HyKeuper Storage Project

Planning a Large Hydrogen Storage in the UK

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INEOS at a Glance

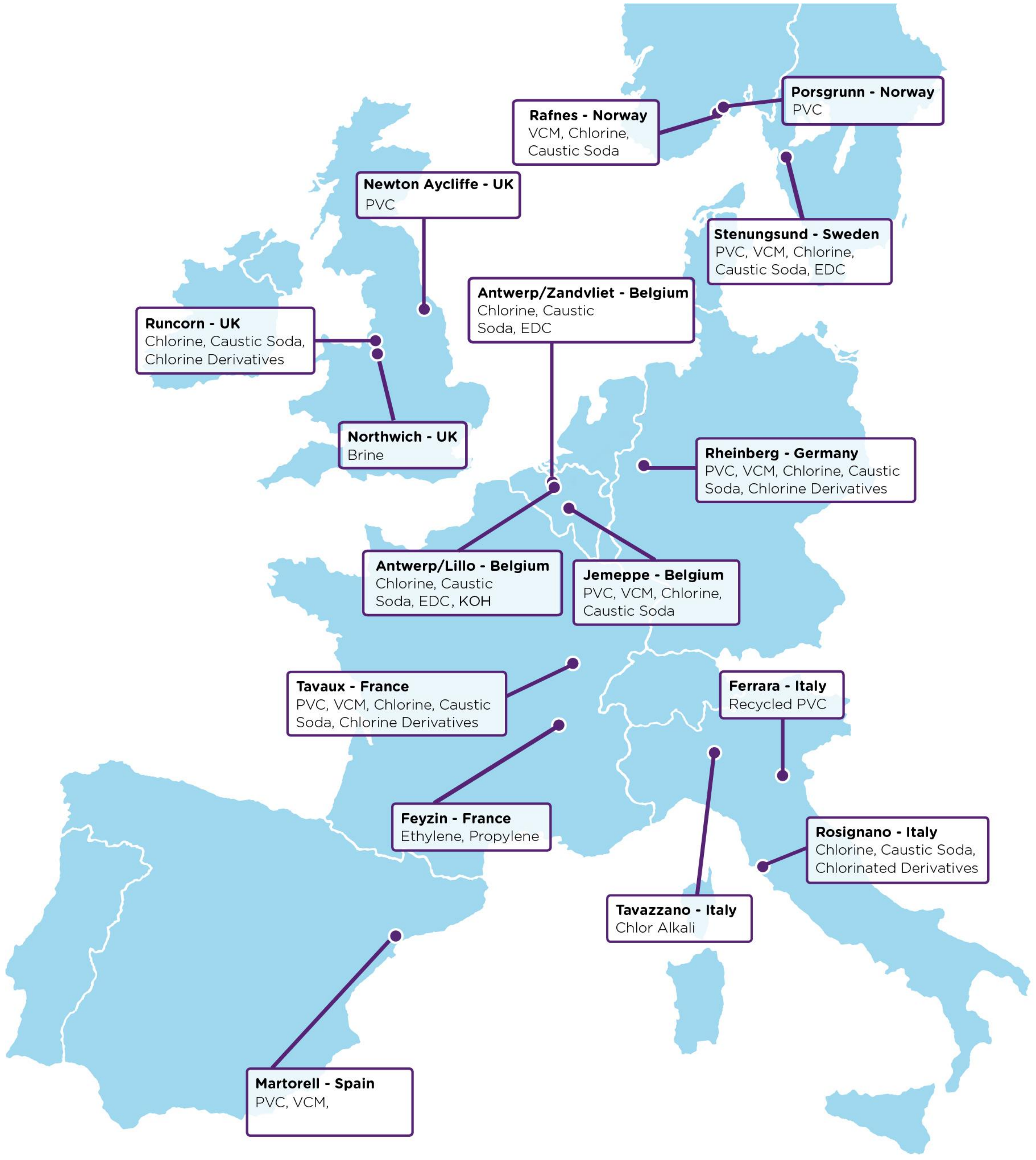
INOVYN at a Glance

Key dimensions:

- Number of employees: around 4,300
- Production: 40 million tonnes per annum
- Number of sites: 17 in 8 countries
- Countries of operation: Belgium, France, Germany, Italy, Norway, Spain, Sweden, United Kingdom
- Turnover: €3.5 billion

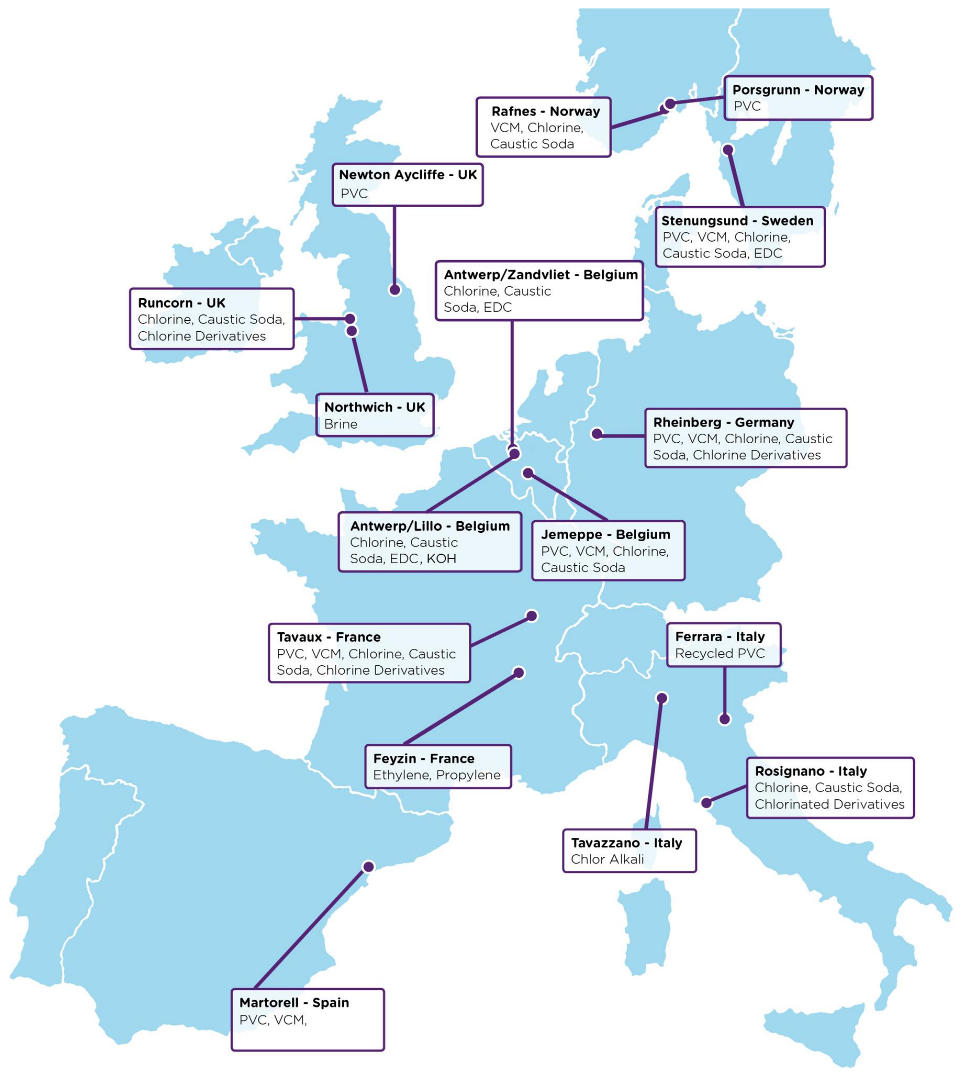
INOVYN market share by key products:

- General Purpose Vinyls: #1 in Europe
- Specialty Vinyls: #2 in Europe
- Chlorine: #1 in Europe
- Caustic Soda: #1 in Europe
- Caustic Potash: #1 in Europe
- Chloromethanes: #1 in Europe
- Epichlorohydrin: #1 in Europe (merchant market)
- Allyl Chloride: #1 in Europe
- Chlorinated Paraffins: #1 in Europe



INOVYN Brine Winning and Underground Gas Storage

- INOVYN and precursor companies have operated controlled solution mining in Cheshire since the 1920s. The 2000Ha Holford Brinefield operation comprises over 200 caverns.
- Purified saturated brine is supplied to customers for the manufacture of chemicals, including chlor-alkali, soda ash and white salt.
- INOVYN UGS know-how includes ethylene and natural gas storage. The company has previously been involved in development of large-scale gas storage projects in Cheshire (28 caverns, across the Stublach and Holford Gas Storage Projects).



