



**INTERNATIONAL TEST NETWORK FOR CO₂
CAPTURE: REPORT ON 4th WORKSHOP
(5th October 2002, Kyoto, Japan)**

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INTERNATIONAL TEST NETWORK FOR CO₂ CAPTURE: REPORT ON 4th WORKSHOP

(5th October 2002, Kyoto, Japan)

1. Overview of the network and past workshops

This workshop was the fourth in a series to discuss co-operation in development of MEA and related solvents to capture CO₂ from power plant flue gases. The previous events were, in Gaithersburg, USA in October 2000, and Calgary, Canada in November 2001, and Apeldoorn, Netherlands in May 2002.

Carbon dioxide capture and disposal is now included in most OECD countries' energy policies and R&D programmes as a potential contributor to carbon dioxide mitigation strategies. Techno-economic studies have generally concluded that in any widespread deployment the largest element of capital and operating costs will be associated with the capture element of the chain.

The overwhelming majority of fossil fuel fired power plants produce a low pressure low CO₂ concentration flue gas and actions to remove these are first likely to be based on some form of solvent scrubbing with separate solvent regeneration and recycle.

A number of proprietary processes capable of such capture are on the world market and have been for many years, based on the use of monoethanolamine (MEA) or a derivative of it. However, these have not been developed for large power plant operations and could be much improved in efficiency and economic performance. Considerable R&D and systems modelling is being undertaken to these ends. The network encourages collaboration and speeds the prospects for meaningful demonstration and dissemination of CO₂ capture and storage.

Gaithersburg

At the Gaithersburg workshop participants identified a number of areas for potential technical co-operation and/or information exchange. These included:-

- Solvent design to suit the particular composition of flue gases, especially the presence of SO₂.
- Absorption column design, in particular identification of suitable packings and packing heights
- Integration of the energy system within the power plant flowsheet and minimising the thermal penalty associated with solvent regeneration.
- Modelling and evaluation to determine potential economies of scale and impact on sent out power costs
- Collaboration and possibilities for cost sharing in R&D activities.

Arising from the above considerations 4 tasks were identified for further investigation:-

- A. Process Simulation
- B. Process and Economic Assessment
- C. Innovation at Test Facilities
- D. Feasibility Study

Calgary

The Calgary workshop was convened to further develop possibilities associated with Task A and to some extent Task B. Presentations were made on the following topics

- a review of the status and confidence in available vapour – liquid equilibria data
- rate data modelling
- mass transfer
- the International Test Centre (ITC)
- the Boundary Dam project, GTI's test facilities
- the benefits and limitations of pilot plant work software issues and systems

Apeldoorn

The primary intentions for this workshop were to

- advance work on simulation and modelling
- begin review of practical results
- consider finances for future events

The delegate list showed an increase in European attendees and a decline in USA and Canadian citizens. Hence, the Agenda contained a number of country reviews and up-dates on the general topic of CO₂ capture and storage before moving to specific activities related to process modelling, systems modelling and economics and practical activities concerned with MEA and similar solvent based CO₂ capture.

An outstanding action from this meeting was to provide information on the IEA GHG database on RD&D projects on carbon capture and storage. This is now available on <http://www.co2sequestration.info>. At the moment it contains some 84 entries of which 31 relate to capture.

A highlight was the identification by the system modellers of ways of collaboration, which were developed in an off-line meeting between meetings.

2. Kyoto Workshop attendance and agenda

This was the biggest workshop so far with 39 registrants from 9 countries. Breakdown by country and type of organisation is given below. It reveals the dominance of the fundamental research community.

Attendee Origins

Canada	13	Government	6
Japan	11	Industrial companies	9
USA	7	Research Organisations (not universities)	9
UK	2	Universities	15
Netherlands	2		
Australia	1		
Italy	1		
Sweden	1		
Switzerland	1		
Total	39	Total	39

Because this was a one day event only 11 presentations were made in 4 sessions. The fullest session concerned the system modelling and process economics reflecting the increasing co-operation and exchange between Canadian, US and UK contributors. For the first time there was a significant

Japanese presence, which included an overview introduction by NEDO and two excellent presentations by MHI and RITE. New insights into the rate data for MEA and its potential fit to available models were also revealed and the delegates heard about the intentions of a Canadian consortium to have retrofit and a new build power plants with solvent based CO₂ capture up and running in 2007 and 2010.

