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SCIENTIFIC AND STRATEGIC ENVIRONMENTAL CONSULTING

COMSOL
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Assessment of feasible strategies for seasonal underground hydrogen storage in a saline aquifer

Elena Abarca, Alvaro Sainz-Garcia, Fidel Grandia

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Underground Hydrogen Storage (UHS)

- More renewable energy production to meet climate protection agreements
- Temporary mismatches between demand and supply → **Energy storage**
- Conversion of **surplus energy** to H_2 by hydrolysis
- Storage of H_2 for its later use → vehicles, re-electrification,…
- Large volumes → Geological storage
  - **Saline aquifers** have large potential storage capacity

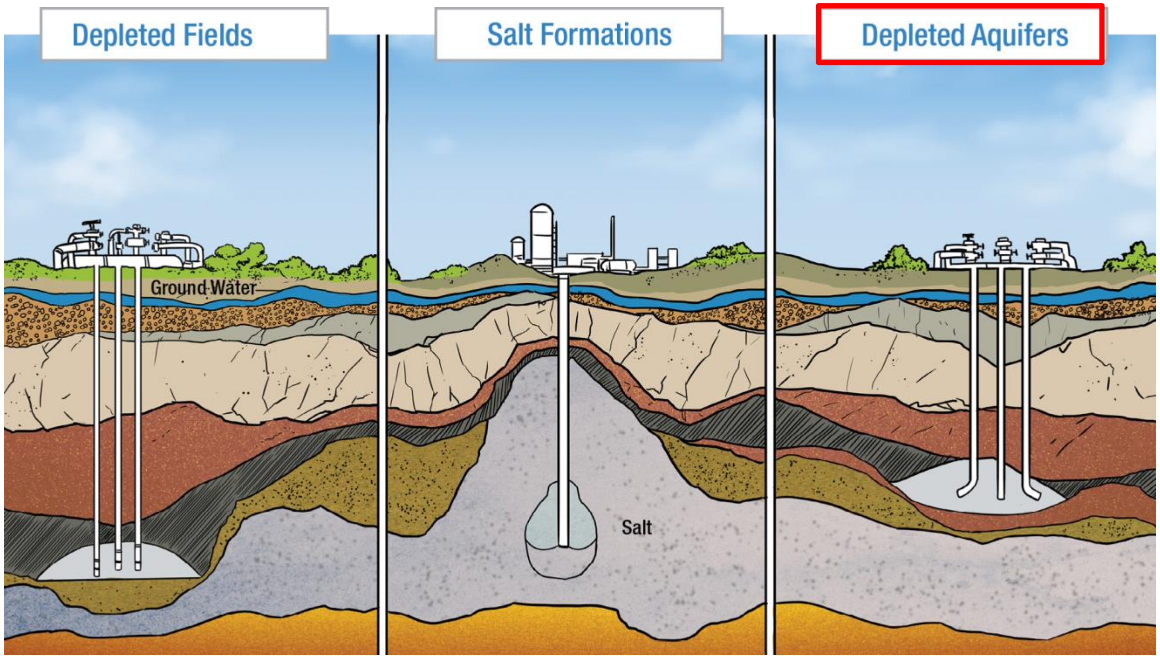
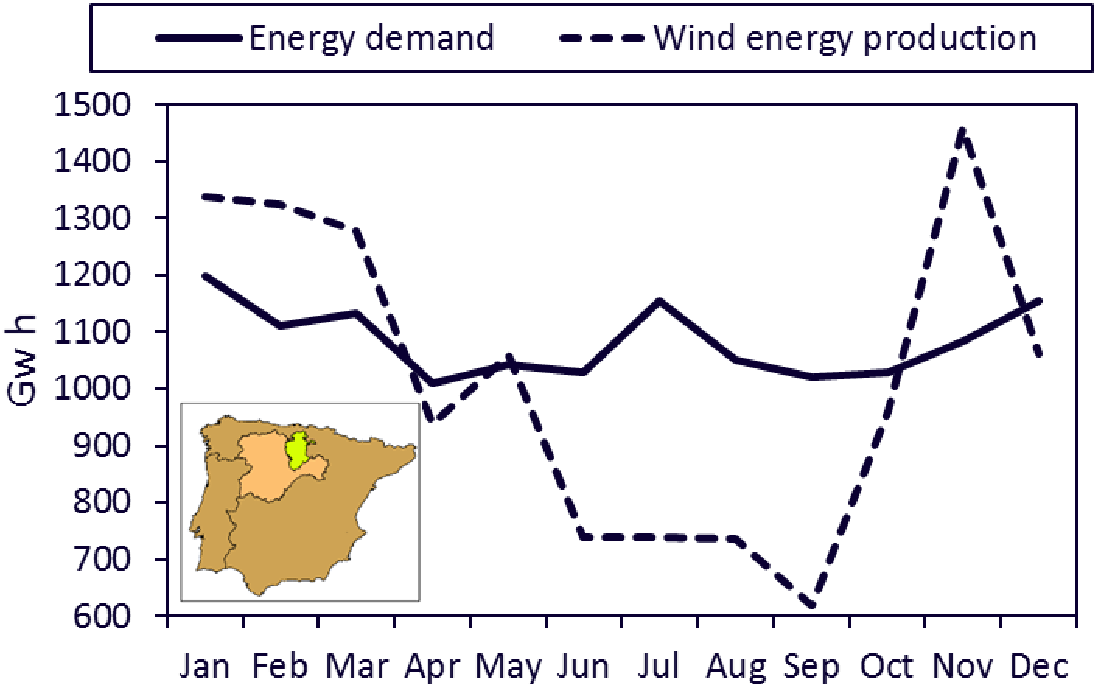


