Thematic Report: Storage Session

3rd sharing event at Łodz meeting

Hosted by the Bełchatów CCS project September 28-29, 2011

A report from the European CCS Demonstration Project Network

contents

Storage sessions

As part of the 3rd sharing event in of the European Network of CCS Demonstration projects in Łodz - Poland, members gathered to share experiences on CO_2 storage. Representatives of Bełchatów, Compostilla, Don Valley, Jänschwalde, Porto Tolle and ROAD discussed topics related to an integrated approach to modelling, monitoring, and site characterisation, MVA techniques and Storage models. Participation of a guest from the United States Department of Energy supported knowledge exchange between Europe and the US.

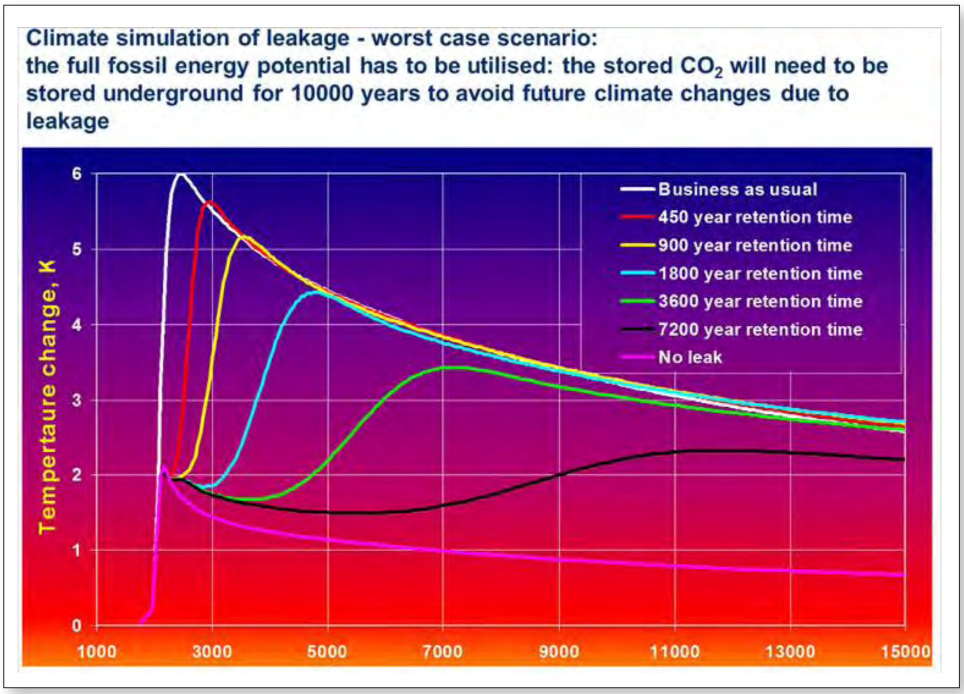
Integrated approach

The integrated approach on modelling, monitoring and site characterisation is a risk-driven, iterative process that strives for maximum internal consistency. Such consistency needs to be site specific: monitoring plans and activities, models and modelling for forecasting future performance, particularly related to future risks of CO_2 leakage and movement of displaced brine. Results of each step will help to focus and improve the next step.

The network members discussed the status and good practices of an 'integrated approach'. The discussion was fuelled by an external expert view using a webinar 2 weeks before the knowledge sharing event in Łodz. During the latter meeting, conclusions were reached on the key messages from the webinar. The status of the 'integrated approach' in each projects was then presented.

Lessons learned from the Webinar on integrated approach on modelling, monitoring and site characterisation.
On 16 September the Network organised a Webinar on "modelling, monitoring and site characterisation" with Dr E. Lindeberg from Sintef as keynote speaker.

Key messages
Dr. Lindeberg expressed the view that CO_2 storage only makes sense if the CO_2 is retained for at least 1000 years *(see Figure 1 on the following page)*. "No leakage" cannot be *a priori* guaranteed for such a period. Several reasons contribute to this situation: natural geological activity and events can occur that disturb this; many candidate storage sites are very data sparse and even the best surveyed saline aquifer sites can only achieve 'needle point' geological information, and in general, most sites require well bore data which is very costly and time-consuming to obtain. This results in a situation where much remains unknown even after a commitment is made to use a specific site.



