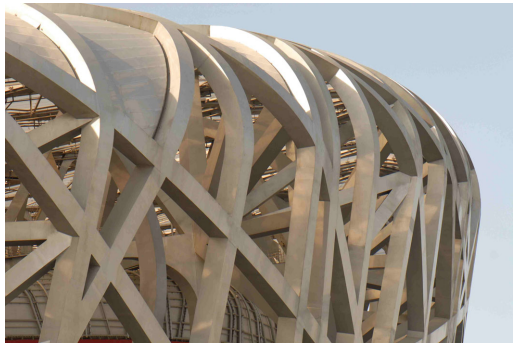
China-EU Cooperation on Near Zero Emissions Coal: Phase I results and next steps

Findings from COACH



Beijing 29 October 2009
presented by

SINTEF---Jens Hetland
jens.hetland@sintef.no
TPRI---Xu Shisen
xushisen@tpri.com.cn

COACH - Cooperation Action within CCS China-EU
EC/FP6 Contract #038966. Coordinated by IFP, France

Topics

- **Looking to China; The specificity of the Chinese power sector**
- **WP2: *Capture Technologies* work structuring**
- **D2.1: *Inventory study of power generation and optional carbon capture***
  - **Inventory Identifying technology opportunities and evaluating potential for geological storage of CO_2**
  - **Benchmarking**
- **D2.2: *Concept studies for coal-based plants with carbon capture in China***
- **D2.3: *Potentiality studies of polygeneration schemes linked with coal-based power plants in China***
- **D2.4: *Recommendations for pre-conditioning of CO_2 for transfer from plant to storage site in China***
- **Concluding remarks**

Power sector (1)

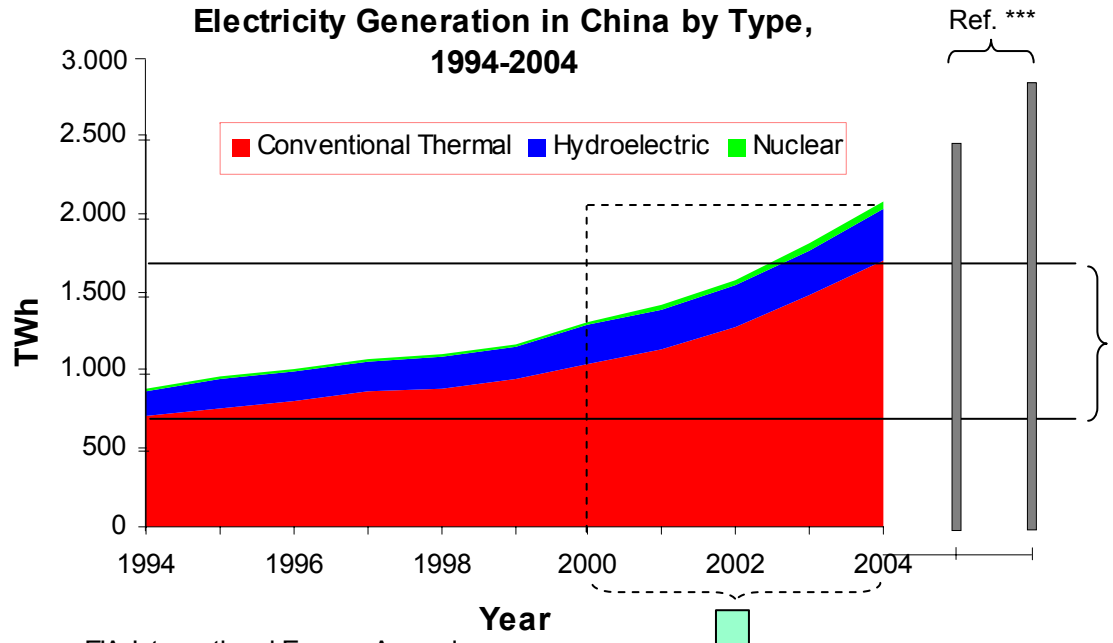
Development pace

China/EU-27:

Population:	**2.6/1**
Area:	**2.2/1**
CO_2 emission:	**1,6/1**
CO_2 per capita:	**0.6/1**
Energy intensity:	**2.2/1**

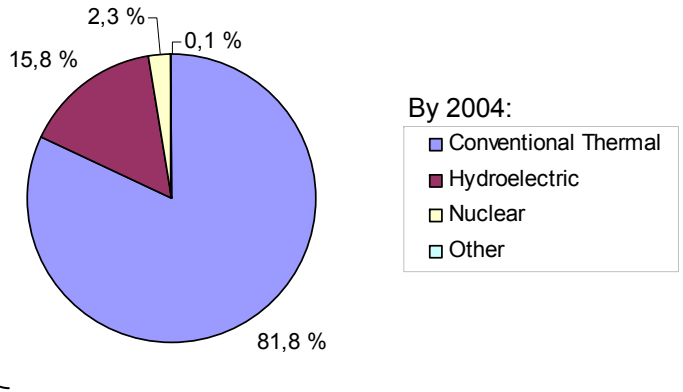
Installed el-generation capacity: 0.8/1

Source: BP Statistical Review of World Energy 2009, CIA information, EIA, Eurostat, Wikipedia



Source: EIA International Energy Annual

➔ 1000.6 TWh pa over 10 years (1994-2004)



Capacity growth:

- **2000-2004: 127 GW_e ***
- **2005: 63 GW_e**
- **2006: 102 GW_e ****
- **2007: 100 GW_e (85.4 GW_e net)**
- **2008: 90.5 GW_e (73.8 GW_e net)**

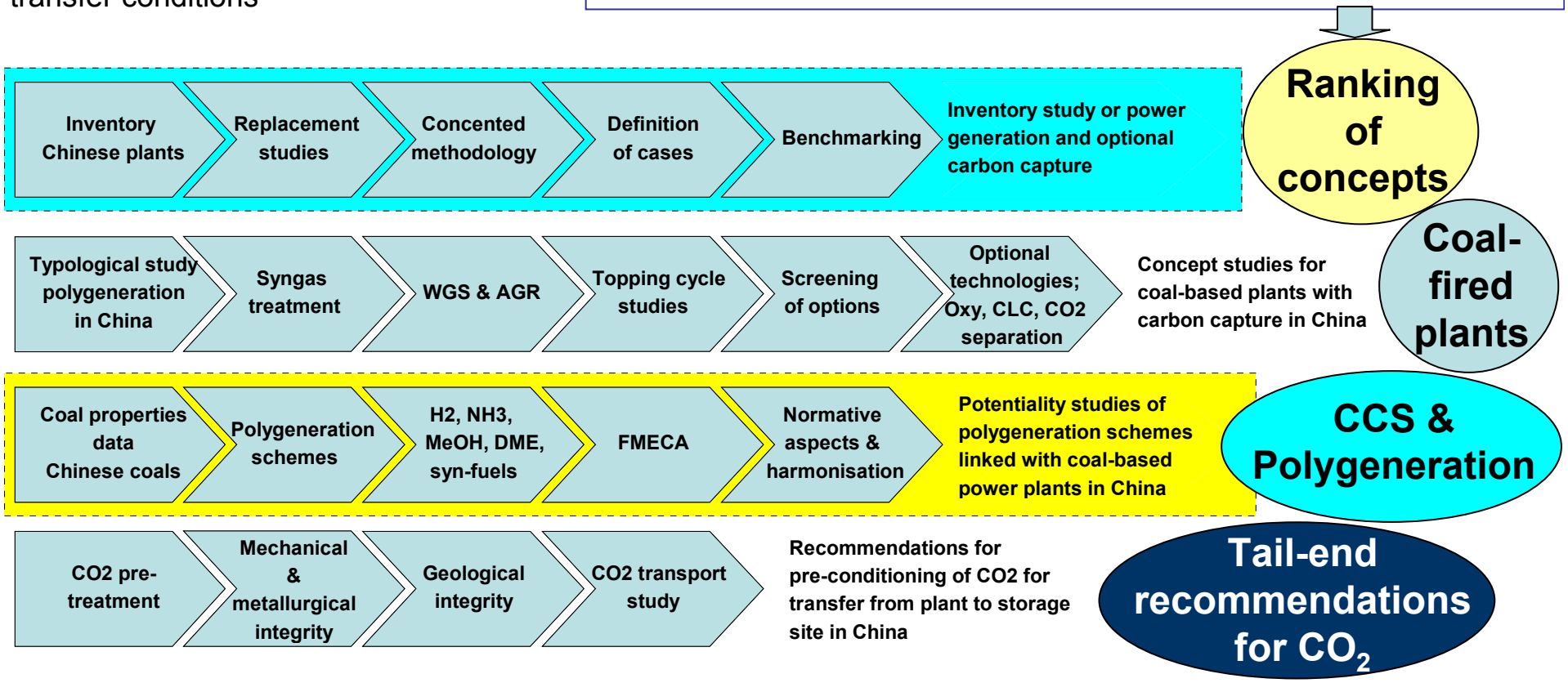
*Source: * Guodon Sun: "Advanced Coal Technolgies in a Sustainable Energy System. Preparing and Preserving the Appropriate Technological Options in China", Workshop Report from Harvard University in Cambridge, Massachusetts, USA, 19-20 Sep 2005.*

