GEOLOGICAL STORAGE OF CO_2 IN SALINE AQUIFERS
REPORT ON A WORKSHOP TO DISCUSS FUTURE RESEARCH PRIORITIES

April 4th - 5th 2000, Leeuwenhorst Congress Centre, The Netherlands

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SUMMARY

The IEA Greenhouse Gas R&D Programme (IEA GHG) and Statoil organised a workshop on geological storage of CO_2 on the 4th and 5th of April 2000. This workshop was held at Leeuwenhorst in the Netherlands. This report describes the main presentations and outcomes of the workshop and provides copies of the presentations.

Background

The Saline Aquifer CO_2 Storage (SACS) project was formed at a workshop held in Trondheim in November 1997. SACS was established to monitor underground CO_2 storage from the Sleipner field in the North Sea. The Leeuwenhorst meeting aimed to continue the discussion of research requirements that began in Trondheim.

It was agreed at Trondheim that there would be 3 parts to the programme of monitoring and research:
- Establish baseline data,
- Monitoring of the injected CO_2 - European Commission supported SACS project[1]
- An international research and monitoring project.

To date, the first 2 parts of this programme have been implemented. The third step, loosely termed *"The Umbrella Project",* was the general objective of the Leeuwenhorst workshop. Specific aims were to engage international participation in this work, agree the priorities for further work and identify methods of funding.

Workshop attendance

67 delegates, including members of the IEA GHG Programme, governmental organisations, industry and the research community from North America, Europe, Asia and Australasia attended the Leeuwenhorst workshop.

Presentations

Hans Pont, the Director General of the Netherlands Ministry of Housing, Spatial Planning and the Environment (VROM) opened the workshop. Keynote speeches by Olav Kaarstad of Statoil, Paul Freund of the IEA Greenhouse Gas R&D Programme and Jip Lenstra of VROM followed the opening address. The first technical session opened with an overview of the SACS project by Tore Torp, the project co-ordinator from Statoil. This was followed by 3 papers on initial results from the project :

- Status of geological interpretation, Sam Holloway, British Geological Survey
- Status of Utsira formation - CO_2 flow properties and flow modelling, Bert van Meer, NITG-TNO
- Status of Seismic Monitoring, Ola Eiken, Statoil

[1] Now continued under SACS2

This was the first time that results from the SACS project had been presented to an international audience; the level of questioning after the presentations testified to the amount of interest in these results.

Working group sessions

After the initial presentations, 4 working groups were formed to examine the specific research needs in geology, geochemistry, reservoir modelling and seismic/monitoring techniques. Each working group opened with a presentation by a member of the SACS project, discussing their ideas for future research in the topic. A fifth working group considered how best to support the research ideas that would be generated by the technical breakout groups.

The results of these working groups were presented to the plenary session at the start of the second day; again this produced considerable, active debate. After this session, it was decided that the groups should be re-formed to consider in more detail main the ideas generated in the first breakout session. The following issues were then addressed:

- Cap rock integrity
- Fluid Flow in the reservoir
- Monitoring techniques
- Public perceptions

The working groups again reported back to a plenary session of all delegates with recommendations for future research in each area.

Presentations on Related Work

The final afternoon gave other delegates the opportunity to present their own work. 15 presentations were made in two parallel sessions. Papers presented included overviews of research programmes underway in the USA, Australia and the EU and progress with ongoing projects in the EU, Canada, and the USA.

Outcomes

Overall the workshop was very successful in bringing together an international group of experts to identify future research priorities, which included:

SACS specific proposals

a) ***Cap rock integrity -***There was a need to focus on the integrity of the cap rock in the Utsira formation, which will require the acquisition of core samples. The seismic results should be reprocessed and well logs re-evaluated to look for evidence of cap rock fractures.
b) ***Evaluation of alternative monitoring techniques -*** It was accepted that monitoring will need to continue past the end of the existing SACS2 contract and that cheaper alternative options to surface seismic monitoring were required. Options suggested included: electrical resistance tomography, micro-seismicity, fixed seismic arrays and vertical seismic profiling (VSP).
c) ***Observation well*** - There was considerable interest in an observation well for monitoring the CO_2 bubble in the Utsira. It was noted that this was a high cost research option. The suitability of an observation well will be evaluated under the second phase of the SACS project.
d) ***Modelling Code Comparisons*** - a study should be conducted to compare the various simulation codes developed with oil industry standard codes. The key point was to establish some level of credibility that such codes could capture the physical flow correctly, as demonstrated by a match with the standard oil industry codes before moving on to refine the geochemistry.

e) ***Advanced processing/reprocessing of seismic data***.- Reprocessing of the existing seismic data used existing or advanced reprocessing techniques should be undertaken to assist in defining the strata of shale within the Utsira formation and in identifying faults/fractures in the cap rock.

Related research on geological storage of CO_2 in aquifers

Safety of storage - There was considerable information available from other industries, in particular that relating to natural gas storage, that might be relevant to CO_2 storage. Storage of natural gas is going on around the world at numerous sites and does not appear to generate much public concern. There is, therefore, a need to understand why and what standards are applied and their applicability to CO_2 storage. This work would assist in building confidence in geological storage of CO_2.
Natural analogues - Research on naturally occurring geological stores of CO_2 should be undertaken. This research should focus on the mechanisms of storage and understanding of the reaction chemistry that has occurred. This work can then be used to see if reservoir and geochemical models can predict such storage, which would give confidence that CO_2 can be stored for geological timescales.

Shale Database - A global reference database on shale characteristics and permeability should be developed.

Data Exchange/Dissemination

In addition, to these research activities a general conclusion was that a continued exchange of information was necessary through similar workshops. The GHGT-5 conference in August 2000 in Cairns Australia, will be a focal point for researchers in the field of geological storage of CO_2. It will also allow discussions on project ideas that started at Leeuwenhorst to continue in a timely fashion. IEA GHG should consider further workshops in 2001 and 2002, to ensure the dialogue is maintained and expand international networking opportunities.

PROGRESS SINCE THE WORKSHOP

Since the workshop a number of early actions have commenced. These actions include:

- **SACS2 Programme review -** The content of the SACS2 contract was reviewed at a meeting one week after the Leeuwenhorst workshop. A number of ideas from Leeuwenhorst such as seismic reprocessing, well-log evaluations and more work focusing on cap rock integrity were considered in the project schedule.

- **Natural analogues -** A proposal on this subject has been co-ordinated by British Geological Survey and submitted to the EC for funding. The proposal includes seven research organisations within the EU. A complementary proposal has been made to the recent USDOE solicitation; it has been agreed that the projects will, if both are successful in gaining funding, collaborate to share data and results. The GEODISC project in Australia will also co-operate in data exchange and dissemination, as will BP Amoco. IEA GHG will also participate to assist data dissemination between EC supported projects and internationally.

