Underground Hydrogen Storage Parametric Cost Model

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Acknowledgment

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Clean Hydrogen Partnership

Agenda

1. Objectives & background
2. Underground H2 Storage Conceptual design
3. Life Cycle Cost Analysis (LCCA)
4. Conclusions

1. Objectives & background

Comprehensive parametric cost model for Underground H2 Storage site screening and selection :

- Suited to underground H2 gas storage
- Simple assumptions and reduced data input
- High-level costs estimates based on a clear and transparent approach
- Split between costs related to H2 injection/withdrawal flowrates and cost of H2 stored volume

⇒ Costs estimates used as a ranking criteria for prospect ranking and selection.

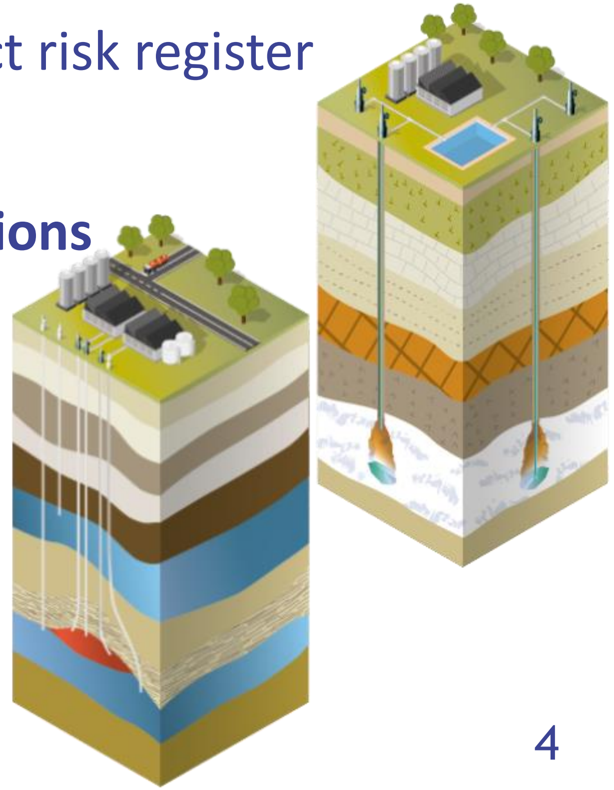
⇒ Link technical / subsurface investigation work with business / economic assessments.

2. Conceptual Design | Underground H2 Storage Conceptual Design

Basis of Design with preliminary overall system configuration for underground storage focusing on:

- Preliminary production / injection and control wells architecture
- High-level description of H2 gas storage process facilities
- Outline project development plan, associated schedule & simplified project risk register

⇒ **Considering both Salt cavern & porous media underground storage solutions**



2. Conceptual Design | Salt Cavern H2 Storage Design Basis

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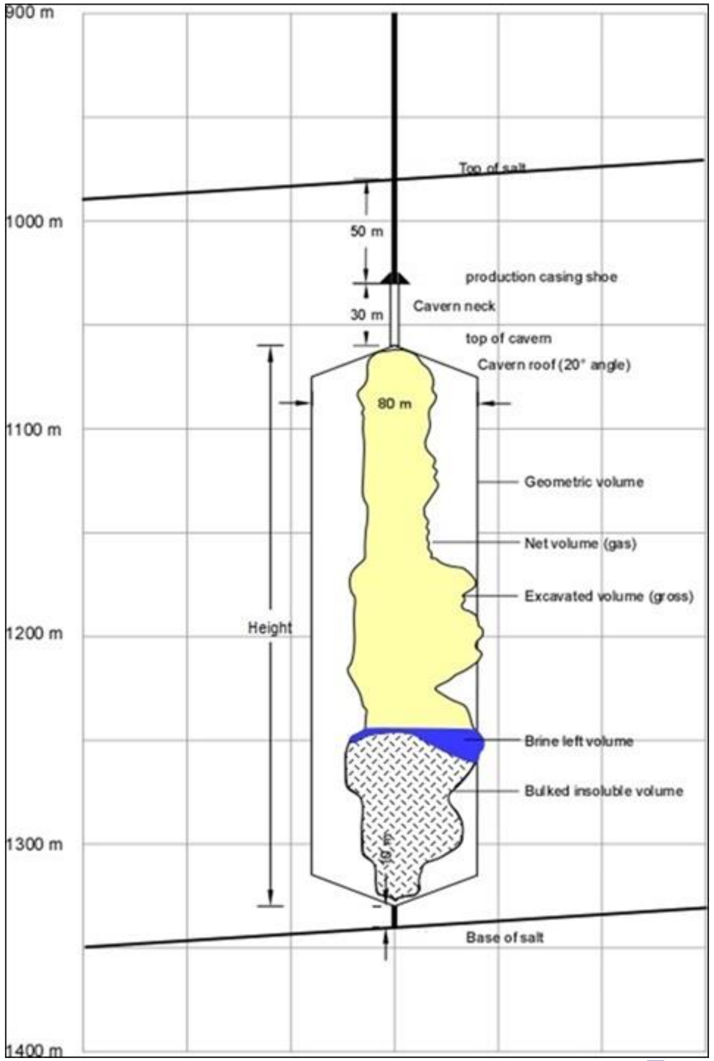
Key assumptions:

- Last Cemented Casing Shoe Depth @ 1,000m
- Cavern max. diameter ~80m
- Solution mining ~300 m3/hr
- "Average" values assumed for leaching parameters and cavern shape

250 MSm3 Working Gas Vol. Target	Low case	Medium Case	High case
Cavern Free Gas vol. [m3]	815 000	380 000	185 000
Cavern & well count	4	8	16
Total Peak Withdrawal rate [MSm3/d]	23.6	22.3	21.8
Cavern Working Gas Vol. [MSm3]	62.5	31.3	15.6
Working Gas / Total Gas [%]	53	57	59

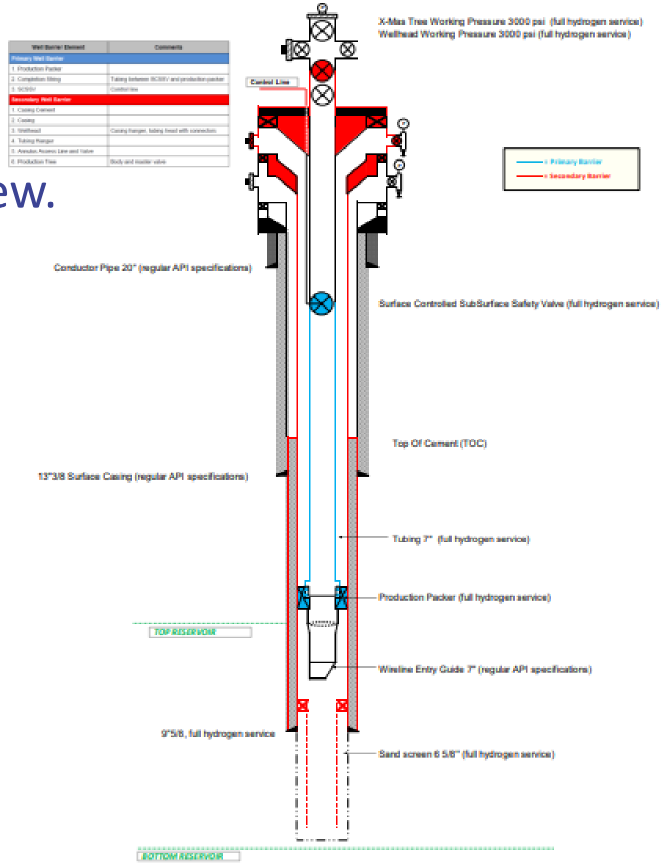


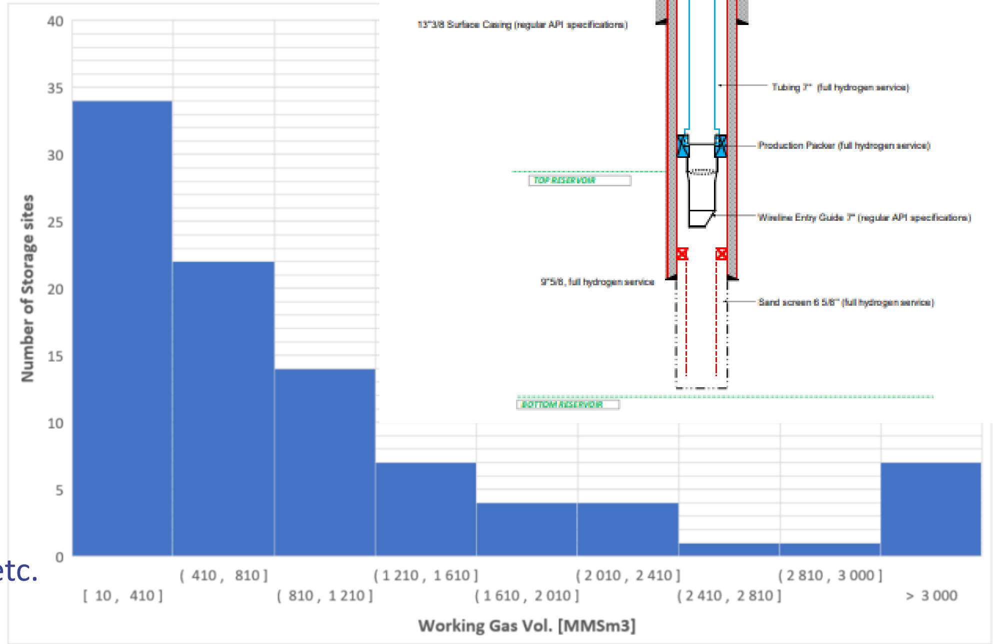
2. Conceptual Design | Porous media H2 Storage Design Basis

Mixed approach based on:

- Set of key assumptions deemed « reasonable » from an engineering point of view.
- Statistical analysis on European natural gas storage databases (IGU, CEDIGAZ).