*** The Wall Street Journal, June 15-17, 2007*

COACH structuring capture part

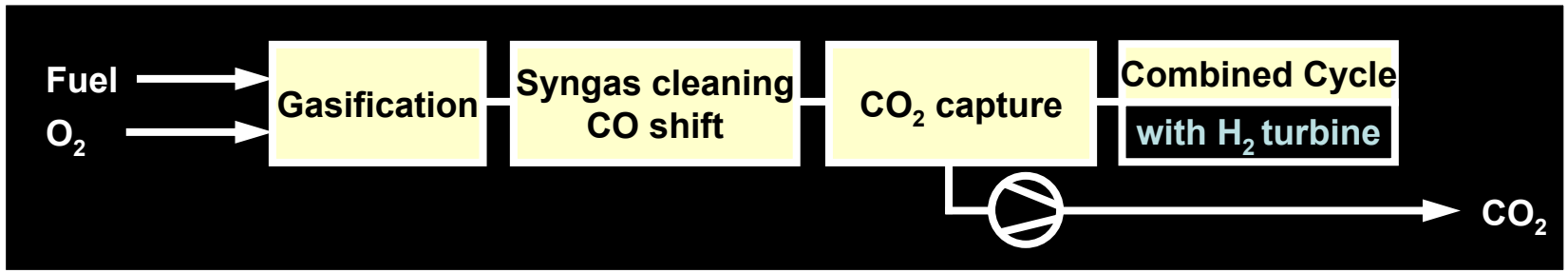
Inventory study, optional technologies, concept study coal based plants, polygeneration, benchmarking, CO_2 transfer conditions

Assessing and ranking of candidate capture techniques in a Chinese setting in order to identify the best options for China on a short-term basis.



Capture technologies

- Inventory of coal power plants (> 300 MW, later than 2000) ➔ capacity, fuel, use, efficiency, environmental impacts*, unit cost, age
- Review technical options for IGCC + polygeneration + CO_2 capture
  - configuration of power island
  - polygeneration scheme: electric power, hydrogen production, ammonia, methanol, DME
  - CO_2 preconditioning for transfer to storage sites
    - guidelines for CO_2 stream, CO_2 compression, drying, purification



Note*: These data are difficult to survey: Fast development in the power sector. Hard to get access to complete information on the numerous power plant projects under construction and in the planning phase. >10 IGCC projects are planned, but none in the list despite GreenGen IGCC has obtained approval from NDRC

Segment of the list

New coal-based power generation capacity on China (in part)

Province	Power plant number	300MW Units	300MW-600MW Units	600MW Units	1000MW Units
Inner Mongolia	3			6	
AnHui province	6			10	2
FuJian Province	4	6	2	2	
GanSu Province	4	4		2	
GuangDong	3		4	4	
HeiLongjiang Province	1	2			
HeNan Province	5	3	2	4	
HuBei	2			4	
HuNan	2			6	
JiangSu Province	2			2	2
JiangXi	3	2		4	
LiaoNing Province	1			2	
NingXia province	2	2	2		
ShaanXi Province	2	1		2	
ShanDong Province	1				2
ShanXi Province	3	2		2	
SiChuan Province	2			2	
YunNan Province	2	2		4	
ZheJiang province	2		10		
ChongQing City	2	6			

Typical impacts and demands

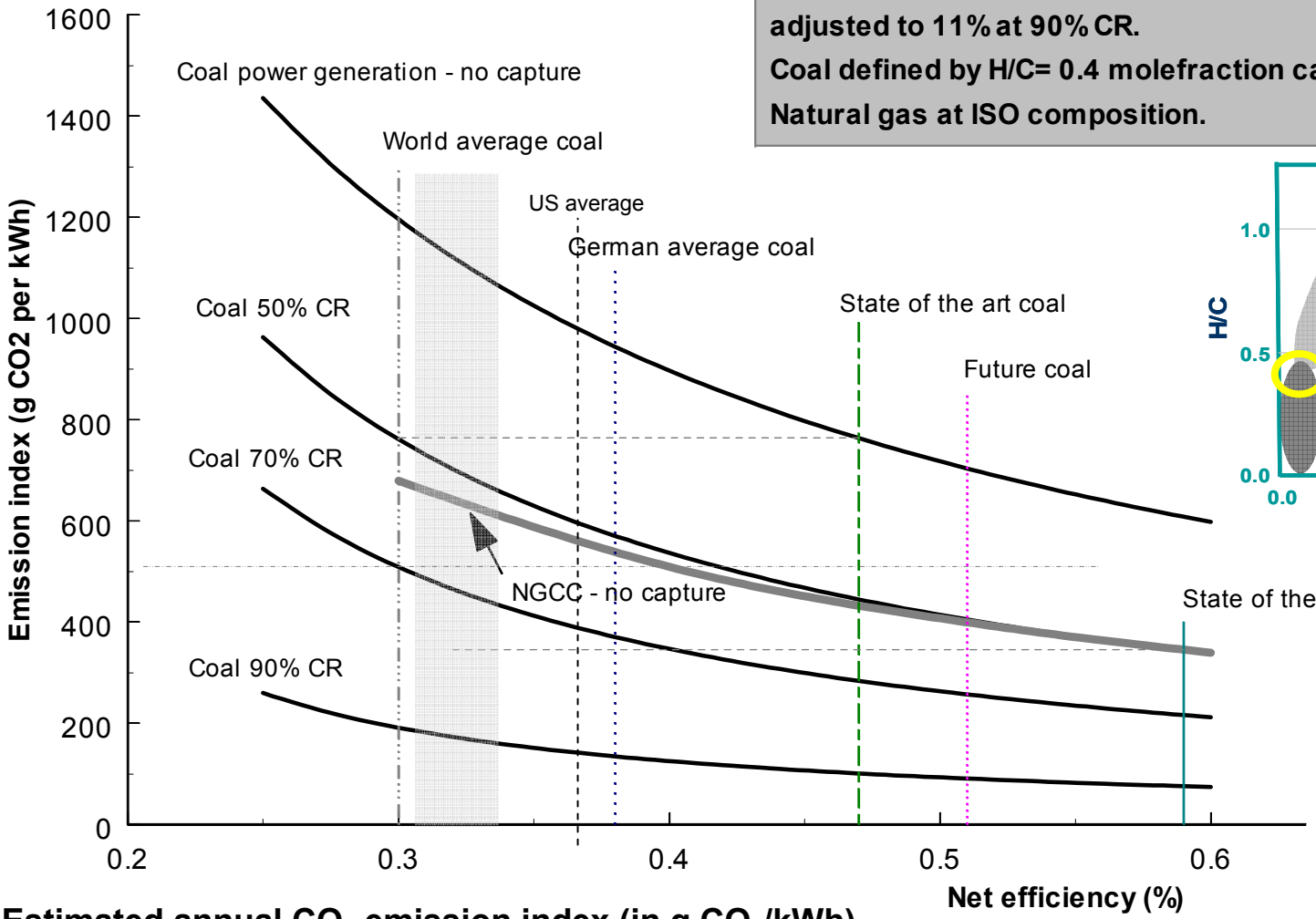
Typical annual output and input per GW electric power generated from coal

