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The French National Institute for Industrial Environment and Risks

# Potential impacts of new underground land use practices on groundwater quality in the context of the energy transition

Philippe Gombert*, Elodie Lacroix*, Stéphane Lafortune*, Angélique Poulain**

** Ineris, France*
*** University of Mons, Belgium*

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controlling risks for sustainable development

# OUTLINE

❶ The underground storages in the context of the energy transition

❷ The new energy products to be stored underground in the near future

❸ The potential geochemical risks of these emerging technologies

❹ Conclusion

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# The underground storages in the context of the energy transition

# The 2015' French law relative to the energy transition and its implications

Main objectives of the French law relative to the energy transition (by 2050):

- **Divide by 2** the global energy consumption
- **Divide by 4** the greenhouse gas emissions

} **Increase x 4** the Renewable Energy production

Main problems:

- **Hydropower** is the main renewable energy source (in F) but there are **no new potential sites**
- **Eolian** and **solar** energy are **intermittent** ⇨ **Storage solutions** are needed

Main advantages of underground storage:

- **Good feedback** (>600 hydrocarbon storage sites in the world since 1915)
- **More safe** than surface storage
- **Less footprint**

Main disadvantages of underground storage:

- Difficulty of underground **access** ⇨ **higher costs** (CAPEX)
- Risks of **underground perturbations** ⇨ geomechanical, thermal and <u>hydrogeochemical</u>.

# Different Underground Storage Types and Stored Products (in France)

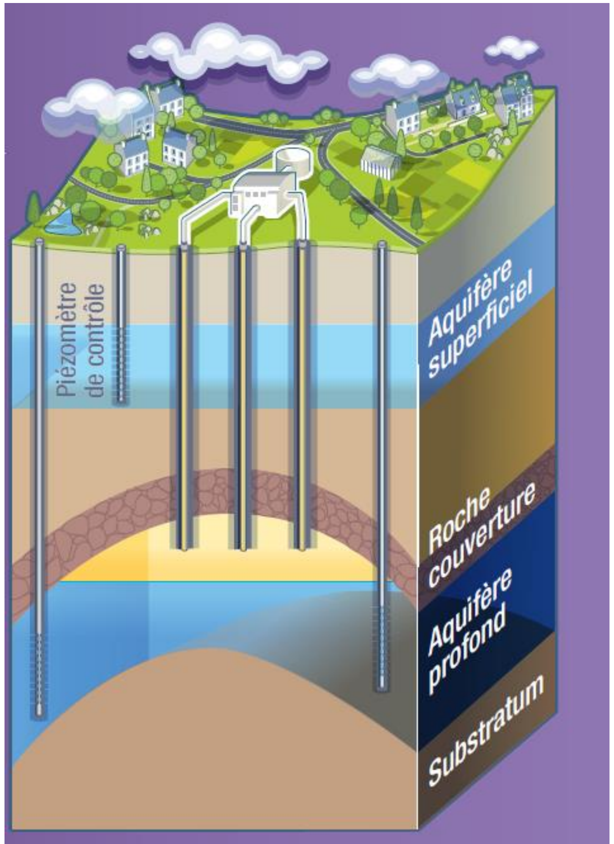
Three underground storage types:

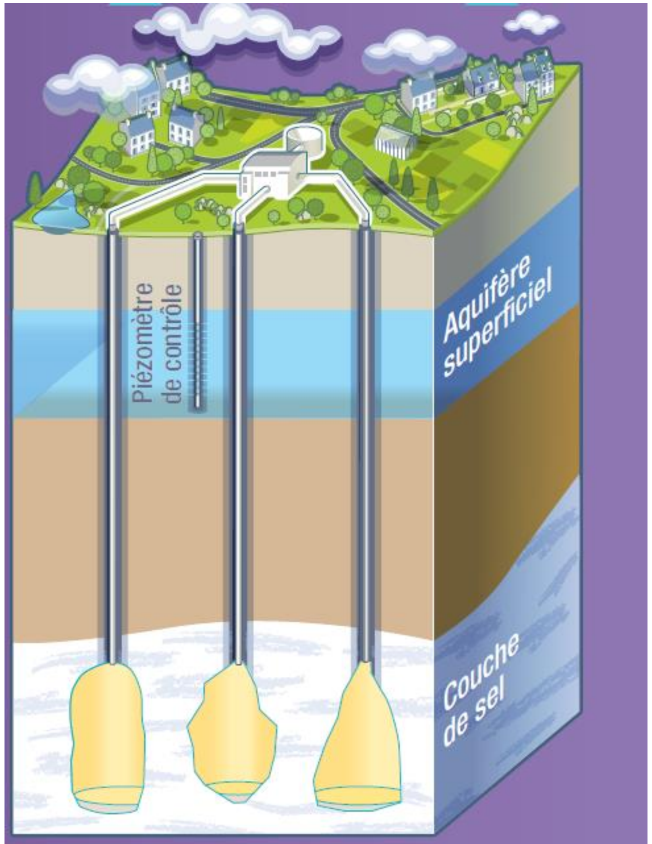
- in (deep) **aquifers** (13)
- in **saline dissolution cavities** (78)
- In **mined cavities** (9)