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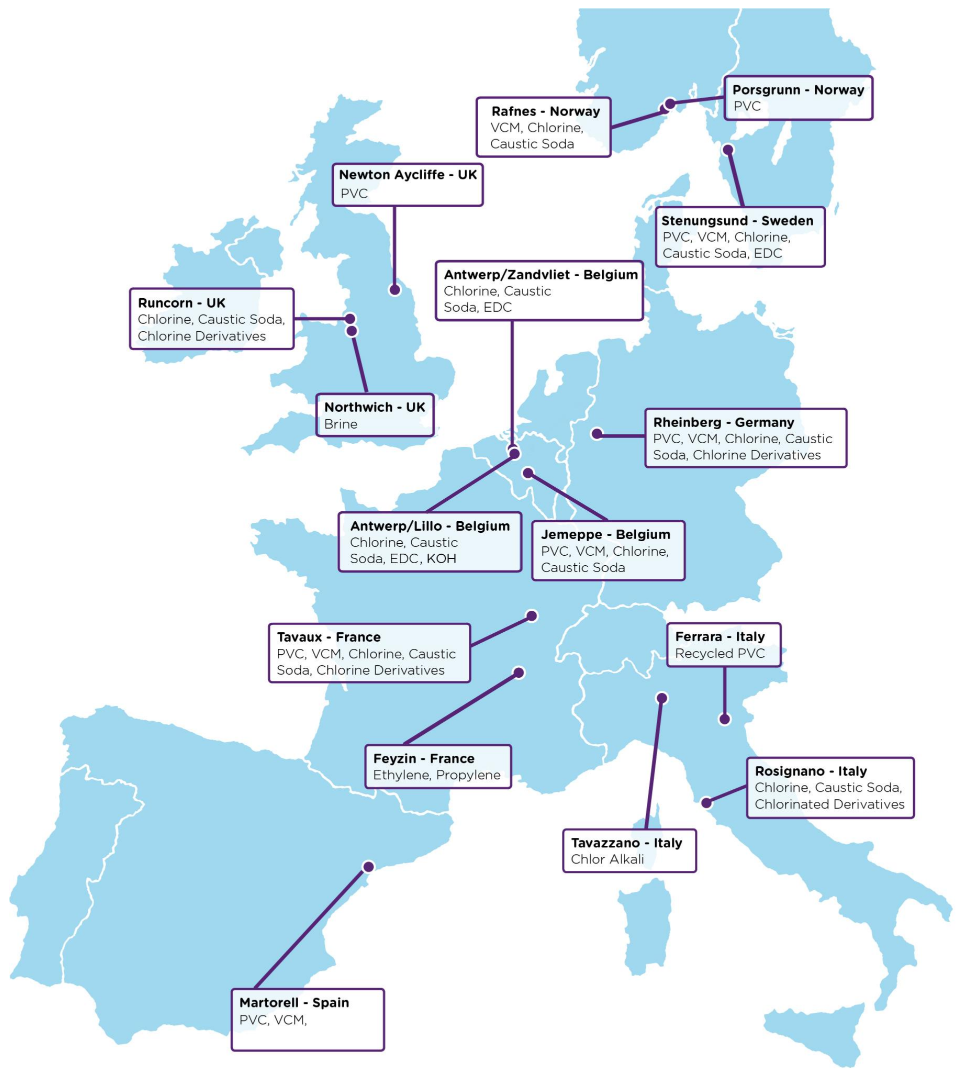
INOVYN Underground Hydrogen Storage

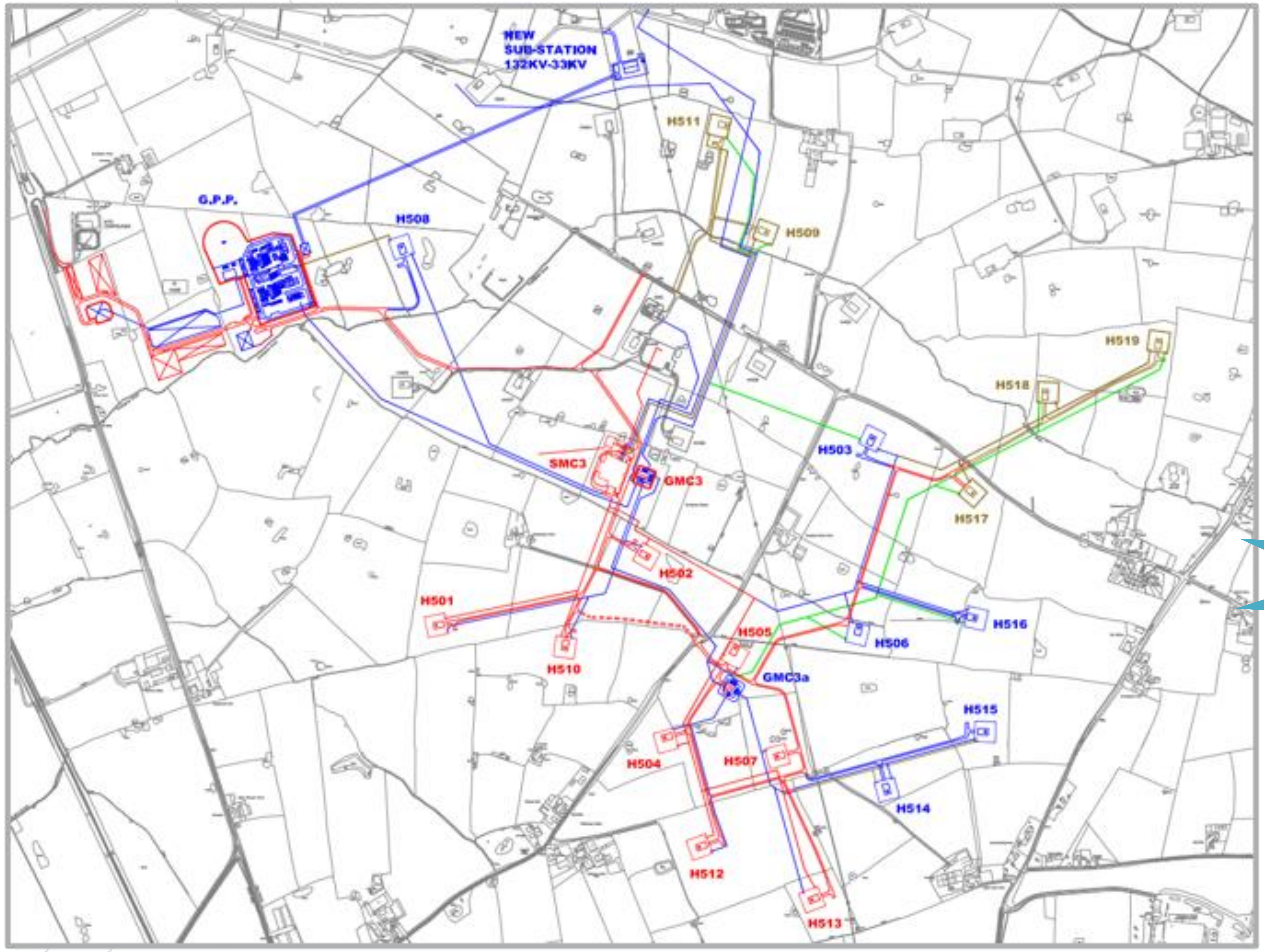
INOVYN has been involved in hydrogen projects such as:

- Centurion - UK Research Institute funded study for 100MW Cellroom with natural gas cavern conversion to hydrogen
- HySecure – UK Department for Business, Energy and Industrial Strategy funded study of new build 350,000m3 hydrogen cavern
- HyPster - EU funded pilot facility to study hydrogen cycling in Etrez, France
- INOVYN is Europe's largest operator of electrolysis technology (for chlorine, with co-produced hydrogen).

Co-product hydrogen is available to prime development of key hydrogen applications in UK NW region and other regions of Europe.



HyKeuper Project Location



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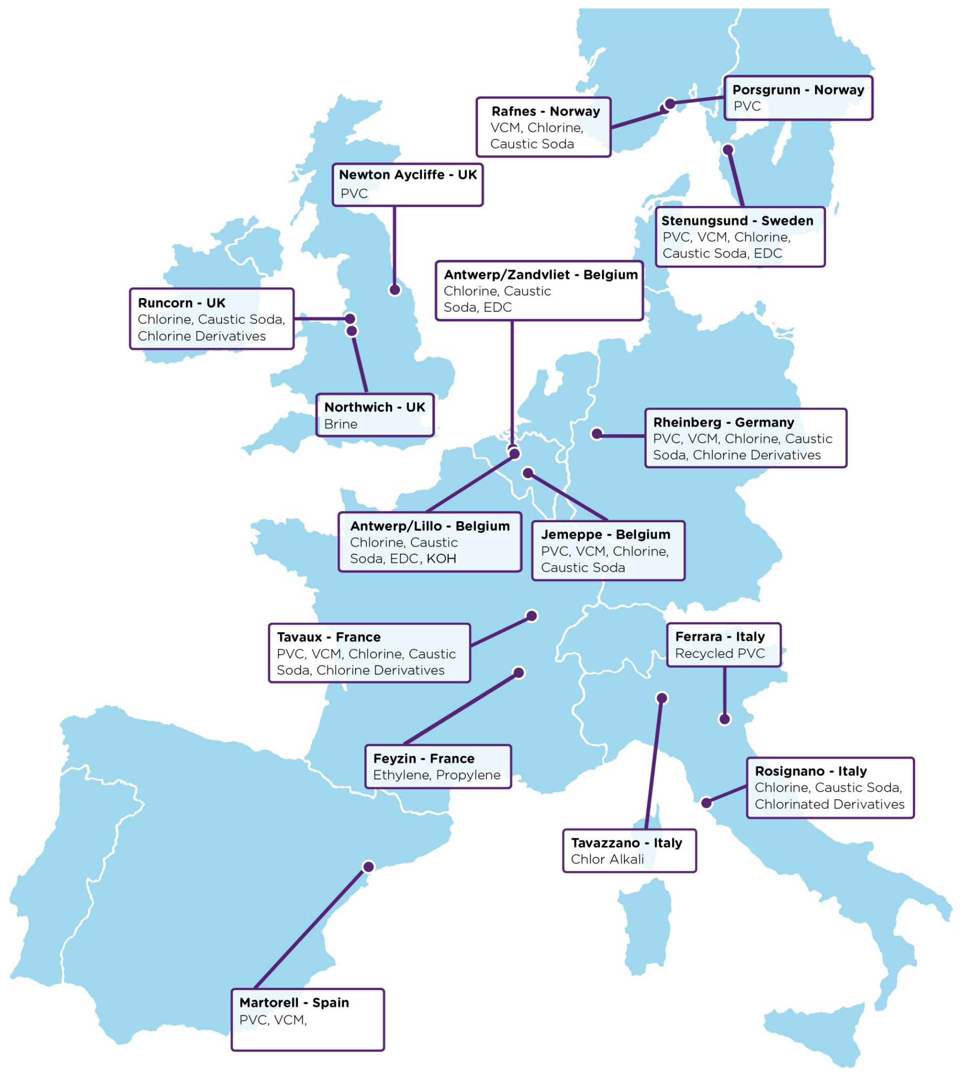
HyKeuper Project Background

- INOVYN has previously been granted planning permission (Development Consent Order or DCO) for large scale natural gas storage – **19 new salt caverns** in Cheshire.
- The HyKeuper Project is actively engaged in the conversion of the existing DCO to provide **1.3 TWh hydrogen storage**.
- FEED studies have been completed / are being carried out on the **subsurface** and **surface facility** designs and **safety case** demonstration.
- HyKeuper is working with the **UK North-West regional HyNet project**, a consortium of operating, engineering and consultancy companies, to provide carbon capture and storage for carbon emitters and the production, distribution and storage of low carbon hydrogen.



