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Immediate Strategies for CO_2 Capture

实现二氧化碳收集的当前战略

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假如中国引入二氧化碳收集和储存技术，以下两项将会非常重要：

1. 降低成本 （尽可能降低给电力和化工产品带来的额外成本）

2. 加快实施的速度 （无论现有的还是新建的火电厂）

而二氧化碳收集的“当前战略”正是为两项目标服务。

If CO_2 capture and storage is introduced to China in the future it will want to be done:

1. **As cheaply as possible**
   (minimise additional cost of electricity, chemicals etc)
2. **Probably, as rapidly as possible**
   (Existing plant as well as new plant)

‘Immediate strategies’ are preparations for this.

Immediate strategies apply to all current capture technologies:

- Post-combustion
- Pre-combustion
- Oxyfuel

以下是“当前战略”所涵盖的收集技术：

- 燃烧后收集
- 燃烧前收集
- 氧燃料（二氧化碳混合气）燃烧后收集

1. Improve capture technologies to retrofit to the plants that will exist when capture is required
2. Build new fossil fuel plants so it is cheaper to retrofit capture
3. Develop new energy conversion technologies that will include capture from the start

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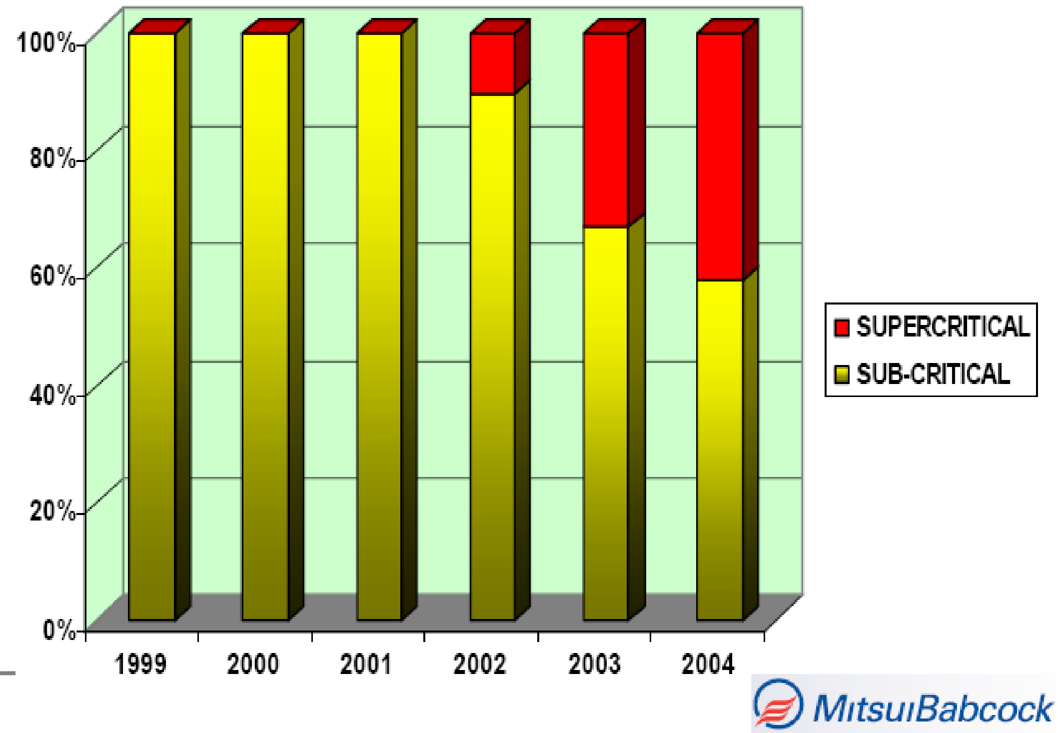
1. 提高收集的技术，可对已有发电站进行收集
2. 新的发电厂则可比已建的发电厂便宜地安装和使用收集装置
3. 开发新的，可在一开始就把二氧化碳收集囊括在内的能源转换技术

• 国务院发展研究中心的信息显示，到2020年，中国电力总装机容量将会达到950GW，至少是现在的两倍还要多，而煤依然是主要燃料，意味着中国可能仍需要兴建大量以煤为原料的的发电站。

• 另一方面，由于过去十年电力建设波动很大，将来的发展并不容易准确预测，但从现有的资料和情况来看，大体的趋势为：很多的超临界锅炉会投入使用，煤粉燃烧仍将主导一段较长的时间。

中国煤燃烧锅炉订单类型趋势 (>200MW)

Trend in Coal–FiredBoiler Orders



• **State Council DRC predicts that, China's total electrical capacity will reach 950GW by 2020, at least twice the current amount, and that coal will still be the main fuel.**

• **From present trends, supercritical power plant will dominate new construction for the foreseeable future.**

燃烧后收集二氧化碳的技术现况

1. 现阶段的研究主要集中于液体吸收溶剂（如胺）
2. 固体吸附以及二氧化碳“固化”是可发展的方向
3. 最好可配合超临界发电站
4. 吸收程度灵活性——能够通过调整收集的程度来实现最大的经济回报
5. 生物能的伴烧是容易的

Post-combustion capture

1. Current studies mainly use liquid solvents (amines)
2. Solid adsorbents and ‘frosting’ CO_2 by cooling also being considered
3. Best with supercritical power plant
4. Flexible – can adjust capture level to get best economic return
5. Co-combustion with biomass is easy

帝国学院积极参与燃烧后收集二氧化碳的研究包括：

1. 设法使得发电厂燃烧后回收二氧化碳变得更加可行
2. 提升联合蒸汽循环
3. 与**Fluor, Mitsui Babcock** 和 **Alstom** 合作共同为国际能源组织温室气体部门进行重要的工业研究
4. 加拿大正在建可在将来增加收集二氧化碳设计和装置的煤粉燃烧发电站

Work involving Imperial on post-combustion capture:

1. Rules to ensure good post-combustion capture from power plant
2. Improved integration with steam cycle
3. Industrial study for IEA GHG with Fluor, Mitsui Babcock and Alstom
4. New pulverised coal plant in Canada designed to have capture added later