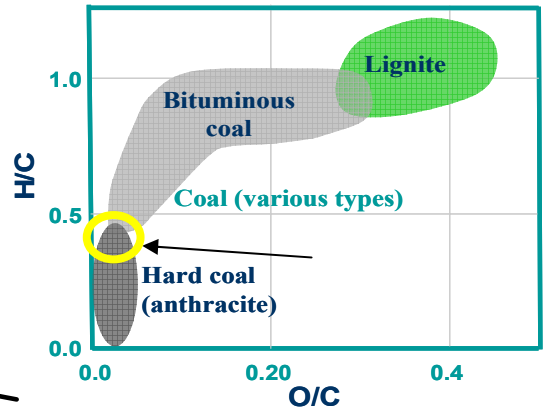
Flue gas	Mtpa	37.8
CO_2	Mtpa	8.1
SO_x	ktpa	25.92
NO_x	ktpa	25.2
Mercury	kgpa	216
Coal	Mtpa	3.6
Combustion air	Mtpa	34.2
Water	Mtpa	18

~940 g/kWh
~10 Mtpa O_2

CO_2 formation from coal (emission index)
- relating to the state of technology

Fuel penalty (heat demand) proporitionate to CR adjusted to 11% at 90% CR.
Coal defined by H/C= 0.4 molefraction carbon.
Natural gas at ISO composition.



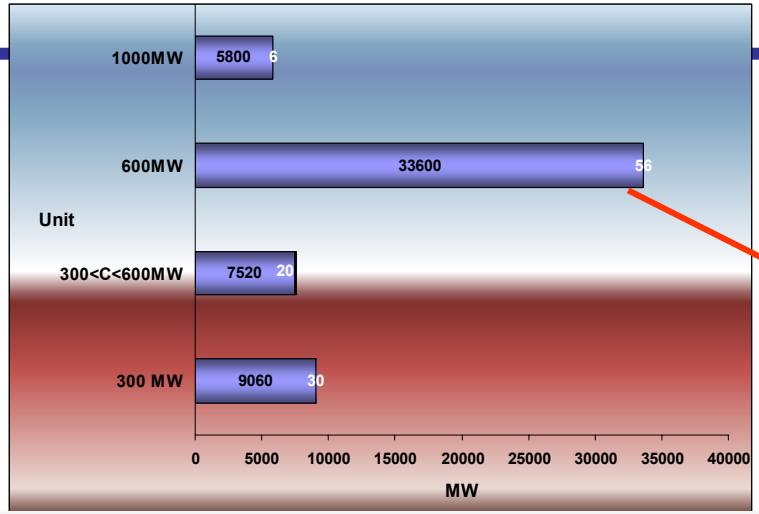


CR: Capture rate
NGCC: Natural gas combined cycle

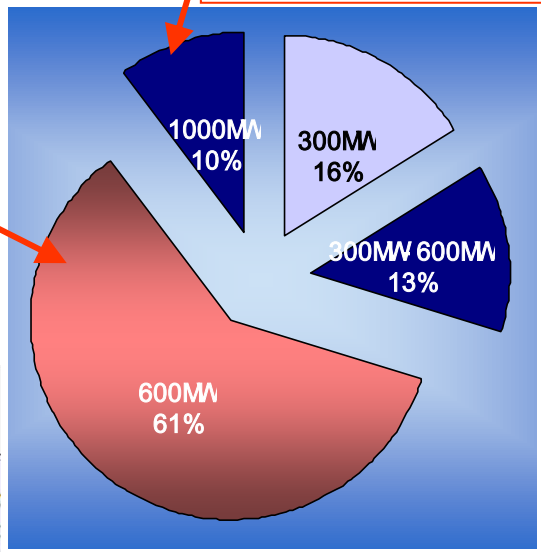
Estimated annual CO_2 emission index (in g CO_2/kWh) versus plant efficiency (%) at given capture rate (CR).

SINTEF Energy Research / Jens Hetland, 2008

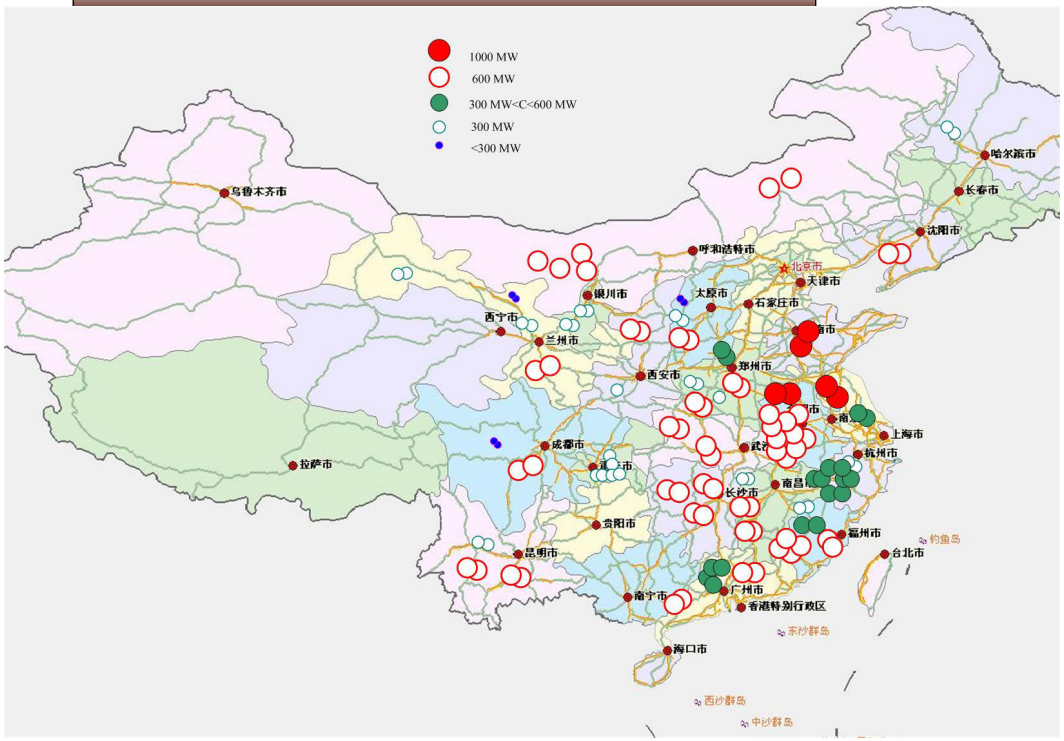
Larger units in China's new power plants



