Definition of Selection Criteria for a Hydrogen Storage Site in Depleted Fields or Aquifers

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1. Introduction

1.1. Experience in underground storage of hydrogen

There is industrial experience for pure hydrogen storage stored underground in salt caverns: storage has been undertaken since 1972 in Europe (at Teeside, UK). Réveillère and Hévin (2019) note that this was only 11 years after the 1st natural gas cavern started operating in Michigan, USA.

There is industrial experience for storage of hydrogen mixed with other gases in depleted fields or aquifers. The technical Association of the European Natural Gas Industry (Marcogaz, 2017) stated that "historically, manufactured gas was produced in the 19th Century and the first half of the 20th Century. It is also referred to as town gas or water gas. It typically contained 30%–50% hydrogen and was used for heating and cooking until its replacement by natural gas". Marcogaz (2017) includes a table with at least seven sites, now decommissioned or used for natural gas storage, that stored such gas with "30%-50% Hydrogen". All those sites are in Europe: Engelbostel, Hähnlein, Eschenfedlen, and Ketzin aquifers in Germany, Kirchheiligen depleted gas field in Germany, Lobodice aquifer in Czechia and Beynes aquifer in France. More recently, some new pilot sites injected hydrogen/natural gas admixtures: Hychico in Argentina, or the Sun project in Austria, in the very small, isolated, depleted gas field HP3A (no active aquifer) with injection gas containing as much as 10% H_2 (Pichler, 2019).

There is currently no industrial experience in storage of pure hydrogen in depleted oil and gas fields.

This report identifies a set of parameters to be used to characterize possible aquifers and depleted hydrocarbon fields, to screen and select prospects for pure hydrogen storage. This report focuses on characteristics of particular interest for pure hydrogen storage. As there is a lack of industrial experience of hydrogen storage in porous media, these parameters are largely based on experience from natural gas storage and town gas storage in porous media. Additional criteria have been added where particular geochemical reactions would be expected based on the sensitivities of hydrogen.

1.2. Methodology for defining criteria for the selection of new storage sites

The main purpose of the screening criteria and of H_2-relevant parameters is to identify a set of parameters to assess if aquifers and depleted hydrocarbon fields have potential for storage and to use this to assess regional performance in terms of capacity (volumes) and deliverability (storage performance in injection and withdrawal) for pure underground hydrogen storage.

These parameters will then need to be stored in a referenced database and displayed in a dedicated georeferenced system (i.e. using GIS system) to ensure site selection based upon the technical challenges which could be foreseen or encountered during the development of an underground hydrogen storage site.

There is currently no established procedure for selecting an underground storage site for pure hydrogen. Therefore, it seems necessary to adapt the selection procedures from those used for underground natural gas storage (UGS) and experience from studies of natural gas storage field conversion into storage of a blend of hydrogen and natural gas. In addition, new criteria must be introduced to consider the underlying fundamental processes specific to hydrogen in the subsurface (e.g. fluid flow, diffusion geochemistry, and microbial activity).

In the context of the start of the Hystories project, without a precisely identified storage demand, the screening will be quite broad. Without an objective storage capacity already defined, it is difficult to exclude sites based on size, porosity, expected capacity, etc. Without an objective deliverability (injection and withdrawal flow rates), storage site prospects with various degrees of homogeneity, continuity, shape, permeability and depth can be considered.

Hydrocarbon fields are deemed to be highly suitable for hydrogen storage as they have been trapping and storing natural gas and oil for geological periods of time. However, there is some question over the reaction of H2 with the native pore fluids.

Aquifer formations are generally less explored and characterized than hydrocarbon fields. They can contain traps suitable for hydrogen storage. Particular attention will be paid to the overburden formations which must demonstrate effective sealing properties.

2. Applicability of Selection Criteria Used in Natural Gas Storage to Hydrogen Storage

2.1. Underground gas storage site selection criteria fundamentals

There is no experience, and therefore no standard practice, for screening or ranking aquifer or depleted oil/gas field candidates for pure hydrogen storage. However, hydrogen storage in porous media is in principle similar to natural gas storage.

