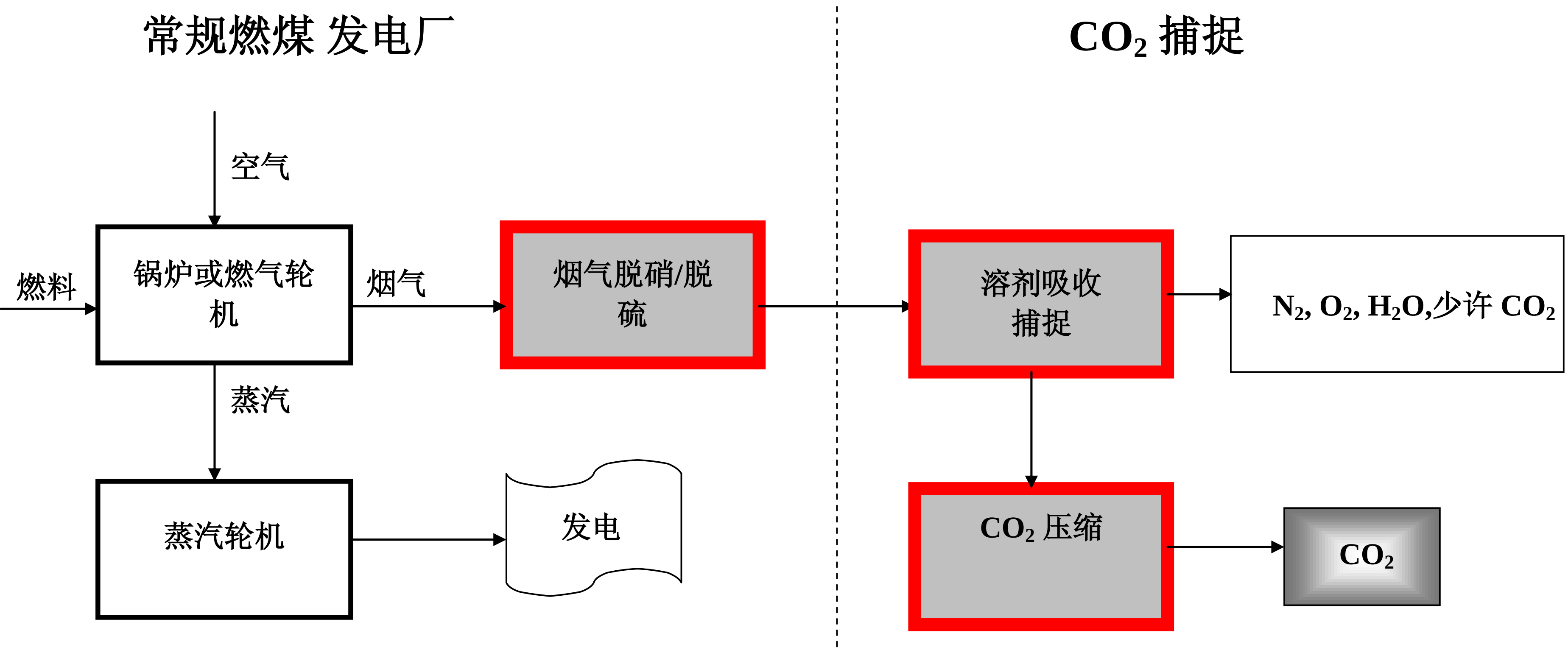
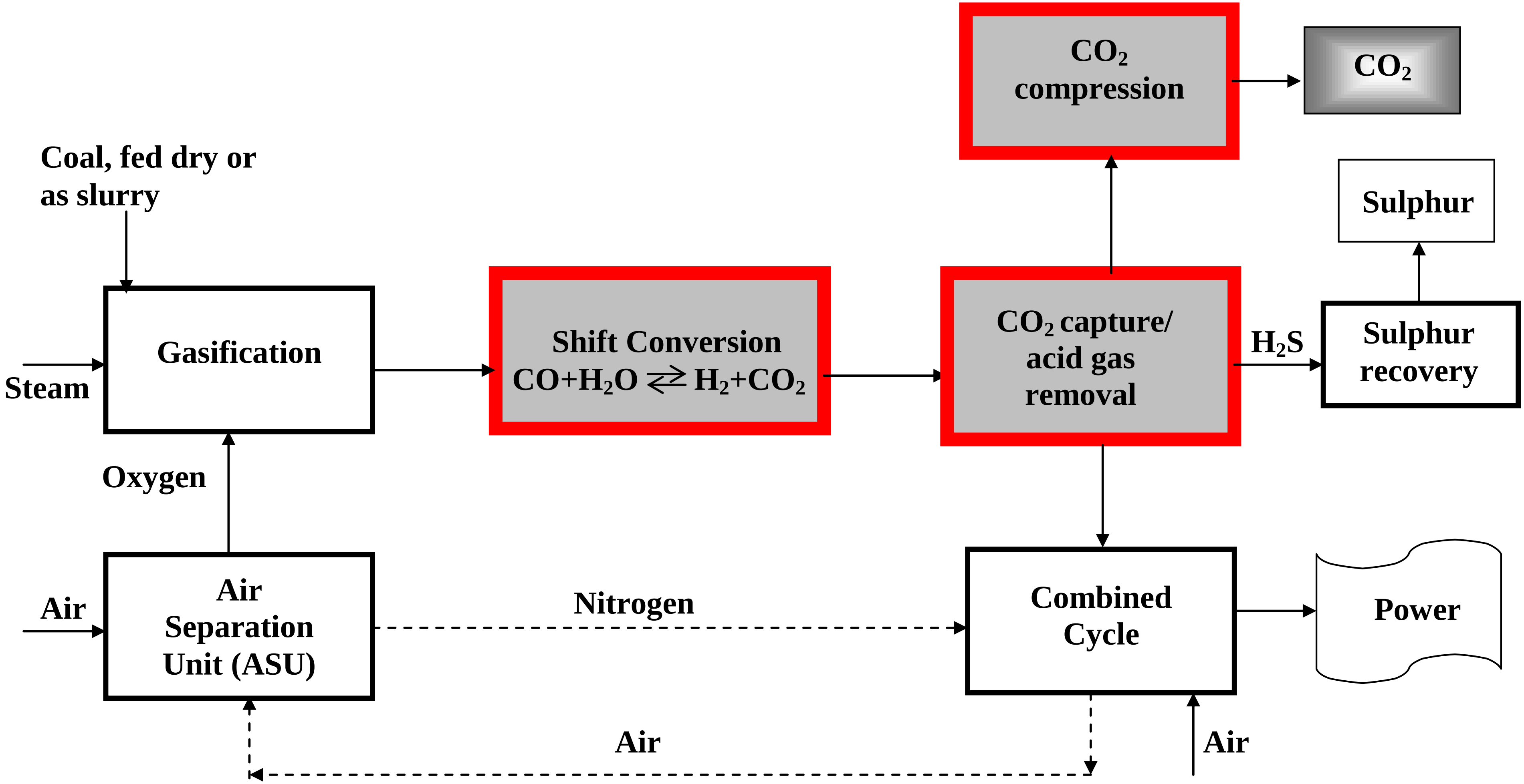
PCC, post-combustion capture, with additional plant noted in red



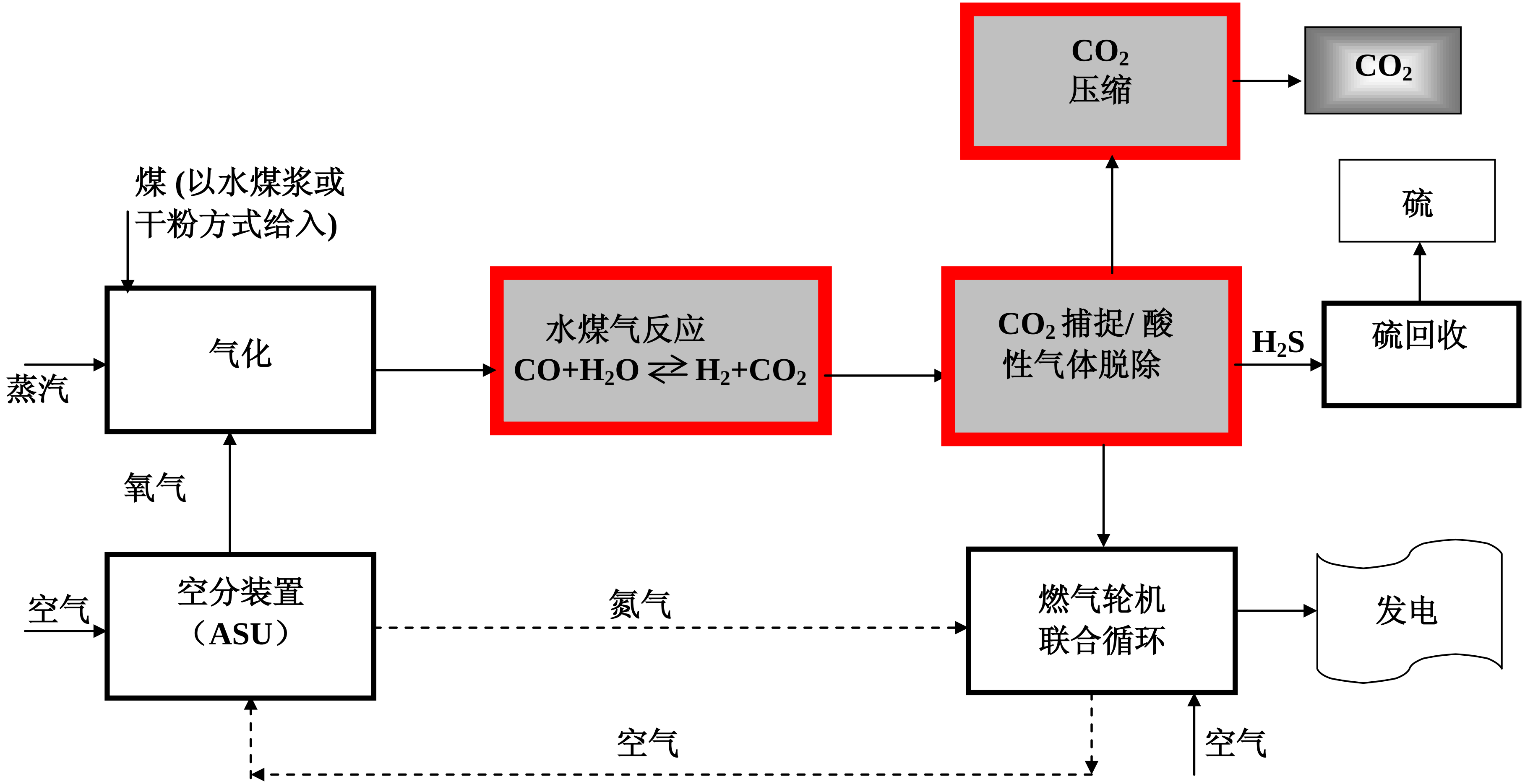
燃烧后捕捉(PCC, post-combustion-capture)
红色部分新增设备



