Role of underground hydrogen storage in the European energy system

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Acknowledgment

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Clean Hydrogen Partnership

Outline

1 Background

WP5: Energy system modelling to identify demand for underground hydrogen storage in Europe.

Objective: modelling of **European energy system** on EU-level considering individual countries (EU27+UK) to estimate **demand for underground hydrogen storage** (UHS) and required infrastructure capacities

Approach: LBST's inhouse energy system model LENS (**L**BST **EN**ergy **S**ystem model**),**
four different scenarios for 2030, 2040 and 2050 (with/without porous media, role of imports)

Results: key **H_2 storage-related parameters** on EU27+UK & country level (technology-specific):

1. Total storage volume capacity (TWh_{H2}) & total storage throughput (TWh_{H2}/a)
2. Maximum injection & withdrawal capacities (GW_{H2})
3. Number of Full Cycle Equivalents (= storage throughput / storage volume)
4. Impact on H_2 flows and infrastructure needs

Note: All publications of WP5 available on HyStories website: https://hystories.eu/publications-hystories/.

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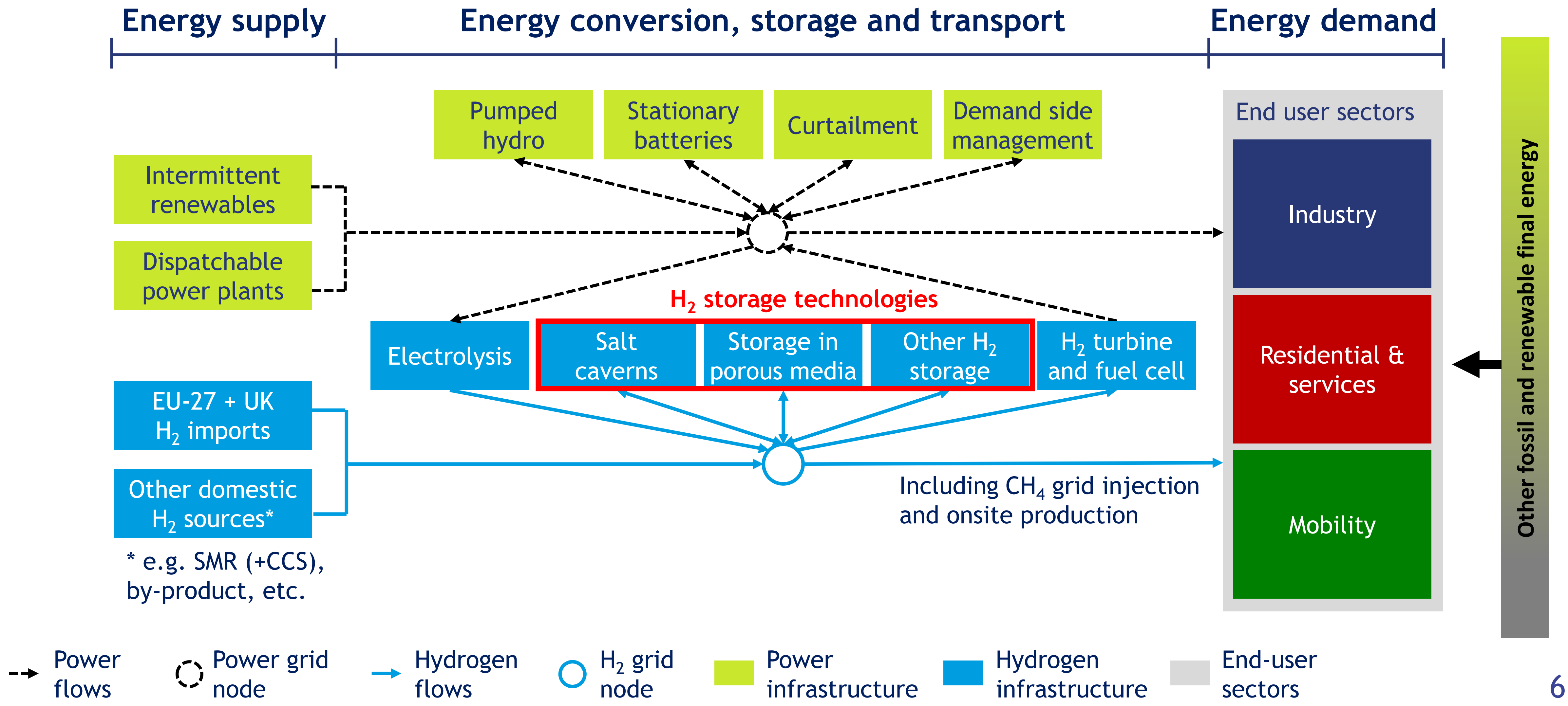
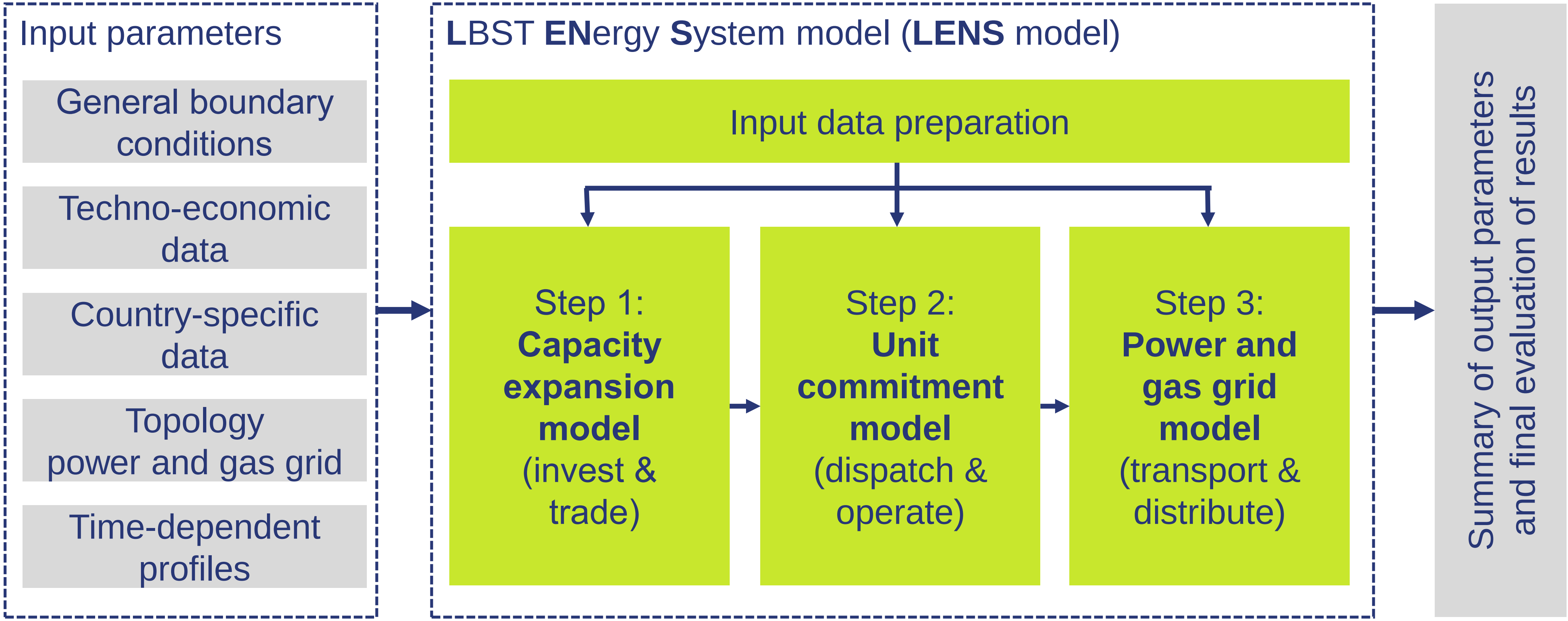
Approach

Model covers different hydrogen technologies as linkage between power and gas sector.



