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A Draft of Guidance from the Scientific Research Programme GEOTECHNOLOGIEN to Underpin the Implementation of the CCS Directive in Germany

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Introduction

Within the GEOTECHNOLOGIEN funding scheme for geological CO_2 storage by the Federal Ministry of Education and Research (BMBF) in Germany 32 projects have been funded with a budget of 58,3 M€ excluding industry funds from 2005 to 2014. In 2012 the German government passed the transposition of the EU CCS Directive 2009/31/EG – Das Kohlendioxid-Speicherungsgesetz (KSpG). Beside differences of both laws Annexe 1 and 2 match which define the criteria how to set up and monitor a CO_2 storage. In 2012 an umbrella project called AUGE has been launched in order to compile and summarise the results of the projects to underpin the Annexe scientifically. This presentation gives a draft overview of the project results ordered by the KSpG with an assessment of the development status.

Nomenclature status:
prototype: method developed in the project based on the physical principal, available to developing research groups
demonstration: method well tested within a project, in principal available to the storage community
established: method well tested before or available on the market

Summary

The knowledge base of CO_2 storage research is good enough to start a demonstration project (injection of 1 Mt CO_2).
It is actually needed to progress the technology.

Annex 1: Criteria for the characterisation and assessment of the potential storage complex and surrounding area

1.1 Data collection

Project	Methodology	Status
CO_2SINK CLEAN CO_2MAN CO_2CRS CO_2DEPTH PROTECT CSEGR COMICOR	geologic field mapping, well logs for near well parameters, hydrologic field experiments, usage of different reactive tracers	established
	4D seismics at pilot site Ketzin, improvement of analysis of seismic data, approach of combining seismic data analysis with 3D kinematic modelling for an improved understanding of fault (re)activation	established-demon-stration
	determination of petrophysical reservoir parameters and mineral composition, batch experiments for CO_2-rock interaction	established
There is a good understanding of the reactivity of individual minerals with $scCO_2$-H_2O which allows a correct evaluation of the reservoir rock. However in batch experiments rocks show a higher reactivity than in real life (coring at Ketzin). Chemical modelling is limited due to missing thermodynamic constants and kinetic rates.		
CO_2SONO-StRA	batch experiments with cores, $scCO_2$, formation fluid and impurities NO_2, SO_2 and O_2 showed some damage within the 28 days testing period – concentra-tion of impurities used were too big than today's capture technology suggest	
CO_2SINK CO_2MAN RECOBIO CO_2BIOPERM	At Ketzin the microbiological community in the dump of the well changed during injection but still exists. An influence on the permeability of cores infiltrated by microorganisms has not been proven jet but is a focus of CO_2BIOPERM.	
CO_2TRAP COSMOS CO_2SEALS	batch experiments of $scCO_2$-water-clay show • a very low reaction rate: alteration are insignificant for the tested time periods • that clay stones with a significant amount of Smectit, Illite and Kaolinite have a high CO_2 sorption potential	

Table 1: Summary of deployed and developed characterisation techniques.

1.2 Building the three-dimensional static geological earth model

Project	Methodology	Status
CO_2SINK, CLEAN, BRINE, CO_2MOPA, CO_2MAN	Among others Petrel, GOCAD, EarthVision are software packages to generate static 3D geological models.	established
Geo-statistic is needed to derive petrophysical parameters from few drilling cores for the whole modelling grid but therefore cannot reproduce preferential pathways of the CO_2 plume flow. An appropriate fault model needs to be developed and implemented. The static geological model as a base for dynamic model runs will be improved by further monitoring data with ongoing CO_2 injection and other measurements. The approaches "one geological model fits all" versus "a number of simplified geological models for different parameters" need to be considered, Fig. 1.		

Table 2: Brief summary of methods to establish a static geolgocial model.

Wellbore integrity

Project	Part	Technology	Status
CSEGR COSMOS	well fitting	steel and other materials are available in which are resistant against corrosion	established
COSMOS COBOHR COBRA	cement	advanced cements have been developed to withstand the corrosion by carbonic acid by an increase of NaCl or replacement of Portland cement clinker with quartz powder or flue ash	prototype
COBOHR COBRA	cement	elimination of imperfections in wellbore cements by optimizing 1. the viscosity/ hardening of the cement using different by-products 2. the filling technology	prototype
Oil and gas production proves that wellbores are safe for 50+ years, new materials suggest that for CO_2 storage as well. The conservation of the technical integrity of abandoned wells for more than hundred of years remains unproven. A higher level of security can be achieved by introducing natural barriers wherever possible (Fig. 2), CLEAN.			

