decisions with confidence

Natural hydrogen exploration

Leveraging existing skillsets and technologies, some case studies

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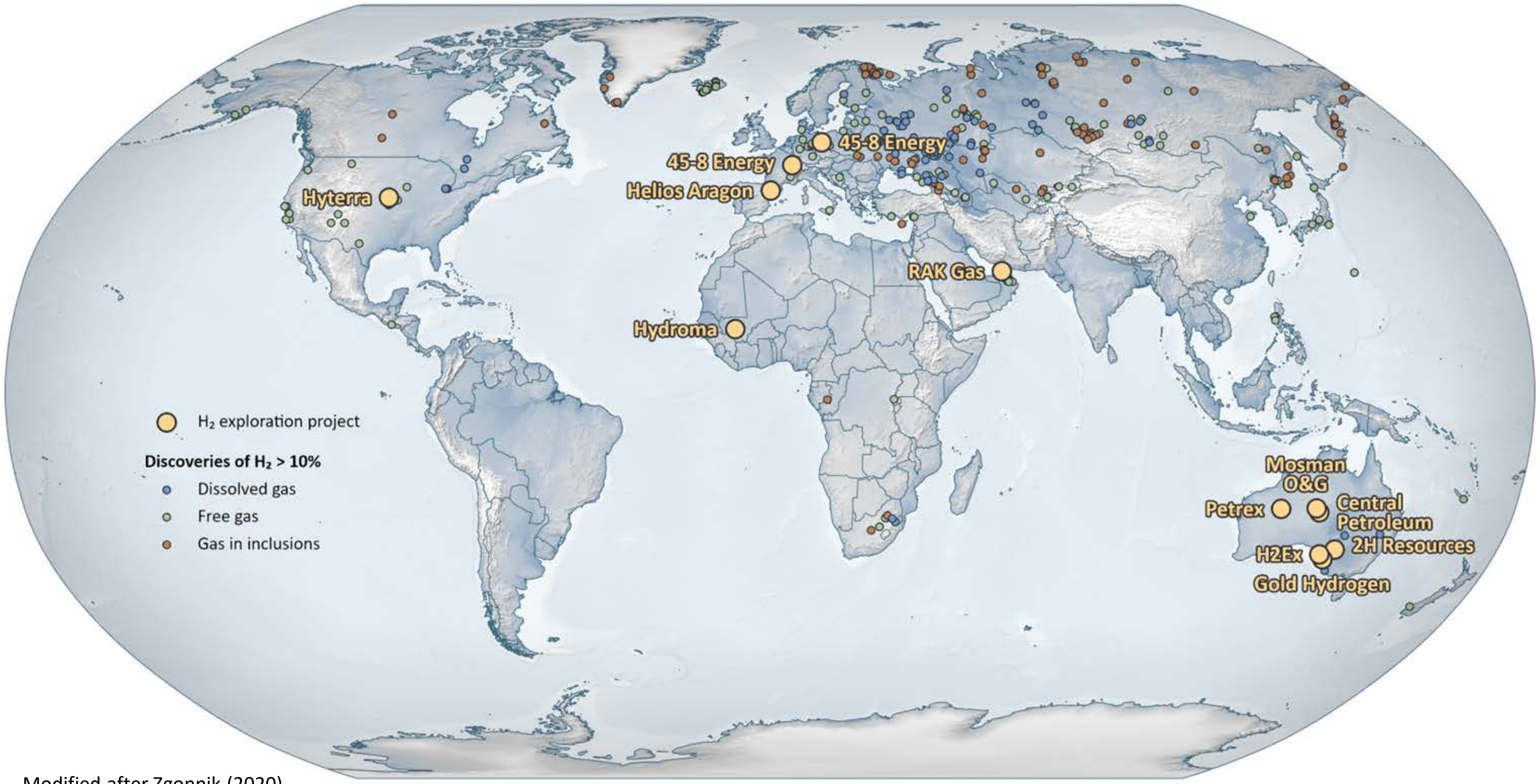
Presentation outline

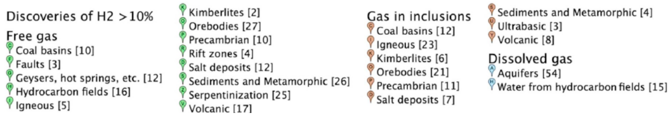
- Natural hydrogen global exploration activity
- The natural hydrogen system
- PRMS and natural hydrogen
- Case studies
- Summary
- Acknowledgements

Global natural hydrogen exploration activities

‘Gold’ or ‘white’ hydrogen = natural hydrogen

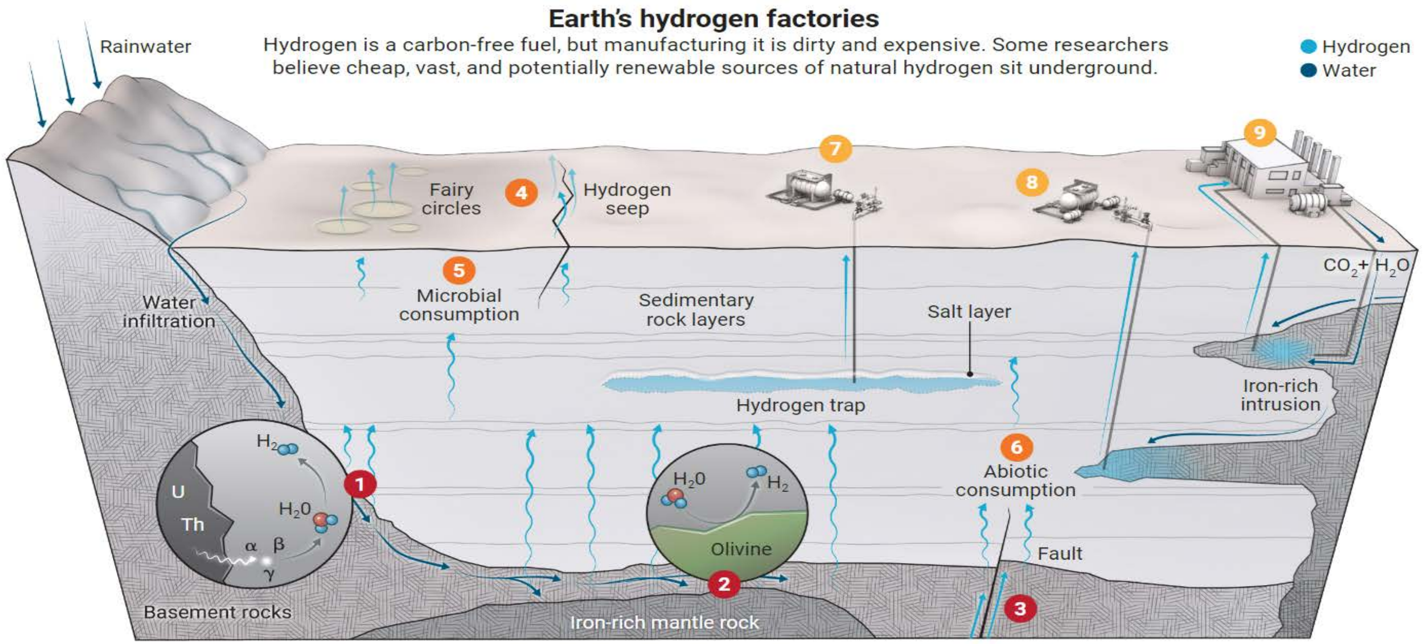


Modified after Zgonnik (2020)



- **1987 Bourakébougou discovery in Mali stimulates natural hydrogen interest.**
- Many occurrences of natural hydrogen identified globally
- Exploration and evaluation has commenced, with a view to commercial exploitation
  (*some examples shown*)
- Being undertaken by commercial enterprises (public and private companies) in addition to state-controlled entities
- **There will be a requirement for quantification of natural hydrogen resources**
  - **CPR/ITSR for prospectus’ or bourse admission documentation**
  - **Regulatory reporting**
    (license conditions and/or bourse)
  - **Transaction support**
  - **Valuations**

The natural hydrogen system



Generation

1 Radiolysis
Trace radioactive elements in rocks emit radiation that can split water. The process is slow, so ancient rocks are most likely to generate hydrogen.