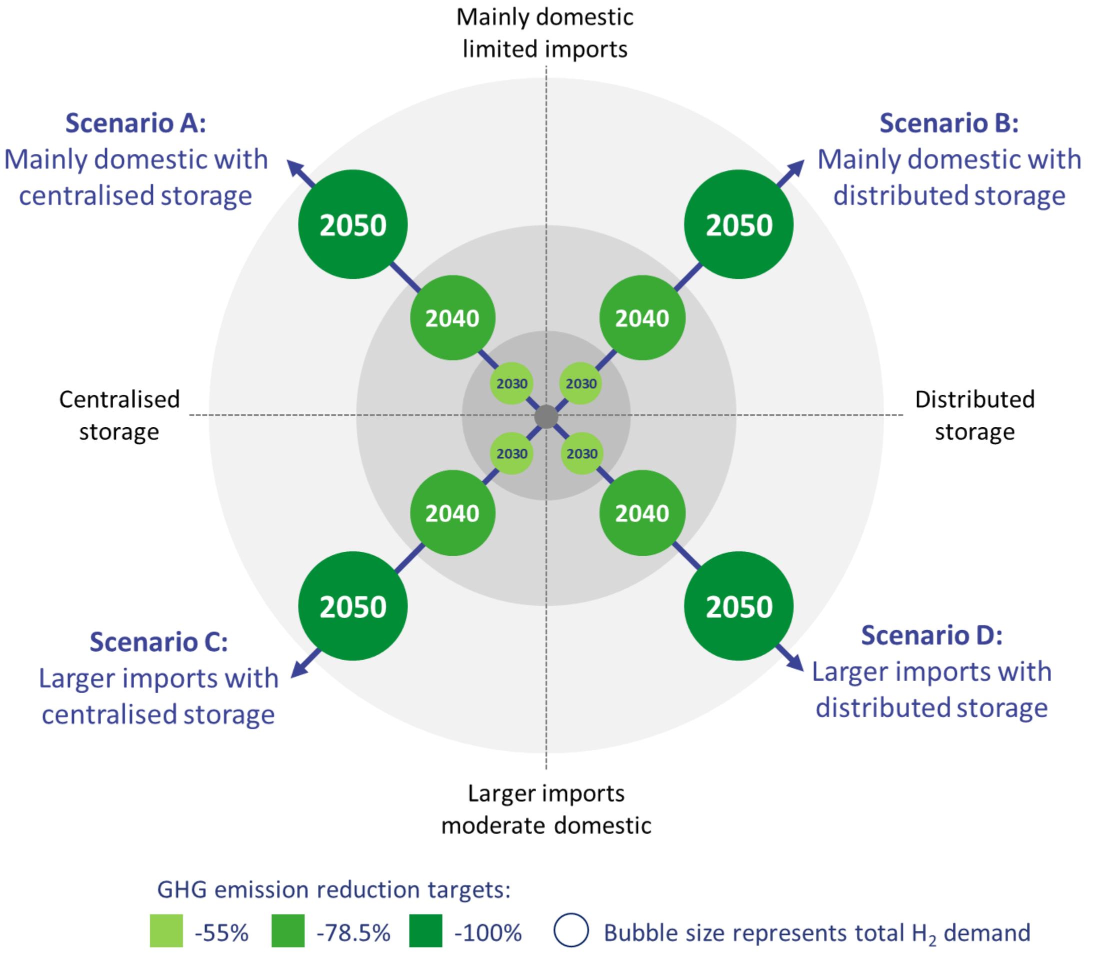
LENS model uses three-step approach for modelling temporal and spatial dimensions of energy system.



Linear programming for minimization of overall system costs by simultaneously optimizing the size and hourly operation of all system elements in two steps

Four scenarios with different UHS technologies and role of imports were analysed in this study.

	Scenario A	Scenario B	Scenario C	Scenario D
General assumptions				
GHG emission reduction (vs. 1990)	(2025: -37.5%) | **2030:** -55% | **2040:** -78.5% | **2050:** -100%			
Hydrogen demand	Identical for all scenarios to ensure comparability			
Scenario differentiation				
Hydrogen production	**Mainly domestic,** limited imports	**Mainly domestic,** limited imports	Moderate domestic, **larger imports**	Moderate domestic **larger imports**
Hydrogen storage	**Salt caverns**	**Salt caverns, porous media**	**Salt caverns**	**Salt caverns, porous media**



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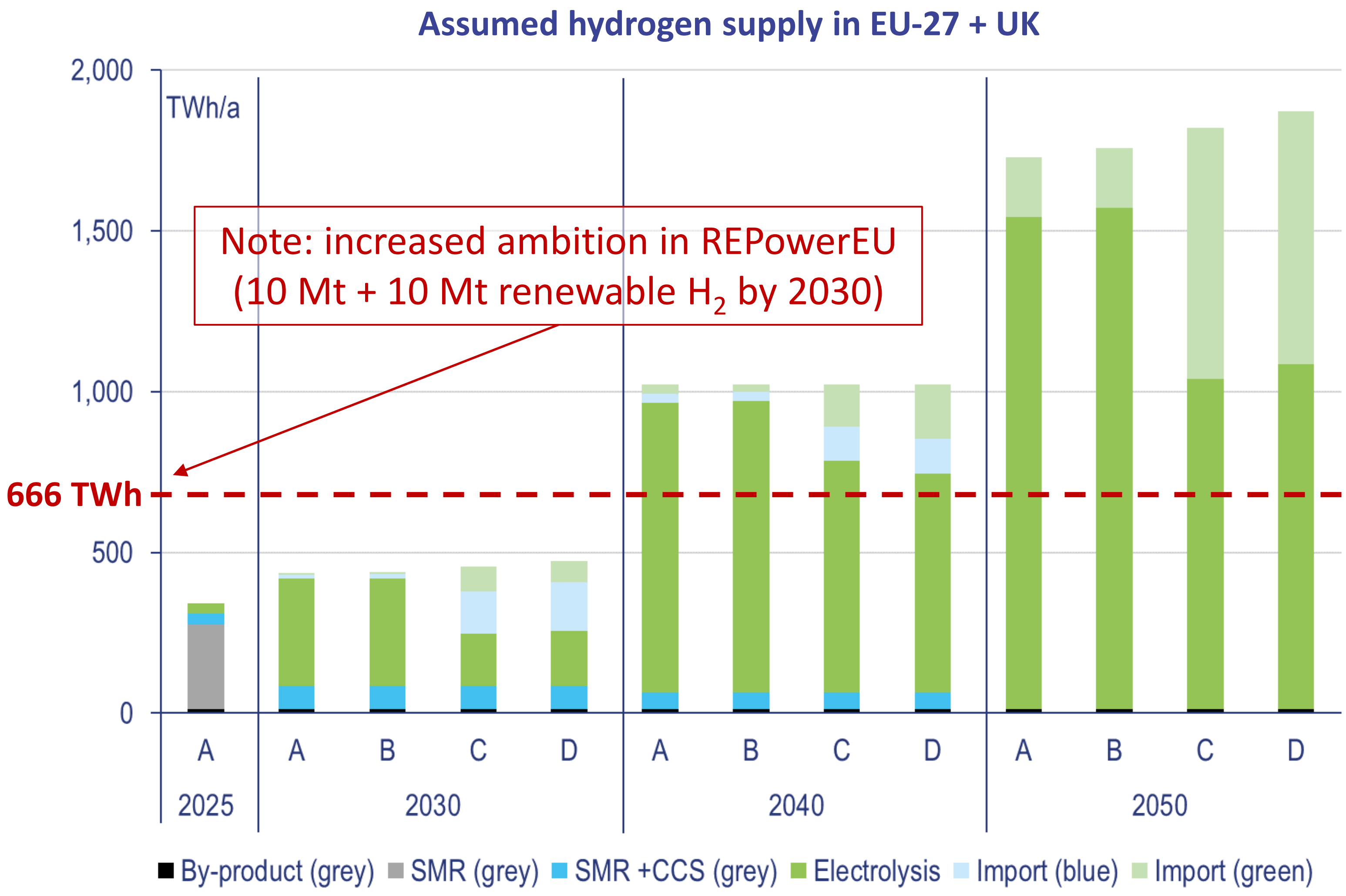
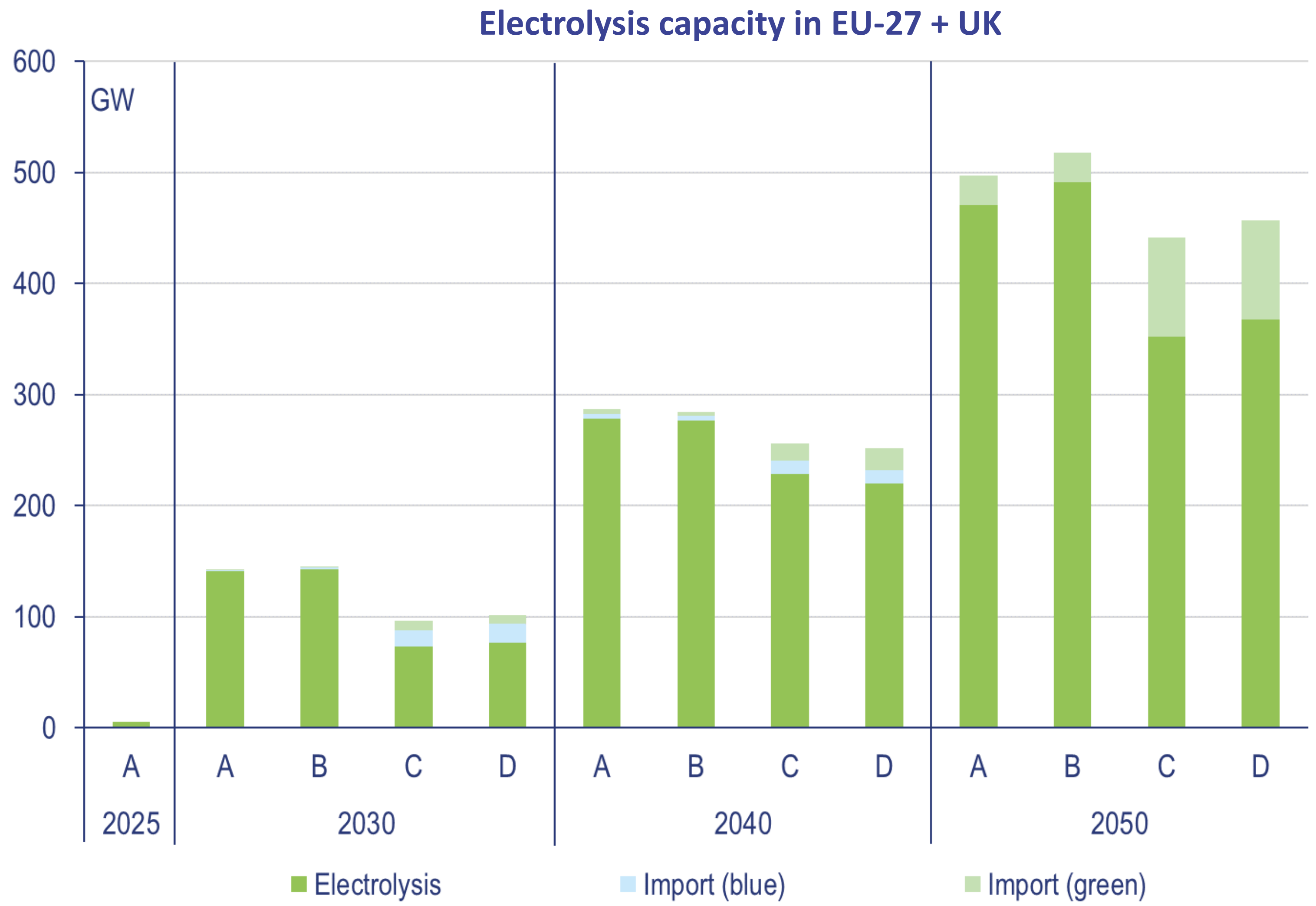
Modelling results I: general results

