ARDENT UNDERGROUND
HYDROGEN STORAGE

A new hydrogen storage technology for buffering the input to green ammonia plants

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Ammonia Energy Association
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ABERGELDIE
COMPLEX INFRASTRUCTURE

https://ardentunderground.com//

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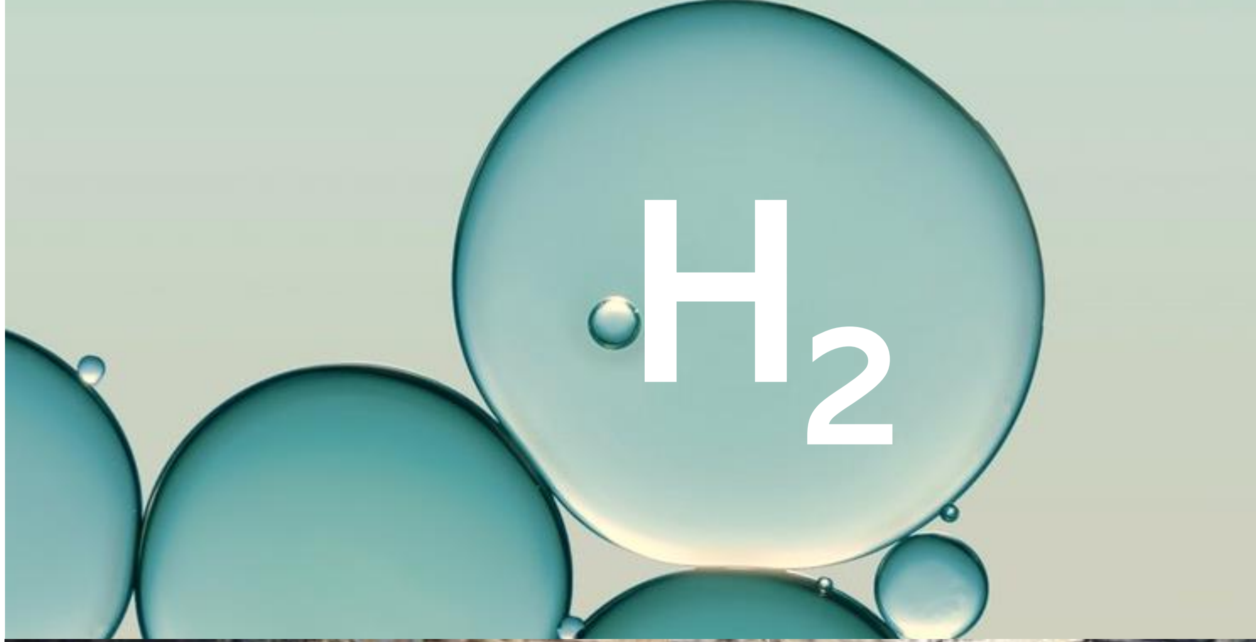

