International Test Network for CO_2 Capture: Report on a Workshop

Report Number PH3/33
December 2000

This document has been prepared for the Executive Committee of the Programme.
It is not a publication of the Operating Agent, International Energy Agency or its Secretariat.

CONTENTS

COVER PICTURE: The CO_2 capture facility at the AES power plant, Warrior Run, Cumberland, USA (see Annex 12)

WORKSHOP ON: INTERNATIONAL TEST NETWORK(S) FOR PRACTICAL CO_2 CAPTURE

1. Workshop overview

In recent years there has been a sharp increase in interest in the use of carbon sequestration as a long-term greenhouse gas mitigation strategy. Studies over the past 10 years have concluded that to make carbon sequestration a realistic technical option, achieving drastic reductions in the cost and energy penalties is a critical research priority. CO_2 capture can constitute 60-80% of the overall cost of sequestration.

There has been much discussion recently on the establishment of CO_2 scrubbing test facilities where basic concepts could be verified and advanced concepts developed. Small pilot plants and laboratory units have been built and are currently in operation in various countries; a limited number of larger test centres either exist or are proposed (See Annex 10). Members of the IEA Greenhouse Gas R&D programme suggested that an international test network could be established which would act as a forum for, and promote the work of, those involved in these activities.

The workshop was organised by the IEA Greenhouse Gas R&D Programme with assistance from representatives of its members in the United States Department of Energy, and ABB Lummus Global. It was held in Gaithersburg, Maryland, USA on the 11^{th} and 12^{th} October 2000 (see Annex 1 for Agenda). The objective was to stimulate world-wide collaboration and encourage practical development of CO_2 capture technology.

Participants invited to the workshop are actively engaged in practical research on CO_2 capture or seeking ways to promote such activities. Approximately 40 people from 9 different countries attended (see Annex 13). The workshop aim was to identify potential areas of co-operative agreement for the research, development and demonstration (R,D,&D) of CO_2 capture technology. The focus was on capture of CO_2 using regenerable solvents-based scrubbing systems. (Co-operative activity could be expanded at a later date to include alternative methods of CO_2 capture, but this was not discussed in any detail at the workshop.)

Workshop participants showed a keen interest in taking part in a series of international test networks to stimulate world-wide collaboration on research, development, and demonstration (R,D&D) of CO_2 capture technology. The networks would have a common objective, which is to work towards a large-scale demonstration plant for CO_2 capture. Such a demonstration plant would serve as an international test bed for best available CO_2 capture technology.

Plant integration is seen as the key to reductions in the cost of CO_2 capture. Participants in the workshop believe that a 'whole plant' demonstration is needed; this will allow the following individual components to be developed and demonstrated as an integrated process:

- solvent
- packing
- energy integration
- economies of scale
- large-scale engineering innovations

The target demonstration plant is assumed, at this stage, to be a coal-fired unit in which CO_2 capture is fully integrated into the power generation process. It would demonstrate that CO_2 capture can be operated integrally with other advanced environmental control systems, and that emissions of particles, SO_x, NO_x, etc. are satisfactorily dealt with. Capture using amine solvent from flue gases is the preferred option, but on-going evaluation to confirm the preferred technology is an integral part of the overall development. The target start-up date is provisionally set at 2007. A feasibility study to define the characteristics of the demonstration plant and a programme for its construction is one of the proposed activities.

Participants in the workshop agreed that international test networks will work on a series of related projects, referred to as 'tasks'. These tasks will support the common objective of building a demonstration plant. Each participant would take part in one or more tasks. Some tasks will be very specific and have a short life whereas others could continue throughout construction and operation of the demonstration plant. It is envisaged that key decision points related to the tasks will be built into an overall development programme for a demonstration plant.

1.1. task A: process simulation. The purpose of this task is to evaluate and improve the predictive capabilities of CO_2 scrubbing performance models. Process licensors have agreed to provide performance data that can be used to compare simulation models of amine treatment processes. These models deal with fundamental data such as mass transfer rates, kinetics, heat of reaction, etc. The models include customised versions of commercial modelling packages and in-house programmes. Initial work will focus on modelling using commercially available programmes. The aim will be to evaluate and compare the predictive capabilities of the models. Strengths, weaknesses, and limitations in specific regimes/applications will be identified and a reconciliation of differences sought. It is known that some existing data is incorrect/inconsistent. There is no comparative data on process performance in the public domain.

Several institutions agreed to participate in this task using their existing models. New funds are not required at this stage as participants are willing to carry the costs internally.

It is expected that this activity will identify 'data holes' and that a plan to obtain such missing data will be developed. It is envisaged that this work will lead to requests for further data sets from existing plants. This would require funding and the agreement of plant operators and process licensors.

Ultimately, work in this area could lead to the formation of a computer model which represents a 'virtual pilot plant' for the proposed demonstration plant.

IEA GHG agreed to provide administrative services, at no cost, until the task was established.

1.2. task B: process and economic assessments. The purpose of this task is to develop an agreed process assessment and costing methodology that can be used by participants as common frame of reference.

Participants in the network will need base-line assessments covering the leading process options for CO_2 capture. These assessments are needed for regular checks on developments that could influence successful application of the technology. For example, to ensure that amine scrubbing of flue gas continues to be a leading option for CO_2 capture.[1] In the event that newer or alternative technology becomes more promising the aims and objectives of the overall task would be reviewed. (Test networks covering CO_2 capture options other than amine scrubbing were seen as a desirable potential development.)

There are two main demands of the base-line assessments: (1) that the assumptions are acceptable to all participants and are clearly stated so that they can be changed if participants want to customise their own assessments. (2) some of the assessments are in sufficient detail that the high cost areas can be clearly identified to help target R,D&D and in particular, cost-reduction efforts.

IEA GHG have done a lot of work in this area at various levels of detail. Discussions with EPRI on the possibility of work based on extending the EPRI TAG assessments were suggested. (It was noted that there are also initiatives by (i) Statoil, and (ii) BP and partners in the JIP/CCP[2] to produce assessment base-lines.)

It was agreed that IEA GHG develop a specific proposal for this task following an exploration of co-operative possibilities with others working in this area. In particular, delegates agreed that a joint activity involving EPRI and IEA GHG would establish credibility.

1.3. task C: process innovation at test facilities.

The purpose of this task is to promote co-operation between research test facilities working on CO_2 capture so as to obtain maximum benefit from their capabilities and resources.