*Figure from energyinfraestructure.org

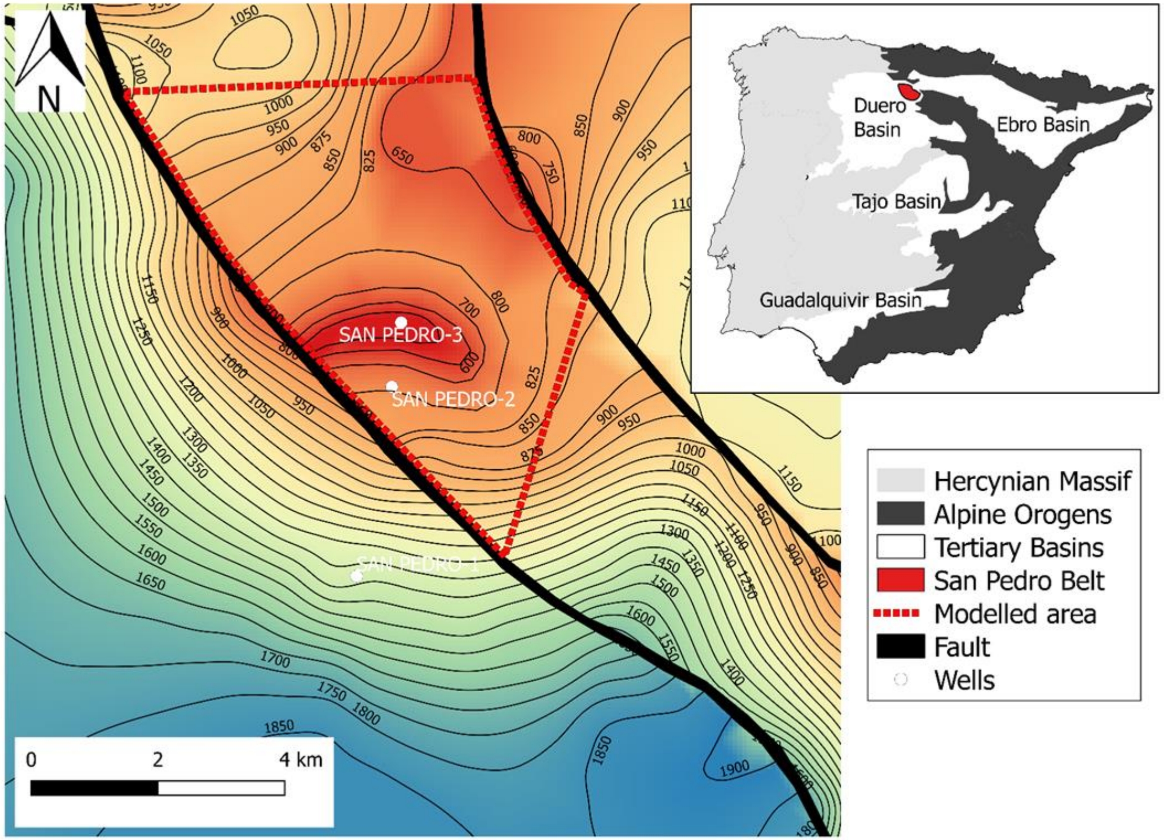
The Castilla León (Spain) case

- Leading wind power generation in Spain with **24%** of the national production
- Energy consumption is quite constant along the year, whereas wind power production is higher in fall and winter
  - Extra energy needed from June to September
  - Excess from October to May → 377 GWh assuming a **4% of surplus energy**
- If all this energy is converted to hydrogen → **7242 tons H_2**.