- **Simulation Code Comparisons -** An outline for a project to compare the various reaction codes has been developed by SINTEF since the workshop and circulated to the SACS members. This proposal may lead to a co-operative research project starting initially with comparisons on a hypothetical 'Utsira type' reservoir.

- **Enhanced Seismic Processing-** An outline proposal has been made to SACS by a research group in the USA, since the workshop, to undertake enhanced processing of the seismic data.. The proposal has been circulated to the SACS members for comment, and a more detailed proposal for consideration has now been requested.

- **Safety issues -** IEA GHG should consider developing a study to review some of the safety issues raised, in particular what standards and lessons can be learnt from natural gas storage and other industries that store material underground and how these could lead to standards for CO_2 storage.

The SACS steering committee is developing a policy on handling proposals on research related to SACS or geological storage of CO_2 in aquifers. Suggestions on research topics, either complimentary or additional to those set out above, will be welcomed by SACS.

GEOLOGICAL STORAGE OF CO_2 IN SALINE AQUIFERS REPORT ON A WORKSHOP TO DISCUSS FUTURE RESEARCH PRIORITIES

1. WORKSHOP AIMS AND OBJECTIVES

A workshop was held in Leeuwenhorst in the Netherlands between 4th and 5th April 2000 to discuss future research needs for the Saline Aquifer CO_2 Storage (SACS) Project. SACS was established to monitor the storage of CO_2 in a deep saline on the Sleipner field in the North Sea. The objective of the workshop was to develop international collaboration in the Sleipner project. This objective will be achieved by drawing together experts both from Europe and outside, to discuss the status of knowledge of geological storage of CO_2 in deep saline reservoirs, with particular reference to Sleipner. The workshop presented the current state of knowledge on geological storage in deep saline reservoirs. It the workshop l considered the work that needed to be done, agreed the priorities, and considered how to engage international participation, and identify methods of funding.

It is considered that only by developing a comprehensive, detailed and sound scientific and technical background through focused research can geological storage of CO_2 gain recognition as a technical mitigation option in the eyes of the international community.

2. BACKGROUND

2.1 Sleipner and the SACS Project

The Sleipner West field in the Norwegian sector of the North Sea began production in 1996. The licensees of the field are Statoil (operator), Esso Norge, Norsk Hydro and Elf Petroleum Norge. A special feature of the natural gas from the Sleipner field is that it contains about 9% CO_2. This must be reduced to 2.5% for commercial sale. CO_2 is stripped from the natural gas in an amine scrubbing plant and then injected into a saline water bearing structure, known as the Utsira formation. The Utsira formation is a sand formation about 800 metres below the seabed.

The Sleipner project, the world's first commercial-scale CO_2 storage project, has now been operating for over 3 years with in excess of two million tonnes of CO_2 now stored underground. As part of this project a monitoring exercise is underway to determine the fate of the stored CO_2. The monitoring activity has included a new seismic survey of the Utsira formation, to determine how the CO_2 bubble is developing in the deep saline reservoir. The seismic survey was taken during August 1999, with the evaluated results becoming available in late 2000.

To monitor the storage of CO_2 a demonstration project, called the Saline Aquifer Carbon Dioxide Storage (SACS) project, was established with the following partners: Statoil (co-ordinator), BP Amoco, Norsk Hydro, ExxonMobil, Saga Petroleum and Vattenfall.

In addition to the partners, the following R&D organisations are actively involved in the SACS Project; British Geological Survey, BRGM[2], GEUS[3], Insitut de Francais de Petrole, NITG-TNO[4], SINTEF Petroleum Research and the Nansen ERS Centre

The IEA Greenhouse Gas R&D Programme (IEA GHG) are participating in the SACS project as an associated contractor and have a place on the steering committee. IEA GHG is specifically mentioned in the EC[5] project for its "umbrella" project role.

[2] Bureau de Geologiques et Minieres
[3] Geological Survey of Denmark and Greenland
[4] Netherlands Organisation for Applied Scientific Research
[5] European Commission

The SACS project, due to the scheduling of the EC funding, will be carried out in two phases.

The Thermie Programme under the EC FOURTH Framework R&D programme in part supported phase 1 of the SACS project. The Phase 1 programme ends in December 1999. This phase will, amongst other activities, include a new seismic survey of the Utsira formation to determine the extent of the CO_2 bubble.

Phase 2 of the programme has now commenced, starting in April 2000. The aim of this phase of the project is to verify the distribution of the stored CO_2 and use the information to predict the destiny of the stored CO_2 for thousands of years into the future. In addition, to demonstrate the long-term feasibility of CO_2 storage in saline aquifers, such as the Utsira formation, the project will develop a Best Practice Manual for CO_2 storage in deep saline reservoirs. The manual will provide a guidance note for future CO_2 storage projects in deep saline aquifers.

2.2 SACS and International Co-operation in Geological Storage of CO_2.

The Leeuwenhorst workshop continues the series of discussions that began in Trondheim in 1997, which assisted in establishing the SACS project. It was agreed at the Trondheim workshop that there would be 3 parts to the programme of monitoring and research on Sleipner, which were:

- Work to establish baseline data,
- The European Commission supported (SACS) monitoring project
- An international research and monitoring project.

To date the first 2 parts of this programme have been implemented. The next step, loosely termed *"The Umbrella Project",* was to decide how to engage international participation, agree the priorities for further work and identify methods of funding.

More recently, further geological storage workshops have been held at Weyburn in Canada and Houston, USA in 1999. These discussions have built on those at Trondheim and have begun to establish international collaborative programmes for monitoring and research on projects for geological storage of CO_2 in other reservoirs such as depleted oil fields.

The Leeuwenhorst workshop aimed to present, to an international audience, the current status of the SACS project. The workshop objective was to identify future research needs relating to the storage of CO_2 in geological reservoirs, especially saline aquifers, and discuss the opportunities for co-operation in an open forum. Through these discussions it was planned that companies and research institutes, from many different countries, would be able to find the best ways for them to co-operate in and take advantage of these unique (few) CO_2 sequestration projects. In so doing, it was hoped to initiate the third phase of the Sleipner aquifer storage monitoring/research project.

3. THE GEOLOGICAL STORAGE OF CO_2 IN SALINE AQUIFERS WORKSHOP

3.1 Workshop Overview

The Geological Storage of CO_2 in Saline Aquifers workshop was held between the 4th and 5th of April 2000 at the Leeuwenhorst Congress Centre, Nordwijkerhout, the Netherlands. Sixty-seven experts attended the workshop to discuss future research needs for the SACS project. Delegates were drawn from; members of the IEA GHG Programme, governmental organisations, industry and the research community from North America, Europe, Asia and Australasia. The list of workshop attendees is given in Appendix 1.