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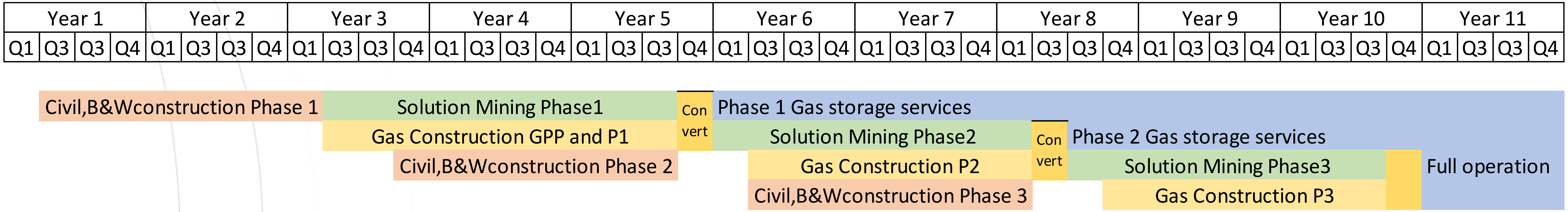
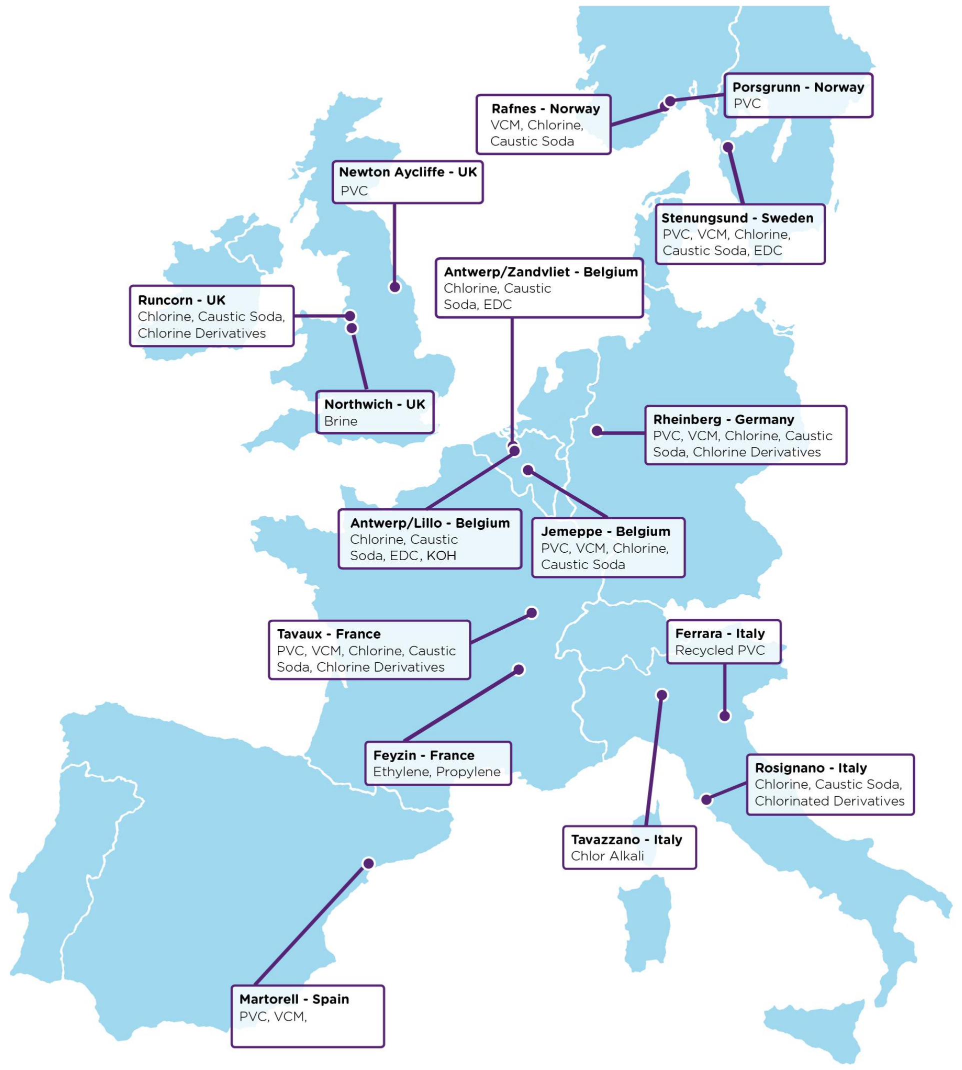
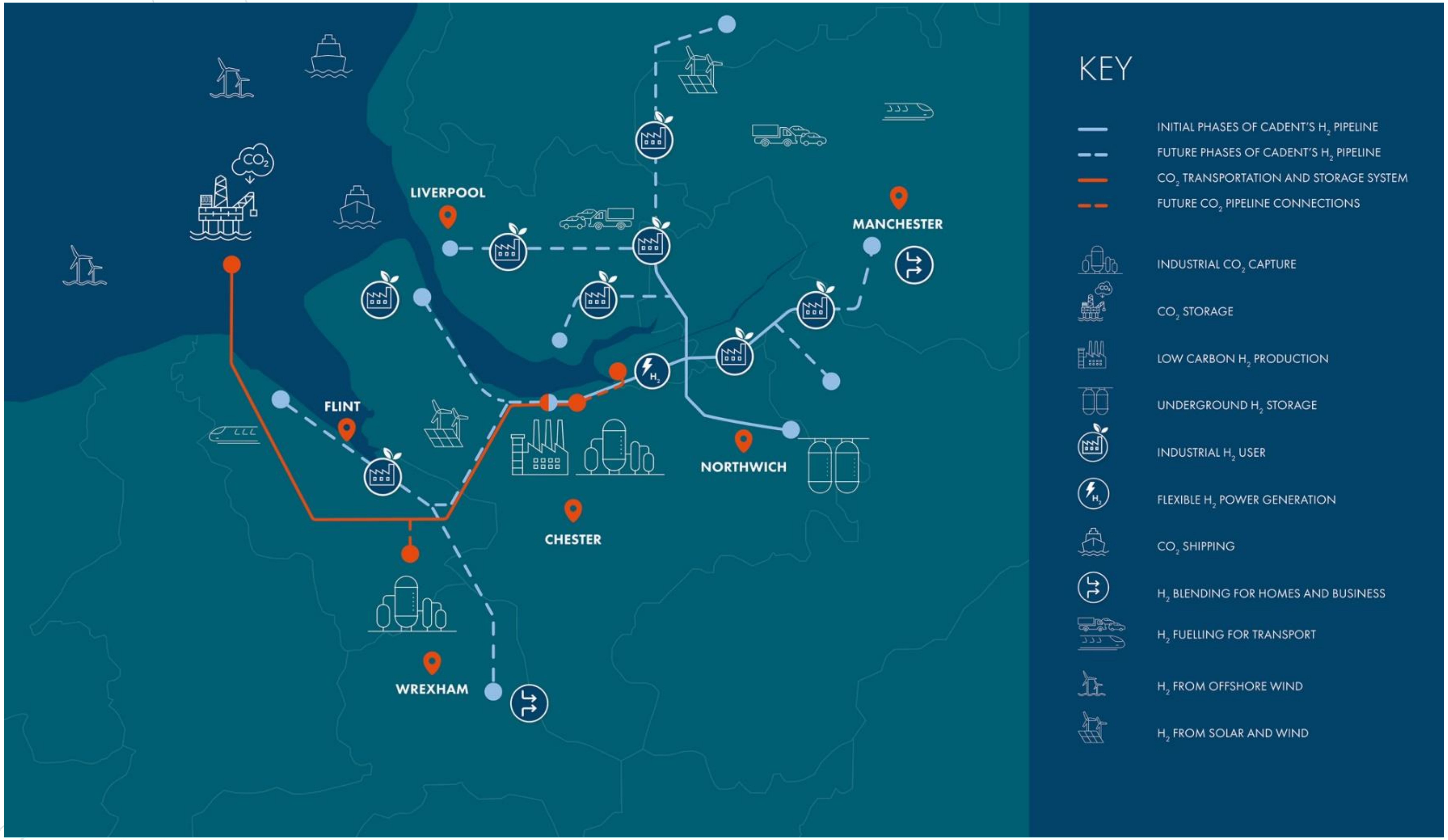
HyKeuper Project Timeline