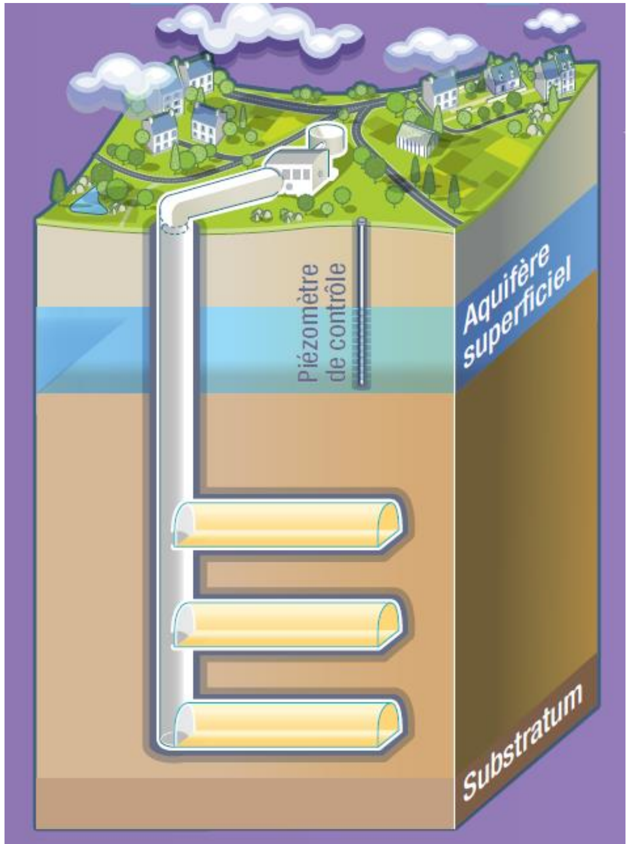
Four stored energetic products:

- Natural gas (11 $Gm^3$)
- Natural gas (2 $Gm^3$), hydrocarbons (14 $Mm^3$)
- Mainly LPG (0.5 $Mm^3$)

} Fossil fuels.



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**The new energy products to be stored underground in the near future:**

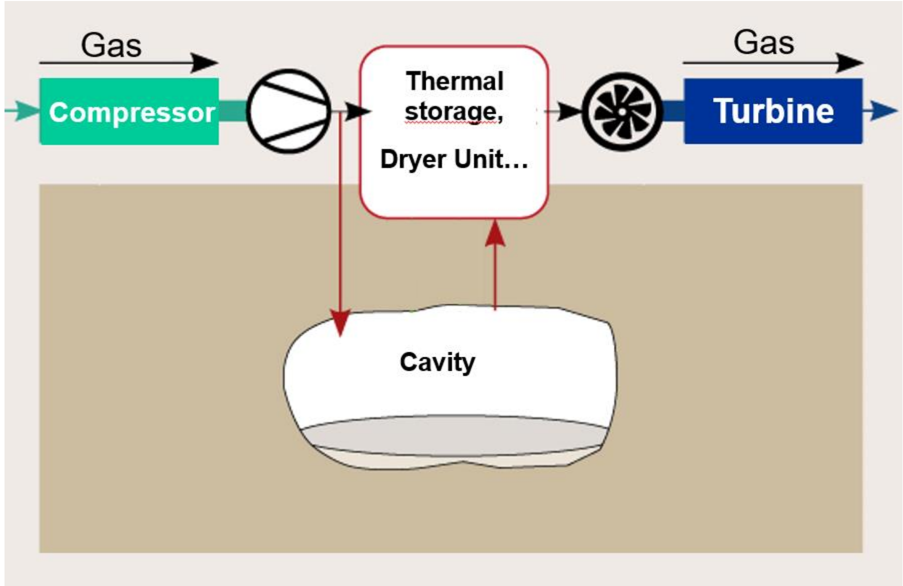
- Hydrogen
- Compressed Air
- Water (Warm or Cold)