THE NEED FOR HYDROGEN STORAGE

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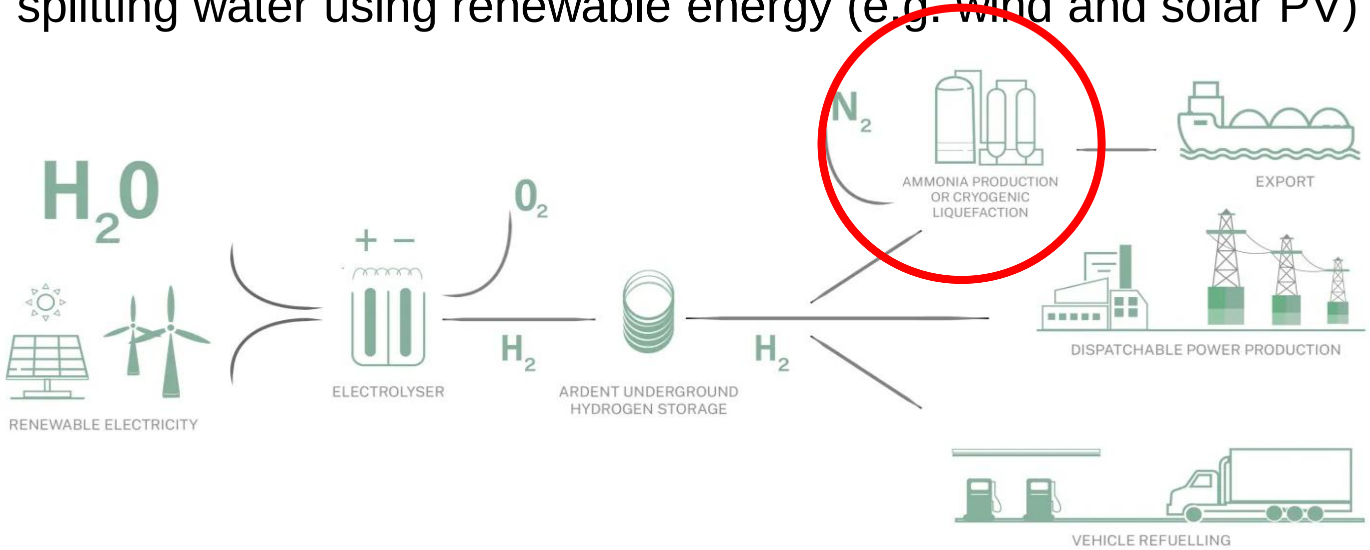
GREEN HYDROGEN: zero emissions hydrogen, produced by splitting water using renewable energy (e.g. wind and solar PV)



- Wind and solar PV power production is **intermittent** and so is the hydrogen production.
- Every hydrogen application requires a **stable flow of hydrogen.**
- **There is no green hydrogen application without green hydrogen storage.**

THE CHALLENGE OF STORING HYDROGEN

- Hydrogen has a very low volumetric density.
- In order to store a considerable amount of hydrogen in a vessel, hydrogen needs to be compressed to high pressures (up to 700 bar).
- Pressure vessels capable of withstanding such pressures are typically small and expensive.
- In order to achieve the transition to a green hydrogen economy, **a low cost, large scale, replicable storage technology is needed.**