Initially the task will cover the establishment of a forum at which process innovations and research findings can be reported on and compared. The work will be based on activities at participant's test rigs and on in-kind contributions. As the network develops it is expected that collaborative partnerships will be identified.

The table of test facilities circulated at the workshop (Annex 10) is a first step to definition of current capabilities. It was agreed to extend the table noting that different facilities have different applications that could complement each other. The improved table will review the flexibility of the test facilities.

A future role was seen for a small number of 'full-scale' tests on slip-streams at operating facilities.

Test facility activities cover fundamental research, process development, and process integration; they could include work on the following:

- CO_2 solubility

[1] Other options most frequently suggested at present are based on IGCC technology and O_2 combustion. More novel process could emerge as serious contenders.
[2] Joint Industry Project – Carbon dioxide Capture Project.

- corrosion
- batch operation and analytical work on degradation (and the role of Fe, S, NO_x) including thermo-speciation
- physical properties (viscosity, mass transfer coefficient, surface tension,) with and without the presence of impurities
- calorimetry (heats of reaction)
- packing/trays/sprays, membranes, novel contactors, gas/liquid ratios
- stripping
- novel/mixed solvents, inhibitors, activators, etc.
- solvents for specific applications

Some work in this area will be proprietary, but it was suggested that much non-proprietary work could be done. It was agreed to tackle IPR[3] issues on a case-by-case basis.[4]

Regular technical meetings were suggested (annually?) and probably password-protected internet communication.

IEA GHG were charged with preparation of a definite proposal.

1.4. task D: feasibility study. The purpose of this task is a feasibility study to define the characteristics of a demonstration plant and a programme for its construction.

An outline specification for a demonstration plant will be developed. Consideration will be given to key factors such as the size of the plant, and whether it could be a retro-fit or would need to be an entirely new integrated power generation and CO_2 capture facility.

It is anticipated that a minimum size of say, 100MW is needed to adequately incorporate commercial-scale equipment. This will produce in the region of 2000 tonnes/day of CO_2[5]; therefore, a store or use for the CO_2 is highly desirable.

1.5. other potential areas for collaboration. A number of other areas were identified as having the potential for collaborative development. These areas were not dealt with in any detail at the workshop as it was agreed they be held over for future consideration. They could develop into additional tasks or be subsumed into one of the other tasks. The requirements for development of a next-generation solvent were discussed, as were possible 'real world' case studies. A discussion on R&D priorities identified the following as potential areas for collaborative development:

- retrofit applications
- break-through technology development such as nano-tubes and ionic liquids
- hybrid systems e.g. membranes and solvents
- combined systems i.e. dealing as a whole with SO_x, NO_x, PO_x, and CO_2
- dynamic process control models

---

[3] Intellectual Property Rights

[4] Cooperation on R,D,&D in Canada, e.g. with the Alberta Research Council, was cited as an illustration that IPR issues are tractable.

[5] Note that the AES plant at Warrior Run captures about 150 tonnes CO_2/day (see Annex 12).

- tailored solvents
- solvents under pressure/vacuum
- standard test devices

1.6. organisation. It is proposed that participants co-operate under the aegis of the existing IEA agreement on technologies relating to greenhouse gases. The activity will be covered initially by the existing Annex (1) to the IEA GHG agreement. This is a simple arrangement as all the likely participants are from countries or organisations that are already members of the existing IEA GHG agreement. The relevant member of the IEA GHG agreement will be asked to approve an organisation's participation.

A rolling programme of tasks is envisaged. Participants will be asked to sign an agreement for each task they take part in. This agreement will cover issues such as, scope of work, programme, contributions, and IPR. Each task will be specified and terminated as required by its participants. Management of a task will be by a committee of participants. Initial activities will be largely based on in-kind contributions. Additional funds will be sought as decided by task participants.

Substantial funding will need to be sought as the series of tasks develops towards the design, construction, and operation of a large-scale demonstration plant. Some of the original participants may no longer be involved and new participants may have joined. At a suitable stage, it is envisaged that a formal project to design and construct the demonstration plant will be agreed; this could be set up as a new separate Annex to the IEA GHG agreement.

The Operating Agent for the existing IEA agreement will provide administrative services free to participants until each task is established. Administrative servicing of each task would be provided by IEA GHG after it is established but at this point some agreed reimbursement for the service would be necessary.

A launch meeting for those intending to participate in tasks under the international test network is planned for April 2000.

2 Comments and recommendations received

Participants at the workshop were surveyed to establish their views on the workshop and the required next steps.

2.1. Several participants noted that there were no solvent manufacturers and not many equipment vendors at the workshop. Attempts to involve them should be made as the networks develop.

2.2. It was noted that this area was one in which, initially, cost sharing and contributions in kind could be effective. However, funding would be needed to make significant progress in reducing the cost of CO_2 capture. It was suggested that IEA GHG take the lead in developing funding initiatives and approaching potential funding agencies.

2.3. Fluor Daniel commented that the demonstration plant was not meant to be a greenfields coal-fired plant. They believe what was meant was a greenfields CO_2

Amine Capture Plant. This could be retrofitted to existing coal-fired plants; integration can also be investigated as part of the feasibility study.

3 Press release
Dr Perry Bergman (NETL) produced the following as a DOE press release; it is included here as a succinct summary of the workshop results.

"Major Steps Taken Toward the Creation of an International Test Network for CO_2 Capture RD&D

On October 11 and 12 a Workshop on establishing an International Test Network for CO_2 Capture, was held at the Hilton Hotel in Gaithersburg, Maryland. The workshop was organized by the International Energy Agency Greenhouse Gas Research and Development Programme (IEA GHG), US DOE, and ABB Lummus Global of Switzerland. Forty two researchers from ten different countries; representing industry, government, and academia, came together to discuss the establishment of an International Test Network to stimulate world-wide collaboration on research, development, and demonstration (RD&D) of CO_2 capture technology, using regenerable scrubbing at atmosphere pressure.

CO_2 capture represents approximately 75-80% of the cost of CO_2 sequestration, the balance being the cost of CO_2 storage and transportation.[6] Although fossil fuel-based CO_2 capture plants are currently operating for customers in the food and fertilizer industry, drastic cuts in both energy consumption and plant costs must take place for CO_2 capture to be successfully introduced into the electric utility industry for CO_2 emissions reduction. Four major areas of collaboration were identified at the meeting: (l) evaluation of the capabilities of current CO_2 scrubbing performance models, (2) development of an analytical framework to perform transparent and consistent analyses of CO_2 scrubbing, (3) improvement of existing scrubbing methods through fundamental research, process development, and systems integration, and (4) initiating a feasibility study to define the characteristics of a future demonstration plant, for investigating advanced CO_2 capture concepts. Such a demonstration plant would be built by the year 2007 and would serve as an international test bed for studying the best available CO_2 scrubbing technology in tandem with other environmental control systems, at a near-commercial scale.