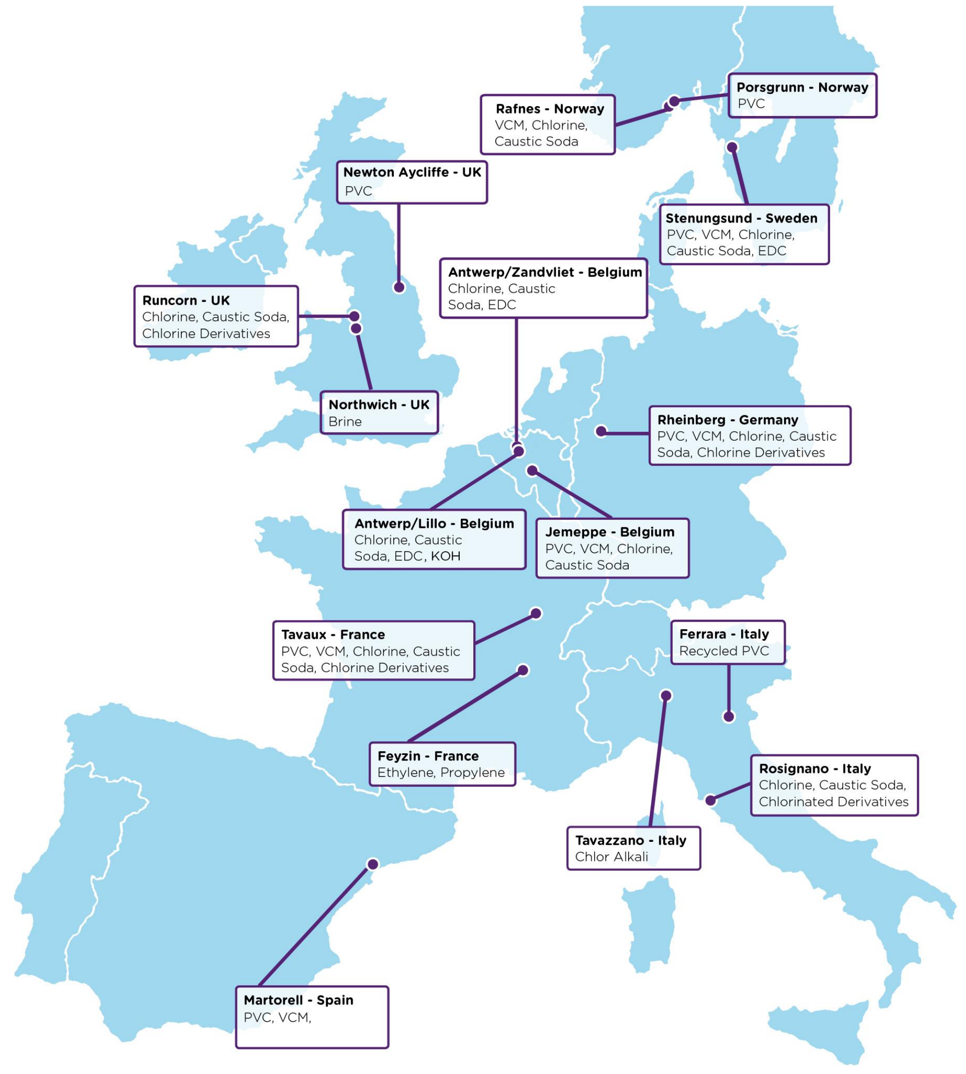
HyNet Project



Hydrogen Storage for HyNet

Within HyNet, bulk hydrogen storage is required:

- For cost effective seasonal supply / demand levelling
- To allow production capacity to be built for ‘average’ demand, whilst enabling the network to support peak demand.
- To provide resilience during shutdown of part of the hydrogen production capacity, to meet hydrogen user demand.
- To provide resilience during sudden network load imbalance events
- To encourage the deployment of additional hydrogen production from variable renewable generation.



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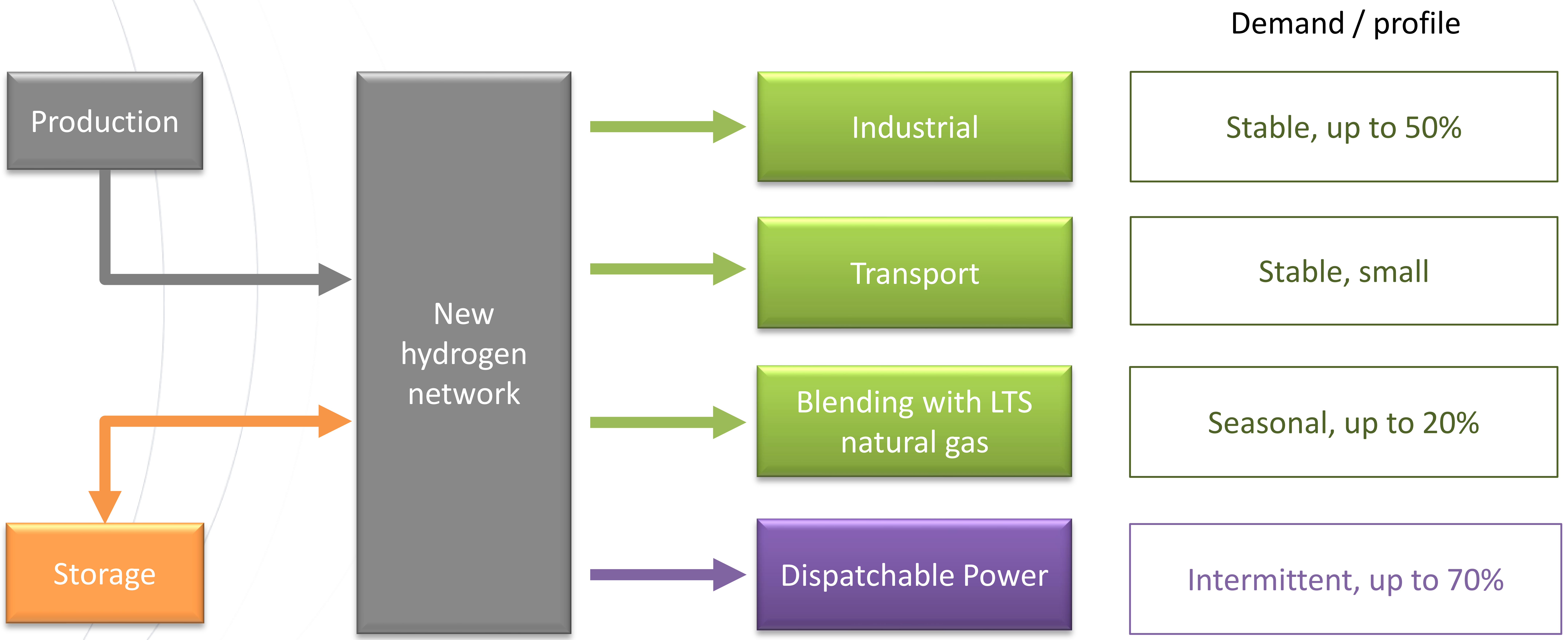
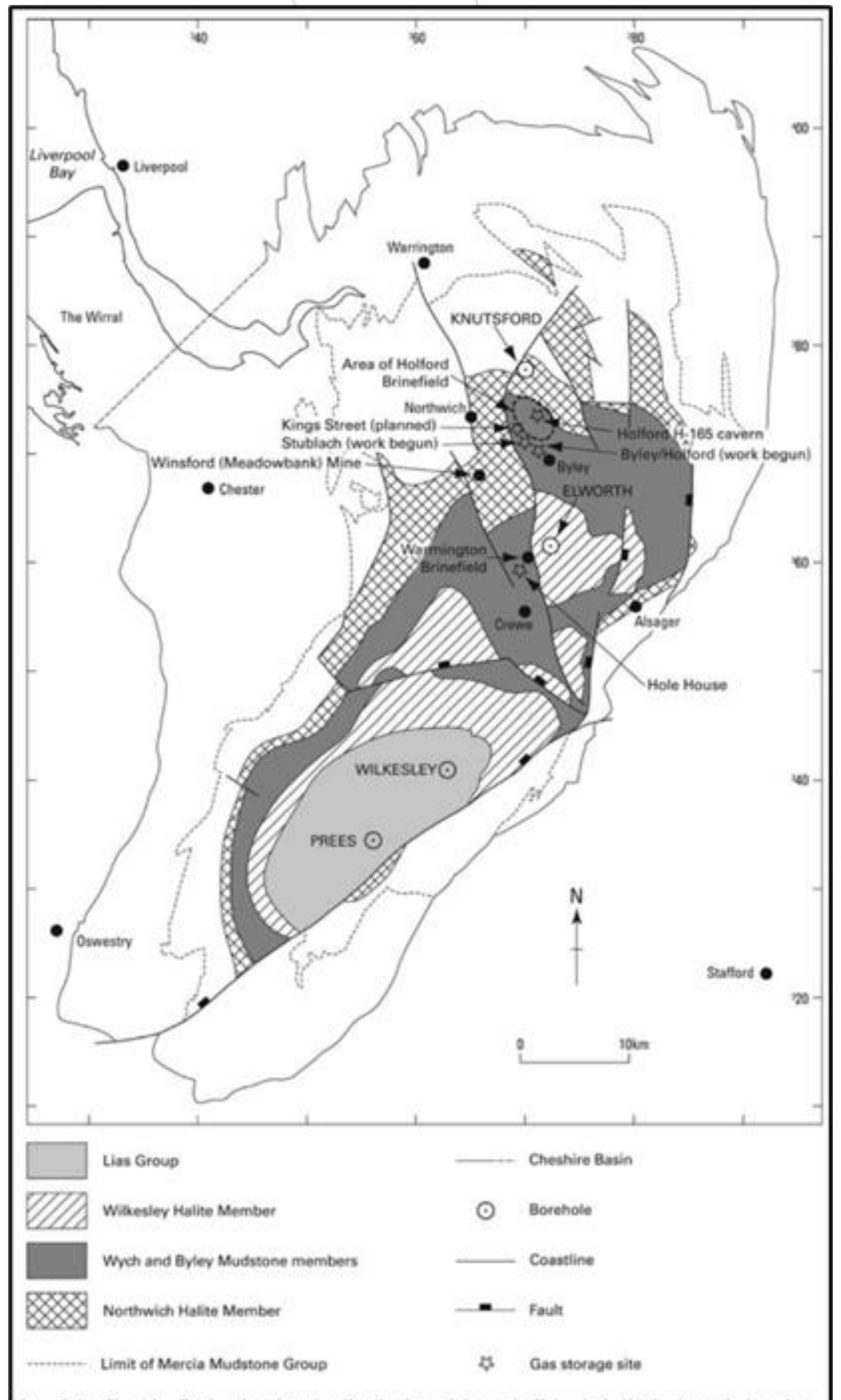
HyNet Network Performance



Cheshire basin configuration



Map of the Cheshire Basin, showing the distribution of the main Triassic halite beds, main locations holes referred to in the text.