帝国学院参与有关燃烧后收集二氧化碳的工作（续）：

5. 对现有的英国发电厂增加收集系统进行工业研究

6. 发电厂和收集系统整体优化研究才刚刚开始

7. 与Regina大学共同发展吸收溶剂

Work involving Imperial on post-combustion capture (Cont.)：

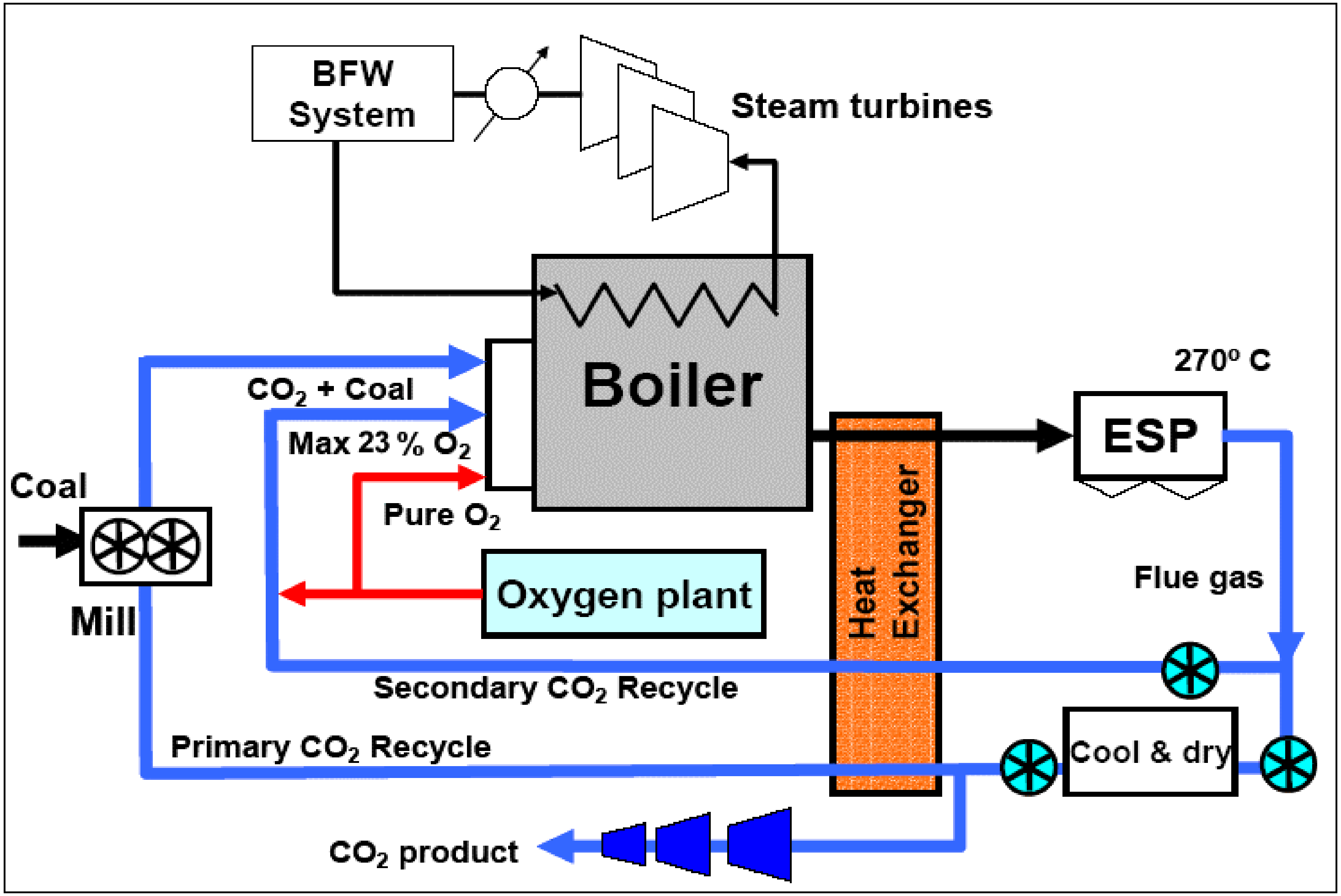
5. Industrial study on adding post-combustion CO_2 capture to existing UK power plants

6. New study with co-optimisation of power plant and capture system just starting

7. Solvent development with University of Regina

IEA GHG PH4/19, Potential for improvement in gasification combined cycle power generation with CO2 capture, May								
Pre-combustion capture on oxygen blown entrained flow gasifier IGCC plant		Shell gasifier				Texaco gasifier		
		Without capture	With capture	Capture penalty		Without capture	With capture	Capture penalty
Net power output	MW	776	676			826	730	
Efficiency	% LHV	43.1	34.5	8.6		38.0	31.5	6.5
Capital cost	$/kW	1371	1860	489		1187	1495	308
CO2 emissions	g/kWh	763	142			833	152	
CO2 captured	g/kWh		809				851	
Increase in fuel use due to capture				25%				21%
Electricity cost	c/kWh	4.8	6.3	1.5		4.5	5.6	1.1
IEA GHG PH4/33, Improvement in power generation with post-combustion capture of CO2, November 2004								
Post-combustion capture on advanced supercritical pulverized coal plant		Fluor amine technology				MHI amine technology		
		Without capture	With capture	Capture penalty		Without capture	With capture	Capture penalty
Net power output	MW	758	666			754	676	
Efficiency	% LHV	44.0	34.8	9.2		43.7	35.3	8.4
Capital cost	$/kW	1222	1755	533		1171	1858	687
CO2 emissions	g/kWh	743	117			747	92	
CO2 captured	g/kWh		822				832	
Increase in fuel use due to capture				26%				24%
Electricity cost	c/kWh	4.4	6.2	1.8		4.3	6.3	2.0

氧燃料燃烧的二氧化碳收集 | Oxyfuel Capture Concept



Source: IEA GHG

帝国理工参与的氧燃料燃烧收集二氧化碳工作：

1. 使用联合蒸汽循环来提高效率

2. 合作**Mitsui Babcock**，**Air product** 和**Alstom** 为**IEA**温室气体部门进行工业研究

3. 研究在英国发电站改装氧燃料燃烧二氧化碳收集系统

4. 与美国伙伴合作比较煤粉在空气中和在二氧化碳氧气混合气中燃烧

5. 对空气燃烧器和氧燃料燃烧器进行计算流体力学建模

Work involving Imperial on oxyfuel capture:

1. **Improved integration with steam cycle**
2. **Industrial study for IEA GHG with Mitsui Babcock, Air Products and Alstom**
3. **Industrial study on adding oxyfuel CO_2 capture to existing UK power plants**
4. **Comparing pulverized coal ignition in air and CO_2/O_2 mixtures (with US partners)**
5. **CFD modelling for air and oxyfuel burners**

IEA GHG PH4/33, Improvement in power generation with post-combustion capture of CO2, November 2004								
Post-combustion capture on advanced supercritical pulverized coal plant		Fluor amine technology				MHI amine technology		
		Without capture	With capture	Capture penalty		Without capture	With capture	Capture penalty
Net power output	MW	758	666			754	676	
Efficiency	% LHV	44.0	34.8	9.2		43.7	35.3	8.4
Capital cost	$/kW	1222	1755	44%		1171	1858	59%
CO2 emissions	g/kWh	743	117			747	92	
CO2 captured	g/kWh		822				832	
Increase in fuel use due to capture				26%				24%
Electricity cost	c/kWh	4.4	6.2	41%		4.3	6.3	47%

IEA GHG 2005/9 Oxy combustion processes for CO2 capture from power plants, July 2005								
Oxyfuel capture on advanced supercritical pulverized coal plant		Oxyfuel, cryogenic ASU				MHI amine technology (PH4/33)		
		Without capture	With capture	Capture penalty		Without capture	With capture	Capture penalty
Net power output	MW	677	532			754	676	
Efficiency	% LHV	44.2	35.4	8.8		43.7	35.3	8.4
Capital cost	$/kW	1513	2342	55%		1171	1858	59%
CO2 emissions	g/kWh	722	85			747	92	
CO2 captured	g/kWh		831				832	
Increase in fuel use due to capture				25%				24%
Electricity cost	c/kWh	4.9	7.3	49%		4.3	6.3	47%

燃烧后收集研究及示范项目的需要：

1. 更好的溶剂 （用于发电厂内）
2. 更便宜的二氧化碳收集装置
3. 装有气体净化装置及有关溶液寿命的示范性电厂

Post-combustion research and demonstration needs:

1. Better solvents (for use with power plants)
2. Cheaper capture equipment
3. Demonstrate gas cleanup and solvent life on real plant

氧燃料燃烧的研究及示范项目需要：

1. 专在氧气和二氧化碳混合气燃烧情况下使用的燃烧器

2. 进一步改善纯氧制造方法：如氧气分离薄膜

3. 研究及确定有关的安全准则

4. Vattenfall (德国**)(30MWth)**及**IHI(**澳洲**)(30MWe)** 有相关试验计划

Oxyfuel research and demonstration needs:

1. Burner designs for oxyfuel – need direct oxygen at the burner

2. Improved oxygen production methods – Ion Transfer Membranes

3. Understand safety implications

4. Vattenfall/Germany (30 MWth) and IHI/Australian (30MWe) trials planned

发电厂的“收集预留”的目标（为新电厂考虑）：

1. 提高回收的技术，可对已有发电站进行二氧化碳收集
2. 新的发电厂则可以在必要时用较便宜地安装和使用二氧化碳收集装置
3. 开发新的，可在一开始就把二氧化碳收集囊括在内的能源转换技术

Purpose of Capture Ready Power Plant

1. Improve capture technologies to retrofit to the plants that will exist when capture is required
2. Build new plants so it is cheaper to retrofit capture
3. Develop new technologies that will include capture from the start

对煤粉发电厂进行“收集预留”的通常准则：

基本要求

a) 在电厂及特定的位置有充足的空间，可以增建二氧化碳收集设备及相互连接的设备

b) 为添加二氧化碳收集设备而准备设计方案，来评估技术可行性及投资效率

经济效益将选择是否进行“收集预留”的投资 （基于净现值和取得回报可能性）

General principles for making pulverized coal plant capture ready

Fundamental requirements:

a) Sufficient space on site and in critical access locations to add CO_2 capture plant and necessary interconnections.

b) Design study for adding CO_2 capture, to assess technical feasibility and cost-effectiveness.

