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Aspen Energy Consulting

ILLMATIC ENERGY

Hydrogen Salt Storage Assessment (HYSS)
Grant Agreement – 21/RDD/673

March Update

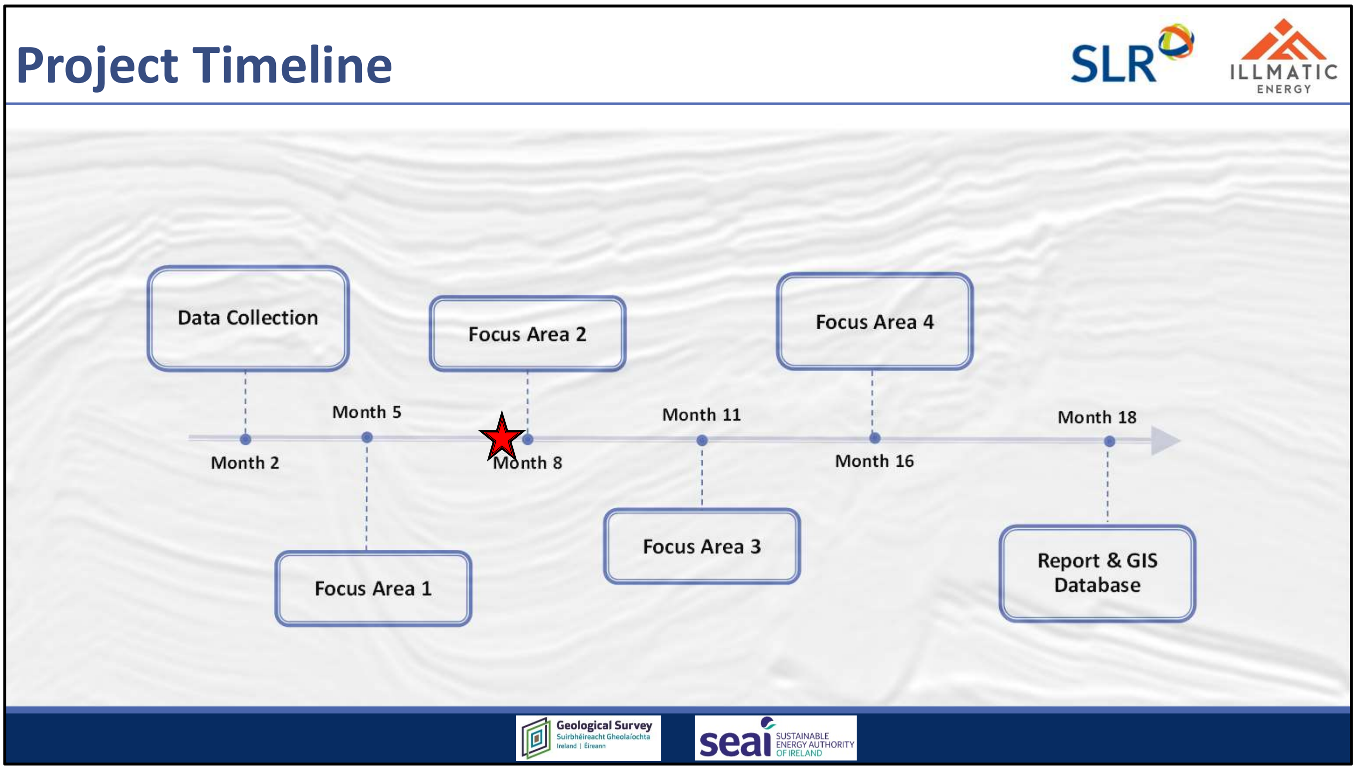
13th March 2023

This is a research project that we secured funding for in April 2022, to investigate the potential for hydrogen storage in salt caverns offshore Ireland adjacent to offshore wind farm licences.

Objectives

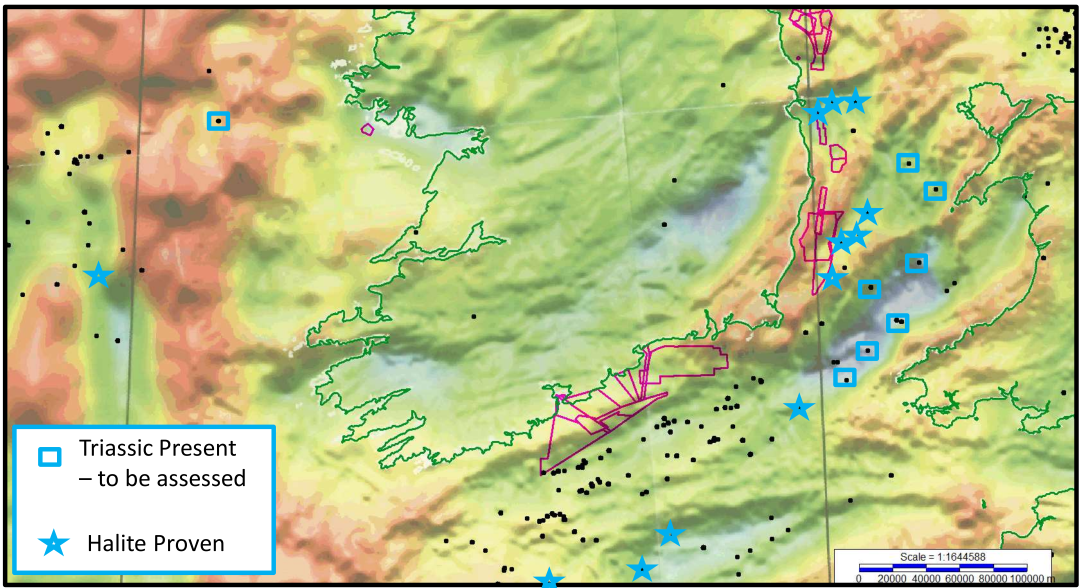
- Assess hydrogen storage potential within manmade salt caverns offshore Ireland.
- Identify potential surface, subsurface and environmental risks.
- Focused on areas suitable for offshore wind projects-
  - Focus Area 1: Kish Bank Basin
  - Focus Area 2: Irish Sea Basins
  - Focus Area 3: Celtic Sea Basins
  - Focus Area 4: Atlantic Margin Basins
- Fill identified data gaps in reports on potential of hydrogen storage offshore Ireland.
- Repurpose existing hydrocarbon industry datasets & engage with ORE industry.
- Assessment of saline aquifers still needs to be assessed.

A central part of this project was to use existing oil and gas well and seismic data to accelerate the energy transition and assist the offshore wind sector. The project employs experienced seismic interpreters and geophysicists from the Irish oil and gas sector. Active interaction with the Offshore wind sector is an integral part of the project, demonstrating the transferable skills to the offshore wind sector.

