Minutes of Technical Day of 4th April 2024

Geomechanical challenges in industrial CO_2 and H_2 storage in geological formation

From: Kun Su **Verified** by all presenters.

Date & place: 4th April 2024, Ecole des Mines de Paris, 60 bld Saint Michel, 75006 Paris
Session co-chaired: by Kun Su from TotalEnergies, & Philippe Cosenza, President of CFMR.
Organized by: CFMR, SPE France, EAGE Paris Chapter
Participants: 44 in person and 34 online via Zoom

CONTEXT: This technical day is proposed in March 2023 by Kun Su, Expert in Geomechanics at TotalEnergies. The CFMR president and the advisory board accepted and scheduled for the 4th April 2024.
Many industrial operators around the world are committed to developing CO_2 storage projects (CCS) in highly permeable sandstone or carbonate reservoirs in order to meet the goals of net zero as per the Paris Agreement (COP21, 2015). At the same time, the storage of H_2 in subsurface salt cavern or reservoirs is also the subject of numerous studies at the pre-development stage. The design and operation of each CO_2 or H_2 storage project require many inputs from various geomechanical topics, from rock mechanics characterization on reservoir rock samples to 3D hydromechanical or thermo-hydro-mechanical numerical simulation of the long-term behavior of host formation and its overburden, including field monitoring and assessment of risk of induced seismicity. Most of them can be addressed with the same methodologies used in conventional O&G developments. Others are more specific, and some are considered as game changers, for example, the maximum allowable injection pressure of CO_2 regarding the subsurface integrity from Geomechanical point of view.
The objective of the technical session is to let the industrial actors to present the key geomechanical topics involved in industrial projects of CO_2 and H_2 storage in geological formations, the progress made and the remaining challenges
In January 2024, SPE-France and EAGE_Paris_Chaper have jointed to the organization of this technical day. The organization committee are: **CFMR**: Philippe Cosenza, Kun Su, Laura Blanco Martin, Nicolas Guy, Nicolas Gatellier, Gregoire Hevin, Siavash Ghabezloo, **SPE France**: Zahraa Alkalby, Natalia Quisel, **EAGE Paris Chapter**: Guillaume Henin.
TotalEnergies has sponsored the lunch buffet.

TECHNICAL PRESENTATION: There were 12 presentations (cf list in the annex), including 4 from TotalEnergies. My note for each presentation are the following:

PRESENTATION 1: The HyPSTERproject : Underground Hydrogen Storage in salt cavern, a pilot experiment, by Grégoire Hévin, **Storengy**
HyPSTER is a **Hy**drogen **P**ilot **ST**orage for large **E**cosystems **R**eplication. It is a EU funded project starting from 2020. There are 9 partners from 4 countries (France, Germany, UK, Norway). The pilot of H_2 storage in salt cavity is located in Etrez (Ain), with a capacity of 3 tons of H2 in experiment phase, and 44 tons in a future operational phase.
The project consists of two parts: i) renewable hydrogen production and ii) pilot of hydrogen storage in salt cavern. **In part 1**: the renewable hydrogen production, the capacity of hydrogen production is 400 kg/day at 30 bars and 15°C, by a 1 MW electrolyser PEM technology. **In part 2**: a salt cavern of about 8000 m3 is created at 950 m depth.

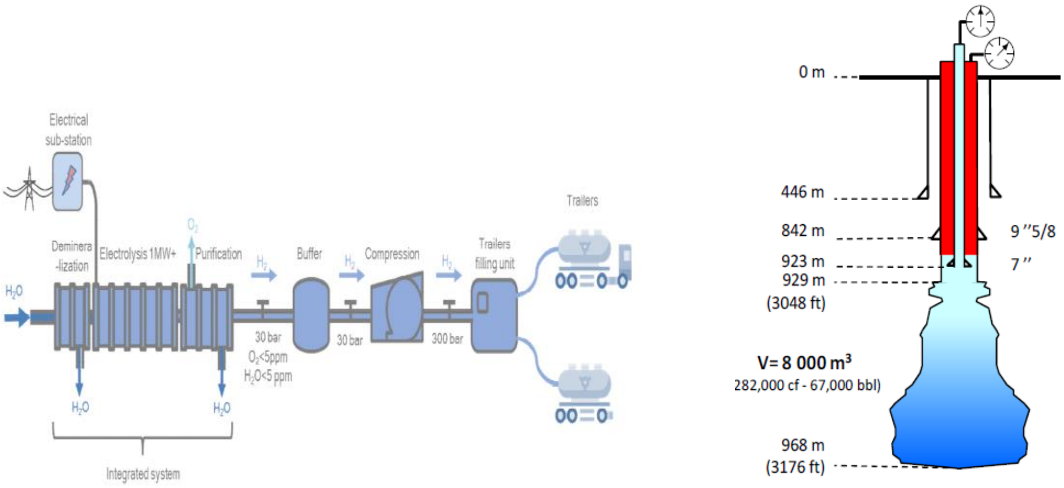


Fig-1: Part 1 (left) and part 2 (right) of HyPSTER project

The sealing of the wellbore, i.e the interface salt/cement/casing, have been tested successfully firstly using N_2 (cf slide 17). The test to H_2 is programmed in October 2024.

From geomechanics point of view, the questions to be dealt with by HyPSTER are:

- the effect of pressure variation of H_2 injection and withdrawal of brine on the stability of the cavern
- the large number of cycling on the change of volume of the cavern due to salt creeping.

Brouard_Consulting works on this topic for HyPSTER project. (More information on https://hypster-project.eu/)

PRESENTATION 2: Hystories project, presented Arnaud REVEILLERE, from **Geostock**, France.

Hystories is a EU funded project with a consortium from 17 European countries, led by Geostock. The context is that while hydrogen storage is needed to bridge the mismatch between green energy production and demand, pure hydrogen storage in porous media has never been done. Technical developments are therefore needed, along with socio-economic studies to support the development of such a heavy infrastructure industry. No obvious showstopper for H_2 storage in depleted fields or aquifers was identified. However, the purity upon withdrawal, gas treatment costs and H_2 grid specifications may impact this deployment.

In Hystories project, there are 7 work packages (WP), cf Figure 2. A mapping of the porous storage capacity has been done based on all public data on aquifers, depleted oil and gas fields and existing natural gas underground storages. It resulted in a database of 800+ geological traps, with the available geological attributes and characterization. A H2 storage capacity estimation was done for each of these traps.