Next steps include obtaining expressions of interest from meeting participants and establishing the broad principles of a collaboration agreement. The network would be established under the auspices of the IEA GHG. Test networks for other available CO_2 capture options was also viewed as desirable. The next meeting of the group is expected to take place in April, 200l."

4. Progress report
The next meeting of the group is planed for April 2000. In the interim the international network(s) and proposed tasks will be developed. Specific developments to date are:

task A: process simulation. A draft scope of work has been circulated to participants who said they were interested in taking part in this activity. A copy is at Annex 11; it was written by Denis Leppin, Gas Technology Institute, USA.

task B: process and economic assessments. Some discussion between IEA GHG and EPRI on the possibility of a joint activity, with input by other interested parties, has taken place. A more detailed discussion will be held in December 2000 when a visit by IEA GHG to EPRI is planned.

[6] Transportation costs are highly dependent of the location on the capture facility and the storage site.

task C: process innovation at test facilities. Nothing to report as yet.

task D: feasibility study. Some discussions have taken place with the Canadian Clean Coal Power Alliance. This new group formed, mainly on TransAlta's initiative has proposed a demonstration project to show that coal-fired plants can be as clean as natural gas-fired plants, including CO_2 capture. The targets are to demonstrate a retrofit technology of amine scrubbing or oxyfuel combustion applied to an existing plant by 2007, and to demonstrate a new clean coal technology plant by 2010. It has been agreed to discuss co-ordination of efforts and activities under the test network with this initiative

AGENDA

PLENARY ADDRESS:
US PROGRESS IN DEVELOPING CARBON SEQUESTRATION TECHNOLOGY

Robert S Kripowicz
Acting Assistant Secretary for Fossil energy
U.S. Department of Energy

U.S. Progress in Developing Carbon Sequestration Technology

Remarks by
Robert S. Kripowicz
Acting Assistant Secretary for Fossil Energy
U.S. Department of Energy
at the
International Test Network for CO2 Capture Workshop
Gaithersburg, Maryland
October 11, 2000

I appreciate the work that has gone into planning this conference and want to thank the IEA Greenhouse Gas R&D Programme, ABB Lummus Global, and all the individuals within the Department of Energy for their cooperation. It takes quite an effort to organize a workshop like this, and I sincerely appreciate those who have worked hard behind the scenes to make this meeting a success.

To set the backdrop for our discussions over the next two days, let me repeat a phrase we've heard a lot these last few years - "You can grow the economy and protect the environment at the same time." It's a true statement. We have seen remarkable economic growth in recent years growth that, in large part, has been due to affordable energy. Economic expansion has led to increasing demands for energy - especially electric power - and fossil fuels have supplied much of that demand. And yet, even though we have more than doubled the use of coal in this country since 1970, we have reduced emissions of sulfur pollutants by 70 percent and nitrogen oxide pollutants by 45 percent. Our air is cleaner, our water is cleaner, and our economy is stronger – largely because we have developed and deployed new and cleaner technology. Technology has served us well in the last 30 years. Now we must look to the NEXT 30 years, and quite likely beyond that- and call on technology again to address the new environmental issues we face.

Just over one year ago, the President's Committee of Advisors on Science and Technology underscored the importance of carbon sequestration research in its report Federal Energy Research and Development for the Challenges of the Twenty First Century. The Committee recommended increasing DOE's research and development program for the capture and long-term storage of greenhouse gases. Subsequently, the DOE Office of Fossil Energy and Office of Science issued a final report on Carbon Sequestration Research and Development last December that assessed (quoting from the report) " the key areas for research and development that could lead to an understanding of the potential for future use of carbon sequestration as a major tool for managing carbon emissions". Many of you have seen this report. If you have not, I encourage you to obtain a copy. It's available from our web site and also from the Oak Ridge National Laboratory's web site.

I want to give a great measure of credit to the DOE Office of Science and its former director Martha Krebs. Although Martha has now left the Department, her office proved instrumental in helping to chart a road map for conducting research on various carbon sequestration options. Global climate change IS a long-term issue. And so too will be its solution. Changing the energy system that has largely been responsible for our economic growth and prosperity - especially changing it overnight - is neither economically feasible nor socially responsible. Premature retirement of our existing infrastructure would be prohibitively expensive and economically unwise. There are better approaches. Someone once said that the hallmark of a progressive society is that it has the wisdom to confront its challenges using ALL of its options.

We can take great steps in addressing the challenge of global climate change by infusing greater energy efficiencies into our existing infrastructure - both at the front end where the energy is produced, and at the back end where energy is consumed. But efficiency alone will not get us to our desired goal. We can - and we must - also turn to greater use of renewable resources. We must continue the dramatic progress that has been made recently in reducing the costs of wind and solar power. But renewable resources also are not the sole answer. We can make greater use of natural gas - and that is largely happening. In this country, it is likely that of the next 1000 power plants to be built, 900 will be fueled by natural gas. But natural gas, by itself, is not the magic solution to the climate change issue. It will take a combination of all of these options - and even then, the progress toward stabilizing greenhouse gases in our atmosphere may not be sufficient. That is why carbon sequestration is important.

The challenge of global climate change also requires that we look out beyond our borders. Electricity is the fastest growing segment of the global energy market. Some have predicted that by 2050, the forces of population growth, urbanization, expanding global commerce, and simple human aspirations could result in the global consumption of electric power that is 4 times greater than today. If we were to set a goal of bringing electricity in some form to every inhabitant of the world in the next half century, it would mean providing power to at least 100 million more people in the world every year for the next 50 years. Some people believe that is the direction we are heading - and I hope they are right. But that rate of power demand is triple the rate of electrification over the past quarter century. It means that the world would have to add the equivalent of a 1000 megawatt power plant every one or two days for at least the next 50 years. And if that is to happen, most of those plants will likely burn fossil fuels. This is a staggering challenge within ANY environmental framework. But within the context of greenhouse gas emissions and global climate change, the challenge is even greater. That is why carbon sequestration may be so critical to our global future. Each generation faces its challenges - and I strongly believe that the dominating challenge we will face in 21st century will be a global environmental challenge, and it, in turn, will be dominated by climate change.