After the initial opening remarks by the host IEA GHG Programme member country and the workshop organisers a series of presentations were given by SACS project members on the current status of the project. Presentations were given on early results on the geology of the Utsira formation, initial results

from reservoir modelling studies and on the latest available data from the seismic survey of the Utsira formation shot in August 1999. After these presentations the floor was left open for detailed discussion of the results presented by the workshop participants.

Following the SACS project results, members of the project team presented their ideas for future work. These presentations were a prelude to the later working group sessions. The future aspects discussed included: geological studies on the Utsira formation, seismic interpretation, reservoir flow modelling and mapping of CO_2 saturation and the geochemistry of the Utsira formation. Once again an open floor discussion was held to review these ideas.

On the last afternoon of Day 1 the participants broke into 5 breakout groups, four technical breakout groups and one to address future funding. The four technical breakout groups were focused on:

1. Geology
2. Seismic and Other Monitoring techniques
3. Reservoir Modelling
4. Geochemistry

Each group had an appointed chairman and a technical facilitator from the SACS project to act as a bouncing board for ideas from the participants.

The aims of the four technical breakout groups were:

1. To identify future research needs
2. To prioritise these research needs
3. To estimate future funding requirements to address these research needs
4. To agree on who will participate in these research activities

The remit of the future funding breakout group was to address how the international community could support the research projects identified by the technical groups.

On the morning of Day 2 the breakout groups presented their findings to the whole audience. After the open floor debate it was decided to reconvene the breakout groups as originally planned but with more focused remits. Four groups then convened to discuss the research requirement for the following topics:

1. Cap rock integrity
2. Fluid Flow
3. Monitoring techniques
4. Public perception

The first three groups were also asked to consider natural analogues studies, since in the earlier discussion this topic had been raised by all groups as a research need but was considered to overlap rather than be separate to the research topics identified for further discussion.

After the breakout group sessions the results were again fed back to the full workshop audience and an open discussion completed before lunch on Day 2.

On the afternoon of Day 2, some 15 papers were presented by the workshop participants on related research activities on geological storage of CO_2.

3.2 Opening Session

The opening session of the workshop consisted of four presentations by the IEA GHG Programme host country (VROM[6] of the Netherlands), Statoil and IEA GHG. Copies of the presentation material from this session are given in Appendix 2.

Hans Pont the Director General for Environmental Protection (VROM) opened the workshop and welcomed the participants to Holland. Hans Pont highlighted the Kyoto Protocol and the need to make deep cuts in CO_2 emissions to tackle the climate change problem. Whilst many people advocate that the necessary reductions can be made by energy conservation and the use of renewable fuels, he felt that it was doubtful that these actions alone would not be sufficient. From a Dutch perspective it has been concluded that fossil fuel use combined with CO_2 capture and storage together with the implementation of energy conservation measures and renewable energy was necessary to prevent climate change. He appealed to the oil and gas company representatives in the audience to invest as much in CO_2 capture and storage as they do in renewables research. He concluded that real projects, such as that underway at Sleipner, were necessary so that discussion could focus on facts not emotions.

Olav Kaarstad of Statoil outlined the Sleipner project and how the concept began some 10 years ago, before Statoil publicly announced the project at the 1st International Conference on CO_2 Removal held in Amsterdam in March 1992[7]. Olav highlighted the recent changes that had occurred in the Norwegian Government, as a result of the outgoing government's policy to build CO_2 free natural gas power plant instead of conventional gas fired plant. The new Labour government will now follow a policy of building conventional plant whilst establishing a research programme to study CO_2 free power generation. Olav highlighted what was to be gained from a research and monitoring project on Sleipner. In particular:

- the need to develop knowledge on the safety of CO_2 storage,
- the need to develop best practise procedures for CO_2 storage,
- to begin the process of constructive dialogue on the role of underground storage of CO_2.

He added his hopes for the future that those promoting underground storage adopt a balanced perspective so that conflict can be minimised.

Paul Freund the Project Director of the IEA GHG Programme initially outlined the activities of the Programme. He followed on by discussing the role that CO_2 storage can play in tackling CO_2 emissions. The technology options currently available to reduce greenhouse emissions included energy efficiency, fuel switching and the use of renewable and nuclear energy. Most countries will meet their Kyoto targets through a combination of energy efficiency, fuel switching and use of flexible mechanisms. However, if further deep cuts in CO_2 emissions are needed then technologies such as CO_2 capture and Storage will need to be used. All these measures will be needed - there is no single technology that provides the solution to the problem of CO_2 emissions.

Finally he outlined the aims and objectives for the workshop. The workshop aimed to launch the international Umbrella project on the Sleipner storage facility, this was the third element of the research which had been identified identified at the meeting in Trondheim held in November 1997 that assisted in launching SACS. The objectives set for this workshop were:

- To make recommendations about priorities for further monitoring and research on CO_2 stored in the Utsira formation.

- To stimulate the formation of an international collaborative programme to carry out this work.

[6] Ministry of Housing, Spatial Planning and the Environment
[7] The ICCR conference series have now been replaced with the Greenhouse Gas Control Technologies series the 5th conference will be held in Cairns, Australia in August 2000.

Jip Lenstra, Head of the Energy Department of VROM, outlined the Netherlands climate policy implementation plan which aims for a 6% reduction in CO_2 emissions relative to 1995 levels by 2010 to meet their Kyoto targets. The plan involves a basic package of measures to reduce emissions from industry and power stations as well as other greenhouse gases. Included in the basic package is a CO_2 buffer project that involves storage of 0.5 Mt of CO_2 from industrial plant in a saline aquifer over winter followed by extraction and delivery to greenhouses during the summer. There is then a reserve package of measures for large industrial sources of CO_2 to store a further 3 Mt of CO_2 as well as actions to reduce N_2O emissions from the chemical industry.

3.3 Session 1 - Demonstration of Aquifer Storage - the Sleipner and SACS Project

Tore Torp of Statoil, the project co-ordinator for SACS, opened the session. Tore Torp presented an overview of the SACS Project. A copy of the presentation material from this presentation is given in Appendix 2. The key goals of the SACS project were as follows:

- To verify under what circumstances CO_2 storage in an aquifer is safe and reliable
- To validate models for geology, geochemistry, geophysics and reservoir tools.
- To initiate new R&D related to the above topics
- Start the development of a "Best Practice Manual"

Tore emphasised that the Sleipner project is the first commercial CO_2 storage project, that the Utsira is a vast formation and there are potentially many smaller aquifers that could be utilised in this way.

He hoped that the SACS project would assist in building confidence in CO_2 storage and as a spin off of this workshop new R&D efforts in IEA GHG member countries would result to help boost international confidence.