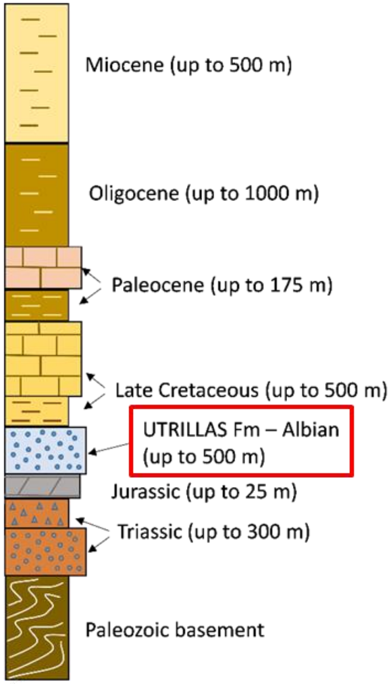


The Castilla León (Spain) case

- Duero basin a number of favorable structures for gas storage recognized in previous CCS projects (*ALGECO2 project*)
- San Pedro belt has been considered as candidate for hydrogen storage
  - Utrillas formation



Stratigraphic column



*Data from ALGECO2 project

Model description

- Mathematical model
  - Immiscible fluids → Low solubility
  - Pure H_2 gas phase
  - Temperature gradient

Mass conservation of each phase:

$$\partial_t(\phi\rho_\alpha S_\alpha) + \nabla\cdot(\rho_\alpha \boldsymbol{q}_\alpha) - q_\alpha^0 = 0\,, \qquad \alpha = l, g$$

$$\boldsymbol{q}_\alpha = -\frac{k k_{r,\alpha}}{\mu_\alpha}(\nabla P_\alpha - \rho_\alpha \boldsymbol{g})$$

Algebraic equations

Total saturation $S_n + S_w = 1$

Capillarity pressure $\begin{cases} P_{cap} = P_n - P_w \\ P_{cap} = P_{cap}(S_w) \end{cases}$

Relative permeability $k_l^r, k_g^r = f(S_w)$

Gas volume $V_g = V_g(p_g, T,)$

Liquid density $\rho_l = \rho_l(p_l, T,)$

Viscosity $\mu_g = \mu_g(p_g, T,)$

…

Model description

- Mathematical model
  - Linear combination of equations with

Variable $\boldsymbol{S_g}$ $$\partial_t(\phi\rho_g S_g) + \nabla\cdot(\rho_g \boldsymbol{q_g}) - q_g^0 = 0$$

Variable $\boldsymbol{P_l}$ $$\sum\nolimits_{\alpha=l,g}\left(\partial_t(\phi\rho_\alpha S_\alpha) + \nabla\cdot(\rho_\alpha \boldsymbol{q_\alpha}) - q_\alpha^0\right) = 0$$