It appears intuitive to transfer the knowledge from natural gas storage to hydrogen storage in depleted oil and gas fields and aquifers. There are limited absolute criteria for natural gas storage site selection but ranking of sites based on favourable and unfavourable characteristics is possible. The same is expected for pure hydrogen storage. Based on Geostock's experience, a selection procedure of natural gas storage sites would first rely on:

- a location compatible with the storage demand, or "objective"
- the identification of a trap with the required pore space volume
- the appropriate connectivity of this pore space to provide the required deliverability.

2.2. Worldwide statistics on Underground Natural Gas Storage

According to CEDIGAZ association (Cornot-Gandolphe, 2020), at the end of 2019, there were 564 underground gas storage (UGS) facilities in porous media in operation in the world (76 in aquifers and 488 in depleted hydrocarbon fields), representing a global Working Gas (WG)[1] capacity of 386 bcm[2] (47 bcm in aquifers and 339 bcm in depleted hydrocarbon fields). The figures below show some statistics about the capacity of existing gas storage facilities in depleted fields and aquifers that might be used as references for the design of pure hydrogen storage in porous media:

- The world average volume of gas stored per site in depleted hydrocarbon fields and aquifer storages is **1.1 bcm.**

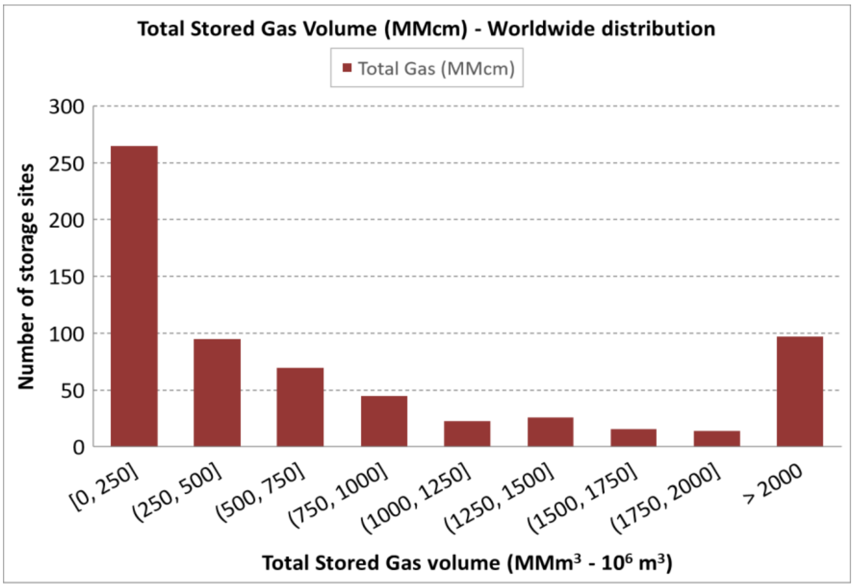

Figure 1: Worldwide statistics of total stored gas volume per site (Source: CEDIGAZ).

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1 Working Gas volume (WG): The volume of natural gas intended to be available to the marketplace through periodic injections and withdrawals.

2 Bcm = Billion cubic meters

- About 75% of the storages in depleted hydrocarbon fields and aquifers have a working gas capacity of less than **1.1 bcm** and 60% have a capacity of less than **0.55 bcm.** These correspond to relatively "small size" fields from the point of view of the oil and gas exploration and production industry. The complete worldwide distribution is presented in figure 2 below:

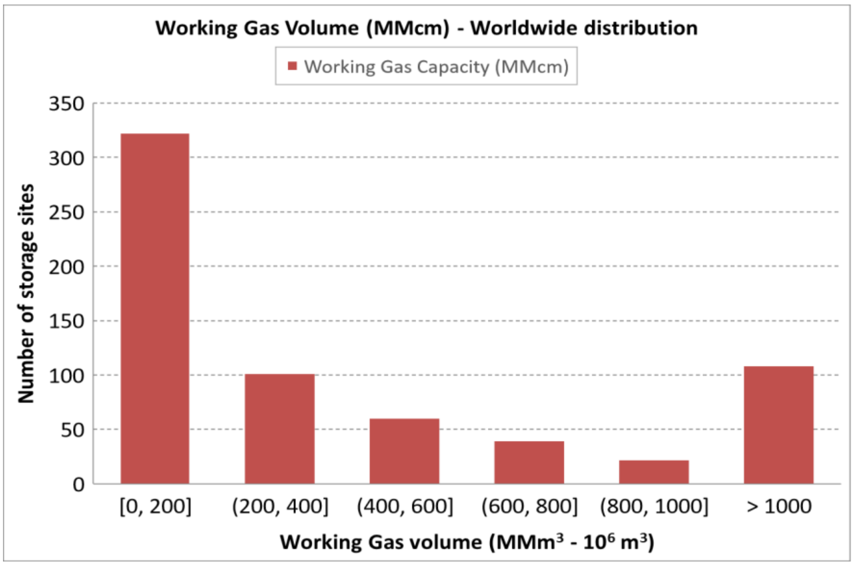

Figure 2: Worldwide statistics of working gas volume per site (Source: CEDIGAZ).

- The world average ratio of withdrawal rate to working gas capacity for depleted fields and aquifer storages is **1.7%/day**: on average, the daily peak withdrawal capacity is 1.7% of the WG capacity (meaning, for example, for WG = 0.55 Bcm, Peak Withdrawal Rate is 4.8 MMcm/d). The worldwide distribution for existing underground storage facilities is presented in figure 3 below:

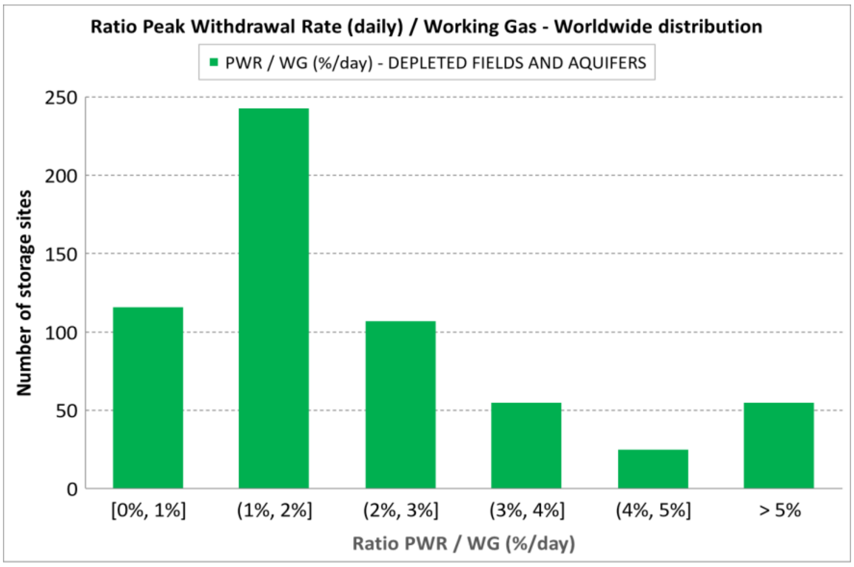

Figure 3: Worldwide statistics of ratio peak daily rate / stored gas (Source: CEDIGAZ).

In addition, some complementary information can be found in the database of the International Gas Union (IGU)[3] regarding the main characteristics of these existing storage facilities (available statistics from 2012):

- About 90% of the storage sites have been developed over an area ranging between 0.3 km^2 and 64 km^2 (based on 328 sites with available data presented in figure 4).