The full Agenda is at Annex I and the delegate list at Annex II.

3. Presentations by Attendees

Presentations were made as listed below. Copies of slides appear in the same order in Annex III.

- **John Topper**, IEA Environmental Projects Ltd, UK – Background and Objectives for this Workshop. This was aimed at first time attendees and summarised the aims and objectives of the series of workshops and introduced the agenda for this one.
- **Koichi Kudo** of NEDO on the Japanese Government programme in carbon capture and storage. He highlighted issues associated with public acceptance of CO₂ storage and capture and went on to emphasise the need to reduce capture costs and gave examples of R&D on membranes and absorption systems which NEDO are supporting.
- **Ed Rubin** on behalf of a group including Universities of Waterloo, Canada, Imperial College, UK and Carnegie Mellon, USA presented some thoughts on future activities for the group. These are reflected in section 4 of this report (below).
- **Shinichirou Morimoto** of RITE gave some comparative process performance and economic analysis for post combustion capture based on a 1000MWe coal fired PC plant using MEA or Pressure Swing Adsorption or Membranes. He presented estimated figures for internal energy consumption for each technology and derived costs per tonne CO₂ avoided. This were \$46/tonne for MEA; \$64/tonne for PSA; and \$59/tonne for a hollow fibre polyamide membrane. He also suggested some ways in which the internal energy penalties might be reduced, and finally gave a summary of RITE's current practical evaluations of the polyamide membrane system.
- **Jon Gibbins** of Imperial College on the potential for energy savings in integrating capture plant with conventional PC power plant. He reminded the audience that it was unsafe to simply develop bolt on technology for retrofit since this inevitably missed opportunities to reduce internal energy consumption arising from optimised integration. He also pointed out that real plant probably would need to operate if the CO₂ capture plant is down, operate at part loads and load follow satisfactorily and in an ideal world would need to be upgradeable to allow for things such as new solvents, packings etc.

He presented some comparisons starting from published studies of IEA GHG and EPRI which modelled CO₂ retrofit to PC plant showing losses in net efficiency of around 28%. By using KS1 (MHI's) solvent he indicated a reduced penalty of about 4% to around 24% which in turn reduced the cost of an avoided tonne of CO₂ from 43-45\$/tonne to around \$37/tonne. He then looked at the steam cycle and by choosing to extract heat from various parts for use in solvent regeneration he predicted further potential reductions to around 34-36\$/tonne CO₂. If confirmed this indicates an early potential for about a 20% reduction in solvent based capture costs.

- **Colin Alie, et al**, of University of Waterloo with and up-date on the use of Aspen Plus in modelling MEA based capture. He reviewed the fit of Aspen Plus embedded VLE data for MEA/CO₂ and concluded that over the temperature range of interest (around 120C) there was a good fit – more on this in the later presentation of Rochelle, *et al*. Using IEA GHG base case of a 500MWe PC plant he reported on the evaluation of two different retrofit routes. In the first a supplementary CCGT plant is built to maintain station output. In the second the de-rating is

accepted as a result of over 40% of the steam being extracted for operating the CO₂ regenerator reboiler. Again this emphasises the importance of carefully considered integration of retrofit CO₂ capture with the existing steam cycle in order to minimise the efficiency penalty.

- **Ed Rubin and Anand Rao** of Carnegie Mellon University on potential to reduce capture costs. Using the NETL sponsored IECM – Integrated Environmental Control Model, they have looked at capture for a new PC plant and are in the early stages of developing a similar appraisal for IGCC, with and without capture. Interesting work in progress is examining capture costs with a probabilistic approach. For instance estimates ranging from \$40-\$80/tonne of CO₂ with a 50% point at around \$54/tonne were shown based on current knowledge. Speculation on reducing both the spread of possible costs and their absolute values was presented and suggestions made as to which plant areas might contribute to equipment cost and energy consumption reductions.

This modelling system was developed with US DoE funding and can be downloaded from the web site at <http://www.iecm-online.com> . Queries to Anand Rao on abr@cmu.edu .