From geomechanics point of view, the questions raised in Hystories are:

1) the consequence of high reactivity of H_2 with microorganisms on gas purity upon withdrawal. This may be used by further works to assess possible impacts on rock mechanical properties

2) the maximum and minimum of H_2 injection pressure, and the pressure cycles over time in porous rocks and in salt caverns. This may be used as a load input for further geomechanical works.

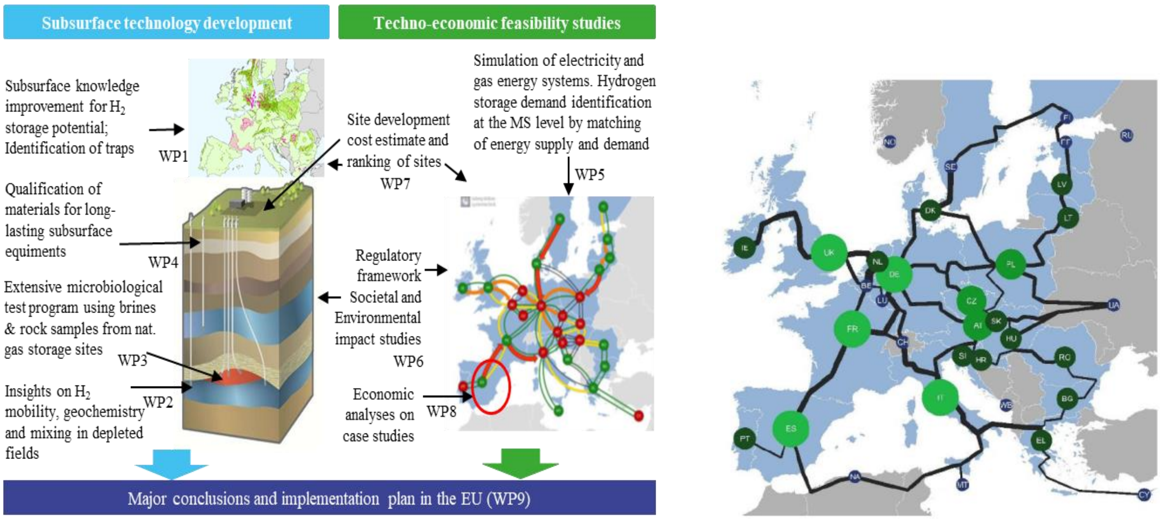


Fig-2: left- the WPs of Hystories project; right- mapping of the European Hydrogen energy sytem demand and exports

PRESENTATION 3: Hydrogen Storage in Lined Mined Rock Caverns Geomechanical aspects, by Nicolas Gatelier, from **Geostock**

The storage in a lined mined rock cavern is one of the 4 options of UHS (underground hydrogen storage), 1-salt cavern, 2- porous rock, 3- unlined mined rock cavern, 4- lined minded rock cavern. A typical concept of UHS in lined cavern is shown in figure 3. The rock cavern is excavated in a vertical silo-shaped at ~100 to 200 m in depth, 20~ 40 m in diameter, 50~100 m in height, corresponding to a volume of storage about 20 000 – 80 000 m^3. The operating pressure range is between 2 to 200 bars, the stored mass is ~200 tons to 1000 tons. A steel membrane provides the tightness of the storage whereas the rockmass plays the role of structural support.

This concept is initially developed in the 1980’s and 1990’s in Sweden for natural gas storage. Industrial scale pilot project is built in 2000’s and operated as natural gas storage since then in Skallen, Sweden (Sydkraft - GdF). Currently a pilot is tested for hydrogen cavern near Lulea, Sweden (HYBRIT Project) for fossil-free steel production.

From geomechanics point of view, the questions raised by UHS in lined rock cavern are:

1) the magnitude of strain on the steel liner, the risks of failure (so the sealing) of the liner due to the cyclic loading of in situ stress. In consequence the prediction of hydro-mechanical interaction between the rock mass (with presence of natural fractures), the concrete support, and the steel liner are key Geomechanics inputs for the design of this UHS concept.
2) the safe operating pressure regarding to the sealing of the cavity and its mechanical interaction with surrounding rock mass.

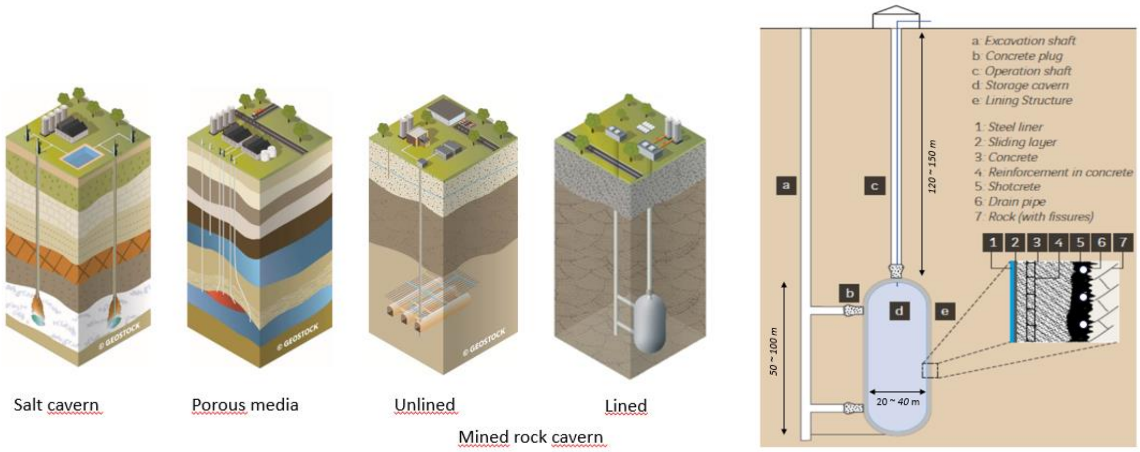


Fig-3: left: four options of UHS, right- Concept of Hydrogen Storage in Lined Mined Rock Caverns

PRESENTATION 4: Stockage de l'hydrogène en cavités salines : quelques points qui mériteraient des réponses, by Professor Ahmed ROUABHI from Ecole des Mines de Paris

This presentation made by Professor Ahmed Rouabhi talked two crucial points of UHS in greater depth, in order to define certain operating choices (injection/withdrawal frequency, volume compensation) and to further ensure storage reliability and integrity.