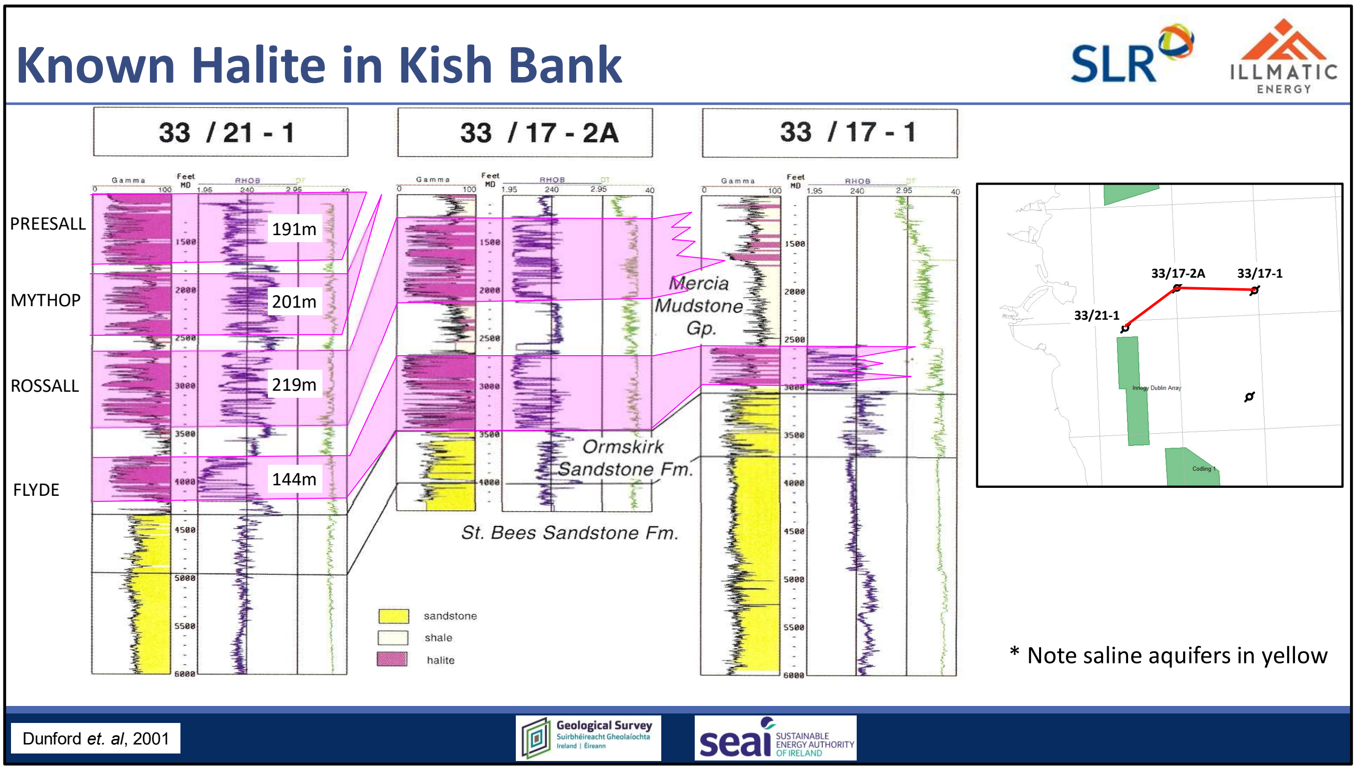


Data collection was significantly delayed due to access issues. Focus Area 1 is complete. Focus area 2 & 3 data has been loaded and QC'd.

Known Halite in existing wells

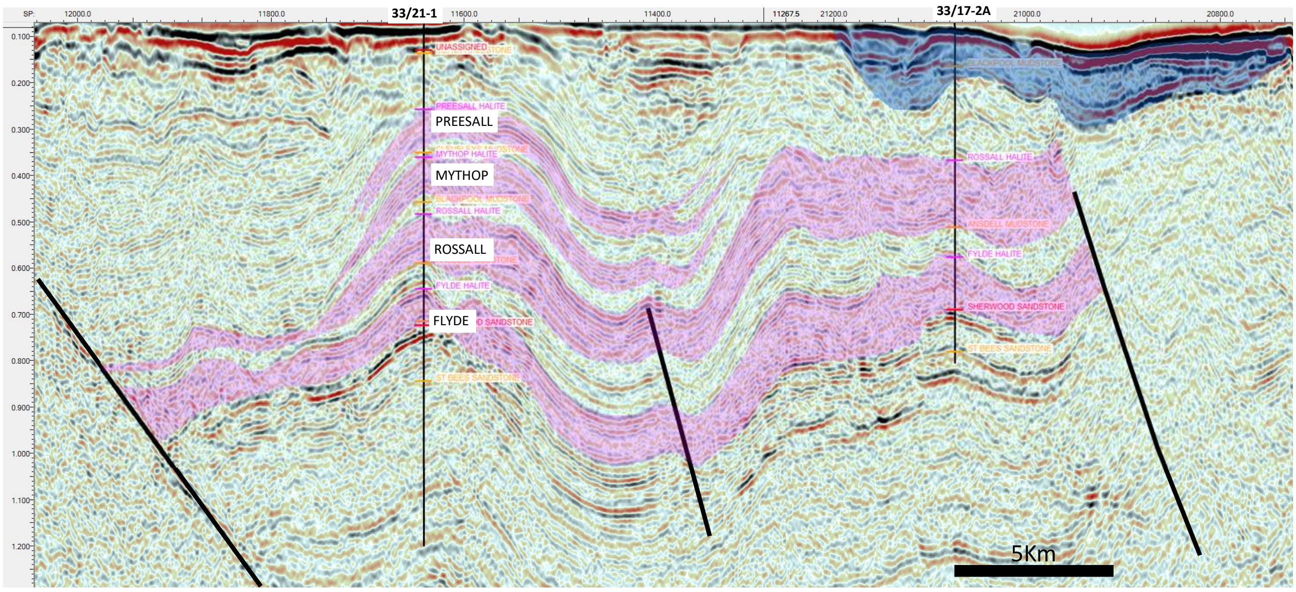


The green boxes show where we have 3D seismic data. The blue stars show where the presence of salt (Halite) offshore is proven. The blue squares show where there is Triassic deposited but the presence of salt needs to be assessed.



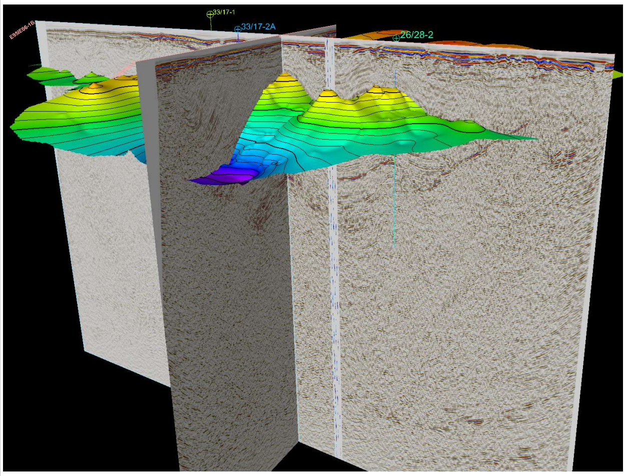
The map to the right shows Dublin Bay with Offshore wind licences in green and the three wells that have been drilled offshore proving the presence of salt – shown on the wireline log response to the left. The purple is halite. The yellow is permeable sandstones, which could also be a storage reservoir for hydrogen. The Irish Centre for Applied Geoscience is doing a research project on this reservoir on behalf of dCarbonex.

