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A new look at hydrogen storage

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Essen, Germany
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Underground spaces can be utilised to store energy in at least) three ways

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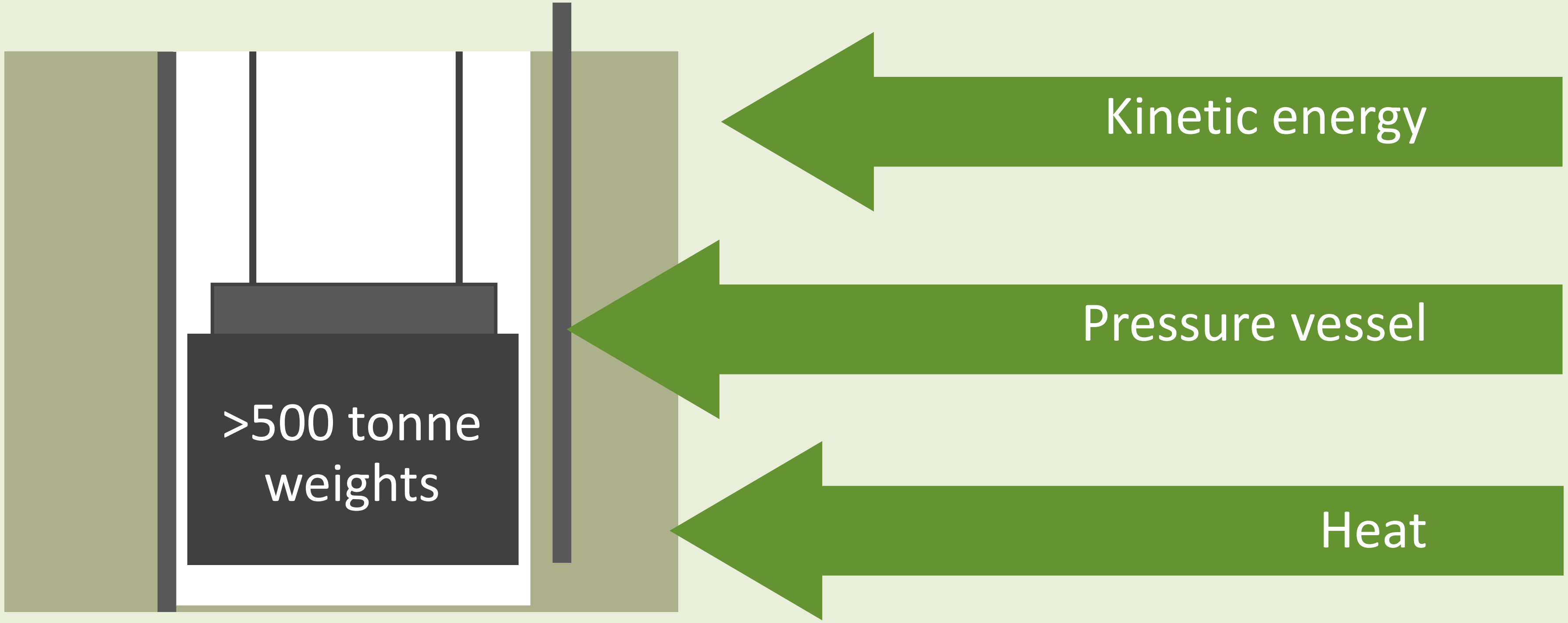
Multiple utilisation of underground shafts will provide long-life infrastructure assets capable of storing significant energy



Gravitricity technology will be deployed in existing mines and purpose built shafts