Plus <u>optional</u> pre-investments, <u>depending on economic justification</u>

(based on NPV <u>and</u> probability of benefiting from the investment)

对煤粉发电站而言，可选择的预投资有：

1.建“收集预留”**IGCC**发电站，而不是“收集预留”的煤粉发电站

2. 对燃烧后收集

a) 高效**(**或可升级的）脱硫装置（如果脱硫装置需要安装）

b) 修正气轮机以帮助蒸汽的抽出

3. 对氧燃料收集

a) 可支持换热器和管道的插入

b) 准备鼓风机以改变气流方向

Possible pre-investment options for pulverised coal steam plant are:

1. Build capture ready IGCC (i.e. not just ordinary IGCC) instead of PC

2. For post combustion capture:

- **a) High efficiency (or upgradeable) FGD (if FGD is required)**
- **b) Turbine modifications to facilitate steam extraction**

3. For oxyfuel capture:

- **a) Support tie-ins for heaters and recycle ducts**
- **b) Provision for fans to operate under changed flows**

燃烧前"收集预留"

1. IGCC可能会有些问题, 如气轮机与气化装置及供氧设备在收集前配合

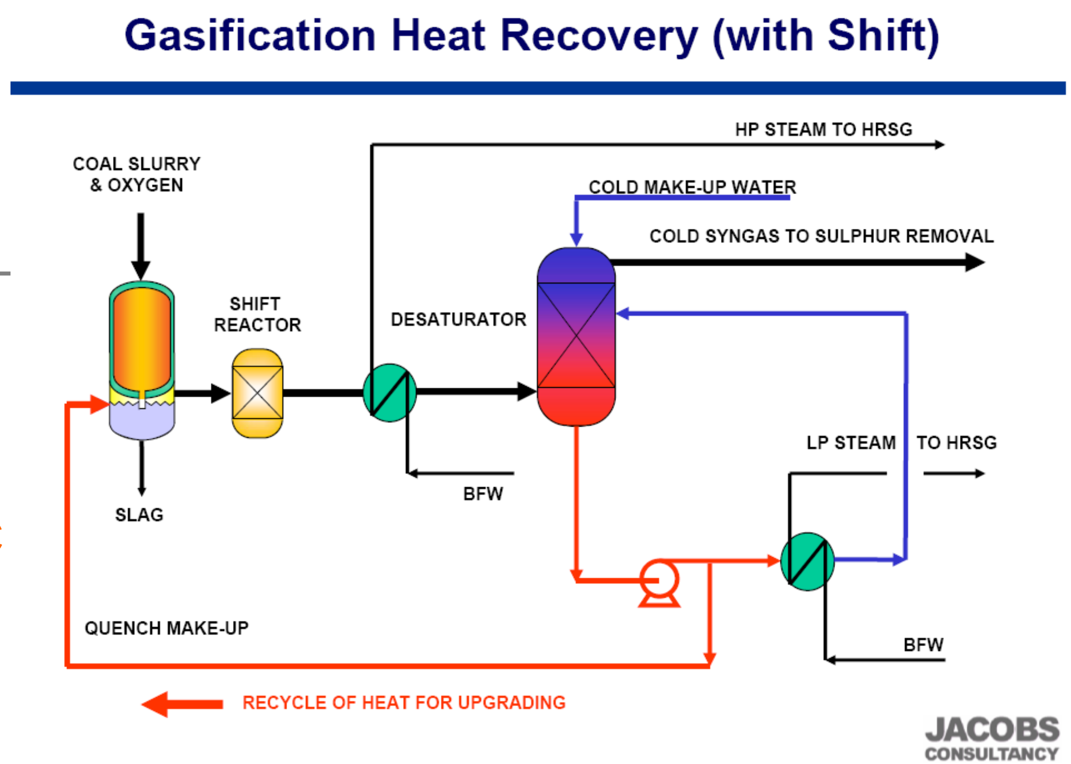
2. 对化工厂，尤其是生产氢气的厂会更容易完成。

Pre-combustion capture ready

1. **Problem for IGCC, if gas turbine is matched to gasifier and oxygen plant before capture is added**
2. **Easier for chemical plants, especially if making hydrogen**

可能办法是将**IGCC**的变换反应炉置前以及回收热散失

Possible alternative for IGCC – have shift from the start and recover the losses



Possible benefits for making plants capture ready

“收集预留” 的可能潜在回报

Adding capture to:		收集预留 Capture ready		没有收集预留 Capture un-ready	
		IGCC	**PC**	**IGCC**	**PC**
Original efficiency 原效率	%LHV	40.0%	42.0%	40.0%	42.0%
Efficiency penalty 效率损失	%LHV	6.5%	8.5%	7.5%	9.5%
Additional electricity cost for reduced output		**19.4%**	**25.4%**	**23.1%**	**29.2%**
Capture plant capital cost ($/kW, % above original)		30.0%	50.0%	45.0%	75.0%
Capture plant capital cost as % of original capital cost		10.6%	24.6%	21.9%	45.8%
Capture plant capital cost contribution to electricity cost for original fuel cost fraction shown	30%	**7.4%**	**17.2%**	**15.3%**	**32.0%**
Loss of 1 year production added to next 20 years at 10% discount rate, % of cost/yr	11.7%			**8.2%**	**8.2%**
Fuel cost fraction (avoided costs)	30%				
Total additional electricity cost, based on ORIGINAL cost for THAT technology 相对回收前电力成本的百分率		**26.8%**	**42.6%**	**46.6%**	**69.5%**

尽管煤粉燃烧发电站收集装置的资本性投资较大，但**IGCC**的原始资本性投资较高

With current technology higher capital cost to add capture to PC, but initial capital cost for IGCC probably higher

Possible benefits for making plants capture ready

“收集预留” 的可能潜在回报

Adding capture to:		收集预留 Capture ready IGCC	收集预留 Capture ready PC	没有收集预留 Capture un-ready IGCC	没有收集预留 Capture un-ready PC
Original efficiency 原效率	%LHV	40.0%	42.0%	40.0%	42.0%
Efficiency penalty 效率损失	%LHV	6.5%	8.5%	7.5%	9.5%
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Fuel cost fraction (avoided costs)	30%				
Total additional electricity cost, based on ORIGINAL cost for THAT technology 相对收集前电力成本的百分率		**26.8%**	**42.6%**	**46.6%**	**69.5%**

		Capture ready PC	Capture un-ready PC
CO2 emissions without capture	tCO2/MWh	0.8	0.8
CO2 emissions with capture	tCO2/MWh	0.1	0.1
Cost of electricity without capture	RMB/MWh	350	350
Cost of electricity with capture	RMB/MWh	499	593
CO2 abatement cost (excluding storage)	**RMB/tCO2**	**213**	**347**
Assuming RMB10 = 1 Euro	**Euro/tCO2**	**21**	**35**

结论：

以下三个当前的战略，是相辅相成，不可或缺的：

1. 提高收集的技术，可对已有发电站进行收集

2. 新的发电厂则可用比已建成发电厂便宜的安装收集装置 （也就是“收集预留”）

3. 开发新的能源转换技术，其中二氧化碳收集被考虑在最初的构想中

Conclusion:

Three immediate strategies, all are needed:

1. **Improve capture technologies to retrofit to the plants that will exist when capture is required**
2. **Build new plants ‘capture ready’ so it is cheaper to retrofit capture**
3. **Develop new technologies that will include capture from the start**

结论（续）：

4. 煤粉发电厂的效率与**IGCC**及其他电厂相比，是具有竞争力的。完全有必要将煤粉发电厂列于二氧化碳收集的战略中。

5. 英国工贸部与中国科技部合作的关于“二氧化碳收集做充分准备”的项目已经被列入计划，并正在寻求潜在的伙伴

Conclusion (Cont.):

4. Pulverised coal efficiency with capture comparable to IGCC and many plants – need to include PC in capture strategies

5. New DTI/MOST initiative on ‘getting ready for CO_2 capture’ planned – looking for potential partners

我们能不能用下面的中文作为二氧化碳“收集预留”的广告词呢？

Could we use this old Chinese Phrase to advertise “Capture Ready” Project?