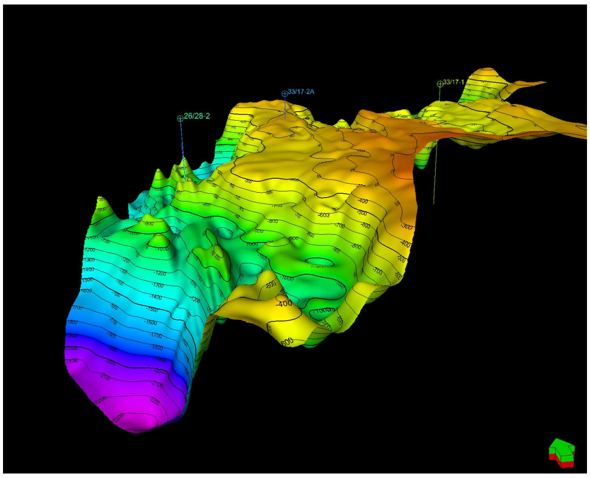
Seismic data showing halite thickness



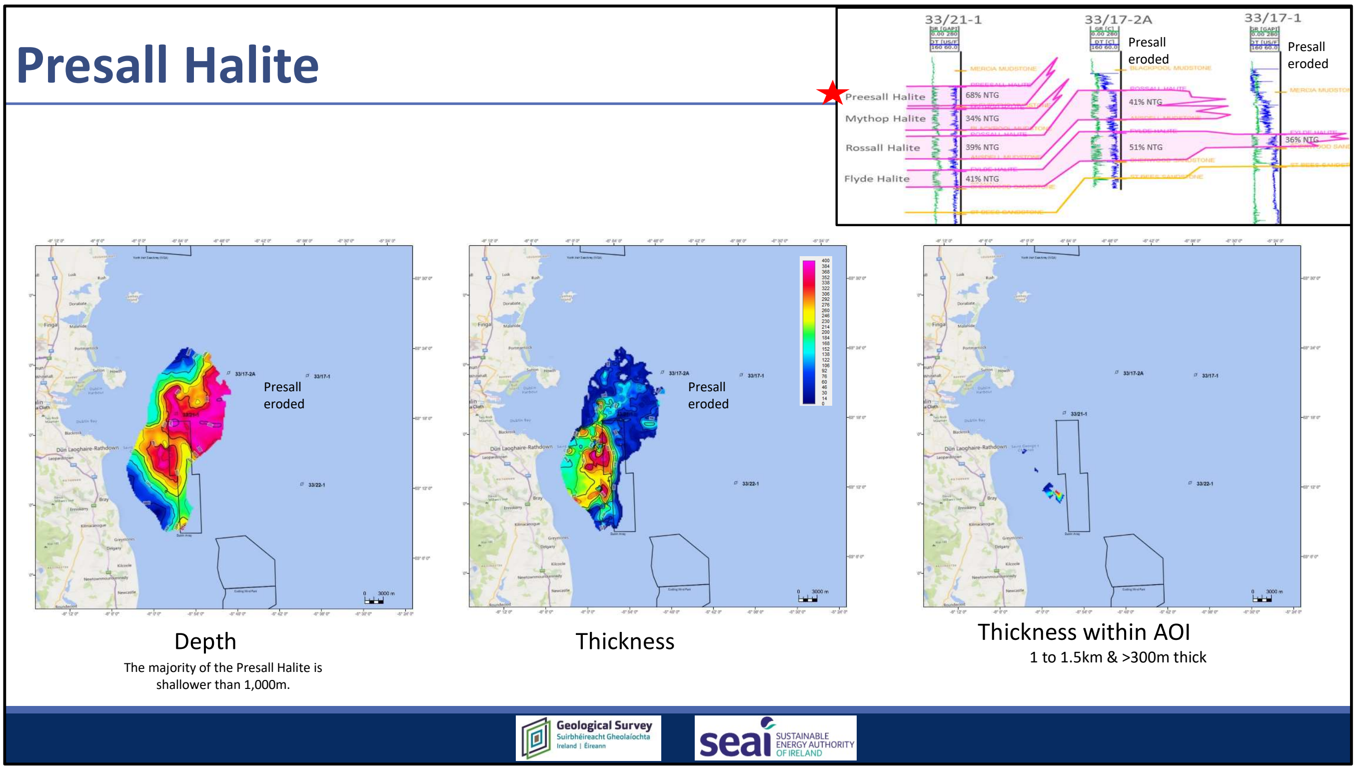
This cross section running West to East shows the variations in thickness of salt (in pink) across the basin.

3D Visualisations



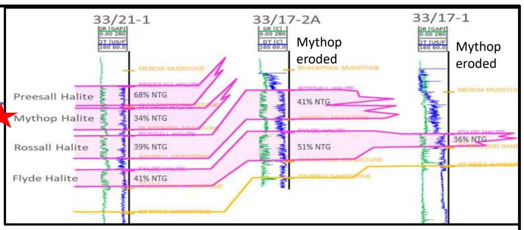


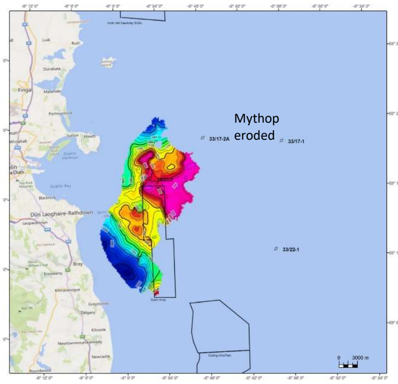
Here is an example of the 3D visualisations we can do which assist us in visualising the structure and morphology of the geological units.



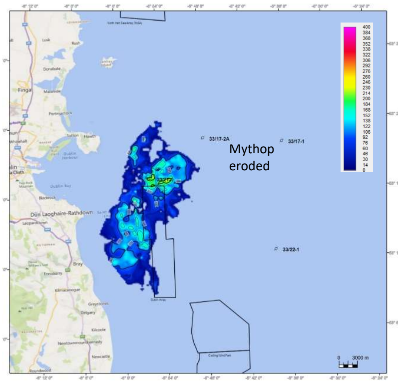
The youngest of the 4 halites does not cover the entire sedimentary basin, is up to 400m thick, and has a large area within the “sweet-spot” of 1 to 1.5km depth and >300m thick.