Technology overview

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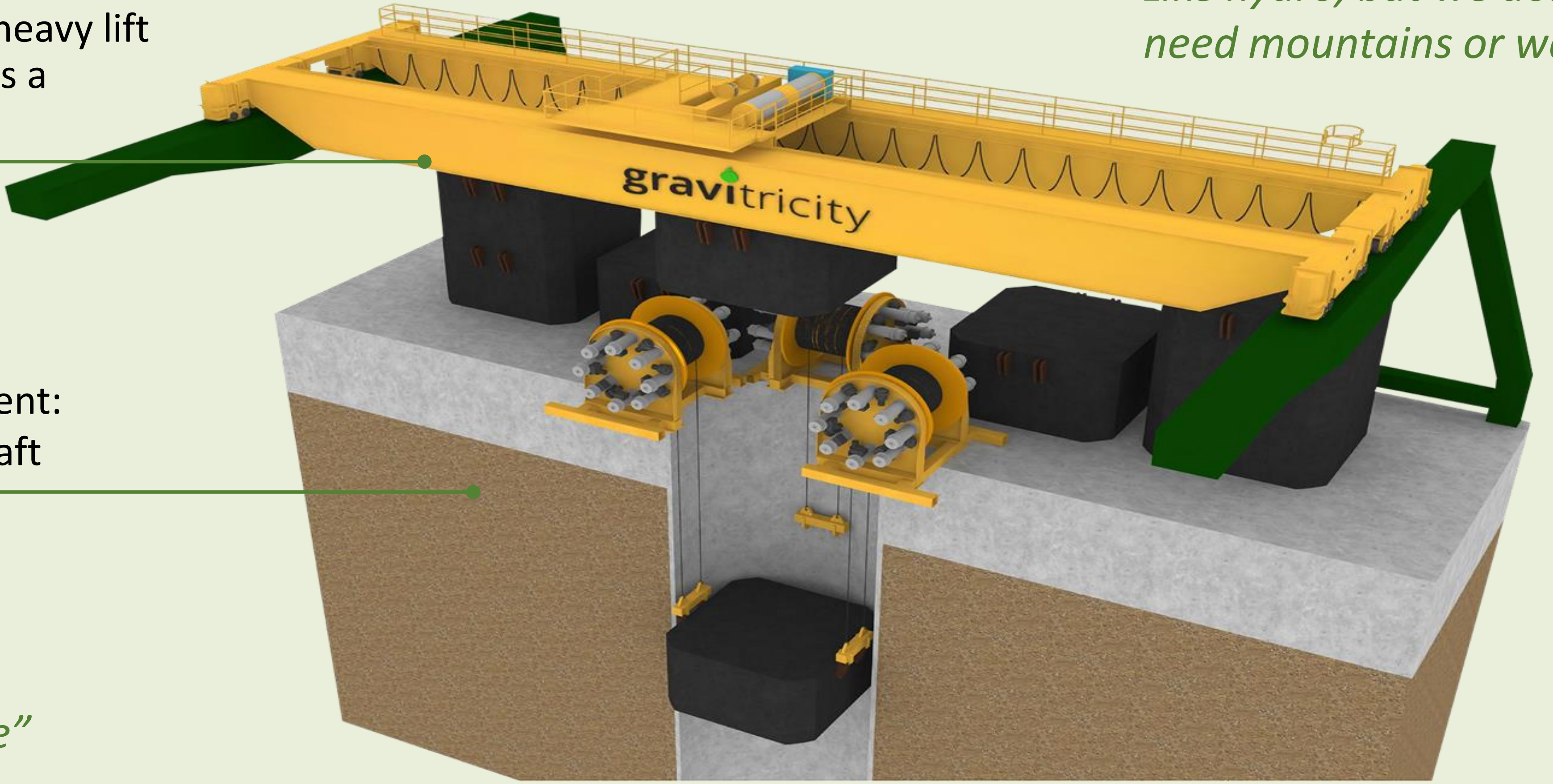
Surface equipment – heavy lift equipment, working as a generator in reverse

Underground equipment: Cables, weight and shaft



"Like hydro, but we don't need mountains or water"

"New engineering, new integration, but not new science"

Design of technology underpinned by scientific principle

E=MGH... Energy = mass x gravity x height

2 design principles

Heavy weights

Tonnes?

Tens of tonnes?

Need weights in **hundreds of tonnes** to generate interesting amount of electricity

Big drops

Cranes?