Those two particular points, which are currently the subject of intense research work at the Centre de Géosciences de l'École des Mines de Paris are ① the humidity of stored hydrogen and ② its permeation through rock salt. These two points form part of the general framework of transfers between the stored product and its environment, which need to be controlled in the short, medium and long term.

Two experimental set-ups, one for the kinetic of humidification, another for the measurement of H_2 permeation in salt have been presented. Moreover, an interesting conceptual model of H_2 mass transfer in metal has been presented, that includes i) the mechanism of adsorption/desorption in gas phase, the molecular dissociation/recombination at the gas/metal interface, and iii) the atomic and molecular diffusion inside the metal.

From geomechanics point of view, the questions raised by this presentation is "Do we have to consider the hydromechanical coupling phenomena in salt ?" for UHS in salt cavern.

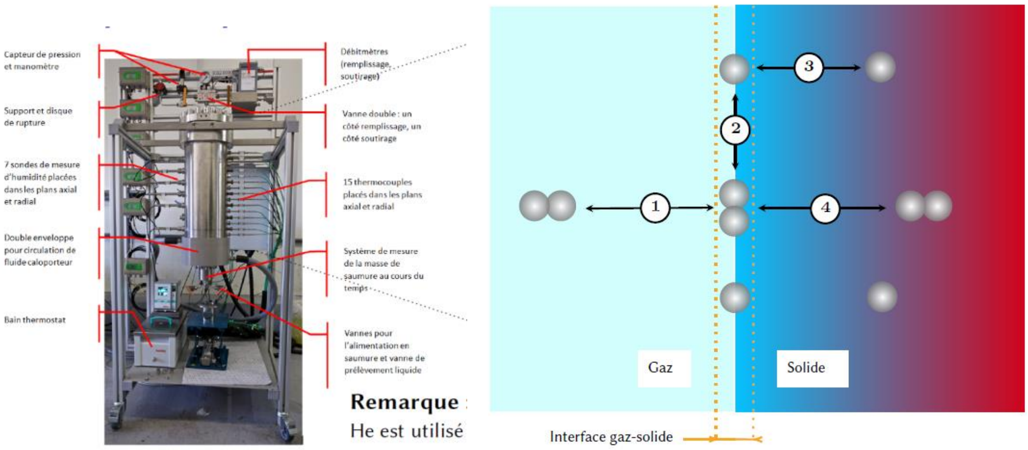


Fig-4: left: experimental set-up for measuring the kinetic of humidification of gas in contact with brine; right: conceptual model of mass transfer of H2 into metal

PRESENTATION 5: Modeling Worst-Case Scenarios for Underground Hydrogen Storage in Salt Caverns, by Hippolyte Djizanne, **Ineris**

INERIS has been conducting advanced research on hydrogen safety for 30 years and, since 2015, on underground hydrogen storage in salt caverns to secure technologies linked to the energy transition and circular economy. Through projects such as ROSTOCK-H (2016-2021), STOPIL-H2 (2019-2020), HyPSTER (2021-2024), HYSTOREN (2022-2026) and FrHyGe (2024-2028), the Institute is assessing the safety of pilots and demonstrators, their environmental impact and regulatory needs. Major challenges include ensuring the tightness of salt caverns and their access structures (wells), understanding the mechanical behaviour of salt caverns and surrounding rock salt, and managing the complex interactions between hydrogen, residual brine and microbial reactions that can affect well completion and hydrogen purity.

The worst scenarios to be considered are:

- Blowout, example in Fig 5.
- Rapid injection (≥ 0,1 MPa/h)
- Rapid withdrawal (≥ 0,5 MPa/h vs. 1 à 2 MPa/j CH4)
- fast cycling (daily)
- Uncontrolled abandonment
- Dynamic loading, earthquake

- Leaks

Fig-5: left: blowout of Moss Bluff, TX, USA2004, right: Prud'homme blowout, Canada, 2014

The energy balance equation, physical model at cavern scale, the constitutive model of salt, the coupling with temperature have been presented. The capacity of the software LOCAS to deal with these phenomena has been presented (LOCAS has been used by TotalEnergies to simulate the stability of salt cavern in 2022 by R&D). The results of numerical simulation of thermal cracking following a blowout in a gas-storage cavern have been presented. During the eruption, the temperature in the cavern can be reduced by ~40°C (Δ), and thermal cracks can appear several meters deep near the rock.

The geomechanics challenges of modelling a cavern in salt are:

1) The salt-cavern thermodynamics is complex. Behavior of two fluids including brine needs to be considered. The convection cells because of the geothermal gradient can occur. Humidity of gas plays a role in gas caverns' behavior.
2) Pressure-cycled gas caverns may experience large temperature variation, so additional thermal stress could be significant. How to consider the cycling effect in the constitutive model of the salt ?
3) Large and/or fast pressure drops may generate net tensile stresses at cavern walls. How to deal with the hydromechanical coupling (the effective stress, the effective tensile stress) in salt ?
4) The question of salt damage through dilation can appear at low cavern pressure. Micro-fracturing, weakening of salt and increase of permeability needs to be investigated in lab and by numerical modelling

PRESENTATION 6: Geomechanics for hydrogen storage, Panorama on our on-going activities, by Sabine DELAHAYE from **TotalEnergies**.

Sabine DELAHAYE has presented the concepted proposed by TotalEnergies for H_2 storage in salt cavern offshore. Which is characterized by i) offshore production of H_2 on Energy Island, ii) Transport by pipes, iii) H_2 storage to accommodate the intermittence of production.