HYDROGEN STORAGE IMPACT ON GREEN AMMONIA ECONOMICS

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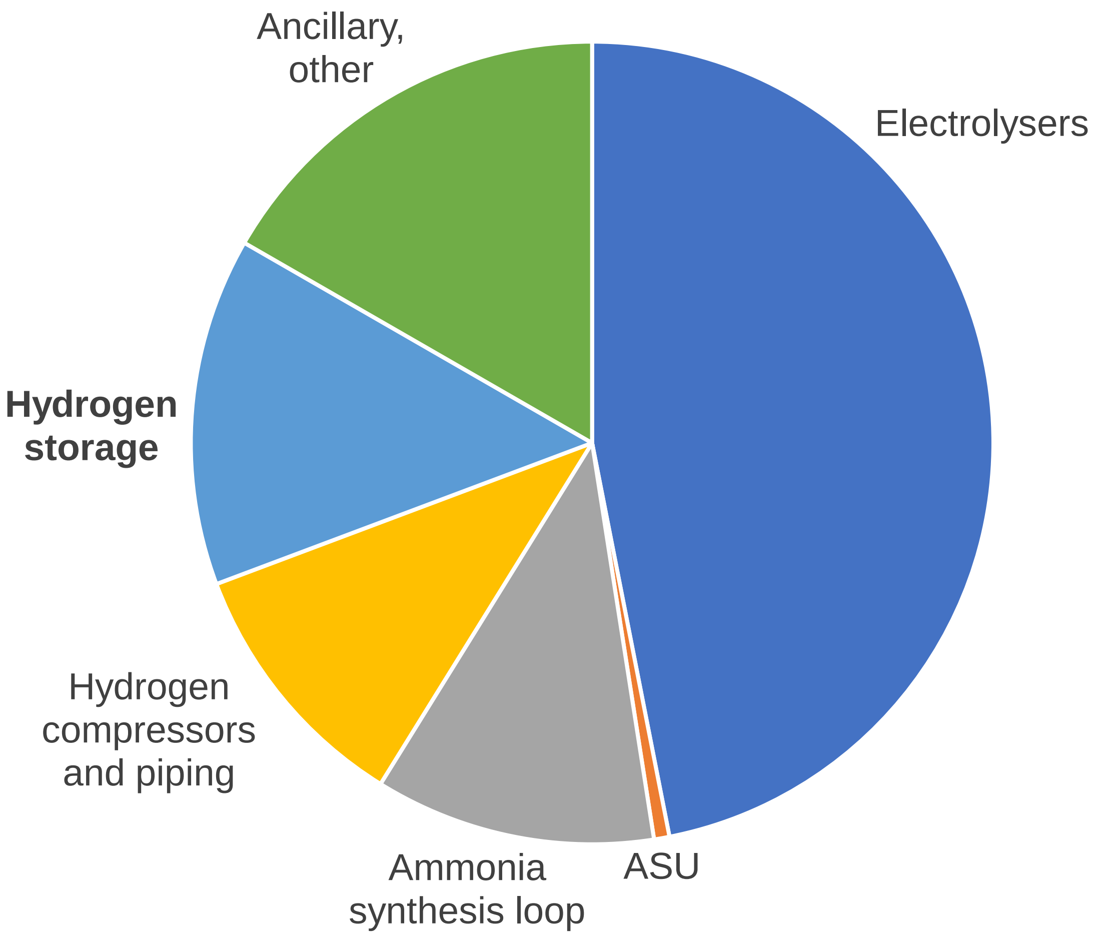
- Storage is needed as buffer between variable hydrogen production and continuous product synthesis both for process and capital efficiency
- Hydrogen storage is a **significant** (but not dominant) capex item
- Estimated specific cost of hydrogen storage vessels in Dyno Nobel feasibility study is $1,207/kg, *(''53T Hydrogen Storage – 260 x 20ft containers holding 204 kg each @ 250 bar'')*
- Specific cost of Ardent Underground storage for same size: $400/kg, reducing after 1st project
- Single point hydrogen storage, reduces piping, valves and land footprint.
- No fixed storage size – lower cost storage feeds into overall system optimization for minimum LCOA

Example Green Ammonia CAPEX breakdown



Capex data adapted from: ANT Energy Solutions and Dyno Nobel Moranbah, July 2020, *DNM Renewable Hydrogen Feasibility Study*
Ammonia synthesis loop data from: ITP Thermal cost model

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Supporting existing ammonia production in Australia with a 2 day buffer = 3000t H_2