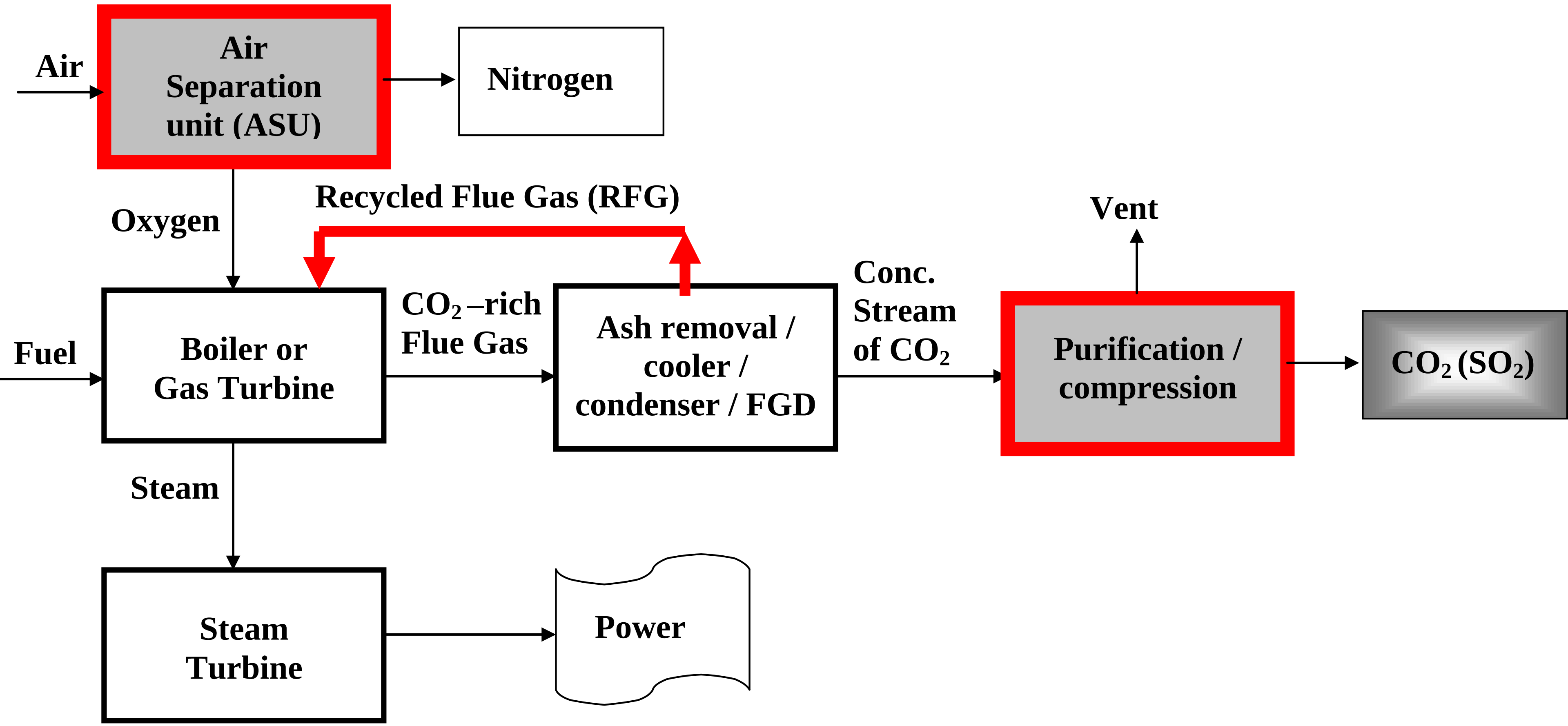
IGCC-CCS, pre-combustion capture



IGCC-CCS, 燃烧前捕捉



Oxy- fuel



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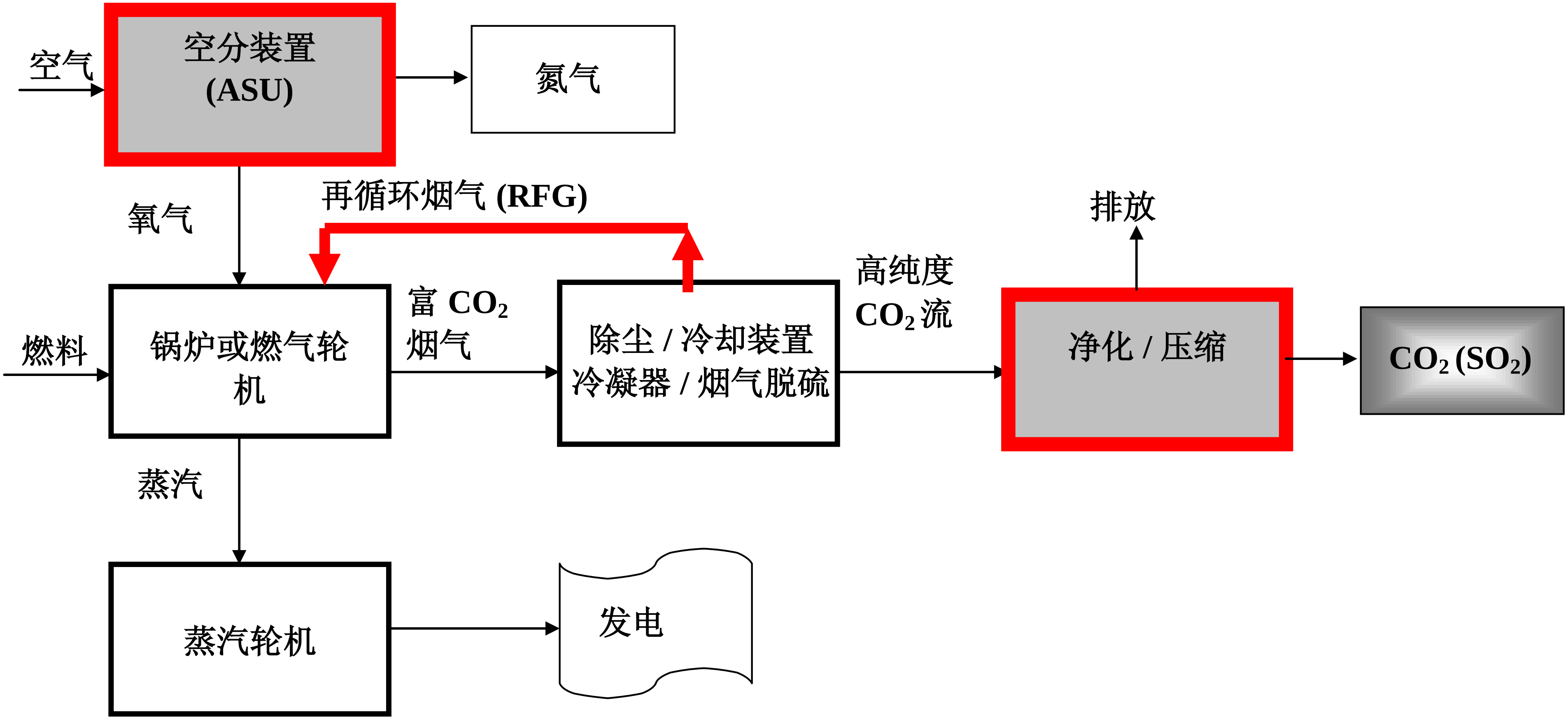
富氧燃烧