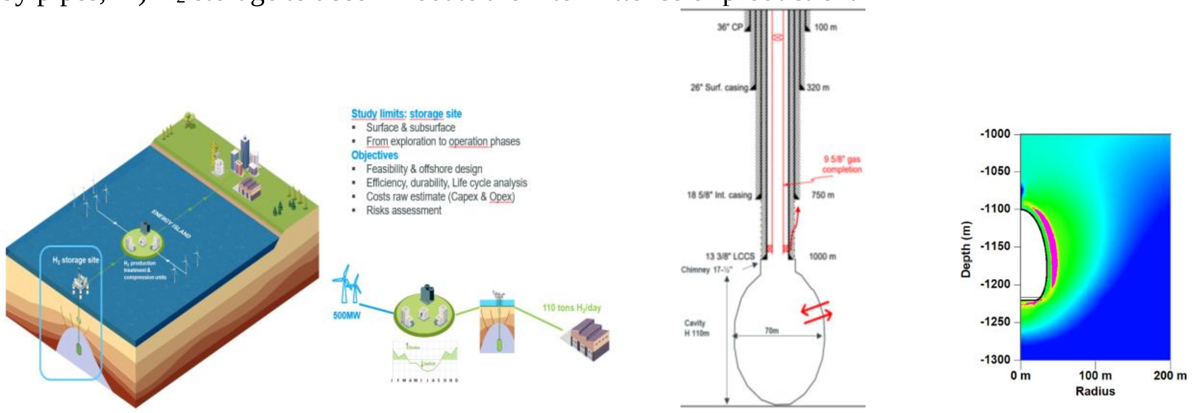


Fig-6: left: Concept of H_2 storage in salt cavern offshore, mid: concept of salt cavern; right: Tensile stress in the wall of salt cavity predicted the 3D model of cavern

North Sea is a mature oil & gas province, and the energy transition plan of the countries near-by is already in motion accommodating the decrease of hydrocarbon production with low-carbon energy production. Therefore, producing and storing hydrogen offshore is now considered as an efficient and competitive way to transport energy from remote wind farms to the continent while buffering the high intermittency of green power production (Fig- 6).
A conceptual salt cavern offshore in North Sea in the Zechstein is proposed and studied by a 3D Geomechanics model. The daily, weekly and monthly variation of storage pressure is assumed from the variation of season wind energy. The geomechanics issues, like the stability over the long run of well and cavity under high frequency cycling, well tightness, and cap-rock integrity have been simulated and presented. Two software were used: ELFEN (RockField UK) and LOCAS (Brouard Consulting, France) in such simulations. The results show that that the reduction of volume of the cavity is less than 10% over 50 years. Effective tensile stresses may occur both at the maximum and at the minimum pressure due to the fast redistribution of the stresses at the cavern wall (Fig. 6). Fracture opening is likely when the effective stress is greater than the tensile strength of the rock salt (estimated to be about 1.5 MPa).
The geomechanics challenges of modelling salt cavern are: i) How to deal with the heterogeneity of salt in a salt dome? ii) What is the effective constitutive model (behavior) of a mixed salt at large scale? iii) Are creep tests in the laboratory representative of the behavior at field scale?
The new lab tests for investigation of the sealing of the interface salt/cement/casing, and cement/casing have been presented. These tests will be carried out in TotalEnergies labs in CSTJF (Geomechanics Lab and Fluid&Ciment Lab) and in Lille University's Lab (LaMCube).

PRESENTATION 7: Aramis CCS project and related geomechanics topics, by Nicolas Agenet, from **TotalEnergies**, (OT/CL/CO2)

Nicolas Agenet, from TotalEnergies, has presented the Aramis project, which is a collaboration between TotalEnergies, Shell, Energie Beheer Nederland (EBN) and Gasunie. This project aims to make a significant contribution to the energy transition by reducing CO_2 emissions for the hard-to-abate industries, thereby aligning with the objectives of both the Dutch Climate Agreement and the European Union's Green Deal.
Some key data of ARAMIS are:

- Depleted natural gas fields at 100km from the coast of Netherlands
- CO_2 will be injected in the Lower Slochteren (LS) permian sandstone reservoir
- LS overlaid by two caprocks with excellent sealing properties, the Silverpit Fm claystones and the Zechstein Fm evaporites
- Current pressure is about 20 bars, initial reservoir temperature is 120°C.
- A delta temperature could reach -100°C, the thermal stress in the reservoir could be significant.
- Open access infrastructure with a maximum capacity of 22 Mtpa of CO_2 storage

The geomechanics challenges in ARAMIS project are: i) demonstration of shale creeping as natural barrier for certain legacy wells, ii) simulation of the THM (thermo-hydro-mechanical) coupled effects in reservoir and in the overburden, iii) Bounding fault stability analysis, iv) Thermal Induced fractures (TIF) effects on the well performance and integrity, v) Assessing the risks of induced seismicity and vi) Ground deformation.
The main hazards identified in this project are: 1) the leakage through legacy wells or faults, 2) Injection well leakage, 3) induced seismicity.
The risk management plan has been presented.

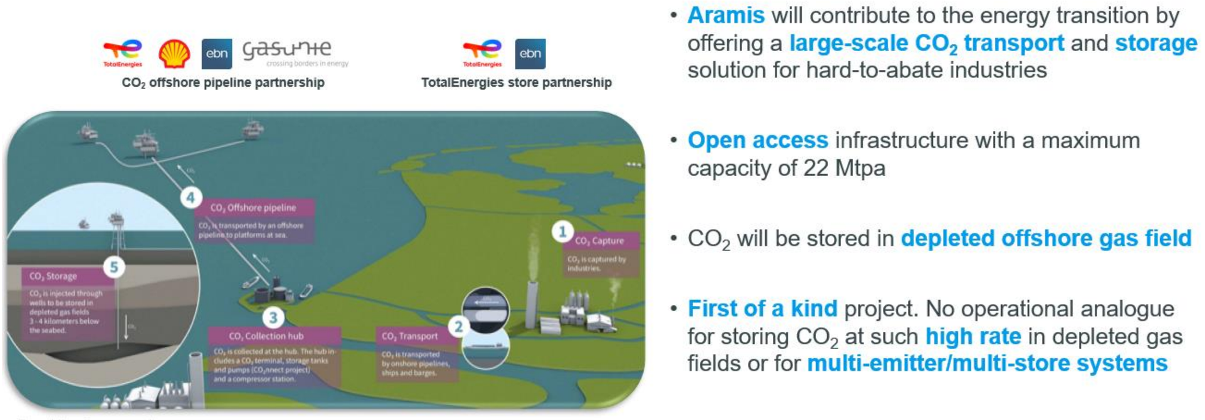


Fig-7. Overview of ARAMIS project

PRESENTATION 8: ARAMIS CO2 storage Case Study – A Geomechanical Assessment of Containment & Demonstration Case R&D challenges presented by Nicolas Mottet and Frederic Bourgeois.

The Aramis CO_2 storage project in the Netherlands, specifically on the L4-A field, has been the subject of extensive geomechanical assessment.