	Low case	Mid case	High case
Working Gas (x10^6 Sm^3)	550		
Operating Pressure Envelope (bar)	60 – 130 bar		
WG/TG ratio	50 %		
Cushion Gas (x10^6 Sm^3)	550		
Peak rate / WG	1.5 %		
Peak rate (x10^6 Sm^3/d)	8.25		
Storage Well count	5	24	71[5]
Aux. Well count	1	6	34[6]





[5] Storage well count may include inactive wells, suspended wells or abandoned wells.

[6] Auxiliary well count may include water disposal wells, wells utilised for fuel gas, monitoring wells, etc.

2. Conceptual Design | Surface Facilities Overview

Injection mode:

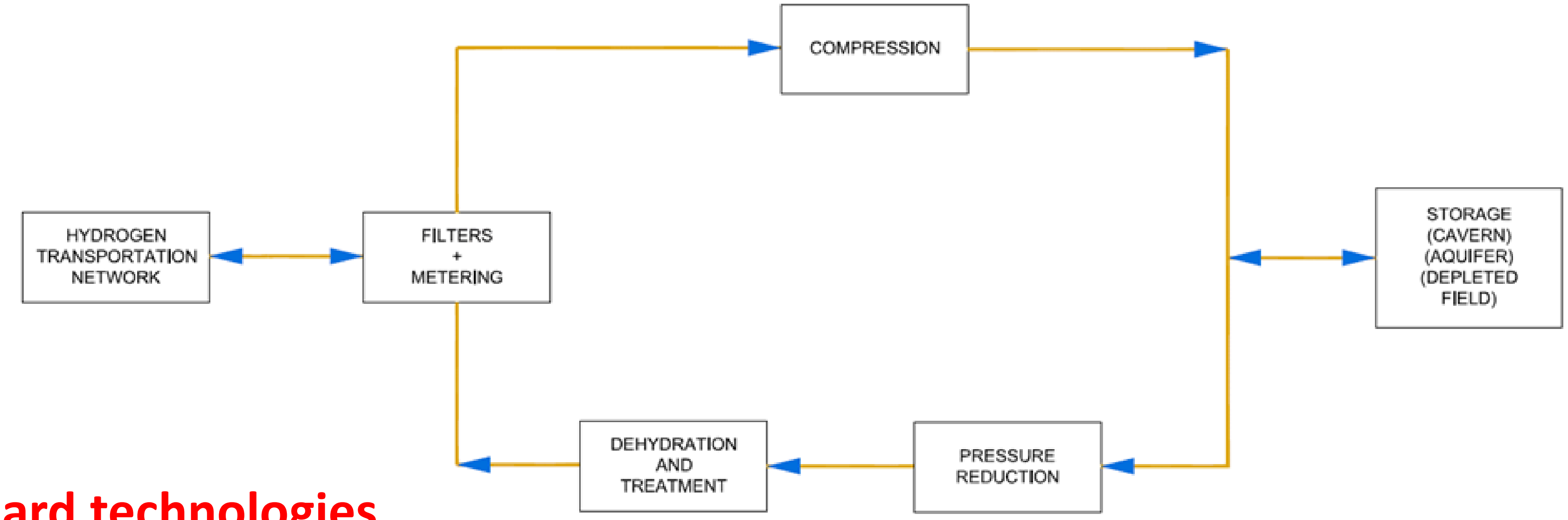
- Filtration Package
- Fiscal metering package
- Knock-out drum + compression package
- Heat exchangers (air coolers)
- Flowmeters & control valves