未雨绸缪，利大于弊

“In Fair Weather Prepare for Foul”

谢谢!

Thank you!

Getting ready for carbon capture and storage: Canadian progress

Overview

Canadian industry is making preparations for a future in which carbon dioxide from fossil fuel production and utilisation activities that would otherwise be released to the atmosphere is captured and placed securely underground. The techniques being developed can make a significant direct contribution to reducing future Canadian CO_2 emissions. Even greater reductions in global emissions are possible through technology transfer and capacity building in other economies with large scale use of fossil fuels, notably the USA, China and India.

Commercial progress in carbon dioxide capture in Canada is taking place along two main avenues. Novel capture technology options are being developed to allow carbon dioxide capture from new power plants using proven coal combustion equipment. Established capture technologies for carbon dioxide in high pressure gas streams are also being considered for use with less-proven gasification plants. This multi-track approach mirrors global developments as the world gets ready, for the first time, for constraints on CO_2 emissions from fossil fuel power plants.

Canada also leads global developments in CO_2 storage in depleted oilfields, with the Weyburn project in Saskatchewan. Canada has, in addition, been investigating enhanced coal bed methane opportunities and technology development and studying acid gas injection as an industrial analogue for geological storage of CO_2.

Industrial developments in CO_2 capture are supported by a number of university and government research centres, including the Canadian Centre for Mineral and Energy Technology (CANMET), the International Test Centre for CO_2 Capture (ITC) and the University of Waterloo (UoW) among others.

'Getting Ready for CO2 Capture'

The title of this paper deliberately uses the terminology 'getting ready for CO_2 capture' as opposed to 'capture ready'. The rationale here is that, although the concept of making new power plants 'capture ready' is beginning to be discussed, this is only one element of the preparations that are required to be able to deploy CO_2 capture and storage effectively at some time in the future. Apart from engineering the necessary flexibility and space to accommodate CO_2 capture equipment in new plant to make them 'capture ready', the scope for their later conversion will also depend critically on research, development and demonstration work over the intervening period to improve the performance and reduce the capital cost of adding capture, also the provision of effective and socially acceptable storage options. It is also quite likely that some technology options could be very effective if capture was required from the outset, but would not be so competitive to build as 'capture ready' before capture was required. So 'getting ready for capture' implies a multi-track approach:

a) Making sure that new fossil fuel plants of all types are built so that, within the limits of the best current understanding, they can have capture retrofitted in the future with the minimum additional cost and performance penalty.

b) Improving the technologies that will be needed to convert these 'capture ready' plants (and other existing plants) to capture CO_2, and feeding experience from this back into capture ready plant design.

c) Making sure that any additional technologies that may not be so competitive until CO_2 capture becomes the norm are also developed for rapid deployment then.

d) Developing proven and socially acceptable CO_2 storage options.

A range of technology options will be appropriate for all of these tracks, depending on numerous site specific factors, including the type of coal used, goals of the power station (polygeneration, electricity only etc.), the timing of addition of capture facilities and other pollutant capture requirements. 'Getting ready for capture' therefore describes a process that will lead us down the road of fully understanding the implications for the design and application of a broad range of capture and storage technologies. Because of the diversity of the Canadian energy market, however, Canada is in a good position to cover major elements of the varied technology portfolio required. The most advanced examples are described below.

'Capture ready' combustion plant and post-combustion capture

The Canadian Clean Coal Power Coalition has examined the scope for carbon dioxide capture from coal-fired electricity generating facilities. As a direct outcome of that work, SaskPower is currently undertaking a prefeasibility study for a new 350-450 MW power plant burning low-rank Saskatchewan lignite that will have the latest emission controls for oxides of sulphur and nitrogen and mercury and will also be able to have equipment added to 'scrub' carbon dioxide from the flue gases before they are emitted to the atmosphere. Costs using current technology are estimated to be approximately 40$Can/tonne CO_2 captured, but will be reduced over time since this is a new application with significant scope for learning. New pulverised coal or fluidized bed combustion power plants can be built 'capture ready' for post-combustion capture from the flue gases at minimal additional cost. Capture equipment can then be added later without taking the plant off-line for extended periods and without unnecessary expenditure or unavoidable loss in plant performance.

The low additional costs for building 'capture ready' combustion plant are an advantage for rapid deployment in the large numbers of new coal power plants currently being built in several of the world's rapidly growing economies, but it is also essential that the full-scale capture technology is demonstrated as soon as possible. This will both establish the commercial viability of this option and start the process of commercial development and demonstration that is required to reduce costs in advance of the time when capture is required for large amounts of recently-built plants.

Gasification, polygeneration and pre-combustion capture

The other major commercial-scale Canadian CO_2 capture initiative is centred around plans to gasify petroleum coke, residual hydrocarbon liquids and/or coal to provide hydrogen, heat and electric power (including a surplus for export) for tar sand processing in northern Alberta and heavy oil elsewhere. Gasifiers normally make large amounts of carbon monoxide gas and this has to be 'shifted' to carbon dioxide and hydrogen by reaction with added steam before 'pre-combustion' CO_2 capture. Both the costs and the energy losses associated with this shift reaction are minimised if hydrogen is required already. Similarly, performance can be improved if not all the fuel has to be converted to a hydrogen product, but can also be used to make electricity, and there is a use for low grade heat from the electricity generation plant. This type of 'poly-generation' plant will generally allow more effective use of gasification technology than stand-alone 'integrated gasification combined cycle' (IGCC) plants producing only electricity.

Nexen is currently constructing a polygeneration plant in northern Alberta to produce hydrogen and electricity. Carbon dioxide capture is being actively considered for enhanced oil recovery in conventional oil bearing regions of Saskatchewan and Alberta offering some potential for CO_2 capture from this facility, either as soon as the plant is built or at some time in the future. Globally, high natural gas and oil prices mean that gasification plant is being built or planned in a number of countries, giving a clear route for wider applications of any gasification-based CO_2 capture technology demonstrated in Canada.

Pre-combustion and post-combustion capture for new power plants

Recent IEA studies have compared the performance of new power plants built with and without CO_2 capture and compression. All relevant factors such as fuel, ambient conditions, interest rates etc. were the same for all studies. Relative differences between plant thermodynamic and economic performance will vary slightly with the absolute factor values selected, but the overall trends are that differences between predicted performance for current pre- and post-combustion capture technologies are not striking. The efficiency drop for building a plant with capture is lowest for the Texaco (now GE) gasifier, but this can be explained by the inclusion of wet quench cooling. This lowers the efficiency without capture but is an advantage when the gas stream needs to be loaded with steam to promote 'shifting' carbon monoxide to carbon dioxide for pre-combustion capture. More significant is the low capital cost for the Texaco gasifier design and hence low overall cost of electricity, but in the current North American power plant market it appears that the price differential between IGCC and supercritical pulverized coal plants without capture is somewhat higher than the 0.1 c/kWh shown here. It is not yet clear, however, how capital costs for these two very different electricity generation technologies will compare if IGCC becomes more widely deployed in the market.

IEA GHG PH4/19, Potential for improvement in gasification combined cycle power generation with CO2 capture, May 2003.