↑ Figure 1 Climate simulation of leakage.

The positive side of the story is that a strategy based on the acceptance of a small probability of leakage and with a strong focus on monitoring and remediation is still likely to provide very significant greenhouse gas emissions abatement benefits over the short and long term. Monitoring should focus on deviations of observations from predictions, rather than have a direct focus on detection of leakage. This requires a portfolio of monitoring strategies from deep monitoring (e.g. well to well) as well as characterisation of the shallower zones and surveying and monitoring of these. This approach will provide early indications that the CO_2 flow is potentially not remaining within the planned boundaries. If a leak would occur; sufficient time will remain for remediation, e.g. diverting the CO_2 flow in the reservoir, stopping injection or in the worst case moving the CO_2 to another reservoir. Ultimately the cost of remediation should be low compared to the cost of stopping operation of the industrial plant that is capturing and storing CO_2 or paying penalties for failed storage.

A strategy that includes at an early point in site development possible remediation of (an unlikely) leakage might be cheaper than a strategy to find and develop a site with an a priori 100% 'no leakage' quality. The EC directive does not exclude such a strategy. Selection of storage sites should also be based on the ability to monitor, i.e. "monitorability". Improved and innovative monitoring techniques should be developed in industrial size projects. Each industrial storage project should act as its own "field-scale test bed" for this purpose.

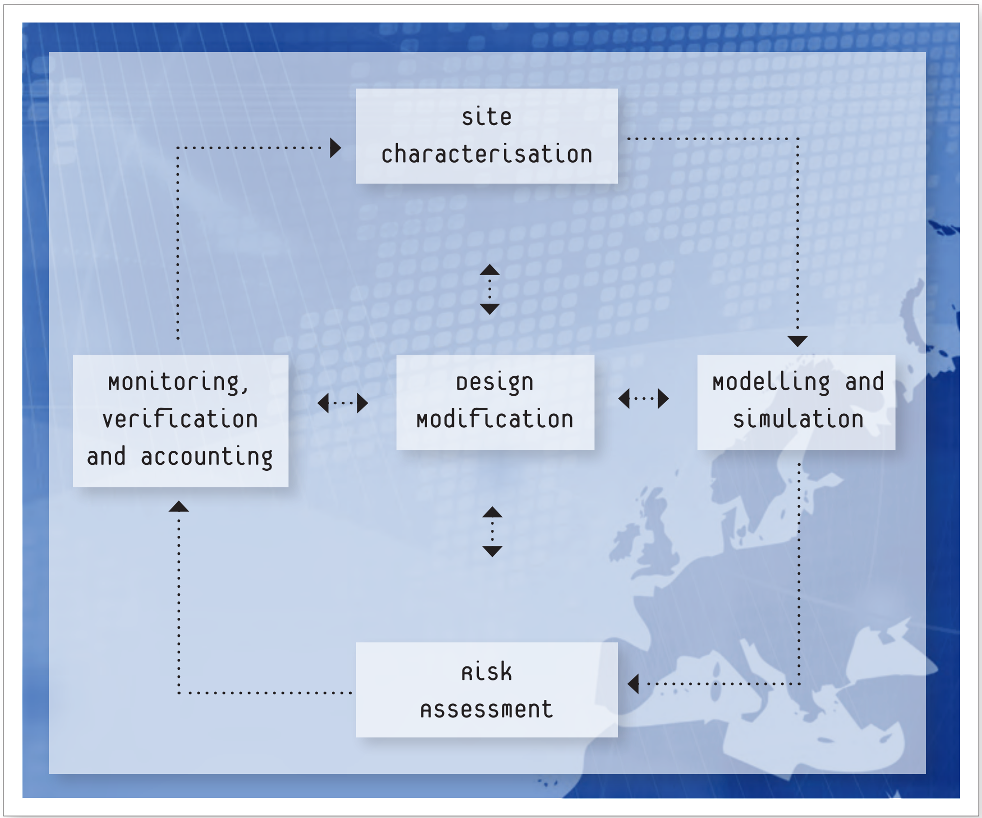
Conclusions and Lessons learned

Most projects agreed that it is necessary to have sufficient understanding and confidence to assume non-leakage on a geological timescale with very high probability to assure the project's effectiveness to mitigate climate change.