Withdrawal mode:

- Flowmeters & control valves
- Slug catcher
- Dehydration unit
- Fiscal metering package

Operating envelope:

- Pressure: 60 – 180 bar
- Max. flowrate: ~6.0 MM Sm3/d i.e. ~20 tons/hr
- H2 supply method: 30 bar / 30 degC



⇒Use of standard technologies

3. LCCA | Selected approach for CAPEX model

Costs estimates based on "bottom-up approach" rather than a "top-down approach":

- Based on conceptual design for salt cavern / porous media H_2 storage solutions.
- Factorization on equipment & Parametric model with in-house data.
- Costs given in Euro, 2020 base, for a typical project located in France.
- No fluctuation of raw materials costs during construction duration assumed.
- No time-value of money assumed (discount factors, DPI, IRR, etc.).
- Class IV estimate[1], leading to a +/- 30% to 50% accuracy.

⇒ Cost assessment tool for analysing various case studies

[1] As per Association for the Advancement of Cost Engineering International (AACEi) Classification.

3. LCCA | Costs inclusions

Technical costs based on:

- Process blocks identification and main components characteristics definition.
- Main equipment Ex-Works cost estimation by scaling factors.
- “Other” costs estimation by Lang’s factors i.e. bulk material, construction costs, allowances, permanent / temporary facilities, infrastructure, interconnections, spare parts, transportation, logistics.

Engineering Management Services (EMS) evaluated as a percentage of Technical Costs:

- Detailed Engineering
- Procurement, purchasing, sub-contracting
- Contractor management, site supervision
- Assistance to plant commissioning and start-up

