NOBIAN

Salt Cavern Workshop 2024

Abandonment research and societal outreach at Nobian

What do we do?

- Salt mining (for more than 100 years already)
- Facilitate storage caverns
- Around 1600 employees
- Focus on salt mining (halite) and large volume base chemicals (i.e., NaOH, Chloride products).
- 3 salt solution mining sites: Mariager (DK), Delfzijl (NL, fields: Heiligerlee and Zuidwending) and Hengelo (NL)

The backbone of our business

Read more ›

An important chemical in day-to-day life

Read more ›

An essential ingredient behind many daily activities

Read more ›

Organic compounds used to make quality products

Read more ›

Safe, reliable, and affordable green hydrogen to help decarbonize industry

Read more ›

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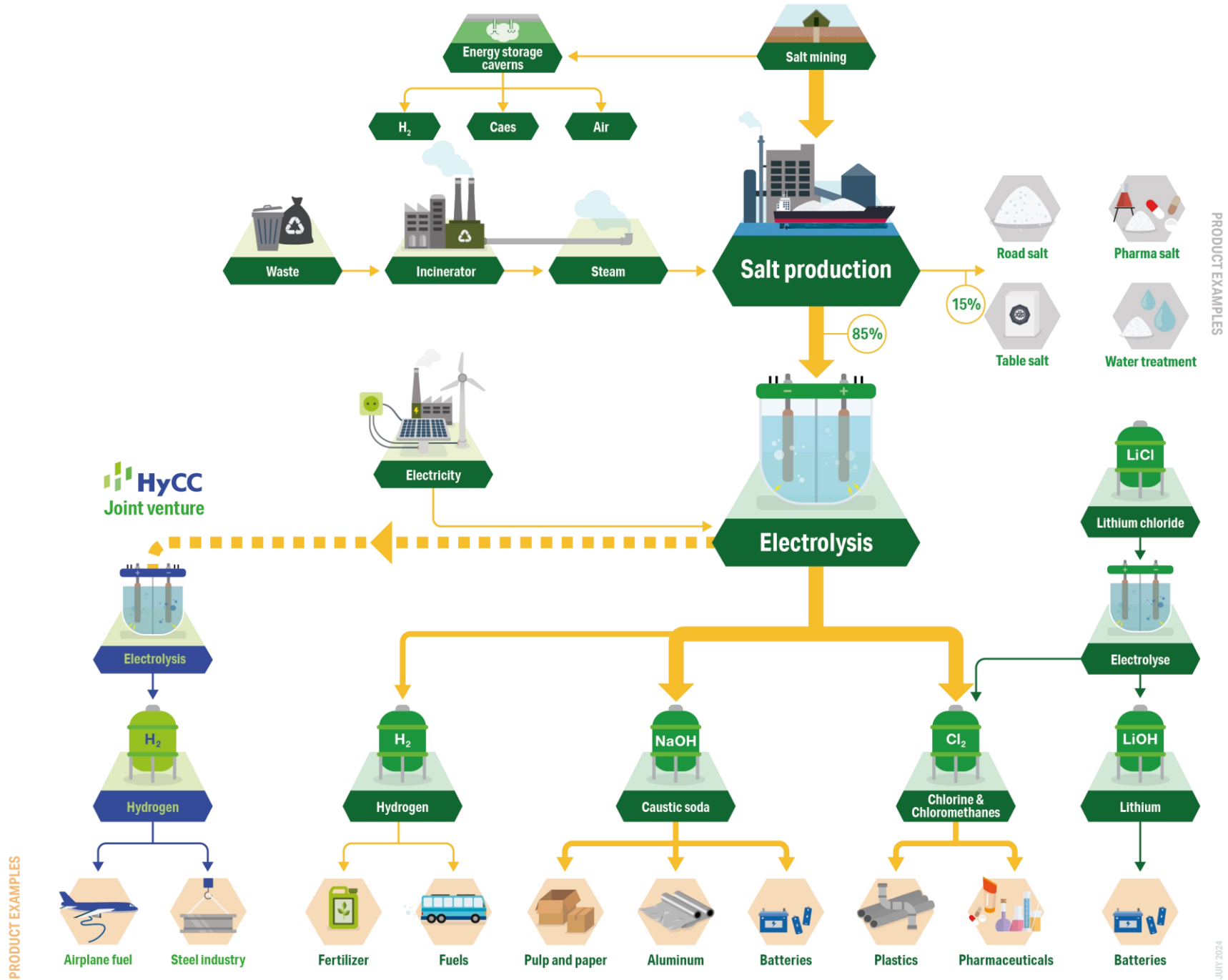