When Secretary Richardson spoke to a conference of the world's coal experts in June 1999, he emphasized that carbon sequestration must become the third leg of our climate change strategy - joining energy efficiency and the greater use of low- or no-carbon fuels. From what I have seen and heard since the Secretary made his remarks, more and more people - in research laboratories, in corporate boardrooms and importantly, in the halls of Congress - now agree. Three years ago, we were scraping together funds to support a few $50,000 feasibility studies to see if carbon sequestration research made any sense. This past week, the House and Senate finished action on our fiscal year 2001 appropriations and approved nearly $19 million for sequestration research.

Three years ago, skepticism abounded. Today, that has changed. Now a sense of momentum exists. There is a growing belief among scientists and policymakers that we are on the right path. One of the important reasons for this new optimism has been the response of industry. The private sector has come forward -- not just with good ideas but with a commitment of resources. This summer we completed our first round of major industry competition. When we started the competition, we thought we would be lucky if the private sector met our cost-sharing threshold of 20 percent. This past July, we announced the first 13 winners of the competition - and the average private sector cost-sharing was more than 40 percent. Secretary Richardson called the competition "our strongest commitment to date for carbon sequestration research." But it was ALSO industry's strongest commitment to date. And that has sent a very clear - and very positive – message to the scientific community AND to the decision makers on Capitol Hill.

A second round of proposals came in at the end of August, and there will be more project announcements in the near future. We have also seen our national laboratories step up to the challenge of carbon sequestration in much the same way they have taken on challenges in the past - putting their best minds and creative ideas together in cooperative efforts with industry.

We now have a solid technical foundation - across all fronts....from capture and separation to geologic, terrestrial, and ocean storage. We now have several advanced concepts in the incubation stage - from exploratory research into light-enhanced bioreactors to studies of cryogenic clathrate formation. We now have an active modeling and assessment program underway, using state-of-the-art computing technology to model state-of-the-art options. All of this in a program a little more than 3 years old.

Due largely to many of you in this audience, we have made a remarkable start. But we cannot let our rapid start cloud our judgements or rush us to conclusions. We cannot cut corners. Carbon sequestration is an area of science and technology that must be approached in a careful, methodical manner. It is a whole new area of research - although much of it clearly borrows from a wealth of other disciplines. Yet, there are still major uncertainties. Cost, practicality, environmental safety...all of these are unanswered questions that must be addressed. We should not get discouraged if there are false starts....if there are some apparently good ideas that don't pan out. Progress breeds expectations. But this is an area of research that is so fundamental to our future well-being, we must do it right. Some want overnight solutions. Some want a silver bullet. But these are expectations we must temper. The technical foundation we are building today must be scientifically strong....the concepts technically, economically, and environmentally valid. The stakes are too high for anything less.

When Secretary Richardson elevated carbon sequestration to a climate change priority in 1999, he called for the best minds in the business to join the effort. I believe the most significant accomplishment of all during the last three years is that the research community has responded to the Secretary's call. The best minds ARE now in the business of carbon sequestration research. Now our challenge is to channel the effort – identify the most productive avenues of research...develop and test the most promising concepts...build brick-by-brick, a solid scientific and technical foundation -

and all the while, not be afraid to encourage new thinking and, if necessary, head in new directions. And we must be in it for the long haul. This is a very long-term problem that requires long-term solutions. That is why meetings like this are important. Here today and tomorrow, we can assess where we have been and where we must go. We can catch our breadth, develop our strategies, and then gather our resources and continue to move forward.

Speaking for all of us at the Department of Energy, we are pleased that you have joined us today in Gaithersburg. You recognize the important challenge ahead...and your presence here today tells us that you have come prepared to face it. Let's use the next two days to make sure, to the best of our ability, that our steps are in the right direction. This is a very important journey.

Thank you and best wishes for productive discussions.

PLENARY ADDRESS: PRACTICAL DEVELOPMENT OF CO_2 CAPTURE TECHNOLOGY

Kelly Thambimuthu
Chairman, IEA Greenhouse Gas R&D Programme

DRAFT – KT TALK

CO_2 workshop –Gaithersburg, MD, USA, 11th-12th October 2000

First of all I would like to thank Mr Assistant Secretary Kripowicz for, finding the time to give his support in person to this initiative, and also for DOE's assistance in sponsoring this workshop on the development of CO_2 capture technology. The contribution of DOE's Carbon Sequestration Roadmap in highlighting the major challenge of reducing the cost of CO_2 capture is much appreciated, and your overview of U.S. progress in the development of sequestration technology is a very useful contribution to the workshop delegate's deliberations. It is a good start to meeting the objectives of identifying activities suitable for the co-operative research, development, and demonstration of improved technology for CO_2 capture.

I especially pleased at the level of interest in this workshop shown by industry. In particular by ABB, who have helped to sponsor the workshop, arranged for delegates to visit the Warrior Run power plant where CO_2 capture using the latest ABB Lummus technology can be seen, and not least, provided us with our very able Chairman – Dr Eliasson. Baldur, is Vice-Chairman of our IEA Greenhouse Gas R&D Programme and I can vouch, first hand, for his enthusiasm and ability to help international meetings such as this to a successful conclusion.

Studies by the IEA GHG, and others, over the past 10 years have consistently concluded that the cost and energy penalties associated with CO_2 capture need to be drastically reduced, if we are to make carbon sequestration a realistic option for reducing emissions of greenhouse gases to atmosphere. However, following such studies, we now need to make practical progress. I am pleased to see that some farsighted industrial organisations and individuals have been making progress on advanced methods of CO_2 capture, and also, that there are a several test centre initiatives. There is reason to believe that these initiatives have been, or will be, successful in reducing the penalties for capture, as I am sure we will be discussing over the next 2 days. However, it is clear that what is needed is a forum through which this success can be consolidated and built on.

It seems to me that, compared to other greenhouse gas mitigation options, for example wind energy, or fuel cells, one problem that CO_2 capture technology has is that there is no ‘industry association’ through which development efforts can be channelled and promoted. Perhaps delegates might like to think about this over the next few days and whether, if a forum for CO_2 capture test centres can be established, it might form a useful initial step in a wider association for enterprises involved with CO_2 capture and sequestration.