2 Serpentinization
At high temperatures, water reacts with iron-rich rocks to make hydrogen. The fast and renewable reactions, called serpentinization, may drive most production.

3 Deep-seated
Streams of hydrogen from Earth's core or mantle may rise along tectonic plate boundaries and faults. But the theory of these vast, deep stores is controversial.

Loss mechanisms

4 Seeps
Hydrogen travels quickly through faults and fractures. It can also diffuse through rocks. Weak seeps might explain shallow depressions sometimes called fairy circles.

5 Microbes
In shallower layers of soil and rock, microbes consume hydrogen for energy, often producing methane.

6 Abiotic reactions
At deeper levels, hydrogen reacts withrocks and gases to form water, methane, and mineral compounds.

Extraction

7 Traps
Hydrogen might be tapped like oil and gas—by drilling into reservoirs trapped in porous rocks below salt deposits or other impermeable rock layers.

8 Direct
It might also be possible to tap the iron-rich source rocks directly, if they're shallow and fractured enough to allow hydrogen to be collected.

9 Enhanced
Hydrogen production might be stimulated by pumping water into iron-rich rocks. Adding carbon dioxide would sequester it from the atmosphere, slowing climate change.

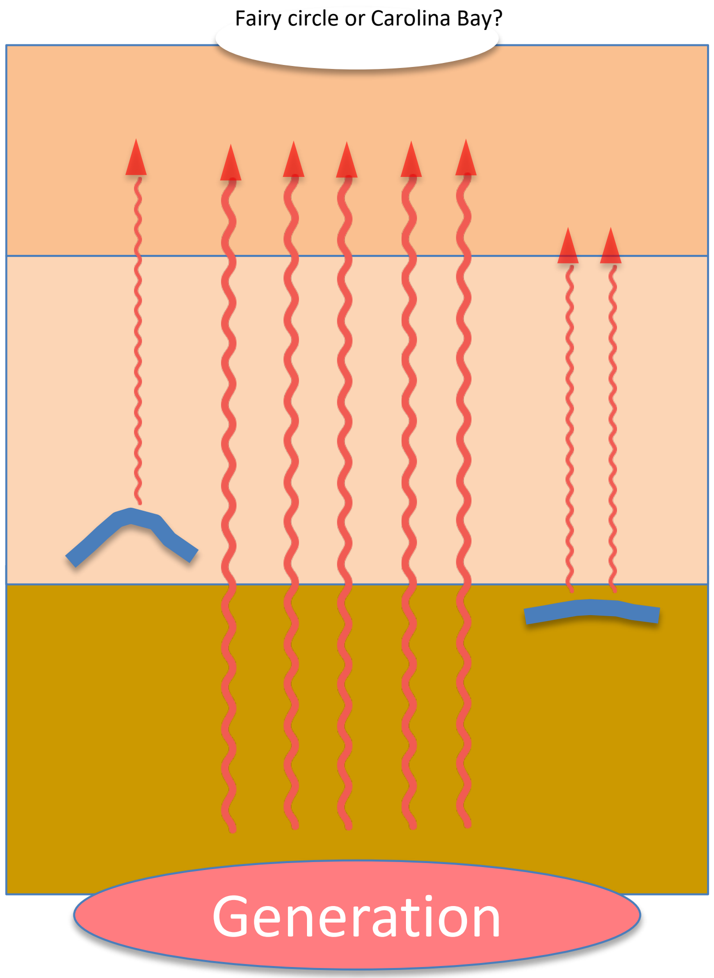
- **The natural hydrogen system is viewed as being similar to the petroleum system**

  "An active source and its related elements"
- Containing the genetic elements of:
  - Source
  - Reservoir
  - Seal
- The processes of:
  - Generation
  - Migration
  - Trap formation
  - Accumulation (including preservation)
- Geological risk elements of preservation are greater than compared to a petroleum system
  - Losses (leakage, biotic, geochemical etc)
  - Conversion (methanation etc)
- Significant research into transitory geological storage (UGS) of hydrogen which is applicable to natural hydrogen

Reference: https://www.usgs.gov/news/featured-story/potential-geologic-hydrogen-next-generation-energy and https://www.science.org/content/article/hidden-hydrogen-earth-may-hold-vast-stores-renewable-carbon-free-fuel

Flux vs entrapment

Flux

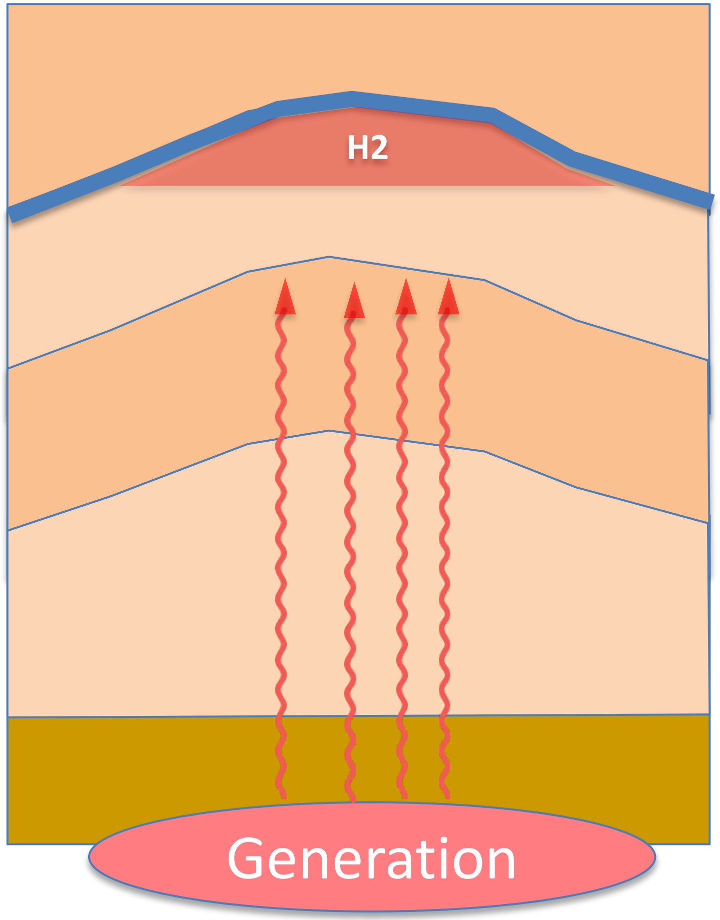


Baffles

'Hotels'

Flux also includes associated gas in aquifers

Entrapment (Accumulation)



Application of PRMS to natural hydrogen

Hydrogen and helium are considered non-hydrocarbons in the PRMS. However, the SPE reserves committee has advised that the principles of the PRMS can be applied to natural hydrogen.

- **The Petroleum Resources Management System ('PRMS')[1] is a system developed for consistent and reliable definition, classification and estimation of hydrocarbon (petroleum) resources.**
- Originally published in 2007 and subsequently updated in 2018. Application guidelines have been published in 2011 and most recently in November 2022.
- 'Petroleum' is defined as "..a naturally occurring mixture consisting of hydrocarbons in the gaseous, liquid or solid phase."
- Hydrocarbons are defined as "..chemical compounds consisting wholly of hydrogen and carbon molecules." By definition, excludes naturally occurring hydrogen (and helium).
- Petroleum may also contain non-hydrocarbon components (i.e. helium) which are not included in Reserves (and Resources).
- In August 2022 the SPE Oil and Gas Reserves Committee ('OGRC') advised that the principles of the PRMS can be extended to substances other than hydrocarbons, including the gaseous extraction of carbon dioxide, helium and hydrogen.[2]

"The OGRC believes that there is a reasonable foundation for the application of PRMS principles to situations such as (gaseous extraction of hydrogen) considering the similarities in exploration, evaluation, and exploitation processes throughout the life-cycle of a project.

SPE/OGRC does not object to the application of the PRMS to these situations that result in the extraction of non-hydrocarbon resources, as long as it is made clear that while such application is outside the scope of the PRMS, PRMS principles have been followed, while involving other subject matter expert parties as appropriate, and applied as though the extracted resources were considered as petroleum."