Renewable hydrogen as major source of supply to cover future hydrogen demand.



- Differences in H_2 demand driven by re-electrification needs
- Mainly renewable (green) hydrogen production in all scenarios
- Rapid phase-out of grey hydrogen after 2025
- Limited role of blue hydrogen (SMR + CCS) in the mid-term
- Imports about 10% (A&B) and 40% (C&D) by 2050

Substantial electrolysis capacities of 70-150 GW already needed by 2030



- Electrolysis capacities:
  70-149 GW (2030),
  350-500 GW (2050)
- Increasing import capacities:
  2-27 GW (Scenarios A&B)
  25-90 GW (C&D)
- Electrolysis utilization:
  >8,000 h (2025)
  3,300-4,300 h (after 2025)
  → increasing importance as flexibility option

Hydrogen will increasingly become a relevant flexibility option as dispatchable power source.

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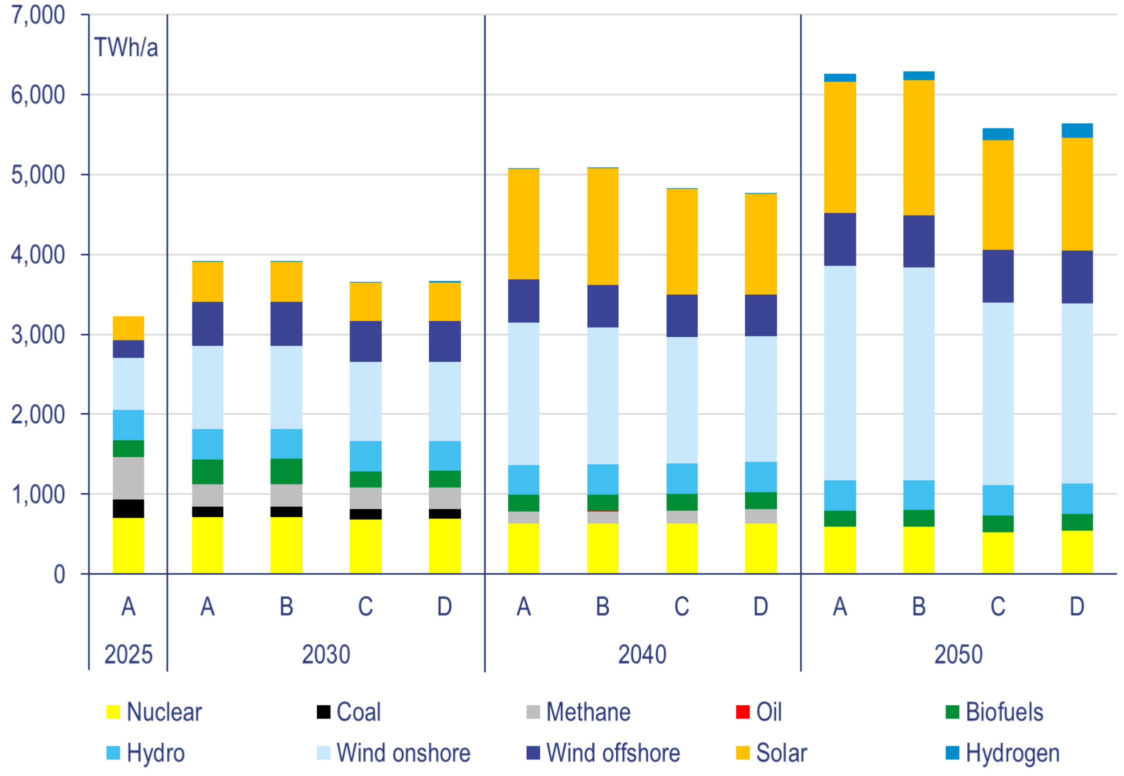
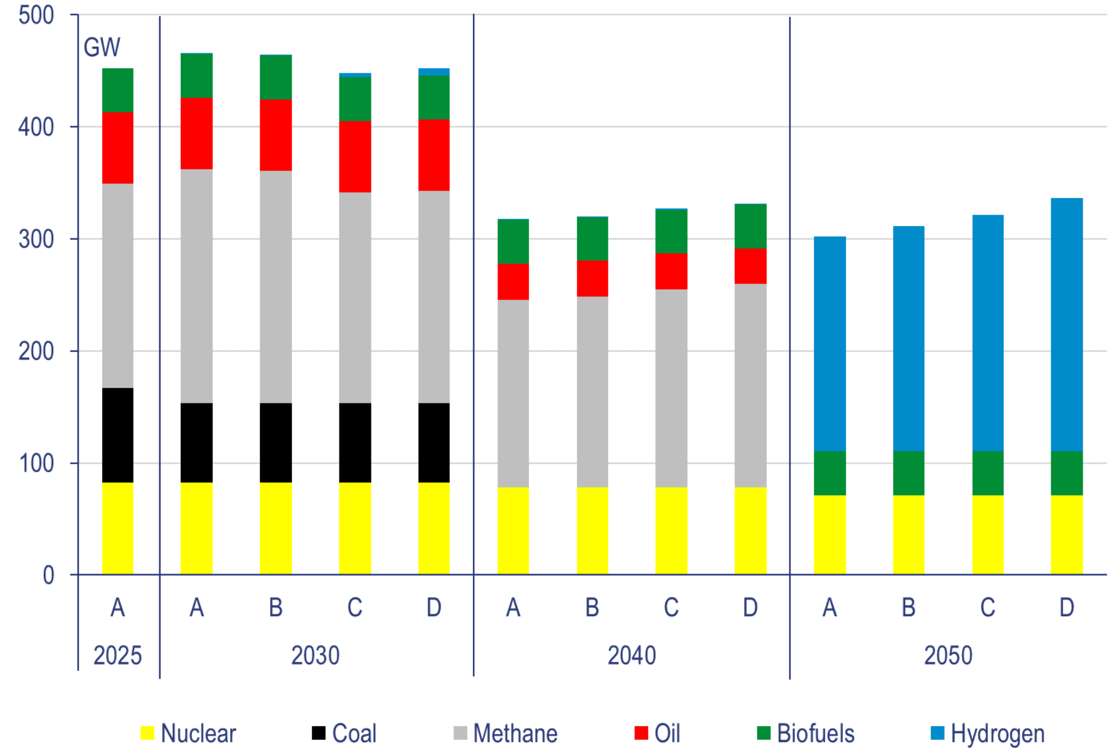
Power supply in EU-27 + UK



H_2 re-electrification: 150 – 300 TWh/a by 2050

Installed capacities in EU-27 + UK (dispatchable power plants)



H_2 gas power plant capacities:
190 – 230 GW by 2050

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Modelling results II: underground hydrogen storage (UHS)

The underground H_2 storage demand will significantly grow until 2050 - in line with increasing H_2 use.