空气
空分装置
(ASU)
氮气
氧气
再循环烟气 (RFG)
排放
燃料
锅炉或燃气轮机
富 CO2
烟气
除尘 / 冷却装置
冷凝器 / 烟气脱硫
高纯度
CO2 流
净化 / 压缩
CO2 (SO2)
蒸汽
蒸汽轮机
发电

Status: Examples of operating plants, www.co2captureandstorage.info

Technology	Location	Coal	Power	Capture	Storage
PCC	Warrier Run*, Chiba*, Bellingham	X*	X	X	
IGCC	4 power plants- USA, EU	X	X		
	Many refineries	X	X	X	
Oxyf	Kimberlina		X	X	
Storage	Weyburn*, Sleipner, In Salah	X*		X	X

Status: Some demonstrations of coal-fired integrated plants

PCC	RWE (Germany)	Post - 2009
IGCC-CCS	Futuregen (USA), 275 MW_e	2012
	RWE (Germany), 400-450 MW_e	2014
	Stanwell (Australia), 200 MW_e	2012
Oxyf	Vattenfall (Germany), 30 MW_t	2008
	Callide (Australia), 30 MW_e	2010

现状：运行电站实例，

www.co2captureandstorage.info

技术路线	位置	煤炭	发电	捕捉	埋存
燃烧后捕集	**Warrier Run(美国)*, Chiba*(日本), Bellingham(美国)**	**X***	**X**	**X**	
燃烧前捕集	**4个发电厂，美国和欧洲**	**X**	**X**		
	许多炼油厂	**X**	**X**	**X**	
富氧燃烧	**Kimberlina**		**X**	**X**	
埋存	**Weyburn*(加拿大,盐水层), Sleipner(挪威, 天然气田), In Salah (阿尔及利亚，油田)**	**X***		**X**	**X**

现状：一些综合燃煤示范电站

燃烧后捕集	**RWE (德国)**	**Post - 2009**
整体煤气化联合循环—二氧化碳捕集与埋存	**未来电力 (美国), 275 MW_e** **RWE (德国), 400-450 MW_e** **Stanwell (澳大利亚), 200 MW_e**	**2012** **2014** **2012**
富氧燃烧	**Vattenfall (德国), 30 MW_t** **Callide (澳大利亚), 30 MW_e**	**2008** **2010**

CCS options, with desirable characteristics indicated X

Option	Integrated plant demonstrated at commercial scale	For retrofit	Can be applied to slip-stream	No O_2 supply	No CO_2 capture	Gives H_2
PCC		X	X	X		
IGCC-CCS						X
Oxyf		X			X	

CCS 选项，用“X”标出

CCS选项	商业规模的示范电站	改造	旁路抽取烟气	无O_2供应	无CO_2捕集	产生H_2
PCC		X	X	X		
IGCC-CCS						X
Oxyf		X			X	

Zero emission technology (ZET) targets and CO_2 release

Emissions, from IEA (2005)

SO2 – 98-99 % removal
NOx – 25-50 mg/m3
Particulates – 1-10 mg/m3

CO_2 release, g/kWh, from IEA technology reports (2003-2005)

Pf+FGD, without capture	710-910
PCC	117
IGCC-CCS, dry	142
IGCC-CCS, slurry	152
Oxyfuel	92

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零排放技术的目标和CO_2排放量

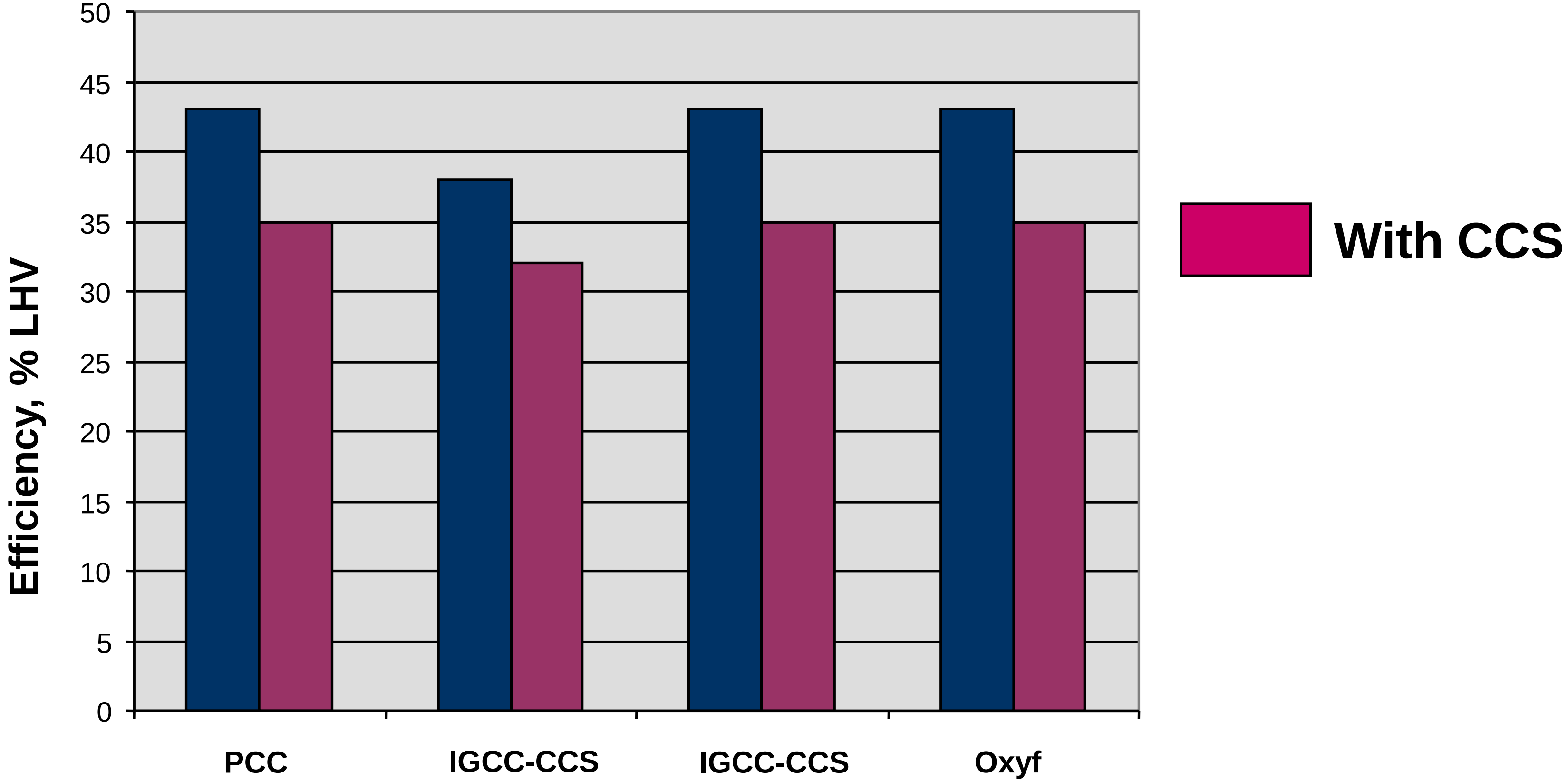
污染物，国际能源署(2005)

SO_2 – 98-99 % 脱除率
NOx – 25-50 mg/m^3
悬浮微粒 – 1-10 mg/m^3

CO_2释放，g/kWh，IEA技术报告(2003-2005)

Pf+FGD,	无CO_2捕集	710-910
PCC		117
IGCC-CCS,	干粉给料方式	142
IGCC-CCS,	水煤浆给料方式	152
Oxy fuel,		92