Note also COGEH does not include H2 (helium, yes), reporting therefore required under NP-51-201 Disclosure Standards and not NI-51-101 Oil & Gas Disclosure Standards

1 Petroleum Resources Management System, prepared by the Oil and Gas Reserves Committee of the Society of Petroleum Engineers (SPE) and reviewed and jointly sponsored by the American Association of Petroleum Geologists (AAPG), World Petroleum Council (WPC), Society of Petroleum Evaluation Engineers (SPEE), Society of Exploration Geophysicists (SEG) and approved by the Board of the SPE in March 2007. The PRMS was subsequently updated in June 2018.

2 https://www.spe.org/en/industry/reserves/non-hydrocarbons/

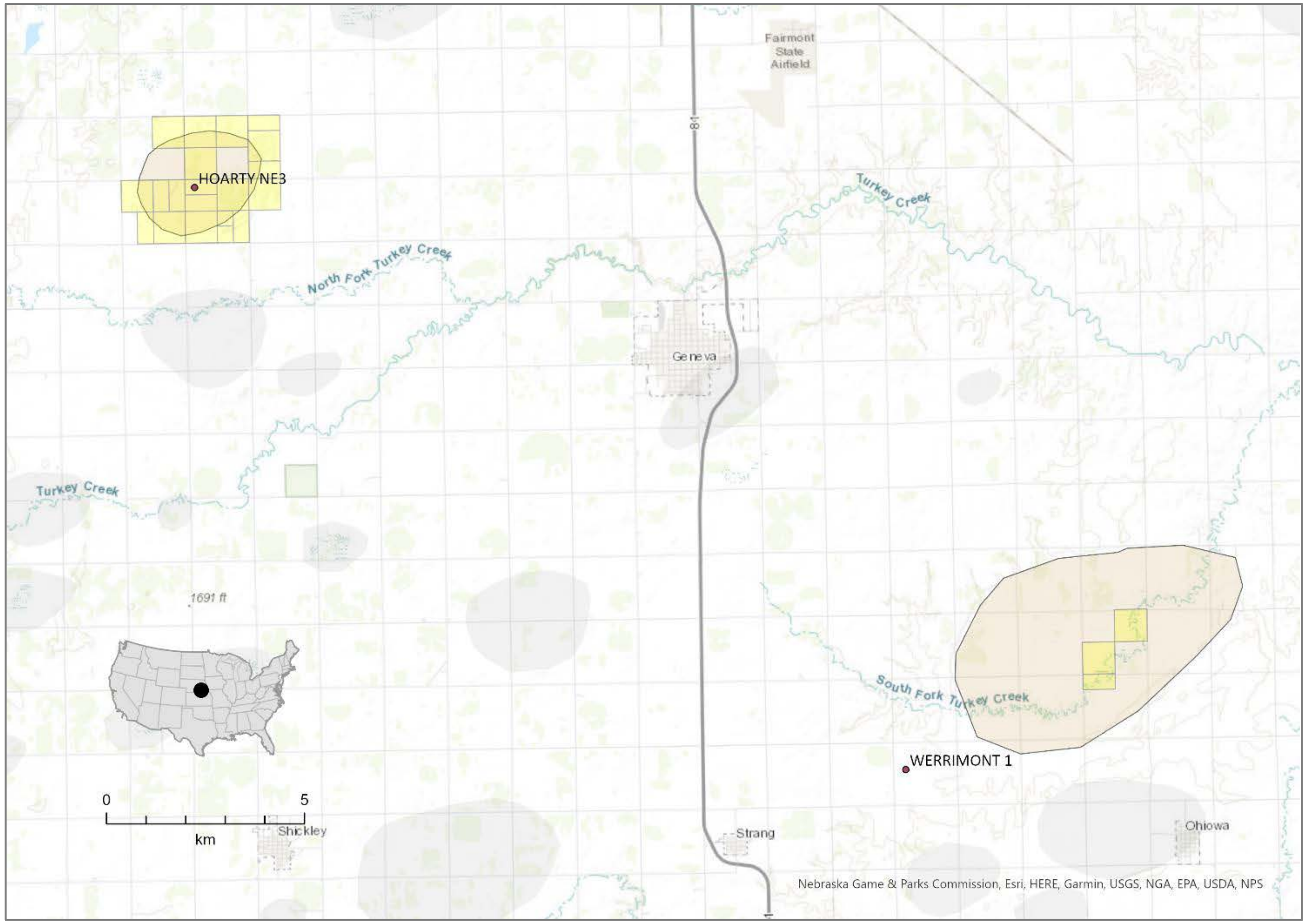
Application of PRMS to natural hydrogen

Flux model	Entrapment model
Entitlement requirement. Regulation and licensing permits hydrogen exploitation, production and transportation.	
No seal	Contains reservoir and seal
Low concentrations and potentially low yield (flux) rates	Concentrated accumulation
Potentially 'Unconventional Resources' as defined in the PRMS "*pervasive throughout a large area*", "*lack a well defined….GWC*" "*Such resources cannot be recovered using traditional recovery……*" **<u>However</u>**, "…. *owing to…….and/or reservoir permeability* "	Clear application of the principles of the PRMS Having an 'Accumulation' and 'Reservoir'
Method of exploitation? Well count/density, production rates	Analogous methods of exploitation (petroleum). Processing, treatment (and transportation) largely unproven.
Uncertainties exist with respect to resource estimation, such as flux rate and losses requiring significant monitoring and quantification (or establishment of analogue). **Pilot production required**	Resources can be estimated given the similarities and analogues of petroleum exploration, evaluation and exploitation.

Case studies

Case study – HyTerra Ltd

Nebraska

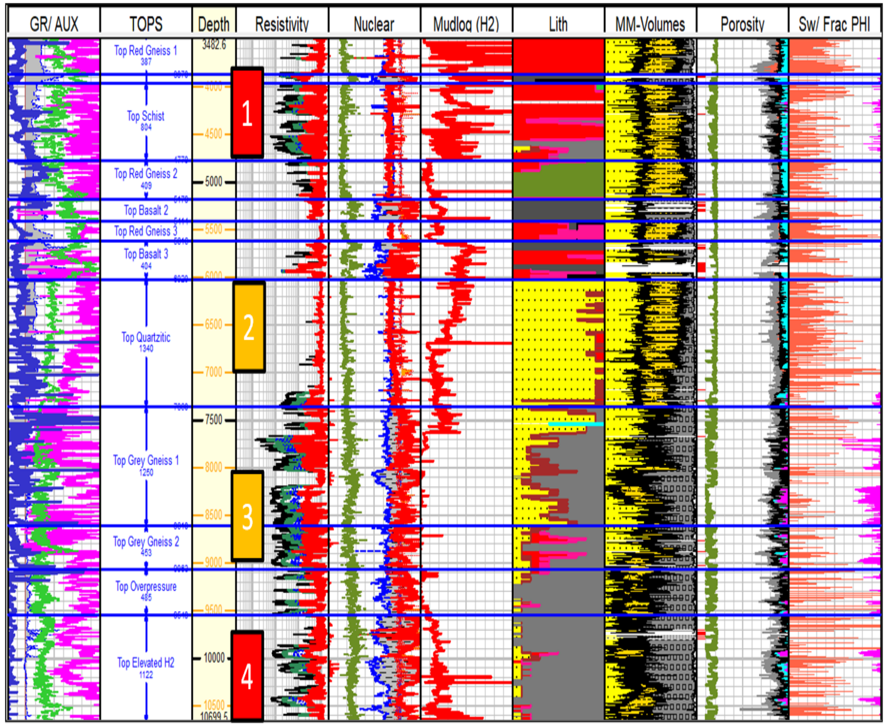


- Triple Energy recomplied with the Australian securities exchange ('ASX') with the acquisition of interests in a joint venture exploring for natural hydrogen in Nebraska and South Carolina.
  - Natural Hydrogen Energy LLC (Operator)
  - Triple Energy changed name to **HyTerra Ltd**
- Acreage acquired over 'Carolina Bays' in Nebraska and South Carolina.
- 'Carolina Bays' are shallow depressions in the ground surface and believed to be hydrogen seeps from the subsurface.
  - Similar features also referred to as 'fairy circles'
- Cambrian to quaternary sediments (dominantly Ordovician – Carboniferous) of the Salina Basin overlying metasediment basement. Not viewed as petroliferous.
- **The Hoarty NE-3 well was drilled in 2018-19 to test the concept.**