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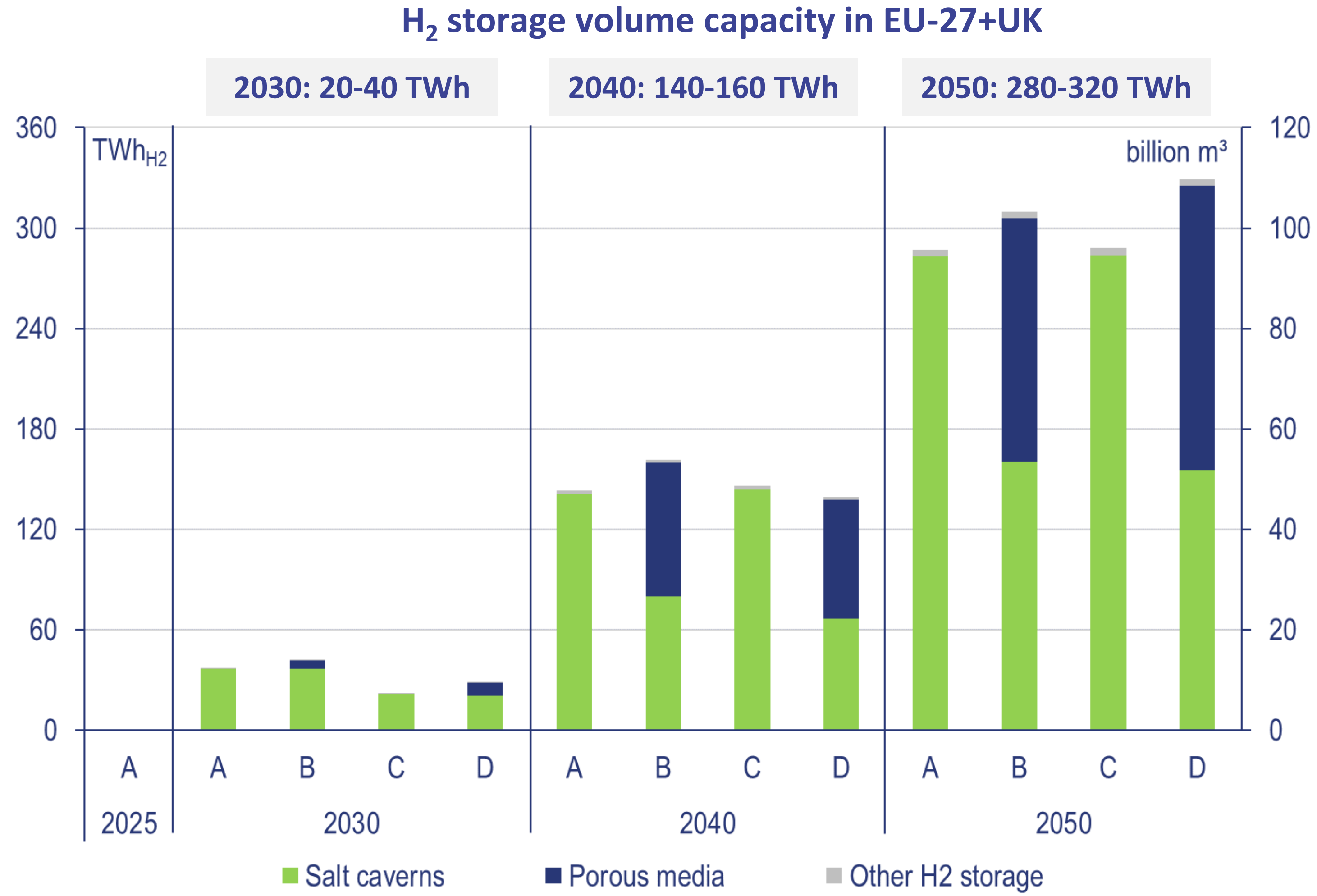
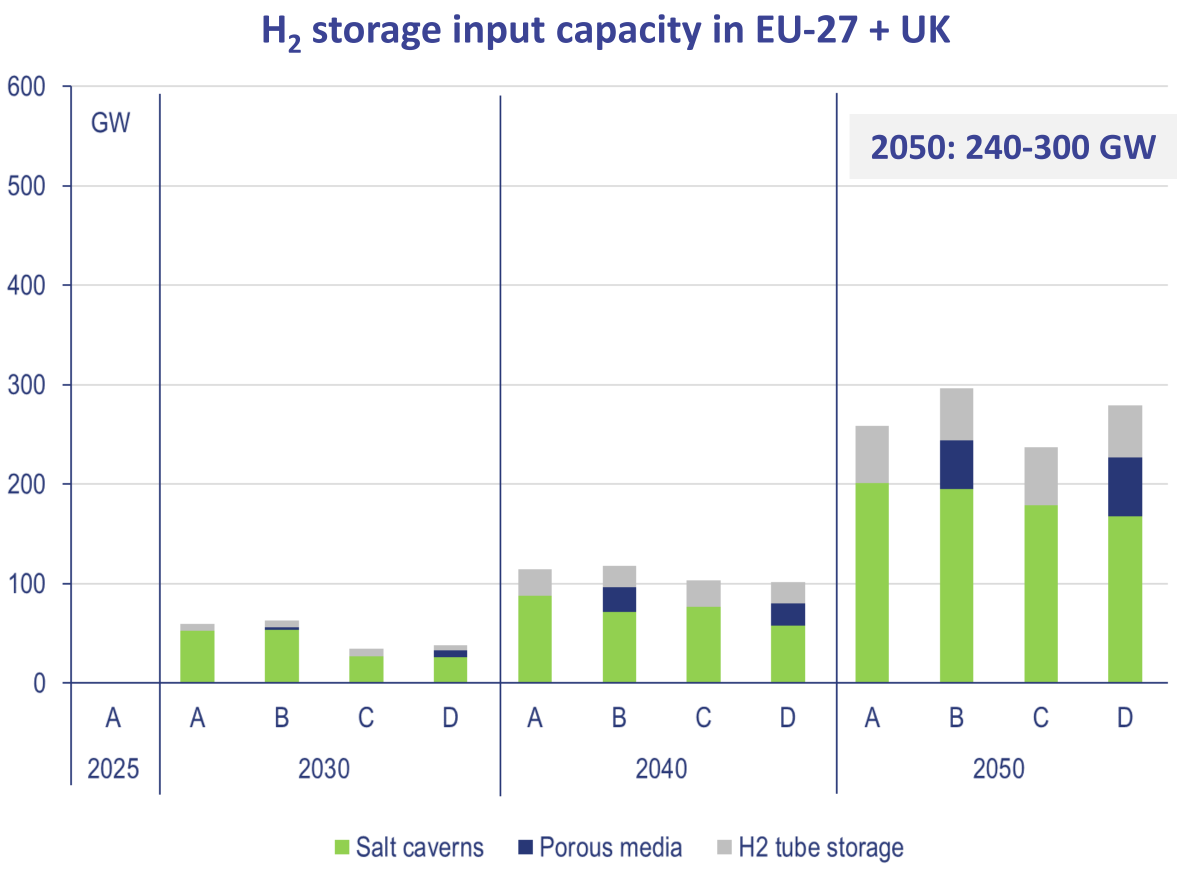
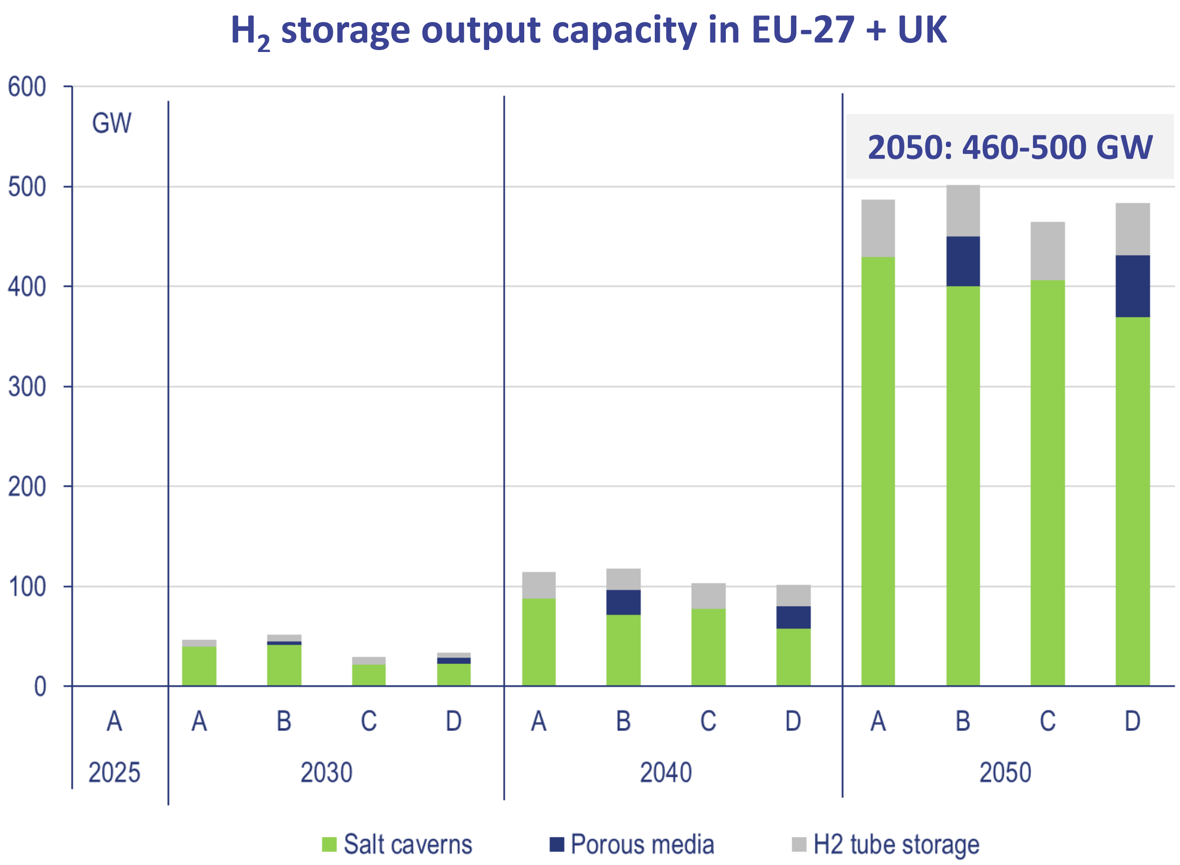