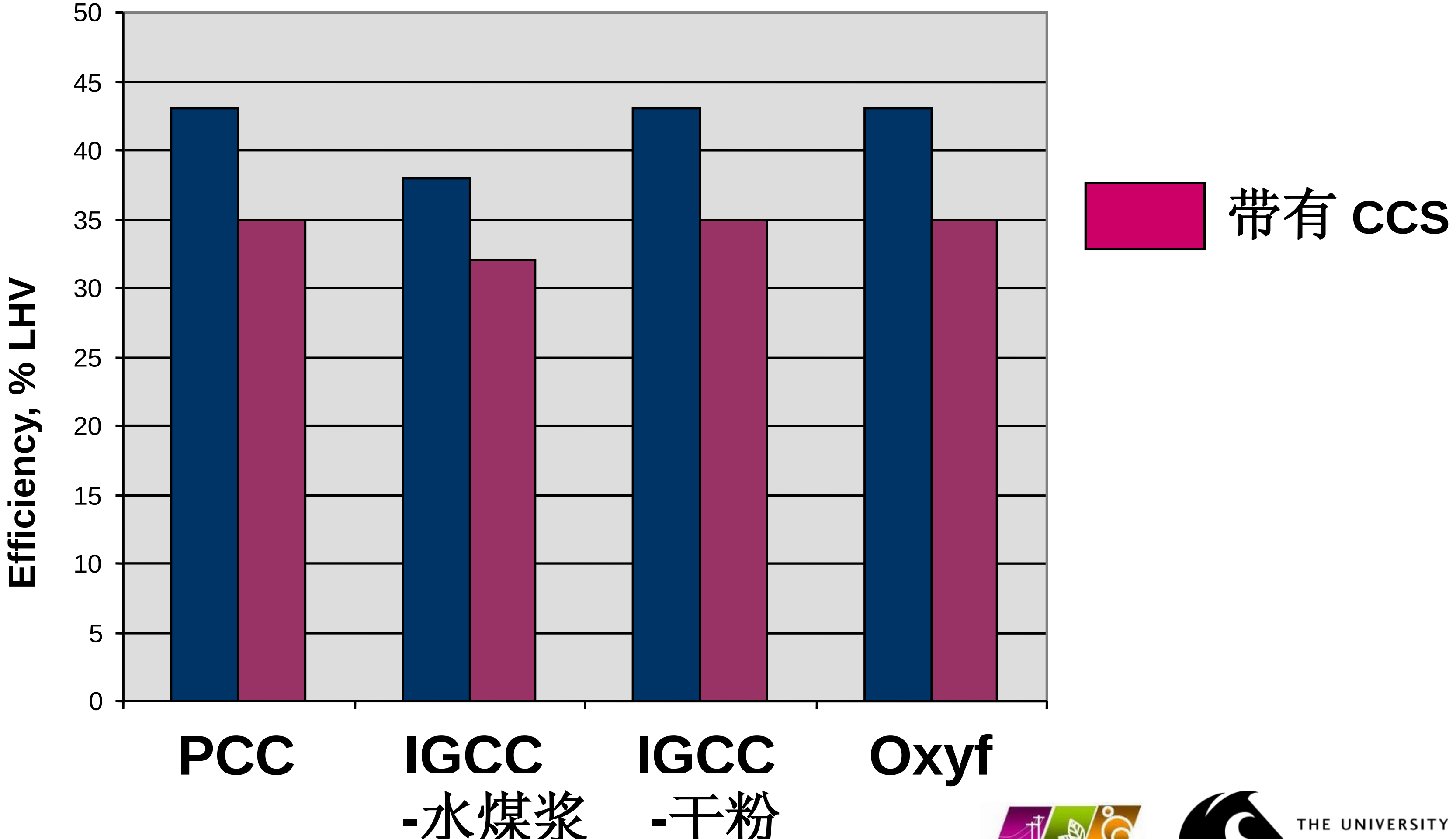
Efficiency comparisons with and without capture, neglecting transport and storage