Mythop Halite



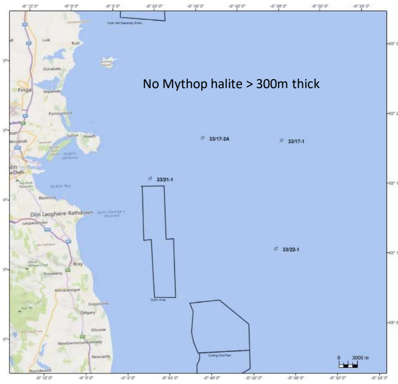


Depth



Thickness

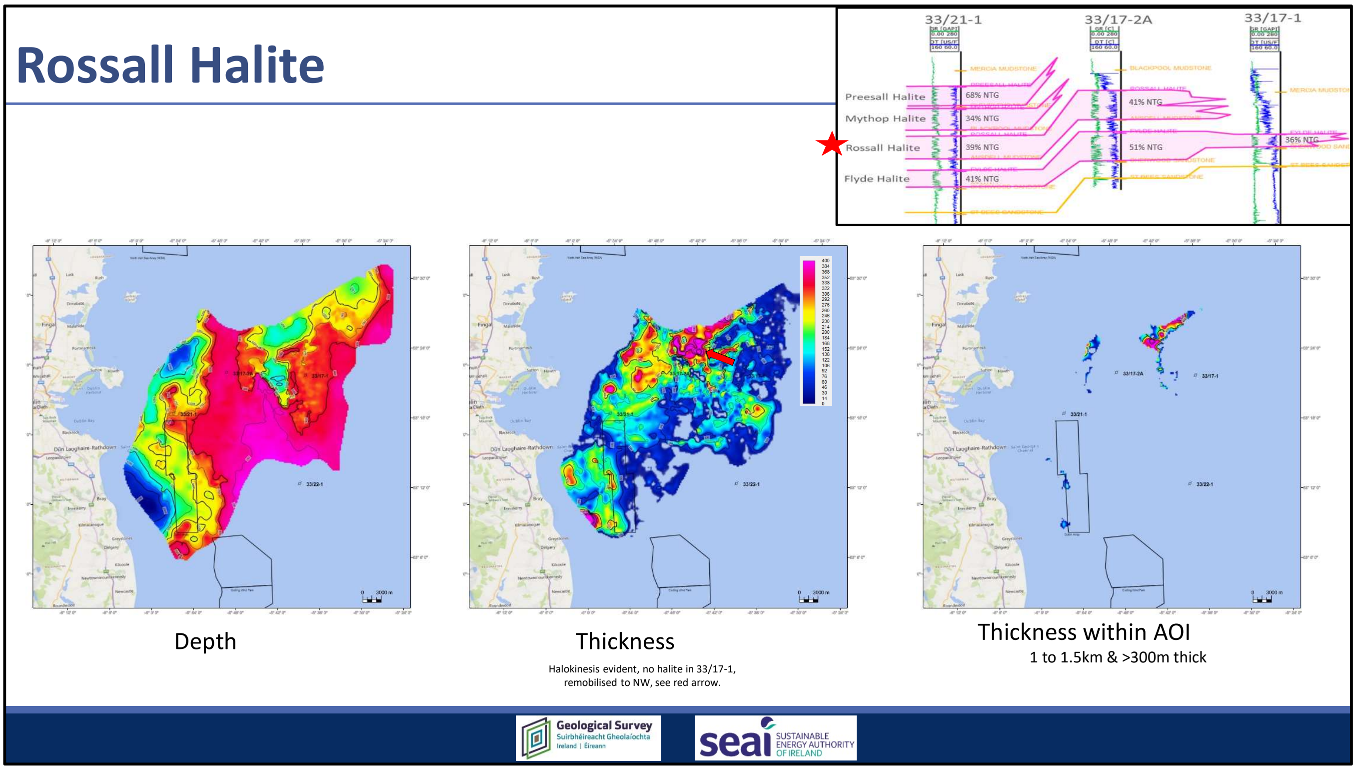
The Mythop Halite is less than 300m thick.



Thickness within AOI

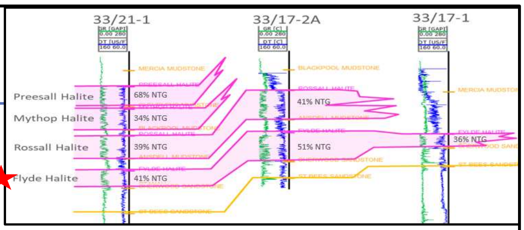
1 to 1.5km & >300m thick

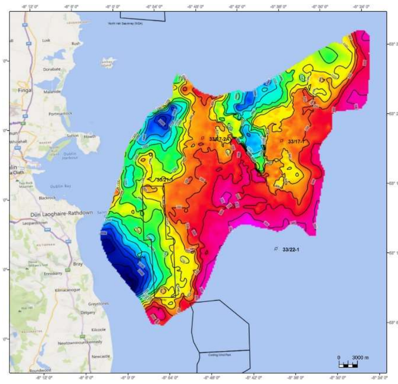
This halite is too thin to have any “sweet-spot” of 1 to 1.5km depth and >300m thick.



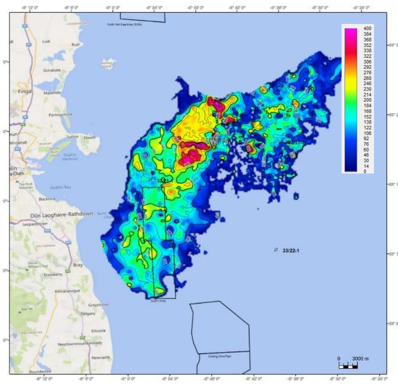
This halite is extensive, up to 600m thick, and has a very large area within the “sweet-spot” of 1 to 1.5km depth and >300m thick. There is clear evidence of halite movement in this unit, meaning cleaner more massive halite, less shale units.

Flyde Halite

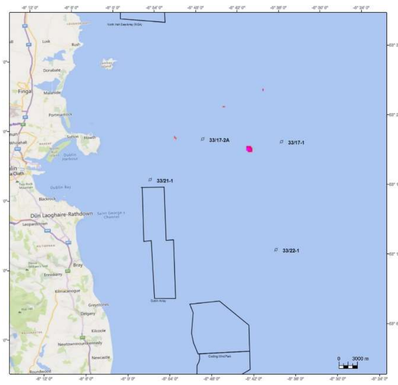




Depth



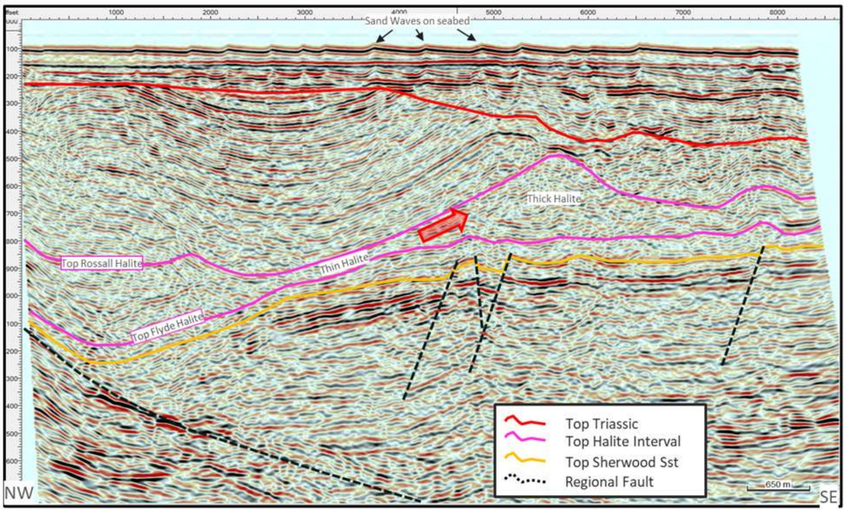
Thickness

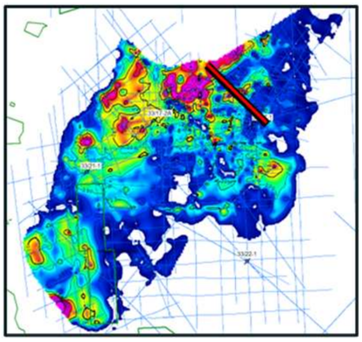


Thickness within AOI
1 to 1.5km & >300m thick

The oldest of the 4 halites is laterally extensive, is up to 400m thick, but is generally deeply buried, leaving limited area within the “sweet-spot” of 1 to 1.5km depth and >300m thick.