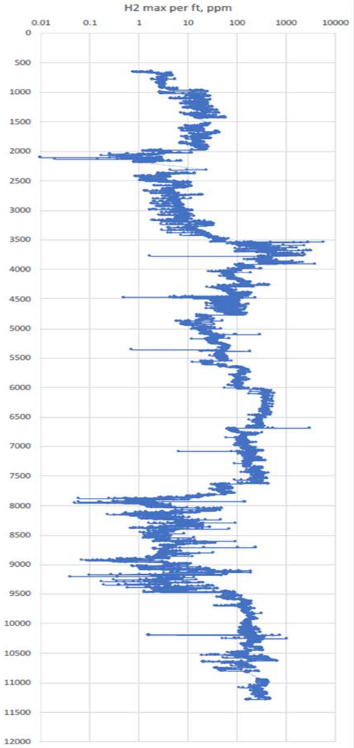
Source: HyTerra Prospectus https://wcsecure.weblink.com.au/pdf/HYT/02568087.pdf

Case study - HyTerra

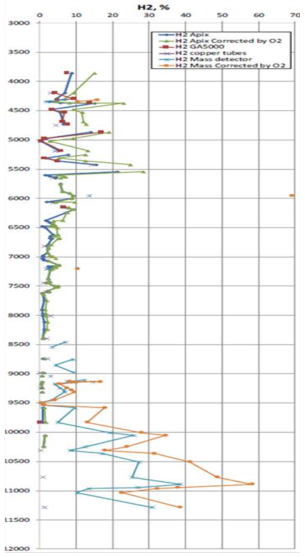
Hoarty NE-3 well logs (basement section)



H2 from gas detection equipment



H2 from manual gas sampling



Hoarty NE-3 well

- TD of 11,287 ft
- 3,478 ft of sediments overlying 7,800 ft basement rocks.
- Hydrogen gas detection equipment deployed alongside traditional mudlogging gas detection equipment, in addition to manual gas sampling of gas from mud flow line.
- Gas samples also taken during swabbing operations and at the wellhead.
- Testing operations pending

Evaluation workflow

- Calculate prospective areas (licensed areas within Carolina Bays)
- Volumetrics parameters calculated from petrophysical evaluation of Hoarty NE-3 (fracture porosity model)
- Gas composition estimated from various sampling methods
  - Low – best – high estimate
  - Hydrogen, methane and nitrogen
  - Helium also observed in samples but excluded from evaluation
- **Probabilistic calculation of GIIP**
- Calculation of resource density (Bcf/acre) which was then applied to remainder of acreage portfolio.

Source: HyTerra Prospectus https://wcsecure.weblink.com.au/pdf/HYT/02568087.pdf

Natural hydrogen occurrences South Australia

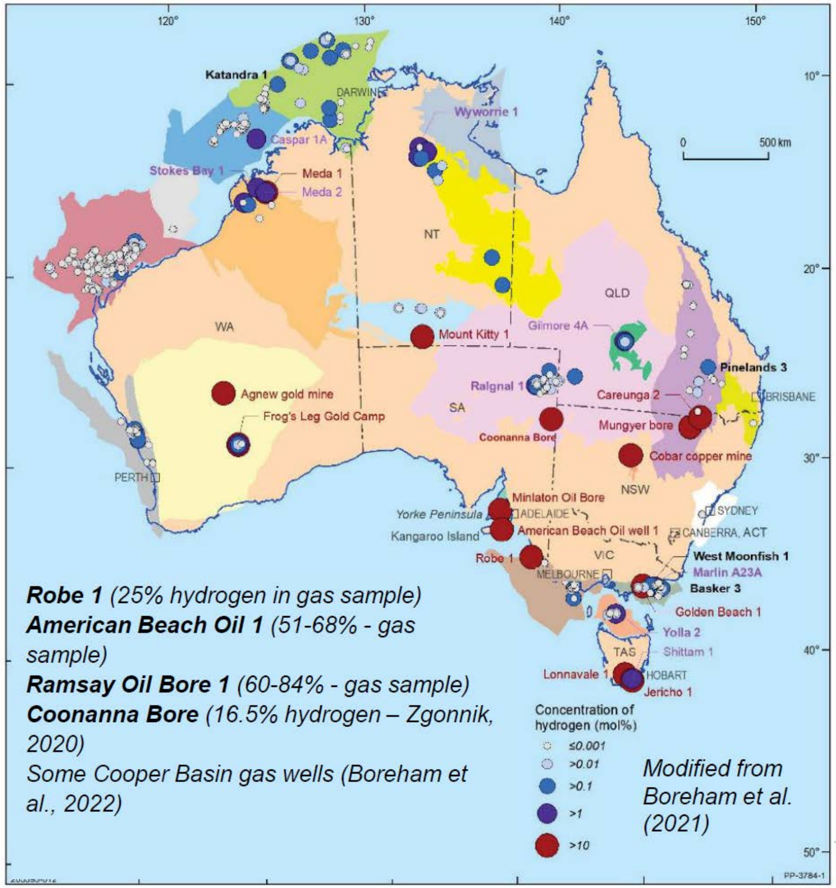
Naturally occurring hydrogen has been reported in many geological settings across Australia. The most significant reported occurrences are in Ramsay Oil Bore 1 (1931), Yorke Peninsula and American Beach Oil 1 (1921) on Kangaroo Island, South Australia.

Natural hydrogen occurrences relevant to 2H Resources acreage.

Well	Drilled	Depth (m)	Age/Rock type	Component Analysis							Source/ Reference
				N2	CH4	>C1	He	H2	CO2	O2	
Ramsay Oil Bore 1 (Minlaton Borehole)	1931	240.8	Pre-Cambrian limestones	16.3	7.5	nil		76.0	0.2	nil	Geol Surv Bulletin 22, Ward (1944)
		262.1		25.4	7.0	nil		64.4	0.8	2.4	
		507.8		14.8	nil	nil		84.0	nil	1.2	
American Beach Oil 1 (American Beach Borehole)	1921	187.5	Pre-Cambrian metamorphics	36.0	2.6	0.5		51.3	5.3	4.3	
		289.6		22.61	4.68	nil		68.64	0.52	3.55	
Robe 1	1915	1202.4	Jurassic / shales	30.7	39.6	nil		25.4	1.3	3	
Magee-1	1992	2345-2349	Heavitree Qtz	43.61	39.81	9.43	6.27	0.04	0.33		WCR
Mt Kitty-1	2013	2144	Basement Granodiorite	79.62	7.29	2.85	4.23	5.05	0.33	0.63	WCR
		2156		61.04	13.14	4.77	8.96	11.46	0.09	0.54	
		2253		99.67	0.04	0.03	0	0	0.08	0.18	

Note: air correction not applied.