Tore then introduced three members of the SACS project team to discuss the initial results from the SACS project. These members were:

- **Sam Holloway** of the British Geological Survey reviewed the current status of the geological interpretation of the Utsira formation.
- **Bert Van Der Meer** of NITG-TNO, who reviewed the current status of the results on CO_2 mapping and flow and reservoir modelling of the Utsira formation.
- **Ola Eiken,** of Statoil who outlined the initial results of the seismic survey taken in August 1999 which indicated the position of the CO_2 bubble within the Utsira formation around the injection well.

The contents of these papers have not been provided in this report. It was agreed by IEA GHG with the SACS Project neither at the outset that because the results available were preliminary, that transcripts and copies of the papers would not be made available neither to the workshop nor in the workshop report.
Results from the SACS project will begin to be made available in the near future at the EAGE[8] Conference in June in Glasgow UK, SEG[9] in Calgary in and at GHGT-5 in Cairns Australia in August 2000. Details of the papers will be posted on the IEA GHG web site that is hosting the SACS home page and in the conference proceedings when these become available.

3.4 Session 2 - Future Research Needs

John Gale introduced this session **from IEA GHG** who set out the aims of the break out-groups, their operation and administrative details for their operation. Details of the breakout-groups were provided earlier in section 2.1. **Tore Torp of Statoil** then introduced four members of the SACS project who

[8] European Association of Geological Engineers
[9] Society of Exploration Geophysicists

provided their initial ideas on future research needs for SACS and geological storage of CO_2 in saline aquifers. Copies of the presentations made available after the event is given in Appendix 3. These presentations were a prelude to the breakout group sessions on future research needs. The presenters acted as the technical facilitators in the break out sessions, acting as sounding boards for ideas and providing advice on co-ordinating future research with data availability within SACS.

Sam Holloway of the British Geological Survey, presented ideas on future geological studies. Current work in SACS was focusing on characterising the cap rock, identifying potential migration paths through the cap rock and on building the best possible reservoir model to input into the reservoir simulation tool. He suggested that in the future studies could focus on migration paths, characterising strata surrounding the Utsira Sand and extending the regional geological study from the Central North Sea into the North Viking Graben.

Areas of research could include:

- Regional seismic studies to look for faults cutting across the Utsira cap rock and gas chimneys to identify possible migration paths through the cap rock.

- A study of the sandy prograding units on the western side of the North Sea to identify whether these provide possible escape routes for fluids

- A study of the North Viking Graben area to see if another major basin-restricted sand unit is present there.

Rob Arts of NITG-TNO, discussed future aspects of seismic interpretation. His ideas included expanding the work on the time lapse survey work done to date, and undertaking a gravity survey and micro-seismic monitoring. The main activities suggested could include:

- Examining the use of multi-component data , VSP[10] data and cross well seismic data to assist in the detection of leakage and prediction of CO_2 flow within the Utsira formation
- Use of permanent sea floor detectors for monitoring leakage
- Linking time lapse seismic to geomechanical models.
- Evaluating and applying new seismic processing and reservoir characterisation techniques to the existing seismic data.

Within the existing SACS project the feasibility of using gravity surveys and micro seismic will be evaluated. If these feasibility studies show promise then it could be possible to carry out a combined gravity survey with the existing time lapse seismic data or consider a future micro-seismic field test at Sleipner or on another site.

Erik Lindeberg of Sintef presented future aspects of reservoir flow modelling and mapping of CO_2. He emphasised that the models needed to make a good history match of CO_2 storage in the aquifer. It was noted that new transport models were available that had been applied to softer sediments by other researchers and SACS could learn from this work. The key ideas presented included:

- Work should concentrate on the integrity of the cap rock in the Utsira formation and in particular the integrity of the seal.

- Regional modelling of the Utsira formation should be considered to look for potential leakage paths

[10] Vertical seismic profiles

- The reservoir modelling needed to consider the shales present in the Utsira and some circular connections needed to be made between the seismic results to identify the position and effect of the shale bands on the CO_2 injected into the Utsira formation and possible leakage pathways.

Erik also emphasised that much closer co-operation was required between the geologists, seismologists and geochemists and the reservoir modellers to fully understand how to model effectively CO_2 storage in an aquifer.

Isabelle Czernichowski of BRGM presented ideas on future geochemical issues at Sleipner. Isabelle reviewed all the possible consequences of chemical reactions induced by CO_2 on the injection operations and storage performance, presented work currently underway within SACS and presented ideas on future geochemical issues at Sleipner.

The work on geochemical modelling within SACS currently is based on laboratory experiments and uses numerical modelling as a tool to interpret the experimental data with some code validation on test cases planned. This work however was essentially modelling short-term effects.

Future research activities should consider:

- The extension of geochemical modelling beyond experimental conditions to reservoir scale and longer timescales.

- The need of field observations to calibrate and "validate" the modelling

- The study of natural CO_2 fields to assess the long-term chemical impact of CO_2 and provide confidence in the extrapolation of the modelling to longer timescales.

- The risk of groundwater contamination by toxic elements mobilised by CO_2, for overlying aquifers in case of CO_2 leakage. However not a key issue for offshore sites.

- Possible bacterial activity within the storage reservoir?

3.5 Break Out Group Session on Future Research Needs

The workshop delegates were divided into five working groups, each with an appointed chairman and technical facilitator.

The five working groups were:

Group 1 - Geology, Chairman Neils Peter Christensen (GEUS), the technical facilitator Sam Holloway (BGS)

Group 2 - Seismic and Other Monitoring Techniques, Chairman Peter Sollie (IKU-Sintef), technical facilitator Rob Arts (NITG-TNO)

Group 3 -Reservoir Modelling, Chairman, Bert van der Meer (NITG-TNO), technical facilitator Erik Lindeberg (IKU Sintef)

Group 4 - Geochemistry, Chairman Bill Gunter (Alberta Research Council), technical facilitator, Isabelle Czernichowski (BRGM)

Group 5 - Supporting Future Research, Chairman, David Beecy (USDOE[11]), facilitator, Paul Freund (IEA GHG).

[11] United States Department of Energy

Each group was given a series of questions to address (see section 1). Each group then reported its findings to an open forum of all delegates for comment and discussion.

The findings of each working group are summarised below. Copies of the scripted overheads produced by the groups are given in Appendix 4.

Working Group 1 - Geology

Shelagh Baines of BP Amoco presented the results of the working group**.** The working group identified five areas where future research was considered important. These areas were:

1. Cap rock studies
2. Modelling of natural fluid flow in the basin
3. Natural analogues for CO_2 storage and leakage
4. Natural gas storage - what can be learnt?
5. Are there cheaper ways of getting an observation well?