# The Underground « Green » Gas Storages: 1) $H_2$ and 2) Compressed Air

**HUS = Hydrogen Underground Storage – CAES = Compressed Air Energy Storage**

## Principle:

- To produce $H_2$, then compress it and store underground
  ⇨ to burn it to produce electricity (or to use it as eco-fuel)
- To compress air, then store it in underground reservoir
  ⇨ to relax it through a turbine to produce electricity




## Achievements in the world:

- 4 Underground Hydrogen storages (3 in USA, 1 in UK)
- 2 Underground Compressed Air Energy Storages (D, USA)

## Potential geochemical impacts in case of leakage:

- $H_2$ is a **reductor** agent ⇨ potential **reduction** of oxygenated water from shallow aquifers
- Air is an **oxydant** agent ⇨ potential **oxydation** of anoxic water from deep aquifers.

# 3) The Underground Pumped Hydro-Energy Storage (PHES)

## Principle:

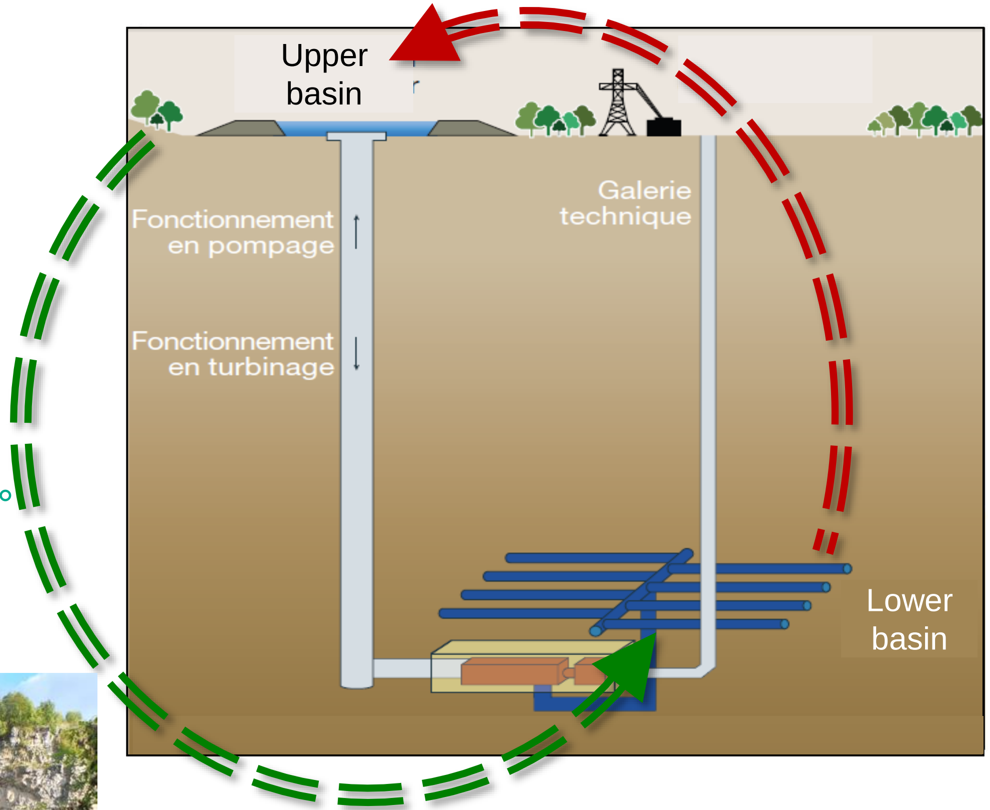
- To use electricity to transfer water from a lower to an upper reservoir ⇨ To turbine water downwards
  - Q-PHES: the lower reservoir is an abandoned **Quarry** basin