I said a few minutes ago that we need to make progress by reducing the cost of CO_2 capture. And I am confident we can. To show you why I say this I want to show you an overhead - I only have the one so you needn’t panic.
<FGD graph>
This is based on information produced by our sister organisation, IEA Coal Research. You can see here a record of 30 years of development for flue gas desulphurisation. I am sure most of you know that, like amine scrubbing, this is a technology based on treatment of flue gases. In 1970 FGD the capital investment for FGD had a specific cost of 400US$/kW. As you can see, 30 years of application has brought this cost down by a factor of 4 to a cost at present of about100$/kW. When FGD first became

an acceptable method of controlling SO_2 the units were relatively small, expensive and unreliable. Through experience and technology development the FGD units grew larger, used advanced techniques for corrosion control, improved process chemistry, changed the design for better removal efficiencies, and became more reliable. FGD units today are single units with a high reliability and efficiency. I am sure you can see the parallels, and why I am confident that the cost of CO_2 capture can also be reduced considerably. You will hear later from Richard Rhudy of EPRI how test facilities and collaboration were important in the development mix for SO_2 capture.

Before we move on to our next speaker and the real business of this workshop, I should take the opportunity to thank Dr Perry Berman from DOE's National Energy Technology Laboratory for his initiative in suggesting this workshop and helping the IEA GHG team to organise it.

Finally, I would like to thank you, the delegates, for making the effort to come to the workshop. It is a workshop – not an exercise in information dissemination - and that means we are expecting input from you. The success, or failure, of the workshop will depend on your efforts. I wish you every success in your efforts to stimulate world-wide collaboration and encourage practical development of CO_2 capture technology. Thank you.

NEEDS FOR FUNDAMENTAL DATA

Garry Rochelle
University of Texas, USA

Research Needs for CO_2 Capture by Aqueous Absorption/Stripping

Innovation from Science

by

Gary Rochelle

Department of Chemical Engineering

University of Texas

Funded by U.S. DOE

PRACTICAL R&D NEEDS

John Barrie, Fluor Daniel
for
Malcolm Wilson, Saskatchewan Energy & Mines

LESSONS FROM WORK ON SO_2

Richard Rhudy
EPRI

Lessons Learned from Work on SO_2

Richard Rhudy
Manager, Environmental Control Projects
S&TD

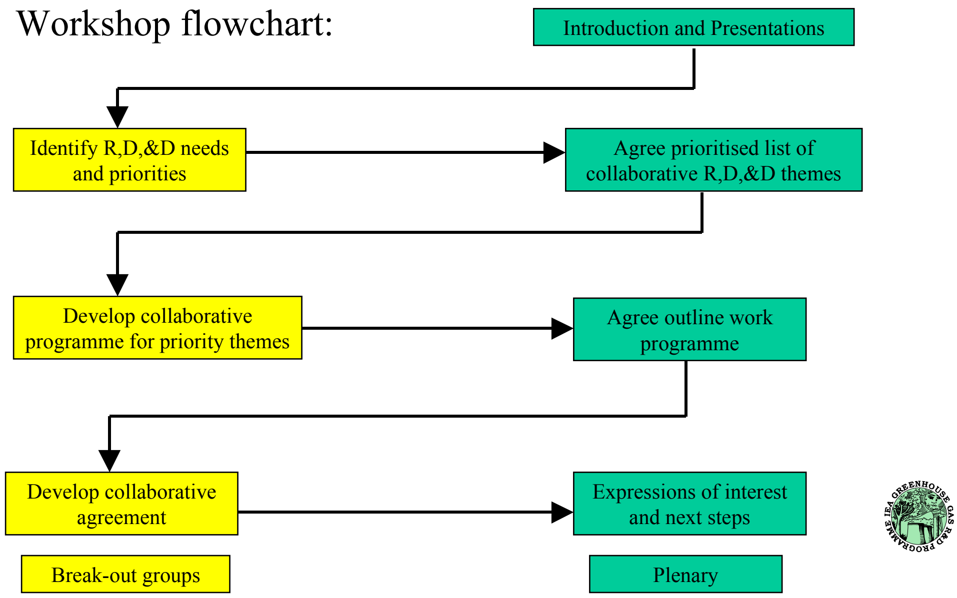
Filename.1

EPRI

INTERNATIONAL AGREEMENT

Harry Audus
IEA GHG

International Test Network for CO_2 Capture



OVERHEADS FROM ADDITIONAL PRESENTATION

Dennis Leppin
Gas Technology Institute, USA


GAS TECHNOLOGY INSTITUTE
Dennis Leppin
Director, Gas Processing Research
October 11-12, 2000

SAMPLE WORKSHEETS:
COLLABORATIVE OPPORTUNITIES

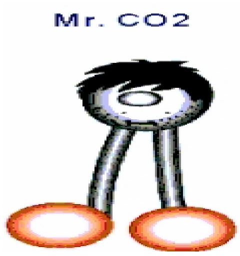
Worksheets

Breakout groups were supplied with worksheets so that they could identify collaborative opportunities and present their results in a structured format. The 2 sheets included here were supplied by IEA GHG to aid discussion and illustrate use of the worksheets.

WORKSHOP ON INTERNATIONAL TEST NETWORK FOR CO_2 CAPTURE

IDENTIFICATION OF COLLABORATIVE OPORTUNITIES

Pre-workshop illustration only



Collaborative Opportunity: Reduce investment costs.

1. Statement of the need/problem:

1. Typically, capital charges will be responsible for over 50% of the cost of CO_2 capture.
2. The capital cost depends on many inter-related factors such as: (a) the quantity and concentration of the solvent, (b) the mechanical design e.g. the packing used, and (c) the materials of construction/corrosion-prevention requirements.

2. Illustration (and/or background information):

Indicative costs are as follows:

		$/t$CO_2$
1. Steam usage; say, 1.5t LP steam/tCO_2 at 7$/t		11
2. Solvent make-up; say 0.4kg/tCO_2 at 5$/kg	2	
3. Capital charges (at 10%DCF, and 25 years ≡ 0.11/year) at Capex equivalent to 220 $/t$CO_2$ captured/year	24	
total steam, solvent, and capital charges, approx. =	37 $/t$CO_2$	

4. (Pipeline CO_2 delivered from a New Mexico CO_2 gas field to Texas costs approx. 25$/t$CO_2$)

3. What are the limitations of the present 'state-of-the-art'?:

Why, to-date, has the problem not been dealt with adequately? What are the barriers to progress? Lack of effort? Inadequate information? Very difficult/impossible (because?)?