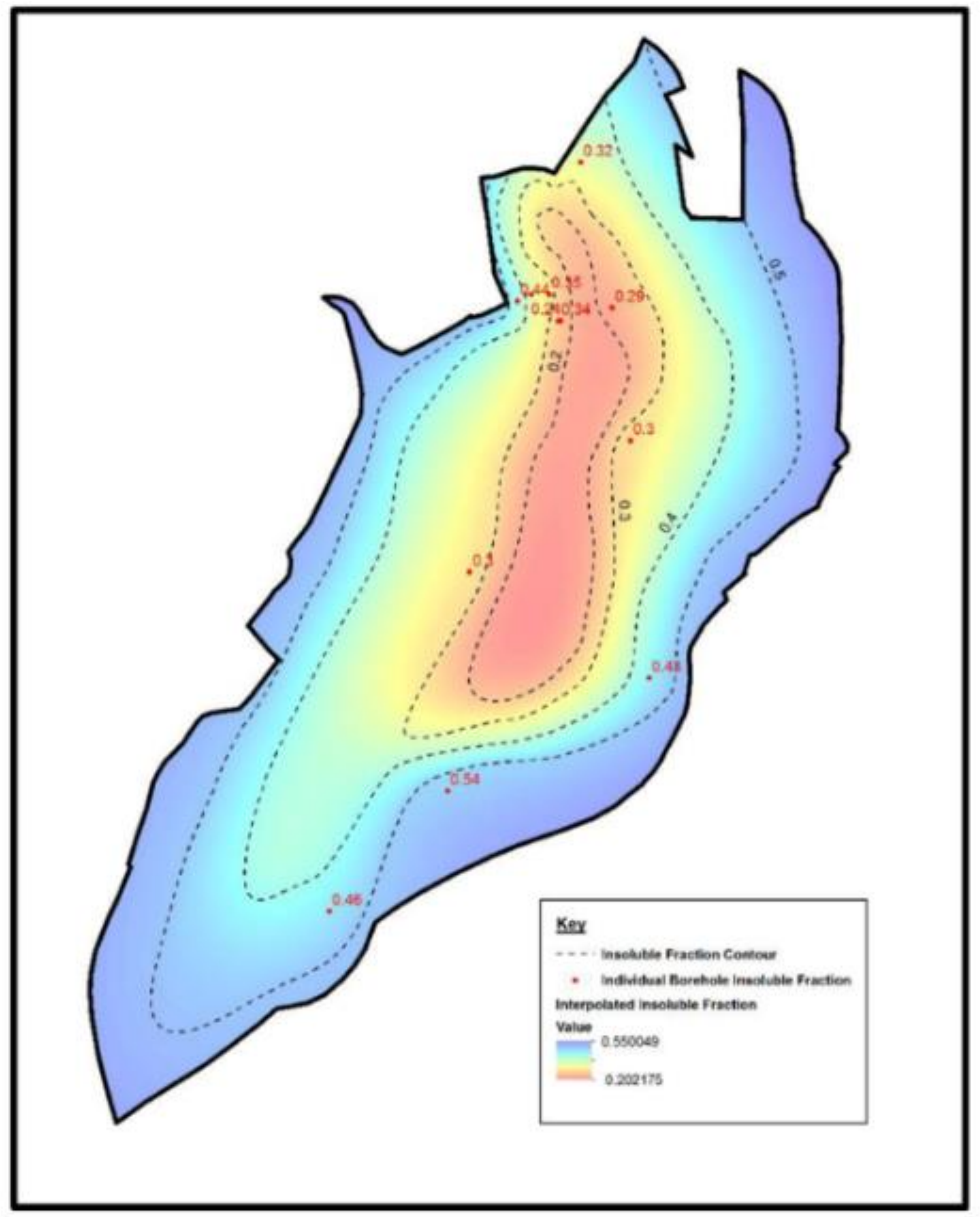


Fig. 8. Mapped insoluble fraction and distribution in the Northwich Halite Member of the Cheshire Basin.