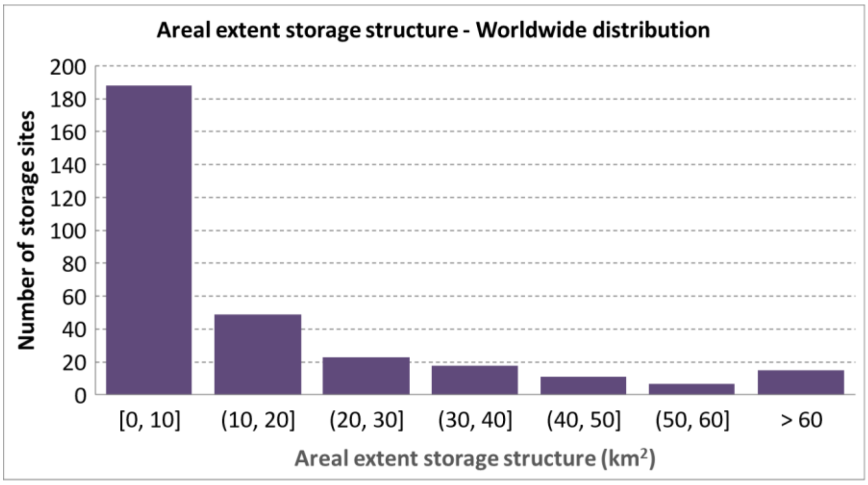

Figure 4: Worldwide statistics of area extent of underground gas storage facilities (Source: IGU).

- About 90% of the storage sites have been developed in porous formations with net thickness of at least 3 m and less than 100 m (based on 447 sites, available data presented in figure 5).

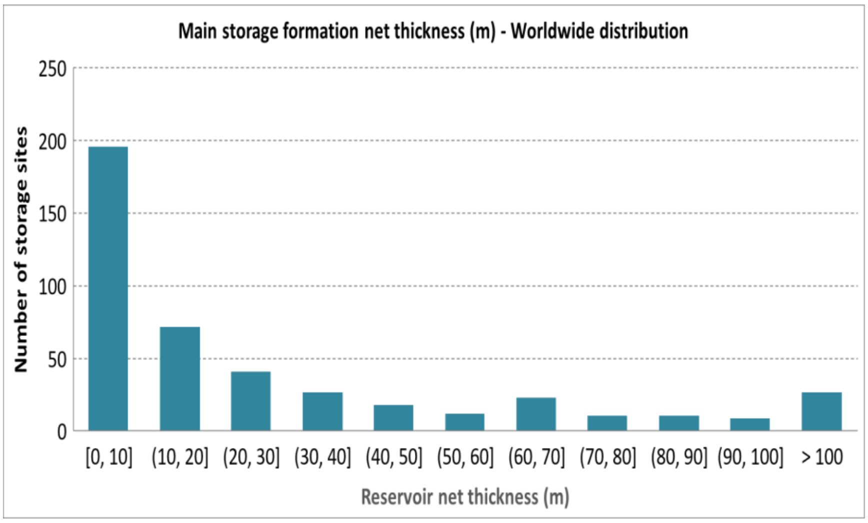

Figure 5: Worldwide statistics of the areal extent of individual underground gas storage facilities (Source: IGU).

[3] https://www.igu.org

- About 90% of the storage sites were developed in porous formations with a top depth ranging from 740 m to 2055 m (based on 448 sites, available data presented in figure 6).