Cap rock studies

The integrity of the caprock is crucial to the storage of CO_2 in any reservoir. The first priority therefore must be to understand the cap rock. At the Utsira formation it was identified that there was a need for:

- A core sample from the caprock
- Information on shale permeability
- The pocks marks identified in the seismic survey need to be understand
- The coloured anomalies identified in the seismic survey need to be understand

Studies on the caprock integrity should consider CO_2 and CO_2/H_2O interactions, shale permeability and composition impacts, and the water rock interactions with time.

A detailed shale permeability study was proposed, focusing on the Sleipner caprock and internal, shales. A global database of shale data should be established giving depth and compositional data, which could assist the establishment of a caprock selection criterion for CO_2 storage. Whilst studies at Sleipner would focus on shales other caprocks such as carbonate minerals should also be included in the database.

The pock mark studies would be a Sleipner based study because it may not be appropriate elsewhere. However the information gained could be used as a screening tool in future studies where appropriate. A study was proposed that mapped the key features in the reservoir i.e. pock marks, seismic anomalies, mud volcanoes and any identifiable faults.

Fluid Flow Modelling

The fluid flow in the reservoir is an important criterion because it may influence leakage routes from the reservoir. It was noted that there was no calibration data for any fluid flow-modelling programme in the Utsira formation, but it was considered important to use multiple high-resolution models to run a range of sensitivities. By incorporating geochemical databases, the study could evaluate fluid models, and develop the understanding of potential flow barriers, investigate fluid compartments and possible fluid outlets.

It was considered that the study would involve a Sleipner based basin model, but could act as a basic tool for studying long term stability of storage sites

Natural Analogues

The study of naturally occurring CO_2 stores, could provide valuable information on long term storage of CO_2 and could be useful for verifying geochemical and reservoir models by identifying any mineral sequestration that has occurred and reactions with the cap rock. It is known that some of these stores are tight and some are leaking. In the case of the tight stores it would be useful to determine how long they have been sealed for, and in the leaking case why are they leaking?

Natural Gas Storage

A study of the standards required for natural gas storage could yield information pertinent to CO_2 storage**.** It was felt that there should be a wealth of data on gas storage that could be readily tapped. Also a review of what monitoring techniques are routinely used could be valuable.

Cheaper ways of getting an Observation well.

Options considered included:

- A drilling ship
- Piggy backing on Sleipner production.

The costs and benefits of these options would need to be considered.

Working Group 2 - Seismic and other Monitoring techniques

Rob Arts of NITG-TNO presented the results of this working group**.**

The group identified the following key research needs:

1. There was to characterise the lateral and vertical movement of the CO_2 in the reservoir.
   Another 3-D seismic survey of the Utsira will be completed in two years, but after that what then?
   Issues that arose in discussion were:
   - Is there a need for a repeat seismic survey every 2/3/4 years?
   - Are there other monitoring techniques that can be applied?

2. Another key issue was the need to define the position of the shales layers in the reservoir

3. The bright spots on the seismic survey need to be defined, before injection commenced

4. Data mining should be undertaken to assist in defining the latter two points. This work could include:

   - Going through the old data
   - Investigate new techniques for data resolution
   - Exploit the existing log data more effectively

5. If there were a well shut down on the Sleipner field, a priority list of measurement needs should be drawn up.

6. An uncertainty analysis could be undertaken on the seismic data to determine how precise the data is.

A number of these points were then reviewed in more detail.

Movement of CO_2

The movement of CO_2 in the reservoir could be monitored by gravity resolution. Although the two time lapse seismic surveys should give an indication of the movement and seismic probably remains the best option.

Other options discussed included:

- Smart wells
- OBC (permanently installed grids) sensors versus surface seismic - most probably high cost
- Surface monitoring

Shales in the reservoir

Options discussed included*:*

- Geological modelling could be used to identify small features in the reservoir. Linking the geological models to the seismic surveys might identify the positions of the shale layers.
- Stochastic modelling could also be applied and again linked to the seismic surveys.
- Reprocessing of the existing seismic surveys could be undertaken to focus on the small features.
- The horizontal well logs could be reinterpreted with the latest evaluation techniques
- Use of VSP techniques, these are not included in the SACS project but could calibrate better to the larger surveys.
- Use MT[12]/EM[13] methods, which could give better resolution on a local level.

Acquiring core samples would identify the shale layers.

Bright spots in the shales

Options to obtain more information include:

- Sheer waves - the best approach may be to do a shale wave survey, apply lithographical or gas wave effects or a better AVO inversion
- Undertake a microseismic survey, this technique will be assessed in SACS2.

Non SACS's aspects that could be considered include the application of other geographical methods. These could include: high-resolution subsurface techniques such as; cross well seismic, electromagnetic tools, VSP (reversed and 3D) and ERT[14]. Pressure tests in the reservoir could also be considered.

Group 3 -Reservoir Modelling

Erik Lindeberg of SINTEF presented the findings of this group. The group identified three major topics for consideration, which were:

1. **Cap rock integrity**, which was divided into two issues:

[12] Magnetotelluric
[13] Electromagnetic
[14] Electrical Resistance Tomography

Cap rock integrity related to storage efficiency, i.e. ensuring that the stored CO_2 does not leak out. Tracers could be used in the injected CO_2 to test for the integrity of the caprock seal. Tracers are commonly used in other parts of the petroleum industry. Extra wells might be needed to monitor tracer distribution, which could be expensive.
Take one or more caprock cores, ideally these should be taken before injection commences.
Cap rock mechanical strength studies should be considered. This may not be a big issue in the Utsira because of the size of the reservoir pressure changes can be expected to be limited and the CO_2 will spread out over a large area because of the high permeability in the Utsira sand.

Cap rock integrity with respect to safety. The discussion considered whether experiences from gas storage projects could offer advice on the safety of CO_2 storage. Natural gas storage in reservoirs is commonly practised throughout the world, similarly CO_2 is stored naturally in reservoirs throughout the world. Neither of these options seems to raise much public concern, there seems to be no public issue relating to the siting of natural gas storage sites. We need to understand why not.

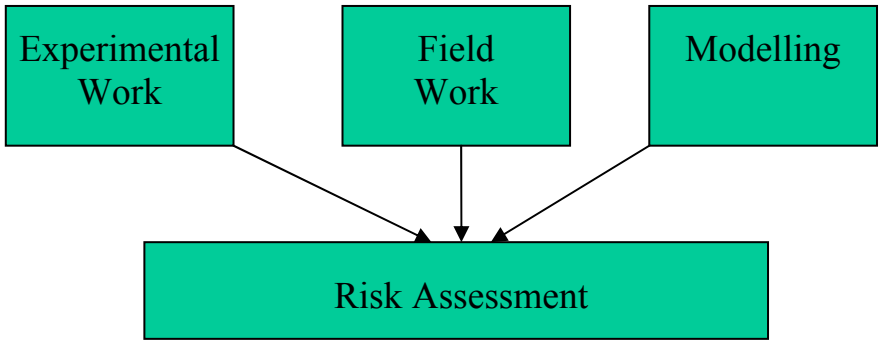
2. **Geochemical Trapping.** Issues include the trapping of the injected CO_2 by chemical reaction needs to be included when long term modelling is undertaken.