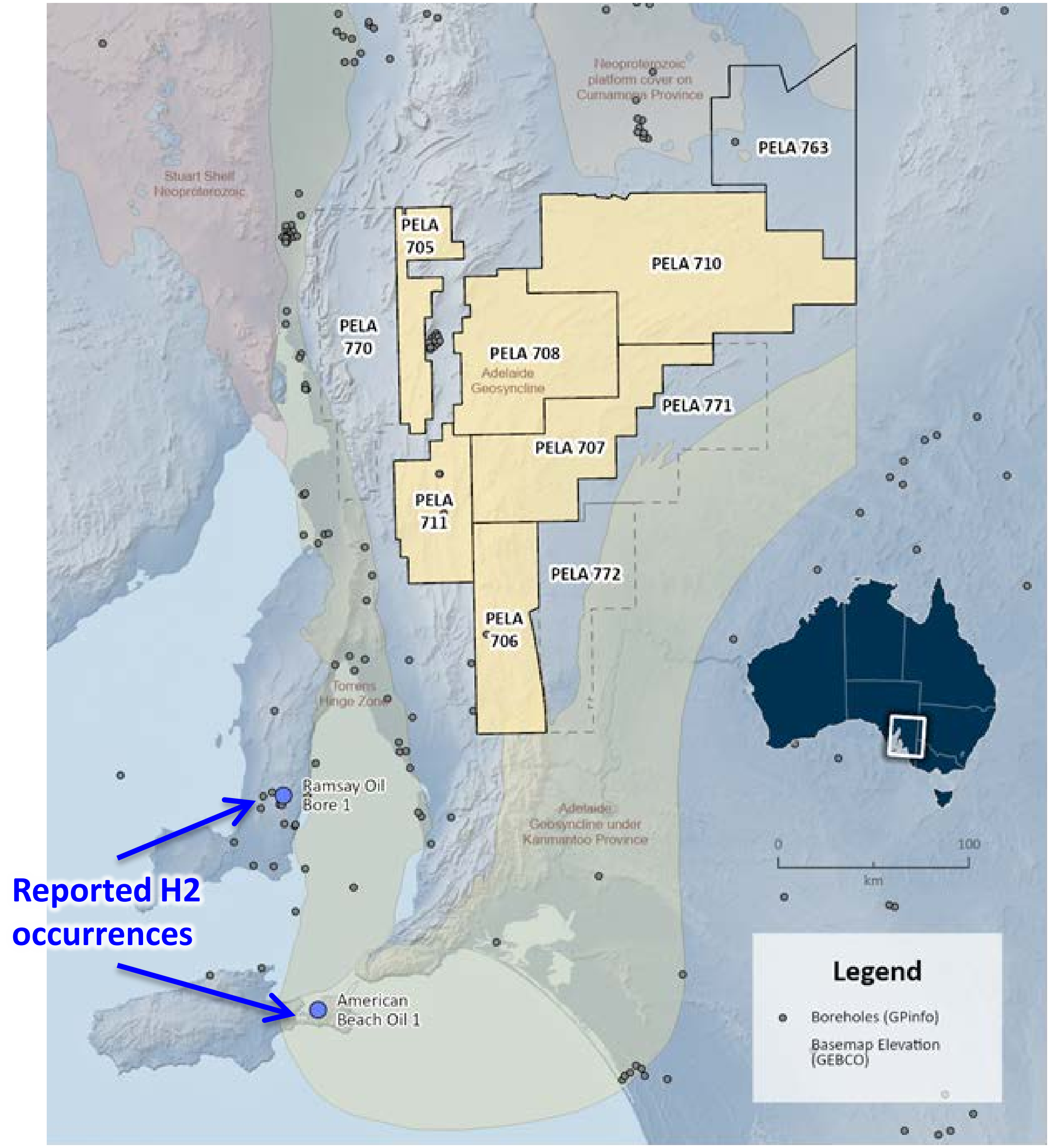
- Natural hydrogen occurrences have been reported in South Australia from Robe-1 in the Otway Basin, Ramsay Oil Bore 1 on the Yorke Peninsula and American Beach Oil 1 on Kangaroo Island.
- Analyses are reported in government publications - Ward (1933) and Ward (1944).
- Insufficient information regarding the samples (method, volume) and the analyses undertaken.
- Anthropogenic source and/or contamination of hydrogen cannot be excluded.
- Mt Kitty-1 in the Amadeus Basin is also of relevance, fractured basement reservoir and basement sourced hydrogen.



Source: Alexander, E. 2022. Natural hydrogen exploration in South Australia. PESA SA presentation June 2022. https://www.energymining.sa.gov.au/industry/energy-resources/data-centre/publications-and-presentations/presentations

Boreham et al (2021) Hydrogen in Australia natural gas: occurrences, sources and resources. The APPEA Journal 61, 163-191
Ward, L. K.(1933) Inflammable gases occluded in the Pre-Paleozoic rocks of South Australia. Transactions and Proceedings of the Royal Society of South Australia, 57, p42-47.
Ward, L. K.(1944) The Search for Oil in South Australia. Geological Survey of South Australia Bulletin 22