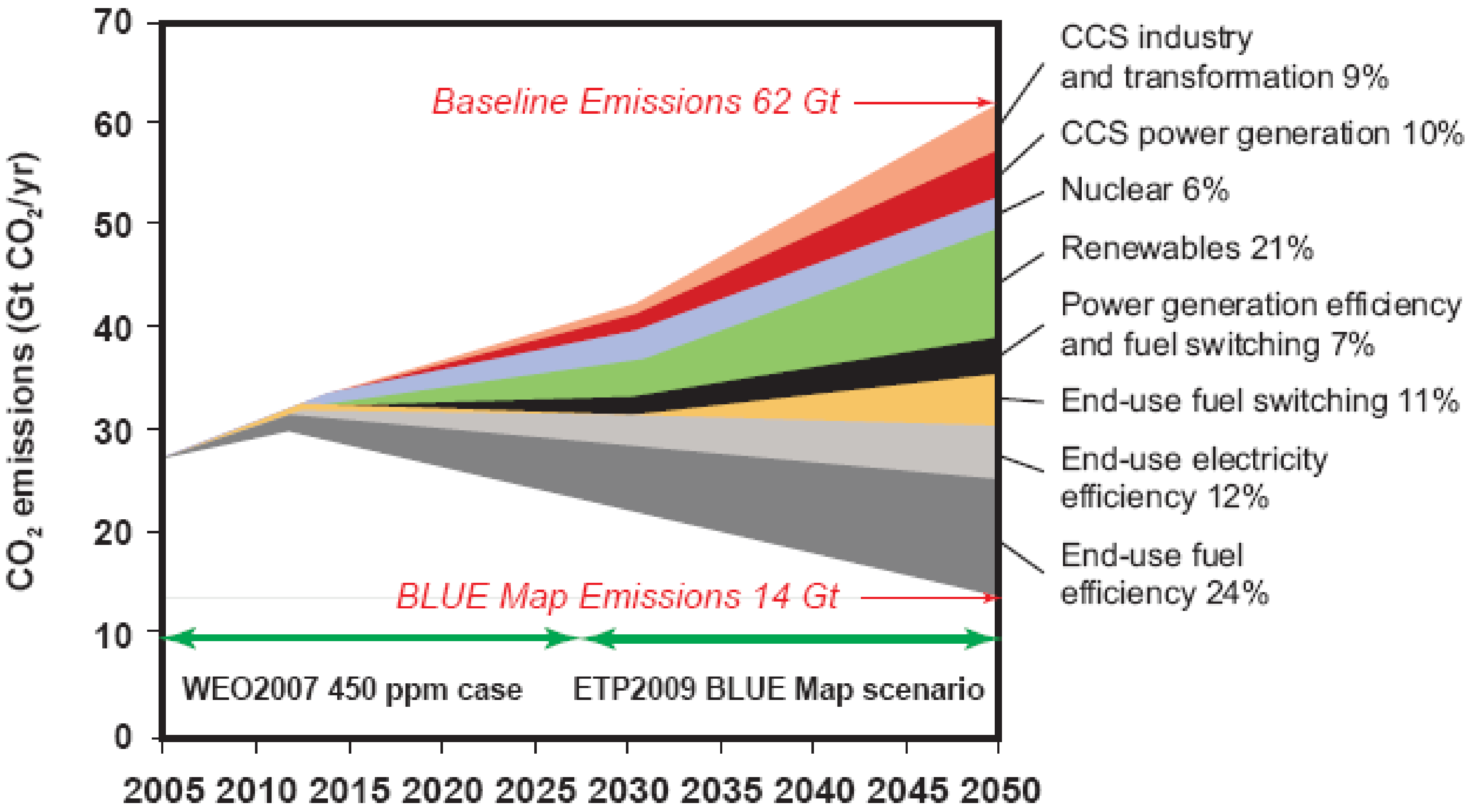
PCC IGCC IGCC Oxyf

-slurry -dry

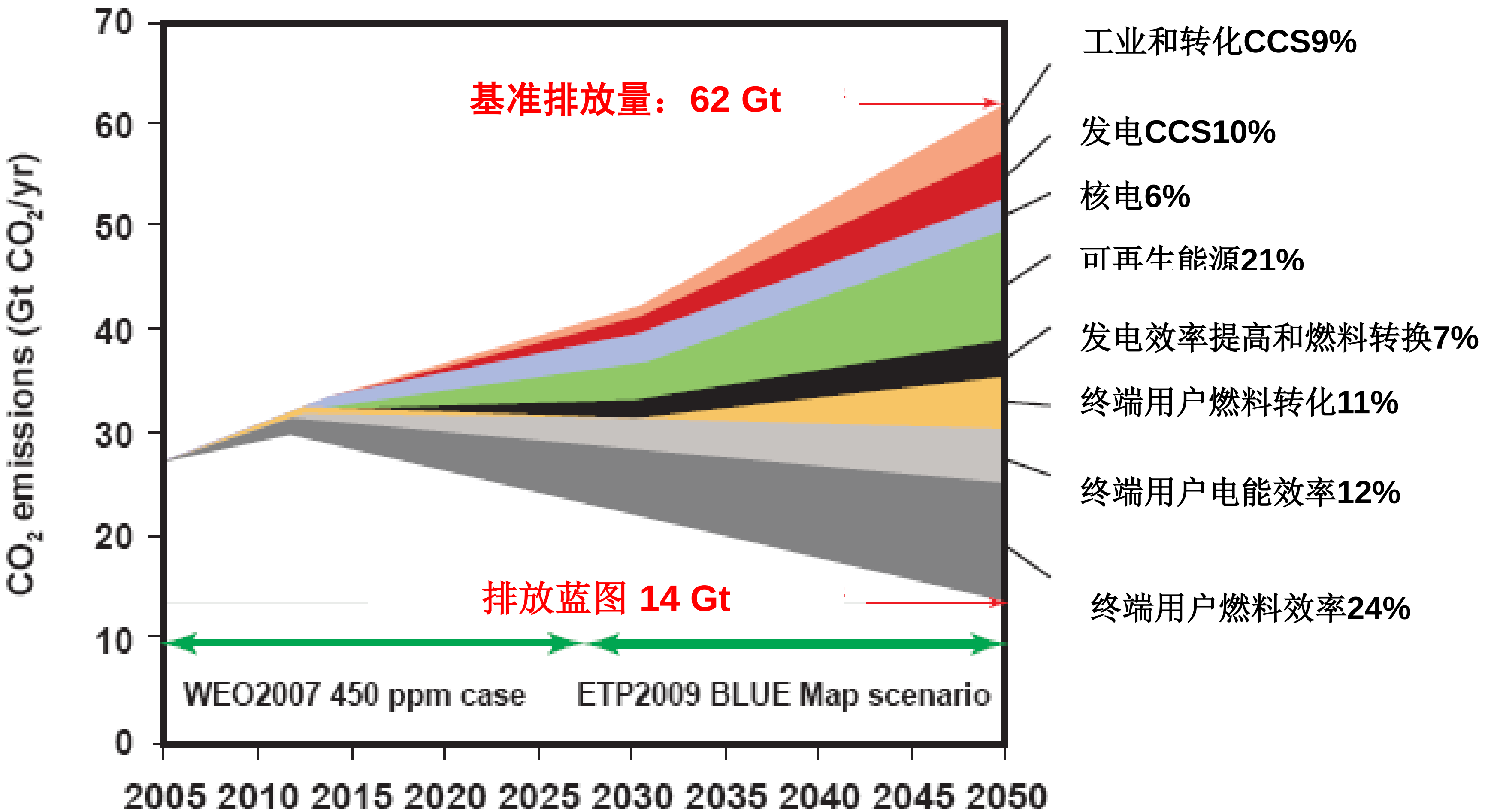
发电效率的比较，考虑CO_2捕集、忽略输运和存储



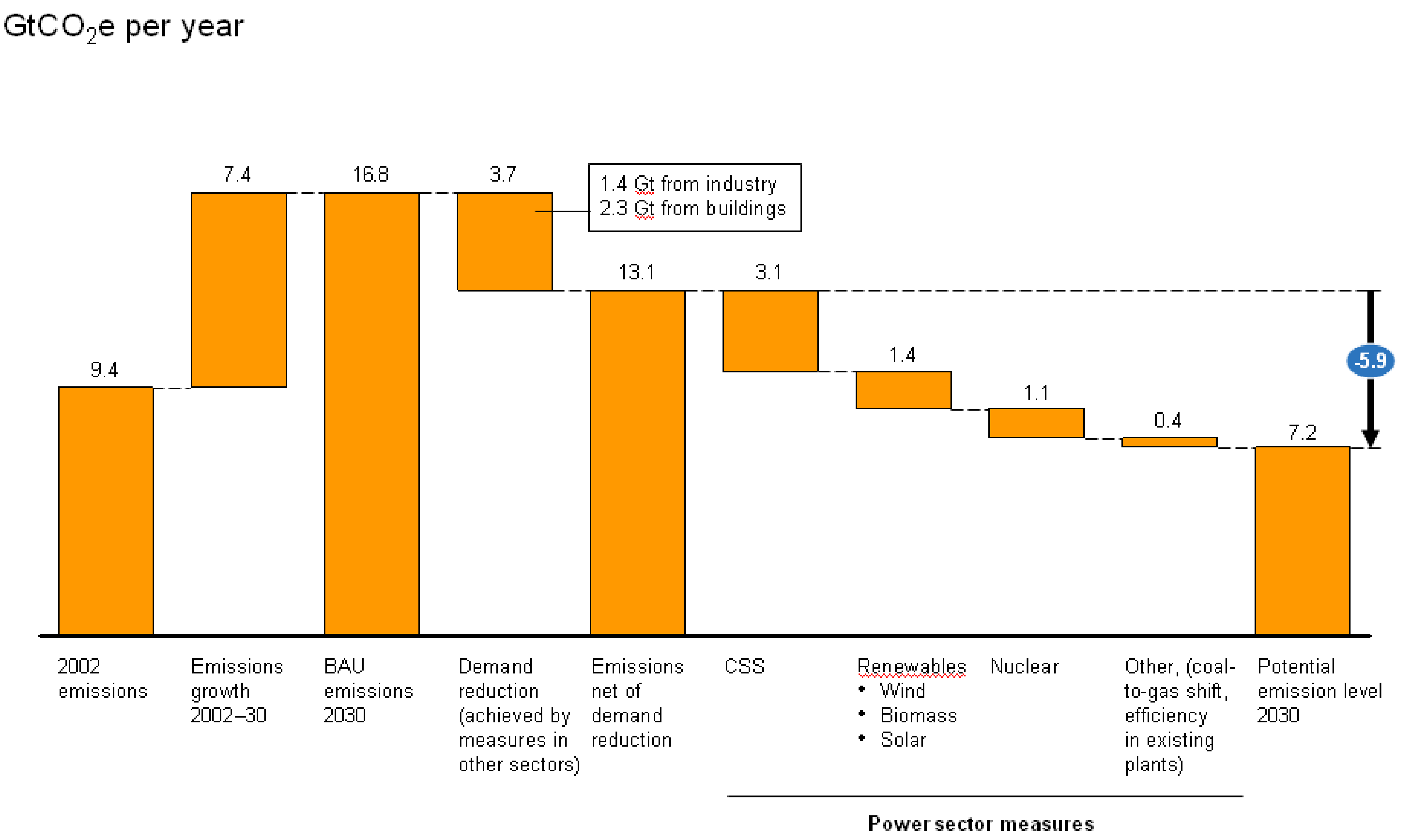
Contribution of industry technology segments to reduce CO2 emissions