3. **Modelling verification and modelling tool improvements,** the results are summarised in the table below.

Physical/chemical phenomena		**Importance**	
		Active	**Passive**
1	Geochemical reaction rates and end points		High
2	Pressure solution of rock (stress effect)		
3	Solubility of CO_2 (p,f, X_{salt})	Low	High
4	Vapour pressure of CO_2 (y_{H2O})	Low	Low
5	Chemo-mechanical effects	Medium	High
6	Chemical reaction effect on injectivity	Medium	
7	Chemical reaction effect on cap rock integrity		Med/High
8	Phase behaviour	High	High

Working Group 4 - Geochemistry

Bill Gunter of the Alberta Research Council presented the results from this working group, who presented an overall geochemistry plan.



The geochemistry plan, which follows was designed to collect the information necessary for risk assessment

Research Needs	EXPERIMENTAL WORK	FIELD WORK	MODELLING
Year 1	(1) Integrated caprock leakage assessment (cost 300-800k Euro/US$)	(2) Natural analogue investigation for long term kinetics and leakage processes (cost 1-2M Euro/US$)	(4) Reactive transport code comparison (cost 500k Euro/US$)
	(6) Kinetics of rock/water/CO_2 interactions (cost: 300-500k Euro/US$)		(4a) Phase behaviour with trace gases (cost 100k Euro/US$)
			(4b) Common thermodynamic database (cost 50k Euro/US$)
Year 2	(7) Bacterial processes (cost: 50k Euro/US$)		(5)Sensitivity studies (cost 100k Euro/US$)
Year 3		(3) Observation well investigations at Utsira (or other site) (cost 2.50M Euro/US$, excluding well costs)	

Note: priorities are given in brackets. All costs are estimated.

For the geochemical portion of risk assessment, the following issues needs to be assessed:

- ground water contamination (slow leakage)
- corrosion or fracturing (fast leakage)
- subsidence or induced seismicity
- permeability modification due to chemical reaction
- mineral trapping of CO_2
- resource contamination/enhancement

Working Group 5 - Supporting Future Research

David Beecy of USDOE presented the results of this working group.

It was recognised that the technical groups would identify three sorts of projects requiring support, which were:

1. SACS specific projects,
2. Projects related to SACS,
3. Other related research.

The group discussed a number of issues, which included:

- How the SACS steering Committee selects proposals to support
- How national and international funders respond to proposals for support

- Public attitudes to sequestration. It was recognised that there was a need to involve more parties in the discussions, for example NGO's[15]

Specific points raised regarding the three types of projects were:

SACS specific proposals

Such projects would enhance or extend the scope of work undertaken on CO_2 storage in the Utsira reservoir. These projects could be co-funded by specific countries or companies - various opportunities for funding were recognised. Such projects would be subject to the agreement of the SACS steering committee. They could be set up using the project-type of agreement available under the IEAGHG implementing agreement, or by other means.

Projects related to SACS

These projects would be welcomed where they were of value to the concept of saline aquifer CO_2 storage. Such projects would most likely involve bilateral exchange of information. Funding could come from countries or companies. Co-operation with SACS would be subject to formal agreement by the SACS steering committee. Data exchange could be facilitated under an IEAGHG project-type agreement. A clear procedure is needed for the SACS steering committee to make decisions on projects of this type.

Other related research

It was considered by the group that a number of general points needed to be raised which were:

- There was a need to facilitate an exchange of information between related research projects
- Further workshops should be encouraged along with other forms of international dialogue
- That there was a need to promote improved public understanding in a co-ordinated way.
- That a collective international effort was needed to improve understanding on geological storage.

Open Forum Discussion

In the open forum discussion following the working group report back session, it was evident that many of the groups had developed common research ideas that were considered to be high priority. These common ideas included:

- Cap rock integrity
- Fluid flow
- Monitoring techniques
- Natural analogues
- Risk Assessment
- Monitoring wells

Tore Torp indicated that a monitoring well was an extremely expensive item and was unlikely to be undertaken merely as a research tool. He indicated that within the SACS project a feasibility study on a monitoring well would be undertaken. In addition, he informed the audience that the Sleipner licence were considering drilling a back up injection well that could act as an observation well. There were also plans to drill two new production wells on Sleipner this could generate the necessary core samples requested by several of the groups and water samples. It was decided that all groups should consider research on natural analogues and that a risk assessment was a follow on activity from the research ideas from all the groups.

[15] Non governmental organisations

It was, therefore, decided to hold three further technical working groups to further quantify research needs on:

- Cap rock studies
- Fluid flow in the reservoir
- Monitoring techniques

There was also considerable discussion about the need to begin considering issues of public perception and a fourth working group was set up to address the research issues that might arise.

3.6 Further Break Sessions

As occurred with the previous break out session chairman were appointed for each group. The appointed chairmen were:

Working Group 1 - Cap Rock Studies, **Shelagh Baines, BP Amoco**

Working Group 2 - Fluid Flow, **Carl Steefel, Lawrence Livermore National Laboratory**

Working Group 3 - Monitoring Techniques**,Roger Sollie, SINTEF**

Working Group 4 - Public Perception, **Neils Peter Christensen,GEUS**

The chairman also reported back for each group in the open discussion that followed. The results of these groups are summarised in the following text. The overheads and flip charts scripted by the breakout groups are given in Appendix 5.

Working Group 1 - Cap Rock Studies

The groups discussions were focused two issues, which were:

1. Cap rock integrity

Discussion focused on the integrity of the cap rock and in particular the seal requirements. It was considered necessary to address what constitutes a seal, what leakage rates are likely, what leakage is acceptable and what standards might apply.

It was felt that there should be a number of sources of data that might assist these deliberations. This data could include Governments standards on gas storage, enhanced oil recovery, natural CO_2 analogues and subsurface waste disposal.

The group proposed that as a starting point a study on standards and their implications for CO_2 storage should be undertaken. This study could include a review of EU[16] standards on gas storage, US State standards on waste disposal and gas storage, and possibly Belgian standards on nuclear waste disposal in fine-grained rocks.

