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Geological processes can generate natural hydrogen, but... What are effective exploration techniques? Can it be produced economically from fluxes or accumulations?

Natural hydrogen has been found in 3 tectonic settings:
- extension zones (Mid Oceanic Ridge, Iceland, and African Rift)
- compression zones with ophiolitic nappes (Oman, Philippines, New Caledonia)
- stable intracratonic basins overlying Archean to Proterozoic basement (Brazil, Russia, USA, Australia, Mali).

Truche et al, 2020, Elements. Vol 16(1)
Global natural hydrogen occurrences

SA was put on the global map of natural hydrogen occurrences in 2019-21 scientific papers as a result of shows in drillholes and possible ‘fairy circles’ (natural seeps).

Regulatory changes to enable natural hydrogen exploration have also attracted global interest.

Zgonnik (2020)

Mali - Bourabougou Field is the world’s only current hydrogen producer – used for local electricity generation over the last 7 years.

Moretti et al. (March 2021)

Figure 5. Location of the areas with many circular depressions in Australia (red areas). The yellow stars are the location of the wells that found H2, the yellow circles highlight the areas where depressions that look like fairy circles can be observed and where statistic has been done in this study.
Bourabougou Field in Mali - active hydrogen system

- In 2011 Petroma (now Hydroma) re-entered Bougou-1 (drilled in 1987 as a water well, P&A due to a gas explosion) and reported 98% hydrogen, 1% nitrogen, and 1% methane in the produced gas.
- Shallow accumulations - 100m-1800m depth.
- Natural hydrogen occurs in Neoproterozoic sediments, hydrogen generated in Archaean basement.
- Triassic dolerite sills act as seals but water also plays a role - H₂ is almost insoluble in water at shallow depths.
- Pressure support, geysering or gas-lift and potentially ongoing recharge of hydrogen.
- Production commenced 2018, hydrogen is being used to generate electricity.

Prinzhofer et al. (2018), Yedinak (2022), Stalker et al. (2022)
Natural hydrogen has been discovered in petroleum wells as well as seeping from faults (Frery et al. 2022) and shallow drillholes in WA.

Most Australian natural gases contain trace-low levels of natural hydrogen (Boreham et al., 2021).

Petroleum drilling rigs can only detect natural hydrogen with a specialised hydrogen detection unit (e.g. Buru Energy in Currajong 1 and Rafael 1). Since the mid-1960s equipment has been calibrated to prioritise hydrocarbon detection. Mineral explorers typically don’t measure gas contents.

So it’s likely that natural hydrogen occurrences have been missed by explorers in Australia and globally.

CSIRO Energy researchers (Perth) are developing exploration techniques and equipment suitable for Australian conditions (Frery et al., 2022).
Potential natural hydrogen sources and indications

- **Ancient basement complexes which contain iron and/or uranium rich rocks** e.g. Archaean greenstone and Precambrian basement terranes, ‘hot’ granites’ - generate hydrogen via:
  - radiolytic processes (radioactive decay breaks bonds in water)
  - oxidation of Fe²⁺rich minerals (serpentinization).

- **fractured and seismically active source areas** - deep-seated faults can both channel migrating hydrogen up from deep sources to surface and introduce water downward for further chemical reaction with exposed iron-rich rocks. Cataclasis can generate hydrogen too.

- **Hydrogen indications in drillholes**.

- Sedimentary cover may reservoir and trap migrating hydrogen particularly if aquifer systems and/or seal rocks like salt are present.

- **Biogenic and abiogenic (thermal) decomposition of organic matter** (Boreham et al. 2022 – Cooper Basin).

Surficial hydrogen seeps? Seeps can be blind or coincident with visible sub-circular topographic depressions on the metre to kilometre scale (‘fairy circles’).

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Thanks to Dr Betina Bendall (DEM-ERD) for her input to this overview.
South Australia has taken the national lead in enabling natural hydrogen exploration.

- Effective licensing, regulatory and investment frameworks are in place - natural hydrogen exploration became possible in February 2021.

- DEM’s online records revealed significant hydrogen contents from Government analyses of gas samples taken from three historic drillholes:
  - 1915 – Robe 1 (25.4% hydrogen)
  - 1921 – American Beach Oil 1 (64.4-80% hydrogen)
  - 1931 – Ramsay Oil Bore 1 (51.3-68.6% hydrogen)

- SA has potential hydrogen source rocks - iron-rich and uranium-rich rocks in basement provinces (Archaean-Proterozoic).

- Salt lakes on Yorke Peninsula and Kangaroo Island have been postulated to be ‘fairy circles’ caused by hydrogen seeps (international researchers e.g. Moretti et al., 2021).

- Easy access to extensive free online maps, data and reports via DEM website, access to cores and rock samples at the Tonsley Drill Core Storage Facility.
**Legislative framework**

*Petroleum and Geothermal Energy Act 2000*
Provides a single window into government for natural hydrogen, includes underground storage and transmission pipelines for all ‘colours’ of hydrogen.

**Natural (gold, white) hydrogen**

*Hydrogen Generation Act 2022*
This will provide a single window into government for all manufactured/generated hydrogen.