- **Substantial need** for underground H_2 storage capacities in EU27+UK – main driver: overall H_2 demand
- General level of total capacities similar in all scenarios
- Demand **comparable to natural gas storage reservoirs in use today** (with volume capacity/demand around 15 - 20%)
- Technology split: **porous media account for up to 52%** of required storage capacities (scenarios B&D)

Required H_2 storage injection and withdrawal capacities up to 300 GW (input) and 500 GW (output).

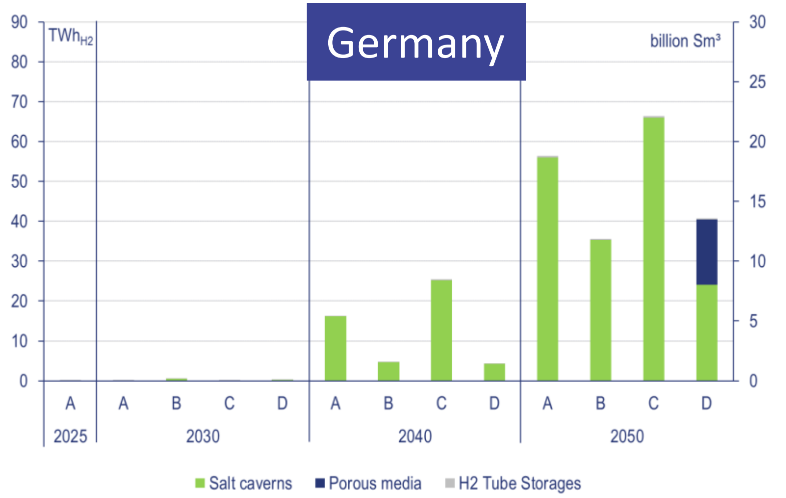


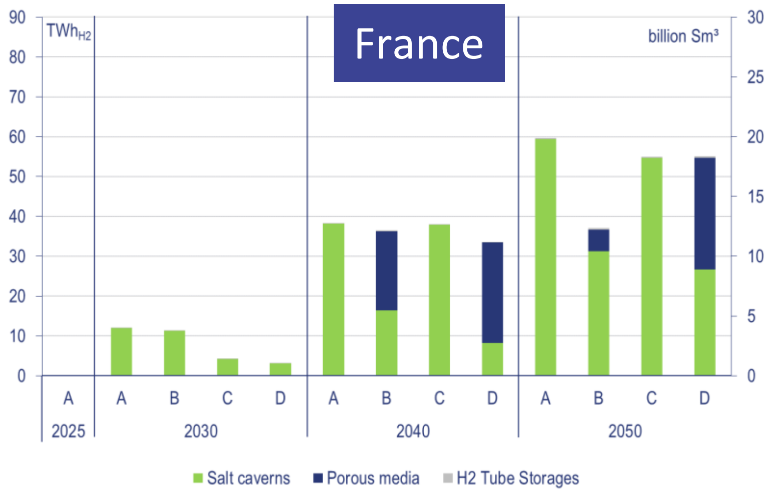


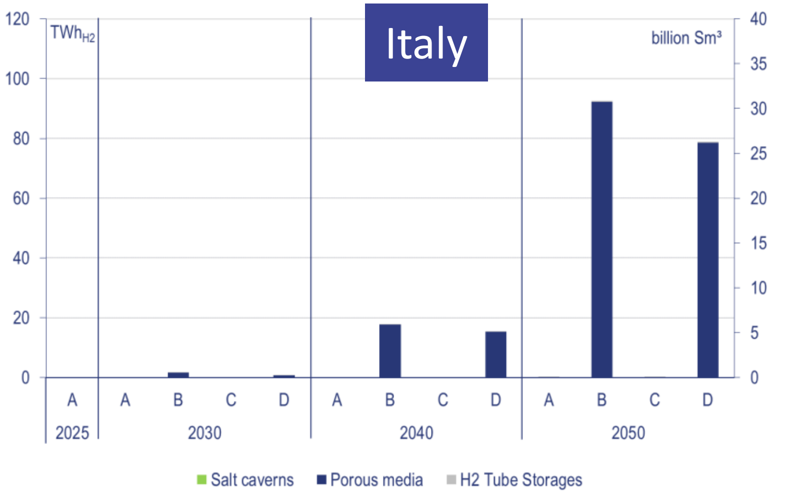
Required withdrawal capacities in 2050 by factor 2 higher than injection (reason: re-electrification demand).

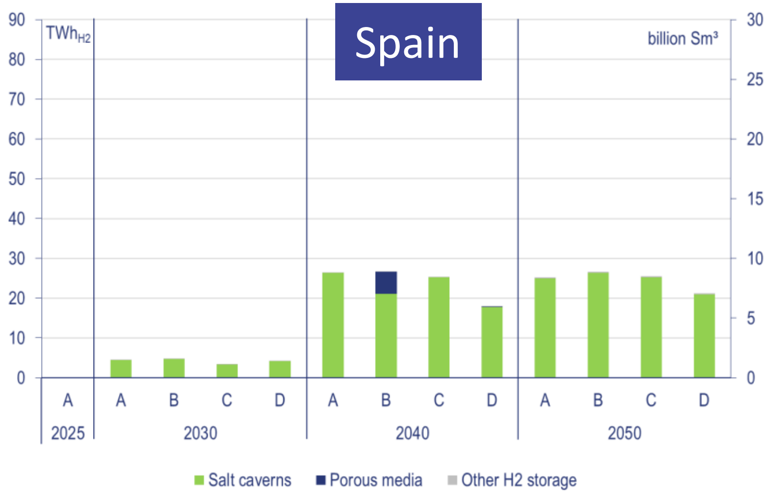
Country results: Six countries account for up to 70% of storage capacity in 2050.

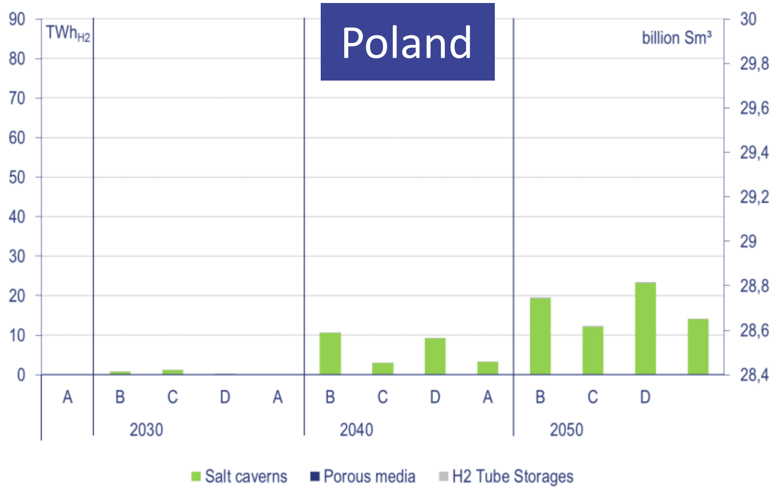
- Six countries (DE, FR, IT, UK, ES, PL) with **55 - 70% of storage capacity** in 2050
- Highly **heterogeneous technology split** per country
- Porous media: strong role in IT (no potential for salt caverns)











Strong seasonal pattern in storage operation for both technologies (example France).