Nicolas Mottet presented the geomechanical conceptual model of 5 paths for migration of CO_2 outside of the storage complex including fracturing the caprock and migration along reactivated faults/fractures within the storage complex cf Figure 8. These mechanisms are controlled by the in-situ stresses, pressures, and temperatures in the reservoir and caprock, as well as injection pressures at the wells. The role of Geomechanics is to predict safe range of injection pressure to maintain the caprock integrity.

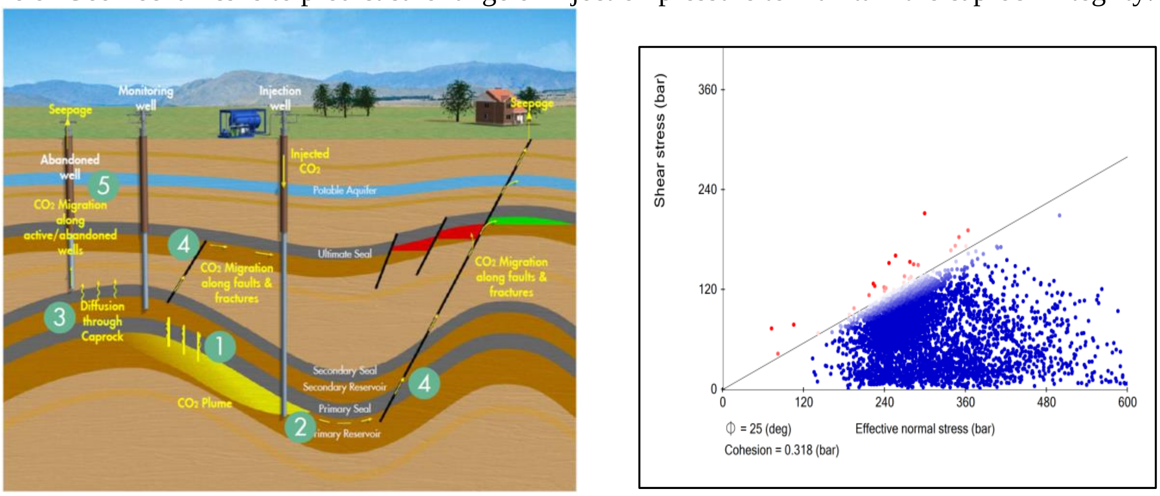


Fig-8. left: conceptual model of potential risks of leakage of CO2; right: stress on faults planes.

The workflow used by TotalEnergies geomechanics team to predict the cap rock integrity consists of 5 steps: ①in situ stress and formations strength model, ②) building the 3D Geomechanical model, ③) setting the initial and boundaries conditions, ④) computation of dynamic stress and strain changes using the reservoir pressure or/and temperature fields from mass and heat transfers code (one way coupling) or from last iteration of pressure or/and temperature fields (two way coupling), and later send the stress/strain as well as the permeability/conductivity changes to the mass and heat transfers code, ⑤) various stability analysis : slipping of fault, change of permeability, energy released for induced seismicity analysis, induced fracture, subsidence, 4D seismic interpretation, etc …

For L4-A4 field of ARAMIS, a 3D model having 13 million elements has been elaborated. The results in one way coupling show limited magnitudes of compaction at the end of depletion and at the end of CO_2 injection. Regarding to the fault stability, only few elements show localized plastic shear strain (Fig 8). The overall slip tendency is very low. The estimation of the induced seismicity based on the modeled relative fault slip from Gutenberg-Richter's Model indicates that microseismic event with magnitude above 2.5 is extremely unlikely.

Frederic Bourgeois presented the code Geos, which is an open-source innovative multiphysics tool currently under development by TotalEnergies and its partners. A new geomodel of the storage complex and the sedimentary pile, using surfaces, faults, and petrophysical has been built within the geoscience workflow. Petrophysical and geomechanical properties have been populated on the unstructured mesh. A reservoir flow model, matching the historical production period, was employed to generate historical pressure changes in the reservoir during production and expected pressure and temperature. The standout features of Geos modelling: field scale, fully coupled, and unstructured mesh capabilities have been presented. These points highlighted the innovative capabilities of Geos in creating accurate and reliable geomechanical models.

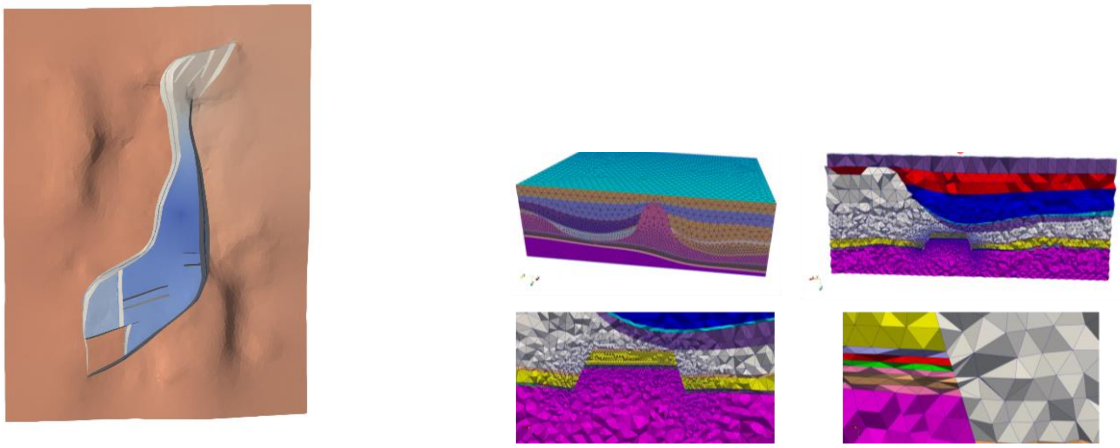


Fig-9. left: Reservoir depletion of Aramis L4-A field reproduced by Geos; right: Example of complex geology requiring tetrahedral meshing.

The geomechanics challenges in such 3D Geomechanical modelling of CCS project are: ①The criteria of FCP (the minimum in situ stress in cap rock) for Pmax injection of CO_2. When no hard of in situ stress data is available or the data present a huge range of uncertainty, how to deal with? ②Are there innovative and cost effective ways of measuring in situ stress ③ Fault reactivation: how to go from slip patch (nucleation) to possible bigger fault displacement without dynamic rupture simulations? ④ Constitutive model of hydromechanical (HM) coupling of fault at field scale. What are the difference in terms of risk assessment if the coupling is processed in different ways: in one-way, two-ways or full coupling. The results of one-way coupling are conservative or optimist?