1. Although amine treatment of gases in a reducing environment has a long history there is limited experience on flue gases i.e. in the presence of oxygen.

2. There are 6 or so (?) operating commercial applications where CO_2 is captured from flue gases using an MEA-based solvent. The plant size is at maximum about $1/10^{th}$ of that needed for a commercial-scale power station.

4. What could be done?

What is the minimum scale at which design data can be generated?

Design and costing improvements can be sought based on pilot plant data, but it is difficult to verify cost reductions without demonstrating them on a commercial-scale plant.

5. Who could solve it?

Why collaborate? What expertise is required? Is there parallel/useful expertise outside the CO_2 capture arena? Does it require a mix of talents?

1. Investment requirements depend on the efforts of various contributors: solvent manufacturer, packing manufacturer, process designer and constructor.
2. SO_2 emission reduction is a useful parallel; since 1970 the specific investment requirements have been reduced from about 400 $/kWe to a present-day cost in the region of 100 $/kWe.

6. Conclusions and suggested 'next steps'

1. A focussed 'task force' seeking investment cost reductions could help e.g. by identification of cost reduction sensitivities (bang-for-bucks).
2. Detailed examination of lessons from SO_2 might help 'short-cut' the learning process.

WORKSHOP ON INTERNATIONAL TEST NETWORK FOR CO_2 CAPTURE

IDENTIFICATION OF COLLABORATIVE

Pre-workshop
illustration only

OPPORTUNITIES

Collaborative Opportunity: Evaluate solvent degradation characteristics.

1. Statement of the need/problem:

1. Solvent degradation is expensive because it reduces efficiency and replacement solvent is costly.
2. Regeneration is required which recovers solvent but produces heat-stable salts that have to be disposed of (by incineration?)
3. Sensitivity to practical operating conditions/excursions needs to be established, e.g. depends on SO_2 level in flue gas.

2. Illustration (and/or background information):

1. MEA consumption is around 2kg/tCO_2 recovered.
2. New generation solvents e.g. hindered amines, are expected to have loses of about 0.3-0.6 kg/tCO_2 recovered.
3. MEA loses from a gas-fired power station could produce about 2000t/year of sludge and about 10t/year of carry-over in the flue gas.

3. What are the limitations of the present 'state-of-the-art'?:

Why, to-date, has the problem not been dealt with adequately? What are the barriers to progress? Lack of effort? Inadequate information? Very difficult/impossible (because?)?

1. Experience of amine solvents in an oxidising environment is limited.

2. Suppliers and users may have different views e.g. on optimum residual SO_2 level in flue gas to be treated. 'Design' and 'achieved' level of flue gas impurities may be different.
3. Stabilisers added to the amine solvent are proprietary.
4. Environmental implications are not well documented. Responsibility of?

4. What could be done?

What is the minimum scale at which design data can be generated?

1. Useful data could probably be generated at a relatively small-scale. Pilot plant data could be validated and calibrated by reference to commercial-scale experience.

6. Who could solve it?

Why collaborate? What expertise is required? Is there parallel/useful expertise outside the CO_2 capture arena? Does it require a mix of talents?

Process licensors need user feedback. Users need to be able to evaluate merits of alternative processes. Research institutions can explore operating parameters and are likely to have access to advanced analytical equipment for characterisation of degradation rates and products.

6. Conclusions and suggested 'next steps'

1. Agree/devise a standard test routine for solvent degradation in terms of the conditions, parameters to be measured, and the equipment used.
2. Independent testing, and validation is a possibility.
3. Solvents could be assessed/ranked relative to a standard (e.g. MEA with a known non-proprietary stabiliser).

TEST FACILITIES:
CO_2 SOLVENT CAPTURE

TEST FACILITES: CO_2 CAPTURE BY SOLVENT

This table has been produced for the information of delegates to a workshop on an International Test Network for CO_2 capture, held in Gaithersburg on 11th and 12th October 2000. Where possible the information has been checked with the facility operator, but it does not claim to be complete list of facilities or capabilities.

OPERATOR(S)	LOCATION	CAPACITY	EQUIPMENT	FUEL	STATUS	CONTACT
CSIRO[7]	Lucas Heights, Sydney, Australia.	200+ kg CO_2/day	250mm i.d. column (physical solvent). 75mm i.d. column (chemical solvent). 3-3.5 m height.	synthesis gas ex. natural gas	operational. Also microturbine & fuel cells.	Dr Narendra Dave narendra.dave@det.csiro.au
Gas Technology Institute 1700 S. Mt. Prospect Road, Des Palines, IL 60018 USA	1.Coral Energy (formerly Shell Oil Company) Fandango Plant Facilities, Texas, USA	Up to100 Nm3/hr CO_2 Up to 70 bar absorber pressure	200 mm ID Absorber, 300 mm ID Regenerator, Reboiler Temperature 200 °C, Plant designed to handle both physical and chemical solvents. Solvent Circulation rates up to 3 m^3/hr.	Natural Gas	Plant built in 1994. Operational.	Dennis Leppin: Dennis.Leppin@gastechnology.org
	2. Des Plaines, IL, USA	Small bench-scale unit up to 1Nm^3/hr CO_2 Up to 70 bar absorber pressure	50 mm ID absorber, 100mm Regenerator	Natural Gas	Plant built in 1990. Non-operational. Need to re-assemble to use.	
KEPRI[8]	LNG power plant in Seoul, Korea.	2 tCO_2/day 600 Nm^3/hr flue gas		LNG	Under construction.	Mr Hee-Moon Eum hmeum@kepri.kr

[7] Commonwealth Scientific and Industrial research Organisation.
[8] Korea Electric Power Research Institute.