Early detection of leakage should enable a prompt response if such leakage should appear. For example, the exact extent of the plume at the level of the base of the cap rock may be uncertain, but as long as various monitoring signals and outputs indicate that no CO_2 has moved outside of the storage complex then the uncertainty is tolerable. Reservoir understanding should always be achieved at a sufficient level to rule out significant leakage on a short time scale which could develop into a safety risk.

Relocation seems an expensive remediation option. Appraisal might be viable, development is not. In the future a portfolio of "ready-to-use" storage locations will provide options for remediation.
The risk of leakage through geological faults is in general much smaller than the risk though wells. Monitoring around wells and remediation (re-cementing or otherwise re-sealing the well bore) if needed is common practice in the oil and gas industry.

The status of an integrated approach on modelling, monitoring and site characterisation in the projects
Each project provided a brief overview of its status on implementing an integrated approach based on the model provided by Ed Steadman of PCOR *(see Figure 2)*.



↑ Figure 2 Model for integrated approach.

Don Valley

EOR option: On-going conversations with the regulator should clarify what is needed for the storage application.

Saline Aquifer Option: The data is available, the models are developed. A risk based appraisal programme will use results of first appraisal well to select next appraisal well. MVA is behind.

Porto Tolle

All steps in the process have been completed once. This has supported the selection of the best areas for monitoring. Porto Tolle takes a pragmatic "Do and improve" approach. Additional data from planned appraisal wells should facilitate "the next iterative loop".

Compostilla

Hontomin site: a very rich set of data is available from current surveys and older surveys. All data is being integrated into a single model. This will help to inform risk analysis. As Hontomin is a R&D site, the amount of injected CO_2 will be limited to 100 kT, resulting in limited inherent risk.

Compostilla site: The initial process of data collection, modelling and risk assessment has started. Four new appraisal wells and a 3D seismic survey are on-going activities, and will provide additional information to update the original models (static and dynamic) and to perform the final risk assessment.

Experiences of monitoring and injection at the Hontomin site will be transferred to the Compostilla site.

Bełchatów

New geophysical surveys have been conducted in two areas (Wojszyce and Pabianice-Bełchatów) together with drilling 2 wells there (one per each area; Kaszewy-1 and Pabianice-1). In order to construct models of the three considered structures, data from two new boreholes and a dozen of old ones have been used. The project has developed the static and dynamic models for the sites and is currently doing a risk analysis to inform site ranking. The integrated risk picture indicates a necessary compromise between storage performance and monitorability, as the best candidate storage site is difficult to monitor using traditional surface seismic survey methods due to the acoustic scattering of the vuggy limestone layer above the target storage formation.

Jänschwalde

The project is planning to apply an integrated approach. Existing datasets are mostly older surveys and wellbores from exploration campaigns 30-40 years ago. New 2D and 3D seismic and four appraisal wells are planned and these will create detail knowledge about the formation. This data will also provide input for further risk assessments, improvement of the initial monitoring plan and the models of the storage location.

ROAD

The project has developed a comprehensive monitoring plan that is in-line with the EU-CCS-Directive and national legislation. The storage site is very well documented (several wells, existing 3D seismic data, comprehensive production data) from the natural gas production operations phase.

Several models exist for the site covering all relevant aspects (reservoir engineering, geo-mechanics, geo-chemical). Thus, an integrated approach as presented here has been developed, which is further developed and executed in the future.

Conclusions

All projects have an integrated approach on modelling, monitoring and site characterisation. In some projects the process is primarily driven by regulatory requirements, in other projects the process is used to support a pragmatic and risk-driven development of required MVA and models.

The integrated approach should be driven by performance targets and results: it should be demonstrated that the approach would detect leakage if it would appear. On-going research and a testing platform could provide relevant insights, and the Compostilla project demonstrates how this can be done with a small-scale field laboratory (<100 kt) working in close collaboration with the main storage project.

