

Underground Hydrogen Storage: A Data-Driven Approach to Site Selection and Performance Optimisation

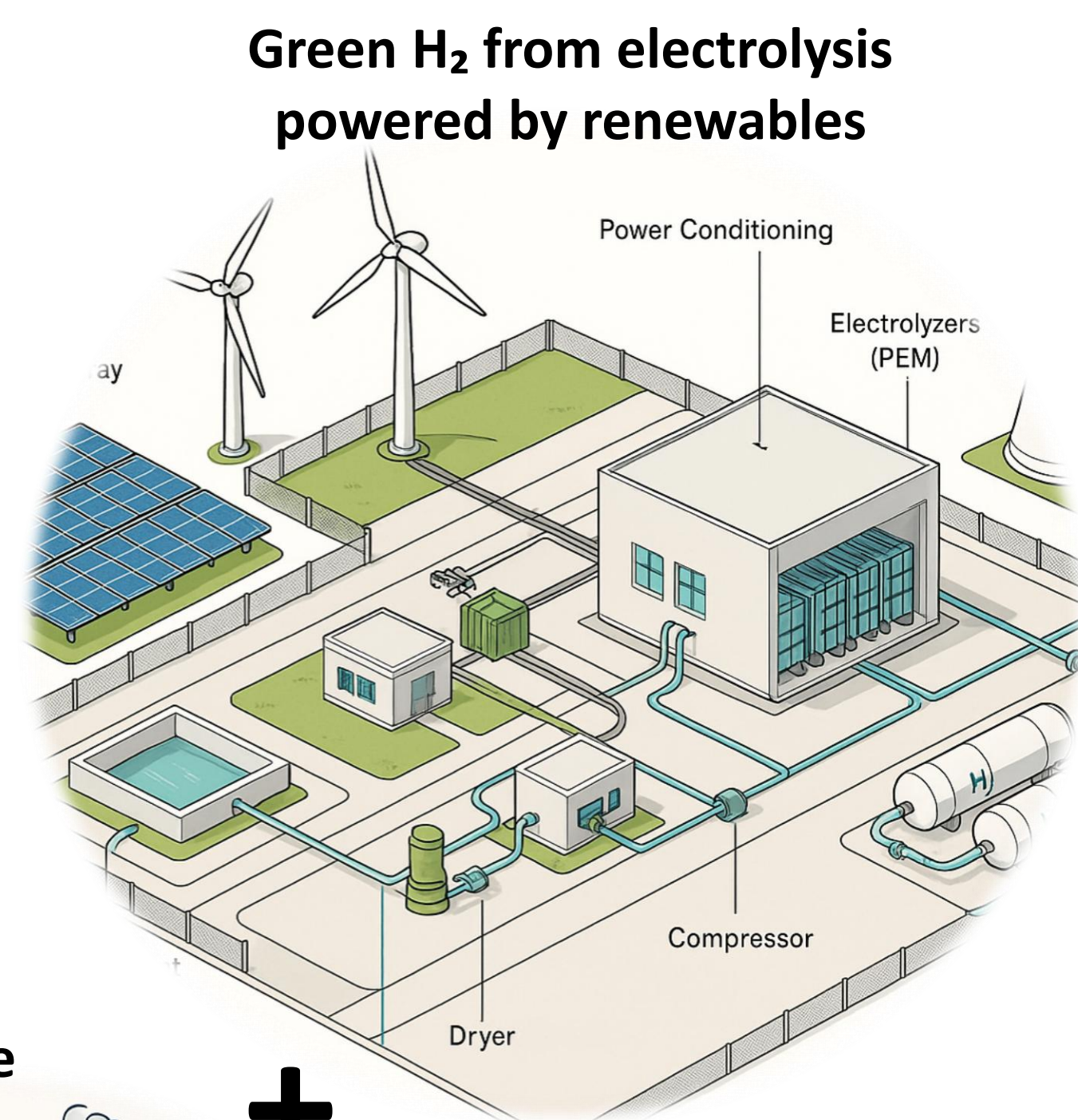
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1. INTRODUCTION

Hydrogen is a **versatile energy carrier** for decarbonising industry, transport, heating and power. Low-carbon production—via electrolysis using renewable electricity and reforming with carbon capture—will expand **unevenly** across time and location, while end-use demand is similarly variable. Without buffering, systems face curtailment of renewable power, stranded hydrogen assets and price volatility. **Underground hydrogen storage (UHS)** provides **temporal and spatial balancing** by absorbing surplus and supplying on demand. Surplus can also be exported where infrastructure and policy allow; otherwise, storage enables reliability, security of supply and better asset utilisation.