2. Evaluation/screening of the ideal reservoir

It was noted that the emphasis of this evaluation must be CO_2 specific.
The evaluation should include:

- Geometry of the shale (regional and internal). This aspect could include a depositional model

[16] European Union

- Burial history modelling including stress history and small scale structures.
- A sampling strategy (cuttings or cores). The question was raised whether cuttings can be considered as representative.
- Characterising cores and drill cuttings in terms of their sealing capacity

Once this work was completed this could lead to a 1st phase Risk assessment that could then act as the focus of future studies.

In addition the group considered that a shale composition and permeability database should be developed. The database could assist in the development of a number of models that collate the available data and identify how to make it CO_2 specific.

Working Group 2 - Fluid Flow

The group's deliberations on future work are summarised below:

It was concluded that there was currently insufficient data to determine the fluid flow in the reservoir. For SACS it was considered that a new depth related seismic survey should be taken. Developing data sets on:

a) Gas-water flow (no exchange)
b) Gas-water flow /CO_2 solubility
c) Include mineral precipitation/dissolution

By then including mineral precipitation/dissolution rates this could lead to the following activities:

1. A comparison of long term behaviour, which should then be compared with data from a study on natural analogues. A comparative natural analogues study was considered as useful to underpin the short term modelling underway to date in projects like SACS.

2. A study on local scale permeability change.

Including b) and c) would lead to the following activities:

1. The actual distribution of CO_2 distribution within the reservoir that could feed into the geophysical modelling studies.

2. A formal study was proposed under an IEA GHG agreement for formal code comparison between reservoir modelling teams this could include, SACS and LLN[17]L, LNBL[18] and Battelle Columbus. The code comparison would involve both such codes as TOUGH2 and NUFT (LBNL and LLNL) and standard industry codes like ECLIPSE. The key point here would be to establish some level of credibility that such codes as NUFT and TOUGH2 could capture the physical flow correctly, as demonstrated by a match with the petroleum industry standards like ECLIPSE, before moving on to the geochemistry.

The group identified that to move SACS forward there were some key data outstanding.
In particular, core samples were considered essential. Core samples were needed to provide the following information:

- Relative permeability
- Mineralogy
- Water chemistry

[17] Lawrence Livermore National Laboratory
[18] Lawrence Berkeley National Laboratory

- For core flood experiments

In addition, existing well logs could be used to maximise available information and more pressure measurements were required to enable the regional fluid flow to be determined.

Working Group 3 - Monitoring Techniques

The group presented three scenarios for further which are discussed below:

Scenario 1 - Access to injection well not feasible

In this case further monitoring working should include:

1. Collating and evaluating all existing well log data from the Sleipner drillings along with the 2 new holes to be drilled

2. Undertake a model driven special reprocessing and interpretation of the 3-D seismic surveys taken to date to focus on the shale layers and the cap rock to look for possible fractures.

3. Pressure measurements at well load need to be taken at every opportunity that the injection well is offline.

4. Consider installing surface monitoring cables and fixed sensors,

5. Undertake feasibility studies on gravity and electromagnetic monitoring techniques as possible lower cost options to seismic.

Scenario 2- Access to injection well allowed

In this case the 5 listed actions above would be undertaken and the further additional activities could be considered, such as:

6. Permanent downhole sensors could be added to measure both temperature and pressure and a temporary passive seismic package.

7. Vertical seismic profiles (VSPs) ands cross well seismic could be considered to create a higher resolution than achievable with surface seismic alone. This should assist in resolving whether there are fractures in the cap rock and any leakage paths through the cap rock.

8. Take a fluid sample

9. Install geophones in the well for microseismic monitoring.

Both microseismic and VSP's can be used to asses the cap rock for possible fractures.

Scenario 3 is if a new production or injection well is drilled in the Sleipner field.

1. This could be set up as a smart well, with installed monitoring equipment
2. Used for cross well seismic analysis
3. Install geophones in the well for microseismic monitoring., better than in observation well than in injection well.
4. Use to obtain core and fluid samples
5. Could be used as a producer of water

Working Group 4 - Public Perception

The public perception work group highlighted that whilst SACS involved off shore CO_2 storage the more contentious site in terms of public acceptance would be any future proposal for an on-shore storage site in a densely populated area.

The SACS project would develop a best practice manual for CO_2 storage, which needs to include all relevant issues including the impact of geological events such tremors on the stored CO_2, consideration of leakage rates and possible ground water contamination. This manual will assist in providing a scientific database for CO_2 storage.

It was considered that the messages that would have to be got over included:

- That CO_2 was a non-toxic benign substance,
- That capturing and storing CO_2 was one way of making continued use of hydrocarbons environmentally acceptable,
- There were positive experiences in storage, natural gas storage and CO_2-EOR for example,
- Hydrocarbon fuels were needed in the interim but we are moving to a H_2 and renewable economy.

It was agreed that there was a need for more dialogue with the environmental NGO's if CO_2 storage was to be accepted as an abatement option. There was a need to for the technical community to inform rather than lobby. The production of a popular report could assist this process.

The group emphasised that if a public relations campaign were to be considered this needs to be done by this needs to be undertaken by professionals, however, they cost.

Open Forum Discussion

A short open discussion then followed the presentation of the results of the workgroups. No key points were identified. A brief summing up of the workshop followed this by Paul Freund of IEA GHG. Tore Torp of Statoil thanked all for attending and participating in what he felt was a very useful workshop.

4. PRESENTATIONS ON RESULTS ON RELATED RESEARCH

The final afternoon gave other delegates the opportunity to present their own work. 15 presentations were made in two parallel sessions. The full list of presentations is given in Table 1 and copies of the presentation material are given in Appendix 6.

The papers presented included details of the USDOE programme on Carbon Sequestration, the work of the USDOE office of Basic Science and United States Geological Survey on geological CO_2 storage. The USDOE presentations provided information on funding opportunities as did a presentation by Massimo Lombardini on EC support opportunities under the Fifth Framework Programme.

Results from ongoing projects funded by the USDOE were presented by Lawrence Berkeley National Laboratory, Lawrence Livermore National Laboratory, Battelle Columbus Memorial Institute and the Bureau of Economic Geology at the University of Texas. Scott Stevens from ARI in the USA presented ideas on future research on natural analogues. Other projects presented included: the Australian GEODISC project, the EC supported GESTCO project, experiences of acid gas storage in Canada by the Alberta Research Council and a costing study on CO_2 storage completed by NITG-TNO of the Netherlands. BP Amoco presented their plans for their Next Generation Capture and Storage (NGCAS) Joint Industry Project. Malcolm Wilson of Saskatchewan Energy and Mines

described the current state of the Weyburn CO_2 EOR project (Greenhouse Issues No. 43) and invited anybody interested in participating in that project to contact him.

5. SUMMARY OF WORKSHOP

Based on the responses received by IEA GHG both at the end of the workshop and after, the attendees felt that the workshop had been extremely useful in bringing together experts in the field from around the world and promoting a worthwhile exchange of ideas on future research.