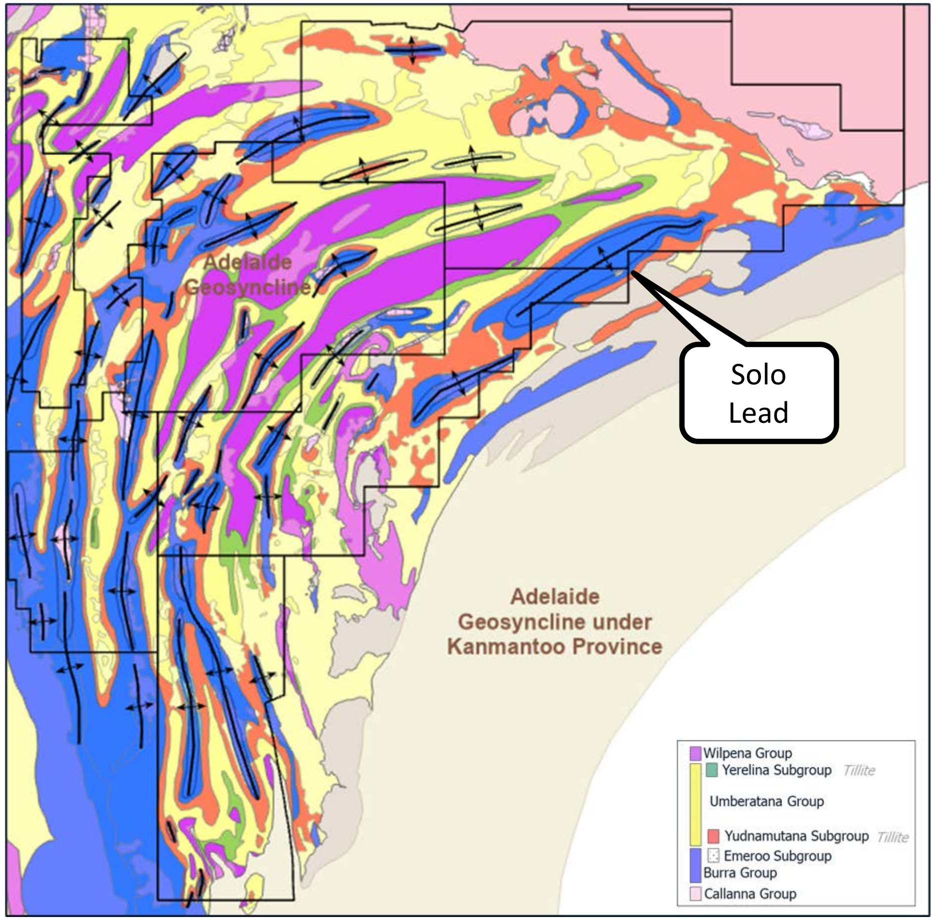
Case study - 2H Resources

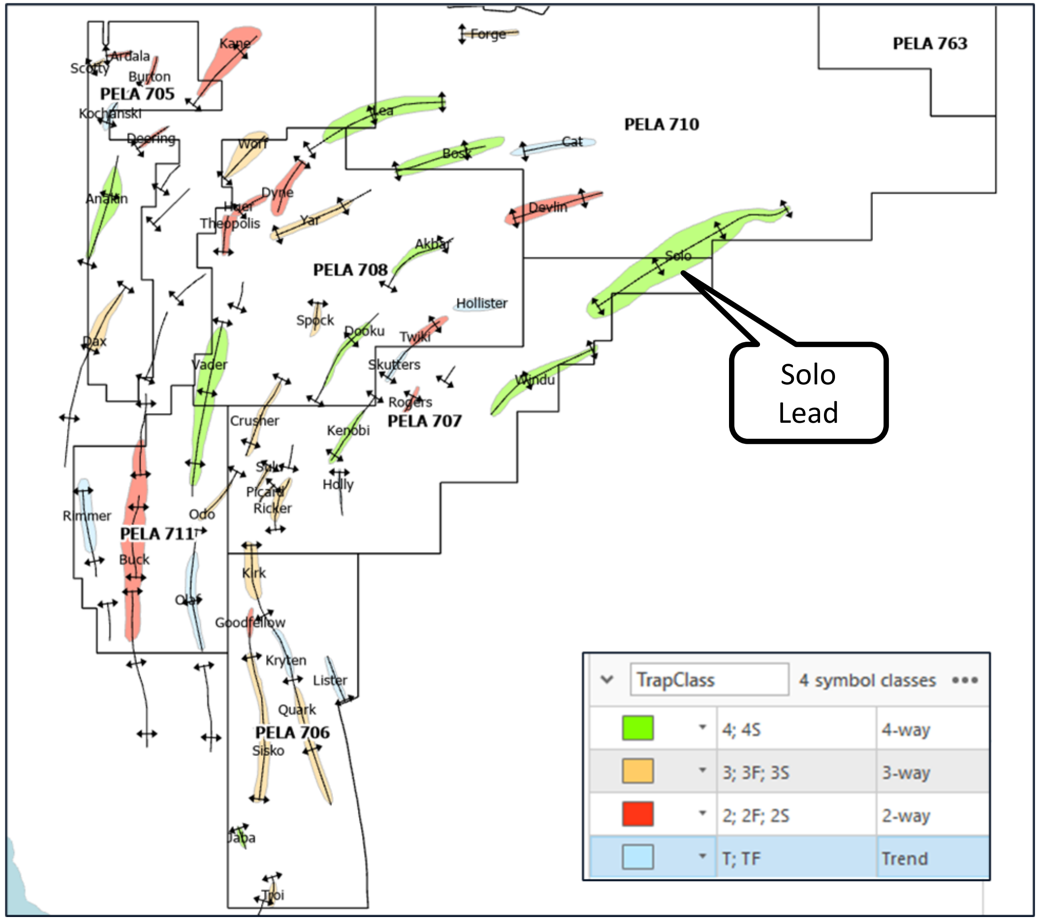


- **The state of South Australia has included gaseous hydrogen as a 'regulated substance' in its petroleum legislation thereby permitted its exploration and exploitation (Entitlement).**
- 2H Resources is a wholly owned subsidiary of Buru Energy (ASX:BRU)
- 7 exploration license applications, onshore state of South Australia
- 30,000 km^2
- Subject to native title negotiations before award of exploration title
- Adelaide Geosyncline, also known as Adelaide Superbasin or Adelaide Rift Complex
- Neoproterozoic in age
- Not considered petroliferous, little petroleum exploration
- **Considered prospective for natural hydrogen**
  - **Basement terrains (*source*)**
  - **Presence of salt in the stratigraphic succession (*seal*)**
  - **Potential for large structural traps**
  - **Offset occurrences of hydrogen**

Case study - 2H Resources

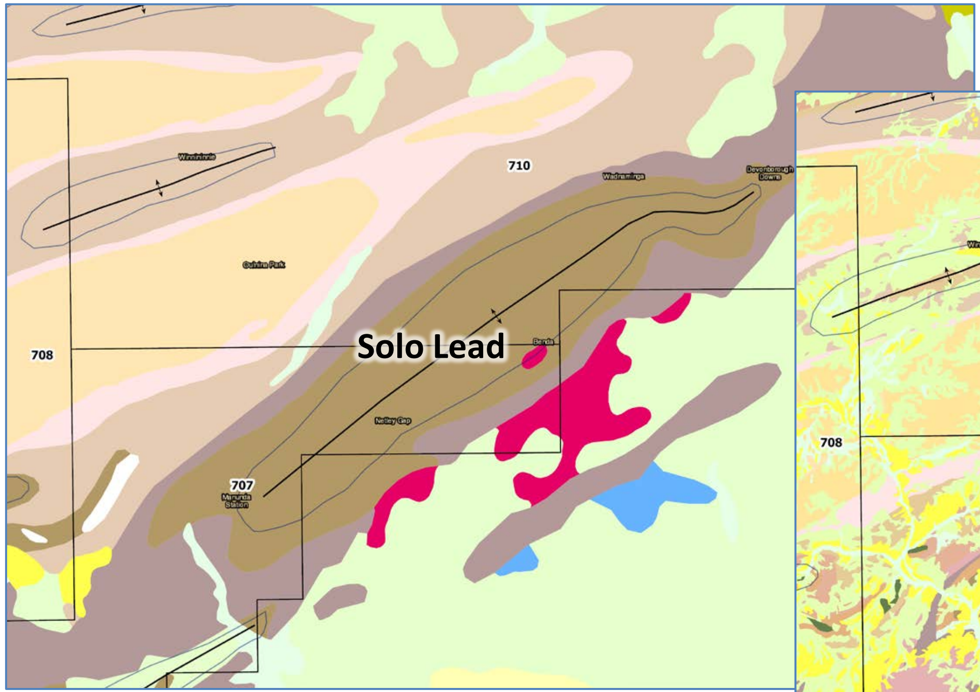
Portfolio of leads defined from surface geological mapping.