Nobuo Imai of Mitsubishi Heavy Industries on the application and use of their KS-1 sterically hindered amine solvent. Mr Imai showed that compared to MEA, KS-1 has better CO₂ loadings, lower heat demand for regeneration, minimal degradation to form heat stable salts and much lower corrosivity. He showed some cost data, which indicated that operating costs would be about 30% lower than for MEA and overall cost/tonne of CO₂ avoided about 20% lower

The original investigation into solvents and packings had been done on a slip-stream pilot plant at the Nanko power plant. There was now a 160t/d CO₂ capture facility at a Urea plant in Malaysia using KS-1 solvent.

- **Paitoon Tontiwachwuthikul** of University of Regina (International Test Centre) reminded the delegates of the extensive facilities, staffing and partnership arrangements at the International test Centre, described the range of pilot and demonstration plant available and gave an up-date on some of the findings on plant data.

The latter related to work on CO₂ loadings in MEA solutions of varying strengths, and the related rate data; also some investigations into higher capacity absorption column packings and some examination of alternative amine solvents.

- **Bill Richards** of Nova Scotia Power on the aspirations of the Canadian Clean Power Coalition. The CCPC is conducting studies to assess the feasibility and costs of retrofitting pulverised coal fired power stations with CO₂ capture and it will also assess in less detail the costs of new plants on a greenfield site. Three Canadian fuels will be considered when selecting the most suitable plant: bituminous coal (Nova Scotia/Ontario), sub-bituminous coal (Alberta) and lignite (Saskatchewan). The main studies that will be conducted will be:
 - Evaluation of amine scrubbing and CO₂/O₂ combustion in new and retrofit plants
 - Evaluation of coal gasification options in new and retrofit plants
 - Evaluation of retrofit emission control options

The work package on retrofit emission control options will calculate the costs of retrofits to control emissions of other pollutants (SO_x, NO_x, particulates and mercury) to the standard that would be achieved by a plant with CO₂ capture. This will enable the net cost of capturing CO₂ to be calculated. The CCPC will also carry out some other smaller studies, for example to investigate options for storing captured CO₂ in Canada.

- **Gary Rochelle** of University of Texas on findings in some recently completed studies on MEA. These looked at rate data and models in wetted wall columns, forcing of data fits with model predictions, rate optimisation, sensitivity to absorber and stripper heights and sensitivity to stripper

pressure. Amongst many interesting observations, the pros and cons of the presence of heat stable salts evinced most reaction from delegates. Although these salts contribute to deteriorating absorber performance a certain level actually enhances CO₂ loading and improves release in the stripper. Other conclusions indicated that :

- Stripper pinches set optimum solvent rate
- Heat duty is not sensitive to stripper height
- Optimum stripper pressure around 2 atm
- Absorber T bulge dramatic
- Absorber intercooling ineffective

4. Direction of future activities

Ed Rubin led a brief discussion on whether the network in order to attempt to focus the supply of data and the systems modelling. A brief presentation is in Annex 3 (the third in the list). He pointed out that so far this was a voluntary group, with no funding and an evolving set of participants. He suggested that it was time to develop some focus, and below in the text box are the suggestions from one of his slides

<p>What to Attempt? Case study of a power plant linking all elements of the interaction hierarchy – new plant? – retrofit plant? IEA premises as a starting point Expectations for the next meeting (9 months) – tightening the network – informal subgroups – defining information needs & connections – preliminary results – new questions and issues</p>
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Since there seemed to be no disagreement about the needs and expectations, the co-ordinator will be in touch to develop some of these themes over the next few months.

5. Resources

Immediately following the workshop the IEA Greenhouse Gas R & D Programme Executive Committee met in Tokyo on 7-8 October. In presenting the development of this network to members John Topper (co-ordinator) pointed out that only one individual (from industry) had attended all 4 workshops and that the influence of location and implications for travel budgets, particularly for some of the key academic researchers. It was agreed that where the co-ordinator considered attendance of particular key individuals might be supported by modest subsidy of travel (ie for non-funded academics) assistance could be rendered from IEA GHG resources.

He reminded workshop delegates that an Expression of Interest to the European Commission for network funding had been submitted in May 2002. All the EOI's had now been published on their Cordis web site. It was notable that a similar EOI was submitted by a CO₂ Net team under the leadership of TNO (Paul Feron). How the Commission intended to proceed in terms of what to support, when to invite proposals and tendering procedures was still unclear. IEA Environmental Projects Ltd would prefer to collaborate rather than compete and are awaiting developments.