Kvaerner	1. Field test unit. at Kårsto, Staoil gas terminal, Norway 2. Lab. unit at SINTEF[9]	4.7 tCO_2/day	Lab unit can run either as conventional amine unit or membrane contactor. Absorber is 150mm i.d. and 5.9m high.	Natural gas. (Exhaust from a gas turbine.)	Commissioned 1998. Membrane/amine. Ready for commercial application.	olav.falk-pedersen@kvaerner.com
MHI[10] / KEPCO[11]	Nanko LNG power station, Osaka, Japan.	2 tCO_2/day 600 Nm^3/hr flue gas		LNG	Built 1990. 1st generation solvent developed.	Nobuo Imai 816913@mcec.hg.mhi.co.jp
NTNU[12]	Trondheim, Norway.	150 m^3/hr and 80 m^3/hr lab. units	One is the same unit as for Kværner. The other smaller conv. absorber/-stripper unit. Plus several equil. and kinetic cells.	Model fluids	Built 1980 to 2000	Prof. Hallvard Fjøsne Svendsen svendsen@chembio.ntnu.no
Praxair, Inc.	Praxair Technology Center, Tonawanda, New York, USA	50 Nm^3/hr flue gas, 0.2 tons/day CO_2	Absorber –6inch dia. 13 ft. tall. Stripper – 3.5 inch dia, 11 ft. tall. Flexible system allows alternate configurations.	N_2/air/CO_2 being used. Natural gas supply exists to generate flue gas.	In use since Jan 2000.	Dr Ami Gupta Ami_gupta@praxair.com Dr. Shrikar Chakravarti Shrikar_chakravarti@praxiar.com
TNO[13]	Apeldoorn, Netherlands.	50+ kg CO_2/day	Mobile test rig with membrane contactor + regenerator	Exhaust of natural gas powered gas turbine.	Operational since 1997. tests performed on power plant off-gas. Scale-up in 2001.	Dr. Frank Geuzebroek F.H.Geuzebroek@mep.tno.nl

[9] Foundation for Scientific and Industrial research at the Norwegian Institute of Technology
[10] Mitsubishi Heavy Industries.
[11] Kansai Electric Power Co.
[12] Norwegian University of Science and Technology.

University of Regina,	International Test Centre, Saskatchewan, Canada: 1. Pilot plant, University of Regina 2. Demonstration plant, Boundary Dam power station, Estevan	1. 500+ kgCO_2/day. 2. 4tCO_2/day	1. Is 300mm i.d. columns, 10m height. 2. 460mm i.d. columns, 20m height.	Coal-fired power station	1. Final design. 2. revamping (reconditioning).	Dr Paitoon Tontiwachwuthikul paitoon@uregina.ca
University of Texas at Austin	Separations Research Program, Austin, Texas, USA.	1. 1500Nm^3/day, 9 tCO_2/day 2. 0.4 Nm^3/hr 3. 0.05 Nm^3/hr	1. Absorber 16.8 inch, 6 inch stripper, 0.1-2 atm. 2. wetted wall column 32cm^2, IR for CO_2 3. sparged reactor, FTIR[14] for NH_3	1. N_2/air/CO_2 2. N_2/CO_2 3. N_2/air/CO_2	1. planned mods. for CO_2. 2. In use since 1992. 3. In use since 1999.	Prof. Gary Rochelle gtr@che.utexas.edu

[13] TNO Institute of Environmental and Energy Technology
[14] (FT)IR – (Fourrier Transform) Infra-Red analysis.

EVALUATION OF PROCESS SIMULATORS: DRAFT SCOPE OF WORK

Dennis Leppin
Gas Technology Institute, USA

TECHNICAL VISIT:
CO_2 CAPTURE FACILITY AT WARRIOR RUN

Harry Audus
IEA GHG

Notes on a technical visit by workshop participants to a CO_2 capture facility

ABB Lummus Global arranged and sponsored a visit to the AES Warrior Run power plant in Cumberland, Maryland. The visit, on 13th October 2000, was made by nearly all the workshop participants.

The power plant is a coal-fired unit with a circulating fluidised bed boiler. Commercial operation started 10th February 2000. The unit is a co-generator producing 180 MW (net) (approx. 200MW gross) of electricity and approximately 400 ton/day (net) of steam. The steam is used for on-site production of approximately 150 tons/day of food-grade CO_2.

ABB Lummus MEA scrubbing technology is used to capture the CO_2 from a slip-steam of about 2-3% of the total flue gas. The flue gas contains about 14% (vol) CO_2 at full load. The oxygen level is 2-3% (vol); at low load it increases and the CO_2 level drops.

Emissions from the plant are below EPA new source standards. The coal contains 1.5-2% sulphur. Annual emission limits are 0.15 lb/MMBtu for SO_2 (and 0.1 lb/MMBtu for NO_x). Sulphur emissions are controlled by limestone addition to the CFB (about 210-275 tons/day c.f. 2 000 tons/day of coal). For CO_2 capture, flue gas SO_2 levels are further reduced to <1ppm before scrubbing with MEA; this is done by a 2-stage caustic soda scrub. This system includes pressure boost to 3psig, flue gas cooler, and mist eliminators.

The photograph illustrates the CO_2 capture facility. Two horizontal CO_2 storage tanks can be seen. The 2 vertical columns are the CO_2 absorption column and the CO_2 recovery (solvent regeneration) column. The CO_2 system includes a solvent reclaimer. The majority of the plant is built in carbon steel with stainless steel used in specific places. A corrosion inhibitor is added to the solvent. Captured CO_2 is purified to 99.99% purity using carbon filters and molecular sieves. Inerts are vented. CO_2 is stored under pressure at 230-240psig.

WORKSHOP PARTICIPANTS

Workshop on CO2 Capture- Attendee List

11 - 12 October 2000, Gaithersburg, USA

Mr Adisorn (Andy) Aroonwilas
Research Assistant / PhD Student
University of Regina
Canada
Tel: +1 306 585 3565
Fax: +1 306 585 4855
aroonwia@uregina.ca

Eur.-Ing. Harry Audus
Project Manager
IEA Greenhouse Gas R&D Programme
UK
Tel: +44 1242 680753
Fax: +44 1242 680758
harry@ieagreen.demon.co.uk

John Barrie
Technical Director
Fluor Daniel Canada Inc.
USA
Tel: +1 403 259 1180
Fax: +1 403 259 1244
john.barrie@fluor.com

Dr Perry Bergman
Project Manager
NETL - US DOE
USA
Tel: +1 412 386 4890
Fax: +1 412 386 5917
bergman@netl.doe.gov

Dr Stefano Brandani
Co-Director, Centre for CO2 Technology
University College London
UK
Tel: +44 (0)20 7679 2315
Fax: +44 (0)20 7383 2348
s.brandani@ucl.ac.uk

Ken R Brown
Senior Staff Engineer, Environmental Affairs
PanCanadian Petroleum Ltd
Canada
Tel: +1 403 268 7992
Fax: +1 403 268 7808
ken_brown@pancanadian.ca

Amit Chakma
Vice-President (Research) & Prof of Engineering
University of Regina
Canada
Tel: +1 306 585 5350
Fax: +1 306 585 5255
amit.chakma@uregina.ca