## Achievements in the world:

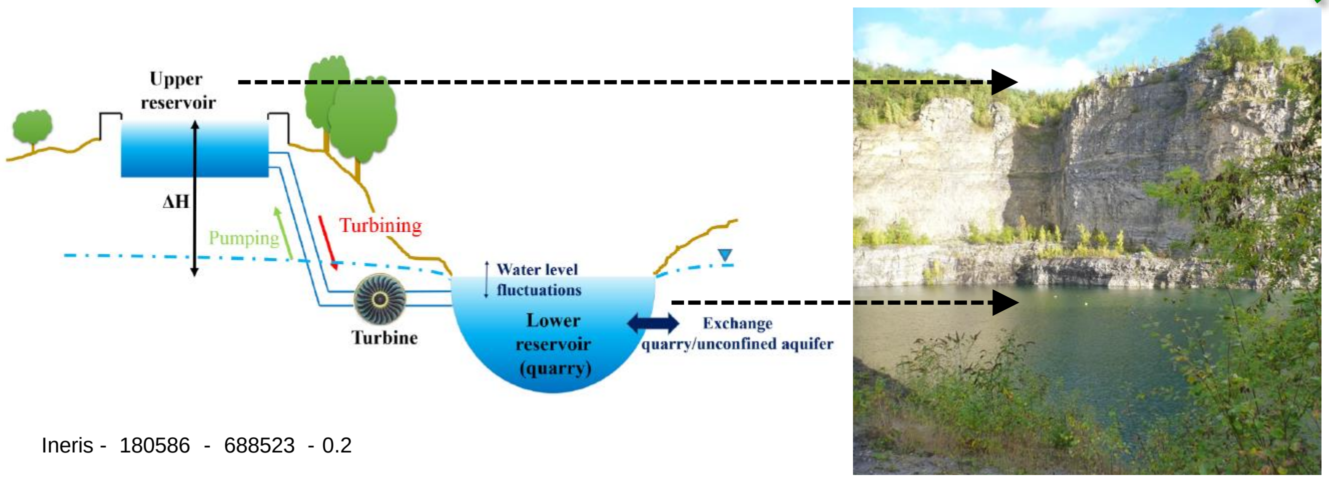
- M-PHES: 1 project in a former coal mine in D
- Q-PHES: None but several hundreds of potential sites

## Potential geochemical impacts:

- M-PHES: oxygenation of anoxic mine water ⇨ Fe/Mn pp°
- Q-PHES: oxygenation of groundwater ⇨ $CaCO_3$ pp°.



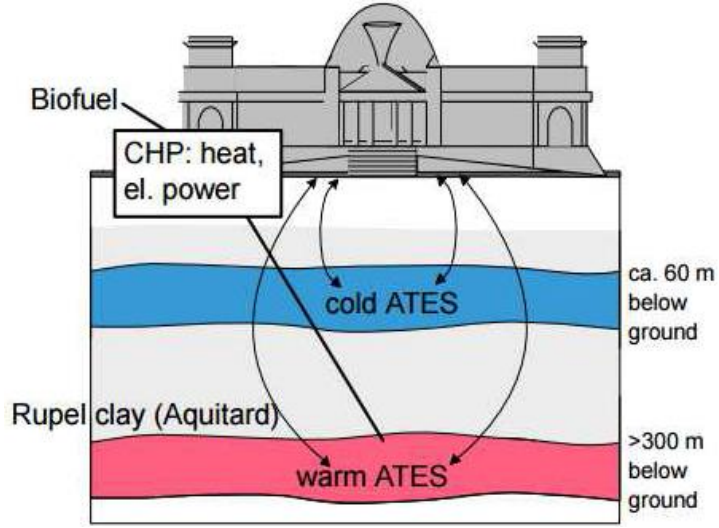

**Most important energy storage technology ~400 surface PHES but none underground**



**A-TES = Aquifer Thermal Energy Storage – C-TES = Cavern Thermal Energy Storage**

## Principle:

- To store excess heat produced in Summer
- To reuse it during Winter (and vice versa with cold in Winter)