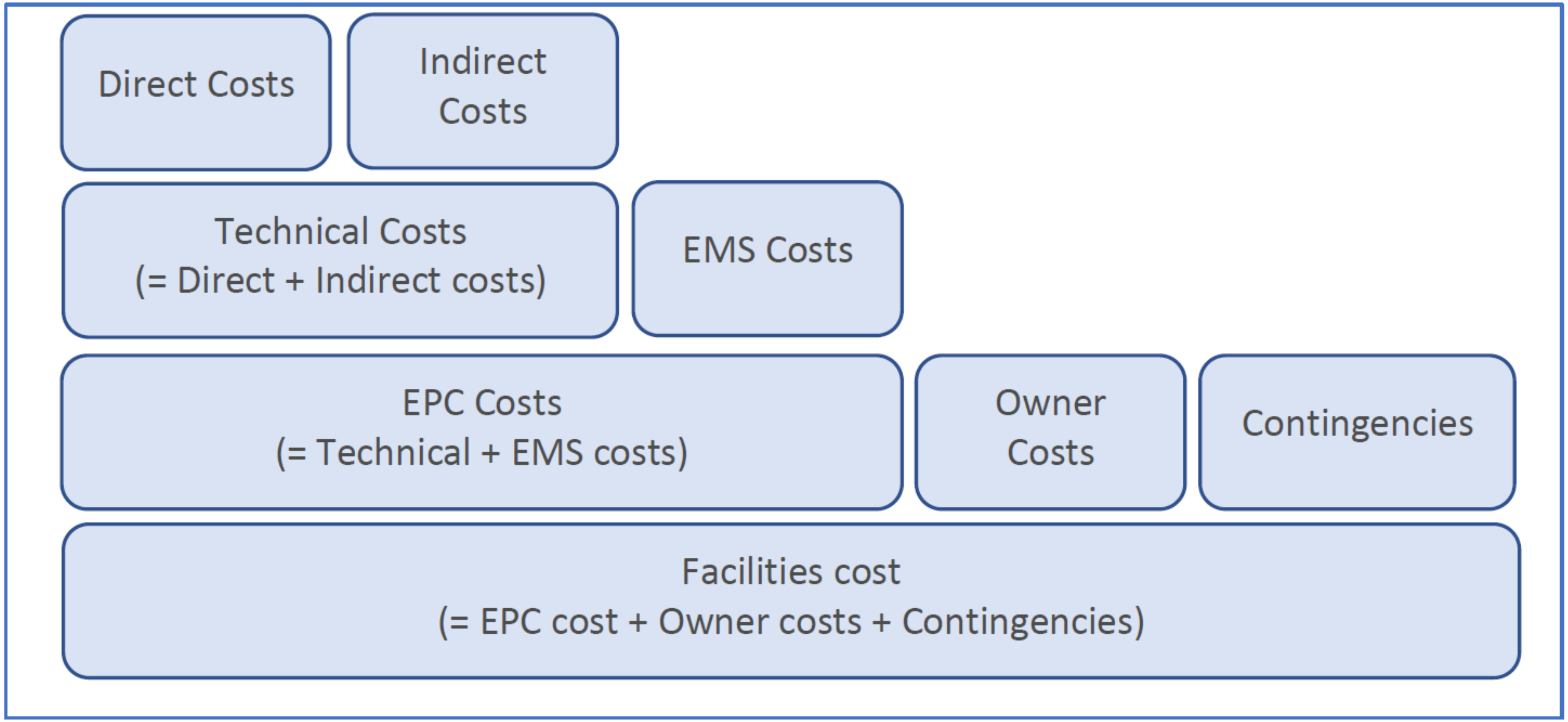
Owner (Company) costs:

- Basic Engineering & Front-End Engineering Design (FEED)
- Project Management Consultant (PMC) – underground storage specialised third-party services during storage construction.

⇒**Exploration/Appraisal costs, H2 production / transportation excluded**

3. LCCA | Scope covered within cost assessment tool