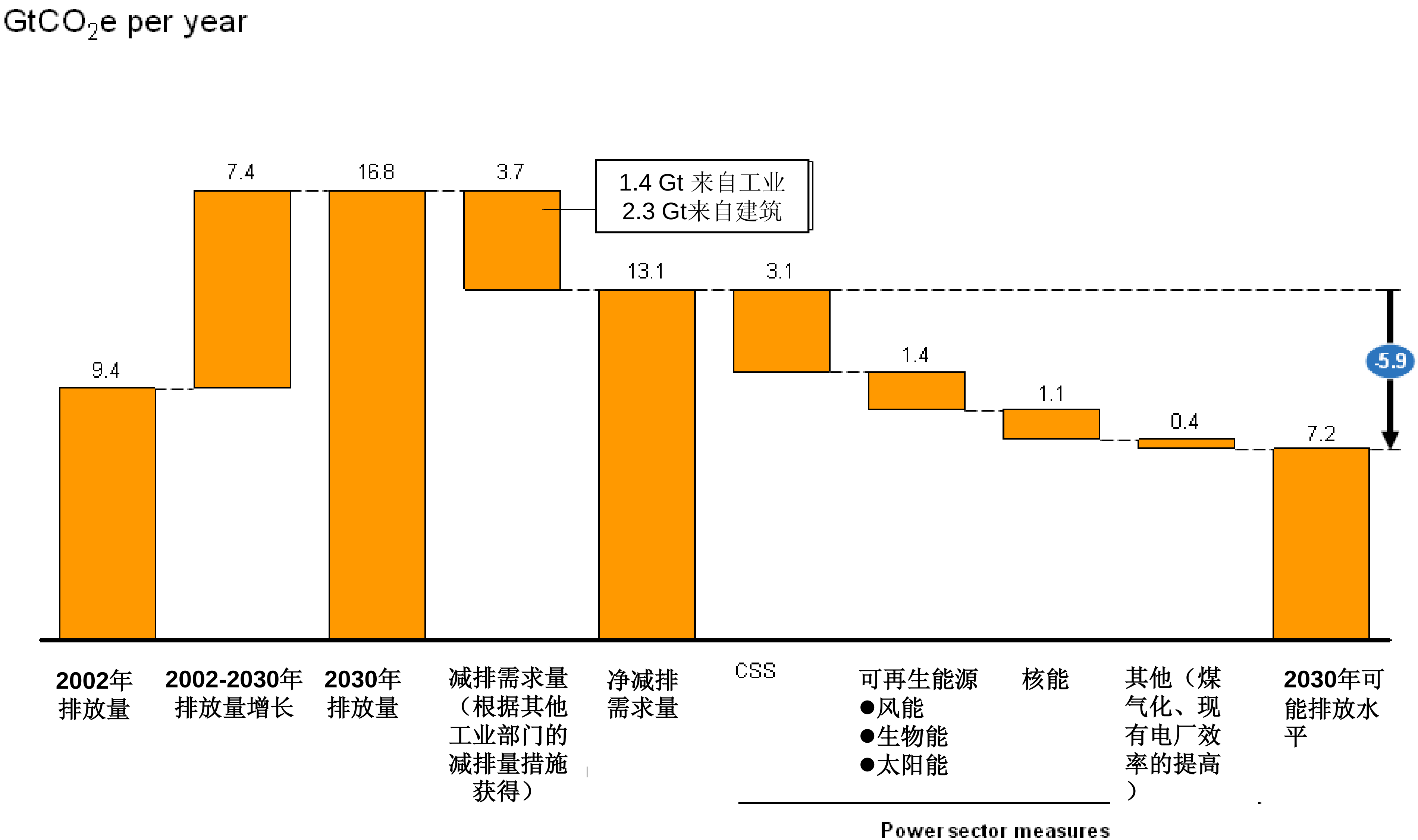
工业技术部门对减少CO_2排放的贡献



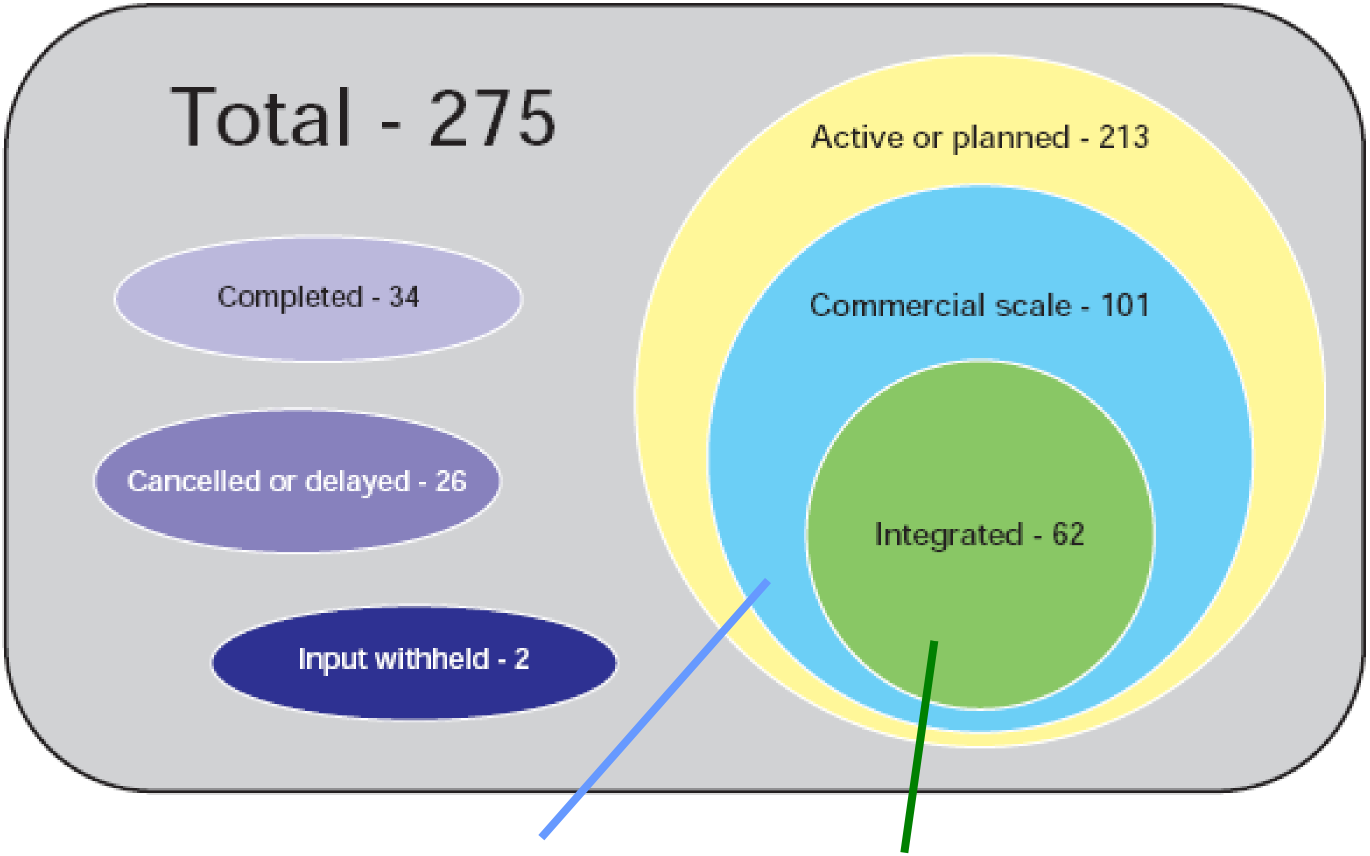
GHG global reductions in the power sector in 2030 – CCS significance



2030年全球温室气体在发电工业部门的减排——CCS的重要性



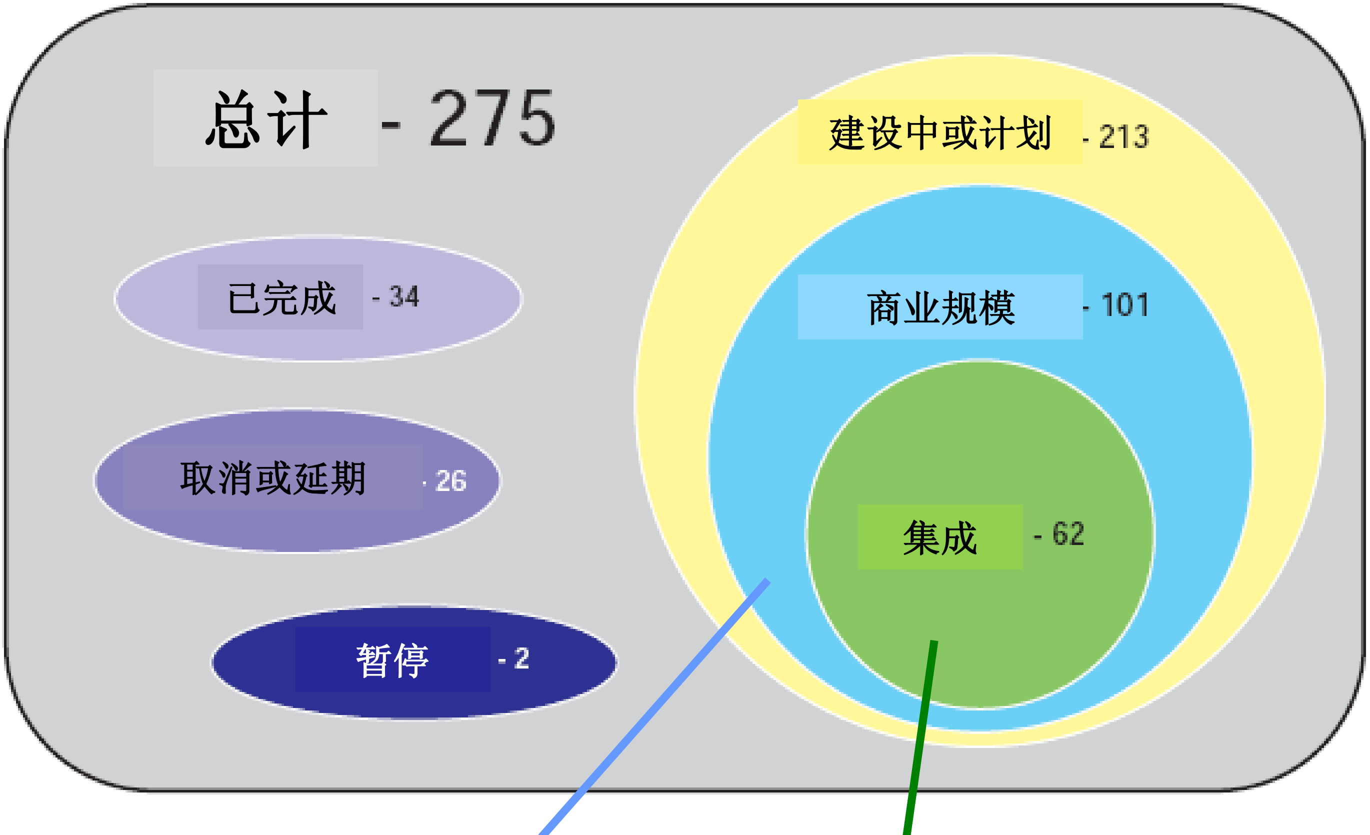
CCS projects worldwide



Commercial scale and **integrated** projects :

- projects storing or proposing to store 1 Mtpa or greater of CO_2
- CCS projects that are integrated, that is, combines the CO_2 capture