PRESENTATION 9: ECBM Feasibility, a case study of the Northeastern Lorraine basin (Grand-Est, France), by V De Gennaro from **SLB**, and F. Nassif from **Francaise de l'Energie** (**FDE**).

La Française de l'Energie (FDE) is defining the optimum strategy to maximize methane (CH_4) production without reservoir stimulation for Bleue Lorraine coalbed methane (CBM) project. Enhanced Coal Bed Methane (ECBM) is being considered. ECBM consists in injecting carbon dioxide (CO_2) in methane bearing coal beds to enhance gas recovery while ensuring carbon capture and storage (CCS). The latter option could also be associated to local production of hydrogen (H_2) as part of the typical Blue Hydrogen cycle by means of Steam Methane Reforming process. Some preliminary results of ECBM feasibility in Bleue Lorraine permit (Lorraine, France) focusing on the strong coupled nature of the poromechanical behavior of coal during CO_2 injection.

SLB has used an implicit staggered coupling, implemented with the Visage (FEM geomechanical simulator) and Eclipse (FVM flow simulator) (Fig-10), to deal with the ECBM hydromechanical coupling in the reservoir. In their model, the initial reservoir compressibility C_{pp} is assumed equal to C_b/ϕ. The porosity is about 5%, the C_{pp} is about 7.5 10^{-4} bar^{-1}. The implicit staggered scheme updates the compressibility as a function of the volumetric strains obtained from the integration of the poromechanical equations. Fig 10 presents the CO_2 concentration and pressure plumes predicted by the numerical model.
The main modelling challenge in such 3D coupled simulations of ECBM is the uncertainty on the thermo-hydro-mechanical coupling parameters that characterize the interaction between the deformable porous medium and the flow properties. It has been shown that the evolution of the bottom hole pressure and the overall cumulative CO_2 storage capacity are strongly influenced by the change of the permeability of the coal as function of the volumetric strain of the matrix and the opening and/or closing of the cleats.

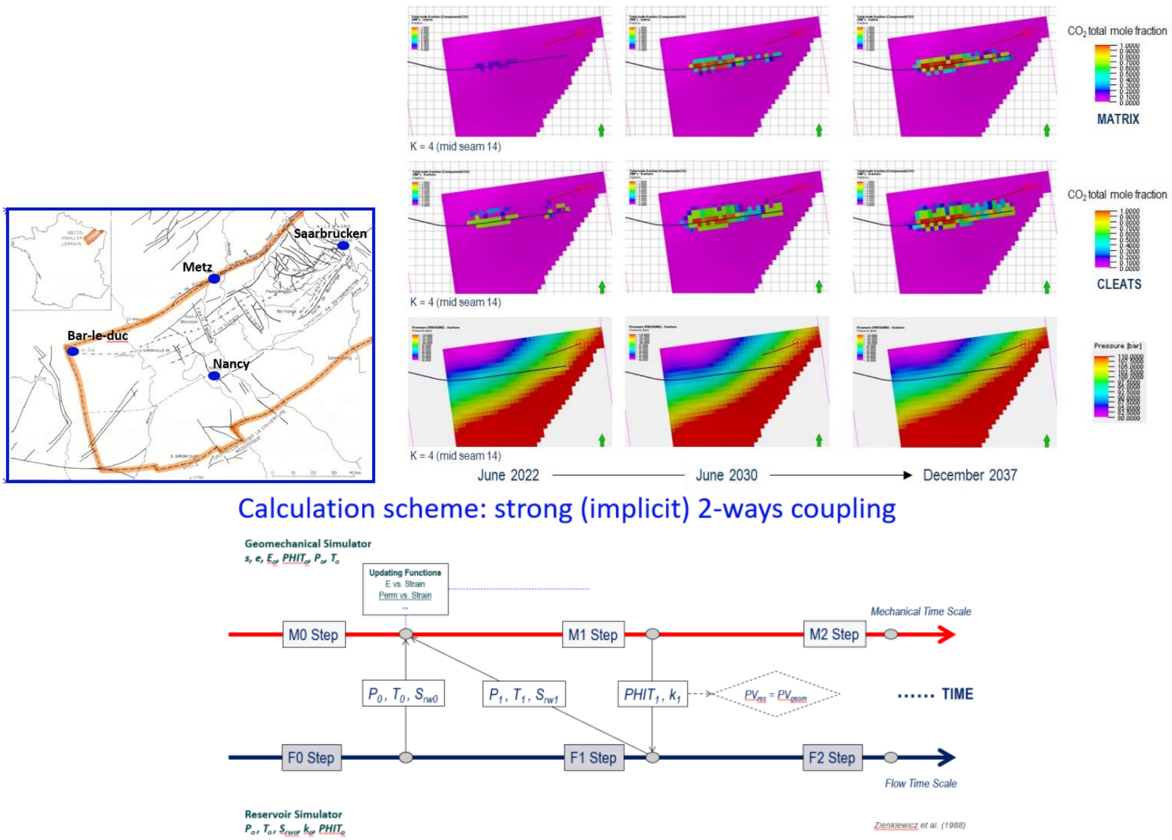


Fig-10. CO_2 concentration and pressure plumes (upper), the two-coupling scheme

PRESENTATION 10: Workflow for populating a geomechanical model with petrophysical and mechanical properties at the scale of a CO2 storage, by E. Bemer from IFPEN

IFPEN presented an integrated basin modelling approach to build a full 3D geomechanical model at the basin scale and test different large-scale CO_2 injection scenarios. The approach was tested for Paris Basin (568km x 430km) (cf Fig 11). Basin modeling can provide full 3D stress and pressure fields to initialize coupled reservoir and geomechanical simulations. Such very large scale 3D geomechanical model can also be used to constrain the boundaries conditions of a 3D model at field scale (x10 km scale).