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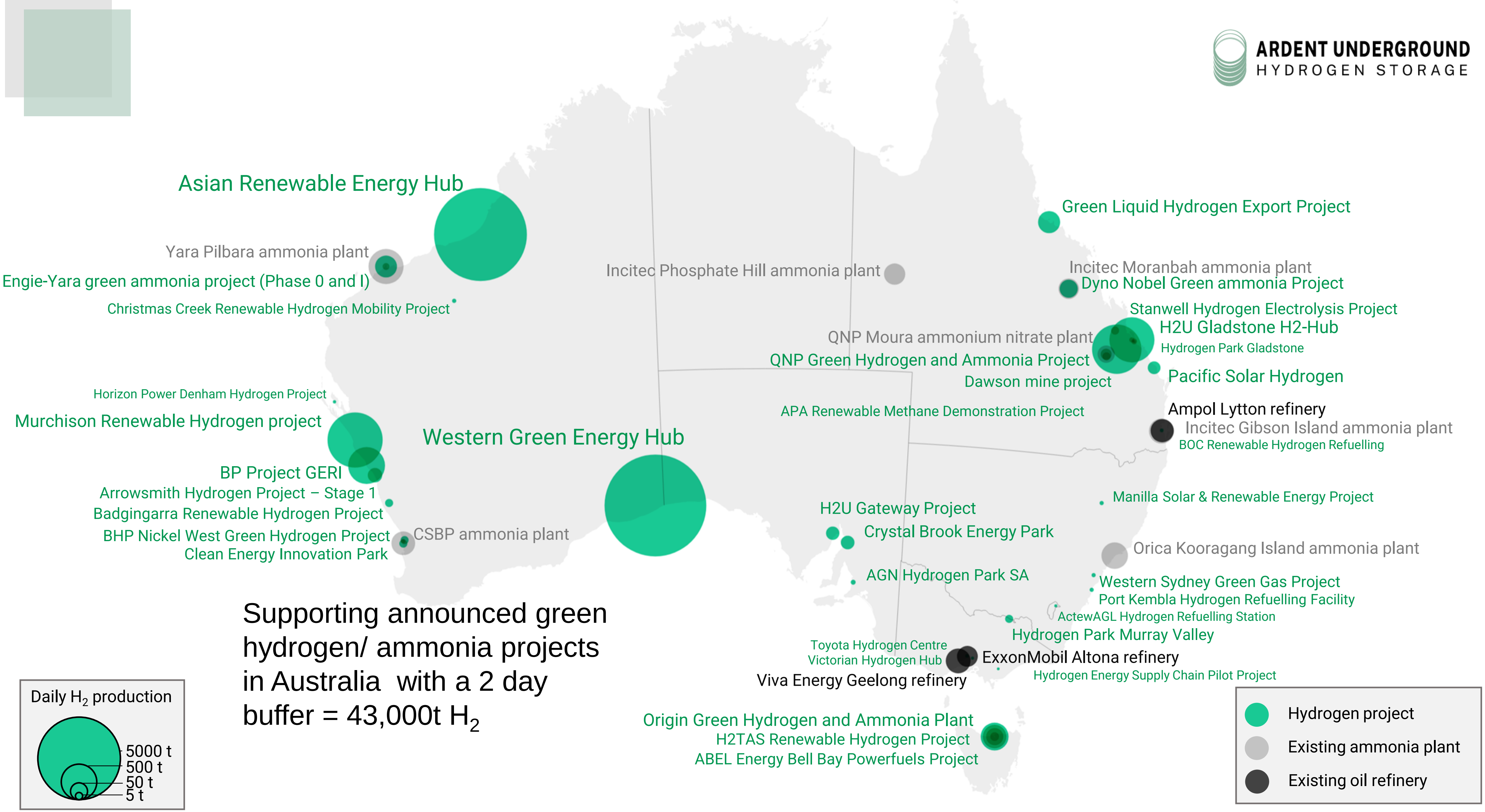

Supporting announced green hydrogen/ ammonia projects in Australia with a 2 day buffer = 43,000t H_2