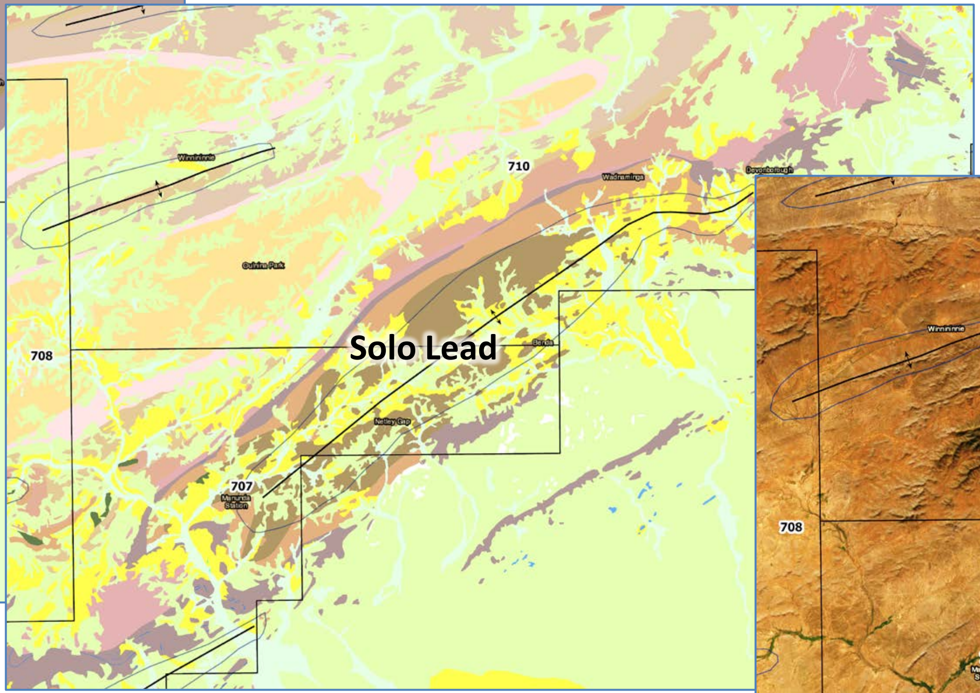


Case study - 2H Resources

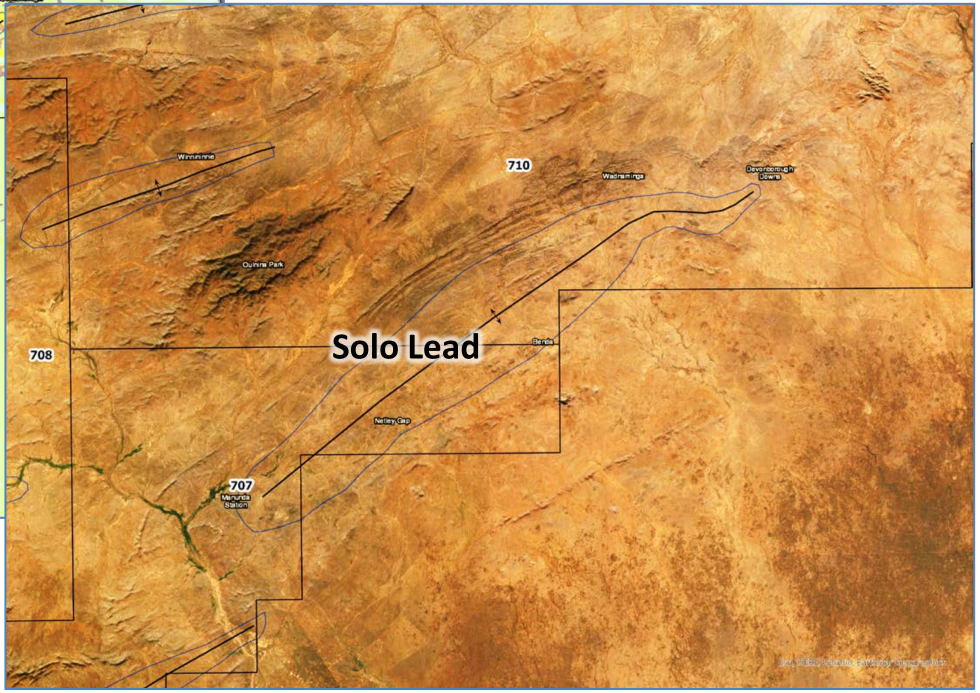
Surface geological maps available from the South Australian Government SARIG online geographical information system have been used to define leads and trapping geometry. Informed the assessment of geological risk.



1:2,000,000 series maps surface geology



1:100,000 series surface geology



Case study - 2H

The following workflow was used to estimate the natural hydrogen resources of the 2H Resources PELA portfolio:

- Confirmation of prospective areas
- Review of regional geology and basement terranes
- Analysis of historical hydrogen occurrences
- Air correction and hydrogen (gas) composition parameterisation
- Estimation of formation volume factor (FVF)
  - Traditional petroleum estimation of FVF uses Standing and Katz gas factors, not ideal for hydrogen rich mixtures
  - Developed a tool to estimate FVF using GERG 2008 equation of state
- Review of water bore Q rates
- Reservoir parameterisation (porosity, NTG, Sw etc)
- Probabilistic prospective resource estimation for Solo Lead (Bcf and tonnes)
- Calculation of hydrogen resource yield (low, mid, high)
- Application of yield to portfolio

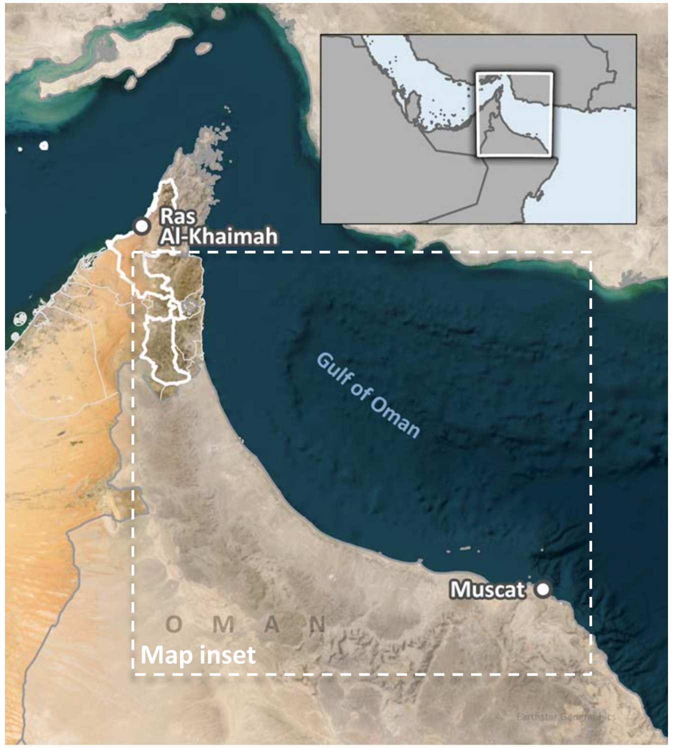
Exploration Portfolio	Hydrogen Prospective Resources					
	Gross Unrisked			Gross Risked		
	1U	2U	3U	1U	2U	3U
Hydrogen (Bcf)	246	1,713	6,567	21	148	566
Hydrogen (t)	570,236	3,977,110	15,249,222	49,850	342,846	1,313,425

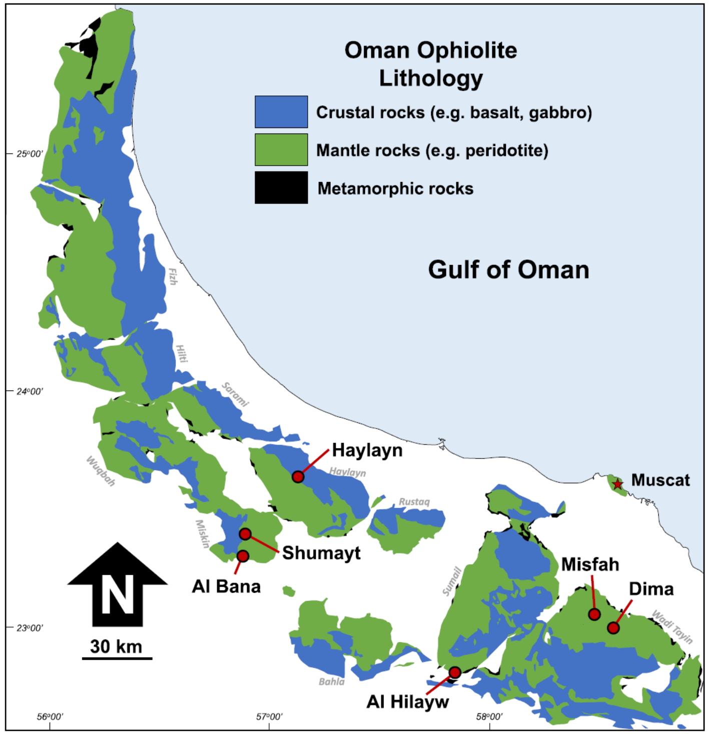
Notes to the table:

1. The estimates are for naturally occurring hydrogen gas only. Adjustments for petroleum gases and inert gases have been made.
2. "Gross" are 100% quantities attributable to PELA 705, 706, 707, 708, 710 and 711.
3. These estimates have both an associated risk of discovery and a risk of development. Further exploration, appraisal and evaluation is required to determine the existence of a significant quantity of potentially recoverable hydrogen and economically recoverable hydrogen.
4. The natural hydrogen resource estimates have been derived in accordance with the principles of the PRMS. The PRMS specifically applies to petroleum. However, the OGRC advised in August 2022 that although the gaseous extraction of natural hydrogen is outside of the scope of the PRMS, the principles can be applied given the similarities in exploration, evaluation and exploitation.
5. The hydrogen Prospective Resources have been evaluated using probabilistic and deterministic methods.
6. No adjustment has been made to the estimates to account for fuel and flare.
7. Totals are by arithmetic summation. As a result, RISC cautions that the Low Estimate aggregate quantities may be very conservative estimates and the High Estimate aggregate quantities may be very optimistic due to portfolio effects.
8. Hydrogen mass conversion is 2,321.98 t/Bcf.
9. The risked Prospective Resources have been adjusted for the associated chance of discovery. The chance of success has been estimated at between 6% and 10% using a 4-factor risk assessment and dependent on trap configuration.

Reference: Kunz, O. and Wagner, W. (2012) The GERG-2008 Wide Range Equation of State for Natural Gases and Other Mixtures: An Expansion of GERG-2004. J. Chem. Eng. Data, 57(11), 2032-3091.