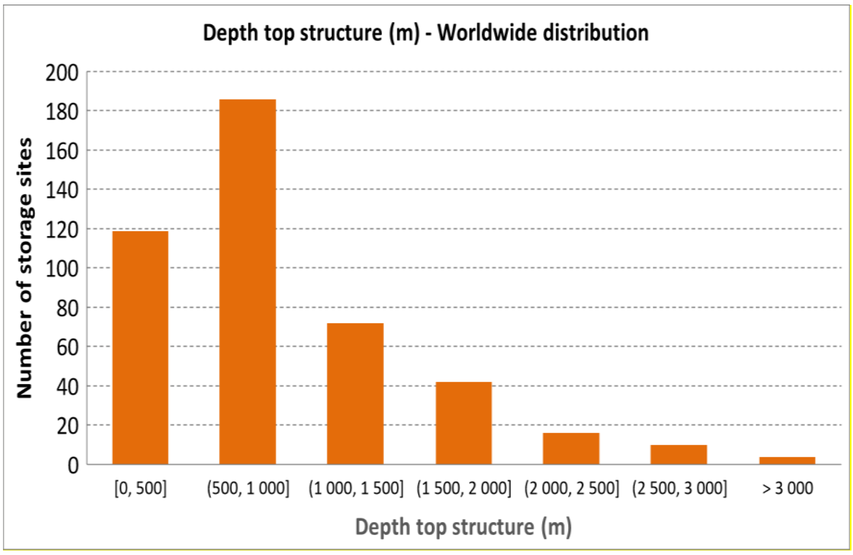

Figure 6: Worldwide statistics of the structure top depth of underground gas storage facilities (Source: IGU).

Although the development of these storages was site- and context-specific, as is expected with future pure hydrogen storage site, as a reasonable recommendation for H_2 storage, it is recommended to target with the following characteristics:

- a net thickness ranging between 3 and 100 meters
- a minimum area of 0.3 km^2 and maximum of 60 km^2
- a maximum top depth of 2500 m.

2.3. Screening (or exclusion) criteria

Criteria are hardly absolute and must be seen as a way to score and rank storage site candidates in a given context. Only a few criteria may be seen as absolute prerequisites and might be considered as exclusion criteria. Based on Geostock's experience, the following are exclusion, or screening, criteria:

- Structure volume is inadequate to achieve the site storage objective
- Structures are too deep
- Structures are strongly faulted
- Structures are not closed
- Seal is not proven or anticipated to be effective
- Structures are beneath big city, international airport, nuclear power station, etc.

2.4. Scoring criteria

The census must be accompanied with a simplified tabulated registry containing key geological and reservoir information (listed in the next chapter) for each potential identified storage candidate.

Ideal candidates for conversion to underground hydrogen storage are fields exhibiting:

- Preferably good reservoir thicknesses,
- A well-delineated structure with sizeable closure height,
- Efficiency of the sealing overburden formation (which might be challenging to assess and prove for an aquifer),
- Good and well-connected porosities and high permeabilities for each reservoir zone,
- A “tank type” production mechanism (influence of cushion gas), even though in some cases a uniform water-drive may be advantageous (pressure support),
- A depth allowing for a pressure range adequate for supply at grid pressure,
- Formation fluids with low impact on storage gas quality and unlikely to result in corrosion issues (sweet gas, low salinity formation water, etc.).

Additionally, a well-documented exploration and production history is expected for depleted fields.

3. Proposed Site Selection Criteria for Pure Hydrogen Storage

3.1. Geological and reservoir selection criteria

The table below summarizes the general criteria recommended for selecting structures for pure hydrogen storage:

Table 1: Geological and reservoir engineering selection criteria

Reservoir	Properties	Proposed criteria for H_2 Storage	Comments	Importance of the criteria for: N/A: not applicable 1: minor for scoring 2: major for scoring 3: exclusion criteria (screening)		
				Location	Capacity	Performance
Geometry	Min depth to the top of the reservoir	500 m	Below typical grid pressure if above	N/A	2	1
	Max depth to the top of the reservoir	2500 m	Max. depth is a CAPEX (e.g. drilling cost), OPEX (e.g. compression), and equipment standard question (e.g. wellhead grades at 6000 psi)	N/A	2	1
	Closure / Spill point	Trap is required with a minimum of height of 20 m	Preferably and not flat: dipping average of the structure value is important	N/A	3	2
	Closed area	minimum of 0.3 km²	Underground storage gets interesting from a sufficient size only	N/A	3	1
	Thickness	Should be identified and documented across the proposed area	This should be known for depleted fields; for aquifers it may in a first approach be based on regional knowledge.	N/A	2	1
	Type of trap	Must be identified and documented across the proposed area	Exclusion can be released with additional exploration. When possible, please estimate degree of additional exploration required	N/A	3	3