The1000MW units show a rapid development

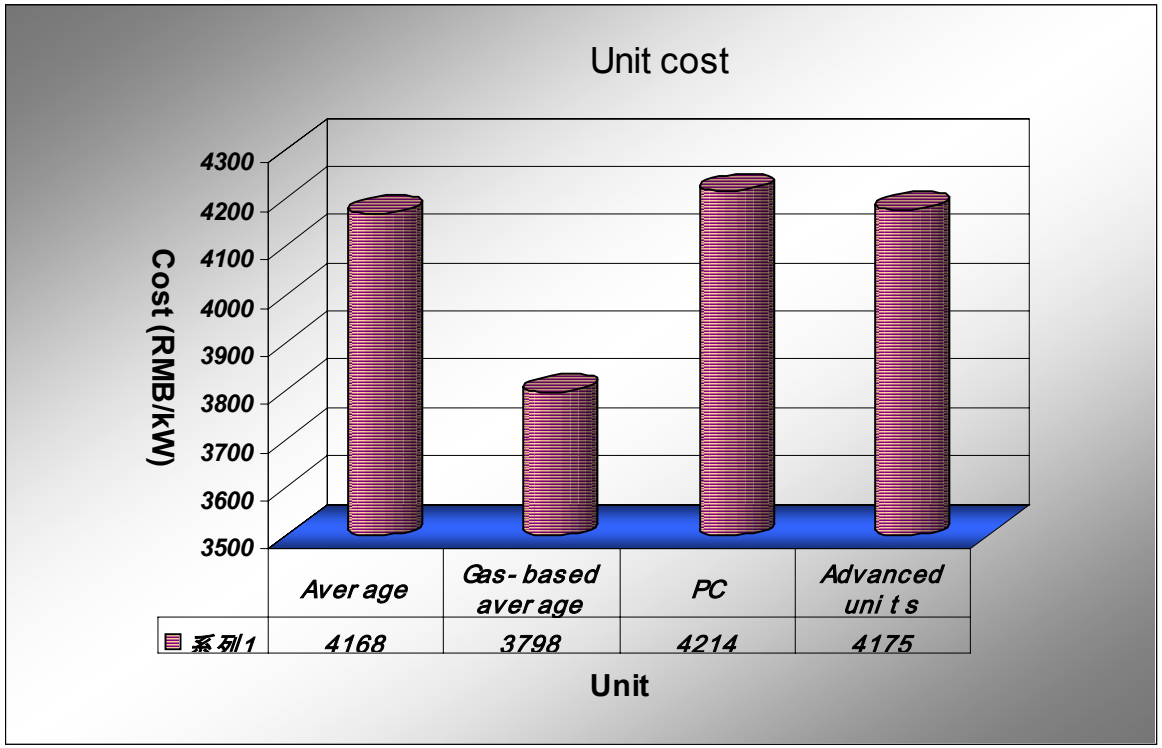


600 MW unit has gained the most important status



Many new projects are distributed to the east and south of China, with the more developed economies, larger energy demand and also with severe emission.

Unit cost – Chinese power plants (no CCS)



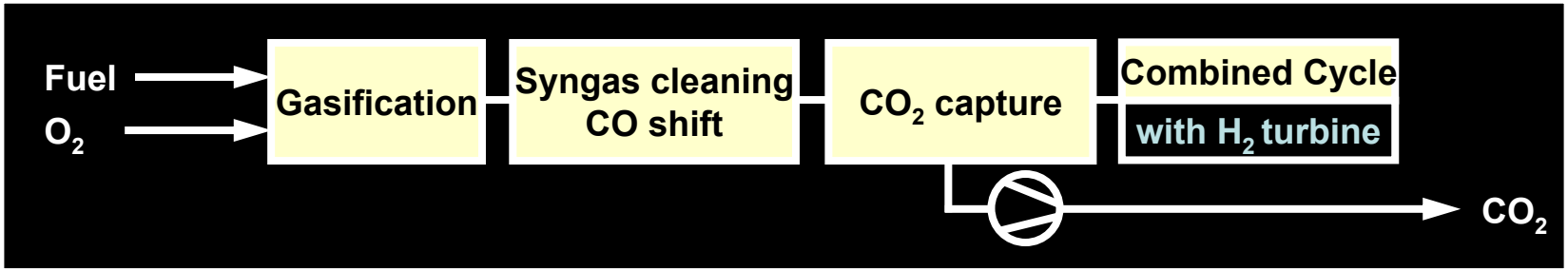
According to the all surveyed power plants, the average unit cost is more than 4100 RMB/kW

Gas-based power plants are cheaper - about 3800 RMB/kW

Traditional PC (Pulverised coal) fired boiler with advanced steam data have a unit cost about 4200 RMB/kW

Reference case: IGCC 250 MWe ➔ 11681 RMB/kW
Base case: IGCC-CCS same feed rate as reference case (lower net power) ➔ 17789 RMB/kW
Both cases are first of a kind.

IGCC-CCS

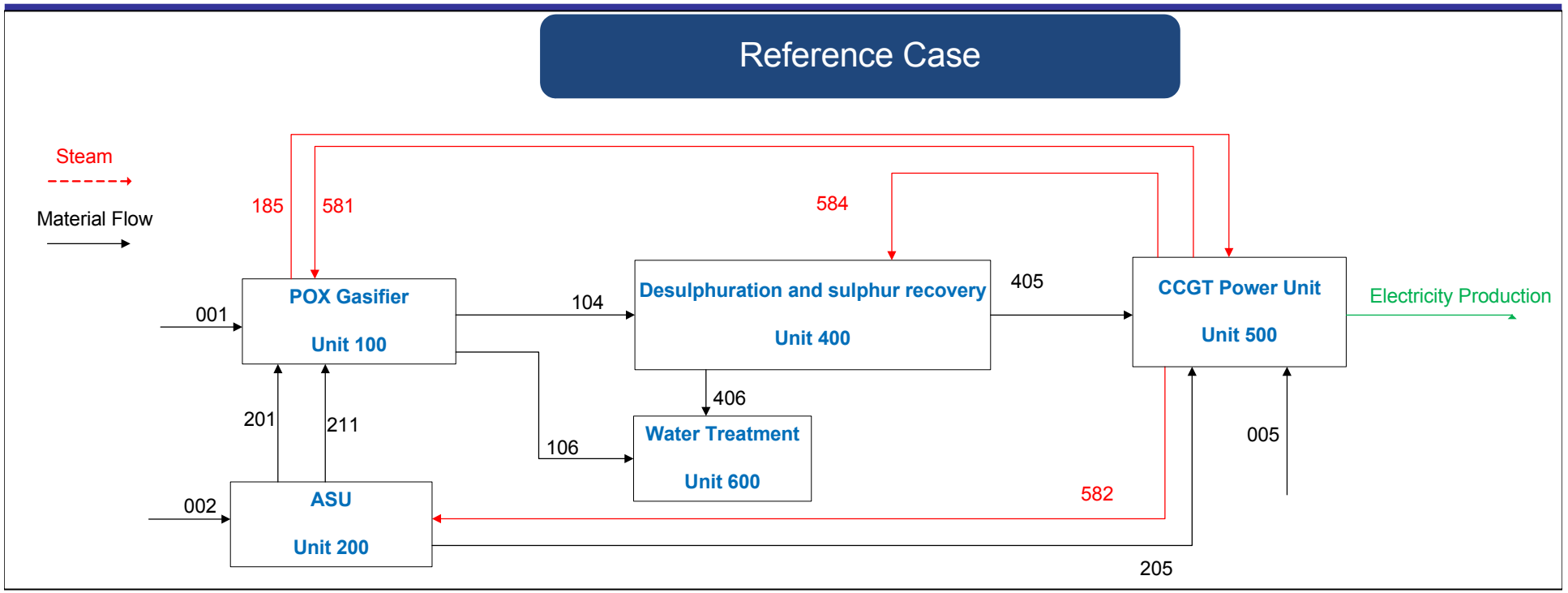


Technology status:

- New IGCC-CCS: Magnum (1200 MW, con), Hatfield Colliery (900 MW, pln)
- Fuel switching (shifted gas/NG)
- Limited operational flexibility
- High fuel flexibility (versatile way of harnessing fossil fuels – solid and liquid)
- Expected availability: IGCC ~86-87%, NG~95%
- Less gas volumes to clean than PC-CCS
- Lower emissions than conventional coal
- Less oxygen demand than oxy-coal
- Easy to capture CO_2 - proved CO_2 capture techniques (chemical and physical absorption)

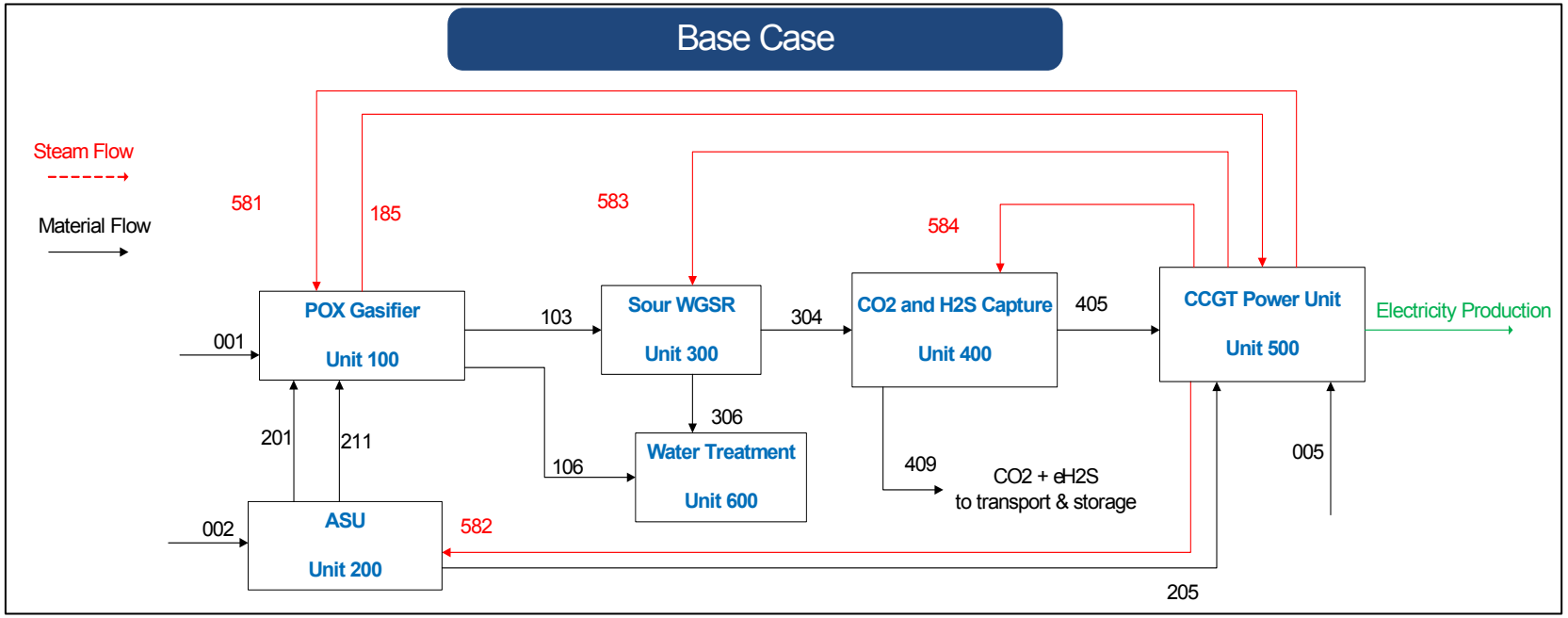
➔ Challenge: Efficiency, availability and cost

Reference case



- IGCC without CO_2 capture, output electricity 250MW
- Consists of coal drying and milling subsystem, gasification, cleanup, air separation unit (ASU), gas turbine (GT), heat recovery steam generation (HRSG) and steam turbine (ST) system.

Base case



- Similar gasifier and feedstock as reference case, feedrate of 2000 tpd of coal
- Made up by a POX gasifier of TPRI design (unit 100), an air separation unit (ASU, unit 200), a two-stage sour shift WGS reactor (unit 300), a CO_2/H_2 capture unit (400) using aMDEA as solvent, a combined cycle power island (unit 500), and a water treatment system (unit 600)

Main process data - reference and base cases

Main flow streams of the reference case

Stream n°		002	005	104	106	201	205	211		405	406
	Unit	Air	Air	Raw syngas	Condens.	Oxygen	Dilution N2	Nitrogen		Syngas	Condens.
Flow rate	t/h	254	1555.2	173.2	19	58.5	130	37.8	25	149.1	19
Pressure	bar	1.01	1.01	28.7		36	1.23	80	10	26	
Temperature	°C	12.6	12.6	160		40	18	80	40	120	
Composition	% wt	% wt	% wt	% wt	% wt	% wt	% wt	% wt	% wt	% wt	% wt
H2				2.2						2.6	
CO				68.3						79.1	
CO2				6.3						4.1	
H2S				0.2						0	
N2		75.5	75.5	11.1			94.5	100	100	12.8	
O2		23.2	23.2			99.6	3.3				
Ar		1.3	1.3	0.2		0.4	2.2			0.2	
H2O				11.1	100					0.5	100
CH4				0.6						0.7	
TOTAL		100	100	100.0	100	100	100	100	100	100	100

Electricity balance (MWe)			
	Demand	Gross product	Net product
Unit 100	7.7		
Unit 200	29.12		
Unit 400	1.39		
Unit 500	0	283.2	244.19
Unit 600	0.8		

STEAM		185		581			582		584	
		LP	MP	LP	MP		LP	MP	LP	MP
Flow rate	t/h		155	14.85	8.2	1.06	1.32	2.75	13	3.1
Temperature	°C		265	160	300	265	160	200	160	265
Pressure	bar		50	5	42	50	5	11	5	50

Main flow streams of the base case

	Unit	002	005	103	106	201	205	211		304	306	405	409
Description		Air	Air	Raw syngas	Condens.	Oxygen	N2 Dilution	Nitrogen		H2 + CO2	Condens.	H2	CO2
Flow rate	t/h	254		173.2	19	58.5		37.8	25	226.3	129.8	49.4	176.9
Pressure	bar	1.01	1.01	28.7		36				28.7	28.7	28	152
Temperature	°C			160		40		80	40	40	40	40	45
Composition		%wt	%wt	%wt	%wt	%wt	%wt	%wt	%wt	%wt	%wt	%wt	%wt
H2				2.2						5.3		24.5	
CO				68.3						1.4		2.1	
CO2				6.3						83.8	0.9	32.1	99.8
H2S				0.2						0.2		0.0	0.2
N2		75.5	75.5	11.1			94.5	100	100	8.4		38.5	
O2		23.2	23.2			99.6	3.3			0.0			
Ar		1.3	1.3	0.2		0.4	2.2			0.1		0.1	
H2O				11.1	100					0.3	99.1	0.7	
CH4				0.6						0.4		2.0	
TOTAL		100	100	100.0	100	100	100	100	100	100.0	100.0	100.0	100.0