Dr Narendra Dave
Principal Research Engineer
CSIRO Energy Technology
Australia
Tel: +61 2 9710 6883
Fax: +61 2 9710 6800
narendra.dave@det.csiro.au

Dr Jon Davis
Rio Tinto - Technical Services
Australia
Tel: +61 7 3327 7617
Fax: +61 7 3327 7640
jon.davis@riotinto.com

Richard D Doctor
Carbon Management
Argonne National Laboratory
USA
Tel: +1 630 252 5913
Fax: +1 630 252 9281
rdoctor@anl.gov

Jim Dooley
Staff Scientist
Battelle Memorial Institute
USA
Tel: +1 202 646 7810
Fax: +1 202 646 5233
dooleyj@battelle.org

Thomas P Dorchak
Project Manager
NETL - US DOE
USA
Tel: +1 304 285 4305
Fax: +1 304 285 4469
tdorch@netl.doe.gov

Mark Austin Douglas
A/Group Leader - CO2 Abatament
CANMET, Natural Resources Canada
Canada
Tel: +1 613 996 2761
Fax: +1 613 992 9335
madougla@nrcan.gc.ca

Bill Downs
Consulting Engineer
McDermott Technology Inc.
USA
Tel: +1 330 829 7359
Fax: +1 330 829 7283
bill.downs@mcdermott.com

Clas Ekström
Vattenfall Utveckling AB
Sweden
Tel: +46 8 739 6417
Fax: +46 8 739 6802
clas.ekstrom@utveckling.vattenfall.se

Baldur Eliasson
Department Head
ABB Corporate Research
Switzerland
Tel: +41 56 486 8031 /7
Fax: +41 56 493 4569
baldur.eliasson@ch.abb.com

Dr Frank Geuzebroek
TNO Environment, Energy & Process Innovation
The Netherlands
Tel: +31 55 549 3151
Fax: +31 55 549 3410
F.H.Geuzebroek@mep.tno.nl

Ronald G Gualy
General Manager, Chemicals Group
GTC Technology Corporation
USA
Tel: +1 281 597 4800
Fax: +1 281 597 0932
rgualy@gtchouston.com

Neeraj Gupta
Senior Research Scientist

Battelle Columbus Laboratories
USA
Tel: +1 614 424 3820
Fax: +1 614 424 3667
gupta@battelle.org

Ami Gupta
Associate Director, R&D

Praxair, Inc.
USA
Tel: +1 716 879 2194
Fax: +1 716 879 7567
ami_gupta@praxair.com

J C Gupta
Director, Refining, Lummus
Technology Division
ABB Lummus Global, Inc.
USA
Tel: +1 713 821 5093
Fax: +1 713 821 3587
j.c.gupta@us.abb.com

Nobuo Imai
Project Manager

Mitsubishi Heavy Industries, Ltd.
Japan
Tel: +81 45 224 9331
Fax: +81 45 224 9933
816913@mcec.hg.mhi.co.jp

Dennis Leppin
Director, Gas Processing Research Group

GTI
USA
Tel: +1 847 768 0521
Fax: +1 781 823 5559
dennis.leppin@gastechnology.org

Tom Lillestolen
Director of Technology &
Strategic Development
ALSTOM Power Inc.
USA
Tel: +1 865 694 5374
Fax: +1 865 694 5205
tom.lillestolen@us.abb.com

Carl L Mariz
Director, Process Engineering
Fluor Daniel
USA
Tel: +1 949 349 7530
Fax: +1 949 349 2898
carl.mariz@fluor.com

Curt Munson
Separations Technology Team Leader
Chevron
USA
Tel: +1 510 242 1612
Fax: +1 510 242 2893
clmu@chevron.com

Dr Nsakala Y Nsakala
Principal Consulting Engineer
ALSTOM Power Inc.
USA
Tel: +1 860 285 2018
Fax: +1 860 285 3473
nsakala.y.nsakala@power.alstom.com

Joe A Pachioli
Manager, Industrial Projects
Mitsubishi International Corporation
USA
Tel: +1 713 652 9235
Fax: +1 713 652 5041
joe_pachioli@micusa.com

Richard Rhudy
Manager, Environmental Control Projects
EPRI
USA
Tel: +1 650 855 2421
Fax: +1 650 855 2002
rrhudy@epri.com

Chris Roberts
Process Engineering Manager
Fluor Daniel
UK
Tel: +44 1276 411 148
Fax:
christopher.roberts@fluor.com

Gary T Rochelle
Professor
University of Texas
USA
Tel: +1 512 471 7230
Fax: +1 512 475 7824
rochelle@che.utexas.edu

Lawrence Saroff
Program Manager
U S Department of Energy
USA
Tel: +1 301 903 9483
Fax: +1 301 903 8350
lawrence.saroff@hq.doe.gov

Bruce Sass
Senior Research Scientist
Battelle Memorial Institute
USA
Tel: +1 614 424 6315
Fax: +1 614 424 3667
sassb@battelle.org

Mike Slater
Gas Processing Network Leader
BP
UK
Tel: +44 1932 764046
Fax: +44 1932 764120
slaterm@bp.com

Miss Andrea Smith
Conference & Publications Admin
IEA Greenhouse Gas R&D Programme
UK
Tel: +44 1242 680753
Fax: +44 1242 680758
andrea@ieagreen.demon.co.uk

Shelly Stanton
Consultant
Nexant Inc.
USA
Tel: +1 415 768 4769
Fax: +1 415 768 6663
sstanton@nexant.com

Professor Hallvard Svendsen
NTNU/Statoil
Norway
Tel: +47 7359 4100 /7358 4403
Fax: +47 7359 4080
svendsen@chembio.ntnu.no

Dr Kelly Thambimuthu
(Chairman, IEA GHG Programme)
CANMET Energy Technology Centre
Canada
Tel: +612 9351 2723
Fax: +1 613 992 9335
kelly@chem.eng.usyd.edu.au

Dr Paitoon Tontiwachwuthikul
Professor of Engineering
University of Regina
Canada
Tel: +1 306 585 4160
Fax: +1 306 585 4556
paitoon@uregina.ca

Dr Amornvadee (Amy) Veawab
(Assistant Professor)
University of Regina
Canada
Tel: +1 306 585 5665
Fax: +1 306 585 4855
veawab@uregina.ca

James Yeh
Chemical Engineer
U S Department of Energy
USA
Tel: +1 412 386 5737
Fax: +1 412 386 6004
yeh@fetc.doe.gov