The projects identified the following R&D needs:

- Criteria for sensitivity and sensibility;
  This should include;
  - Clear specific definitions or thresholds (e.g. ppm of injected tracer or key natural, background isotope);
  - Resistivity changes;
  - Alternatives for radioactive tracers (like SF_6);
- Improvement of in situ testing of the geomechanical strength of the cap rock layer;
- Methods to establish an optimal grid of point measurements, e.g. for soil gas flux);
- In situ K-CO_2 versus laboratory measurements;
- Data source (age) and long term storage of data, quality trends in data;
- Scalability of survey as the plume "footprint" grows;
- Methodology for using monitoring data in Risk Analysis;
- Use of bio-indicators on surface and at shallow depths.

Researchers working on these topics are invited to contact the Network. The R&D topics will be communicated to the European Commission's CCS EII team.

MVA techniques

The projects have agreed to develop an inventory of MVA techniques used to serve as a basis to locate experience and to find potential partners for collaborating on monitoring techniques. In the past period several projects have provided information on the MVA techniques that are deployed or are under consideration for deployment. This process is on-going and will be completed before 2012.

The inventory currently lists 57 MVA (planned) implementations of MVA techniques. It covers a broad range *(see Table 1 on the following page)*. The original intention was to relate the techniques listed to the Monitoring selection tool of the IEA-GHG[1].

1 http://www.ieaghg.org/index.php?/Monitoring-Selection-Tool.html

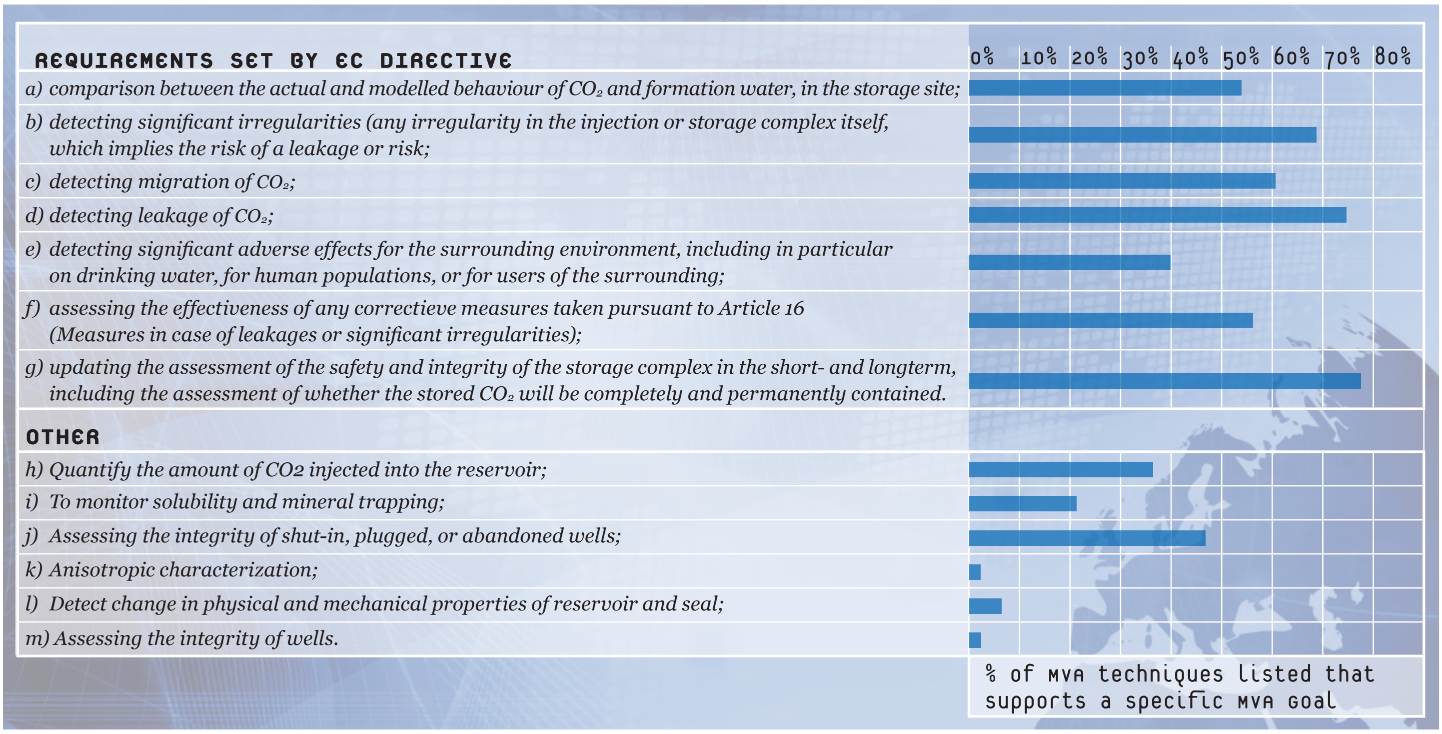
It is observed that a significant part of the techniques listed are not covered within the monitoring selection tool, which was last updated some time ago.

