CRITERIA FOR ECONOMICALLY-COMPETITIVE POST-COMBUSTION CO2 CAPTURE FROM PULVERIZED COAL POWER PLANTS

Jon Gibbins & Bob Crane

Mechanical Engineering Department
Imperial College London

j.gibbins@imperial.ac.uk

THIRD ANNUAL CONFERENCE ON
CARBON CAPTURE & SEQUESTRATION
May 3 - 6, 2004 Alexandria, Virginia

ACKNOWLEDGEMENTS
BCURA - Grant B70
Anand Rao & Ed Rubin

SIX RULES TO BREAK

if you want to make PC + amine scrubbing power plants look bad

1. Add heat at as high a temperature as possible (i.e. be prepared to use best available steam conditions if commercially justified).
2. Reject heat at as low a temperature as possible.
3. Get as much work as possible from any additional fuel, consistent with rejecting heat at required temperature for solvent regeneration.
4. Reject as little heat as possible / make use of waste heat.
5. Use the latest solvent developments.
6. Exploit the inherent flexibility of post-combustion capture.

OBVIOUS? HARD TO FIND A STUDY IN THE LITERATURE THAT HAS NOT BROKEN AT LEAST SEVERAL RULES

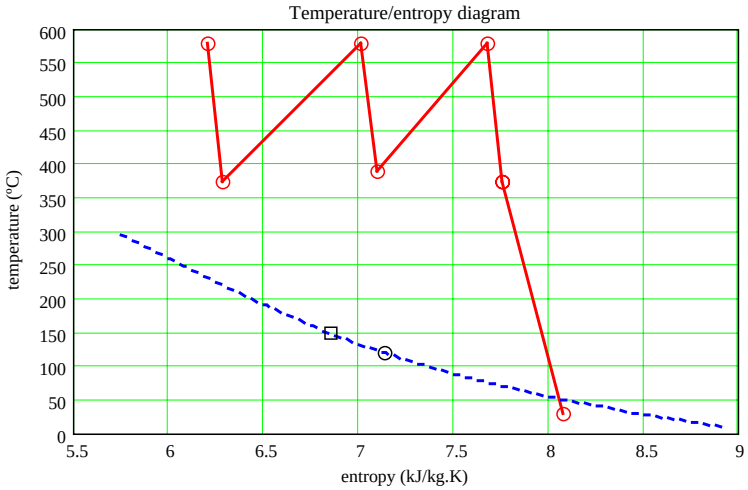
RULE 1 - USE THE BEST STEAM CONDITIONS

- Economics for post-combustion capture plant more sensitive to steam conditions than for plant without capture
- Currently an issue with studies of retrofit to existing sub-critical plant
- Retrofits to obsolete steam plant are unlikely to be competitive with modern steam plants or IGCC - also need advanced supercritical retrofit technology (600/620ºC)
- Also important for plant being built now that will have to operate in a carbon-constrained future
- Sub-critical may be competitive with supercritical plant now, but cannot be considered future-proof = capture-ready