2. HYDROGEN CYCLE

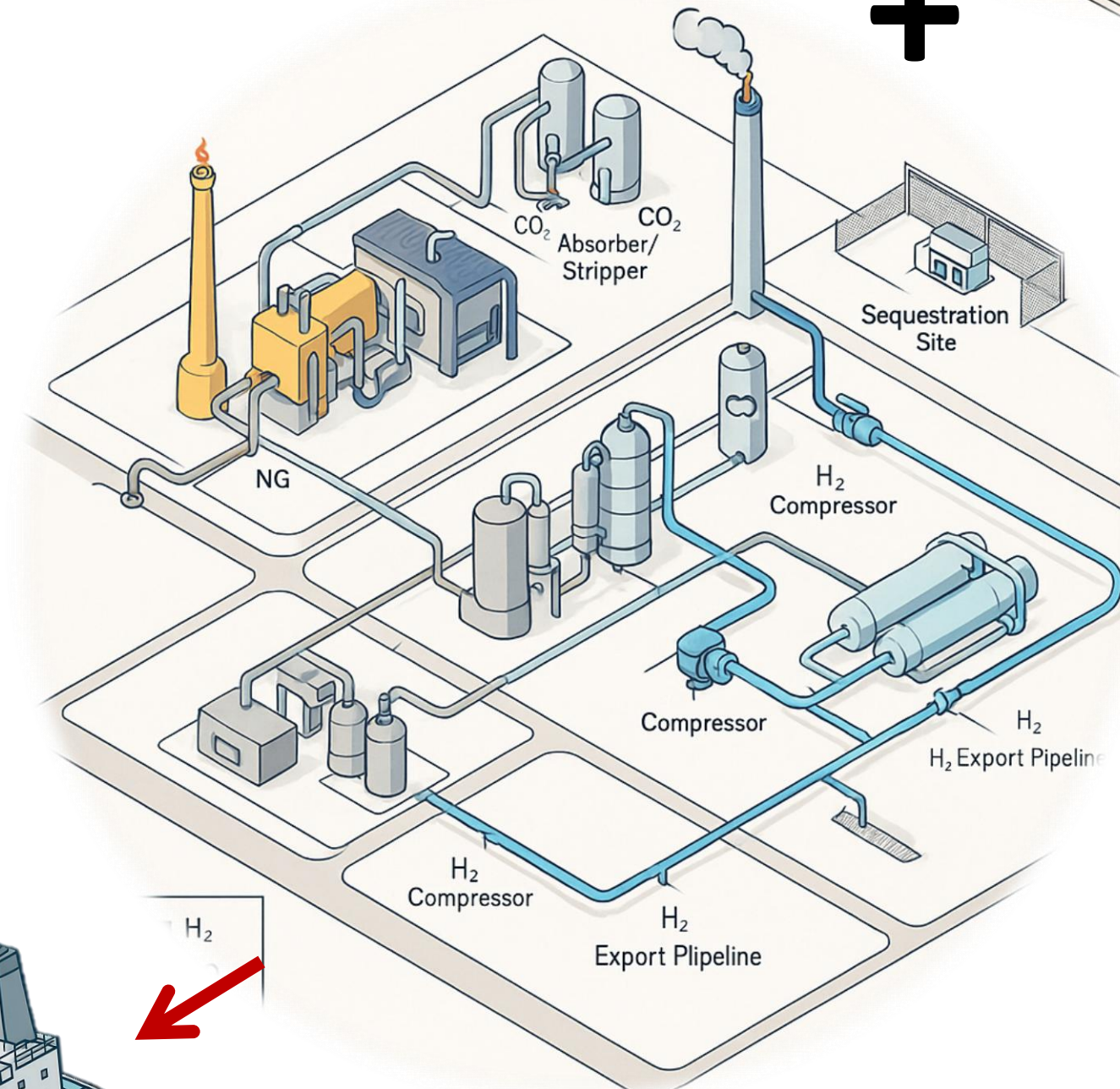
- Electrolysers split water using renewable electricity to produce hydrogen and oxygen. Output varies with wind and solar **availability**, creating periods of **surplus**.