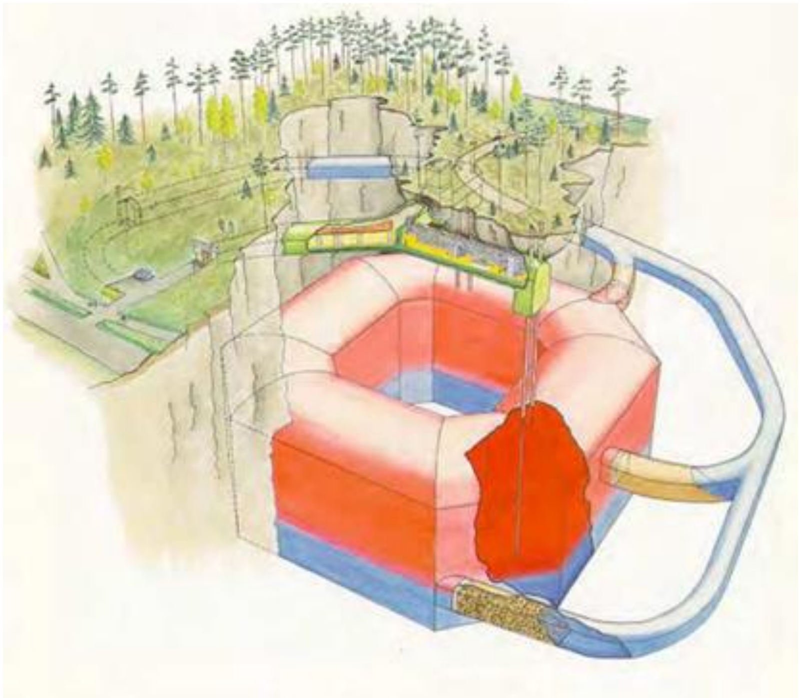

ATES at Berlin (D) ↑

## Achievements in the world:

- A-TES (Aquifer): > a **thousand** in the world (NL, D, USA)
- C-TES (Cavern):< a **dozen** in the world (Scandinavia)

## Potential geochemical impacts:

- Dissolution/Precipitation processes due to fluctuations of water temperature (min. 5°C ⇨ max. 95°C).



CTES at Lyckebo (S) →
*(104,000 m$^3$ of water at 60-90°C)*

③

## The potential geochemical risks of these emerging technologies:

- Hydrogen storage
- Quarry-PHES

# Potential Impacts of Hydrogen Underground Storages on Shallow Aquifers

**ROSTOCK'H: Risks and Opportunities of the Hydrogen geological Storage in salt cavities in France and Europe**

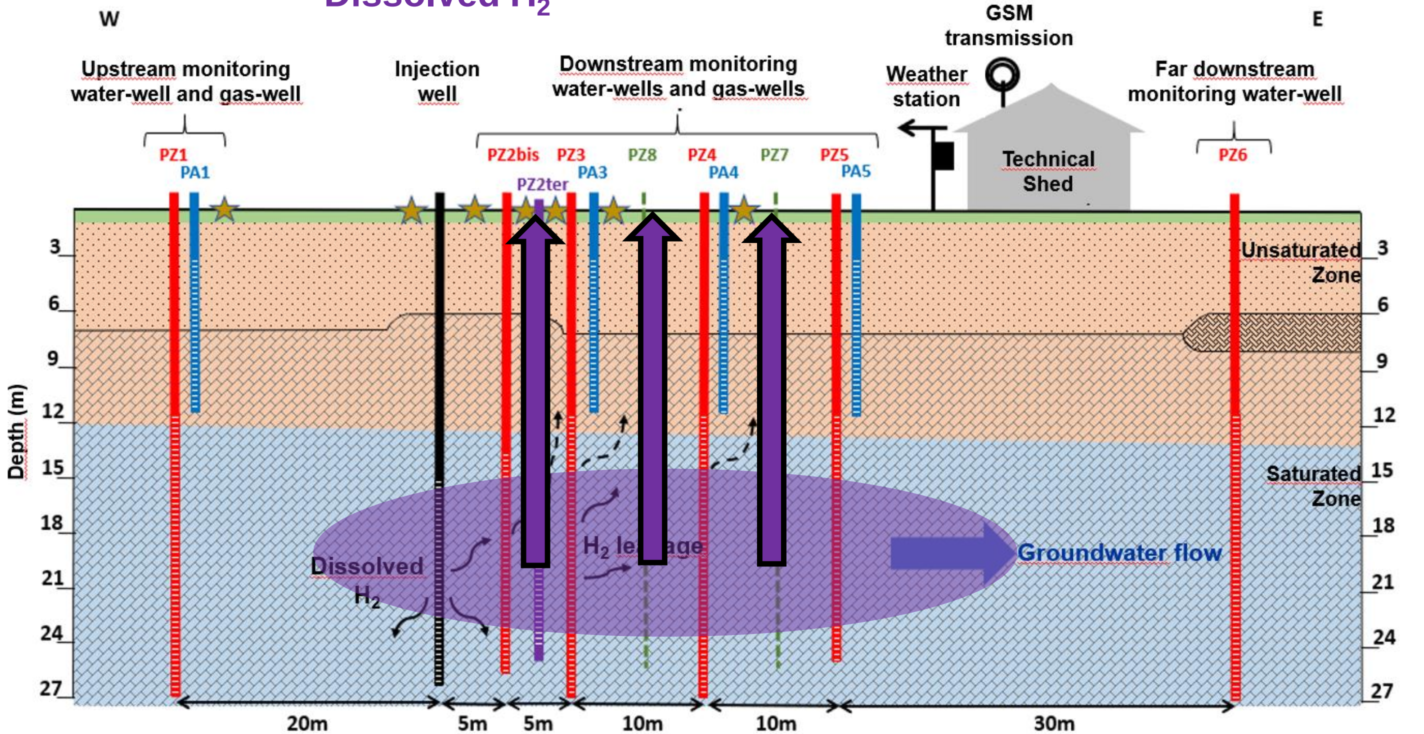
## Objectives of the project:

❶ To develop in-situ $H_2$ **monitoring tools** in SZ and UZ from **leakage experiment** at an experimental site

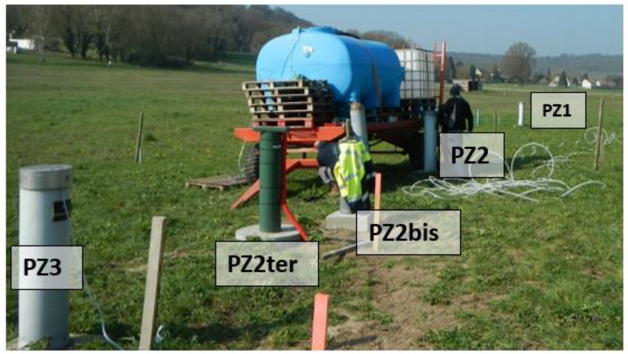
## Bibliographic synthesis + PHREEQ-C model:

- Abiotic reduction of **sulphates**: $\mathbf{4\ H_2 + SO_4^{2-} + 2\ H^+ = H_2S + 4\ H_2O}$
- Abiotic reduction of **nitrates** with **catalyzers:**
  - Steel and stainless steel (borehole/well casings): $\mathbf{NO_3^- + 4\ H_2 + 2\ H^+ = NH_4^+ + 3\ H_2O}$
  - Pd and Cu: $\mathbf{2\ NO_3^- + 5\ H_2 = N_2 + 2\ OH^- + 4\ H_2O}$

**Dissolved $H_2$**




*Previous experiments ($CO_2$, He)*




# Potential Impact of Q-PHES on an Adjacent Aquifer

(from Angélique Poulain's PhD Thesis, University of Mons, B, 2018)

## Simulation of groundwater flow and solute-transport by PHAST (daily cycles):

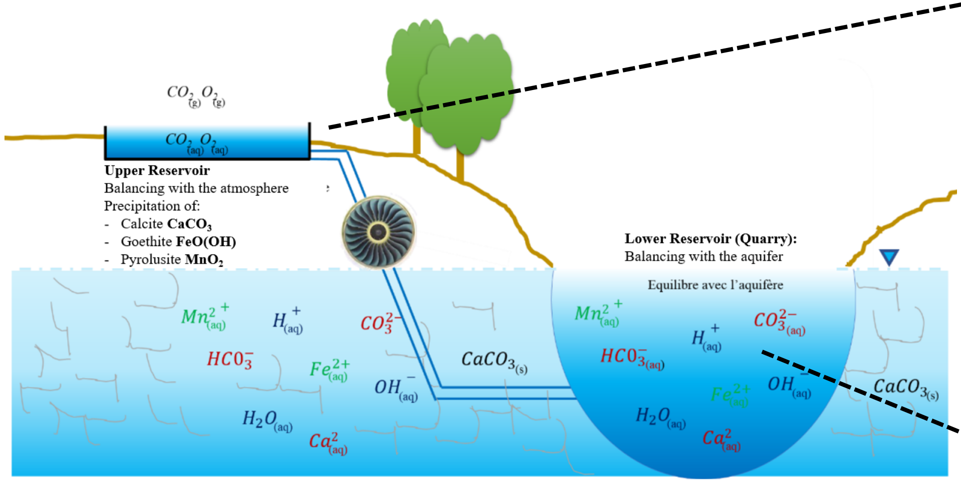
- In the upper basin: $[O_2]$ ↑ + $[CO_2]$ ↓ ⇨ precipitation of calcite, goethite and pyrolusite, +1 pH unit