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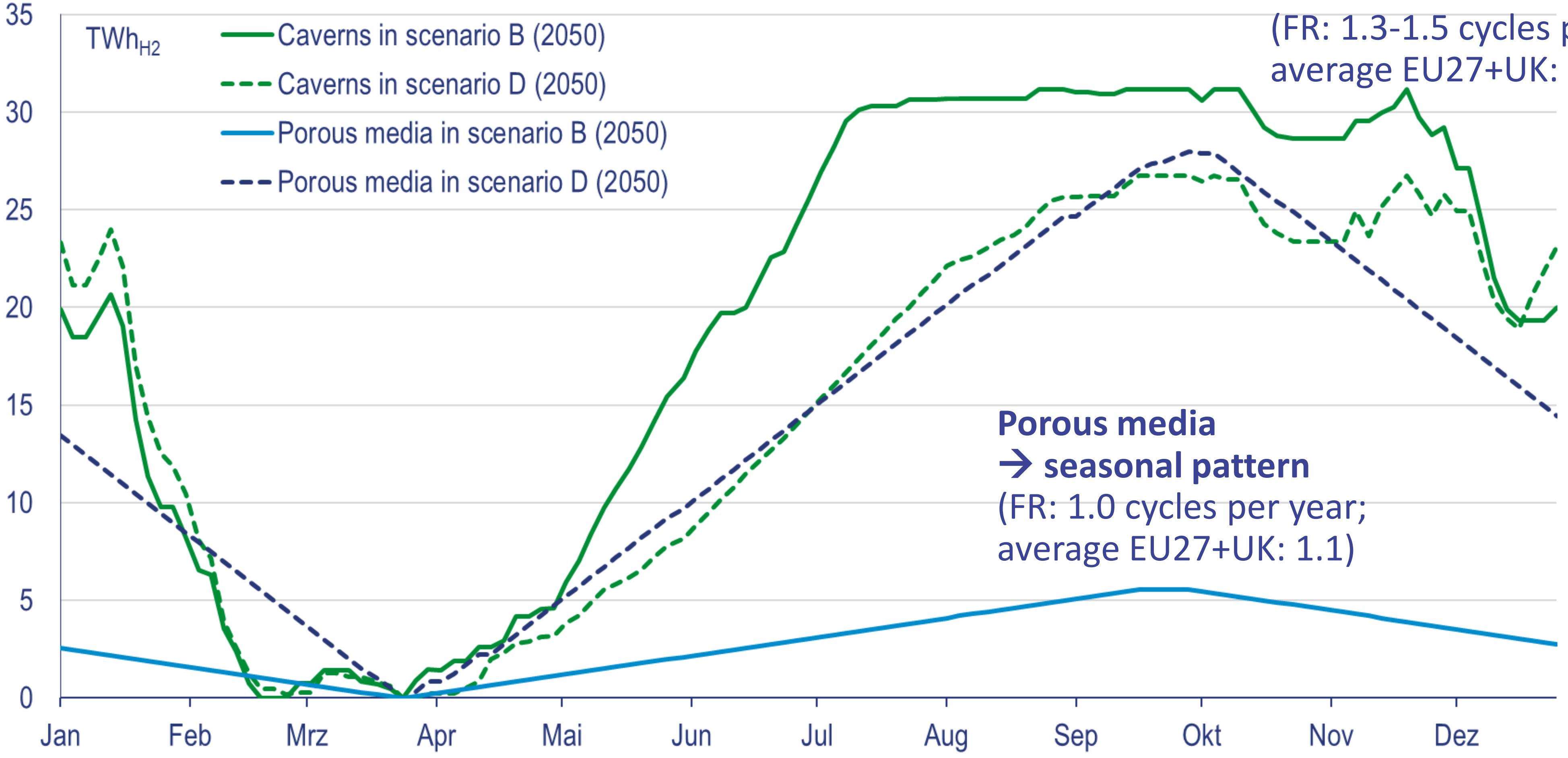
Exemplary storage operation: France (2050)



Salt caverns
→ some short-term fluctuations
(FR: 1.3-1.5 cycles per year; average EU27+UK: 1.9)

Porous media
→ seasonal pattern
(FR: 1.0 cycles per year; average EU27+UK: 1.1)

Different role of salt caverns and porous media storage in energy system.

Salt Caverns (Scenarios A – D)

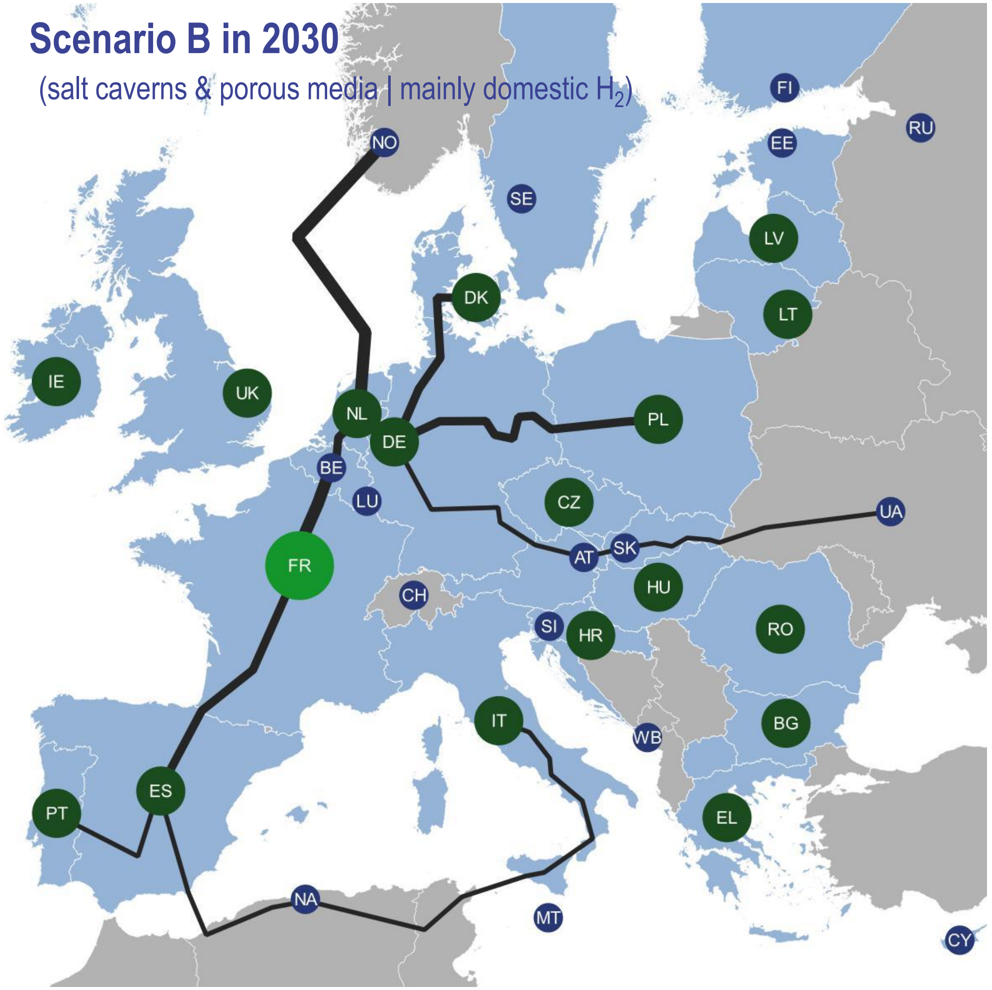
- **Key UHS technology in most scenarios** (280 TWh (salt caverns only) and 160 TWh (with porous media potential)
- 55-90% of overall H_2 **storage throughput**
- **Volume / withdrawal ratio:** 400 – 2,000
- Flexible operation enables **fast cycling** (around 1.5 - 2 full cycle equivalents per year)
- **Limited geographical distribution** → H_2 flows between countries mainly bidirectional