Our value chain

delivers strategic independence of Europe for key materials. Salt caverns to become cornerstone of hydrogen infrastructure.

40%
of all products in the chemical industry are derived from salt.

85%
of Nobain's salt is used in the chemical industry.

100%
of the salt used in the chlorine clusters in Delfzijl and Rotterdam (Netherlands), Frankfurt and Leverkusen (Germany), Rafnes (Norway) and Tessenderlo (Belgium) comes from Nobian.

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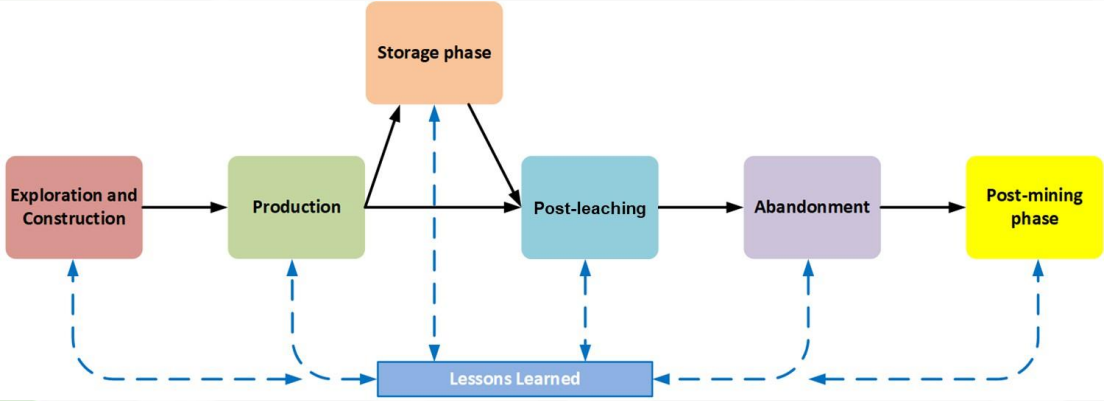
Cavern Stability and Integrity Management System

- Developed after model of WIMS (ISO-16530)
- Translation of company values to actions to continue safe operation of caverns
  - How do we operate caverns?
  - What do we do to monitor and why?
  - What happens after mining is finished?
- CSIMS is evaluated and updated on a yearly
  - Incorporate new findings and insights from science