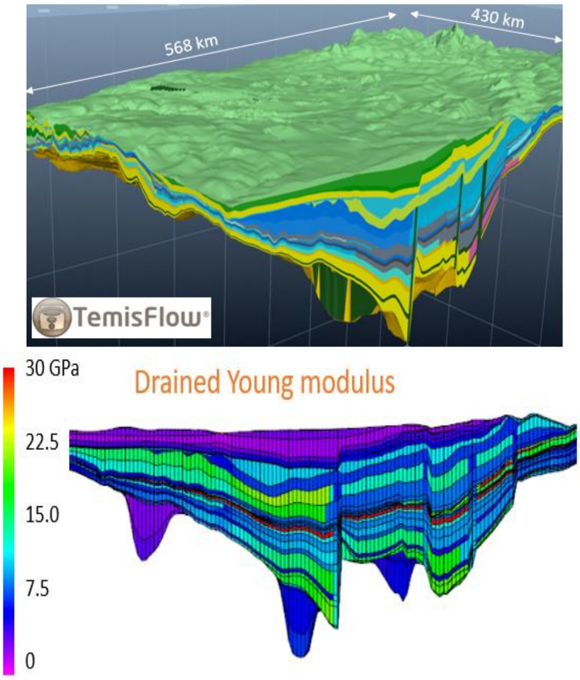


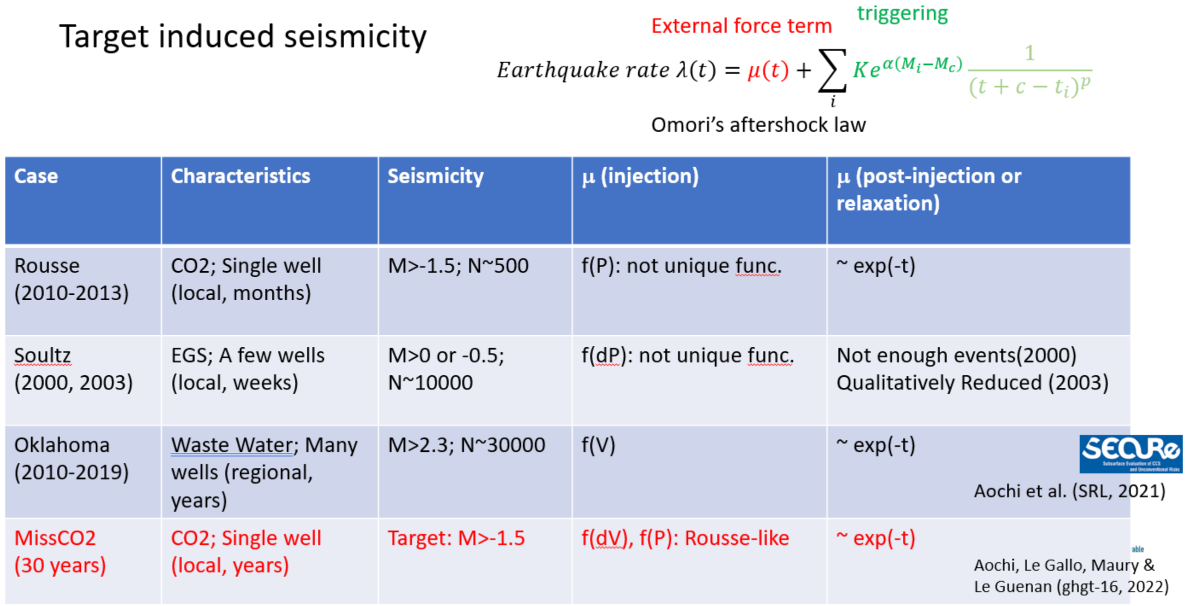
Fig-11. 3D Paris Basin model (left) and Drained mechanical properties (right)

Once the model has been built, it must be populated with poroelastic parameters, drained Young modulus, Poisson ratio and Biot coefficient. An approach combining specific petroacoustic tests and phenomenological laws has been proposed and tested on two limestones, Oolite Blanche and Comblanchian, taken at depths of 650 m and 1790 m respectively in Paris basin. Interesting results have been obtained (cf Fig 11). Phenomenological laws have also been used to constrain the failure strength: effective cohesion and friction angle are expressed as a function of porosity for each formation.

The geomechanics challenges in this type of 3D basin-scale geomechanical modelling are related to the integration of the heterogeneous properties of the different formations and the modeling of the fault behavior.

PRESENTATION 11: Approach of risk analysis applied to a CO2 storage site. Démarche d'analyse de risque appliquée à un site de stockage de CO_2, by T. Le Guenan & H. Aochi, from BRGM.

BRGM has been working on the safety of geological storage sites for over 15 years. Among other things, it has developed methods and tools for conducting risk analyses, in line with the ISO 31000 standard. This standard specifies 3 phases in risk assessment: identification, analysis and evaluation.
An empirical (time function) correlation of induced seismicity rate (Earthquake rate) $\lambda(t)$ is used to retro-simulate and later to predict the magnitude of induced seismicity events (Fig -12).



Target induced seismicity

External force term — triggering

$$Earthquake\ rate\ \lambda(t) = \mu(t) + \sum_i K e^{\alpha(M_i - M_c)} \frac{1}{(t + c - t_i)^p}$$

Omori's aftershock law

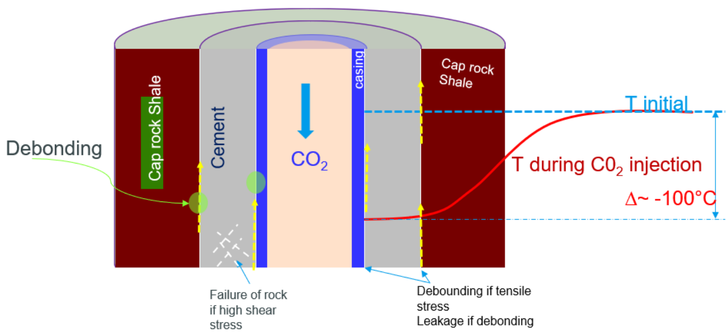
Case	Characteristics	Seismicity	μ (injection)	μ (post-injection or relaxation)
Rousse (2010-2013)	CO2; Single well (local, months)	M>-1.5; N~500	f(P): not unique func.	~ exp(-t)
Soultz (2000, 2003)	EGS; A few wells (local, weeks)	M>0 or -0.5; N~10000	f(dP): not unique func.	Not enough events(2000) Qualitatively Reduced (2003)
Oklahoma (2010-2019)	Waste Water; Many wells (regional, years)	M>2.3; N~30000	f(V)	~ exp(-t) Aochi et al. (SRL, 2021)
MissCO2 (30 years)	CO2; Single well (local, years)	Target: M>-1.5	f(dV), f(P): Rousse-like	~ exp(-t) Aochi, Le Gallo, Maury & Le Guenan (ghgt-16, 2022)

Fig-12: Empirical correlation (time function) of induced seismic rate

BRGM has drawn up generic diagrams following the bowtie diagrams method, identifying the main central feared events, each preceded by causes, and each leading to different consequences, including impacting phenomena. Geomechanical phenomena are thus found in most diagrams.
Once the feared scenarios have been identified, the risks are analyzed and assessed. It's all about making the best decisions. Best practice tends towards quantitative rather than qualitative analysis. The difficulty lies in dealing with the uncertainties associated with geomechanical phenomena. Data quality and quantity guide the level of uncertainty, and expert advice is often essential to increase this data. Uncertainty is propagated by seeking the right compromise between representation of reality and calculation speed. Various tools can be used: analytical models or surrogate models.