MVA techniques listed in the inventory	
2D surface seismic	*Land EM*
3D surface seismic	*Land Electrical resistivity tomography (ERT)*
Atmospheric monitoring	*Microseismic monitoring*
Bubble stream detection (offshore)	*Multicomponent surface*
Cross-well Electromagnetics (EM)	*Satellite interferometry (InSar, DInSar)*
Cross-hole ERT	*Seabottom gas sampling*
Downhole fluid chemistry	*Single well EM*
Downhole probe	*Soil gas concentrations*
Ecosystems studies	*Surface gas flux*
Fluid geochemistry	*Surface gravimetry*
Geophysical logs	*Tracers*
Injection Monitoring	*Vertical seismic profiling (VSP)*
Integration / Multi-source analysis	*Well logging*

↑ Table 1 Listed MVA techniques.

As expected, most MVA tools focus on the monitoring objectives set in the EC directive, including *inter alia* quantifying the amount of CO_2 injected and assessing well integrity. *See Figure 3.*

↓ Figure 3 Objectives of MVA tools.



Only a limited number of listed MVA techniques are currently confirmed to be deployed in the projects due to the early stages of the projects. It is expected that several additional monitoring techniques will be included as the baseline data surveys reveal site features most conducive and appropriate to specific monitoring strategies and techniques.

On-going development of the inventory

The key purpose of the inventory is:

- To support experience exchange with MVA techniques within the network;
- To identify other projects that may share an interest in joint development and testing of a specific technique;
- To provide insight in MVA techniques considered or applied by the Network projects to interested parties outside the network by providing an anonymous sub set of the inventory. This may for example guide research on MVA techniques.

MVA Focus and Gaps

The projects reviewed the focus of their MVA approach and identified gaps in available technologies in 2 groups: onshore and offshore projects.

Offshore projects (ROAD, Porto Tolle, Don Valley)

MVA objectives:

- Satisfy the EC directive and Permitting requirements;
- Protect against unjustified claims. For offshore project, claims from individuals are not expected; claims from other users of subsurface or sea column (other operators, fishery) are possible. In the UK Liability sharing agreements are required;
- To support efficient operation of the site. One example would be to contribute to using the optimal number of wells to achieve both required injectivity and contribute to monitoring surveys and campaigns;
- For accounting: to demonstrate the amount of CO_2 stored;
- To prepare for handover of responsibility to the government for long-term stewardship. Requirements are mostly unclear at this stage; any information that must be provided at handover must quite likely be collected from before start of injection (baseline survey).

Gaps and desired improvements in technology

The offshore projects identified the following R&D needs:

- Establishing a minimum area for coverage by baseline surveys is a common challenge across all projects. The area that is to be included might be hard to estimate as the plume will grow as the project progresses. Projects are interested in options to extend the baseline with plume growth;
- Imaging of the plume based on high-resolution seismic surveys is widely used and has proven to be effective in communicating MVA efforts to regulators and the wider public. There are significant constraints; many sites are not suited for high-resolution seismic and in many cases CO_2 may not be visible on seismic images. It should be made clear that seismic imaging does not work in all cases, and that it should **not** be an a priori requirement that the site be suitable for high-resolution seismic imaging of the CO_2 plume for effective storage. The primary example here is the ROAD storage site, which is below a very thick layer of halite which effectively seals the CO_2 in the target reservoir but also masks the formations below it with respect to seismic imaging;

- Tracer techniques may be useful to support leak detection; however leak detection through natural faults might require vast, impractical amounts of tracer material. Leak detection through well bores might be viable. Potentially bio accumulation may increase the sensitivity of tracer; this would require further research;
- Improved options for through-casing logging would provide a rich source of data;
- In general the cost of development of techniques is high. Adaption of existing techniques in the oil and gas industry is more likely to deliver effective solutions.