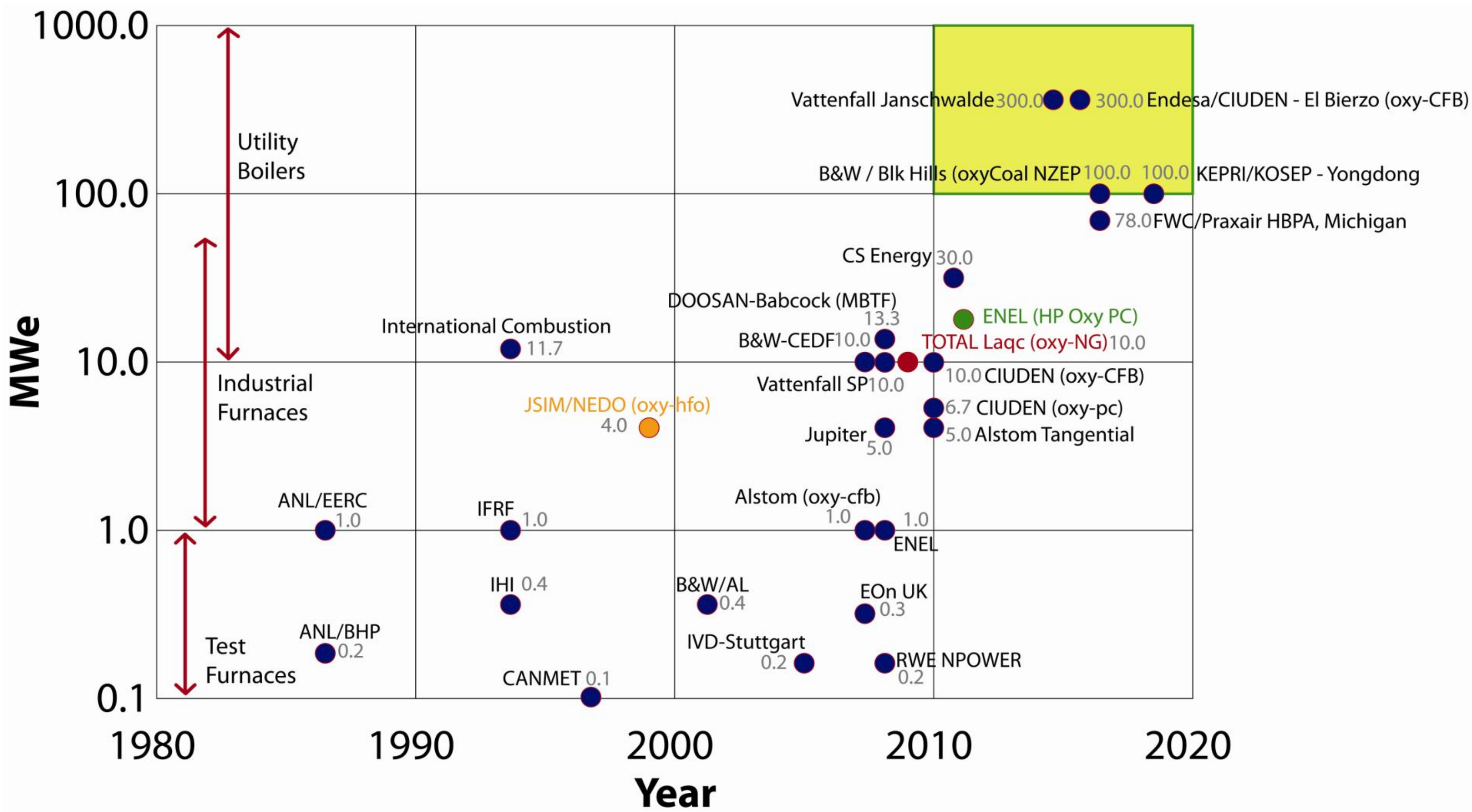
全球的CCS工程



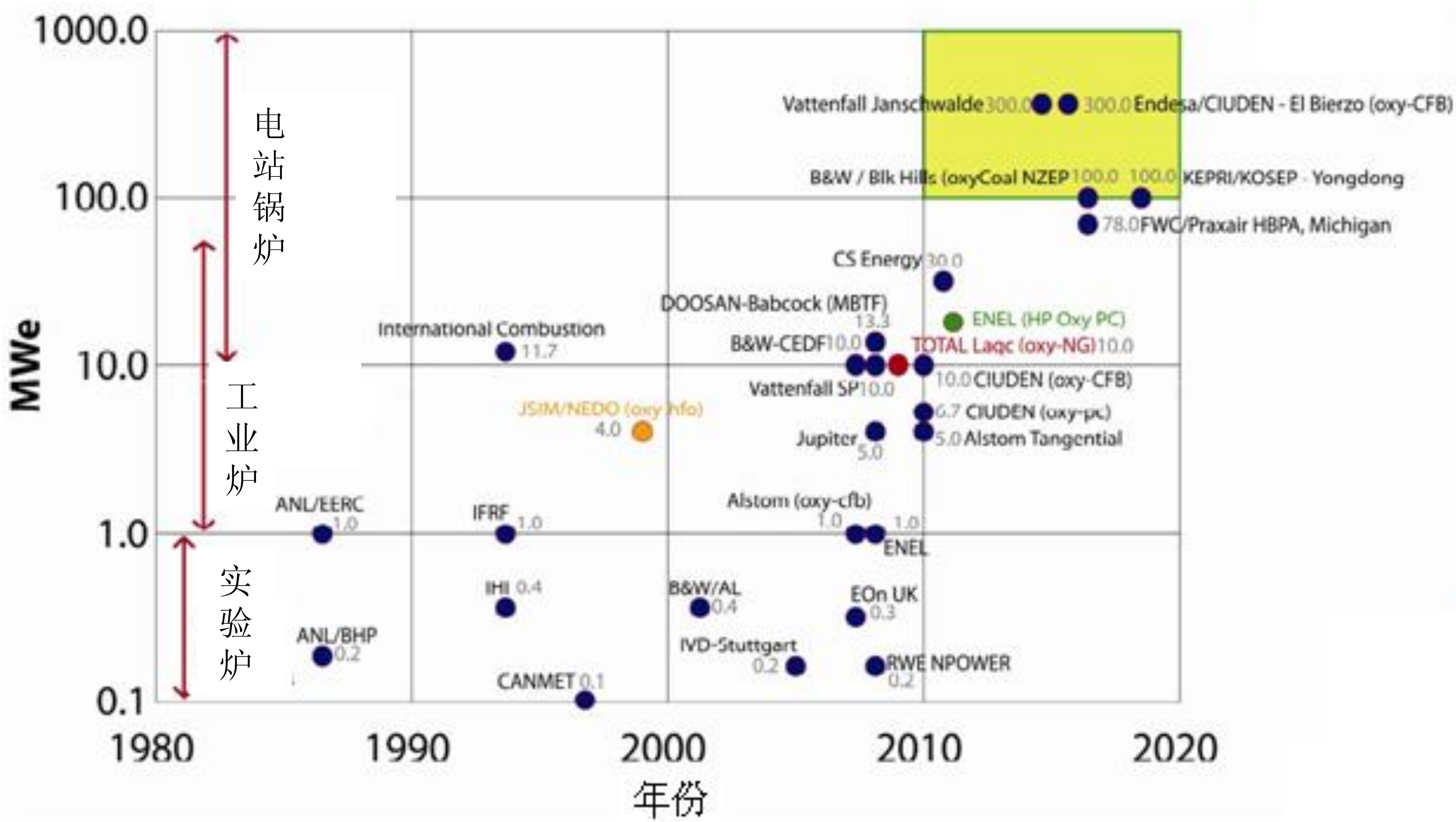
商业规模和 集成 工程：

- 每年存储或预计存储CO_2 超过1Mt的工程
- 集成CCS工程是指和CO_2 捕集相结合的工程

Historical progression of oxyfuel technology, with projects without electricity generation scaled to MWe/3



富氧燃烧技术的发展历程，包括规模不小于MWe/3的项目



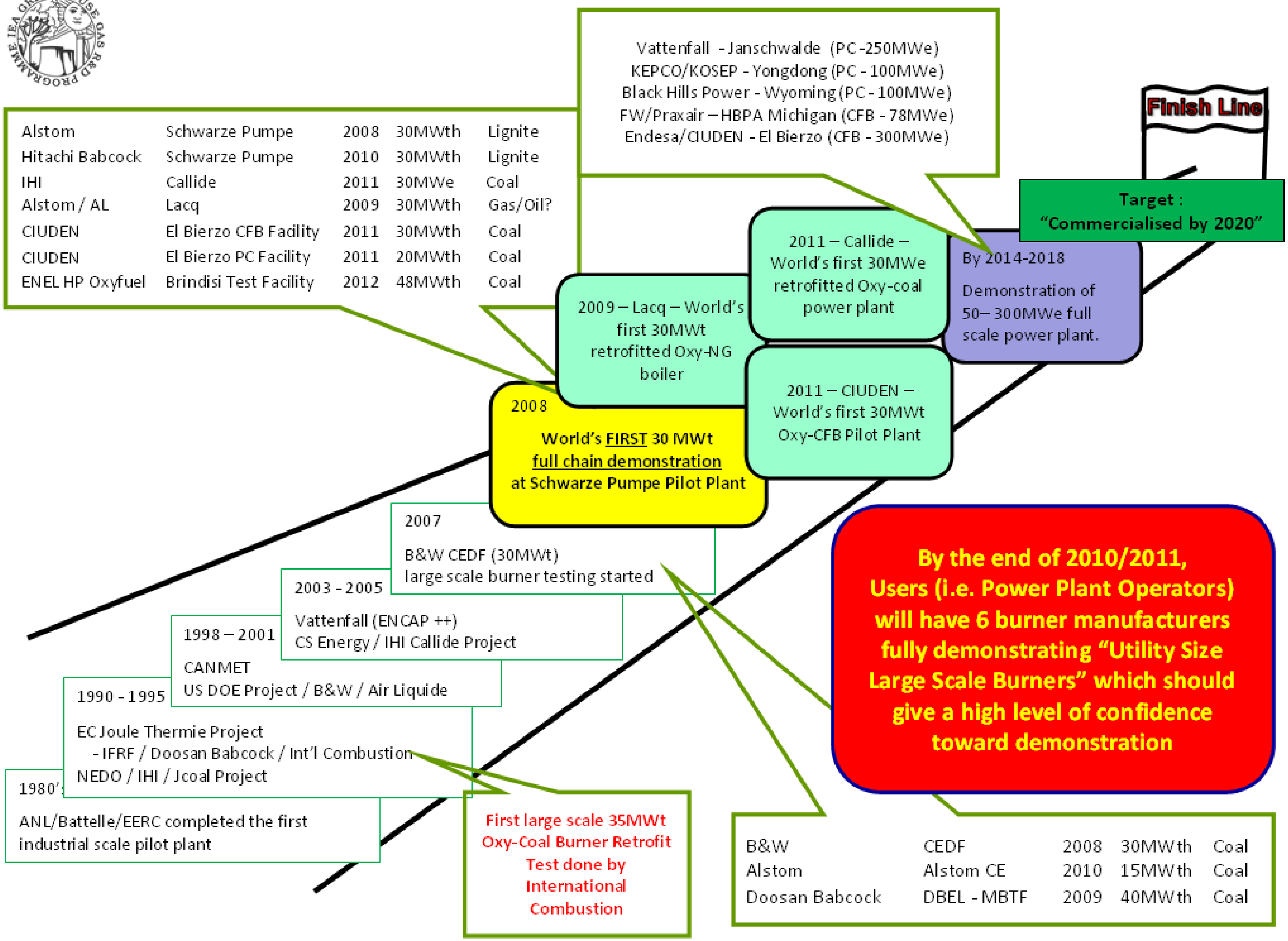
Oxyfuel pilot plants and demonstration projects

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	2011	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	
HBPA – 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	?	?