OUR TECHNOLOGY:
VERTICAL SHAFT HYDROGEN STORAGE

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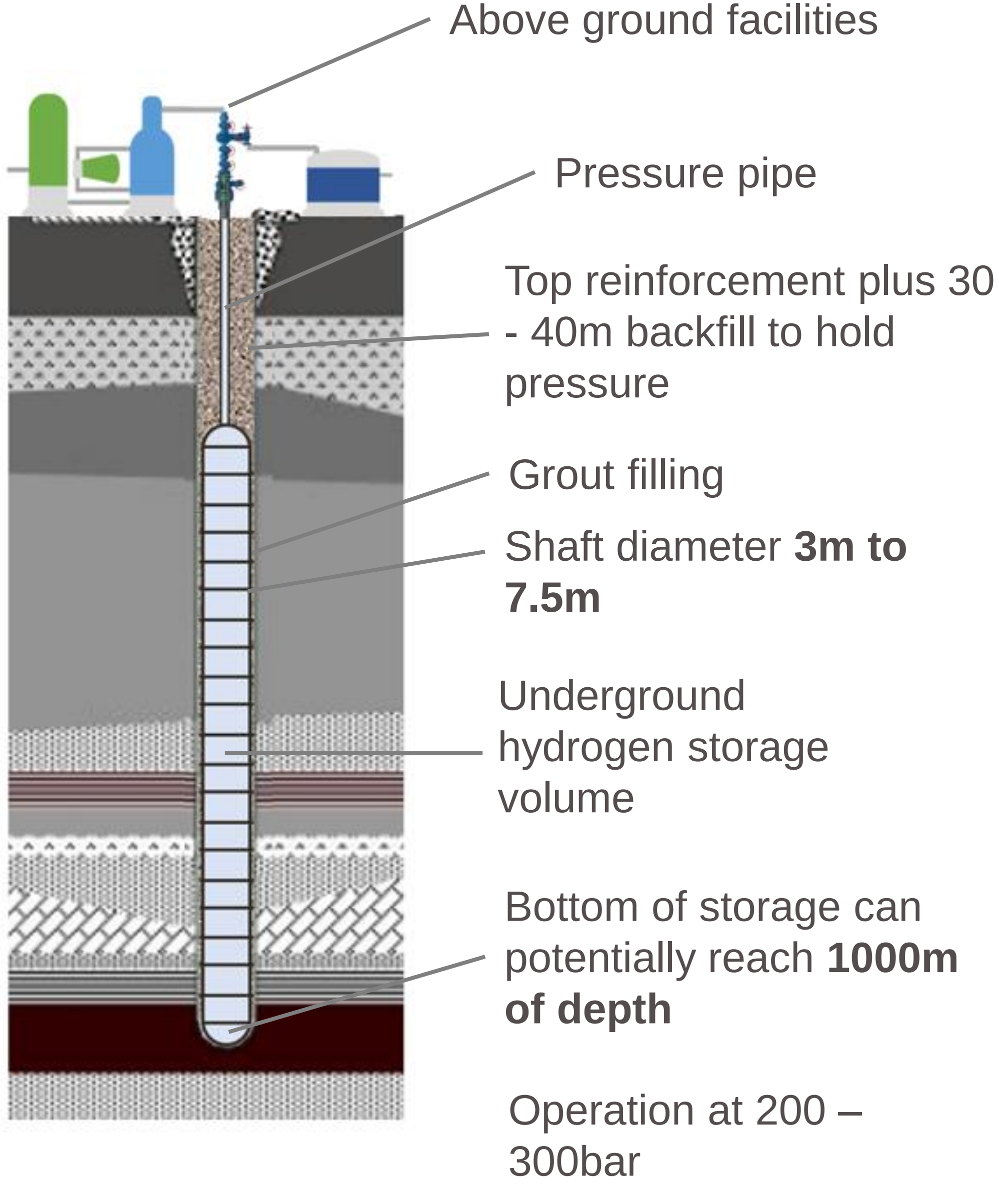
Adapting proven shaft drilling techniques from the mining industry to storing hydrogen in a purposely built underground cavity.

CHEAP
The surrounding rock takes on the duty of containing the hydrogen pressure – **no need for costly pressure containment materials.**

REPLICABLE
The shaft storage construction process can be reproduced in different locations with minimal design adjustment.

LARGE SCALE
Hydrogen storage sizes of **50 to 500 tonnes per shaft.** For larger storage, multiple shafts can be built in the same location.

SMALL FOOTPRINT
The above ground footprint is very small compared to equivalent pressure vessel storage.