Advanced supercritical retrofit, based on DTI Report ED 01806012, May 2003				
Carbon Dioxide Capture and Storage - A Win-Win Option?				
Appendix A – pg 37 – Detailed Results for EOR Case Studies				
Additional values/changes shown in italics				
	Case 1	**Case 1a**	**Case 1b**	**Case 1c**
Original Power Plant	**PF Coal**	**ASCR +MEA**	**ASCR +KS**	**ASCR +KS 90% LF**
Capital (£/kW)	100	*300*	*300*	*300*
Load Factor (%)	80	80	80	*90*
Original Generation Efficiency of plant (%LHV)	36	*43.5*	*43.5*	*43.5*
Generation Efficiency with CO2 capture (%LHV)	24	*31.5*	*34.5*	*34.5*
Plant life (years)	20	*25*	*25*	*25*
Summary costs without capture:				
Capital charges (p/kWh)	0.17	*0.47*	*0.47*	*0.42*
Opex Fixed (p/kWh)	0.20	*0.17*	*0.17*	*0.15*
Opex Variable (p/kWh)	0.07	*0.06*	*0.06*	*0.06*
Fuel (p/kWh)	1.20	*0.99*	*0.99*	*0.99*
Cost of electricity without capture (p/kWh)	**1.63**	***1.68***	***1.68***	***1.61***
Summary costs with capture:				
Capital charges (p/kWh)	1.08	*1.26*	*1.15*	*1.02*
Opex Fixed (p/kWh)	0.30	*0.23*	*0.21*	*0.19*
Opex Variable (p/kWh)	0.11	*0.08*	*0.07*	*0.07*
Additional Opex of capture plant (p/kWh)	0.80	*0.61*	*0.56*	*0.56*
Fuel (p/kWh)	1.79	*1.37*	*1.25*	*1.25*
Cost of electricity with capture (p/kWh)	**4.08**	***3.54***	***3.24***	***3.09***

RULE 2 - REJECT HEAT AT AS LOW A TEMPERATURE AS POSSIBLE

(steam conditions from IEA GHG Leading options for the capture of CO2 emissions at power stations, IEA GHG Report PH3/14, 2000.)



DON'T USE COLD WATER TO DESUPERHEAT HOT STEAM

- Desuperheating with water at condenser temperature* is equivalent to scrapping all the LP feed water heaters!

** Evaluation of Innovative Fossil Fuel Power Plants with CO2 Removal, EPRI, Palo Alto, CA, U. S. Department of Energy — Office of Fossil Energy, Germantown, MD and U. S. Department of Energy/NETL, Pittsburgh, PA: 2000. 1000316.*

<u>BETTER</u> STEAM DESUPERHEATING OPTION
(to minimise overall temperature of heat rejection from the steam cycle)

- Spray with reboiler condensate

<u>BEST</u> STEAM DESUPERHEATING OPTION
- Use superheat for high temperature feedwater heating (**BUT** higher capital cost may not be justified with optimum IP/LP crossover pressure)

	C1w MEA	MEA+ HPFWH
Plant net power	**362.1**	**370.3**
Efficiency penalty	**27.7%**	**26.0%**
COE $/MWh	**63.50**	**62.09**
CO2 avoided ($/tonne)*	**45.4**	**42.7**

(Gibbins & Crane, IMechE Jnl of Power & Energy, 2004)

RULE 3 - MAXIMISE WORK FROM ADDITIONAL FUEL

Plant efficiency = Electricity out / Fuel heating value in

Competitive efficiency levels for power plants require:

- natural gas - gas turbine combined cycle
- coal - single or double reheat supercritical steam cycle

• Amine scrubbing retrofit studies using auxiliary boilers, especially when fired with high cost gas, cannot give competitive economics

• Only options are to take reboiler steam from main turbine or gas turbine combined cycle

• Maintaining exact plant output may be difficult - but can stop capture (or just regeneration) to meet peak demand

RULE 4 - MAKE USE OF WASTE HEAT

Post combustion scrubbing wrongly classified as using large amounts of energy.

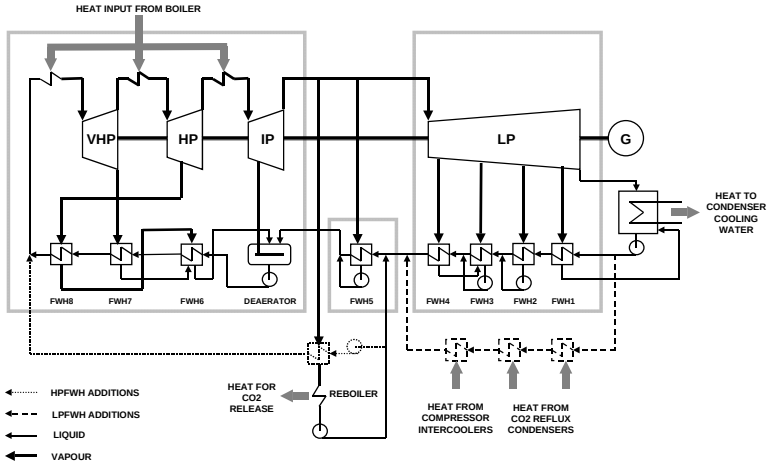
Energy used is relatively modest (e.g 2.1 MJ/kg CO_2 for MEA)
(Rochelle, G., Gaithersburg network meeting, IEA PH3/33, Dec 2000)