Daily cycle = **1 Mm³** ⇨ **140 t of calcite**, **0.4 t of goethite** and **0.1 t of pyrolusite** precipitated in the upper basin !

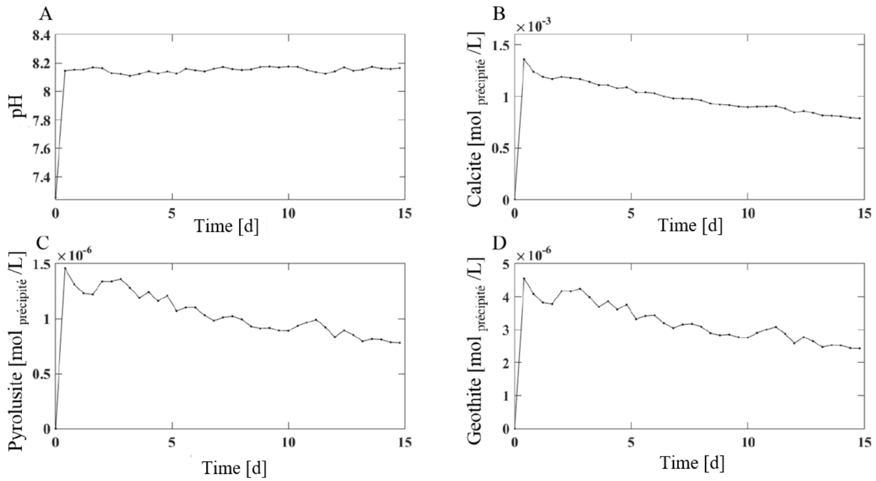
$$4Fe^{2+} + O_2 + OH^- + 2\,H_2O \leftrightarrows 4\,Fe(OH)_{3(s)}$$

$$Mn^{2+}_{(aq)} + \frac{1}{2}O_2 + H_2O \leftrightarrows MnO_{2(s)} + 2H^+$$

$$Ca^{2+} + 2HCO_3^- \leftrightarrows CO_2 + CaCO_{3(s)} + H_2O$$



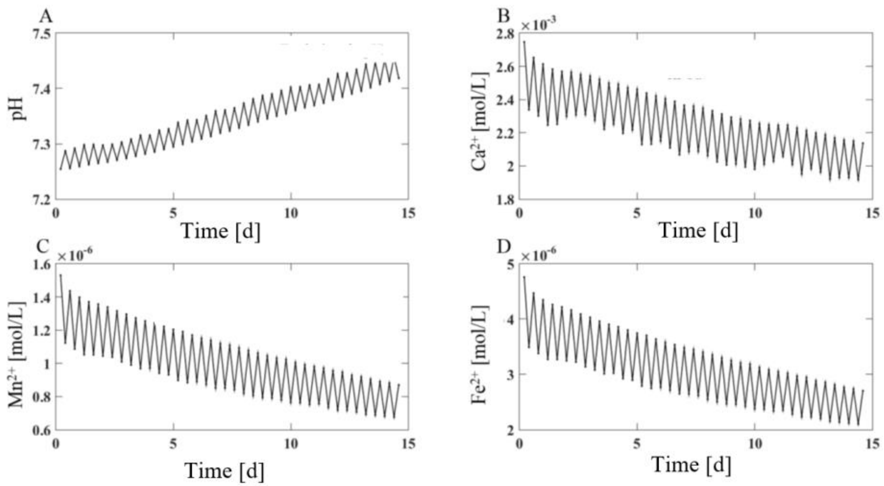

Different chemical elements involved in an open aquifer system




In the upper basin ↑

Evolution of hydrogeochemical variables during 2 weeks

In the lower basin ↓




- In the quarry and the aquifer ⇨ cyclic qualitative variations induced by daily cycles between upper basin and aquifer values: [Ca]↓, [Mg]↓, [Mn]↓, [Fe]↓, pH↑ (+0.2 unit).