  - Brooks-Corey retention curve equations

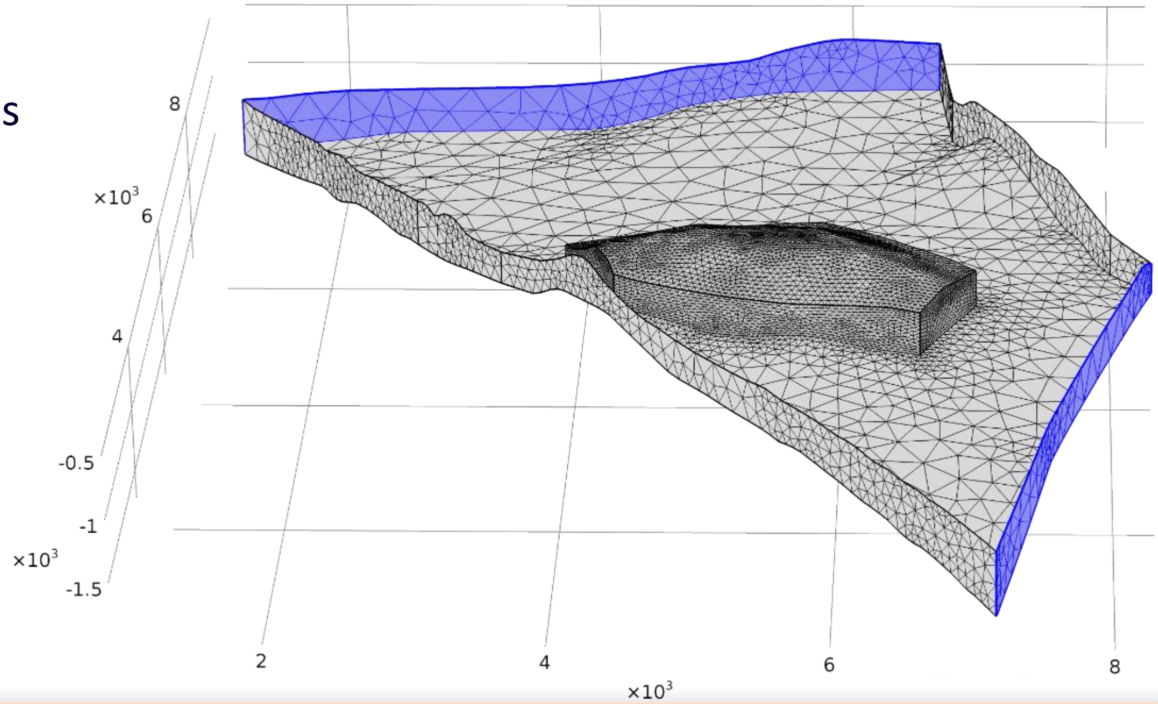
Name	Expression
Effective saturation	$S_e = \dfrac{S_l - S_l^r}{1 - S_l^r - S_g^r}$
Capillary pressure	$P_c = P_t S_e^{-1/\omega}$
Relative liquid permeability	$k_l^r = S_e^{\frac{2+3\omega}{\omega}}$
Relative gas permeability	$k_g^r = (1 - S_e)^2\left(1 - S_e^{\frac{2+\omega}{\omega}}\right)$

  - The model is implemented in the as a coeficient form PDE interface

Model description

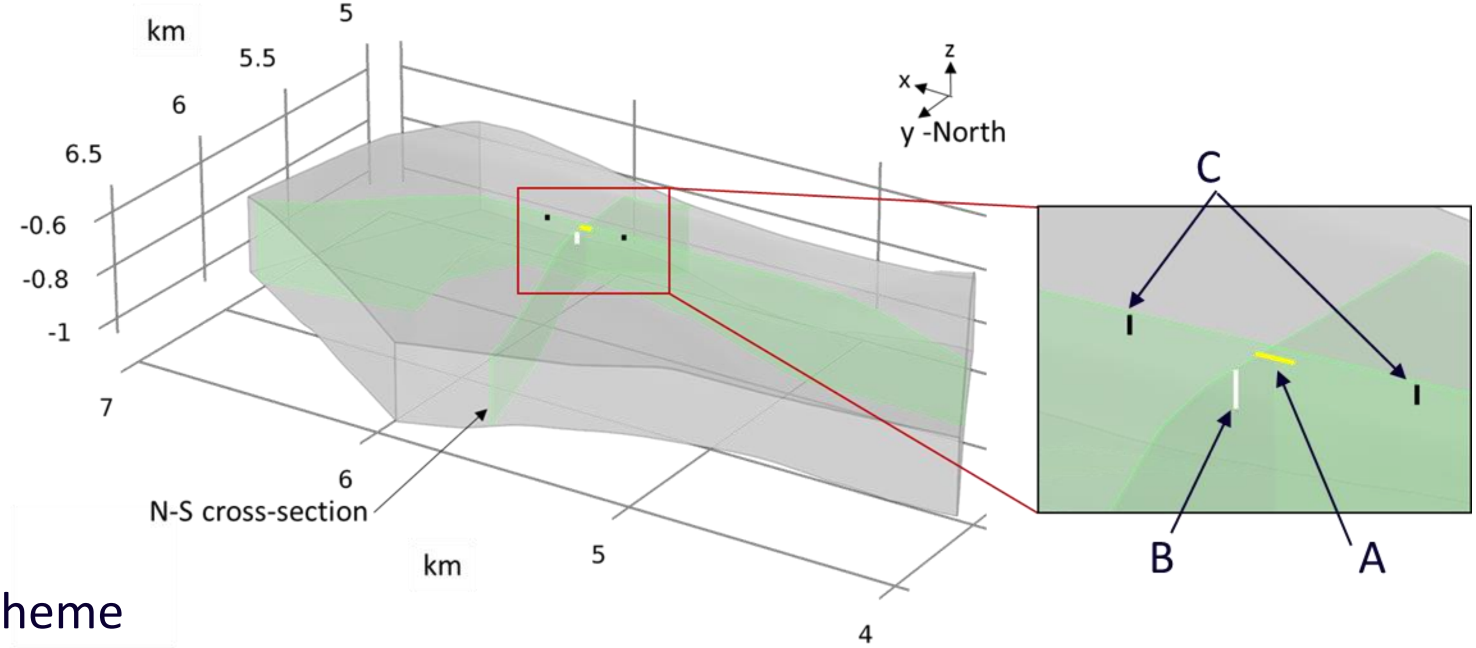
- Boundary conditions
  - Lateral prescribed hydrostatic pressure
  - **Injection** mass flux (Neumann Condition)
  - **Extraction** Cauchy condition in the wells → $q_\alpha^0 = -\frac{k_{well} k_\alpha^r}{\mu_\alpha} \rho_\alpha (P_\alpha - P_{well})$
  - Wells stop if $S_g < 0.4$
  - Pressure kept between 3 and 8 MPa