Table 4: Brief summary on wellbore integrity.

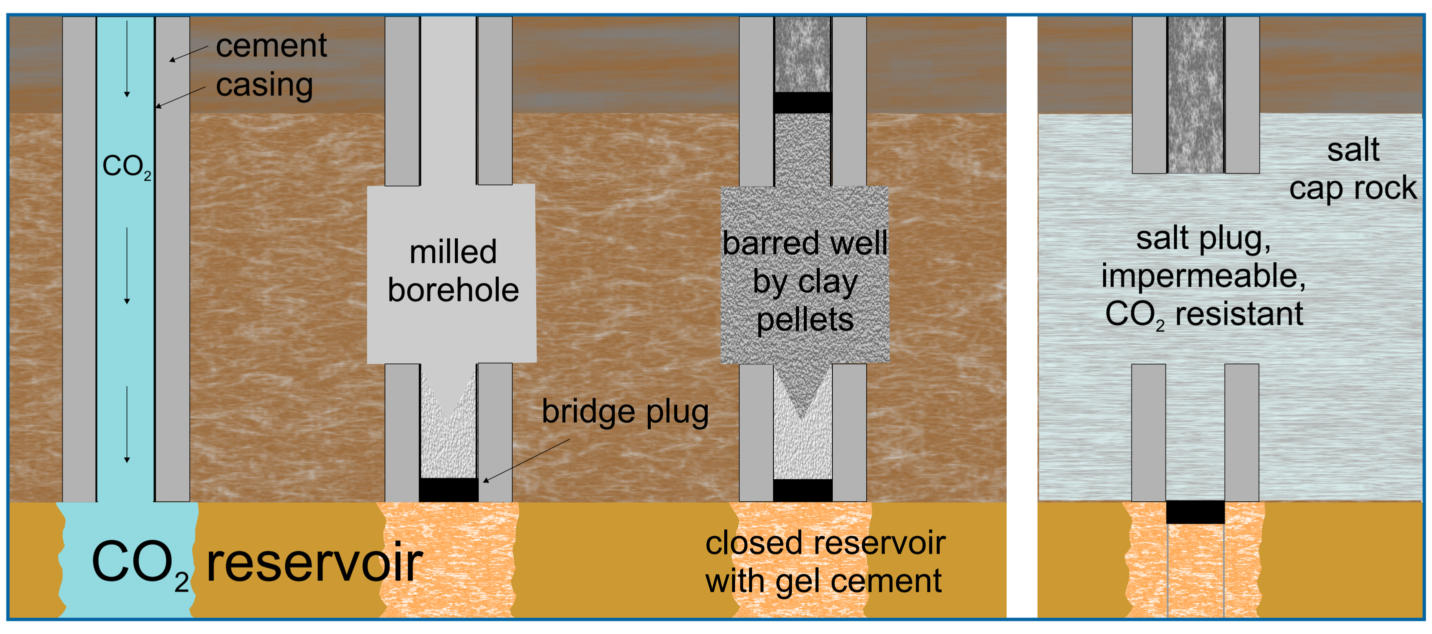

Fig. 2: Schematic showing the use of clay or salt as an additional barrier in wellbore abandonment.

1.3 Characterisation of the storage dynamic behaviour and sensitivity characterisation

Project	Modelling activity	Status
Benchmark, CO_2SINK, CO_2MAN, CO_2RINA, CLEAN, BRINE, CO_2MOPA	Development of fully coupled dynamic models to simulate the effects of injection of CO_2 into the subsurface: multi-phase flow, heat transport, hydrodynamics, geomechanics and chemistry with various simulators and sub-models -> THMC models, shown in Fig. 1.	demon-stration
Individual modules of model systems need to be evaluated by benchmarks. Models need to be calibrated with monitoring data. • Prediction of the CO_2 flow in the subsurface will be very uncertain as it depends strongly on small-scale heterogeneity and large-scale geologic features • Prediction of pressure development in the storage complex can be given with some confidence as it depends mainly on the average permeability. • Prediction on the storage capacity can be estimated with some uncertainty as it depends on the injection rate, depth, temperature, salinity, permeability. • Prediction on geochemistry and geomechanics can be estimated with a big uncertainty mainly due to missing data and missing fundamental constants.		
As a prerequisite for a comprehensive risk analysis within the risk assessment simplified versions of models deployed in characteri-sation should be used and coupled in an statistical approach.		