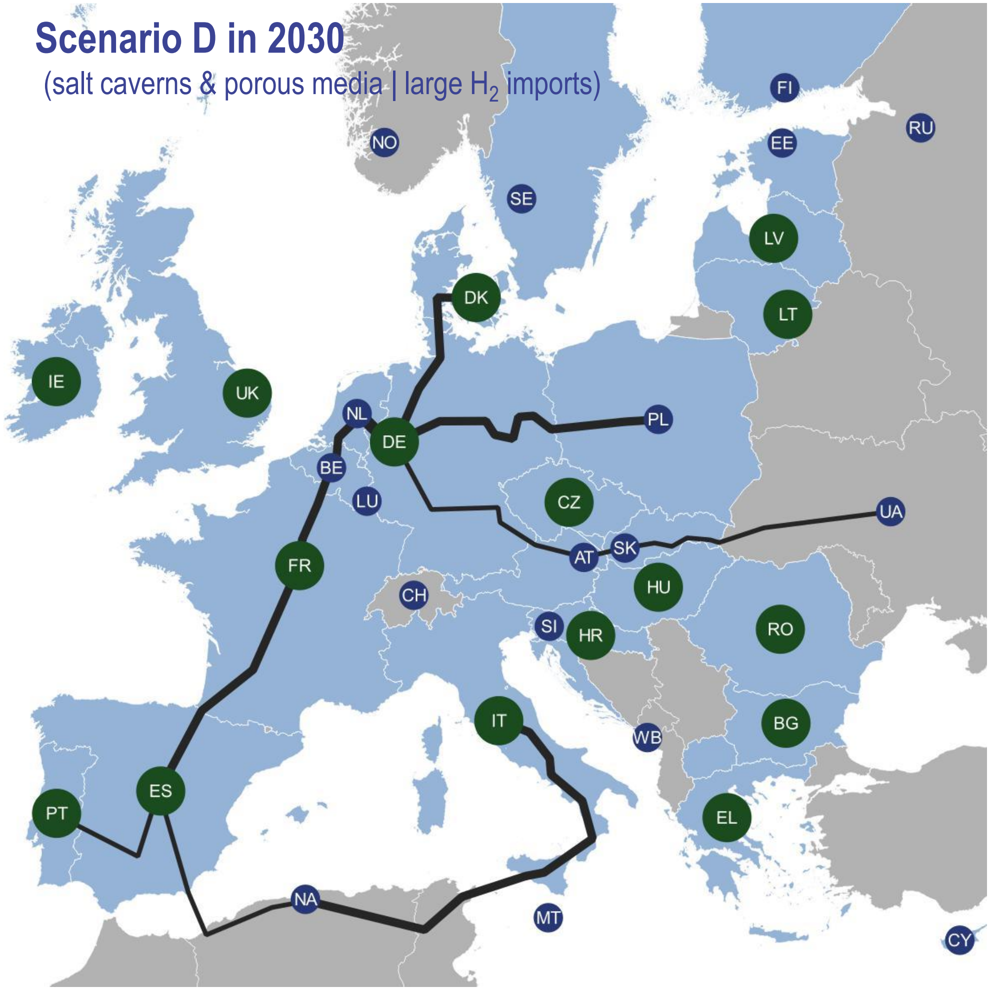
Porous Media storages (Scenarios B & D)*

- **Increasing role after 2030**, around 50% of volume capacity in 2050 (if technically feasible) (150-170 TWh)
- 6-35% of overall H_2 **storage throughput**
- **Volume / withdrawal ratio:** 1,250 – 3,300
- **Seasonal cycling** (around 1.1 full clycle equivalents per year)
- **Higher spatial distribution of UHS** → important role in countries with no potential for salt caverns → less infrastructure need and less curtailment

* In addition to salt caverns.

Hydrogen infrastructure development (1/3): Scenario B & D 2030 – Salt caverns and porous media





Underground H_2 storage size (TWh_{H2})

- None
- <10
- <25
- <150

H_2 pipeline capacity (GW_{H2})

- 0 - 2
- 2 - 10
- 10 - 30
- 30 - 40
- 40 - 50

Detailed country representation

Hydrogen infrastructure development (2/3):
Scenario B & D 2040 – Salt caverns and porous media

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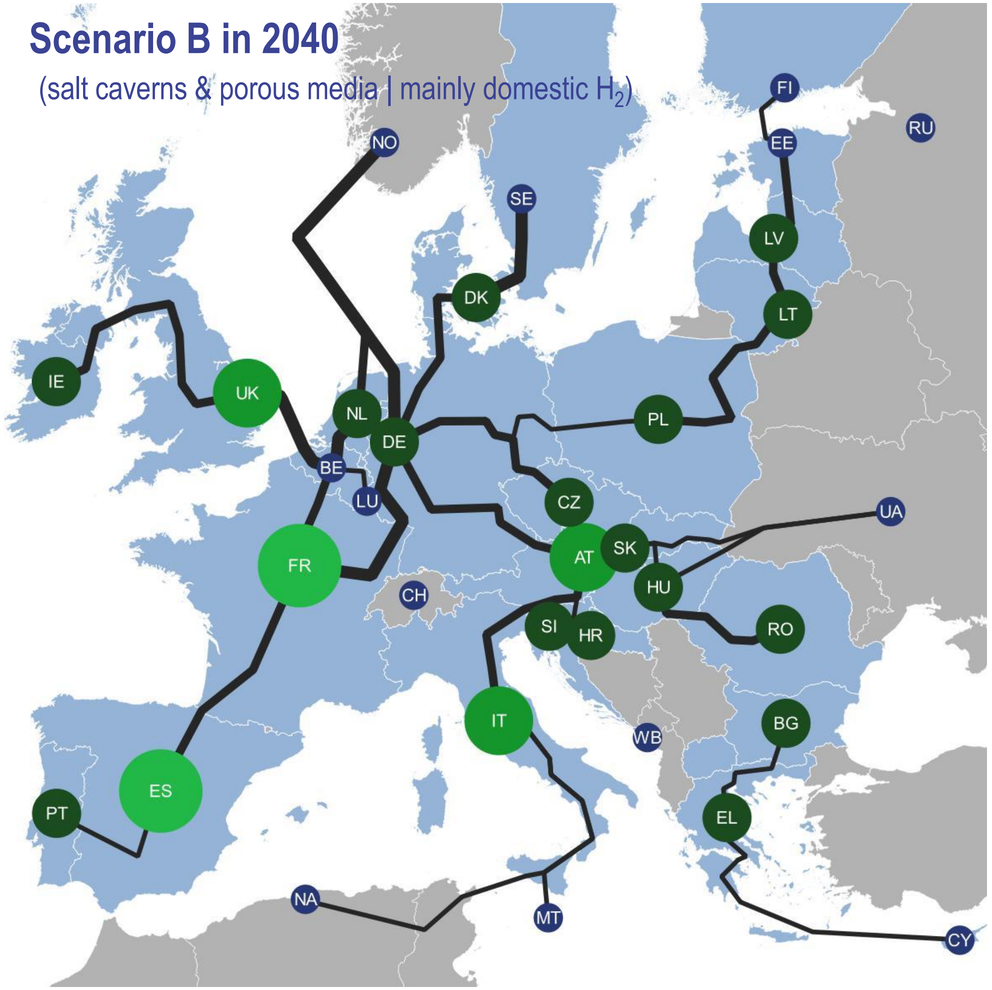
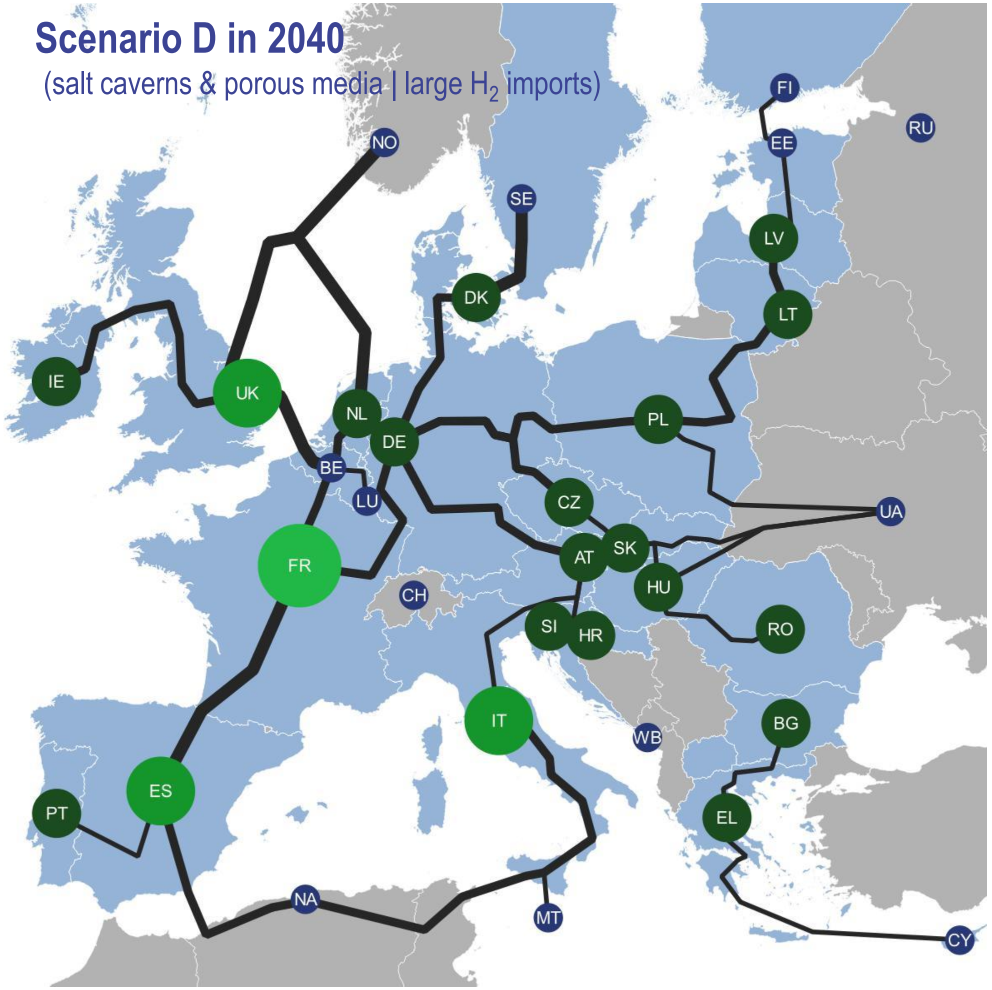