- Implemented in COMSOL
  - 2,7x10^5 tetrahedral elements



Model description

- 1 injection well
- 3 extraction well configurations
  - Case A
  - Case B
  - Case C



- Operation scheme
  - 1st of constant injection of 7492 tons of H_2
  - 3 years of actual operation:
    - Injection of 7242 tons H_2 in 243 days (from October to May)
    - Extraction ???? tons H_2 in 122 days (from June to September)

Model description

- Parameters

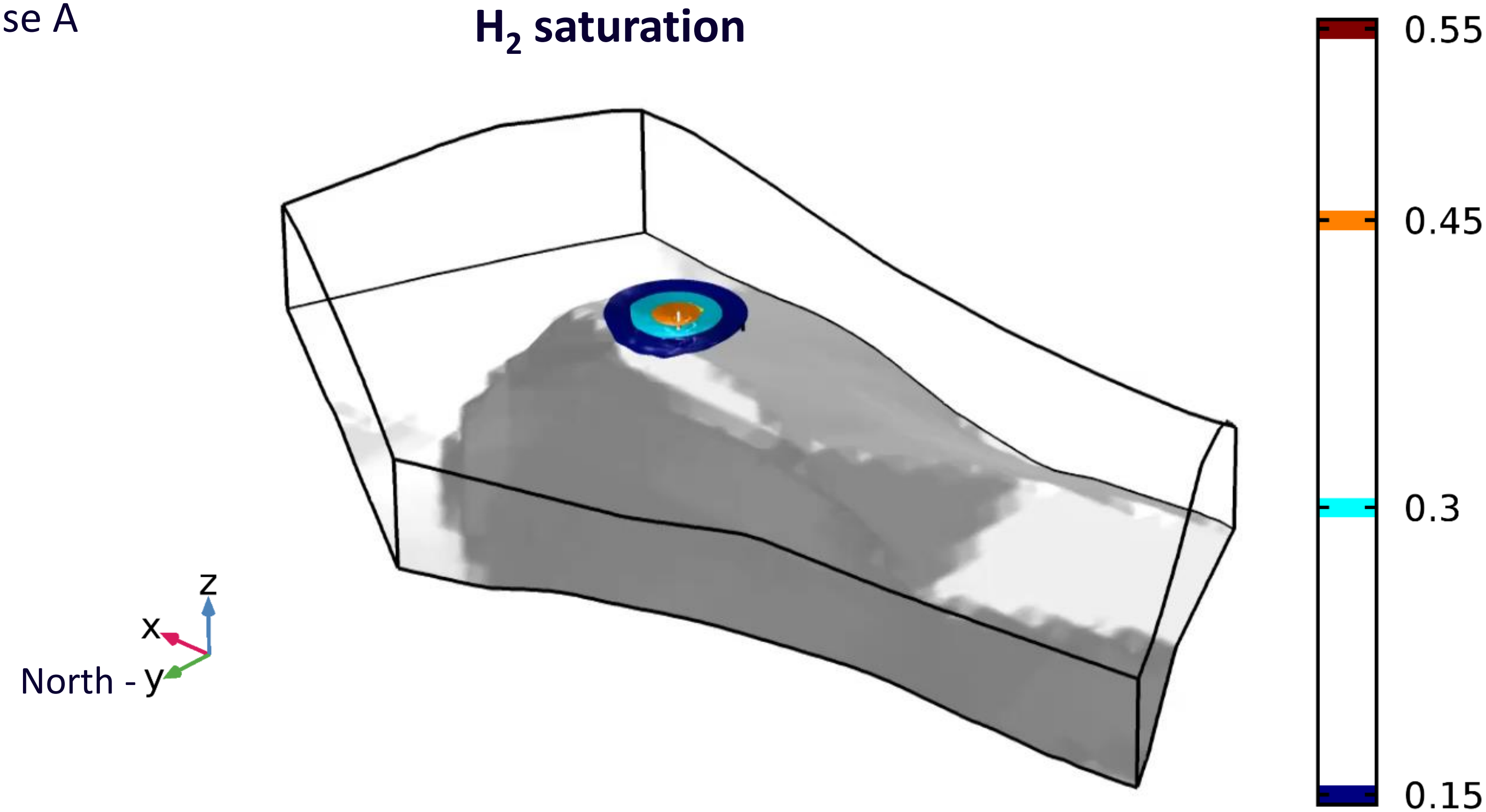
	Parameter	Symbol	Value	Unit
Aquifer	Porosity*	ϕ	0.2	-
	Permeability*	k	1x10^{-13}	m^2
	Earth surface temperature	T_0	298	K
	Thermal gradient	k_T	0.027	$K \cdot m^{-1}$
Retention curve	Entry Pressure	P_t	1x10^{5}	Pa
	Pore index	ω	2	-
	Residual liquid saturation	S_l^r	0.3	-
	Residual gas saturation	S_g^r	0	-
Extraction boundary condition	Well liquid pressure	P_{well}	3x10^{6}	Pa
	Well permeability	k_{well}	1x10^{-13}	m^2