Table 3: Brief summary of methods to establish a dynamic model as described in Figure 1.

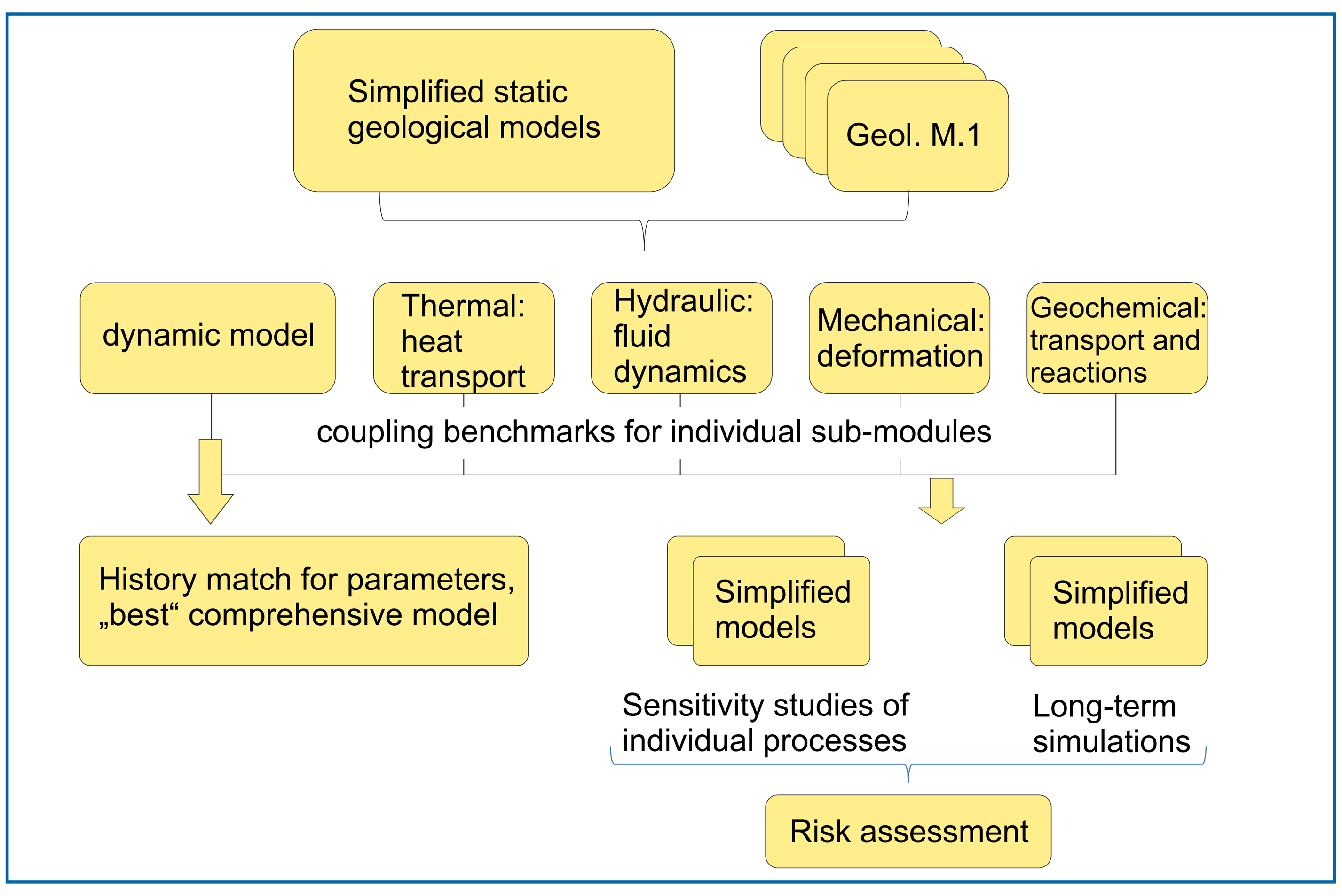

Fig. 1: Workflow for dynamic modelling.