Holistic approach with the aim to include most factors impacting the CAPEX based on:



* EMS – Engineering Management Services

3. LCCA | Example - Main parameters and breakdown for filtering, drying & compression, and metering unit

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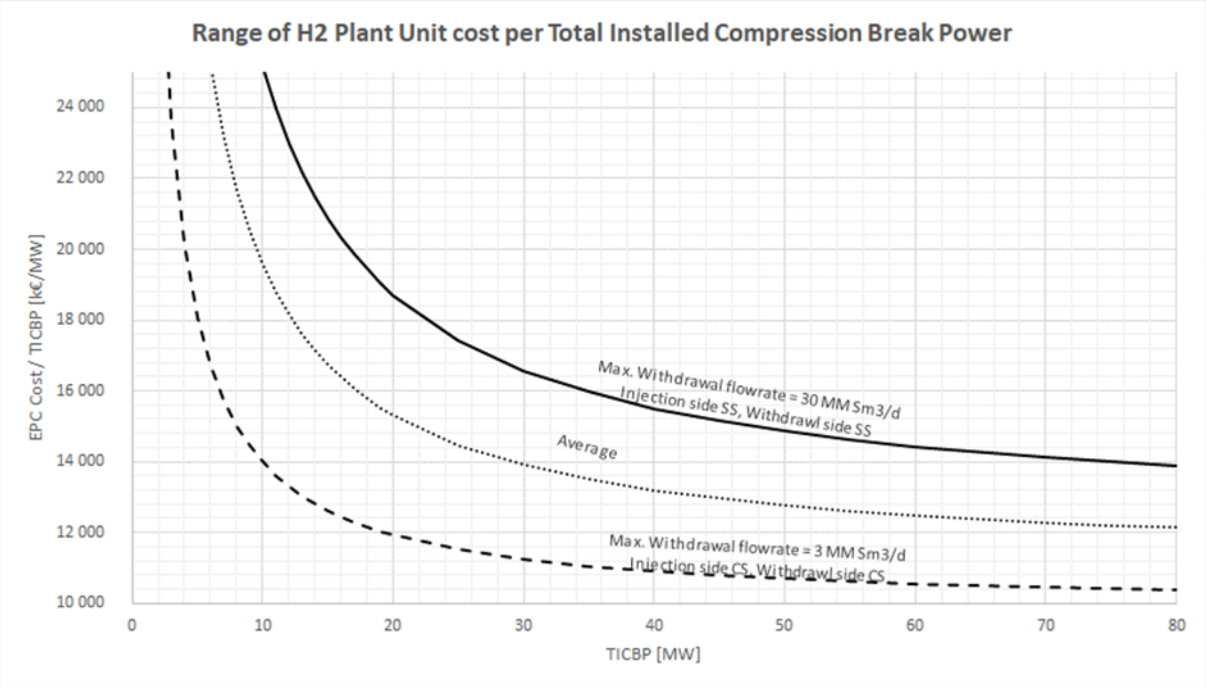