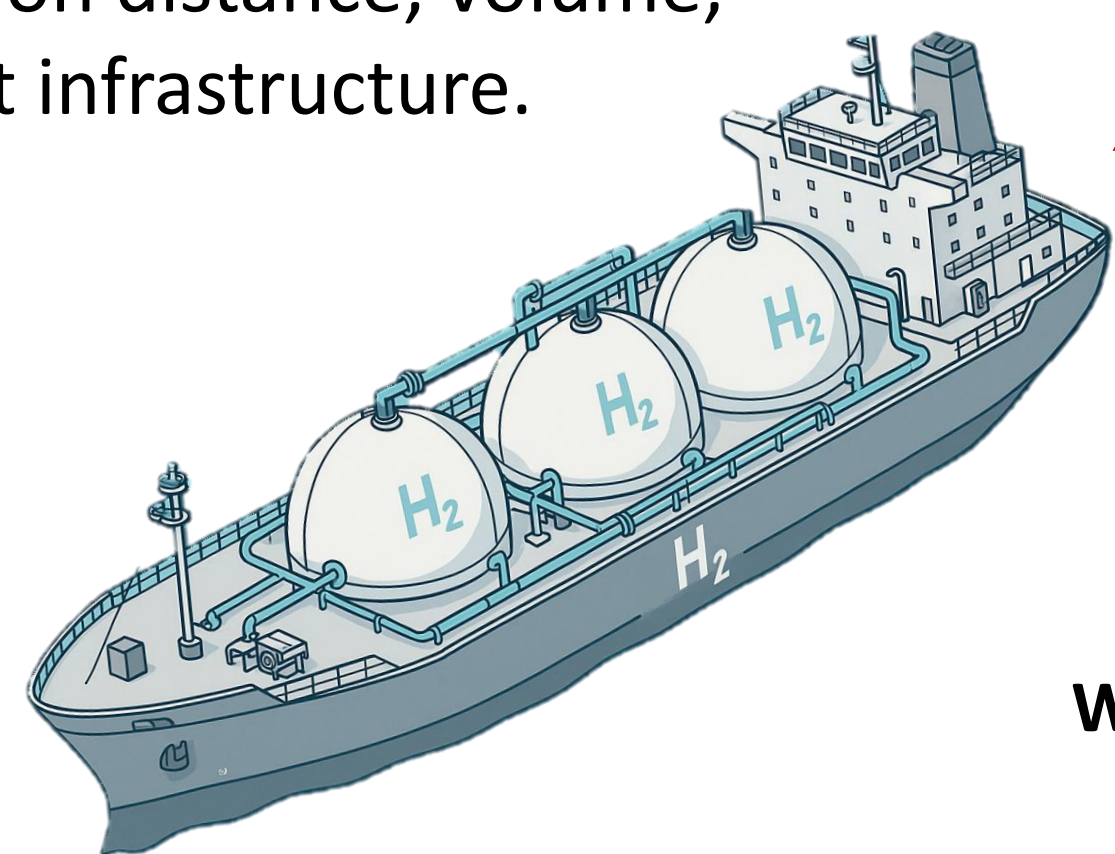
- Demand ranges indicate roughly **18–41 TWh** in 2030 (industry **12–19**, power **5–15**, transport **1–4**, heat **0–3** TWh). Demand is concentrated around industrial clusters and flexible power, with building heat remaining limited pending strategic decisions.

- Plants typically run at a **steady load**, supporting continuous industrial offtake.

Blue H₂ from natural gas reforming with CO₂ capture



- For export, hydrogen can move as **compressed gas, liquefied H₂**, or converted carriers (e.g., **ammonia**). Choice depends on distance, volume, and existing port infrastructure.



When supply > demand → store or export

- Temporal** and **spatial** mismatches arise seasonally. When immediate local demand is lower than production, surplus hydrogen is routed to storage or exported via pipeline/port.