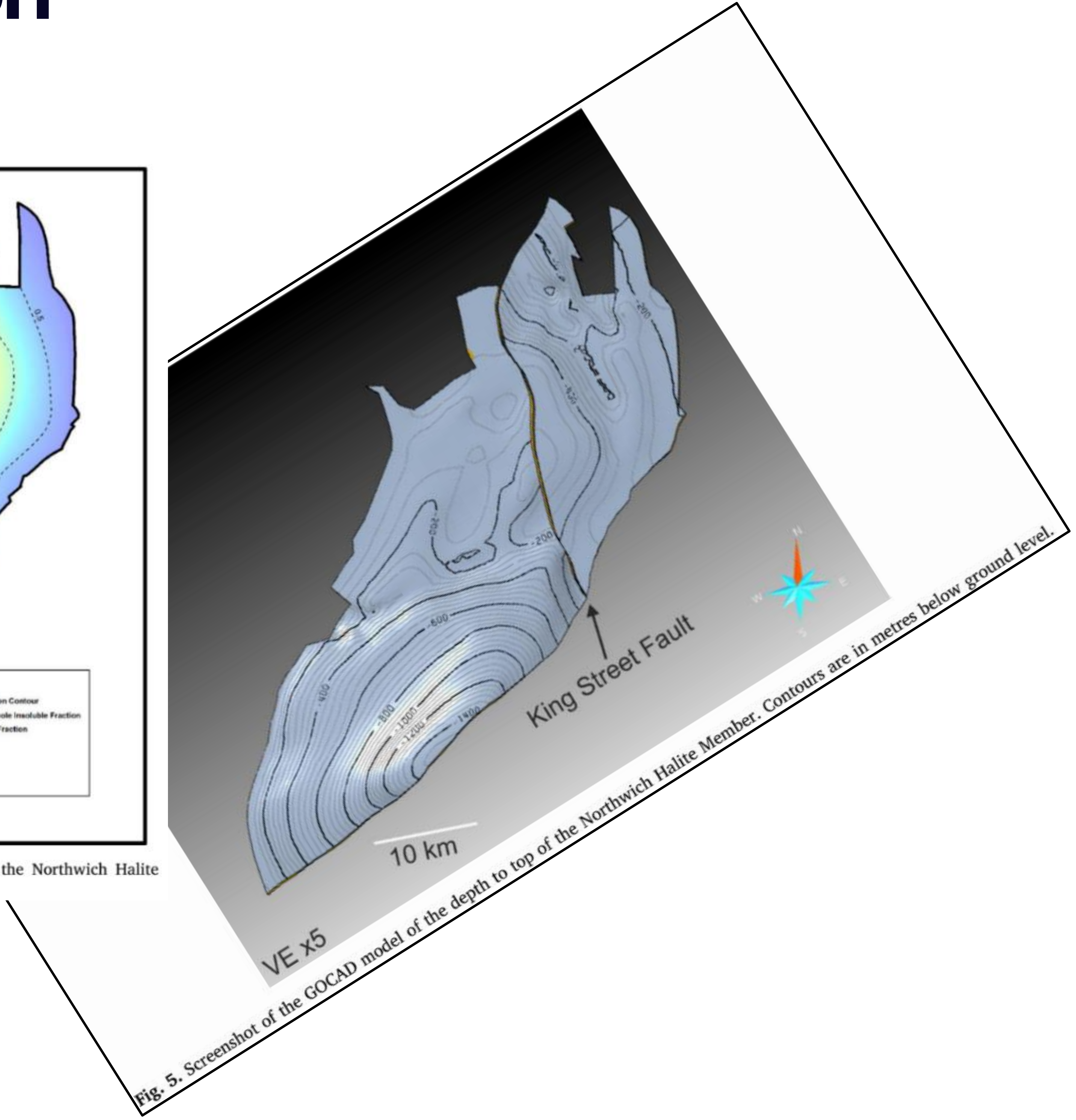
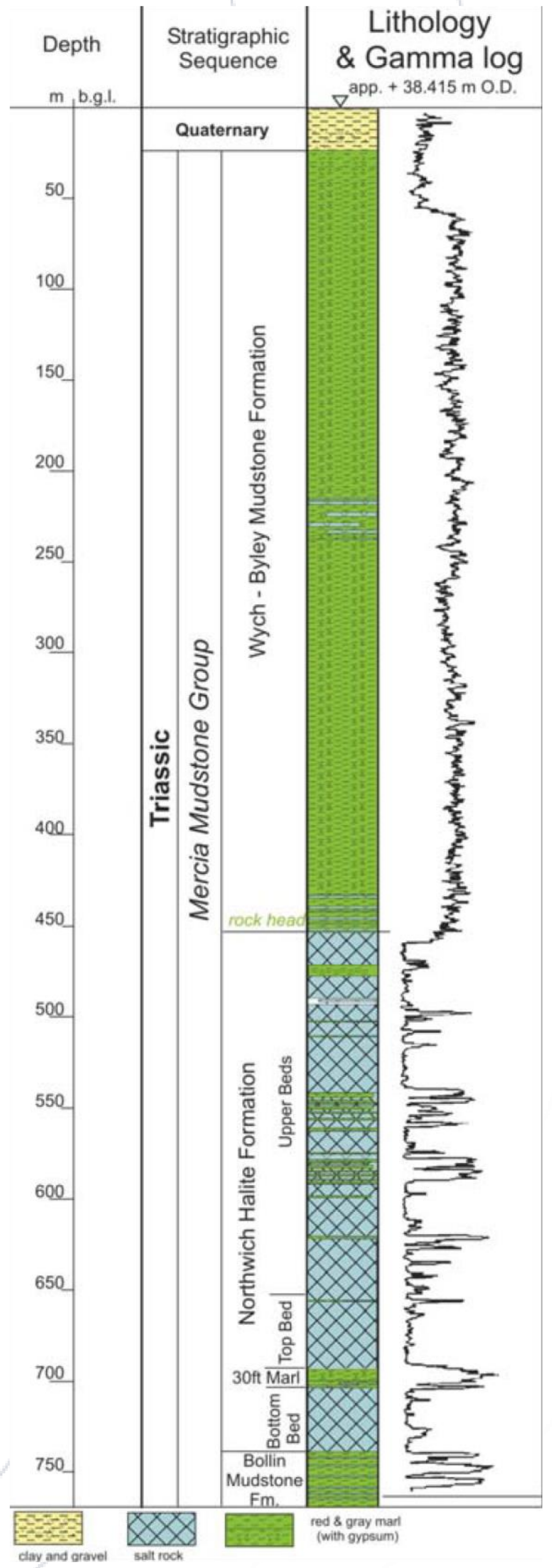
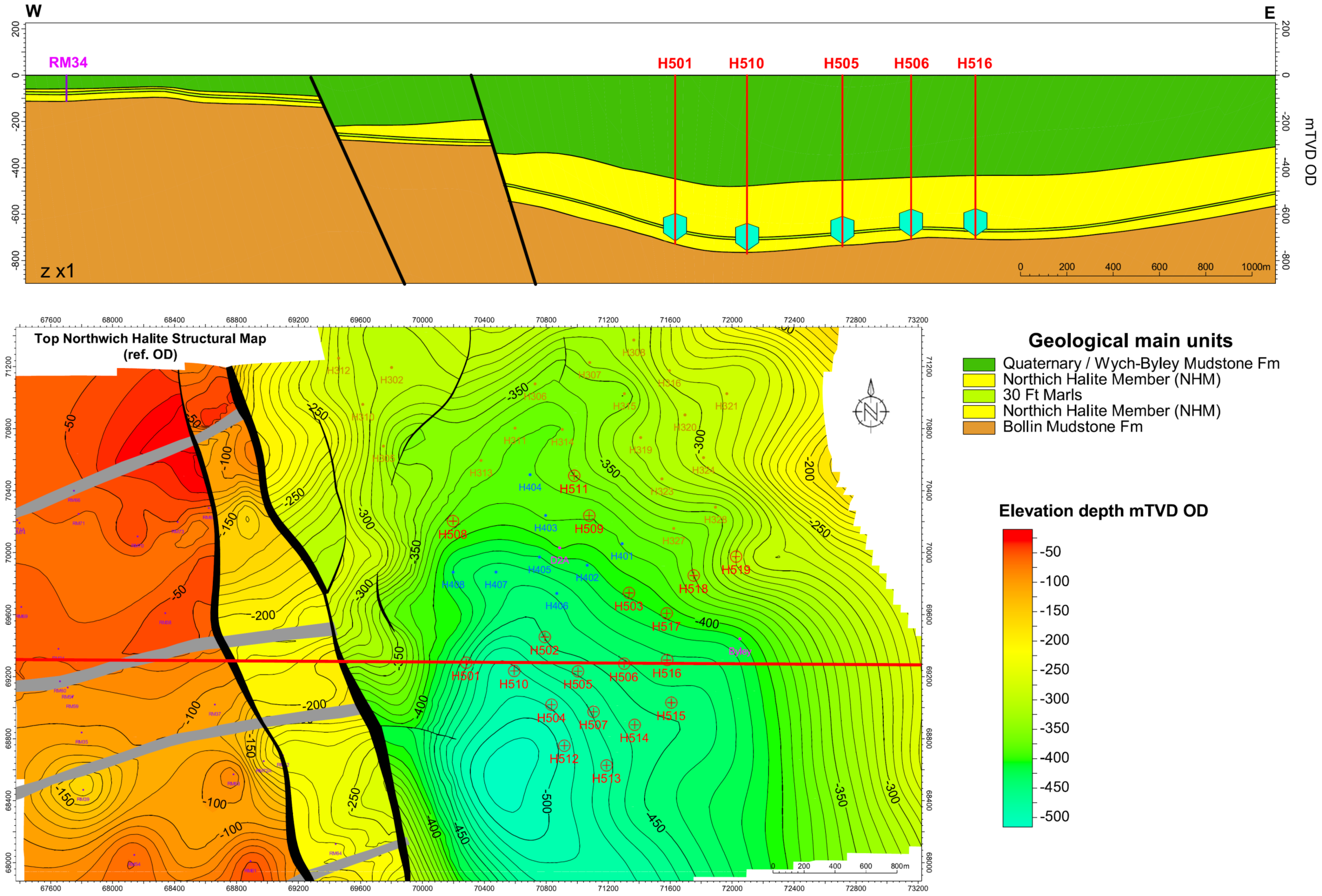


Fig. 5. Screenshot of the GOCAD model of the depth to top of the Northwich Halite Member. Contours are in metres below ground level.

Site Geology



Drakelow 2A exploration well (Beutel, 2004)



Top of salt structural map on the project location (Geostock, 2015)