A number of key future research topics were identified, which were:

SACS specific proposals

f) Cap rock integrity

There was a need to focus on the integrity of the cap rock in the Utsira formation, which will require the acquisition of core samples. The seismic results should be reprocessed and well logs re-evaluated to look for evidence of cap rock fractures.

g) Evaluation of alternative monitoring techniques

It was accepted that monitoring will need to continue past the end of the existing SACS2 contract and that cheaper alternative options to surface seismic monitoring. Options suggested included: electrical resistance tomography, micosesimicity, fixed seismic arrays and vertical seismic profiling (VSP).

It is noted that electromagnetic monitoring has been considered and discounted by SACS as a tool for monitoring in the deep ocean, it was considered more appropriate for onshore monitoring. An evaluation of microseismics as a monitoring tool will be undertaken in the SACS2 contract, but not field-tested. VSP will require downhole sensors most probably in an observation well.

h) Observation well

There was considerable interest in an observation well for monitoring the CO_2 bubble in the Utsira. It was noted that this was a high cost research option. The suitability of an observation well will be evaluated in the SACS2 contract. The Sleipner licences are considering drilling a second injection well as a back up. SACS should, therefore, be prepared that if this well is drilled that it be configured with the necessary sensors to act as an observation well.

i) Modelling Code Comparisons

Before including geochemical mechanisms into modelling tools, it was considered that a first step action was necessary to compare the various simulation codes that had been developed with oil industry standard codes like ECLIPSE. The code comparison would involve both such codes as TOUGH2 and NUFT (LBNL and LLNL) and standard industry codes like ECLIPSE. The key point was to establish some level of credibility that such codes as NUFT and TOUGH2 could capture the physical flow correctly, as demonstrated by a match with the petroleum industry standards like ECLIPSE, before moving on to the geochemistry.

j) Advanced processing/reprocessing of seismic data.

Reprocessing of the existing seismic data used existing or advanced reprocessing techniques should be undertaken to assist in defining the strata's of shale within the Utsira formation and in identifying faults/fractures in the cap rock.

SACS related research

Safety of storage

It was concluded by several groups that there was considerable information available from other industries and in particular that relating to natural gas storage that might be relevant to CO_2 storage. Storage of natural gas is going on around the world at numerous sites and does not appear to be generated much in the way of public concern. There is, therefore, a need to understand why and what standards are applied and their applicability to CO_2 storage. This work would assist in building confidence in geological storage of CO_2.

Natural analogues.

Research on naturally occurring geological stores of CO_2 should be undertaken. This research should focus on the mechanisms of storage and understanding of the reaction chemistry that has occurred. This work can then be used to see if reservoir and geochemical models can predict these storage mechanisms which should give confidence the CO_2 can be stored in geological formations for geological timescales.

Shale Database

A global reference database on shale characteristics and permeability should be developed.

Data Exchange/Dissemination

In addition, to these research activities a general conclusion was that a continued exchange of information was necessary through similar workshops. The GHGT-5 conference in August 2000 in Cairns Australia, will again act as a focal point for researchers in the field of geological storage of CO_2. It will also allow discussions on project ideas that started at Leeuwenhorst to continue in a timely fashion. IEA GHG will consider possible workshop requirements in 2001 and 2002 to ensure the dialogue is maintained and international networking opportunities.

6. PROGRESS SINCE THE WORKSHOP

Since the workshop a number of early actions have commenced. These actions include:

- **SACS2 Programme review**

  The content of the SACS2 contract was reviewed in Trondheim a week after the Leeuwenhorst workshop. A number of ideas from Leeuwenhorst such as seismic reprocessing, well-log evaluations and more work focusing on cap rock integrity were considered in the project schedule.

- **Natural analogues**

  A proposal to the EC 5th Framework call in May 2000 has been co-ordinated by British Geological Survey. The proposal includes seven research organisations within the EU. A complementary proposal has been made to the USDOE solicitation and it has been agreed that the projects will, if both are successful in gaining funding, collaborate to share data and results. The GEODISC project in Australia will also co-operate in data exchange and dissemination as will BP Amoco. IEA GHG will also participate to assist data dissemination between EC supported projects and internationally.

- **Simulation Code Comparisons**

  An outline for a project to compare the various reaction codes has been developed by SINTEF since the workshop and circulated to the SACS members. It is hoped that this proposal can be

firmed up and lead to a co-operative research project in this field starting initially with comparisons on a hypothetical 'Utsira type' reservoir.

- **Enhanced Seismic Processing**

  An outline proposal has been made to SACS since the workshop to undertake by a research group in the US, following initial discussions held at Leeuwenhorst. The proposal has been circulated to the SACS members for comment, and a more detailed proposal for consideration has now been requested.

- **Safety issues**

  IEA GHG will consider developing a study to undertake an initial review of some of the safety issues raised, in particular what standards and lessons can be learnt from natural gas storage and other industries that store material underground and how these could lead to standards for CO_2 storage.

Table 1

List of Presentations on Results of Related Research given at Workshop.

Author	Paper Title
Session 5	
David Beecy, USDOE, Office of Fossil Energy	The US Carbon Sequestration Programme, Opportunities for Collaboration
NickWoodward, USDOE Office of Basic Science	Overview of Activities of the US DOE Basic Science Programme
Sally Benson , Lawrence Berkley NL	The GEO-SEQ Project,
Andy Rigg, AAPRC	The GEODISC Project
Neeraj Gupta, Battelle Columbus	Regional and Local-Scale Constraints on CO_2 Sequestration in the Deep Formations in Midwestern US,
Susan Horovka University of Texas	Exploring for Optimal Environments for Carbon Dioxide Sequestration in Saline Formations, Onshore US,
James W Johnson, Lawrence Livermore NL	Reactive Transport Modelling of Geologic CO_2 Sequestration,
Session 6	
Niels Peter Christensen, GEUS	European Potential for Geological Storage of CO_2 from Fossil Fuel Combustion (GESTCO)
Dr Robert Burruss, USGS	U.S.Geological Survey - Activities to Assess Underground Storage Capacity for Carbon Dioxide -
Scott Stevens, Advanced Resources International	Natural Analogues
Ton Wildenborg, TNO –MEP	Costs of CO_2 Removal by Geological Storage,
Bill Gunter, Alberta Research Council National Laboratory	Geological Storage of Acid Gases in Western Canada,
Massimo Lombardini, European Commission	Funding opportunities in the European Union R&D Programme,
Tony Espie BP Amoco	Next Generation Capture and Sequestration JIP (NGCAS)
Malcolm Wilson, Saskatchewan Energy and Mines	Status of the Weyburn CO_2 EOR Project,