Evidence of halokinesis





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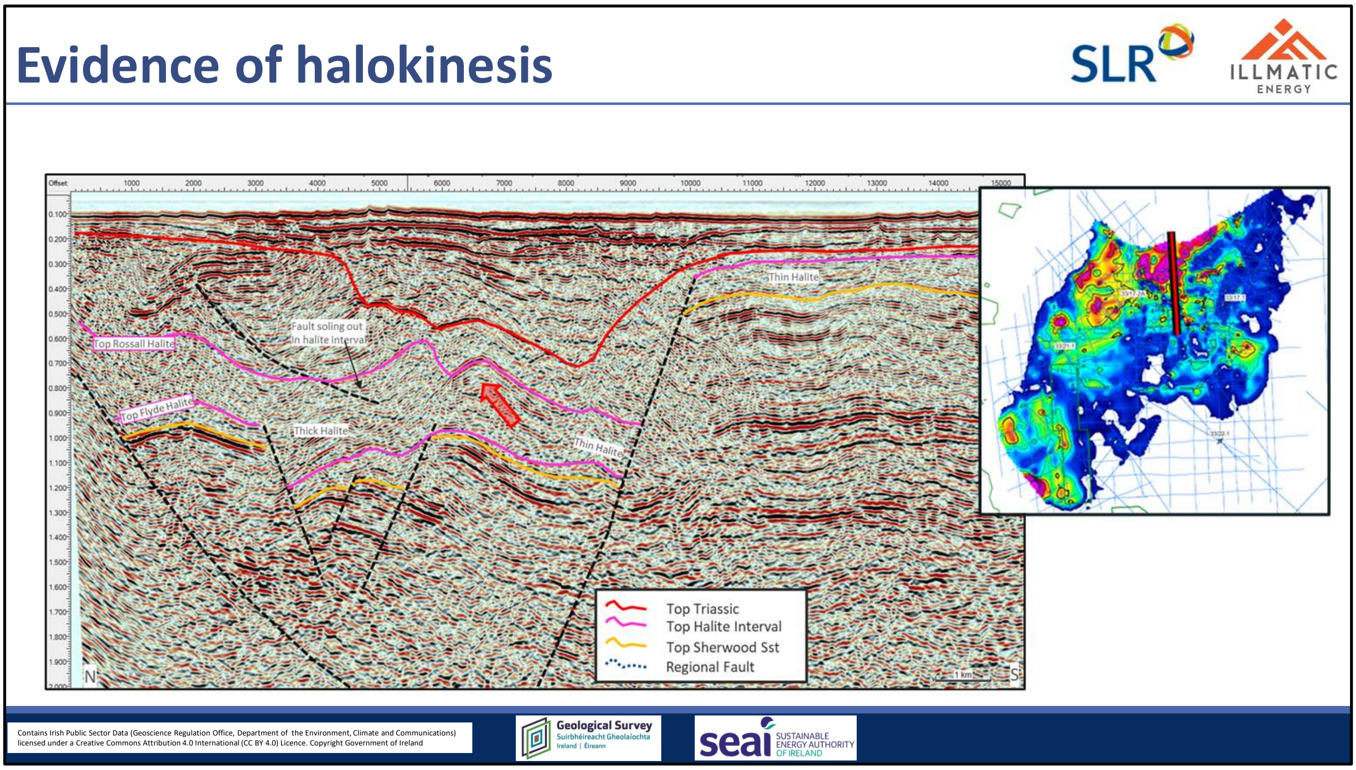
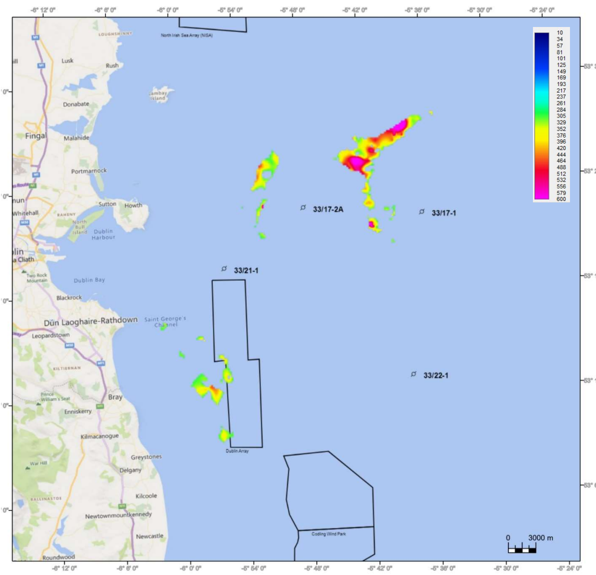
The interpretation of top of the halite units (in pink) shows thickening and thinning, which is evidence of salt withdrawing from one area, and moving to another area. A process called halokinesis.



The interpretation of top of the halite units (in pink) shows thickening and thinning, which is evidence of salt withdrawing from one area, and moving to another area. A process called halokinesis.

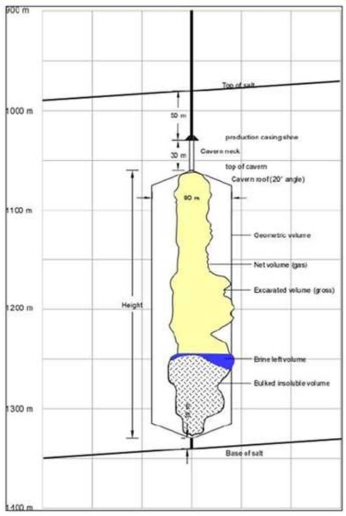
Cavern Potential Locations



Areas with colours have >300m of salt, at a depth of 1000m to 1500m.

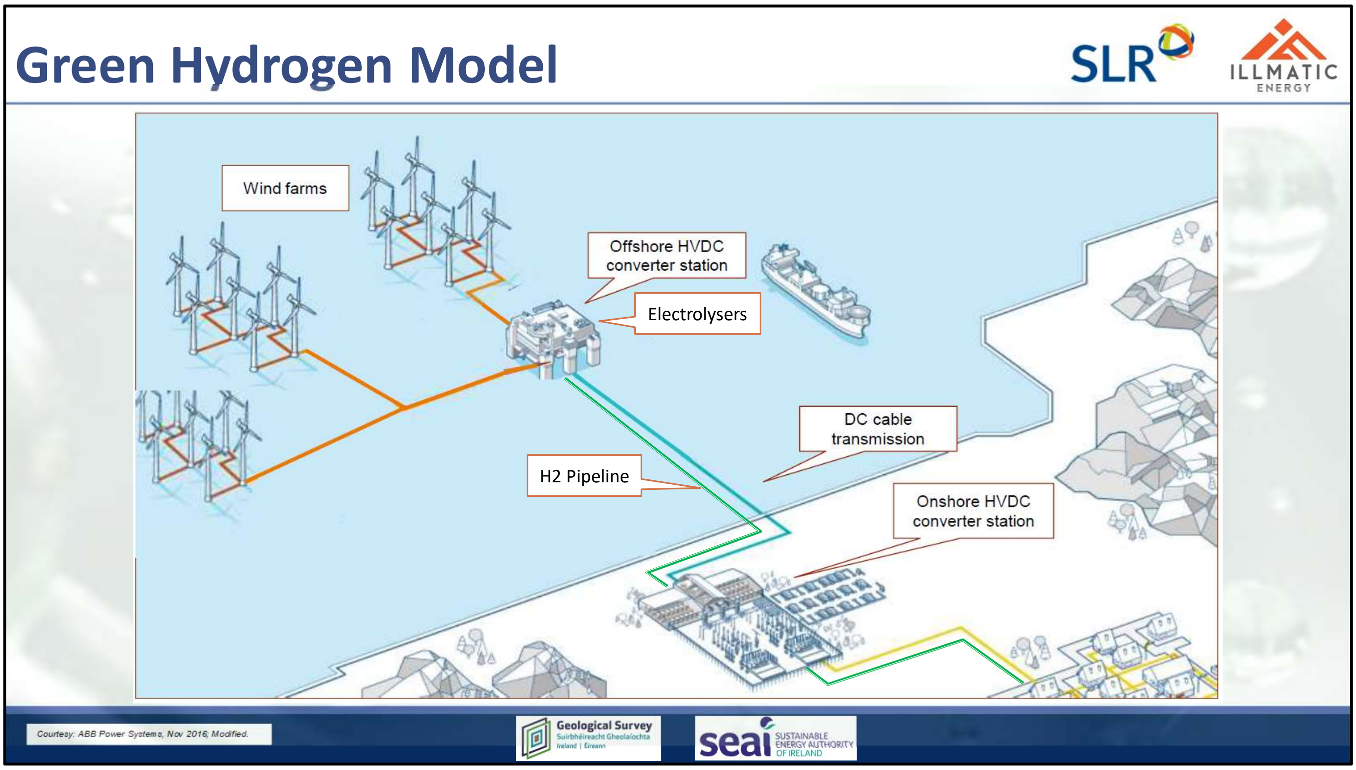
We estimate that 300m gross halite interval will yield ~200m of net halite, suitable for a 120m high potential cavern development.