**Blue hydrogen**

**Grey hydrogen**

**Green hydrogen**

**Carbon capture & storage (CCS)**
Underground hydrogen storage
Pipeline transmission
Uranium and iron occurrences and mines in SA
- uranium and iron ore in the right setting are potential hydrogen sources
### Prospectivity – screening basement provinces

<table>
<thead>
<tr>
<th>Hydrogen play elements</th>
<th>Coompana</th>
<th>Musgrave</th>
<th>Gawler</th>
<th>Curnamona &amp; Mt Painter inlier</th>
<th>Kanmantoo Fold Belt</th>
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<tbody>
<tr>
<td>Gabbros, mafics, ultramafic intrusives</td>
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<td>Iron-rich granitoid/intrusives</td>
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<td>Uranium-rich rocks</td>
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<td>IOCGU*</td>
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<td>Banded iron formations</td>
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<td>Ferruginous duricrusts</td>
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<td>Structural complexity/deep active faults</td>
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<td>Hydrogen shows</td>
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<td>Ramsay Oil Bore. Fairy circles on Yorke Peninsula?</td>
<td>American Beach Oil Bore 1 Fairy circles on KI?</td>
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* Iron Ore Copper Gold Uranium deposits

Thanks to Dr Betina Bendall (DEM-ERD) for her input to this overview
### Prospectivity – screening basins

<table>
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<tr>
<th>Basin</th>
<th>Hydrogen play elements</th>
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<tbody>
<tr>
<td>Adelaide Rift Complex/Arrowie Basin</td>
<td>Mafic intrusives/extrusives (source and seal)</td>
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<td>Officer Basin</td>
<td>Iron stones</td>
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<td>Stansbury Basin</td>
<td>Salt/anhydrite, aquifers (seal)</td>
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<td>Cooper/ Eromanga/ Warburton basins</td>
<td>Deep Faults</td>
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<td>Otway Basin</td>
<td>Over-mature source rocks</td>
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<td>Hydrogen shows</td>
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<td>Ramsay Oil Bore 1, Fairy circles? Coonana 1, Ralgnal 1 etc. Robe 1 (mantle derived CO2 in Caroline 1)</td>
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**Hot off the press**

Boreham et al. 2022 presentation last night at H-NAT:
- Free $H_2$ generated when dry gas generation is complete (Ro>3.5, >250C).
- Cooper Basin has sweet spots for hydrogen generated from over mature coals and shales.
- Estimated free hydrogen is 615-240 TCF – however the fate of the free hydrogen following primary migration is unknown.

Thanks to Dr Betina Bendall (DEM-ERD) for her input to this overview.
Fairy circles?

Pan et al. 2021

Peeley Seaway
Exploration methodologies

Screening

- Company exploration reports, geological maps, geophysical datasets (SARIG, PEPS).
- Satellite imagery, remote sensing – seeps, faults.
- Source rocks - mafics, ultramafics, radiogenic granites, iron and uranium occurrences.
- Seals - subsurface salt. Can shales seal hydrogen? Aquifers?
- Cores – fluid inclusions, mineralogy.
- Analyses of existing gas samples (Boreham et al, 2021, 2022).

Field work

- Soil gas measurements (hand held drill - percussion - not rotary and probe).
- 24/7 monitoring of fairy circles/seeps.
- Sniffer type surveys?

Surveys

- Geophysics – aeromagnetic, gravity, radiometric, resistivity surveys, magnetotelluric surveys, seismic.

Drilling

- specialised hydrogen detection equipment on the rig (e.g. Buru’s Currajong 1 and Rafael 1).
- Well bore design etc.
Enabling hydrogen exploration

• In February 2021 the definition of a ‘regulated substance’ under the Petroleum and Geothermal Energy Regulations 2013 was expanded to include “hydrogen, hydrogen compounds and by-products from hydrogen production regulated substances under the Petroleum and Geothermal Energy Act 2000”.

• Companies can now apply to explore for natural hydrogen via a Petroleum Exploration Licence (PEL).

• Hydrogen, hydrogen compounds and by-products can now be transmitted via a Pipeline Licence.
35 ‘over the counter’ applications have been lodged for PELs targeting natural hydrogen by 7 companies since February 2021.

Applications are assessed by DEM-ERD and if valid, licences are then offered to the applicants.

In areas where Native Title may exist, a Native Title Agreement is required before grant.

The first PEL was granted in July 2021 to Gold Hydrogen Pty Ltd - shown in yellow.

Second PEL has just been granted to H2EX - shown in green.

More PELs are currently being offered to applicants, once granted licence documents can be accessed via the online licence register.
Conclusions

• It is early days for natural hydrogen exploration in Australia and globally – this phase has been compared to 1859 when Colonel Drake drilled for oil in Pennsylvania.

• South Australia has the right rocks and evidence of natural hydrogen occurrences.

• South Australia is currently leading the nation with regulatory, licensing and investment frameworks enabling grant of Australia’s first exploration licences targeting natural hydrogen.

• Geoscience Australia conclude that Australia has enormous natural hydrogen potential.

• Upcoming company exploration activity in SA will test a diversity of natural hydrogen plays.
Uses of hydrogen (CSIRO)