6. Next Meeting(s)

National Energy Technology Laboratories (NETL) in the USA have provisionally agreed to host the 5th Workshop in the Pittsburgh area in May or early June 2003. There remains a possibility of associating this workshop with 2nd National Carbon Sequestration Conference, which is intended to take place at around the same time.

Thereafter, it would be the intention to hold the 6th workshop in Europe at beginning of 2004. Offers from potential European hosts would be welcome. The 7th workshop will probably be in association with the GHGT7 conference in Vancouver in September 2004.

7. Thanks and Acknowledgements

All participants wish to thank Dr Takekawa of NEDO who generously acted as host and supplied a room with very good presentational facilities, lunch and refreshments.

8. Contacting the Co-ordinator

The IEA Greenhouse Gas R&D Programme co-ordinate the development of this network and arrange the workshops.

Queries about or copies of this report can be obtained by contacting:

either John Topper john.topper@iea-epl.co.uk

or Paul Freund paul@ieagreen.demon.co.uk

or via the “feedback” facility in the IEA GHG website’s home page <http://www.ieagreen.org.uk>

Workshop Agenda

CO₂ Capture Test Network – Kyoto Workshop

Saturday, 5th October 2002

0900 – 0915 hrs	REGISTRATION
0915 hrs	SESSION 1 – Welcome, Introduction and Review
John Topper For IEA GHG	Welcome and Introduction Dr Takekawa and Koichi Kudo for NEDO John Topper for IEA Greenhouse Gas R&D Programme
0945 hrs	SESSION 2 – SYSTEMS MODELLING and ECONOMICS
Peter Douglas University of Waterloo	<ol style="list-style-type: none"> 1) Opening Remarks by Peter Douglas and Ed Rubin on vision for future collaboration in systems modelling. 2) CO₂ Separation process review by RITE – Japan 3) MEA capture systems integration by Jon Gibbins, Imperial College – UK 4) Energy Integration of MEA based Capture on a Coal Fired Power Plant by Colin Alie, University of Waterloo – Canada 5) Potential to Reduce Capture costs by Ed Rubin and Anand Rao, Carnegie Mellon University – USA 6) General Discussion
1230 hrs	LUNCH
1400 hrs	SESSION 3 – PILOT PLANT AND PROCESS STUDIES
Malcolm Wilson University of Regina	<ol style="list-style-type: none"> 1) CO₂ Capture Technology of KS-1 by Nobuo Imai and Kazuo Ishida of MHI Japan 2) Up-date on work by I TC Regina, Paitoon Tontiwachwuthikul – Canada 3) Canadian Clean Power Coalition by Bill Richards of Nova Scotia Power 4) General Discussion
1530 hrs	BREAK
1600 – 1645 hrs	SESSION 4 – FUNDAMENTAL STUDIES
Gary Rochelle University of Texas	Modelling of CO ₂ Capture by Gary Rochelle, University of Texas – USA
John Topper 1700 hrs	NEXT STEPS AND SPRING 2003 WORKSHOP FINAL REMARKS AND CLOSURE

CO₂ Capture Test Network

5 October 2002 – Kyoto, Japan

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PRESENTATIONS

Please refer to the individual presentations (on the CD)

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Koichi Kudo, NEDO	<u>ANNEXIII-2 Kudo NEDO.ppt</u>
Edward Rubin	<u>ANNEXIII-3 Rubin1.ppt</u>
Shinichirou Morimoto, RITE	<u>ANNEXIII-4 RITE.ppt</u>
Jon Gibbins, Imperial College	<u>ANNEXIII-5 Gibbins.ppt</u>
Colin Alie <i>et al</i>, University of Waterloo	<u>ANNEXIII-6 AlieWaterloo.ppt</u>
Edward Rubin and Anand Rao	<u>ANNEXIII-7 Rubin-Rao.ppt</u>
Nobuo Imai, MHI	<u>ANNEXIII-8 Imai.ppt</u>
Paitoon Tontiwachwuthikul, ITC	<u>ANNEXIII-9 PT-ITC.pdf</u>
Bill Richards, Nova Scotia Power	<u>ANNEXIII-10 RichardsCCPC.ppt</u>
Gary Rochelle, University of Texas	<u>ANNEXIII-11 Rochelle.ppt</u>