Electricity balance (MWe)			
	Demand	Gross product	Net product
Unit 100	7.7		
Unit 200	29.12		
Unit 300	0.083		
Unit 400	17		
Unit 500	0	232.12	178.22
Unit 600	0.6+(306)		

STEAM		185		581			582	
		LP	MP	LP	MP		LP	MP
Flow rate	t/h		155	14.85	8.2	1.06	1.32	2.75
Temperature	°C		265	160	300	265	160	200
Pressure	bar		50	5	42	50	5	11

583		584	
LP	MP	LP	MP
-74.36	112.39	160	
144	232	160	
4	28.7	5	

Benchmarking – consented methodology – input and outcome

Estimations based on proved methodology, adapted to a Chinese context and economic conditions (Aug 2009)

➔Flowsheeting, process flow diagrams and sized equipment list established by various partners

➔ISBL, CAPEX, OPEX and investment appraisal made at Tsinghua University

ISBL: In site battery limits
CAPEX: Capital expenses
OPEX: Operational expenses

Presumptions:

Construction time	4	year
Repayment time	15	year
Working time (i.e. life)	20	year
Interest rate	7.83	%
Electricity price	0.327	¥/kWh
Working hour	7000	hours/year

Year	-3	-2	-1	0
Investing rate	25%	30%	30%	15%

Price of materials and products:

Material	*Price*
Coal ¥/tce	500
Water ¥/t	0.5
MDEA catalyst ¥/t	15000
Claus catalyst ¥/t	3660
Electricity ¥/kWh	0.327
Sulphur ¥/t	800

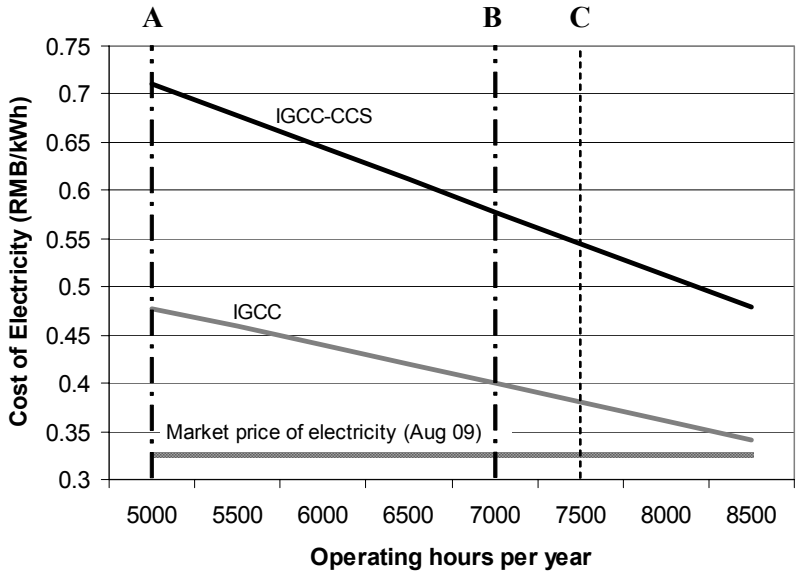
Note:
1 kgce = 7000 kcal/kg

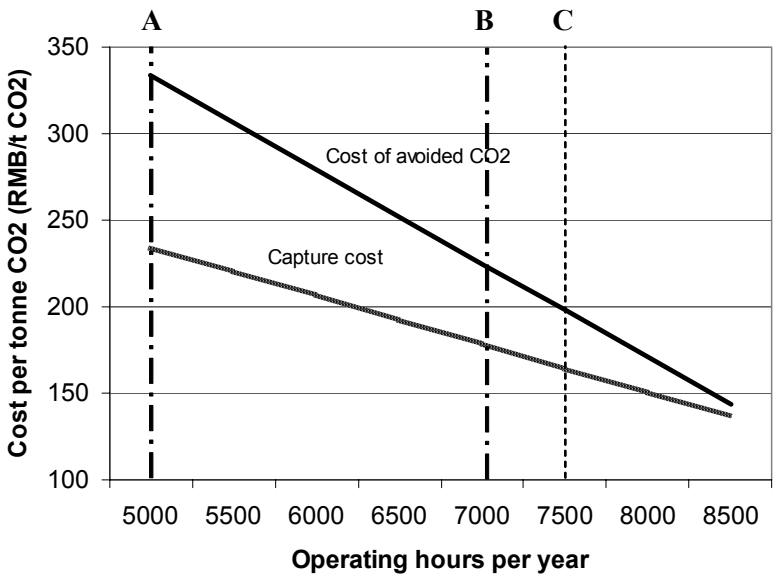
Cost estimation results:

Item	*Unit*	*Reference case (without CCS)*	*Base case (with CCS)*	*Increasing*
COE (gross)	¥/kWh	0.345	0.444	29%
COE (net)	¥/kWh	0.400	0.578	44%
CO_2 emission(net)	kg CO_2/kWh	0.792	0.094	-88%
CO_2 captured (net)	kg CO_2/kWh		0.991	
investment	G RMB	3.31	4.13	25%
Levelized investment (gross)	¥/kW	11681	17789	52%
IRR		0.09%	-12.41%	
NPV	G RMB	-0.75	-2.99	
Cost of CO2 avoided	RMB/ t	225		
Cost of CO2 captured	RMB/ t	179		

Benchmarking – Cost of electricity and capture

Estimations made at A and B (5000 and 7000 hours respectively). Linear approximation is made inbetween. C denotes the target of European IGCC projects with a planned availability around 87% (7500 hours per year).