Underground H_2 storage size (TWh_{H2})

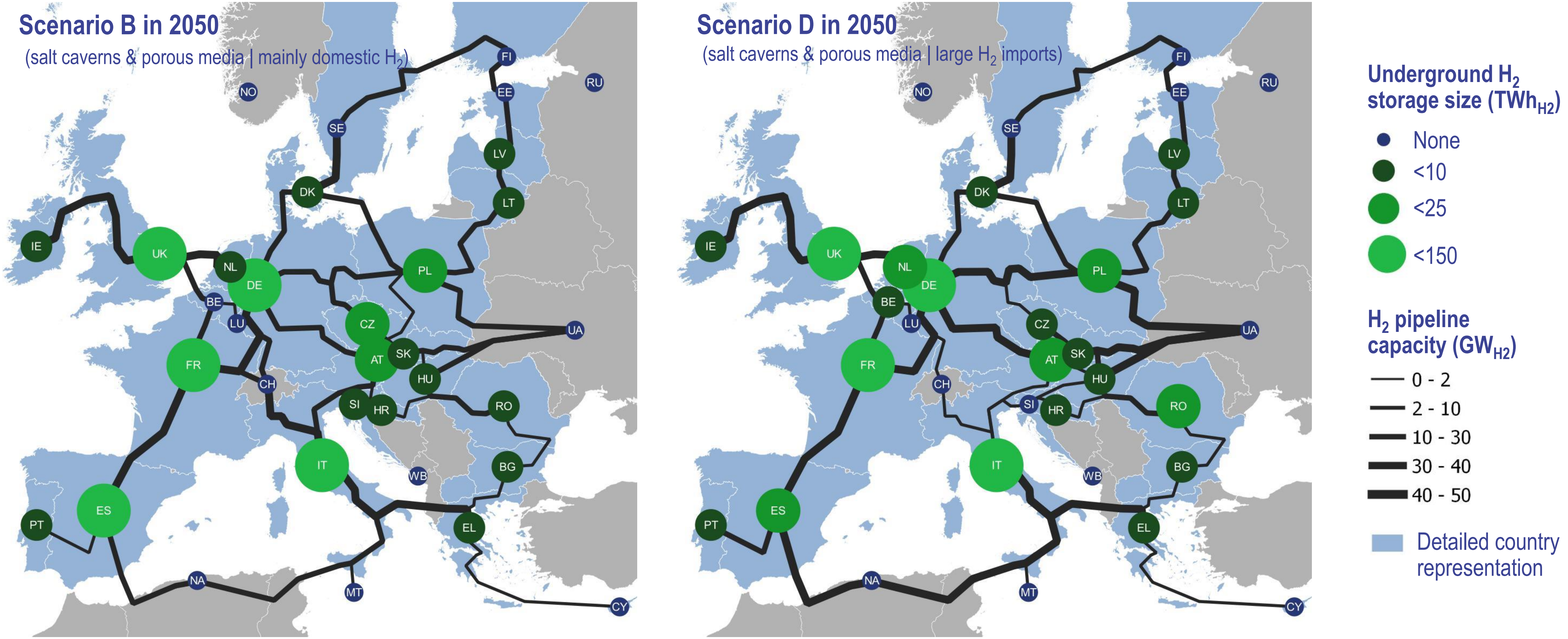
- None
- <10
- <25
- <150

H_2 pipeline capacity (GW_{H2})

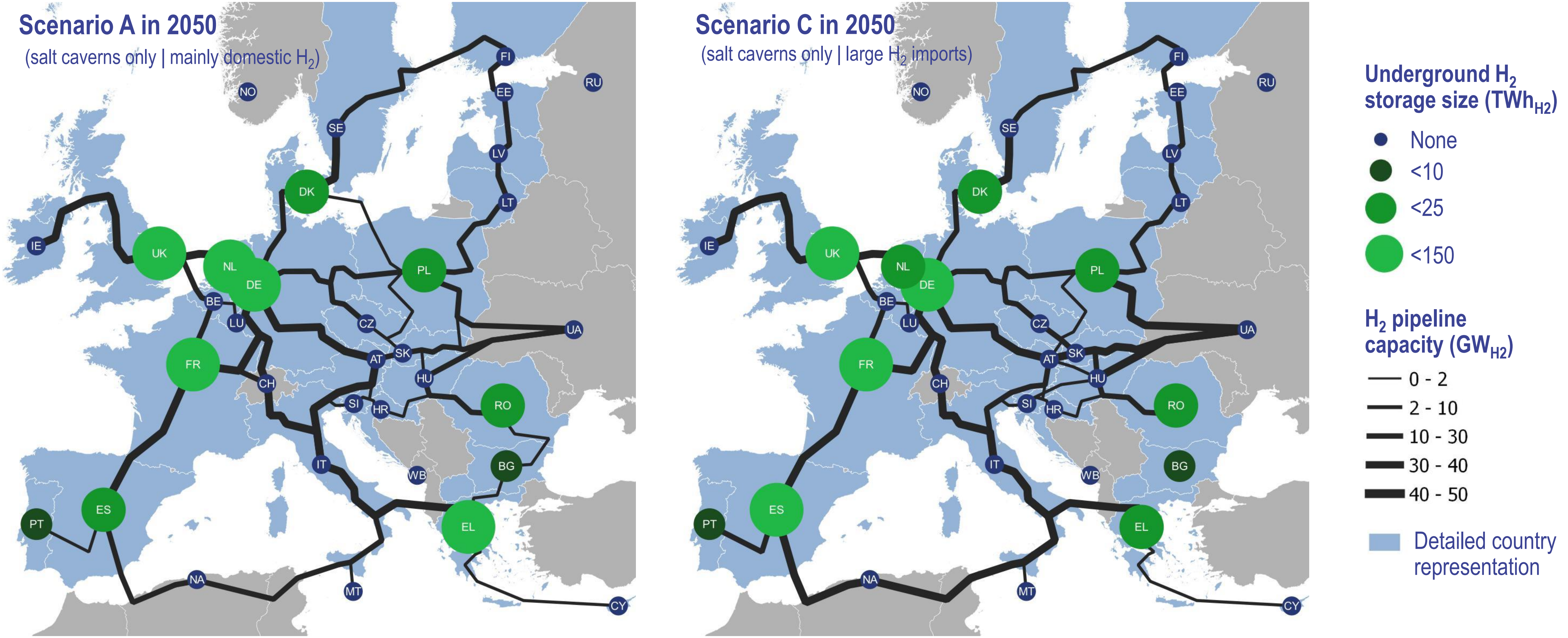
- 0 - 2
- 2 - 10
- 10 - 30
- 30 - 40
- 40 - 50

Detailed country representation

Hydrogen infrastructure development (3/3): Scenario B & D 2050 – Salt caverns and porous media



Hydrogen infrastructure
Scenario A & C 2050 - salt caverns only



5 Conclusions

Underground hydrogen storages are crucial for future energy system.

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- **Pivotal role for H_2 technologies in future energy system**:
  electrolysis (370-490 GW_e) and underground H_2 storage (280-320 TWh) until 2050
- BUT: already in **short term (until 2030) significant demand**
  → planning need to start now
- Green H_2 flows from peripheries (with large renewables potential) to central Europe (with large hydrogen consumption) → **transport infrastructure as key element**
- **Strong seasonal pattern** in storage operation for both technologies with **salt caverns** providing **additional short-term buffer**
- Application of UHS in **porous media …**
  - **… enables broad geographical distribution of storage facilities** across Europe and thus …
  - **… reduces curtailment and infrastructure needs** (helps to integrate RES)

Hystories project consortium

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The Project is co-founded by European Union

Thank you !

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