Project	Parameter monitored	Technology	Location	Status
		Verification measurements		
Surface and above				
MONACO CO_2MAN	CO_2 concentration	FTIR, Eddy covariance, CO_2 sensors in the soil - down to 20 m	on surface of storage area	established
		Monitoring		
Drinking water aquifers				
CO_2Leckage, MONACO, SAMOLEG	fluid electrical resistance, salinity, chemical parameter	established ground water monitoring tools, long electrodes ERT	drinking water aquifer	established
BRINE MONACO	salinity – salt water induced zone	electrical and magnetic fields (EM)	down to 200 m	established
Borehole				
CO_2MAN	p/T		wellhead and in wellbore	established
CO_2MAN	T	distributed temperature sensing	wellbore	demon-stration
COBRA	cement permittivity	time delayed resistivity	wellbore	prototype
CO_2MAN	various parameter of the wellbore	various	wellbore	established
Intermediate region – last drinking water aquifer to cap rock of storage reservoir				
CO_2MAN BRINE	electric resistivity of fluids	ERT	in wellbore and or surface	demon-stration
CO_2MAN CHEMKIN	concentration of substances	gas membrane sampling device connect to gas chromatograph	in wellbore	demon-stration
Reservoir				
MONACO CO_2MAN	surface deformation	satellite imagery for movement of reflectors, GPS measurements of emitters	surface of storage area	established
CO_2MAN	seismic waves	active seismics	surface of storage area, wellbore	established
CO_2MAN	neutron scattering, electrical resistivity, CO_2 saturation	pulsed neutron gamma, ERT	wellbore	demon-stration
CO_2MAN	seismic waves	geophones, passive seismics	wellbore, surface	established

Table 5: Proven and developed monitoring methods.

Annex 2: Criteria for establishing and updating the monitoring plan and for post-closure monitoring

Establishing the monitoring plan
In the GEOTECHNOLOGIEN Program technologies have been developed and applied which allow for a comprehensive monitoring on all levels. It is most efficient to
- implement the monitoring strategy based on the site characterisation, close to planes of weakness,
- implement a hierarchical approach, with low resolution spatial measurements with a relatively high timely resolution which are complemented with high resolution spatial measurements at individual locations where anomalies have been detected.

Most challenging is the monitoring of the region between the cap rock of the CO_2 storage reservoir and the drinking water aquifers as CO_2 can spread laterally in overlaying aquifers, especially
- the task to find new leakage pathways if site characterisation has given no indication,
- the detection of fluid migration in the vicinity of the storage with elevated pressure levels.

Surface measurements of CO_2 should be seen as verification measurements rather than monitoring measurements. They need to be done but probably most damage has been done once CO_2 is detected at the surface.

Updating the monitoring plan
This is one of the most important steps in the life cycle of a CO_2 storage: The adaption/improvement of the static geological earth model (Annex 1.1) with new measurement data is an iterative process. CO_2 can be seen as a tracer for reservoir characterisation and gives additional information about the heterogeneity of the reservoir. Most important is to understand
- the change of geophysical properties of the reservoir and the cap rock over time with ongoing injection,
- the difference between modelled and measured behaviour of the storage complex as signals of leakage might be subtle and fall into the uncertainty of modelled parameters.

Post-closure monitoring
The short post-closure period at the pilot site for CO_2 storage at Ketzin has shown that
- P/T measurements in the wellbores near the reservoir and in aquifers above the reservoirs are most valuable to understand the pressure decrease within the reservoir,
- DTS in the wellbores help to understand the thermodynamic phase behaviour of CO_2 along the sonde,
- Mapping of the CO_2 plume by seismic measurements will provide confidence in the integrity of the reservoir by understanding plume migration.

Acknowledgment

The scientific content of this poster was aquiered by the GEOTECHNOLOGIEN projects as referred to under "Project". We are especially grateful to our colleagues of Phase 3 projects for their input to the Guidance Document.

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