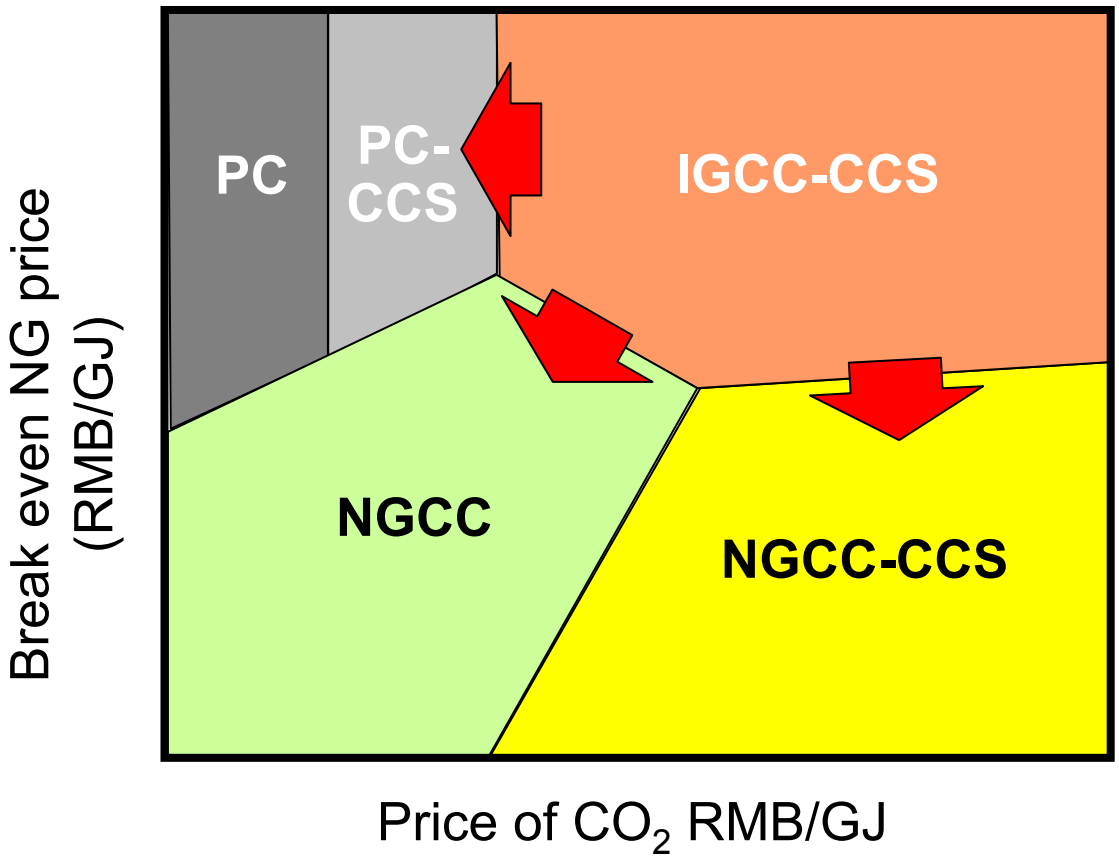


- **COE of IGCC-CCS in COACH: 0.578 RMB/kWh, more than current selling price of electricity in China (0.327 RMB/kWh)**
- **To justify IGCC-CCS under the current energy regime in China, the selling price of electricity should exceed 0.60 RMB/kWh (7000 operating hour/year) or 0.75 RMB/kWh if the plants runs 5000 operating hour/year**

	Euro/tonne of CO2 Stored (NETL 2007)	Euro/tonne of CO2 Stored (Updated 2009)
IGCC	43.54	29.03
Sub-Critical Coal	77.74	51.83
Super-Critical coal	77.74	51.83
CCGT	94.33	62.89

Source: Grant Budge, Powerfuel Power Ltd, MarcusEvance Conference, Amsterdam 27-30 Sep 2009

Technology improvement & optimisation

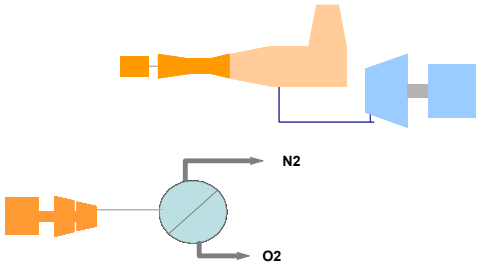


Main challenges:

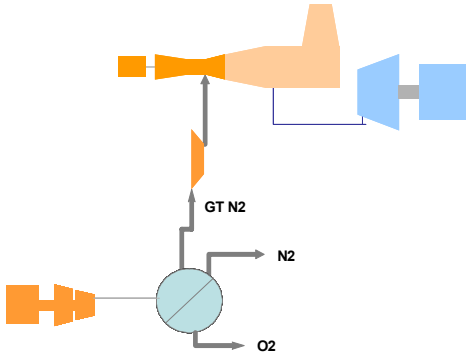
- Hydrogen-burning gas turbines
- NOx reduction
- Design to cost
- Lifetime cost optimisation

ASU integration with IGCC

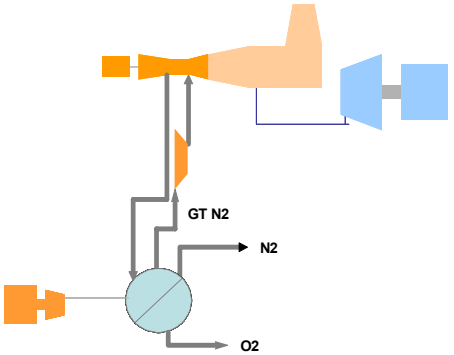
No integration:	Partial integration (1):	Partial integration (2):	Full integration:

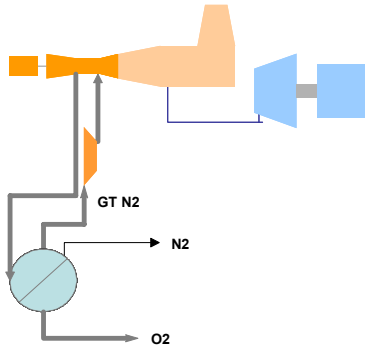


Isab – Italy
Sarlux – Italy
Destec – USA
Exxon - Singapore



Nisseki - Japan



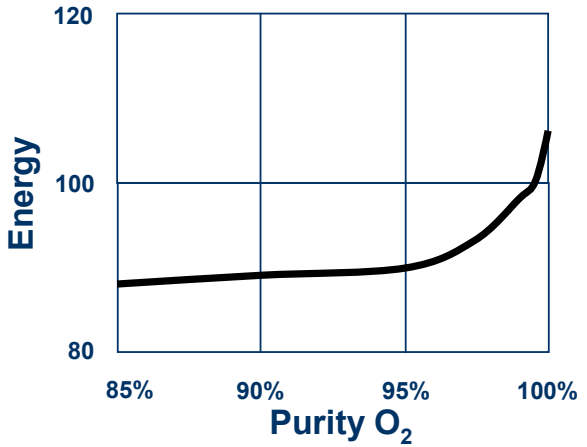


Elcogas - Spain

ASU - 5 main processing steps:

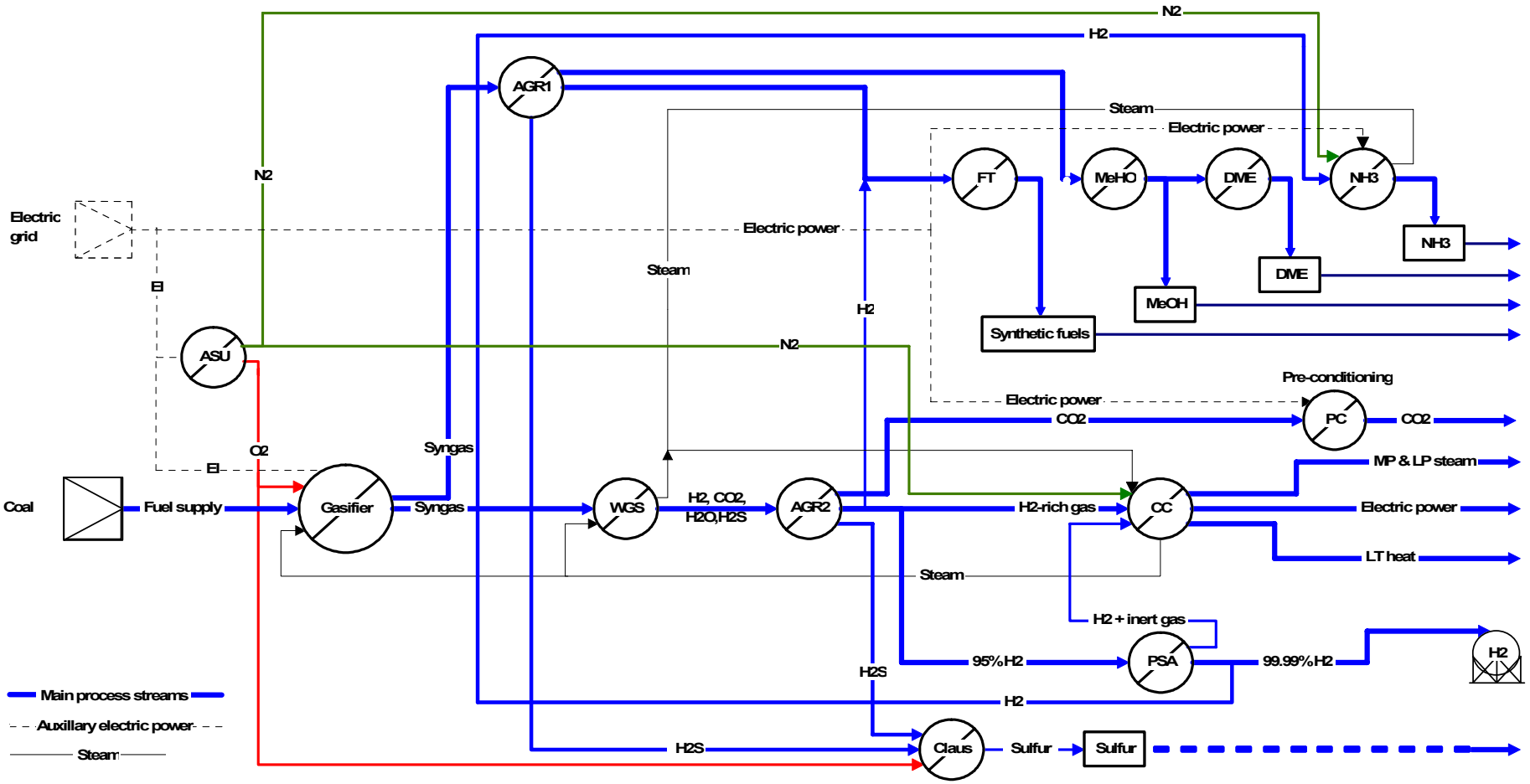
1. Compression
2. Purification
3. Heat exchange
4. Distillation
5. Cold production