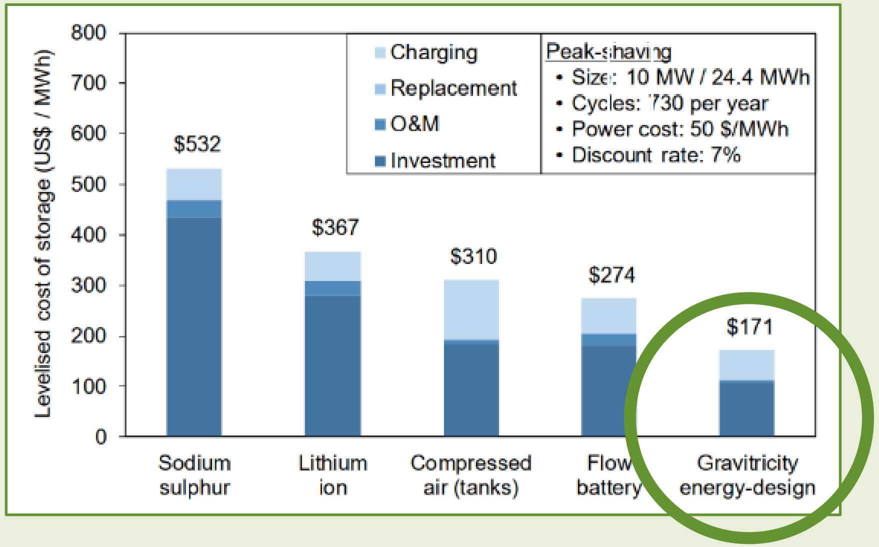
Buildings?

Going underground allows us to use the **geology of the earth** to hold up the weight

Competitors (2) – Gravitricity gravity energy storage

Feature set which equates to highly compelling commercial proposition

Category	Feature / benefit	
Economics	• High efficiency (up to 80% round trip) **with no cyclical degradation** • Long life (>25 years) • No standing losses or parasitic loads	✓
Performance	• Rapid response (<1s) for lucrative fast-response markets • Versatile energy / power ratio (15 mins – 8 hrs) • No depth of discharge limits • High power output without degradation	✓
Implementation	• Low embedded carbon footprint (no ore mining) • No explosive chemistry • Small physical footprint	✓



Ref: Report *Levelised Cost of Storage for energy-designed Gravitricity storage systems,* O Schmidt, **Imperial College. July 2019.**

LCOS = (Capex (initial) + Capex (replacement) + O&M + Charging cost) / units generated; <u>n.b. no end of life costs are included</u>

Long-life, reliable, energy storage for critical national grid infrastructure

Timeline of achievements and next steps…

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2018-2021

- **>£3.5m** — Total R&D funding
- **> £4m** — Raised in equity funding
- **8** — Patents filed (5 granted, 3 pending)
- **2** — Independent studies by Imperial College London verifying levellised cost of storage over 25yrs below Li-ion, CAES, Flow batteries
- **1** — Grid connected, 250kW **Concept Demonstrator** validates technology capabilities (<s response, multi weight system)

2022-2024

1
Sub scale system – 1MW / 80kWh – short duration

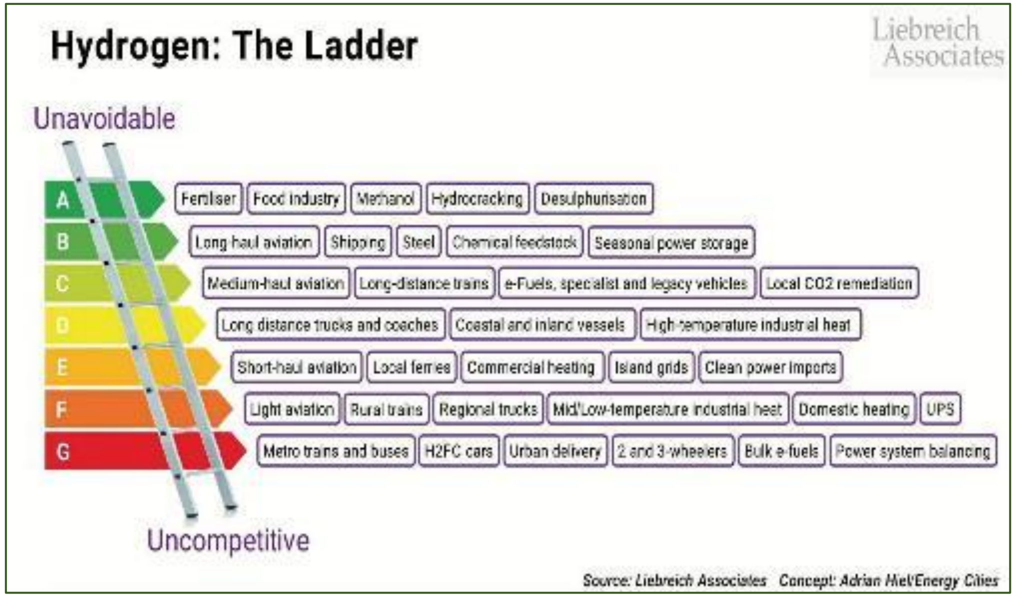
2
4MW / 1MWh, single-weight system designed to optimise revenues from balancing services

3
Hydrogen storage deployment

4
Fundraising!

Designing a hydrogen storage solution starts with likely use cases – where else?