PRESENTATION 12: Experimental and numerical modelling of CO_2 injector to THM cyclic loading, Maria PEREZ-FERNANDEZ , Mohamed Oukil BENMESBAH, Kun Su

Kun Su presented the topics of well integrity (sealing) for CO_2 project, both for legacy wells and for new wells. Indeed, the integrity of well barriers and durability over time are critical to successful carbon storage operations since CCS wells need to be designed to assure their integrity beyond their service lives, sometimes up to hundreds of years or more. The range of temperature variation in the well is much bigger than the temperature variation in conventional O&G. For example, in case of injection into a depleted reservoir, the near wellbore components and the surrounding rock mass could see, at shallow interval, a temperature down to -20°C, while the initial temperature is about 40°C. At reservoir level, the temperature could be decreased from 120°C to ~20°C, so a ΔT ~100°C. Lots of geomechanical questions were raised about the consequences of such thermal loading (Fig 13).



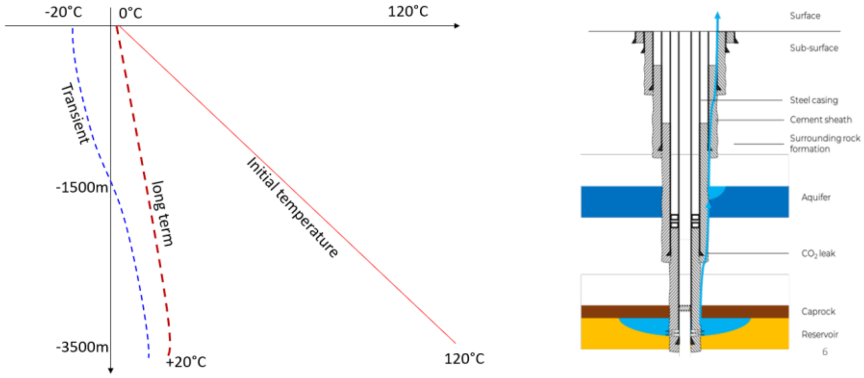


Fig-13: Conceptual model of thermal loading on near-wellbore components of a CO_2 injector (upper), scheme of possible leaking through rock/cement/casing interfaces

The WINTEC project has been presented. It was designed to investigate the well integrity understanding under stresses and temperature variations in a typical CO2 injection well. The experimental setup was built to reproduce a mini well that can be put at downhole conditions (pressure: 0 bars – 700 bars and temperature: -30°C to +130°C). The change of axial permeability of casing-cement sheath-rock, the development of cracks, the deformations and the debonding of interface rock/cement and cement/casing are monitored using various strain gauges, temperature, pressure and acoustic sensors.

At the same time TotalEnergies launched the development of numerical simulation and interpretation of the experimental results and well integrity prediction for CCS projects. The objective is to predict the risks of debonding and fracturing of cement sheath.

The geomechanics challenges are:

- Complex constitutive models of cement sheath, rock and interfaces representing their behavior under huge ΔT, cycling of T and P in the injector. The numerical simulation of near-wellbore components involves the thermo-hydro-mechanical coupling, needs many input parameters which are difficult to characterize in lab: thermal expansion coefficient, Biot coefficient, strength, water saturation of cement after setting, etc …
- Questions on legacy wells, can we believe the shale creeping in certain cases for the sealing of legacy wells ?
- New formulation cement for CO_2 storage and the question of initial stress in the cement sheath.

Annex -1 : Agenda

CFMR COMITÉ FRANÇAIS DE MÉCANIQUE DES ROCHES — SPE International France Section — EAGE Paris Chapter

Geomechanical challenges in industrial CO_2 and H_2 storage in geological formation

Technical Session, 9H00-17h00, 4th April 2024, Room V106, at Ecole des Mines de Paris, 60 bd Saint Michel, Paris

9h00: Mots du President CFMR

9h05 **(25 min / présentation)**

1. HyPSTER, 1er pilote de stockage d'hydrogène en cavité saline en France — Gregoire Hevin, **Storengy**
2. Hystories project: Hydrogen Storage in European Subsurface — Arnaud Réveillère, **Geostock**
3. Hydrogen Storage in lined mined rock cavern : geomechanical aspects — Nicolas Gatelier, **Geostock**

Pause : 10h20-10h40

4. Stockage de l'hydrogène en cavités salines : quelques points qui mériteraient des réponses — Ahmed Rouabhi, **Ecole des Mines de Paris**
5. Numerical modeling for risk control around UHS — Hippolyte Djizanne, **INERIS**
6. H2 offshore storage project — Sabine Delahaye, **TotalEnergies**

Buffet du midi 12:15- 13:30

(25 min / présentation)

13:30

7. Aramis CCS project and related geomechanics topics — Nicolas Agenet, **TotalEnergies**
8. Aramis CCS project: Cap rock integrity and faults stability: — Nicolas Mottet, Frederic Bourgeois, **TotalEnergies**
9. ECBM Feasibility, a case study of the Northeastern Lorrain basin (Grand-Est, France) — Vincenzo De Gennaro, **SLB**

Pause : 14h50-15h10

10. Workflow de remplissage en propriétés pétrophysiques et mécaniques d'un modèle géomécanique à l'échelle d'un site de stockage de CO_2 — Elisabeth Bemer, Jeremy Frey, **IFPEN**
11. Démarche d'analyse de risque appliquée à un site de stockage de CO_2 — Thomas Le Guenan, Hideo Aochi, **BRGM**
12. Experimental and numerical modelling of CO_2 injector to THM cyclic loading — Maria PEREZ-FERNANDEZ, & Mohamed Oukil BENMESBAH, Kun Su, **TotalEnergies**

16:30-17h00

13. Discussions