Products are: O_2, N_2, Ar (gas or liquid)
Waste: Impure N_2



Polygeneration from coal

IGCC-CCS



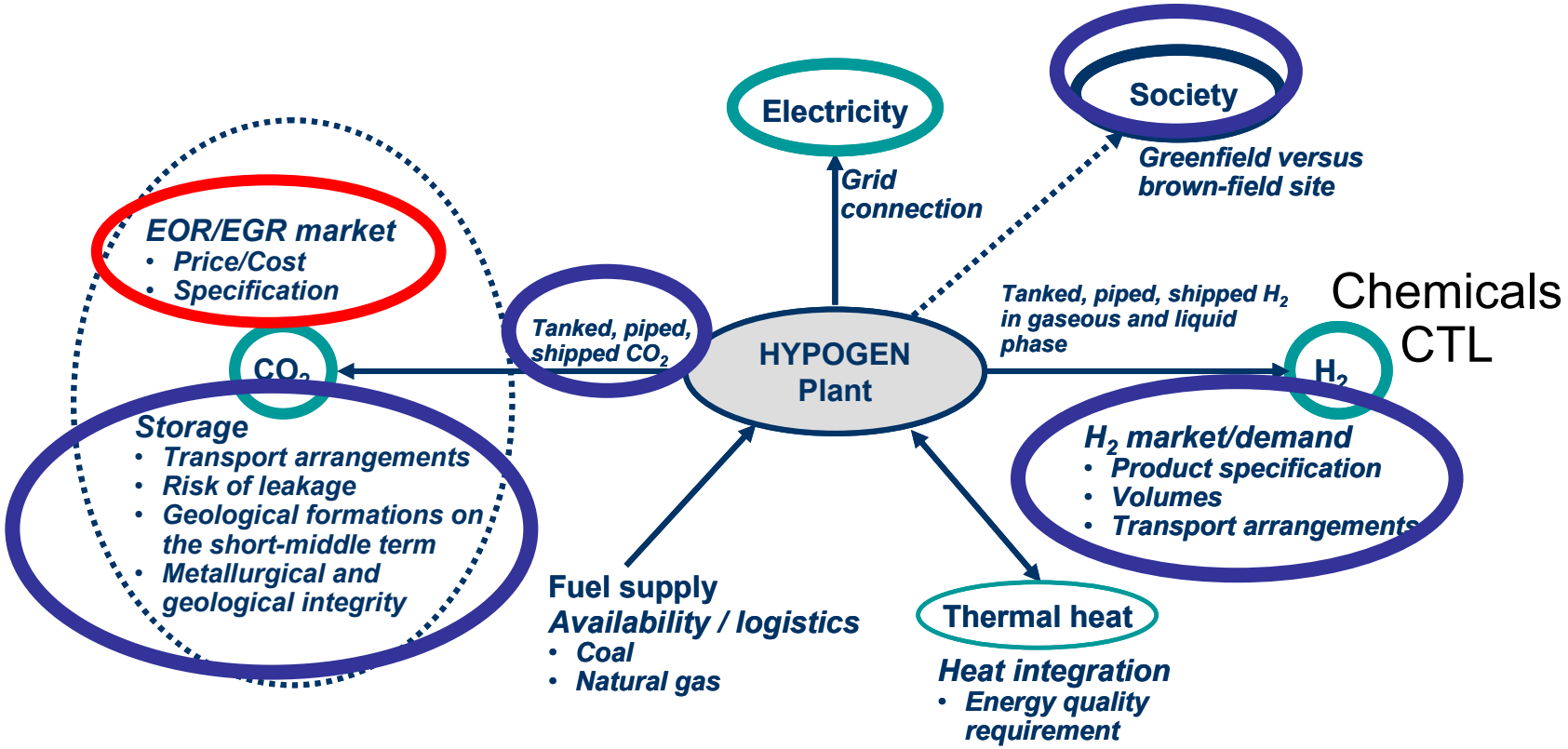
SINTEF/COACH project 2008

CO_2 pipeline specification

Component	*Concentration*	*Limitation*
H_2O	**500 ppm**	Technical: below solubility limit of H_2O in CO_2. No significant cross effect of H_2O and H_2S, cross effect of H_2O and CH_4 is significant but within limits for water solubility.
H_2S	**200 ppm**	Health & safety considerations
CO	**2000 ppm**	Health & safety considerations
O_2	Aquifer < 4 vol%, **EOR 100 – 1000 ppm**	Technical: range for EOR, because lack of practical experiments on effects of O_2 underground.
CH_4	Aquifer < 4 vol%, EOR < 2 vol%	As proposed in ENCAP project
N_2	< 4 vol % (all non condensable gasses)	As proposed in ENCAP project
Ar	< 4 vol % (all non condensable gasses)	As proposed in ENCAP project
H_2	< 4 vol % (all non condensable gasses)	Further reduction of H_2 is recommended because of its energy content
SO_x	**100 ppm**	Health & safety considerations
NO_x	**100 ppm**	Health & safety considerations
CO_2	>95.5%	Balanced with other compounds in CO_2

[1] The concentration limit of all non-condensable gases together should not exceed 4 vol%.

Localisation and transport issues



Main findings

- **Polygeneration from coal with CCS is seen as a contender in the emerging CCS market** ***(ref. the Chinese GreenGen, European studies (DYNAMIS) etc.)***
  - **Technology seems available (already) for early deployment at commercial scale using proved and financeable equipment**
  - **Yields and optimal heat integration are crucial (economically)**
- **Investment cost in China amounts to roughly 1.8 M€/MW (depending on case, complexity and location)**

A net efficiency level of around 35% (LHV) can be reached with coal-fired IGCC plants using "F" class gas turbine technology and with a full CCS chain.

Concluding remarks

- **Pilots are ramping up (globally)**
- **Demos will go on stream by 2012+**
- **2020: Some tens of CCS plants**
- **2030: Some hundreds of commercial CCS plants**

Commitments:

- EU will support 10-12 CCS demonstration plants (> 300 MW_e) to go on stream by 2015-2020
- G8 urges for 20 operational plants by 2020
- The Obama Administration (US) announced its desire of establishing 20 commercial operational CCS projects by 2020, and sees China as an integral part of reaching that goal*
- China gave its permission to complete the GreenGen project and may (perhaps) beat Europe and the US on a milestone

* *New York Times article 22 June 2009*

WP2 Partnership

Acknowledgements

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