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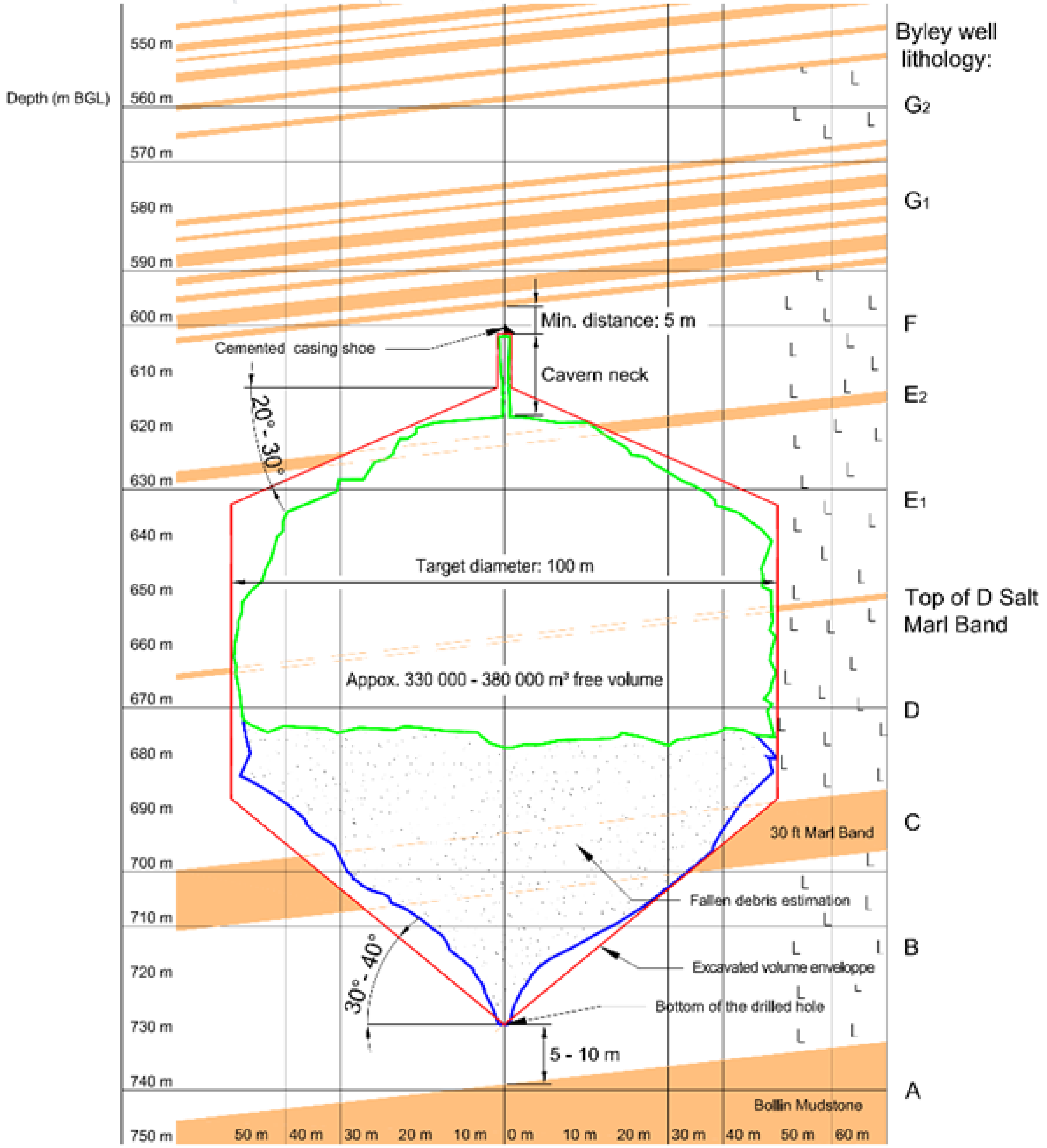
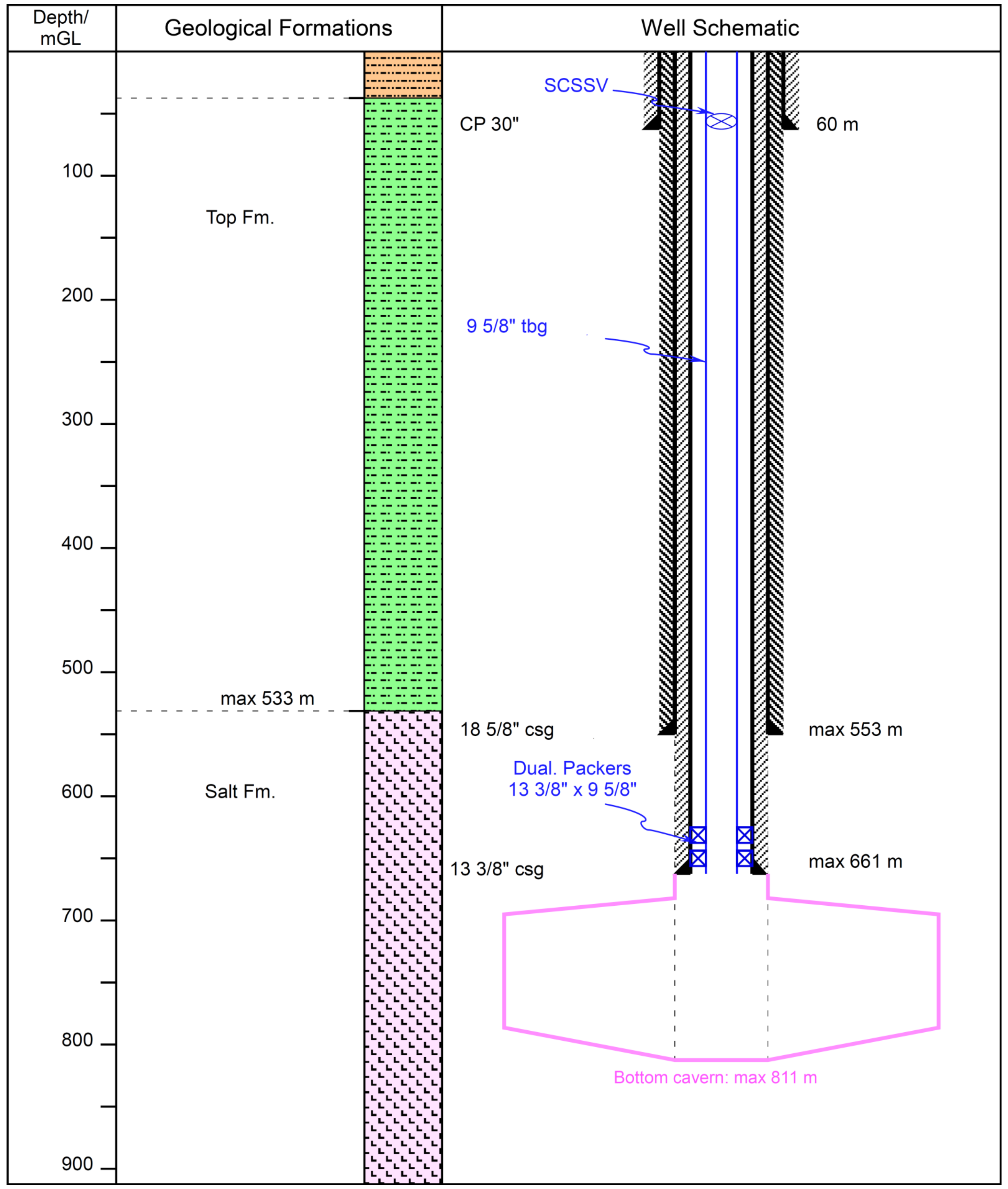
Hydrogen Cavern and Well Configuration





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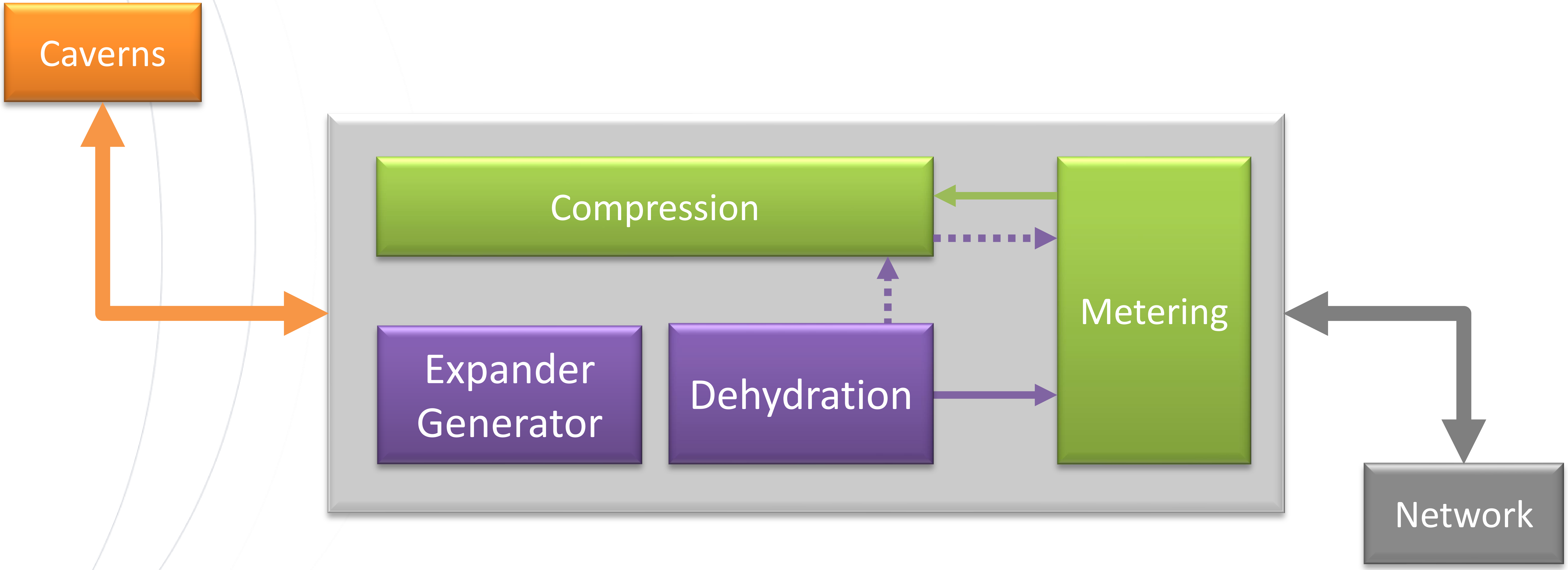
Storage operating parameters

Operating pressure gradients	0.185 bar/m (at casing shoe) 0.052 bar/m (at 2/3 of the cavern depth)	0.82 psi/ft 0.23 psi/ft
Operating pressures (at casing shoe)	Pmax. 96 bar to 123 bar Pmin. 31 bar to 39 bar	1392 – 1784 psi 450 – 566 psi
Operating temperature in normal operations	Tmax = 45 °C, Tmin = 10 °C	113°F, 50°F
Design Temperature (Extreme values)	Tmax = 60 °C, Tmin = 5 °C	140°F, 41°F
Total usable volume of caverns (19 caverns)	6,745,000 m3 (355,000 m3 per cavern)	42.4 MMbbl (2.23 MMbbl)
Working gas (average per cavern)	21.3 MMsm3 (72 GWhr, 1815 Tons)	0.75 Bcf (2.46 MMtherm)
Total working gas	405 MMsm3 (1360 GWhr, 34508 Tons)	14.30 Bcf (46.41 MMtherm)
Total cushion gas	239 MMSm3 (802 GWhr, 20364 Tons)	8.44 Bcf (8.16 MMtherm)
Total stored gas	644 MMsm3 (2162 GWhr, 54872 Tons)	22.74 Bcf (21.97 MMtherm)

Hydrogen Storage Schematic



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Hydrogen Storage Schematic

Export

- Export is from the salt caverns to network, often termed withdrawal or production
- Caverns are at a higher pressure than the network for majority of export phase and ‘free flow’ hydrogen to network
- Gas is dried to remove residual water from cavern solution mining process, which sits in the base of the cavern
- Gas is metered and flow and pressure is regulated to network requirements
- Compression can be used to export hydrogen when cavern pressure is below network pressure

Import

- Import is from network to caverns to network, often termed injection or filling or import
- Caverns are at higher pressure than network for majority of import time and compression is required