Onshore projects (Jänschwalde, Bełchatów, Compostilla)

The MVA objectives of the projects are apart from satisfying the EC directive requirements to provide protection against unjust claims; in particular:

- CO_2 leakage;
- CH_4 induced leakage;
- Displaced brine;
- Ground uplift or displacement and;
- Seismic events.

Discussion

The projects discussed the need to develop an alternative for seismic characterisation. Bełchatów is experiencing poor seismic signals at the best ranked site (Wojszyce) that are due to the nature of the limestone layers above the storage complex that scatter all acoustic signals; Jänschwalde is unsure about signal quality before the first major seismic surveys are performed and Compostilla prefers less invasive techniques, i.e. do not require a large grid of sensors and acoustic signal sources (either vibrating, dropped weight or small, buried charges). The "seismovie" technique which is developed at the Hontomin site may provide a good alternative to repeat 3D seismic surveys. Please refer to the website of the proprietary supplier (CGGVeritas, no commercial connection to DNV) for an explanation of the "seismovie" technique.

Compostilla is developing a three-way approach to surface deformation:

1. Satellite techniques (e.g. INSAR and variations on this);
2. Tilt meters;
3. A combination of Laser, GPS and fixed datum points.

Gaps and desired improvements in technology

The onshore projects identified the following R&D needs:

- Criteria for sensor sensitivity and selectivity;
  This should include:
  - > Clear specific definitions of thresholds (e.g. ppm of various important geochemical components or tracers);
  - > Resistivity changes;
  - > Alternatives for radioactive tracers (like SF_6);
- Improvement of in situ testing of the geomechanical strength of the cap rock layer;
- Methods to establish an optimal density of discrete (either temporally or spatially or both) measurements, e.g. for soil gas flux);
- In situ K-CO_2 versus laboratory measurements;
- Data source (age) and long term storage of data, quality trends in data;

- Scalability of survey as the plume “footprint” grows;
- Methodology for using monitoring data in Risk Analysis;
- Use of bio-indicators, i.e anaerobic microbes.

Concluding remarks on MVA

The projects are facing many challenges in satisfying MVA requirements for a number of purposes. R&D may be able to provide some of the answers. There are concerns in the project that R&D projects will not be able to deliver results in time to contribute to project success.

Bob Wright (DoE) suggested that useful lessons can be learned from US projects on a case study basis. A possible approach could be to invite a couple of people from a specific US project and organise focussed interviews by the Network members.
Bob offered to help to get in touch with the people with the relevant experience.

Storage models

In a workshop setting all projects developed posters of the storage models in use and under development. The posters provided insight in:

- Models in use: Purpose, characteristics supplier;
- Future improvements of existing models;
- Future extensions;
- Recent successes.

Bełchatów

Models	Improvement ambitions and challenges
Models include Static and dynamic models of the geological structure, geochemical model, a model to support selection of well locations and a model to support risk assessments.	• *To support evaluation of the monitorability of the structure.* • *A pilot injection project is setup to confirm/ evaluate the injectivity of the Jurassic aquifer in Poland.* • *Monitoring techniques will be tested and the resolution accuracy determined.*
Future extensions	**Successes**
A more detailed Site characterisation model will be developed, including new wells and geophysics.	• *Preliminary structure selection (To be confirmed for other scenarios)*

ROAD

Models	Improvement ambitions and challenges
Models developed cover all relevant areas, like geological model, dynamic reservoir models, flow assurance model, geochemical and geomechanical models	• *Coupling / interfacing of models* • *Evaluation of possible injection testing*
Future extensions	**Successes**
Further improvement of all models (incorporate latest R&D insights, develop further reasonable scenarios, incorporate laboratory tests, etc.)	• *History matching gas production period* • *Development of robust models for all relevant areas* • *Prognosis of development upon CO_2 injection*