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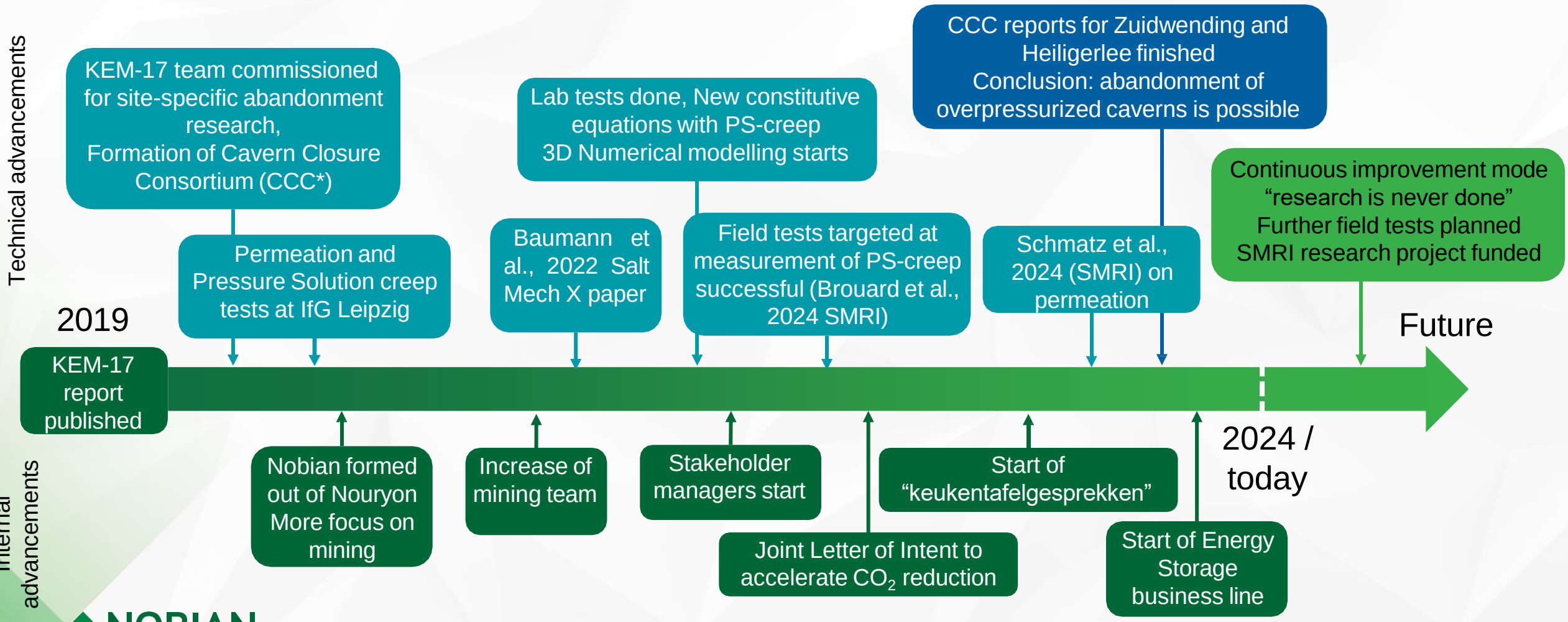
Developments at Nobian after 2019, key events



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*The CCC team consists of: Baumann, T.S., Bérest, P.†, Brouard, B., Kaus, B., Klaver, J., Kottwitz, O., Popov, A., Schmatz, J., Urai, J.L.†, Wellmann, E., and Zakharov, V.,

Lessons learned since KEM-17

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5 years since KEM-17, what has happened with the recommendations?

BROUARD CONSULTING

MaP Microstructure and Pores

smart Tectonics

CONCLUSIONS AND RECOMMENDATIONS OF THE OVER-PRESSURED CAVERNS AND LEAKAGE MECHANISMS PROJECT (KEM-17)

In summary then, using the present state of engineering practice, it is not possible to say with sufficient reliability if a deep abandoned cavern will evolve by localized brine flow, hydraulic fracturing and major loss of containment, or with a pressure build-up that is is moderate with leak-off by diffuse permeation and no hydraulicfracturing.

- CCC (2024) suggest gradual pressure build-up with moderate leak-off by diffuse permeation and no hydraulic fracturing
- Pressure above lithostatic are reached, but dilatation is only expected in near-cavern area
- Details given in talks later in program.

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5 years since KEM-17, what has happened with the recommendations?