OTHER HYDROGEN STORAGE SYSTEM OPTIONS

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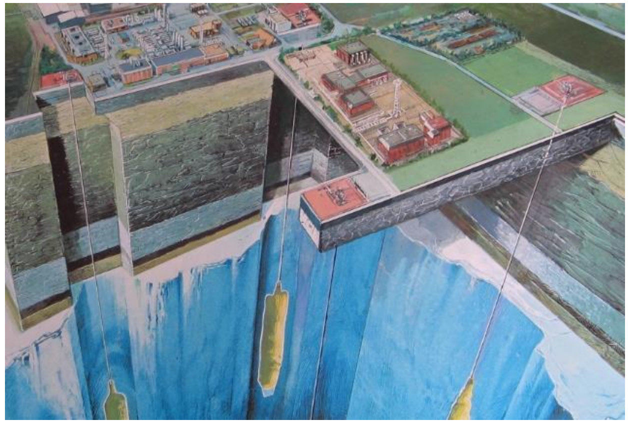
ALREADY IN USE

Composite Pressure Vessels

Salt Cavern

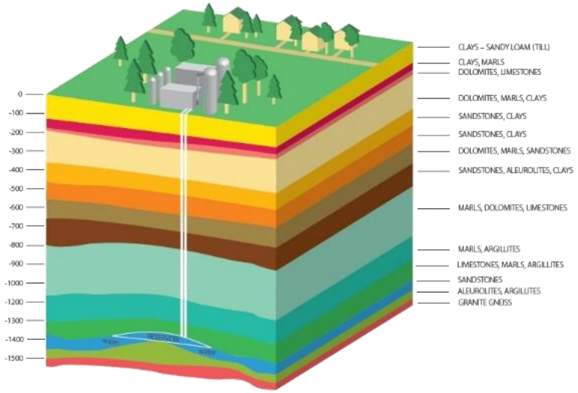


UNDER DEVELOPMENT

Concrete – Steel Vessels

Underground Pipe Storage

Aquifer



Rock Cavern

MARKET FOR HYDROGEN STORAGE?

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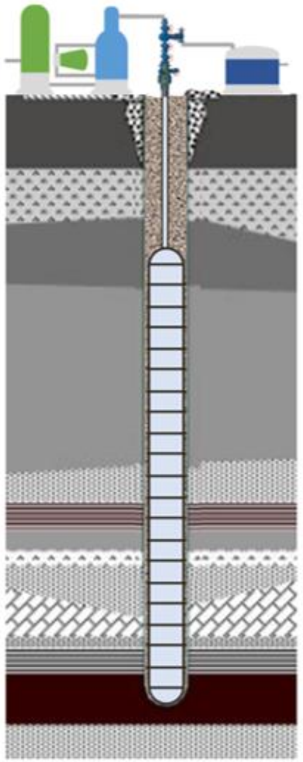
Supporting existing ammonia production in Australia with a 2 day buffer: 3000t H_2