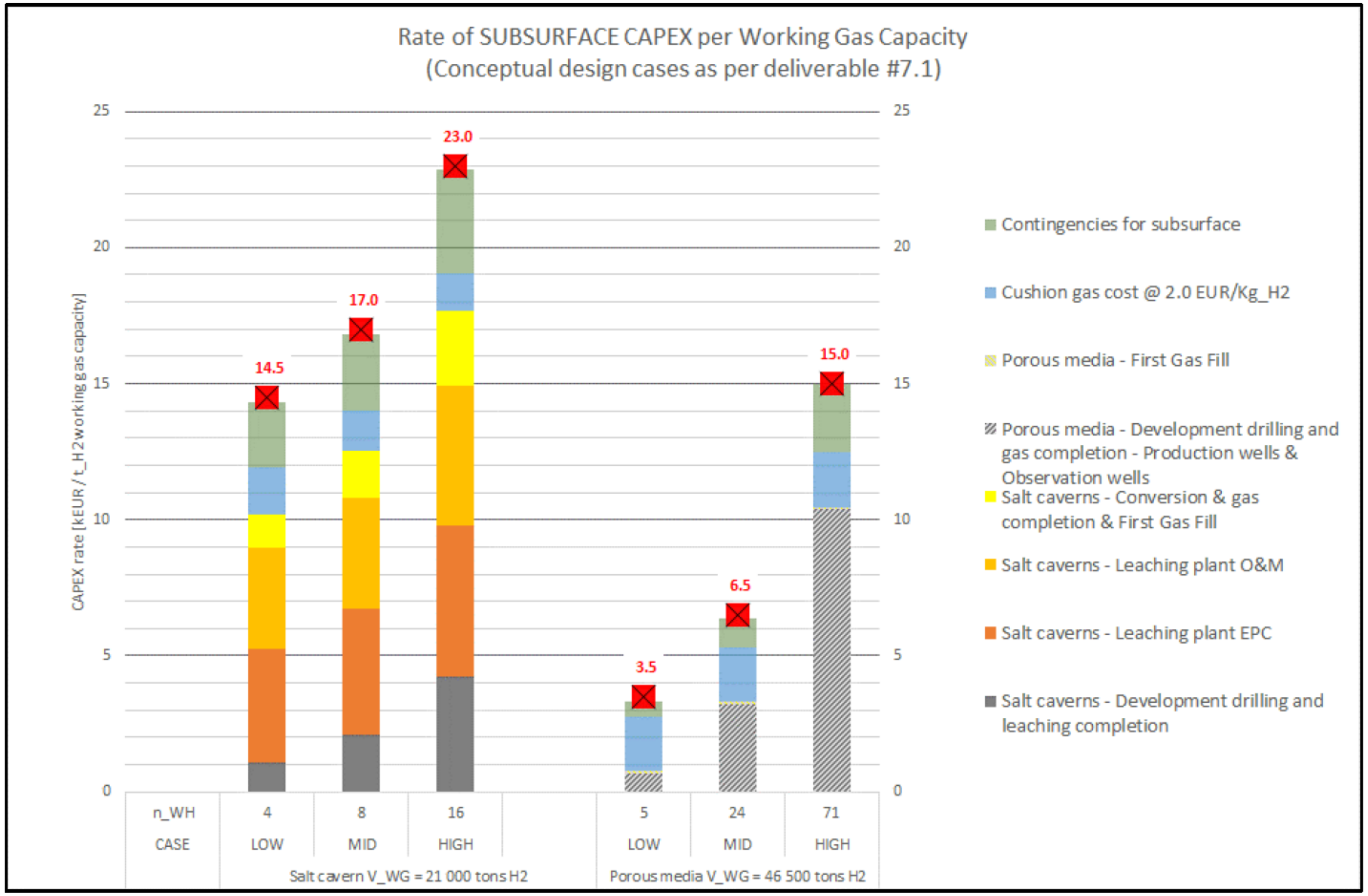
<table>
<tr><td rowspan="6">Cost drivers</td><td colspan="4">Material of construction for process parts in contact with H_2</td><td>Site specific, see chapter 0</td></tr>
<tr><td colspan="4">Total compression brake power</td><td>See chapter 4.1.2
and below formula</td></tr>
<tr><td colspan="4">Total maximum withdrawal flowrate</td><td>Site specific, see chapter 4.1.2</td></tr>
<tr><td colspan="4">Withdrawal-to-Injection Capacity Ratio (WTIR)</td><td>See chapter 4.1.2</td></tr>
<tr><td colspan="4">Maximum storage operating pressure</td><td>Site specific, see chapter 4.1.2</td></tr>
<tr><td colspan="4">Minimum compression suction pressure</td><td>See chapter 4.1.2</td></tr>
<tr><td>EPC COST</td><td>EPC_1 $[k€]$</td><td colspan="4">$$EPC_1 = \begin{cases} 8\,655 \cdot (1 + MCF_i \cdot 14\%) \cdot TICBP + 20\,700 \\ + 9\,100 \cdot (1 + MCF_w \cdot 11\%) \cdot Q_w^{0.643} \end{cases}$$
With
MCF_i = Material Cost Factor for injection (compression) stream
MCF_w = Material Cost Factor for withdrawal stream
$TICBP$ = Total Installed Compression Brake Power in [MW]
Q_w = Total storage maximum withdrawal flowrate in [million Sm^3/day]</td></tr>
<tr><td>EPC Cost breakdown</td><td colspan="2">Engineering (EMS):
14-19%</td><td>Procurement:
35-51%</td><td>Construction:
25-39%</td><td>FEED & PMC
9%</td></tr>
</table>