3. HOW TO MAKE UHS HAPPEN (Dynamic Site Selection)

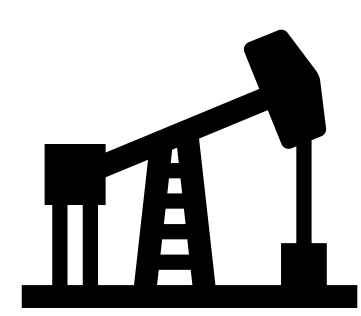
- Selecting suitable storage sites poses significant challenges due to **geological variability** and **operational uncertainties**.
- Most studies have focused on the **static properties** of geological formations, including rock porosity, permeability, and risk factors such as existing faults.
- Hydrodynamic parameters**—including hydrogen trapping, reservoir heterogeneity, and hysteresis in flow functions—also play a key role in determining more realistic storage capacity and efficiency.

Static Screening is not enough
The solution is:

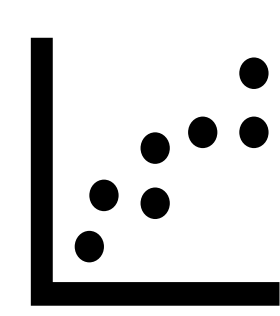
Integrates machine learning (ML) with static and dynamic screening to enhance site selection