=

× 6000

OR



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HOW IT WILL BE DONE

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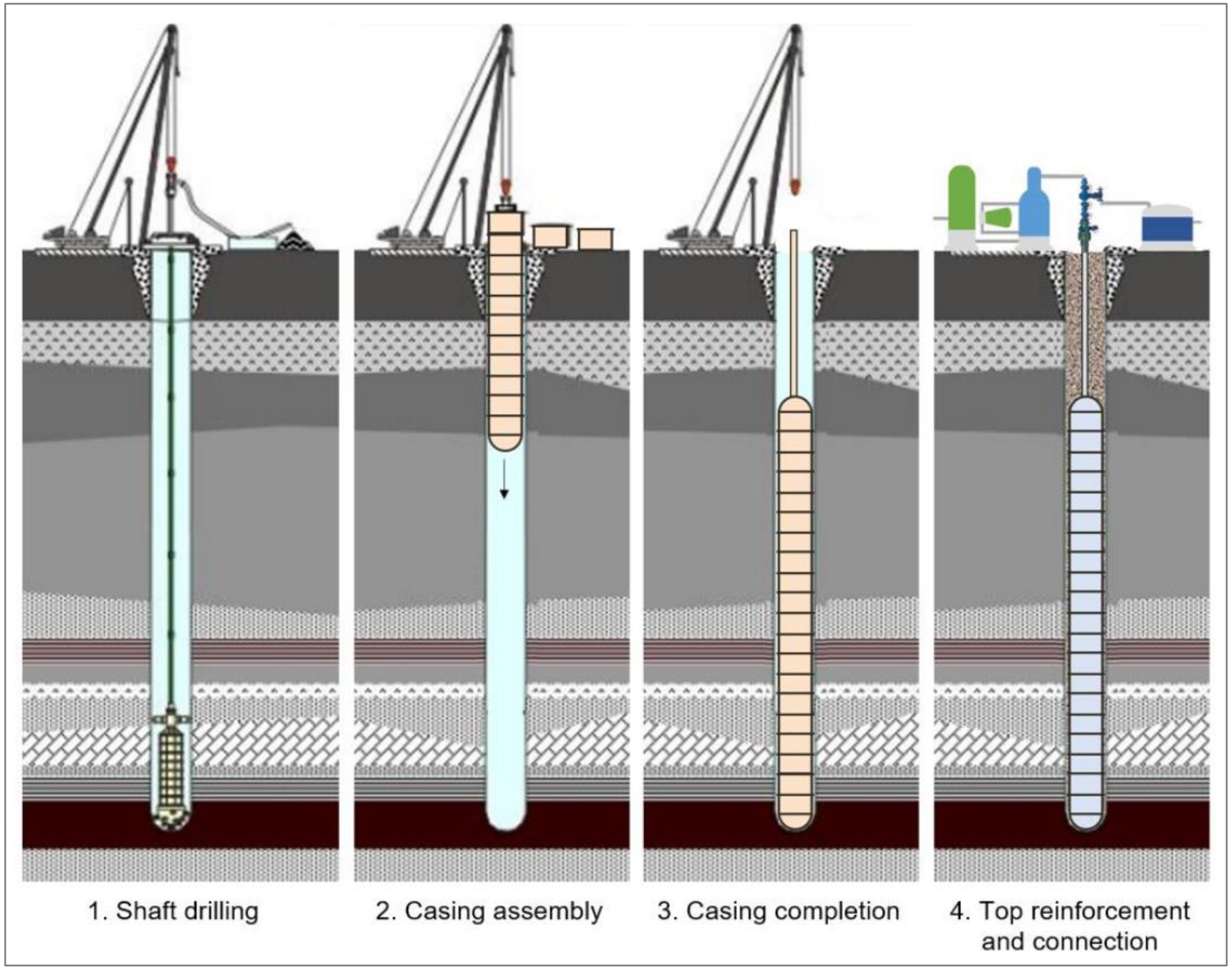
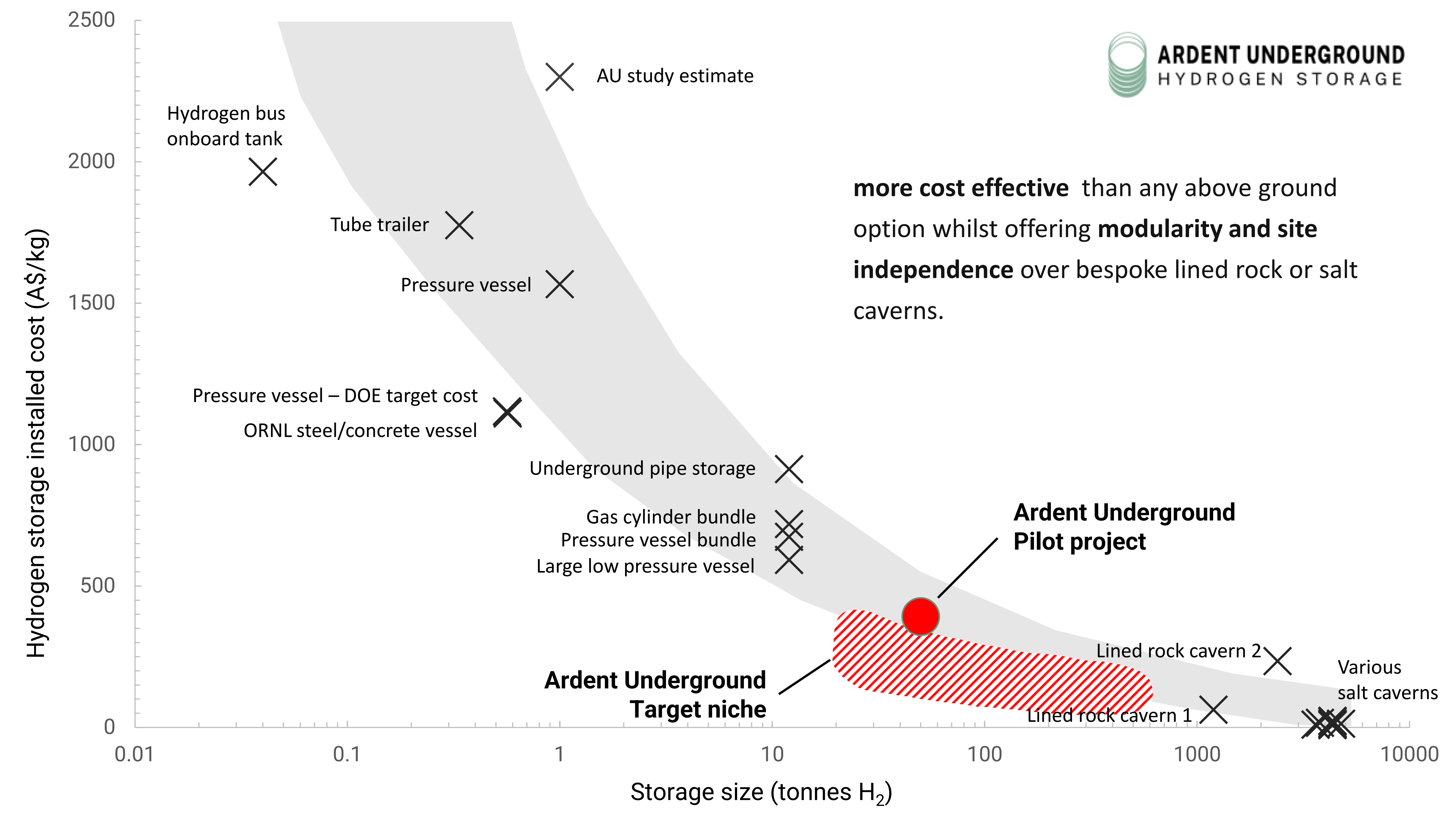
1. **Shaft Drilling**
   A rotating large diameter drilling assembly is lowered into the rock

2. **Casing Assembly**
   A casing with a steel liner (approx. 12mm) is assembled and lowered into the shaft

3. **Casing Completion**
   The cap is installed to the top of the casing and it is connected to ground level with a pressure pipe.

4. **Top Reinforcement and Connection**
   The space between steel liner and rock is filled with grout and the shaft storage is connected to the above ground facilities.

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HYDROGEN STORAGE
more cost effective than any above ground option whilst offering modularity and site independence over bespoke lined rock or salt caverns.
Hydrogen storage installed cost (A$/kg)
Storage size (tonnes H_2)
2500
2000
1500
1000
500
0
0.01
0.1
1
10
100
1000
10000
AU study estimate
Hydrogen bus onboard tank
Tube trailer
Pressure vessel
Pressure vessel – DOE target cost
ORNL steel/concrete vessel
Underground pipe storage
Gas cylinder bundle
Pressure vessel bundle
Large low pressure vessel
Ardent Underground Pilot project
Ardent Underground Target niche
Lined rock cavern 2
Lined rock cavern 1
Various salt caverns