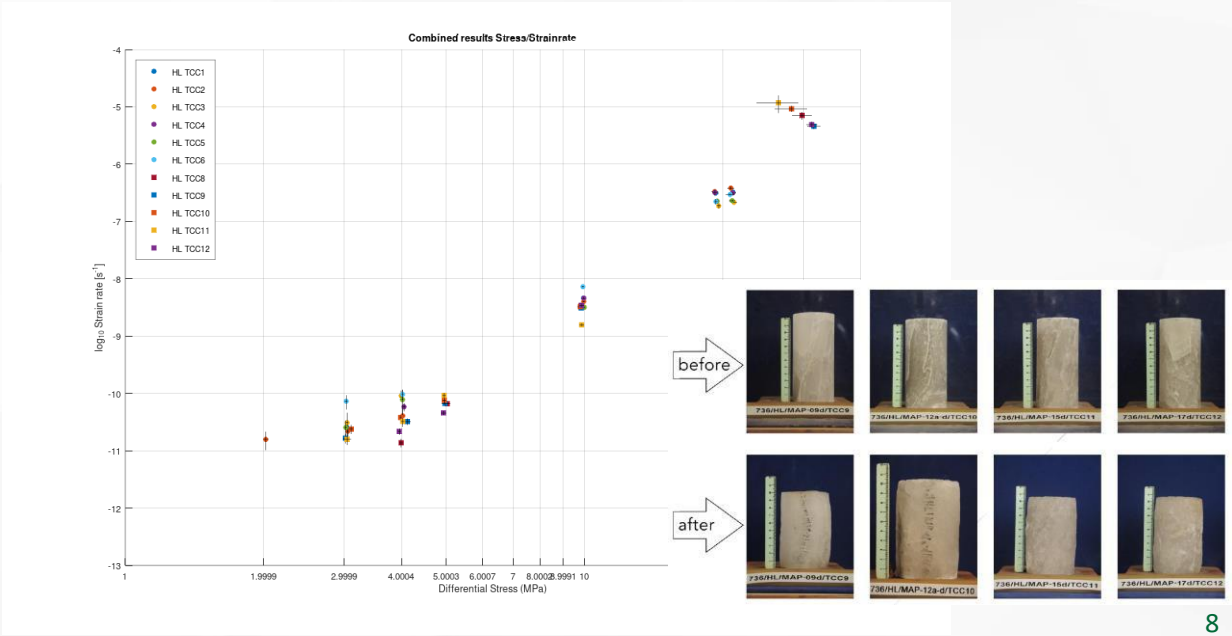
- Micro scale - Rheology and Deformation mechanisms

We recommend more materials science-based investigations of the changes in the properties of the rock salt at the cavern wall, during operation and during abandonment.

Materials science studies of rheology, AND microstructure of salt cores from cavern intervals to provide much improved constitutive equations for calculating deformation during solution mining and during abandonment, withe site-specific predictions of rheology to much improve predictions for cavern abandonment.

Development of a knowledge base of microstructure and mechanical properties for a series of rock salt samples, to allow better extrapolation and the development of microstructure-based rock salt rheology predictions.

- Lab tests at IfG Leipzig targeting PS-creep
- Lab tests in Altaussee mine targeting PS-creep
- Microstructure details in talk of Dr. Schmatz (CCC/MaP)
- Results integrated in upscaled flowlaws using Bayesian approach



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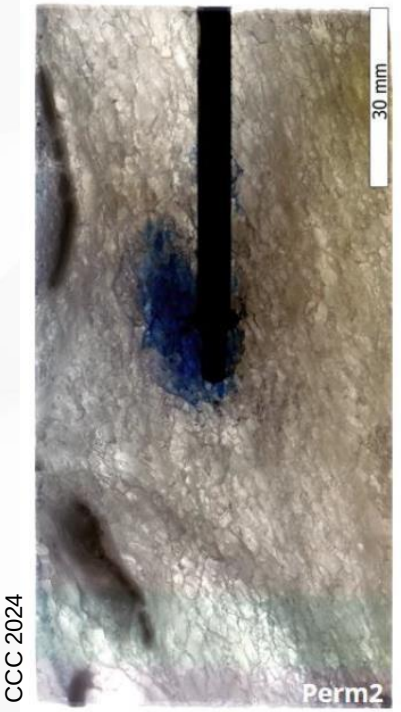
5 years since KEM-17, what has happened with the recommendations?