With each potential cavern of 85m diameter, with a 330m standoff between caverns, we estimate a first pass potential of >200 caverns.

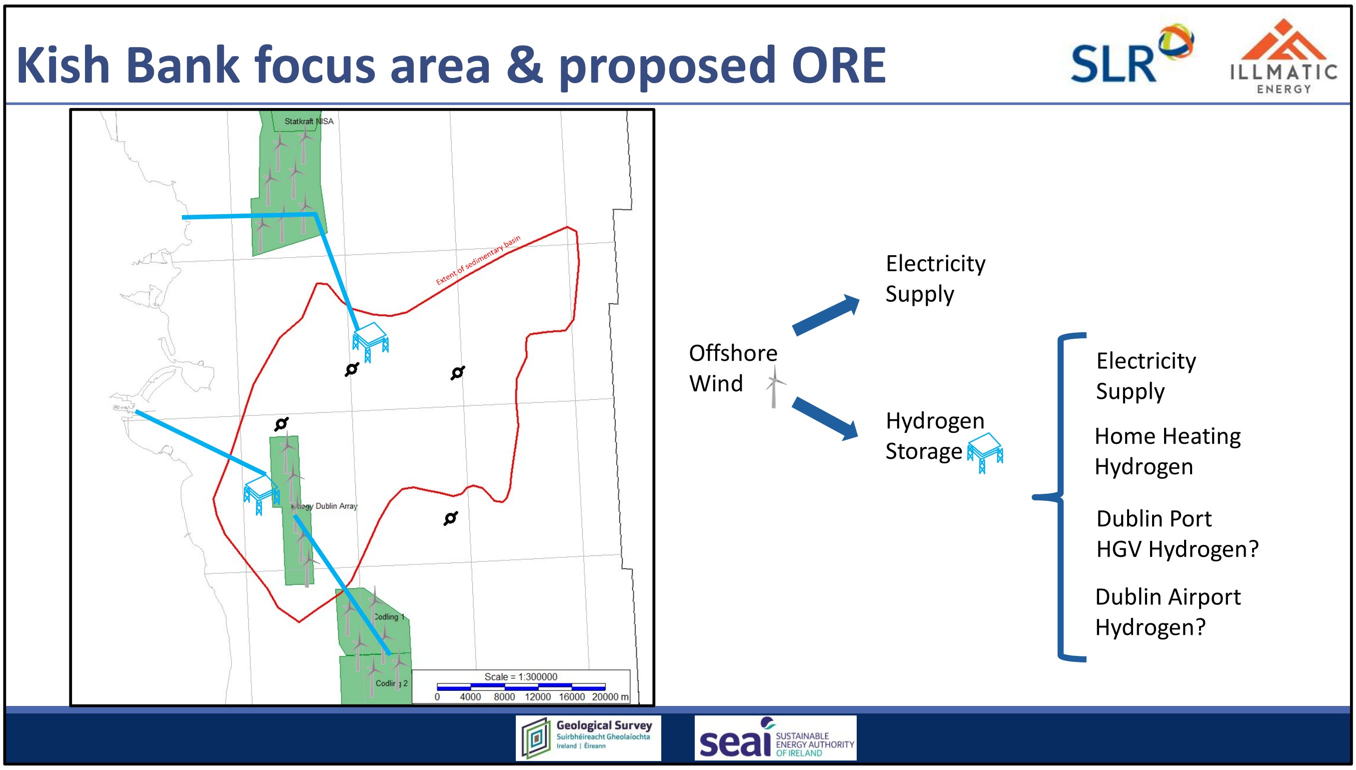


Cavern Geometry. Source: Hystories

This map shows the areas where the salt (from all units) is greater than 300 m thick at a depth of 1 to 1.5km. This is the optimum depth and thickness recognised by industry for hydrogen storage as you can see from the diagram on the left from an EC funded project Hystories.

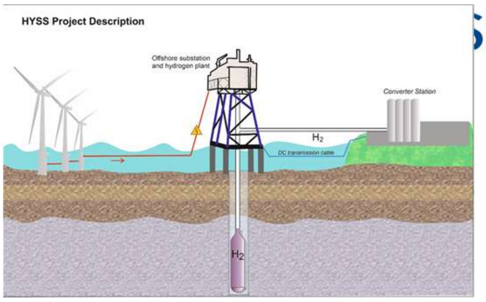


This is what the surface facilities for an offshore wind farm with hydrogen production and storage might look like. The hydrogen is produced by electrolysis on an offshore platform from curtailed offshore wind generated electricity. The hydrogen can be stored offshore in salt caverns under the platform until market conditions are favourable for export of hydrogen for blending into the natural gas network, supply of HGVs and public transport, or local ferries.



A schematic view of offshore wind, hydrogen storage facilities and pipelines in the area offshore Dublin.

Figure 3 Hydrogen Production Platform.
Source Poshydon



Stage 1 Construction of Offshore Wind Farm

- seabed foundations
- turbine installation
- offshore substations
- inter turbine array cables
- export DC cable to shore
- onshore substation

Stage 2 Geological Site Characterisation of Subsea Salt Cavern

- 3D seismic survey acquisition
- 3D processing & interpretation
- drill appraisal well
- data analysis & interpretation
- salt cavern modelling

Stage 3 Cavern Solution Mining and Installation of Hydrogen Plant Offshore Platform

- re-enter appraisal well
- cavern solution mining
- completion of production well
- installation of hydrogen production platform
- export hydrogen pipeline to shore

Figure 5 Kish Basin Offshore Green Hydrogen Production Facility Construction

We have identified three stages in the Hydrogen Production Facility Construction. For each of these stages we are carrying out a high level environmental impact assessment to identify the most significant barriers to be addressed.

Activity		Output	Impacts			Mitigation	
Nature	Duration	Type	Nature	Importance	Type	P/Y/N	Description
Re-enter appraisal well to enable installation of a leaching completion to create the salt cavern	Estimated 10 days using jack up drilling rig	This is an extension of the drilling operation with the same outputs as above – oil spill, engine & solid waste emissions, noise & habitat disturbance	Marine & air pollution, disruption to shipping & fishing operations, impact on biological environment	L-M	D,C	Y	As above for drilling operation
Cavern solution mining dissolves the naturally occurring salt formation using nitrogen gas as a blanket to prevent dissolution in the salt cavern roof	Estimated 2.5 years using jack up drilling rig	Impacts on water quality due to produced brine	Marine pollution, impacts on biological environment & wild life & fisheries	H	D,C	P	Dilute brine with seawater before disposal; disperse brine where currents are strongest;
		Oil spill	Marine Pollution	L	D,C	Y	Oil spill contingency plan in place, Probability of a major accidental spill of hydrocarbons during the exploration drilling is very low therefore little chance of transboundary and cumulative effects.
		Engine emissions	Air pollution	L	D,C	Y	Regular maintenance
		Physical presence	Disruption to fishing/shipping operations	M	D,C	Y	Notifications of operational schedule
		Impacts on water quality due to solid waste	Marine pollution	L	D	Y	Shore disposal at port No Impacts
		Habitat disturbance, pollution, displacement	Marine, air, noise pollution impact on Wild life	L	D,I,C	Y	Implementation of management procedures to ensure environmental controls are operating effectively and efficiently
		Noise	Impacts to Biological Environment	L	D,C	Y	The potential sound impacts from drilling operation are considered to be minimal and will not contribute to cumulative effects.
Completion of production wells	Estimated 10 days per well using jack up drilling rig	This is an extension of the drilling operation with the same outputs as above –oil spill, engine & solid waste emissions, noise & habitat disturbance	Marine & air pollution, disruption to shipping & fishing operations, impact on biological environment	L-M	D, C		As above for drilling operation
Installation of offshore substation and hydrogen production platform	Estimated three months using heavy lift barge to install steel jacket platform	Physical presence	Disruption to shipping & fishing operations,	L-M	D, C	Y	
		Oil spill	Marine pollution	L	D, C	Y	Oil spill contingency plan in place
		Engine & solid waste emissions,	Marine pollution	L	D, C		Regular maintenance and waste disposal to shore
		Noise – pile driving	Impact on cetaceans	H	D	Y	Soft starts, acoustic buffers/screens
		Seabed disturbance	Habitat disturbance	L			Enhanced marine habitat on artificial reef
Lay export hydrogen pipeline to shore	Using pipe laying barge	Physical presence	Disruption to shipping & fishing operations,	L-M	D, C	Y	Notifications of operational schedule
		Seabed disturbance	Impact on marine areas of conservation	L-M	D, C	P	Adjust operational schedule to minimise impact
		Habitat disturbance	SPA, SAC, Annex IV	L-M	D, C	P	Adjust operational schedule to minimise impact
Beneficial impacts							
Substation & H2 production platform	20 years	Physical presence	Impact on marine life	M	D, C		Enhanced marine life habitats due to artificial reef affect