* Data taken from the ALGECO2 project.

Results

Case A

H_2 saturation

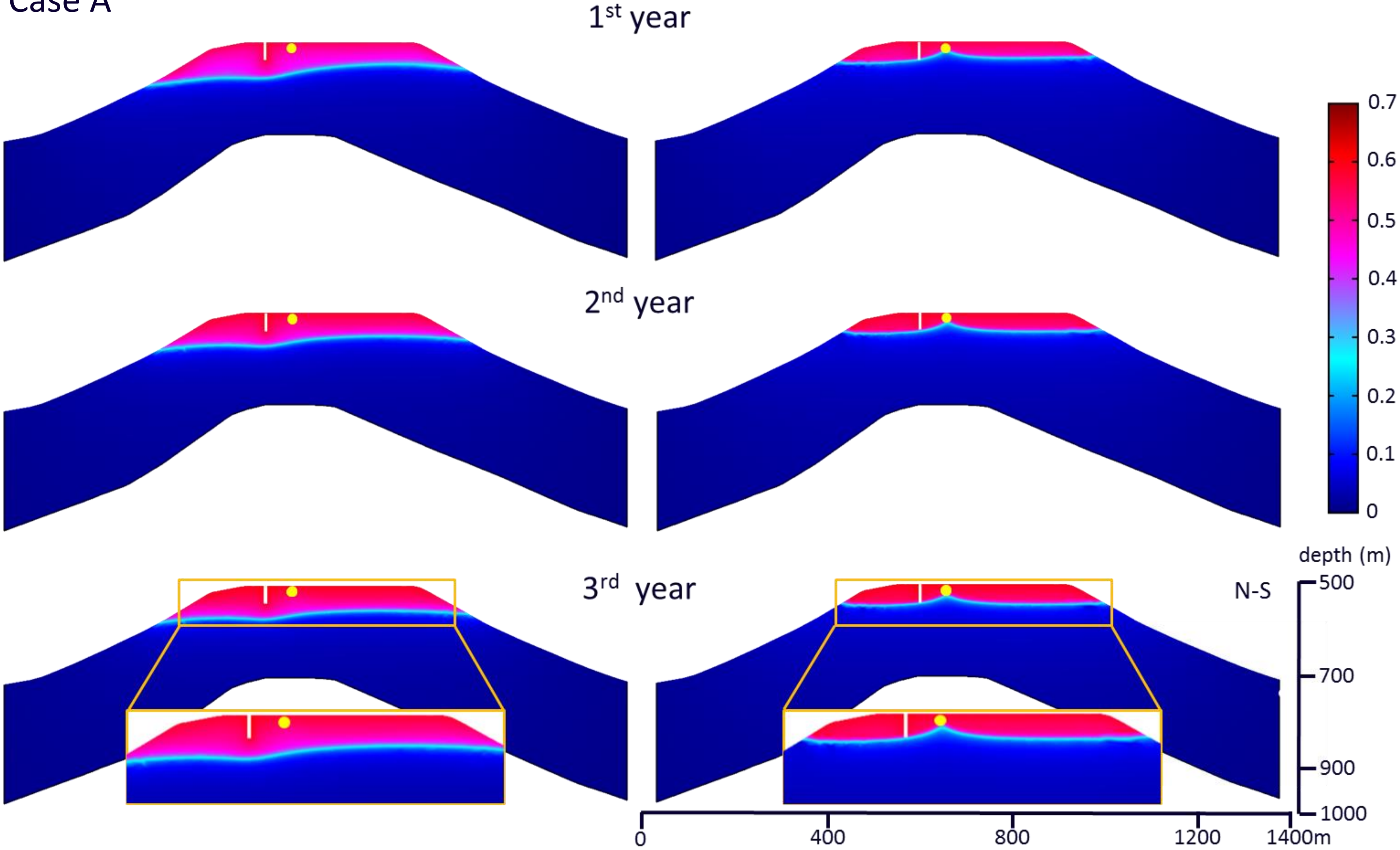


Results

H_2 saturation

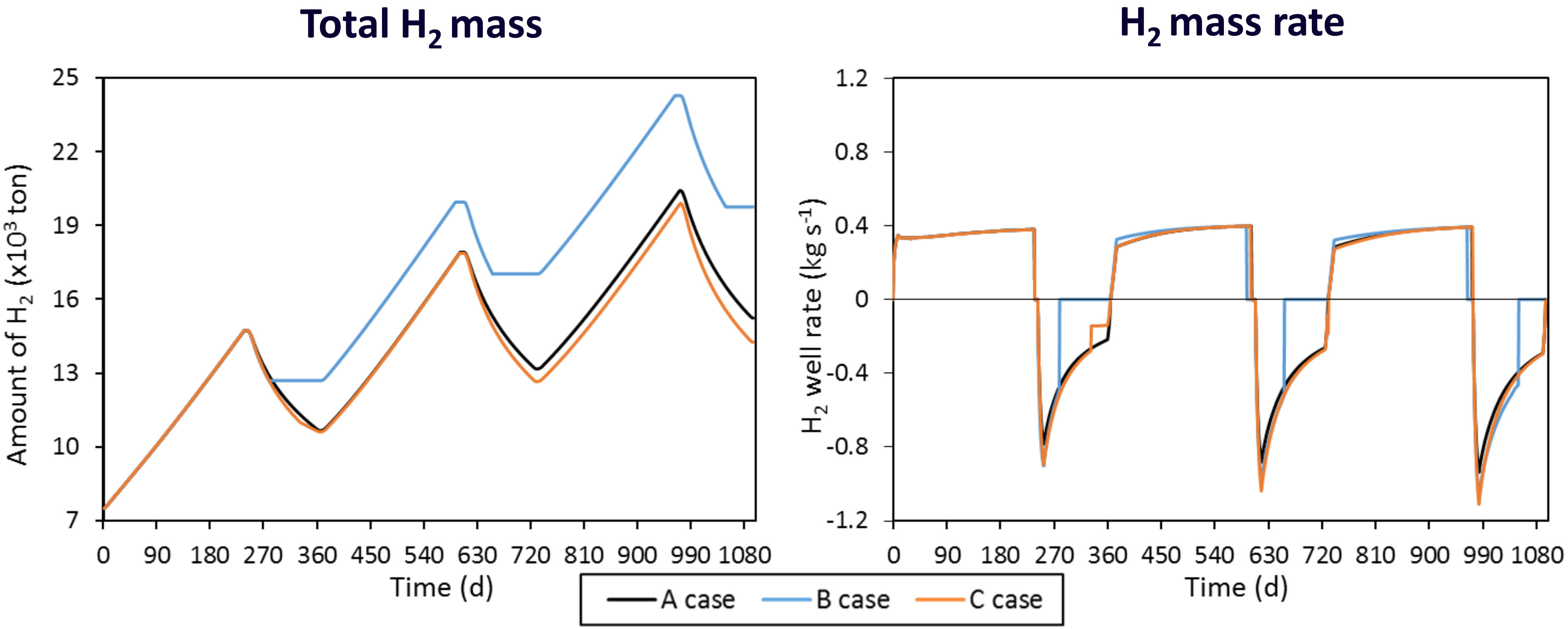
Injection **Extraction**

Case A



Results

- The location of the extraction wells controls the efficiency of H_2 storage
- Injection → similar flow rate between models
- Extraction → Case B and Case C (1st year 1 well) shut down due to upconing