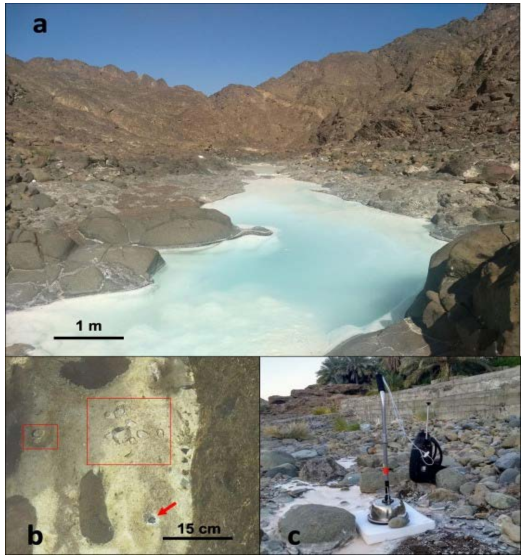
Case Study – RAK South





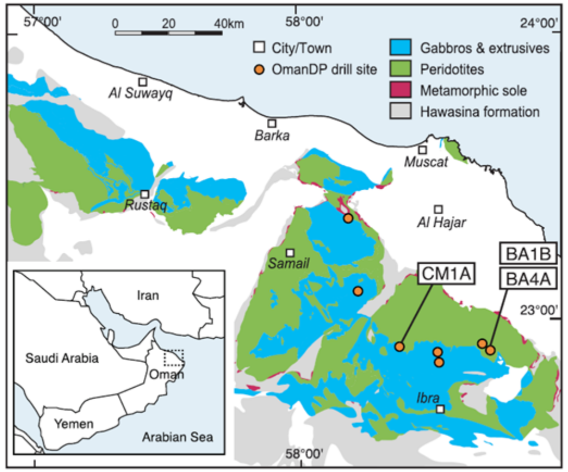
Site	mol H_2/year		Stream area (m^2)	Yield kg H_2 per year		Yield tonnes H_2 per km^2 per year	
	min	max		min	max	min	max
Haylayn	2,165	70,685	200	4.36	142.50	21.8	712.5
Al Bana	12,725	21,205	50	25.65	42.75	513.1	855.0
Shumayt	684	1017	50	1.38	2.05	27.6	41.0
Dima	22	0	50	0.04		0.9	
Misfah	1,630	3,615	1,000	3.29	7.29	3.3	7.3
Data from Leong et al, 2023				Calculations by RISC			

- **Samail Ophiolite, Oman & RAK South**
- Leong et al (2023) conducted measurements of hydrogen bubbles found in hyperalkaline 'blue' streams and pools in Oman.
- **Flux system**
  - These measurements were converted to a yield tonnes/per annum.
  - Significant variation in rates/yield.
  - Losses and air contamination?



Leong et al, *H_2 and CH_4 outgassing rates in the Samail ophiolite, Oman: implications for low-temperature, continental serpentinization rates*, Geochimica et Cosmochimica Acta, 2023)

Case Study – RAK South



oman drilling project

Figure 5. Photomosaic of a mountainside in the Muscat Massif. As at all scales, dunite orientations measured across the image area are used to correct dunite widths as measured from the image mosaic. The lighter rocks are dunite, the darker are harzburgites. The two geologists in the center of the image are standing ~50 m apart.

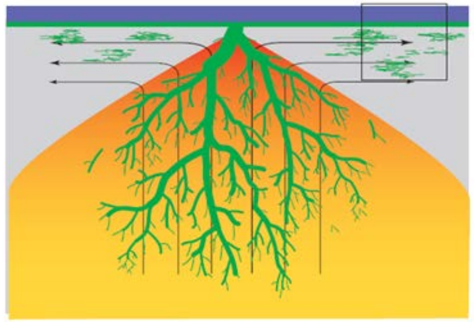
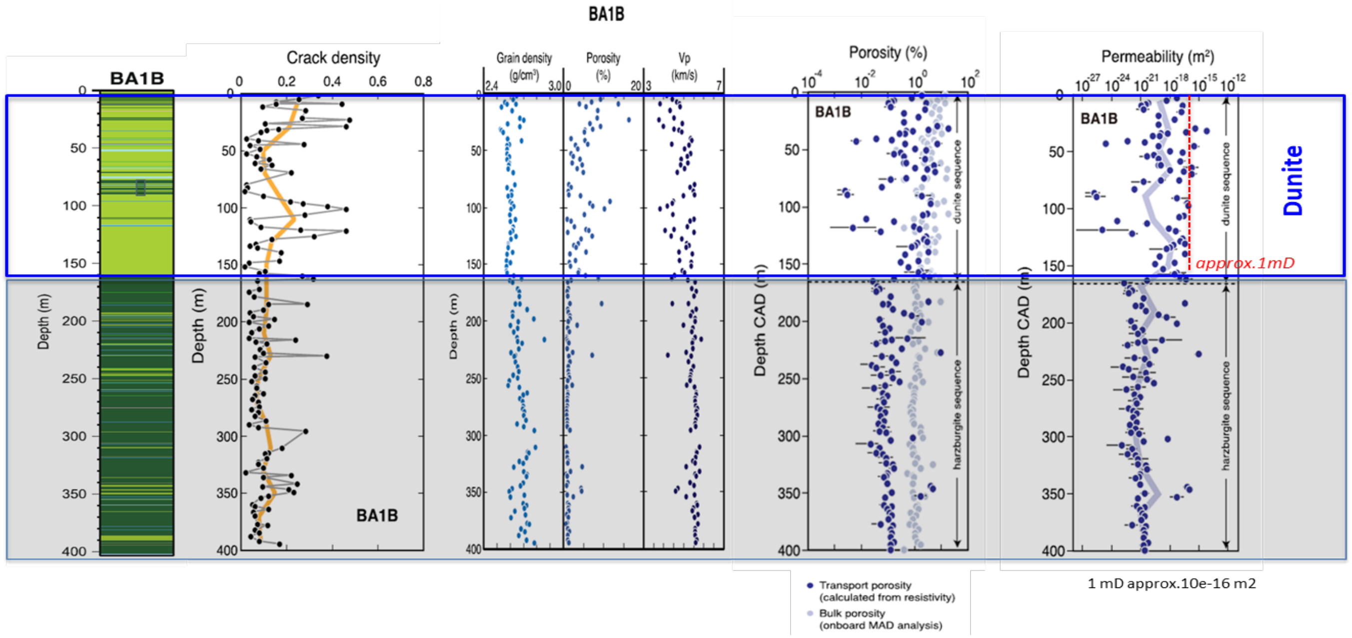


Figure 16. Schematic illustration of a coalescing dunite network beneath an oceanic spreading center based on observations in the Oman Ophiolite. Dunites are shown in green, the crust in blue, and melt is presumed to be present throughout the red and yellow region. The box in the upper right corner indicates the scale of the lithologic section preserved in Oman. The preserved dunites may have been thinned, for example, via simple shear, during transposition resulting from corner flow. We have implicitly assumed that this thinning affected all dunite widths by the same percentage. Thinning in this manner would affect the magnitudes of the dunite widths but not change the ratio of smaller dunites to larger ones. Therefore the power law slope would remain unaffected.



Entrapment model evaluation workflow

- Assumption that Dunite forms a subsurface reservoir through the process of serpentinization (and generation of hydrogen)
- Estimate prospect area and ‘reservoir’ thickness from published analysis of outcrop and published geological model.
- Volumetrics parameters estimated from Oman Drilling Project scientific literature (fracture porosity model)
- Gas composition range estimated from published Oman alkaline streams analysis (Leong et al 2023)
- **Probabilistic calculation of prospective resources**

Sources: Katayama et al (2020) Permeability Profiles Across the Crust-Mantle Sections in the Oman Drilling Project Inferred From Dry and Wet Resistivity Data. Journal of Geophysical Research: Solid Earth, 125
Katayama et al (2021) Crack geometry of serpentinized peridotites inferred from onboard ultrasonic data from the Oman Drilling Project, Tectonophysics (814).
Braun and Kelemen (2002) Dunite distribution in the Oman Ophiolite: Implications for melt flux through porous dunite conduits. Geochem. Geophys. Geosyst., 3(11)

Summary

- Natural hydrogen exploration is being established globally, and continues to grow
- Hydrogen system is considered analogous to the concept of the petroleum system
- Flux versus entrapment (accumulation)
- Regulation is being established for entitlement, production, transport
- PRMS can be applied to natural hydrogen
  - Similarities in methods of exploration, evaluation and exploitation
  - However, resource estimation for flux systems requires further quantification before any resource estimates can be ascribed
  - Further maturity required in both models to mature beyond Prospective Resources
- Case studies presented to demonstrate some resource estimation workflows

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