Liebreich Ladder



Gravitricity perspective

1. **Existing uses** – hydrogen production by electrolysis will replace existing, carbon emitting production techniques for applications such as ammonia production, steel production and methanol production[1] ✓

2. **High grade heat** – hydrogen is the only low carbon way of reaching temperatures needed in some industrial applications ✓

3. **Grid scale energy storage** - Electrolysis of water can generate hydrogen from (otherwise curtailed) renewable generation providing GW scale storage for daily peaks, long duration and inter-seasonal requirements ✓

4. **Shipping and aviation** – requirements of these sectors will drive growth of hydrogen production and storage facilities at ports and airports ✓

Notes
1. Currently these 3 use cases represent 90% of the c. 90Mt of hydrogen production today

Hydrogen storage market

Exponential increase in green hydrogen production requires localised hydrogen storage

Global initiatives

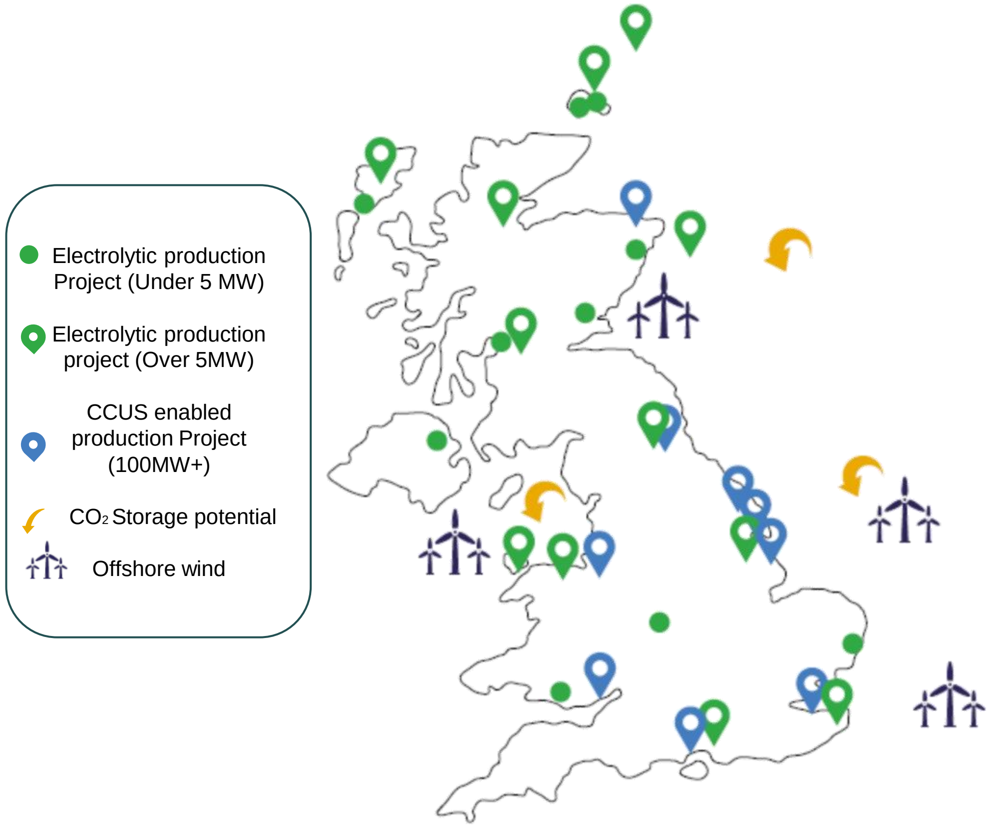
260 GW — Total size of 26 largest hydrogen projects globally