- Micro scale - permeation

We recommend materials science-based research to provide a microphysical understanding of the permeation and healing processes:

- Understand microphysical processes of permeation to allow upscaling to constitutive models which can be extrapolated to long time scales and incorporate heterogeneous material
- Develop a standardized microstructure characterisation protocol
- Integrate macro and micro analysis by developing constitutive equations which are implemented in 3D simulation codes to model the full evolution of abandoned cavern.

- Lab tests at IfG Leipzig
- Results published and presented at SMRI spring 2024 (Schmatz et al., 2024)
- Microscopic scale: fluid pathways identified
- Upscaling remains main challenge
- Numerical model results show limited importance of exact values (creep main driving force)



SOLUTION MINING RESEARCH INSTITUTE

679 Plank Road
Clifton Park, NY 12065, USA

Telephone: +1 518-579-6587
www.solutionmining.org

Technical Conference Paper

Microstructural Investigation of Heterogeneous Rock Salt Permeation: Unraveling the influence of Anhydrite and Mega-Grain content on Fluid Transport

Joyce Schmatz, Eva Wellmann, Mingze Jiang, Jop Klaver
Microstructure and Pores GmbH, Junkerstraße 93, 52064, Aachen, Germany
Richard R. Bakker, Marinus den Hartogh
Nobian Industrial Chemicals B.V., Van Asch van Wijckstraat 53, 3811 LP Amersfoort, The Netherlands
Johannes Herrmann, Christopher Rölke and Dirk Naumann
IfG - Institut für Gebirgsmechanik GmbH, Friederikenstraße 60, 04279 Leipzig, Germany

SMRI Spring 2024 Technical Conference
22-23 April 2024
Krakow, Poland

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5 years since KEM-17, what has happened with the recommendations?

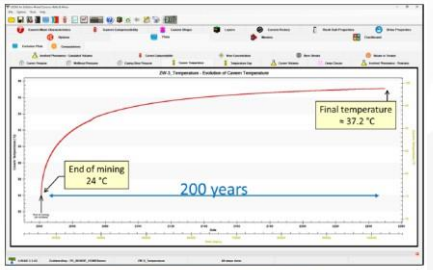
- Cavern Scale

[2] The thermal status of the cavern must be perfectly known. How large is the gap between brine temperature and rock temperature? How fast is the temperature change rate? How long is the waiting time needed to lower this gap to sufficiently small values?

[3] Information must be gathered on hydraulic (permeability) and mechanical (ability to creep) properties of the salt formation. Together with thermal properties, they allow building of a thermo-hydro-mechanical model able to predict the long-term behaviour of the shut-in cavern and cavern pressure evolution during the monitoring period (see below). This model should take uncertainties in rheological parameters into account. It is advisable to create dome-scale models that take the stress-state of the overburden into account, to monitor the expected stress evolution of the overburden along with the deformation of the cavity. A shut-in test should be performed before abandonment

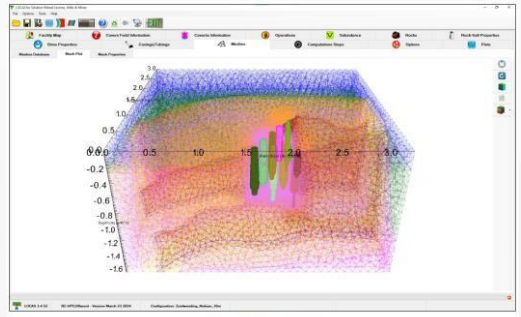
[6] A safety file including geological information, cavern history, *in situ* test results, results of numerical computation, and assessment of abandonment consequences for health and environmental protection should be prepared. It is likely that, in some cases, abandonment should be delayed (for instance, to allow the temperature gap to reach a small value). Monitoring will be mandatory for several years or decades before a final decision can be taken. In some cases, it will be difficult to avoid transferring monitoring and the abandonment decision to the state.