Porto Tolle

models

Models include geological/structural models, a petrophysical model, a set of dynamic flow models, a geochemical and geomechanical models

improvement ambitions and challenges

- *Update of the models using field data coming from appraisal well*
- *Improvement of the interfaces of the models*

future extensions

- *Validation of the petrophysical model*
- *Validation of the flow model for injection strategy*
- *Development of the geochemical model*

successes

- *Tuning of the model's results (all dynamic models) carried out by different codes and contractors*

Compostilla

models

Models include dynamic and static models, a hydrogeological conceptual model for the deep flow in the reservoir and models to check the use of monitoring techniques

improvement ambitions and challenges

future extensions

- *Extension of the geochemical model to include multiphase flow and reactive transport*
- *Risk Assessment methods based on probabilistic Bayesian networks*

successes

- *Confirmation of the probed borehole prognosis*

Jänschwalde

models

Models include static geological models, a regional shallow ground water model, a local, detailed reservoir (dynamic) model and a regional, coarser reservoir dynamic model

improvement ambitions and challenges

- *To combine the shallow groundwater model and the reservoir model*
- *Modelling fault behaviours*
- *Ground water models using a closed/complex Rupelian layer*

future extensions

- *Develop/improve models based on new data from exploration*
- *Model of the Rupelian layers*
- *Design monitoring concepts as based on results of the models*

successes

- *Very good knowledge about the groundwater fresh/salt water boundary (more than 700 water quality gauges were evaluated by several contractors)*

Don Valley EOR

Models	Improvement ambitions and challenges
Models include sector models for 3 areas, 2 full field models and a long term storage model to examine integrated migration and leakage scenario's	• *Improve run times through parallel processing or better software* • *Use of extremely large grid & large time steps*
Future extensions	**Successes**
• *Geochemical analysis models* • *Probably no need for a reactive transport model*	• *Good run times with large compositional models* • *Optimised gridding*

Don Valley Saline aquifer

Models	Improvement ambitions and challenges
Models include static, dynamic and coupled models and near well bore models	• *Incorporate sensitivity output into appraisal programme data acquisition* • *Improved run times* • *Optimised cell size relating to injection points*
Future extensions	**Successes**
• *Brine migration models*	• *Eclipse sensitivity study, e.g. to understand the effect of cell size layers within reservoir*

The overviews will provide the basis for a model inventory which will be developed over the next months.

The projects identified areas of interest for knowledge exchange (based on existing experience or common interest. Typical topics included:

- Comparison of software packages;
- Ground water displacement and Brine modelling;
- Gridding strategies;
- Modelling of Fractured and Faulted Rocks and Formations;
- Risk analysis methods;
- Managing conflicting or competing use of nearby reservoirs or subsurface resources;
- Geochemical modelling.

These topics will be explored in more detail on a bilateral basis.

Gaps and areas for further research

The results of the posters and the discussions were analysed and identified the following potential research topics:

- Ground water (shallow) modelling;
- Brine modelling, i.e. displaced brine from the target formation;

- Improving model interfaces;
  - > Automating interfaces;
  - > Guidelines and practices for effective coupling or interfaces;
- Model requirements for Risk assessments;
  - > How this can be included in an integrated approach;
  - > How to do semi-quantitative risk assessments;
  - > Comparing public and commercial methods and tools;
  - > Learning from existing projects and used methodologies: QRTT (Quantitative Risk Through Time method). The software is protected by IP, but results and methodology were published from In-Salah;
- Comparing Software Package Performance;
  - > Compare simulation times for long storage times (centuries or more);
  - > Lessons learned from practical experience;
  - > Coores (IFPEN) simulator-modelling the hydrodynamic behaviour of CO_2.

Concluding remarks on storage

Bob Wright (DoE) suggested developing a benchmark case, e.g. a well-documented geological site, that allows all projects to test and compare their models. This will help to improve the models and increase confidence in the model output.

A reference was made to a study of the University of Stuttgart which compared available dynamic models used by different modelling teams. A peer-reviewed article can be found at http://www.springerlink.com/content/51846140783h1320/

It was observed that once practical experience in modelling grows, more practical insights can be shared. The current shared understanding of project activities and progress will accelerate sharing in the coming years.

Close of the session.