Develop data-driven criteria for UHS site selection in the UK



Optimise storage efficiency through dynamic reservoir simulations



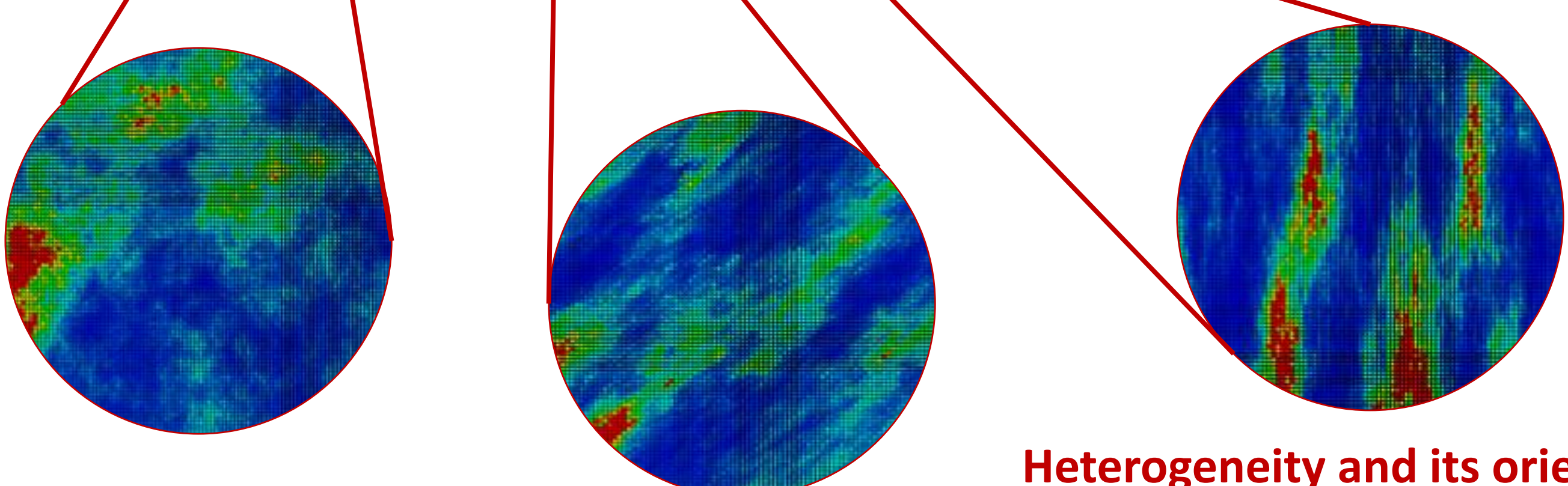
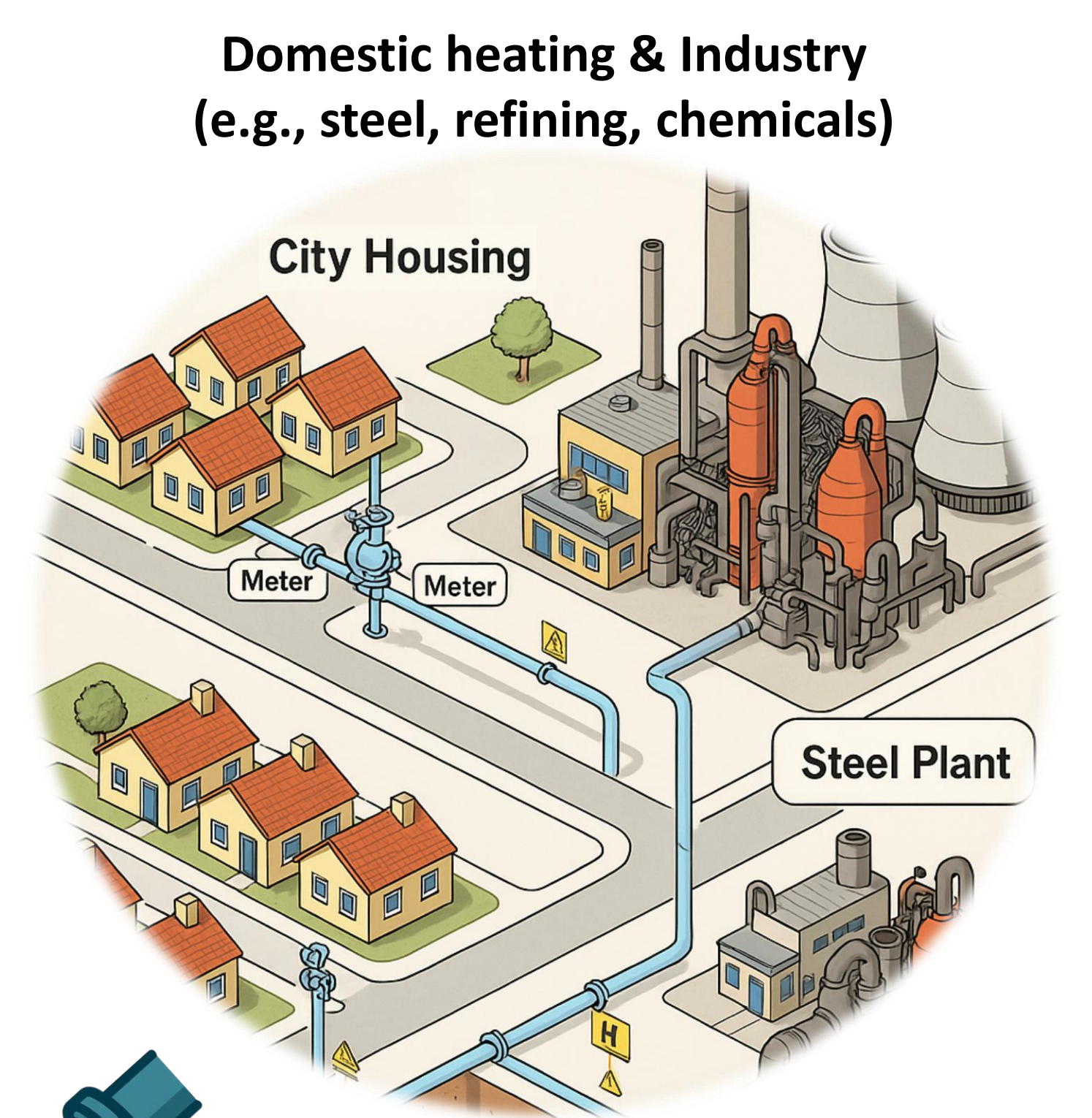
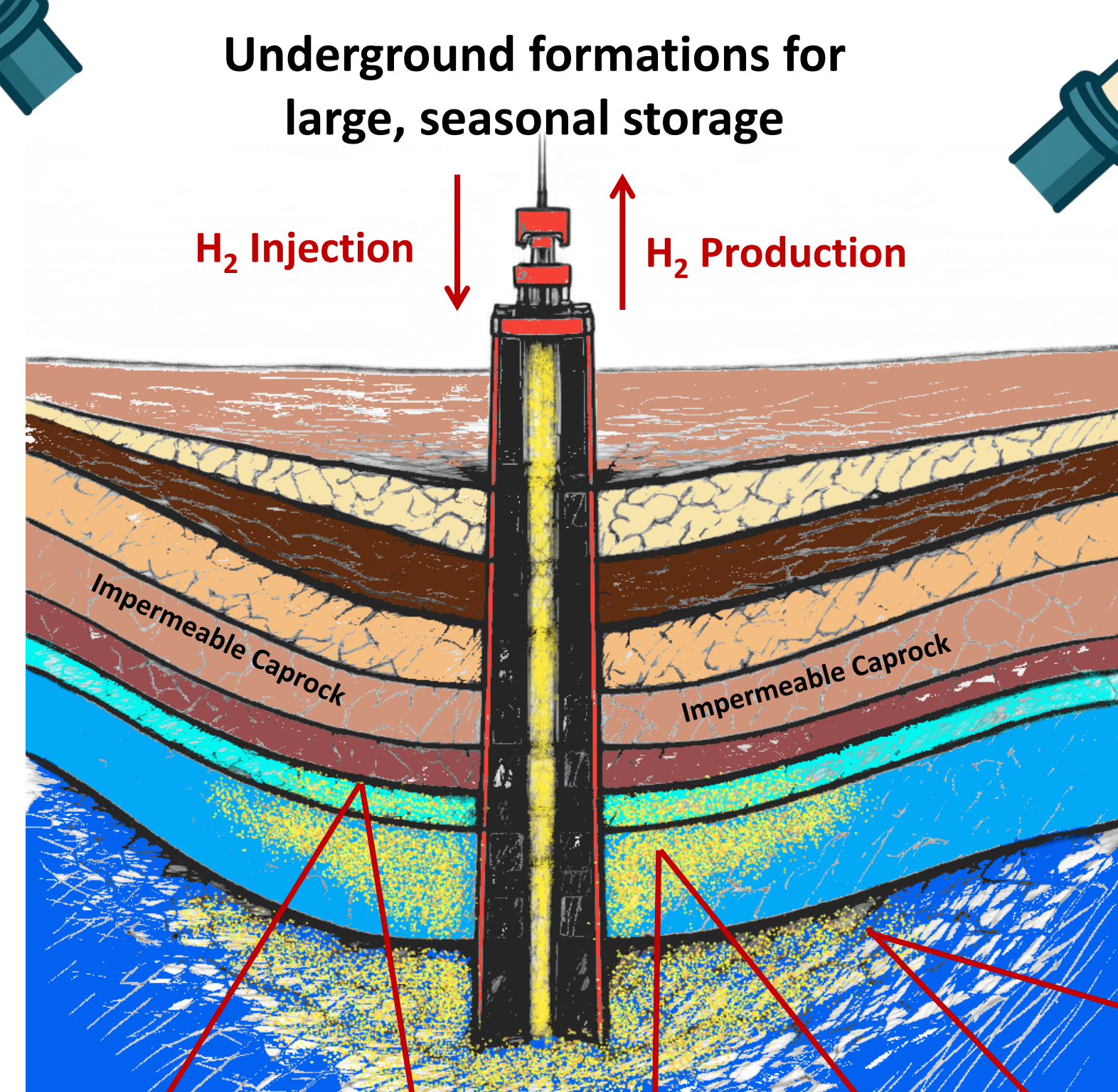
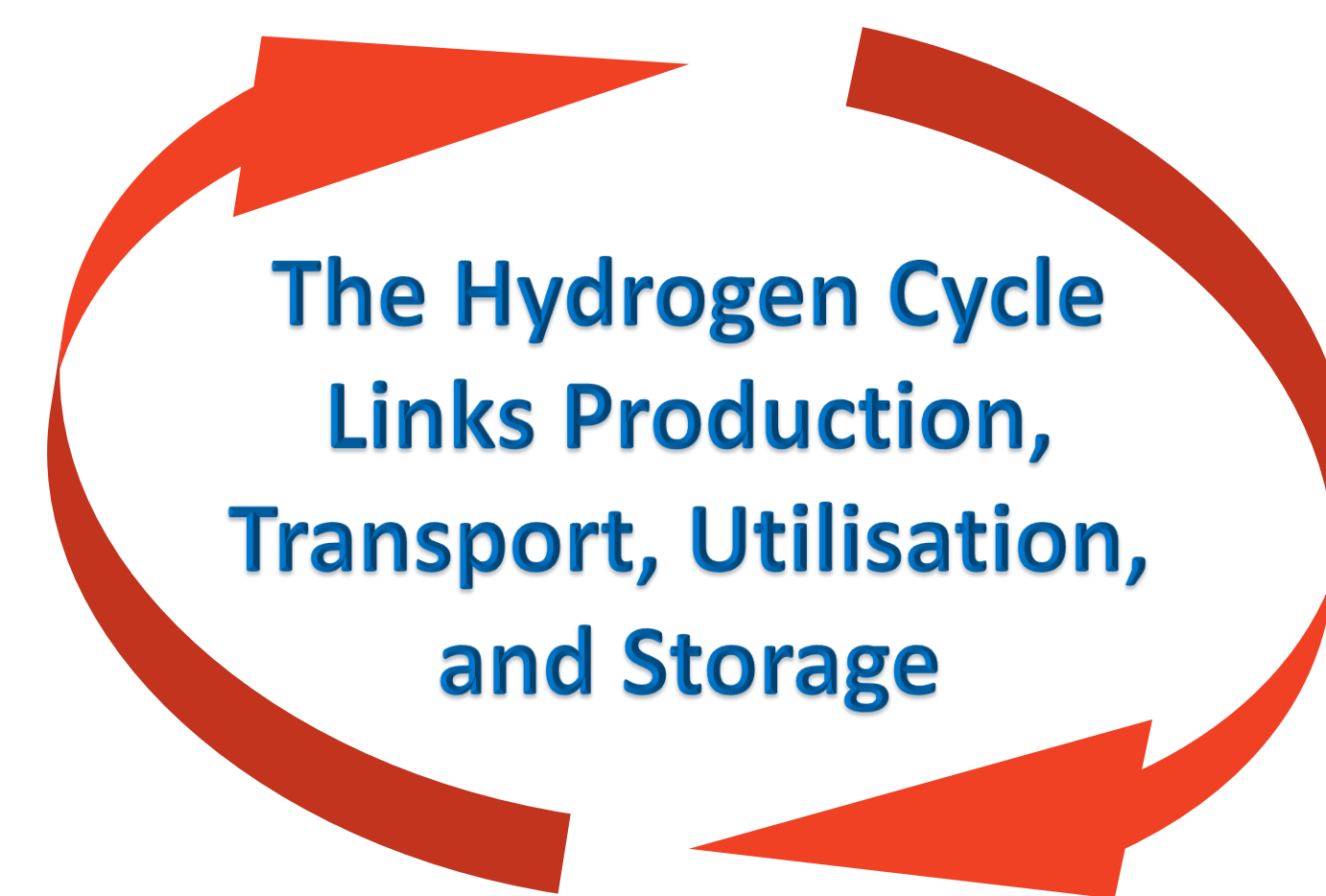
Establish Hydrodynamic correlations for H₂ via ML for diverse geological settings

4. CONCLUSION

- The **interplay between geological heterogeneity and fluid dynamics** critically controls the efficiency of underground hydrogen storage. Our numerical models demonstrated that these factors are not secondary considerations but primary drivers of hydrogen loss and recovery.
- Beyond static volume:** The methodology presented here offers an improved tool for the initial screening and characterisation of potential storage sites, highlighting the necessity of moving beyond static assessments.
- Tailored Operational Strategies:** Adjusting injection/production rates based on hydrogen production and demand, reservoir characteristics, geomechanical stability and other factors is a must.
- System fit matters:** Storage in proximity of production clusters and demand hubs to cut transport cost, losses, and turnaround time.

References

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Heterogeneity and its orientation control storage performance

Why store? avoid curtailment, improve asset utilisation, and security of supply

Routing drivers: distance, pipeline/transport, market priced, policy

Storage use: daily balancing (salt caverns), seasonal balancing (aquifers/depleted fields)

Heat demand varies daily and seasonally