3. LCCA | Unit CAPEX (per units of stored volume)

Unit CAPEX (per units of Working Gas):

- Simplifying assumption – Subsurface CAPEX only

⇒ Unit CAPEX mainly driven by well count to reach storage target performance.



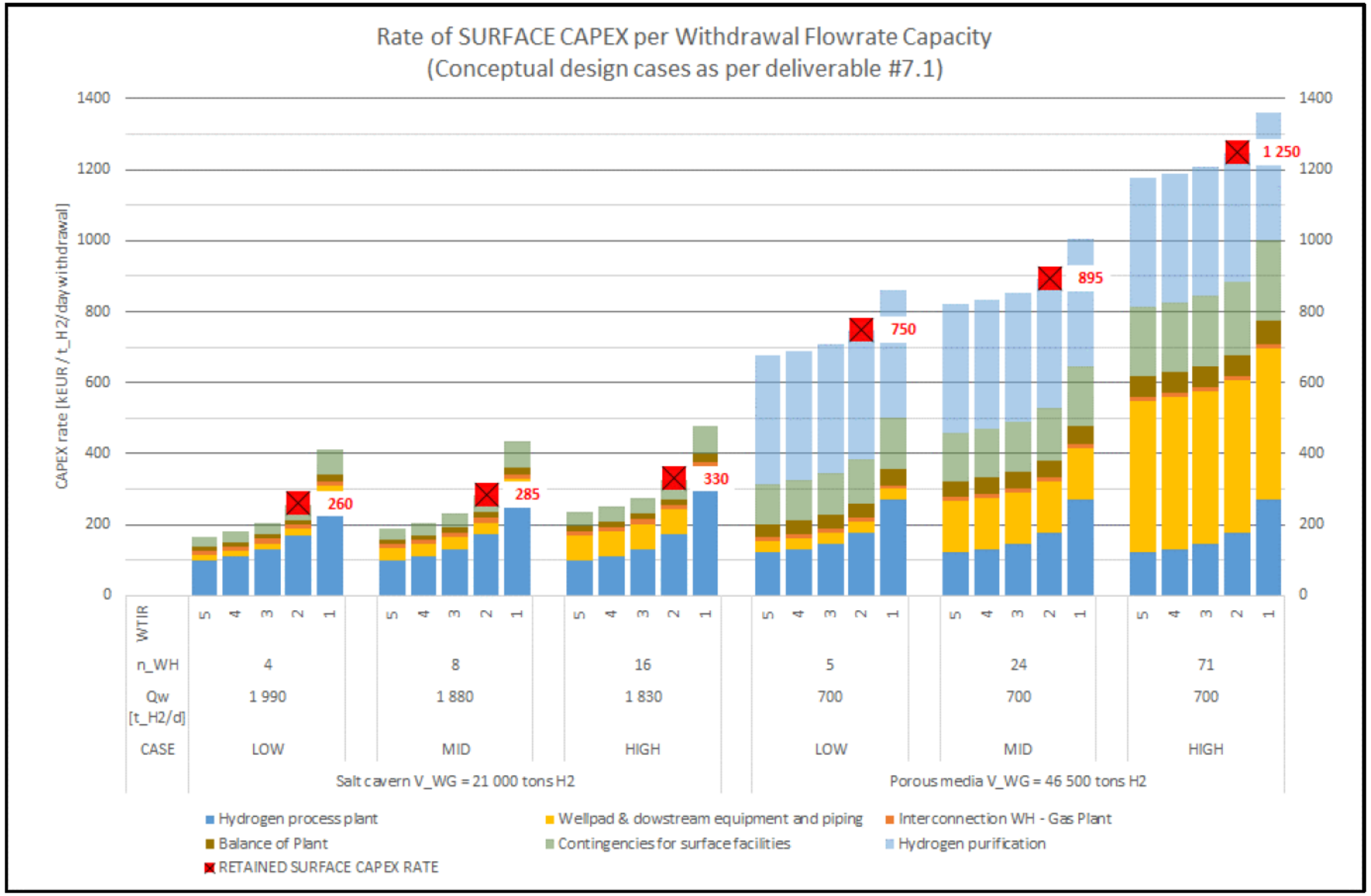
3. LCCA | Unit CAPEX (per units of withdrawal flowrate)

Unit CAPEX (per units of withdrawal flowrate):

- Simplifying assumption – Surface CAPEX only

⇒ Unit CAPEX highly dependent on purification unit requirements and on installed compression power (see WTIR).

⇒ Unit CAPEX also dependent on well count.



* WTIR – Withdrawal To Injection capacity Ratio (No units). Techno-economic parameter set by defining the cycling with injection / withdrawal cycles based on business needs and storage operation strategy.

4. Conclusion & Orders of magnitude (Medium Case)

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Deliverability- and storage- based CAPEX; Fixed and Variable OPEX:

COST RATE	UNIT	SALT CAVERNS	POROUS MEDIA
SUBSURFACE CAPEX RATE per working gas capacity	EUR per KWh_H_2(LHV) *[Range]**	0.51 *[0.44 – 0.69]*	0.20 *[0.11 – 0.45]*
SURFACE CAPEX RATE per withdrawal flowrate max. capacity	EUR per KW_H_2(LHV)	205	645**
VARIABLE OPEX RATE per cycled quantity For COE = 60 EUR/MWh	EUR per MWh_H_2(LHV)	2.25	3.83
FIXED OPEX RATE*** % of related CAPEX / year	% Surface CAPEX / year	3.7%	3.7%
	% Subsurface CAPEX / year	0.4%	1.5%

→ Different cost structure. Subsurface cost (€/MWh) are higher for salt caverns ; surface costs (€/MW) are higher for porous media

→ These costs were used in Hystories' energy modelling work

Application to the Medium case:

→ CAPEX per storage capacity is ~2€/Nm3, or ~20 €/kg

→ Same figure is found for salt caverns and porous storages

Hystories project consortium

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Thank you !

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