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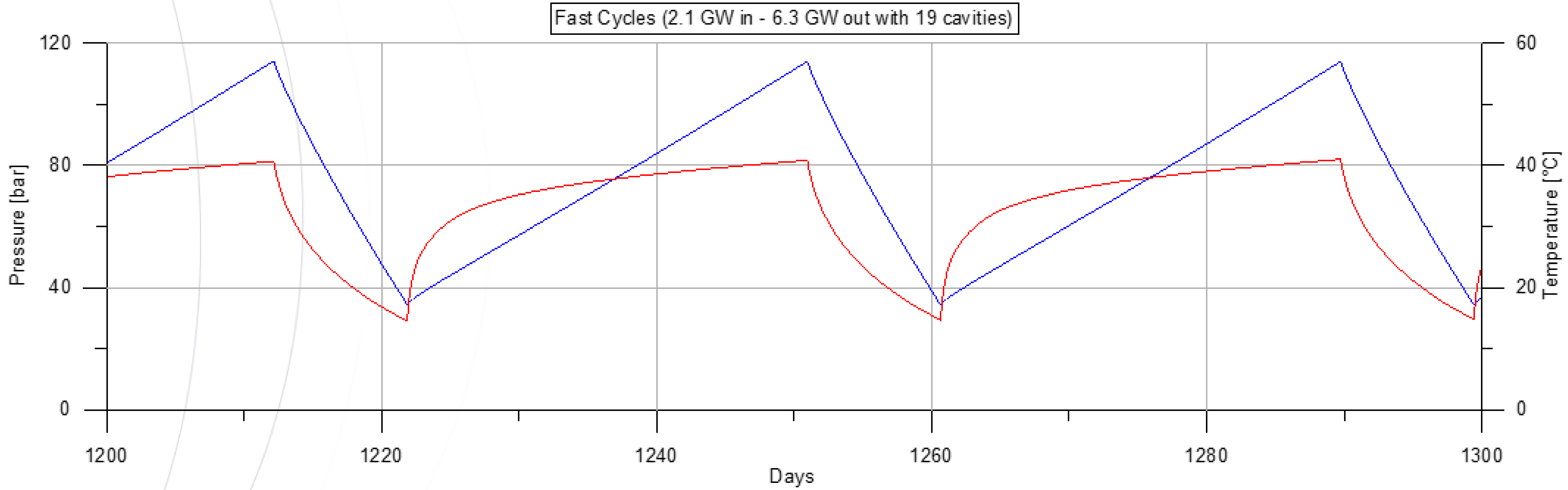
Storage flow rates (site and per cavern)

Site flow rates	GW	MMSm3/d	Ton/d	Bcf/d
Injection routine min	0.6	4.29	365	152
Injection routine max	0.8	5.72	487	202
Injection max	2.1	15. 01	1 279	530
Withdrawal routine min	0.6	4.29	365	152
Withdrawal routine max	1.5	10. 72	914	379
Withdrawal max (month)	2.0	14.30	1 218	505
High withdrawal (weeks)	4.0	28.59	2 436	1 010
Peak Withdrawal (several days)	6.3	45.03	3 837	1 590

Cavern flow rates	MW	MMSm3/d	Ton/d	MMcf/d
Injection routine min	32	0.226	19	8.0
Injection routine max	42	0.301	26	10.6
Injection max	111	0.790	67	27.9
Withdrawal routine min	32	0.226	19	8.0
Withdrawal routine max	79	0.564	48	19.9
Withdrawal max (month)	105	0.753	64	26.6
High withdrawal (weeks)	211	1.505	128	53.1
Peak Withdrawal (several days)	332	2.370	202	83.7

Storage cycling simulation



Thermodynamical simulation with hydrogen (Geostock's GUSTS software)

Hydrogen storage schematic

Expander Generator

- Multistage expander

- 1 GW H2 flow per train (7.2 MMSm3/d, 250 Bcf/d)
- 2 trains
- 3- or 4- stage
- Electric generation up to 3MW per train (4025 hp)
- Provides water removal prior to dehydration

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Dehydration – Technology Selection

Solid desiccants such as silica gel, alumina or molecular sieve

- Track record in numerous gas processing applications at this scale
- Very fast start-up and ramp capabilities
- Compact footprint
- High availability and minimal maintenance requirements with appropriate sparing
- Potentially lower capacity than TEG
- Regenerated using high temperature wet or dry gas that is returned to the process
- Generates aqueous effluent
- Desiccant change out required periodically

TEG

- Preferred technology for most recent UK salt cavern gas storage facilities
- Low CAPEX solution
- High availability and minimal maintenance requirements with appropriate sparing
- Large footprint for TEG storage and regeneration facilities
- Regenerated using heat and stripping gas to drive water from TEG
- Non-condensable gas stream (H_2, N_2, CO_2, H_2S) and aqueous effluent

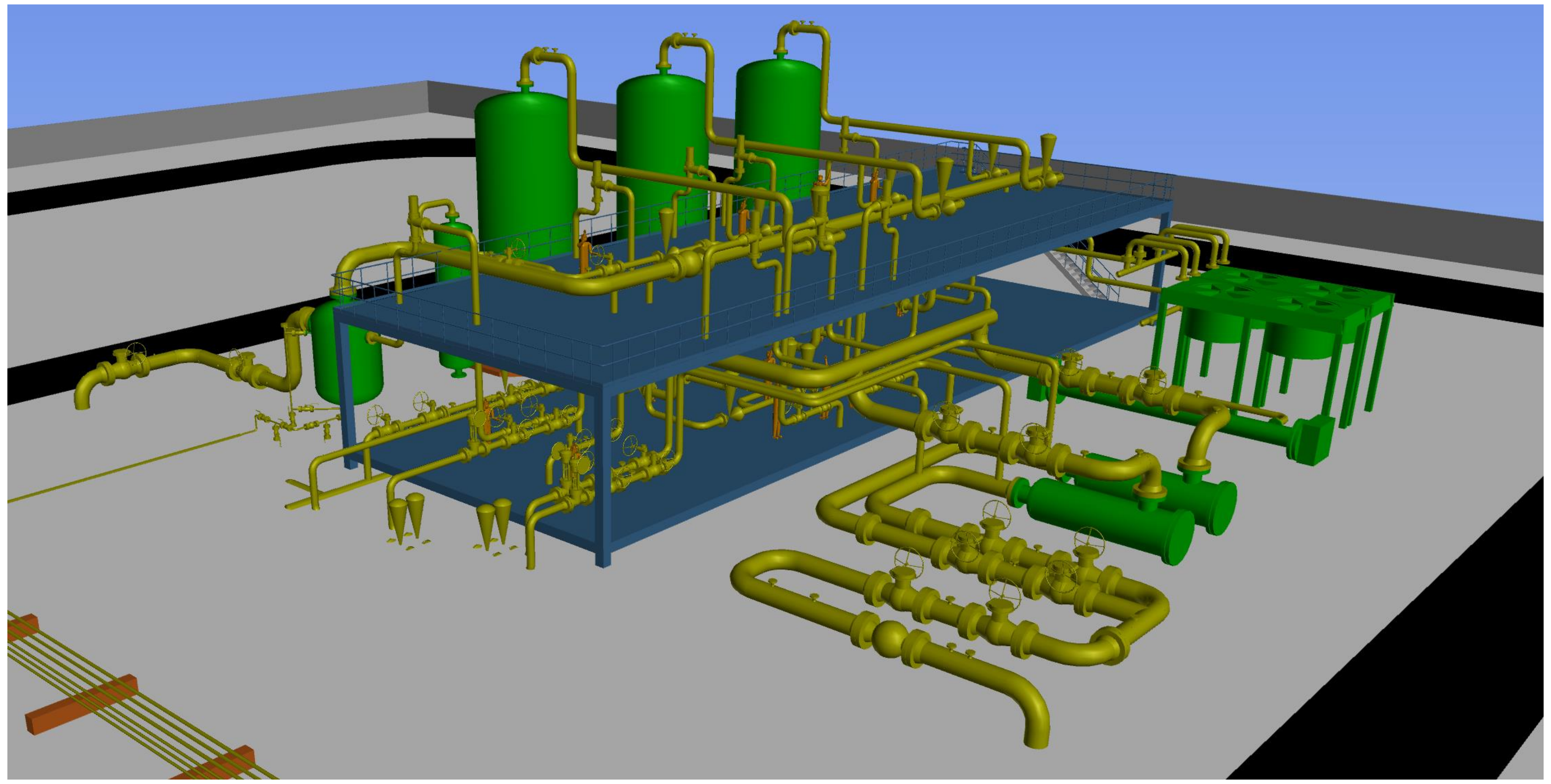
Potential for odour from both technologies due to odourant in network gas – natural gas odourant is added only at lower pressure

Dehydration

Adsorption – Temperature Swing

- Silica gel or alumina

- Peak hydrogen flow 3.2 GW per train (22.9 MMSm3/d, 808 Bcf/d)
- 3 adsorbers per train (2+1), 2 trains
- Electric regeneration heating 4 MW (13.6 MMBtu/hr)



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Compression – Technology Selection

Reciprocating

- Lubricated and non-lubricated types available
- Proven track record in hydrogen service at required scale – chemicals, refineries etc.
- Six or eight cranks required – 15 to 20MW range
- Large machines (circa 300 tonnes) with large footprint (circa 15 x 15 x 8 m) and auxiliaries (lube oil, cooling etc.)
- Availability and maintenance requirements mean sparing is essential

Centrifugal

- Conventional machines operate up to 350 m/s tip speed
- Low molecular weight gas requires many impellers and casings with hydrogen (compared to natural gas)
- Two, two stage machines required in series (four stages in total)
- Large footprint and capital cost
- Good availability and minimal maintenance requirements
- High speed machines offer opportunity to reduce number of stages and casings (higher tip speeds), but machines are not typically available in the marketplace / proven

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Compression

Reciprocating, lubricated

Image supplied courtesy of Baker Hughes

- 1 GW H2 flow per train (7.2 MMSm3/d, 250 Bcf/d), 2 trains
- API 618 machines
- 39 to 125 barg (565 to 1815 psig)
- 16MW electrical drive per train (21,500 hp)
- 300 tonne units
- Electric motor driven, main site electrical power consumer

Thank you for listening

Any Questions?