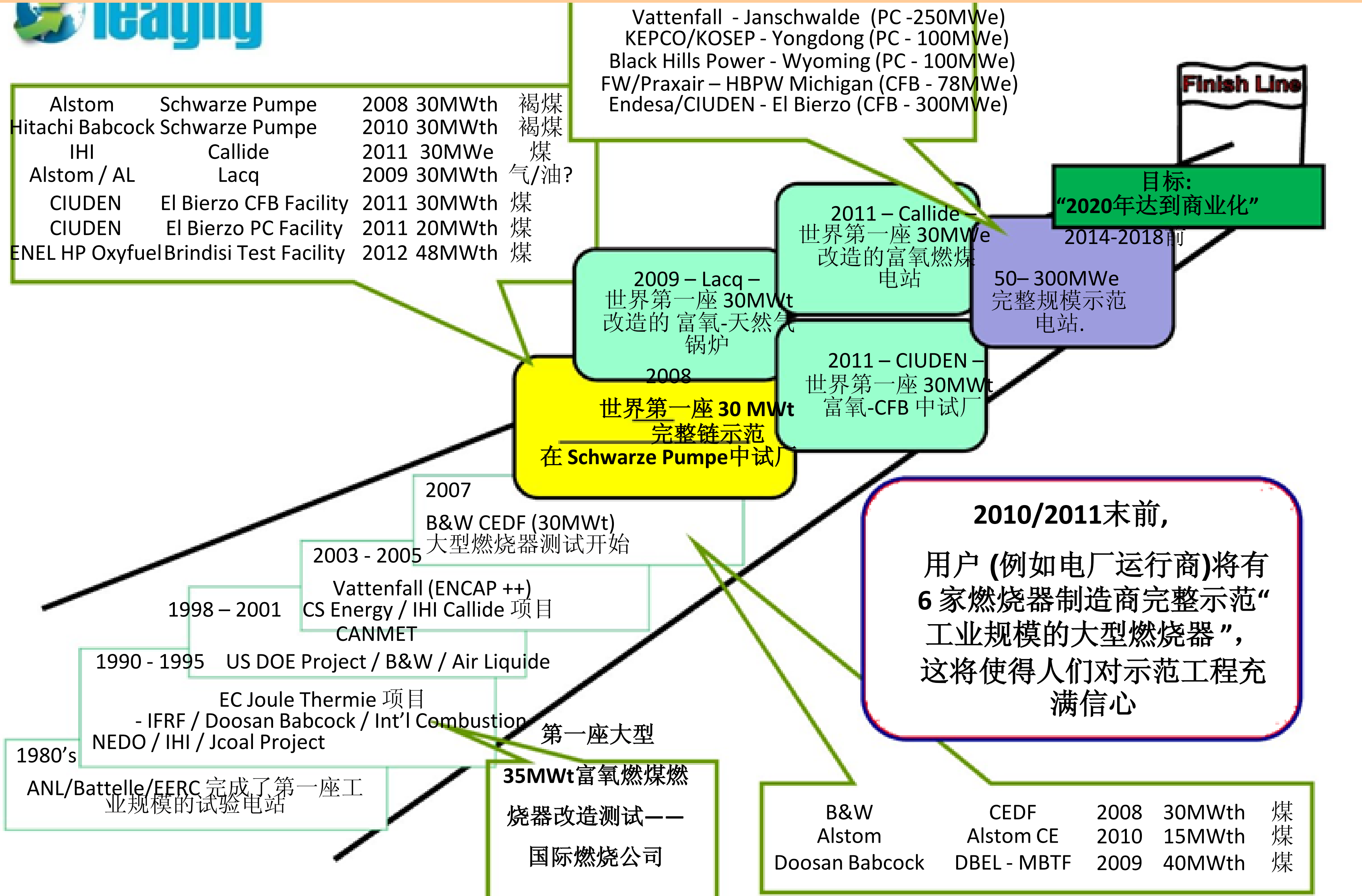
富氧燃烧中试厂和示范项目

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	?	?

Sequence to commercialization, proposed by S Santos, at the IEA Oxyfuel Conference, 2009

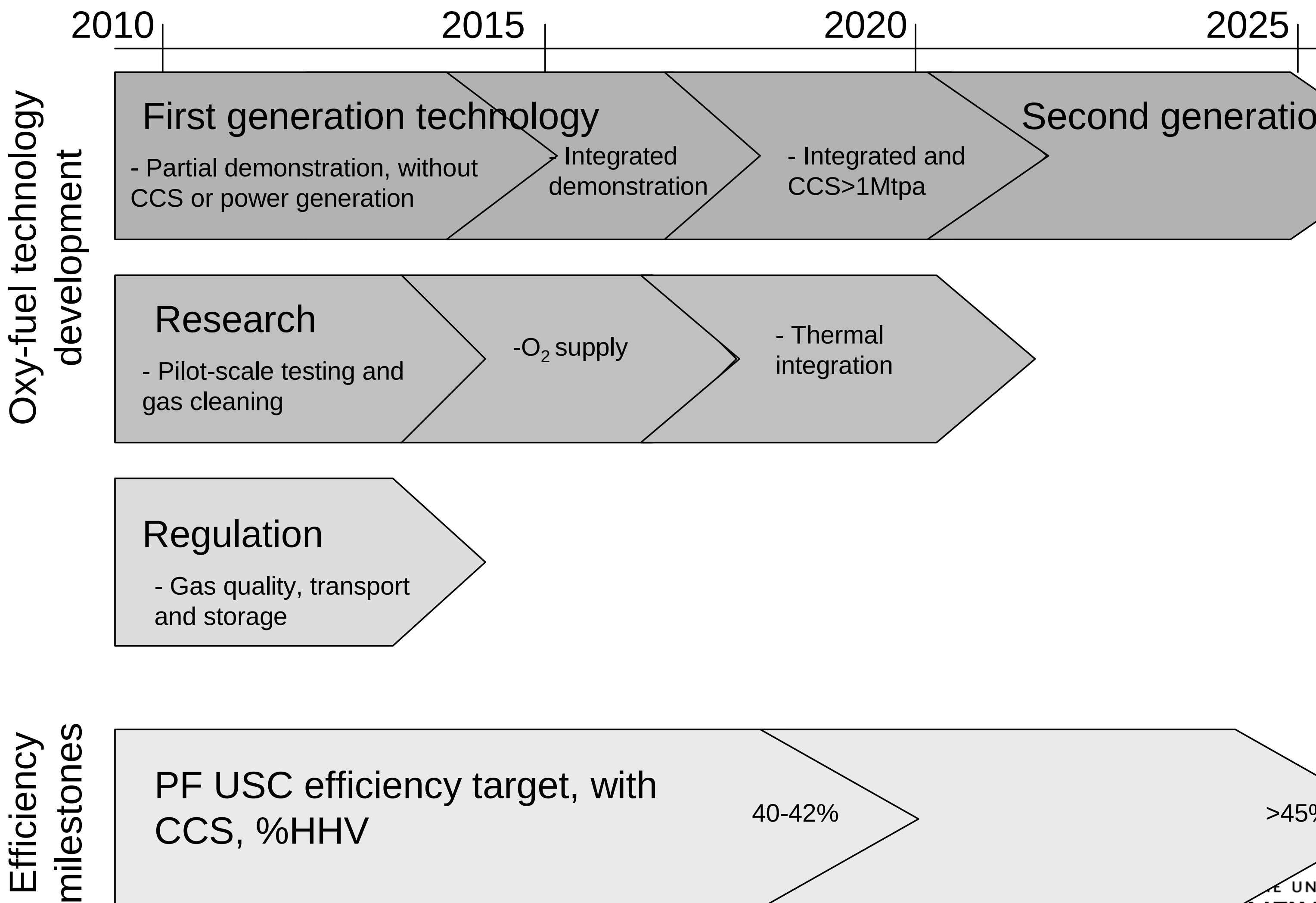


商业化进程
（引自S Santos在 2009年IEA 富氧燃烧会议上的报告）



由S. Santos更新 (05/09/09)

Components of the roadmap to deployment



富氧燃烧技术发展路线图