Table 4 Stage 3 Environmental impact of Cavern Solution Mining and Installation of Hydrogen Plant Offshore Platform

Here is an example of this high level assessment with the critical impacts in red with mitigation measures identified.

Phase 1: Integrating Geo Datasets

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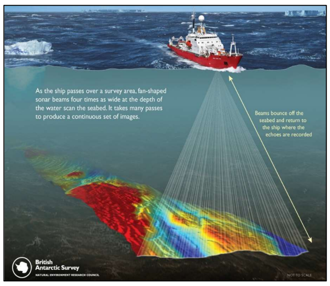

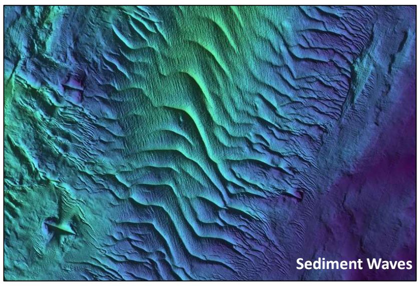

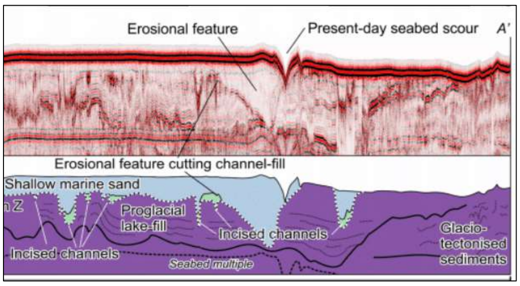

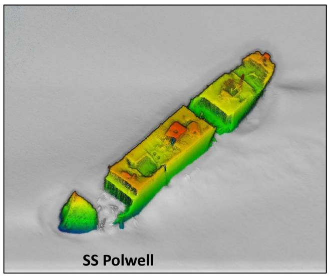

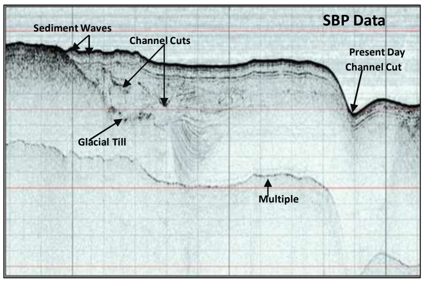

- The primary acoustic devices used by the INFOMAR programme are Multibeam Echosounder (MBES), Singlebeam Echosounder (SBES), Shallow Seismic / Sub Bottom Profiler (SBP), and Side Scan Sonar (SSS).
- The bathymetric data is a dataset that has being acquired and processed is to international hydrographic standards. It produces high quality digital maps that are easily accessible through the INFOMAR data portal.
- The SBP/HRSS are the most valuable geophysical datasets when constructing an accurate ground model particularly for offshore fixed bottom installations and cabling onshore. Data acquisition gaps should be considered, as there are areas where data still needs to be acquired as part of programme strategy to end 2026.

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This shows another aspect of the project, a review of the Infomar datasets and shallow risks, geological and non-geological.

Theoretical hydrogen storage potential

Temperature (K)	Overburden Pressure	*Compressibility Factor*	Gas Density (ρ_{H2})	*ρ_{H2} maximum*	*ρ_{H2} minimum*	Mass of Working Gas (kg) (m)	Cavern Capacity (GWh_{H2})
Temperature (T) = 288+0.025(depth-cavern height/2)	Overburden (P) = rock density (ρ) x Gravity (g) x (depth - cavern height)		(ρ_{H2}) = pressure (P) x molar mass (M) / compressability factor (Z) x universal gas constant (R) x temperature (T)	*(ρ_{H2}) = pressure (80% of overburden) x molar mass (M) / compressability factor (Z) x universal gas constant (R) x temperature (T)*	*(ρ_{H2}) = pressure (24% of overburden) x molar mass (M) / compressability factor (Z) x universal gas constant (R) x temperature (T)*	m = (ρ_{H2} max - ρ_{H2} min) x cavern volume (V) x safety factor (0)	working gas (m) x lower heating value of gas (LHV)
K	Pa	Z	kg m^{-3}	kg m^{-3}	kg m^{-3}	kg	GWh_{H2}
316.5	23308560	*1.05(estimate)*	17.852	13.541	4.101	4394270.85	146.418

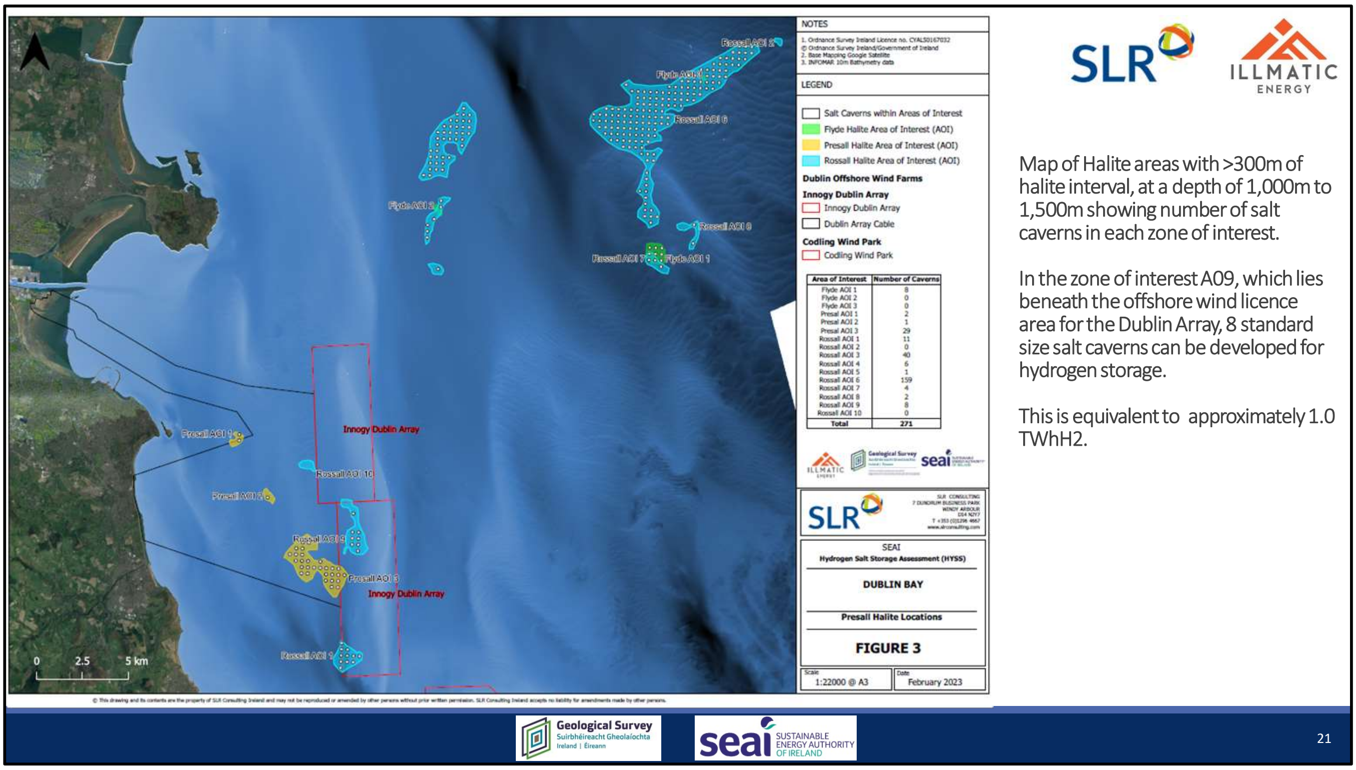
Table 1: Calculation of cavern storage capacity Source: Caglayan et al 2020