Reservoir	Properties	Proposed criteria for H_2 Storage	Comments	Importance of the criteria for: N/A: not applicable 1: minor for scoring 2: major for scoring 3: exclusion criteria (screening)		
				Location	Capacity	Performance
Petrophysics	Knowledge of the depositional environment	Must be identified and documented across the proposed area	Exclusion can be released with additional exploration. When possible, please estimate degree of additional exploration required	N/A	3	3
	Effective Porosity	Carbonates: 5% primary porosity or equivalent with secondary porosity (fractures, diagenetic effects, karsts) Sandstones: 10%	Useful information: average and range values for each rock type; porosity type	N/A	2	1
	Permeability	Carbonates: minimum 10 mD of equivalent permeability Sandstones: minimum 50 mD	Useful information: average and range for each rock type and associated porosity types	N/A	N/A	2
	Rock types & mineralogy	Must be identified and documented across the proposed area	Lithology preferred: homogeneous sandstone and carbonate Avoid sulphide and disulphide if possible Mineralogical composition is required (e.g. avoid Pyrite)	N/A	N/A	1
Tectonics	Tectonics events: main faults and their continuities	Availability of information across the proposed area	Required to assess the integrity of the containment. For example, types of faults	N/A	2	2
	Connection: fault networks, fractures, corridors…	Availability of information across the proposed area	E.g. compartmentalisation of the reservoir	N/A	N/A	2

Reservoir	Properties	Proposed criteria for H_2 Storage	Comments	Importance of the criteria for: N/A: not applicable 1: minor for scoring 2: major for scoring 3: exclusion criteria (screening) Location	Capacity	Performance
Reservoir fluids	In-situ fluid (Gas Oil, Water)	Availability of information across the proposed area	Preferred depleted gas field	N/A	2	2
	Initial pore pressure	Availability of information across the proposed area	Must be identified by proper exploration at some stage of the development; but can be estimated before	N/A	1	1
	Fluid temperature	Availability of information across the proposed area	Must be identified (notably for bacterial activity assessment) by proper exploration at some stage of the development; but can be estimated if necessary	N/A	1	1
	Type of aquifer and its hydrogeologi cal activity	Availability of information across the proposed area	Must be identified at some stage. Usually available through regional scale context	N/A	3	3
	In-situ fluid characteristic s (density, viscosity …)	Availability of information across the proposed area	Must be identified and documented in order to predict PVT exchange in the reservoir (native fluid and storage gas). Salinity, pH, ions composition, any info about bacteria, to predict microbiology reactions. Avoid CO2, sulphurous or iron rich fluids	N/A	1	1
	Initial and current fluid contacts (depleted fields)	Availability of information across the proposed area	Must be identified and documented across the proposed area	N/A	1	1
	Production history	Knowledge of the various produced fluids		N/A	2	2

3.2. General environmental selection criteria

Below the general environmental criteria for selecting potential location for gas and hydrogen storage:

Table 2: Geological context related selection criteria

Properties	Proposed criteria	Comments	Importance of the criteria for: N/A: not applicable 1: minor for scoring 2: major for scoring 3: exclusion criteria (screening)		
			Location	Volumes	Performances
Overlying strata	must be identified and documented across the proposed area	Impact from and to neighbouring activities	2	N/A	N/A
Overlying aquifers	must be identified and documented across the proposed area	Impact to drinking water aquifer or other conflict of uses	2	N/A	N/A
Seismicity	Understanding / knowledge of local seismicity regime		3	N/A	N/A

Table 3: Surface environment related selection criteria

Properties	Proposed criteria	Comments	Importance of the criteria for: N/A: not applicable 1: minor for scoring 2: major for scoring 3: exclusion criteria (screening)		
			Location	Volumes	Performances
Accessibility	must be identified and documented across the proposed area		2	N/A	N/A
Subsidence	Subsidence and its impacts are to be assessed		2	N/A	N/A
Land ownership	Must have a possibility to secure		3	N/A	N/A
Mining rights, regulatory compliance	Must be identified		3	N/A	N/A
Acceptability	Public acceptance has to be considered		3	N/A	N/A

4. References

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Hystories project consortium

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