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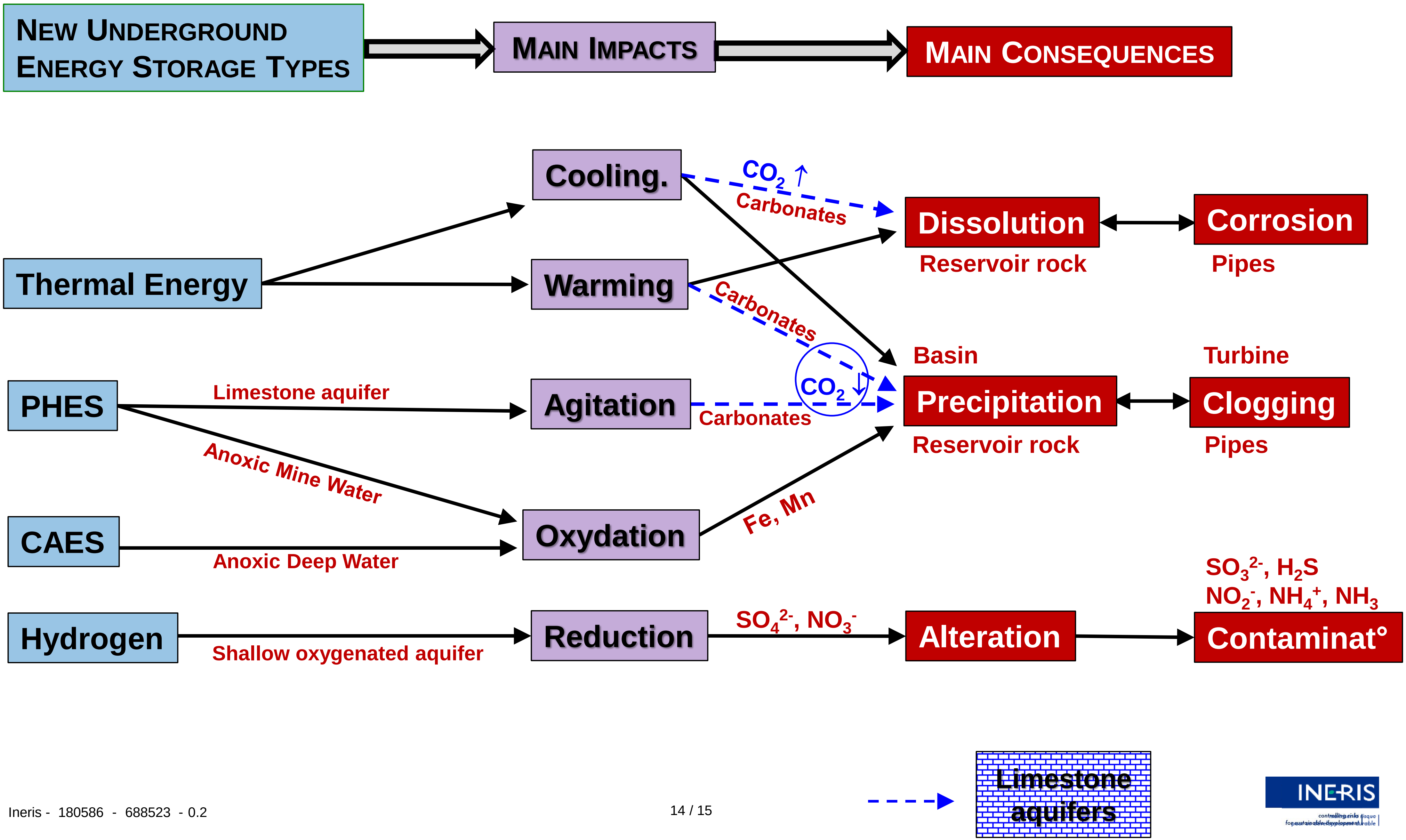
# Conclusion

# Geochemical Risks devoted to New Underground Energy Storages



# Thank you for your attention

# Merci de votre attention

# Dank U voor uw aandacht

*Data come from a report available (in French) at: www.ineris.fr*