Pre-combustion capture on oxygen blown entrained flow gasifier IGCC plant		Shell gasifier			Texaco gasifier		
		Without capture	With capture	Capture penalty	Without capture	With capture	Capture penalty
Net power output	MW	776	676		826	730	
Efficiency	% LHV	43.1	34.5	8.6	38.0	31.5	6.5
Capital cost	$/kW	1371	1860	489	1187	1495	308
CO2 emissions	g/kWh	763	142		833	152	
CO2 captured	g/kWh		809			851	
Increase in fuel use due to capture				25%			21%
Electricity cost	c/kWh	4.8	6.3	1.5	4.5	5.6	1.1

IEA GHG PH4/33, Improvement in power generation with post-combustion capture of CO2, November 2004

Post-combustion capture on advanced supercritical pulverized coal plant		Fluor amine technology			MHI amine technology		
		Without capture	With capture	Capture penalty	Without capture	With capture	Capture penalty
Net power output	MW	758	666		754	676	
Efficiency	% LHV	44.0	34.8	9.2	43.7	35.3	8.4
Capital cost	$/kW	1222	1755	533	1171	1858	687
CO2 emissions	g/kWh	743	117		747	92	
CO2 captured	g/kWh		822			832	
Increase in fuel use due to capture				26%			24%
Electricity cost	c/kWh	4.4	6.2	1.8	4.3	6.3	2.0

Carbon dioxide geological storage

Canada hosts the world's first demonstration of carbon dioxide storage as part of an enhanced oil recovery (EOR) CO_2 flood, at the Weyburn field in southern Saskatchewan. This EOR project is receiving some 5,000 tonnes or more per day of CO_2 generated at a coal gasification (for methane synthesis) plant in North Dakota. The research associated with this EOR project is designed to demonstrate the integrity of geological storage and other issues surrounding the geological storage of CO_2. Preliminary findings indicate the technical success of EOR with CO_2 as well as demonstrating that monitoring of the CO_2 movement in the subsurface is feasible. Early results strongly indicate the long-term safety of storage in this type of environment, although much work remains to be done to confirm these preliminary studies. Globally, there is intense interest in the results coming from this project.

Research activities

On the capture side, significant research is underway at Canadian institutions to better understand the operational issues associated with large scale capture, the development of new technologies and helping to develop 'capture ready' facilities. This work includes:

- ITC (the International Test Centre for CO_2 Capture) - post combustion capture technology development. Facilities include two pilot plants, a one tonne per day using a flue gas stream from the combustion of natural gas and a four tonne per day attached to a lignite-fired electrical generating station, to demonstrate at scale both process improvements and new chemicals for CO_2 capture from flue gases. Outputs are demonstrating the extensive opportunities for cost reductions in potential commercial operations.
- CETC (CANMET Energy Technology Centre) - oxyfuel combustion for CO_2 capture. Work at the Ottawa facilities is designed to demonstrate at the pilot scale the denitrification of the flue gas before combustion. In this system, the fossil fuel is combusted in relatively pure oxygen, moderated by recycling combustion gases from the combustor. In this way, the concentration of CO_2 in the flue gas can become high (90% plus) making it essentially ready for storage. For EOR, additional purification may be required depending on the nature of the contaminants. One of the most significant benefits of this methodology is the ability to capture other pollutants along with the CO_2 stream and to store these safely in the subsurface.
- University of Waterloo - system modelling. The University of Waterloo has developed capacity in system modelling for better understanding of the relative merits of different methods of capture from the combustion of fossil fuels. Work at Waterloo also includes the development of membranes for use in the separation of gases to purify the CO_2 in a flue gas stream.
- Other institutions in Canada have expertise in activities such as gasification. These can be further developed to provide greater insight into opportunities for Canada in the future.

Weyburn Field

In the late 90's, a major Canadian oil company, PanCanadian Petroleum Limited (now EnCana Corporation) announced plans to undertake a large-scale CO_2 Enhanced Oil Recovery (EOR) operation on a mature field in southern Saskatchewan. The field was nearing the end of its prime production, and some form of enhanced recovery would be needed to keep the field viable. The company also indicated that they would be interested in operating the program as a demonstration project for CO_2 geological storage. This opportunity possessed all of the key elements for a sufficiently large storage demonstration project: a large-scale EOR program in a partially depleted reservoir, an anthropogenic CO_2 source, a reservoir appropriate for storage, and an opportunity to collect a baseline dataset. However, this site also offered something that could not be found at any other site in the world – a vast and publicly accessible collection of historical records dating back to the discovery of the field. All of this data was available to the researchers to provide a thorough historical dataset in addition to the pre-injection dataset. Thus, there could be no better picture of a suitable reservoir.

The essential findings of the project were that the CO_2 will be safely contained and the storage project can be economic. Geological settings such as the Weyburn reservoir appear to be highly suitable for long-term storage of CO_2. A good geological description of the reservoir and a large surrounding area was developed, demonstrating that the regional geology provides multiple containment zones. If CO_2 were to leak past the primary sealing caprock, there are a number of other zones with sealing capacity and several saline aquifers above the primary storage zone. However, caprock integrity issues were examined and found to be negligible. The risk assessment modelling showed that CO_2 will almost certainly never reach or penetrate overlying saline water zones through geological formations, nor will it reach either potable water zones closer to the surface or the ground surface above the storage reservoir. Numerical simulations showed that, after 5000 years, 100% of the CO_2 will remain stored underground. Of this, 73.2% will remain in the Midale reservoir, where it was injected, 18.2% will seep into the geosphere below the reservoir, 8.6% will migrate within the Midale reservoir to areas outside the initial EOR zone, and only 0.02% will seep to the geosphere above. Geochemical fluid sampling allowed researchers to track the CO_2 in the reservoir. Seismic surveys were able to detect the changes in the reservoir that result from CO_2. As a result, we can essentially 'see' the movement of CO_2 in the reservoir.

Capture ready power plant options for IGCC and PC

The ideal 'capture ready' approach would allow a plant to be built which had the both the same costs and performance as a normal plant without capture when it was built, and then also the same performance and equivalent capital cost as a plant that was built with capture from the outset after capture is added at some time in the future.

In achieving this 'capture ready' ideal, there is a fundamental difference between PC and other combustion plants and conventional IGCC. Carbon dioxide (CO_2) must be produced to be captured. Pulverized coal and fluidized bed combustion plants do this in their normal configuration. Post-combustion capture units can then be added to 'scrub' the CO_2 out of the combustion products (e.g. using an amine solvent) before they go to the chimney. The only major change required to the original plant is adding a pipe to take steam out before it is fully used in the turbine, so that it can be used to heat up the solvent to release the CO_2. This reduces the power output from the turbine; more power is also required to run compressors and pumps associated with the capture plant.

In normal IGCC plants, most of the carbon in the fuel is converted to carbon monoxide (CO) to use as a fuel, not to carbon dioxide. To allow pre-combustion capture of CO_2 the carbon monoxide must first be shifted to CO_2, with its fuel value transferred into extra hydrogen and heat (some of which can be recovered as steam for power generation). The CO_2 is then removed from the pressurised gas mixture and taken away for storage and a hydrogen-rich fuel gas (diluted with nitrogen from the air separation unit supplying oxygen to the gasifier) is fed to the gas turbine. When IGCC plants that are designed to burn carbon monoxide in the gas turbine are converted to pre-combustion CO_2 capture, the amount of fuel gas for the gas turbine is therefore reduced and its combustion properties are changed. The consequence is that the gas turbine may operate less efficiently, giving a further performance penalty in addition to the other pre-combustion capture penalties (shift, CO_2 removal, compression) found in plant built with capture from the start.

One proposed solution for 'capture ready' IGCC plants is to oversize the gasifier and associated equipment initially, to allow the gas turbine fuel deficiency when capture is added to be made up, but this incurs obvious up-front capital costs. An alternative route, being developed by Jacobs in the UK, is to incorporate a shift reactor to make CO_2 and hydrogen in the plant from the outset. In the original 'capture ready' plant the CO_2 passes to the gas turbine, where it is expanded to do useful work. When the CO_2 is captured upstream of the gas turbine it is replaced by nitrogen in the fuel gas mixture going to the turbine. It is claimed that both the cost and performance penalties of the shift process under normal operation can largely be offset by careful heat integration and savings on alternative heat recovery equipment. While this new concept offers promise, it must be emphasised that conventional IGCC, particularly configurations not employing a water quench, are unlikely to meet 'capture ready' ideals very closely.

All 'capture ready' plants will require some additional space to be left on site to accommodate capture and compression, but the necessary initial costs involved are likely to be low. Both IGCC and PC 'capture ready' plant may benefit from improvements in capture technology up to the time capture is fitted but, because the capital cost and efficiency change are currently larger for post-combustion capture, there is arguably more scope for this to impact on the latter.