- 3D Thermal state calibrated
- Thermal evolution of all caverns modelled



CCC 2024

- Thermal-hydro-mechanical models for entire field.
  - 3D Large scale FEM models, spanning 1960 – 2250
  - Interplay between creep and permeation included
  - More details in talk of Dr. Brouard (CCC/ Brouard Consulting)
- Generic abandonment strategy built upon principles of thermal equilibration period
  - Monitoring of pressure and microseismics included



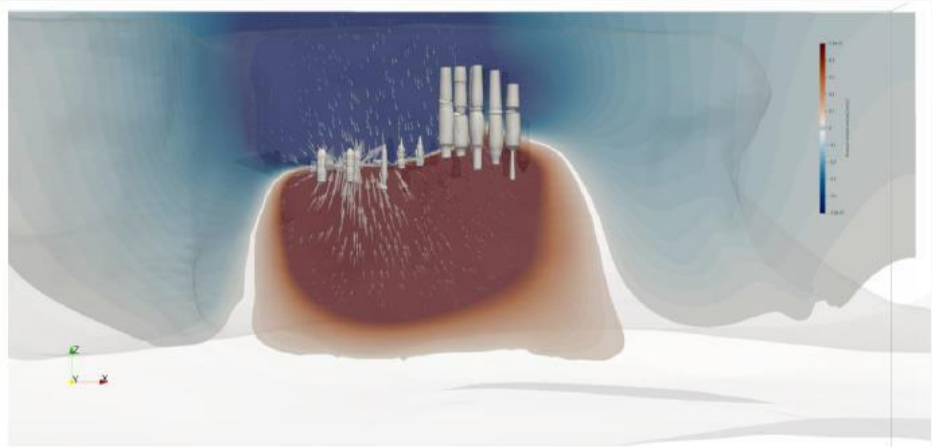
5 years since KEM-17, what has happened with the recommendations?

- Dome Scale

[3] It is generally advisable to consider a range of creep rheologies in models of cavity closure, including non-linear ones, as the uncertainties in rheology remain large. At this stage, it remains unclear whether closure is mostly sensitive to the rheology of the salt immediately surrounding the cavity or also to the rheology further away. This is a critical point that deserves further studies, as the creation of the cavity may re-activate grain boundaries and therefore induce pressure solution creep which micro-structural observations suggest to be otherwise currently largely inactive in many of the salt structures in the Netherlands. It is advisable to take dome-scale models into account in this, as a switch in deformation mechanism in parts of the salt structure may induce larger scale flow within the salt (and potentially activate, for example, the sinking of anhydrite stringers).

[4] In order to improve the predictive power of subsidence, subsurface deformation, and stress-state, we suggest that studies of cavity abandonment should employ integrated 4D models of the geological salt structure and its overburden, while taking the cavity construction, operation, and its abandonment phase into account. These models should not only concentrate on deformation within the salt, but also on the stress-state at the salt-host rock interface to allow estimating how this changes as a result of abandonment and evaluate the potential of hydrofracture formation there in case highly pressurized brine escapes the salt.

- Various creep parameters considered
  - Simplified to expected (medium) and conservative (fast) creep due to computational restrictions
- Dome-scale models show similar pressure/temperature evolution to cavern-scale models
- New insight into long term subsidence prognosis
  - More details see talk of Dr. Baumann (CCC / SmartTectonics).