Challenge is to use the rest of the (heat) energy that is just degraded to a lower temperature (probably more low grade heat available than can be used).

LP feed water heating is obvious application.
(Mimura, T., Shimojo, S., Suda, T., Iijima, M. and Mitsuoka, S. , Energy Convers. Mgmt, 1995, 36, 397-400)

Also can recycle energy within amine cycle
(Reddy, S., Scherffius, J., Freguia, S., Roberts, C., Proc. 2nd Nat. Conf. on Carbon Sequestration, NETL/DOE, Alexandria, VA, May 5-8, 2003)

LOW TEMPERATURE FEED WATER HEATING - LPFWH



(Gibbins & Crane, IMechE Jnl of Power & Energy, 2004)	C1w MEA	MEA+ HPFWH	MEA+ LPFWH	MEA+ HPFWH+ LPFWH
Plant net power	**362.1**	**370.3**	**368.6**	**376.7**
Efficiency penalty	**27.7%**	**26.0%**	**26.4%**	**24.8%**
COE $/MWh	**63.50**	**62.09**	**62.38**	**61.04**
CO2 avoided ($/tonne)*	**45.4**	**42.7**	**43.3**	**40.7**

RULE 5 - USE THE LATEST SOLVENT DEVELOPMENTS

Quoted energy requirements for commercial processes:
(but basis usually unclear?)

MEA ~ 4 MJ/kg CO_2

Econamine FG plus 3.25 MJ/kg CO_2
(Reddy, S., Scherffius, J., Freguia, S., Roberts, C., Proc. 2nd Nat. Conf. on Carbon Sequestration, NETL/DOE, Alexandria, VA, May 5-8, 2003)

KS2 3.00 MJ/kg CO_2
Mimura, T., Simayoshi, H., Suda, T., Iijima, M. and Mitsuoka, S., Energy Convers. Mgmt, 1997, 38 (suppl.) , s57-s62.

	C1w MEA	KS2
Plant net power	**362.1**	**388.1**
Efficiency penalty	**27.7%**	**22.5%**
COE $/MWh	**63.50**	**59.2**
CO2 avoided ($/tonne)*	**45.4**	**37.4**

(Gibbins & Crane, IMechE Jnl of Power & Energy, 2004)

RULE 6 - EXPLOIT INHERENT FLEXIBILITY OF POST-COMBUSTION CAPTURE (SHORT & LONG TERM)

- Inherently low CO_2 partial pressure
- Large volumes - high capital cost
- Active solvent - high energy requirements
- High compressor power (~7% of plant output)

BUT

- Can operate main plant without capture = extra power
- Solvent storage = low-cost pumped storage
- Easy to upgrade to latest solvent

- <u>Very difficult to quantify benefits</u> of following this rule, so everybody breaks it!
- Could be significant (capture penalty halved?), but site and time dependent.
- Evaluation methods needed for use in comparative studies by DoE, IEA GHG etc.

CONCLUSIONS

- Capture economics study conditions can pre-determine outcome

- Most post-combustion capture studies have broken some (or all) of the Rules

- Likely that a misleading impression of the capabilities of amine scrubbing would be gained from the literature

- Post combustion capture has natural potential market niches, defined by the need to follow the Rules

Market now

Capture-ready, new supercritical steam plant
Retrofit, if can be combined with advanced supercrit
Capture-now plant (solvent improvements needed?)

Possible longer-term market