Illustrative relative performance and cost penalties for adding capture to 'capture ready' and 'capture unready' IGCC and PC plants are shown below. For capture ready plant, IGCC will incur the lower relative increase in the cost of electricity when capture is added, but this advantage would be offset if the original cost of electricity was higher for the IGCC plant. The balancing margin would reduce rapidly from the 16% difference in the bottom line if the time to capture was delayed, reflecting the inherent disadvantage of paying more money earlier to save money later.

For both IGCC and PC 'capture unready' plant, however, the worse performance, capital cost and conversion time for adding capture all add up to give large unnecessary increases in the cost of subsequently capturing CO_2. Such increases could either delay the installation of capture for longer than needs to be the case or, if they affect large proportions of a nation's installed power plant capacity, have a serious effect on the economic, political or social costs of making the transition to CO_2 capture.

Adding capture to:		**Capture ready**		**Capture un-ready**	
		IGCC	**PC**	**IGCC**	**PC**
Original efficiency	%LHV	40.0%	42.0%	40.0%	42.0%
Efficiency penalty	%LHV	6.5%	8.5%	7.5%	9.5%
Additional electricity cost for reduced output		**19.4%**	**25.4%**	**23.1%**	**29.2%**
Capture plant capital cost ($/kW, % above original)		30.0%	50.0%	45.0%	75.0%
Capture plant capital cost as % of original capital cost		10.6%	24.6%	21.9%	45.8%
Capture plant capital cost contribution to electricity cost for original fuel cost fraction shown	30%	**7.4%**	**17.2%**	**15.3%**	**32.0%**
Loss of 1 year production added to next 20 years at 10% discount rate, % of cost/yr	11.7%			**8.2%**	**8.2%**
Fuel cost fraction (avoided costs)	30%				
Total additional electricity cost, based on ORIGINAL cost for THAT technology		**26.8%**	**42.6%**	**46.6%**	**69.5%**

Conclusion

There are two principal messages to be delivered by this paper. The first is that there is research and industrial demonstration capacity for carbon dioxide capture and storage in Canada, but that its optimum exploitation requires more engagement between industry and government and more capacity building. This capacity is, however, some of the best in the world at present and can provide significant assistance in the development of global responses to the need to capture CO_2 to prevent it reaching the atmosphere. As an aside, it should also be noted that there is also significant CO_2 storage capacity in geological formations in the country, although not always in convenient locations for large sources. Again, much work is required on developing a full understanding of storage capacity.

More importantly, it is important to understand the complexity of determining the technologies that will be required to become ready for carbon capture and storage. There can be no single, simple response to this question. The technology will be very dependent on site specific issues such as coal type, economics, existing infrastructure, need to deal with pollutants in the gas stream, the presence of regulations or financial incentives etc. Each of the three basic technologies, post-combustion, oxy-fuel combustion and gasification (and possibly some hybrids of the above) may be required to achieve Canadian and global goals. As importantly, each of these technologies will need to be demonstrated at commercial scale to prove its effectiveness and bring industrial inventiveness to bear on technology improvement. As an example, industrial input in the development of sulphur dioxide capture from power plants resulted in significant cost reductions in a relatively short time. Without demonstration, this activity will not occur. While research can suggest new process options and new systems, the combination with industrial demonstration is essential to provide solutions that can actually deliver large scale CO_2 emission reductions.

It is the intent of the authors of this paper to offer a workshop on the theme of 'Getting ready for carbon capture and storage' in the fall of 2005, possibly in connection with the COP/MOP meeting in Montreal. This will bring together a number of experts in the area of capture technology to provide a sound, un-biased review of technology availability, status and related issues involved in planning and preparing for widespread use of capture and storage to help mitigate dangerous climate change. A particular area for discussion will be how the urgent need to make new power plants 'capture ready' can best be integrated into the broader technology development and deployment process for carbon dioxide capture and storage technologies.

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Energy INet

The Energy Innovation Network, is a newly established Canadian technology development network designed to improve the collaboration and integration of research into energy related activities, particularly low emission technologies. The Network is currently in the process of incorporating as a self-supporting entity, developing partnerships with industry, government and international agencies and working with technology developers to pursue research and demonstration opportunities. More information on Energy INet can be found on the website www.energyinet.com or by contacting Malcolm Wilson at CO2@energyinet.com.

为二氧化碳收集和储存作充分的准备：加拿大的进展
（Getting Ready for Carbon Capture and Storage: Canada’ Progress）

Malcolm Wilson, Jon Gibbins

概览

加拿大工业界正在为配合化石燃料生产和电力设施，对其向大气释放的二氧化碳进行安全收集和埋存作积极准备。发展该技术将会为减少加拿大二氧化碳排放作出充分贡献。通过技术转让，或者投资建厂，此技术的发展也将会为美国、中国、印度等排放大国的减排做出贡献。

加拿大二氧化碳收集和储存的商业化进程，主要沿两个主要方向发展：建新的燃煤发电站（应用成熟的设备）使之能够选择一系列的碳收集技术；当气体的压力很高时，应用碳收集技术于技术尚未成熟的气化炉。通过两个方向同步的发展，当全球对二氧化碳收集和储存这一问题达到共识时，就可以将依靠化石能源燃烧发电的电厂排放的二氧化碳进行收集。

加拿大对于全球范围内的二氧化碳油井注入储存技术也处于领先水平。位于萨斯卡万的 Weyburn 工程就是一个很好的例子。与此同时，加拿大也对通过注入二氧化碳增强煤床内甲烷收集进行了研究。

加拿大政府及许多大学的研究中心，包括加拿大矿产及能源中心（CANMENT），国际二氧化碳收集中心（ ITC ），滑铁卢大学（ UoW ）均对工业上的二氧化碳收集提供了支持。

关于“为二氧化碳收集作充分的准备”

这篇文章的标题特意用了“为二氧化碳收集作准备”而不是“收集预留”的术语。其中的原因是，尽管对新的发电厂进行收集预留已经提到了议程上，但这只是众多必需准备中的一个元素，以使得二氧化碳收集的成本更低。除了对新建工厂预留空地，未来安装的收集设备的大小很大程度上取决于现在的研究，介于两段时间内的示范性电厂的表现，以降低添加收集装置的成本。以及储存的效果和社会认同性。当需要收集时，已经“收集预留”的发电厂会更具竞争力。所以“为收集作准备”意味着要进行多方位的准备：

一、确保新的以化石原料为燃料的电厂（或化工厂）能在建厂的时候，基于现在的技术水平，为收集二氧化碳作准备，使得未来的翻新费用达到最小，对燃料的消耗达到最少。
二、提高技术，使得“收集预留”的厂及现有的发电厂，都能够进行二氧化碳收集，并把这一技术带到发电厂“收集预留”的设计之中。
三、确保现在还不是很高效的附加技术能够在二氧化碳收集被规范前就发展到一定的水平。
四、继续发展已被确定的二氧化碳储存技术。

为实现以上目标，一系列的技术需要得以发展，同时还需要考虑各发电厂自身的特征，包括发电厂燃烧的煤差异，电厂的目的（多联产或是只供电等），添加收集设备的时间，及添加其他防污染设备的时间。因此，“为二氧化碳收集作准备”将会使我们完全理解收集这一过程的设计及应用含义。因为加拿大能源市场结构多元化，加拿大对涵盖各项技术的应用有一个很好的平台。而一些先进的例子将在下面的文章中进行介绍。

“收集预留”发电厂及燃烧后收集

加拿大洁净煤联盟曾对煤发电站的二氧化碳收集进行过研究。350450 MW 的发电站（燃烧低等级的萨斯卡万褐煤）运用最新技术控制氧化硫，氧化氮，水银的排放，以及分析二氧化碳从烟道气中收集的可行性的这项研究的直接结果之一是 SaskPower 对新建的一个,运用现行的技术，收集的成本大约是 40 加币/ 吨，但这个价格将会不断地降低，因为这个新的应用将会有重大的学习价值。新的煤粉燃烧发电站或者流化床发电站可通过燃烧后收集把成本降到最低。收集设备在加至发电厂时并不需要停产或者长时间的调整炉内环境来改善发电厂表现。