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Stakeholder management

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Stakeholder management at Nobian

- "We don't operate within our own fence only. We also operate out in the field and sometimes close to where people live"
  - Increased need for stakeholder management with high approachability
- Each field has an "omgevingsmanager", stakeholder manager at each site
  - "keukentafelgesprekken" – open communication with neighbors
  - Weekly walk-in meetings (site office)
  - Information meetings
- Internal strategy: "perfect execution" strategy
  - What we do, we do in a safe, clean and orderly manner
- External strategy: more effort on informing
  - Stakeholders invited to share thoughts for existing projects but also new:
- New projects ➔ participation (more on next slide)

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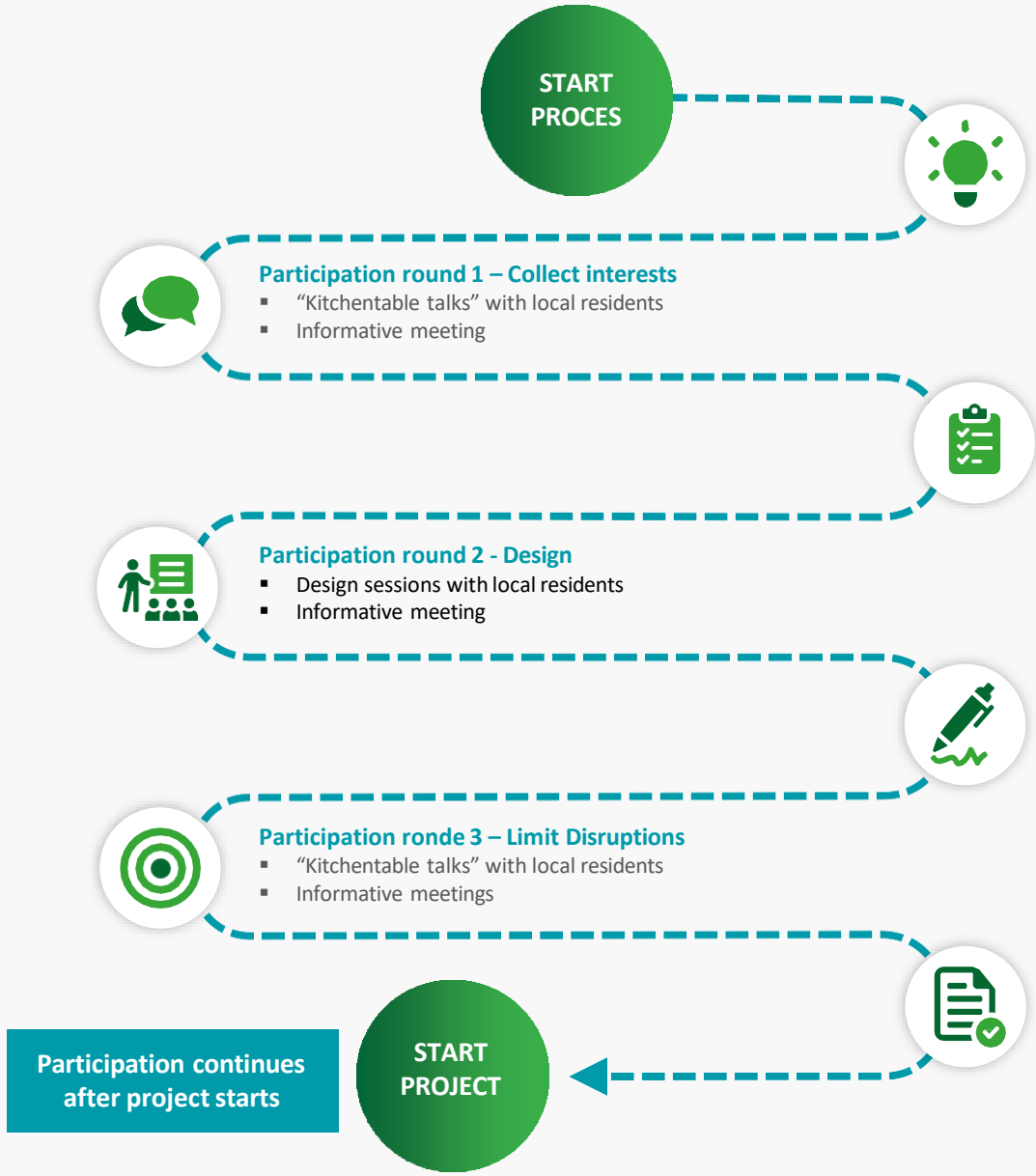
Stakeholde-management with new projects