Modelling cavern volumes	*Estimation of hydrogen storage volumes*				*Caglayan*		*Energy Storage Capacity*				
Volume available for storage	Temperature (Midpoint)	Lithostatic Pressure	Max Op Pressure	Min Op Pressure	ρ_{H2Max}	ρ_{H2Min}	Equation of State	Max H2 Density	Min H2 Density	Mass of Working Gas	Energy Storage Capacity (GWh_{H2})
V_{cav} = SCF x (1 - IF x INSF x BF) x V_{Bulk}	$T_{Midpoint}$ = T_{0} + Δ_{T} x (Z_{Casing} + 0.5 x H_{Cavern})	P_{Casing} = ($\rho_{Overburden}$ x $t_{Overburden}$ + ρ_{Salt} x t_{Salt}) x g	$P_{MaxOperating}$ = 0.8 x P_{Casing}	$P_{MinOperating}$ = 0.3 x P_{Casing}	*(ρ_{H2}) = pressure (80% of overburden) x molar mass (M) / compressability factor (Z) x universal gas constant (R) x temperature (T)*	*(ρ_{H2}) = pressure (24% of overburden) x molar mass (M) / compressability factor (Z) x universal gas constant (R) x temperature (T)*	Williams uses equation of state from Bells et al. to calculate ph2 Max and Min	$m_{MaxOperating}$ = ρ_{H2Max} x V_{Cavern}	$m_{MinOperating}$ = ρ_{H2Min} x V_{Cavern}	$m_{Working}$ = $m_{MaxOperating}$ - $m_{MinOperating}$	E = $m_{Working}$ x (LHV/3,600,000)
m^3	K	Pa	Pa	Pa	kg m^{-3}	kg m^{-3}				kg	GWh_{H2}
318530.01	314.65	26977500	21582000	8093250	16	6		5045234	1891963	3153272	105.074

Table 2: Calculation of cavern storage capacity Source: Williams et al 2020

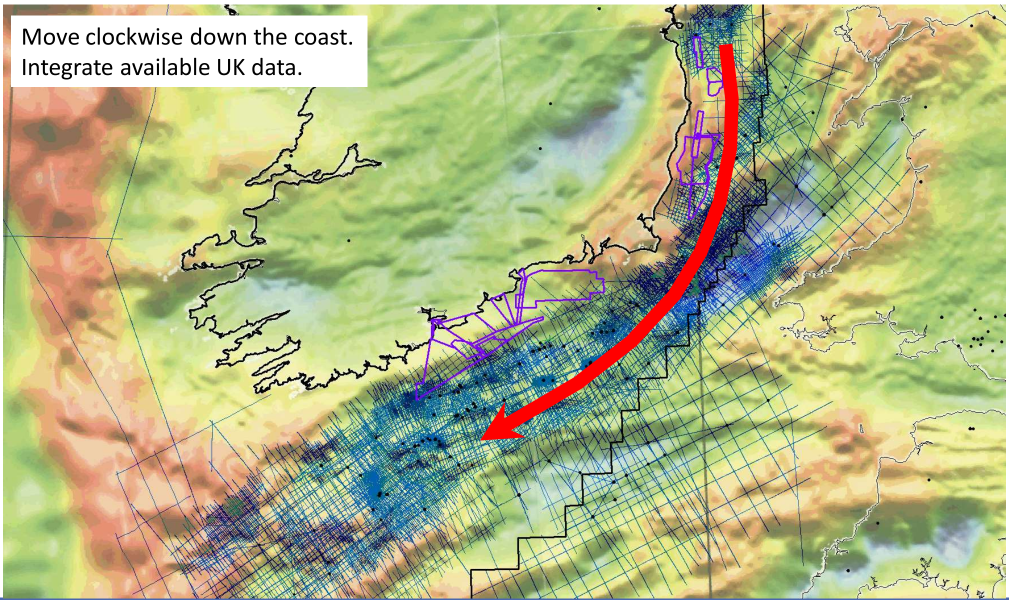
- The calculations of cavern storage capacity were made using the methodology of Caglayan et al 2020 and Williams et al 2020.
- The extent of salt occurrence in the Kish Basin at the required depth of 1,000m and 200m thickness is such that many salt caverns could be solution mined, sufficient for seasonal hydrogen storage.
- A typical salt cavern can store between 146 GWh_{H2} and 105 GWh_{H2} of hydrogen.

The calculations of cavern storage capacity were made using the methodology of Caglayan et al 2020 and Williams et al 2020. The results are shown in Table 1 and Table 2. There is a difference of 41 GWh_{H2} for a typical salt cavern at a depth of 1,200m with a height of 120m, diameter 84m and safety factor of 70%. The safety factor is applied to take account of the bulk insoluble residue and brine volume left after the cavern solution (see Fig 2). The difference can be attributed to the slightly different methodologies used.



This map shows the areas where the Halite Formations occur at depths greater than 1,000m and is more than 300m thick, the optimum depth and thickness for salt cavern storage of gas. The table in the legend shows that in the zone of interest A09, which lies beneath the offshore wind licence area for the Dublin Array, 8 standard size salt caverns can be developed for hydrogen storage. This is equivalent to approximately 1.0 TWh_{H2}. Additional maps are provided in the Appendices.

FORWARD PLANS



Focus Area 2 is the Irish Sea area, moving down to the Celtic Sea off the south coast. Data has been loaded and interpretation is due to commence imminently. A huge UK dataset has also been accessed to ensure integration across the international boundary.

Questions?

Website WWW.HYSS.IE is live and will have regular updates

We are open to collaboration with the ORE Industry and are keen to engage to ensure our project is aligned with your priorities and is relevant to your needs.

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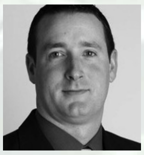

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Here we finish off with the three main players in the project. Keith & James manage the database and geological/geophysical assessment. Nick leads the SLR team which includes Alice Mitchinson on GIS compilation of data, Sam Irwin on volume calculations and Aldona Binchy on Environmental impact. Thanks.