以较低的额外成本为新燃烧发电厂进行“收集预留”，对一些经济仍在迅速增长，待建的煤燃烧发电站项目多的国家来说是很有好处的。另一方面，一些工业规模的，具有示范性收集设备的发电厂也需要尽快的建成。这将不仅仅加速新建的带收集设备电厂的商业化进程，同时可对大量近期将建成的发电厂起到降低成本的示范作用。

气化，多联产及燃烧前收集

加拿大另一个商业化规模，带二氧化碳收集设备的发电厂的基本情况是，以石油焦炭，残余的碳氢化合物及煤为原料，为北部的亚伯达沥青砂生产及其他地区的重油精炼提供氢气，热，及电力（包括出口的硫）。伴随气化，生成的大量一氧化碳气体将会与加入的水蒸汽反应转化成二氧化碳及氢气，而二氧化碳将会在燃烧前被回收。如果氢气是主要产品，与转化反应相联系的成本及能量损失将会降到最低。类似的，如不是所有的燃料都需要转化成氢气，部分燃料可以用于发电，并且部分由发电产生的热可以被利用，反应的效率可以提得更高。这一类的 " 多联产 " 通常能使得气化技术比单独运用 IGCC 提供电力更为有效。

Nexen 在亚伯达北部地区计划建立一个多联产式的工厂来生产氢气和电力。收集二氧化碳也在被考虑中以增加如萨斯卡万和亚伯达的石油产量，而收集设备将在建厂的时候同步建造或者于主体电厂建好后添加进去。全球范围内，持续走高的天然气价格和石油价格使得煤气化厂在许多国家都被列入了战略考虑范围，而加拿大的这个基于二氧化碳收集的多联产厂则可提供给他们一个更明确的关于气化应用收集技术的示范。

新发电厂的燃烧前及燃烧后收集

最近的 IEA 研究将有二氧化碳回收及加压，无二氧化碳回收及加压的新建发电厂进行了比较，当中假设所有进行学习的发电厂，其燃料，大气状况，利率等相关因素都是相同的。相对不同的是每个发电厂由于一些特定因素导致的热力学及经济表现的些微差别，但显示出来总的趋势，是燃烧前回收和燃烧后回收的表现差距并不显著。其中， Texaco(现为 GE) 的气化炉，在进行二氧化碳收集时的效率减少最低，但这也可能与已有的急冷器有关。虽然急冷器在不需要在进行收集时会降低效率，却可在需要燃烧前收集时提供用于促进一氧化碳转化成二氧化碳的水蒸汽。而且， Texaco 气化器的资本性投资较低，因此使得整体的电力成本降低。但现在反映在北美电力市场 IGCC 和超临界煤粉燃烧发电厂在没有安装收集装置前的电价比这里显示的高 0.1 c/ kWh 。现在还没有明确的是，如果 IGCC 更广泛的应用话，这两个很不同的生产电的方法应该如何进行比较。

二氧化碳的埋存（地理上的储存）

在加拿大的南 Saskatchwan 的 Weyburn 油田同时也进行着全球第一个通过二氧化碳地质储存并且促进石油产量（ EOR ）的示范工程。这一工程每天注入约 5000 吨的二氧化碳，由位于北达科塔的煤气化（为合成甲烷）厂产生。与这一个 EOR 工程有关的研究是为了示范关于地理储存二氧化碳及其相关范围内的完整性。初步的结果显示出 EOR 通过注入二氧化碳在技术上是成功的，研究同时成功的监视了二氧化碳在地下的运动。早期的结果显示出了通过这种方法储存二氧化碳将是长期安全的，但过去的工作仍需要进一步的加以证明和论证。全球范围内均对这一工程的结果感到强烈的兴趣。

研究活动

- 在收集的方面，加拿大的研究机构已经开始进行重要的研究，从而更好地了解相关的大规模收集所需要面对的问题，包括新技术的开发，以及辅助“收集预留”。这些工作包括：
- ITC(国际二氧化碳测试中心)- 燃烧后回收技术发展项目。设备包括两个实验规模的发电厂，一个收集天然气燃烧排放烟气中的二氧化碳，二氧化碳产量是 1 吨/ 天；另一个则在褐煤发电站，二氧化碳产量是 4 吨/ 天。通过这两个发电厂来示范及改善新的过程以及新的从烟道气中吸收二氧化碳的化学成分。该结果可用于未来的商业规模的发电站进行二氧化碳收集降低成本的依据。
- CETC(CANMET 能源技术中心)- 氧燃料燃烧的二氧化碳收集。在渥太华的实验规模的设备是为了展示烟道气在燃烧之前的脱氮作用。在这一系统中，化石燃料在相对洁净的氧气中燃烧，通过循环回来的燃烧后的气体来缓和燃烧。通过这一过程，在烟道气中的二氧化碳含量可以变得很高（约 90% 以上），使得它可以更方便的进行储存。如需进行 EOR, 则根据气体成分，判断是否需要进一步的洁净工序。这一方法最显著的好处是，它不仅可以将二氧化碳安全的储存，还能将另一些污染物同时储存起来。
- 滑铁卢大学——建立系统模型。滑铁卢大学已经开发出基于不同二氧化碳收集方法，根据其吸收的二氧化碳量不同，而对化石燃料燃烧后气体收集的相关系统模型。其研究还包括用薄膜对烟道气体进行分离从而获得二氧化碳。

其他加拿大的机构也具有相关的一些专业技术，如气化。这些技术可以在未来进一步发展二氧化碳收集时起到很大的作用。

Weyburn 油田

在 90 年代后期，加拿大的一个主要石油公司， PanCanadian 石油有限公司（现名 EnCana 公司）宣布将对南 Saskatchwan 一个已成熟的油田进行大规模的通过二氧化碳注入来提高石油产量（ EOR ）的计划。而通过这一增产所得的额外收益又将用于维持这一油田的运营。同时，这一公司也宣布愿意将这一个项目作为地理上储存二氧化碳的示范性工程。这一工程涵盖了所有的大规模储存所需要的重要元素：在一个将枯竭的油田内的大规模的 EOR 项目，一个二氧化碳源，一个恰当的储存位置，以及收集数据的机会，更可贵的是，这个储存地提供了在全世界其他地方无法找到的数据——一个庞大和公开的从油井被发现时就有的历史纪录。以上的这些除了为研究者提供了准备注入二氧化碳前的数据，更提供了彻底的历史数据。所以，应该很难找到比这更好的资源条件了。

这项工程一个重要的发现是，二氧化碳能够安全地埋存于地下，而这个储存项目也十分经济。

Weyburn 的地理状况显示出它十分适合对二氧化碳进行长期储存。不仅这个储存处，其周边地区的地貌也被进行了研究，显示出这一地区的地理状况能够提供多样的关联区。如果二氧化碳从最初的封闭阀泄露出来，还有一些其他区域有封闭的能力，以及一些盐土蓄水层在最初的封闭区域之上。无论如何，封闭阀的完整性是经过考验的，其失效的可能性也是可以忽略的。对于这个风险的评估显示二氧化碳几乎没有可能会接触或者穿透在地理位置上的盐土蓄水层，更不会接触到离地面较近的饮用水层，或者地面。这些二氧化碳中， 73.2% 将会留在被注入的区域， 18.2% 会渗漏到注入处岩石圈之下， 8.6% 将会在注入层之间但又在最初用于 EOR 的区域之外，仅有 0.02% 回渗漏到注入处的岩石层之上。地理流体力学采样时的研究人员可以对储存的二氧化碳进行追踪。地震研究也可探测出由于二氧化碳注入而引起的储存层的变化。以此，我们可从本质上“看到”二氧化碳在储存层的运动。

IGCC 及 PC 收集预留的可行性

最理想的“收集预留”是使发电站的运营成本及效率达到与未进行收集时的发电站相同，同时，在收集设备安装之后，总的资本性投资及表现也相同。

为了达到 " 收集预留 " 这一理想状态，对 PC 及其他发电厂，或是通常的 IGCC 是有根本性不同的。对生产出来的二氧化碳必须进行收集。煤粉及流化床燃烧的发电厂可在其本身的基础上进行安装。通过燃烧后收集将二氧化碳从燃烧后的产物中集中起来（比如用胺）。唯一的不同是在蒸汽进入轮机之前将其通过一个添加的管道输出，从而可将吸收了二氧化碳的胺溶液在蒸汽所释放的热作用下释放出二氧化碳。这将降低输出的效率，而且更多的电力将提供于与收集部分相连接的压缩机和泵。