Participation



Legal procedures

Intention of project
- Project proposal shared with central government (Ministry of Climate and Green Growth)

"Notitie Reikwijdte en Detailniveau" (NRD)
- Participation plan
- Concept NRD (cNRD)
- Possibility to respond (via opinion collection or formal appeal)
- Reactions processed in final NRD and participation plan

"Milieueffectrapportage (MER)", Extraction plan en Permits"
- Concept environmental impact report, extraction plan and permits for physical aspects
- Possibility to respond (via opinion collection or formal appeal)
- Reactions processed in final NRD and participation plan
- Definitive versions

Permits for implementation
- Surface installations etc.
- Possibility to respond (formal appeal)
- Responses weighed in permit decision

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Actions during projects

Work takes place during the preparation, execution and aftercare of drilling- and workover activities.

The work will have consequences for the surrounding environment and its users. The basic principle is to prevent possible nuisance caused by these works as much as possible.

All local residents will receive a letter prior to the work. We also announce the activities via the NobianApp (or BouwApp) and via our website.

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Vibrations

1. Monitoring at nearby buildings
2. Architectural Baseline measurements within 300 m of activities (*for drilling activities*)

Sound

1. Monitoring
2. Physical screens where possible
3. Limiting operating hours (7 am – 7 pm)
   exception for drilling activities

Light pollution

1. Shielding of lights
2. Lights only in operating hour
3. Possibly adapt color temperature of lights

Traffic (construction)

1. Traffic plan
2. Adapt access roads
3. Build safe (bike) passages
4. Create temporary parking spots
5. Keep roads clean
6. Heavy transport outside of congestion hours

Social safety

1. Close off terrain in case of absence
2. Security at entrance
3. Camera survailance
4. Respond to complaints within 2 days

Environmental

1. Soil and water protection
2. Fluid tight floors and use of road plates
3. Baseline assessment
4. Collect rainwater and test

Thank you for your attention

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NobianApp

Concepteurs bv

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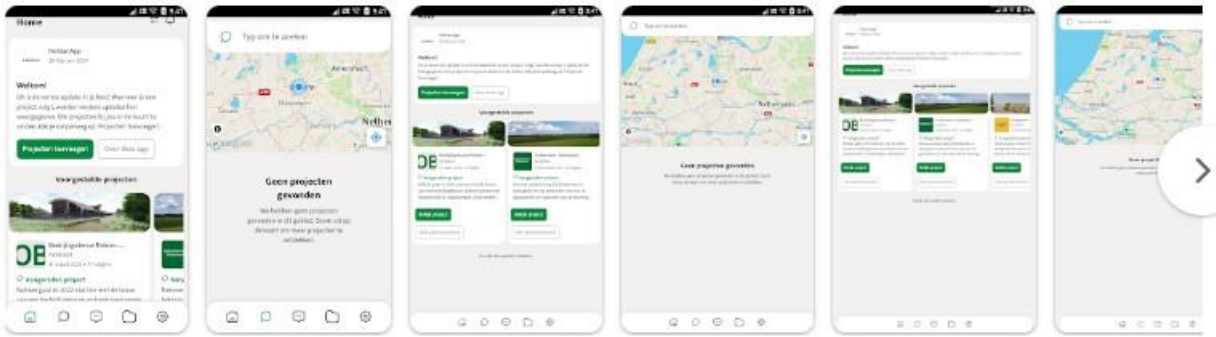

About this app →

Install the NobianApp for news and updates about Nobian's salt extraction projects, area processes and/or activities. Nobian has been extracting high-purity salt from the deep Dutch subsurface for over 100 years. Salt is an important and irreplaceable raw material. The substances made from salt are found in many of the materials we use every day. Due to the extraction of high-purity salt, various industries in the Netherlands and Western Europe always have access to this raw material. Salt extraction also plays an important role in the energy transition through energy storage in selected salt caverns.