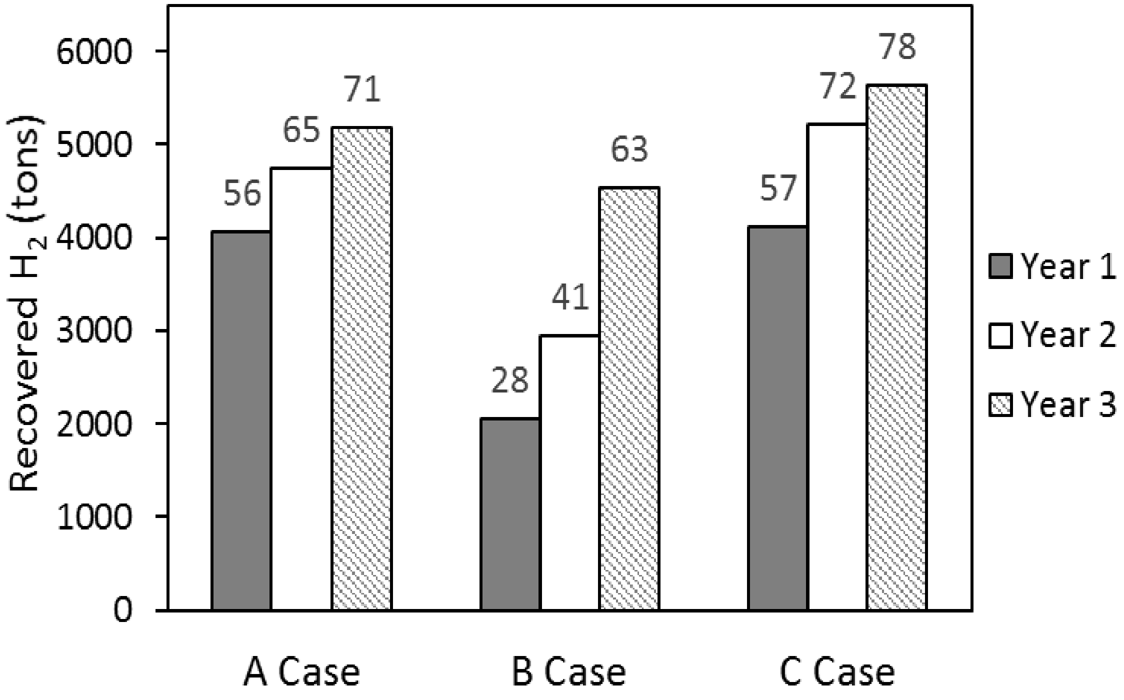
Total H_2 mass

H_2 mass rate

Results

- Each year the amount of produced hydrogen increases for all cases
- Case C the best recovering ratio
- After 3 years all cases have reasonable recovery rations (up to 78%)

Amount of H_2 produced



Conclusions

- Reasonable recovery ratios for seasonal energy mismatches
  - 15% of the electricity consumed in the city of Burgos (175.000 inhabitants) in from June to September*
  - No H_2 crosses the spill point
  - no viscous fingering occur
- Steeply dipping structures are critical
- Upconing is the major risk on saline aquifer storage without using cushion gas
  - Appropriate extraction well configuration
  - Monitoring

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ESPAÑA
Paseo de García Faria, 49-51
08019 Barcelona
Tel.: +34 93 583 05 00

Paseo de la Castellana 40, 8ª Planta
28046 Madrid
Tel.: +34 620634729

CHILE
Avda. Nueva Tajamar, 481
WTC – Torre Sur – Of 1005
Las Condes, Santiago
Tel.: +562 2 7991630

PERÚ
Jr. Pietro Torrigiano 396
San Borja, Lima 41
Tel.: +51 1 592 1275

FRANCE
92 Rue du Sergent Blandan
54000 Nancy
Tel.: +33 645 766 322

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