在通常的 IGCC 发电厂中，多数的碳被转换成一氧化碳而用来做燃料，而不是把碳转化成二氧化碳。如果希望通过燃烧前收集的方法，则需将一氧化碳转化成二氧化碳，并把燃烧的燃料转变成为额外的氢气和热（有一部分可以恢复为蒸汽进行电力生产）。二氧化碳这时就可以从带有压力的气体混合物中被分离并储存，而含氢量很高的燃料（由经空气分离而得到的氮气稀释）将被输入到轮机。当燃烧一氧化碳的 IGCC 发电厂转换成燃烧前收集的二氧化碳收集发电厂时，由于进入轮机的气体总量减少了，其燃烧特性将产生变化。结果是轮机效率可能会降低，并可连带的有其他方面的效率降低（如一氧化碳转化成二氧化碳，二氧化碳移除，压缩）。

" 收集预留 " IGCC 的另一个目的是在最初建厂的时候就将气化炉及相关设备的尺寸加大，来弥补进行收集时的能量损失，但这将加大最初的资本性投资。另一个由英国的 Jacobs 开发，可供选择的方法是在一开始，就将转换装置加到设计中。在“收集预留”的电厂，二氧化碳将会通入轮机，并会膨胀做功。如果二氧化碳在这之前被收集了，则将由氮气代替二氧化碳而进入轮机。但是，因转换作用而增加的成本及效率的降低都可以通过完整的热循环来恢复。这一概念的前提是，对通常的 IGCC, 特别是没有急冷水配置的，可能不能十分好的达到 " 收集预留 " 的要求。

所有“收集预留”发电厂都将需要一些额外的空间留在厂区位置来配合收集和压缩，但预留所需的成本将较低。而 IGCC 及个人计算机的 " 收集预留 " 发电厂在增加收集装置时都将因收集技术的提高而使增加的成本相对较少，但燃烧后回收设备的资本性投资较大，及其对总体效率的改变较多，尤其对 PC 的影响更大。

有 " 预留 " 及无预留的 IGCC 及 PC 发电厂在效率上的区别将在下面的表格中显示。对有预留的发电厂，当收集装置加上的时候， IGCC 的发电成本增加量相对的较小，但这一优势是因为 IGCC 本身较高的发电成本。而 IGCC 和 PC 之间效率差别（最下方一行）随着时间的推移也将小于 16% 。显示出提早进行投资将在未来节省的更多。

对 IGCC 和 PC 未进行收集预留的发电厂，最不幸的是，当需要进行二氧化碳收集时，将要很大一笔资本性投资，而效率也有很大的降低。而这样的情况下，可能会延长安装收集设备的时间，而对于大型的发电站，更有可能因停工而影响经济。

结论

这篇论文主要是想传递两方面的信息。第一，加拿大正在研究，并进行工业规模的示范性二氧化碳收集及储存项目，不过更进一步的开发则需要企业与政府之间更紧密的合作，以及更多的收集储存项目的开发。这些项目包括，一些当今世界最好的，全球范围内的，可提供显著协助作用的防止二氧化碳进入大气层的项目。补充说明的一点是，二氧化碳地理上的可储存量在加拿大是巨大的，尽管不全是在陆地范围内的大容量储存点。而为了使二氧化碳在地理上的储存得到更深入的理解，更多的工作是必要的。

更重要的是，需要明白为二氧化碳收集和储存而作出技术准备是很复杂的，这一点是很重要的。这一准备将不会仅仅是单一的，简单的答案，而是会根据各个发电厂不同的特征，比如煤的类型，经济，已存在的设备，对烟道气中污染物的处理，规章的限定及财政上的投资而定。所有的这三个基本技术，燃烧后收集，氧燃料及气化可能都需要被应用，来达到加拿大以至全球的目标。同样重要的是，所有的这些技术都需要通过商业规模的示范厂来证明其效率，并通过工业上的独创性来证明其技术上的进步。在工业发展中，以收集发电厂发出的二氧化硫，并在短时间内取得显著的成本降低就是一个这方面的很好的例子。如果没有示范厂的建设，这一成功将不会发生。二氧化碳在这方面的研究可以使新的处理方法，新的系统将有进一步的发展，而工业上示范厂的建设足以证明对大的二氧化碳产生源进行收集是十分可行和重要的。

这篇文章作者的目的就是对在 2005 年的秋天“为二氧化碳收集及储存”的工作提供一些材料，以及与 Montreal 的 COP/MOP 会议进行联系。届时许多在这一领域范围内的专家聚集在一起从而提供一个更理性，中立的技术回顾，现状报告及对全球范围内与收集二氧化碳相关的事项的讨论，从而降低气候变化带来的危害。一个值得讨论的领域就是，到底如何使得新建的发电厂进行“收集预留”，而有关安排究竟有多紧急，从而把更广范围内的技术上收集与储存二氧化碳的发展更完整地结合在一起。

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重要文件

IEA GHG PH4/19, 由汽化器的的CO2收集，2003五月								
IGCC的预燃烧收集		Shell 汽化炉				Texaco 汽化炉		
		无收集	有收集	收集时的效率降低		无收集	有收集	收集时的效率降低
净功率输出	MW	776	676			826	730	
效率	% LHV	43.1	34.5	8.6		38.0	31.5	6.5
资本性投资（每千瓦容量）	$/kW	1371	1860	36%		1187	1495	26%
CO2 排放	g/kWh	763	142			833	152	
CO2 收集	g/kWh		809				851	
收集消耗的额外燃料				25%				21%
电力成本（每度）	c/kWh	4.8	6.3	31%		4.5	5.6	24%
IEA GHG PH4/33, 燃烧后收集，2004十一月								
先进的超临界煤粉发电站燃烧后收集		Fluor 胺技术				MHI 胺技术		
		无收集	有收集	收集时的效率降低		无收集	有收集	收集时的效率降低
净功率输出	MW	758	666			754	676	
效率	% LHV	44.0	34.8	9.2		43.7	35.3	8.4
资本性投资（每千瓦容量）	$/kW	1222	1755	44%		1171	1858	59%
CO2 排放	g/kWh	743	117			747	92	
CO2 收集	g/kWh		822				832	
收集消耗的额外燃料				26%				24%
电力成本（每度）	c/kWh	4.4	6.2	41%		4.3	6.3	47%
IEA GHG 2005/9 氧燃料对CO2的吸收, 2005七月								
先进的超临界煤粉发电站氧燃料二氧化碳收集		氧燃料，低温分离空气				MHI 胺技术 (PH4/33)		
		无收集	有收集	收集时的效率降低		无收集	有收集	收集时的效率降低
净功率输出	MW	677	532			754	676	
效率	% LHV	44.2	35.4	8.8		43.7	35.3	8.4
资本性投资（每千瓦容量）	$/kW	1513	2342	55%		1171	1858	59%
CO2 排放	g/kWh	722	85			747	92	
CO2 收集	g/kWh		831				832	
收集消耗的额外燃料				25%				24%
电力成本（每度）	c/kWh	4.9	7.3	49%		4.3	6.3	47%

增加收集至:		"收集预留"电厂		未预留电厂	
		IGCC	**PC**	**IGCC**	**PC**
原始效率	%LHV	40.0%	42.0%	40.0%	42.0%
效率降低	%LHV	6.5%	8.5%	7.5%	9.5%
应减少输出而增加的电力成本		**19.4%**	**25.4%**	**23.1%**	**29.2%**
收集设备资本性成本 ($/kW, % 高于原始)		30.0%	50.0%	45.0%	75.0%
收集设备资本性成本相当于 % 原始成本		10.6%	24.6%	21.9%	45.8%
收集设备成本占总电力成本的分数	30%	**7.4%**	**17.2%**	**15.3%**	**32.0%**
减少一年的产能并加至期后的20年，10%的折旧率 % 成本/年	11.7%			**8.2%**	**8.2%**
燃料成本作用	30%				
基于原始成本的增加的电力成本		**26.8%**	**42.6%**	**46.6%**	**69.5%**