983 — Total number of initiatives in IEA's 2021 database of hydrogen projects

37 — No. of governments which have adopted a hydrogen strategy,

$16bn — National subsidies for hydrogen projects between 2022 and 2030

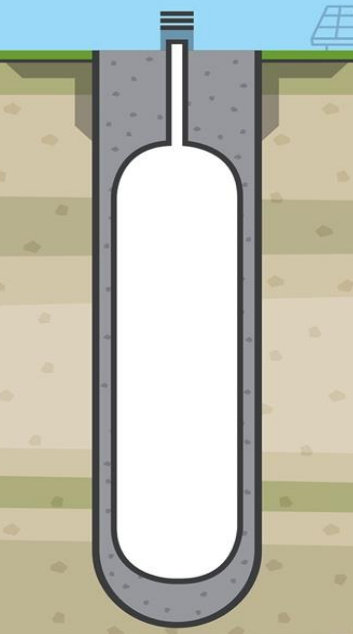
Proposed UK hydrogen production projects



Multi layer composition consisting of a gas tight steel liner surrounded by steel, concrete and grout

Using the geology of the earth to achieve higher pressures and greater storage volume at less cost

- ✓ Shaft lined with a combination of steel and concrete to allow pressure to be transferred into surrounding rock
- ✓ Higher pressure allows for greater storage potential for a given volume
- ✓ Minimal surface footprint / space requirement
- ✓ Highly competitive cost per unit of hydrogen by weight
- ✓ Locational flexibility



Gravitricity hydrogen storage occupies offers mid – scale storage

Low — **Tonnes of hydrogen stored** — **High**

Pressurised vessels

- ✓ locational flexibility
- ✘ Expensive
- ✘ Limited capacity / vessel
- ✘ Large footprint

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Gravitricity lined rock shafts offer a mid-scale solution: lower cost than pressure vessels, and more versatility than salt caverns

Salt caverns

- ✓ Low cost ($ / kg H stored)
- ✘ Lacks locational flexibility
- ✘ Limited number of cycles / year
- ✘ High losses and impurity problems

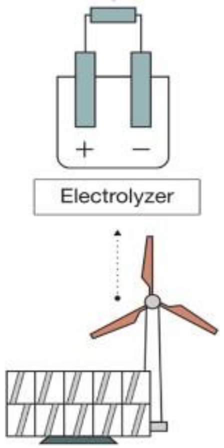
Storage use cases and specific requirements will diversify, driving demand for technologies which address the limitations of incumbents

Gravitricity hydrogen storage

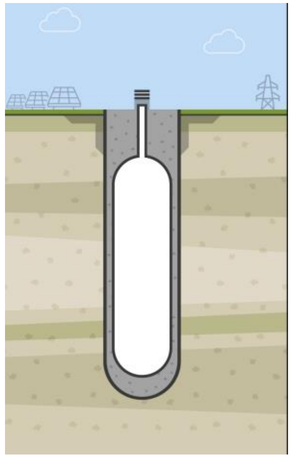
Promising BEIS funded feasibility study with Arup on underground hydrogen storage

Storage of green hydrogen in lined shaft for offtake to industrial users

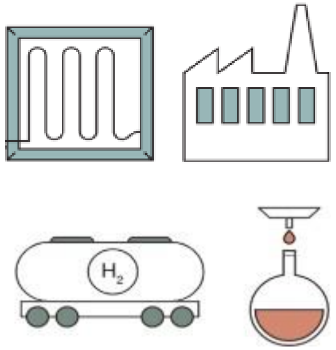
Production



Storage



Offtake



- Shaft diameter: - 6m x 200m
- Hydrogen storage - 100 tonnes of pressurised hydrogen @ 220 bar = 3.3GWh)

Key advantages of underground hydrogen storage

- ☑ Pressure transferred to surrounding rock reducing steel and concrete costs
- ☑ Minimal surface footprint / space requirement
- ☑ Geographical flexibility - generation, storage & distribution next to existing infrastructure
- ☑ Highly competitive cost per unit of hydrogen by weight
- ☑ Hydrogen Purity - No scrubbing needed at additional cost vs salt cavern storage

Primary target markets: four distinct use cases, although one is particularly well suited to hydrogen economy

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Balancing Services

Energy Access & Mini Grids

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Solar co-location

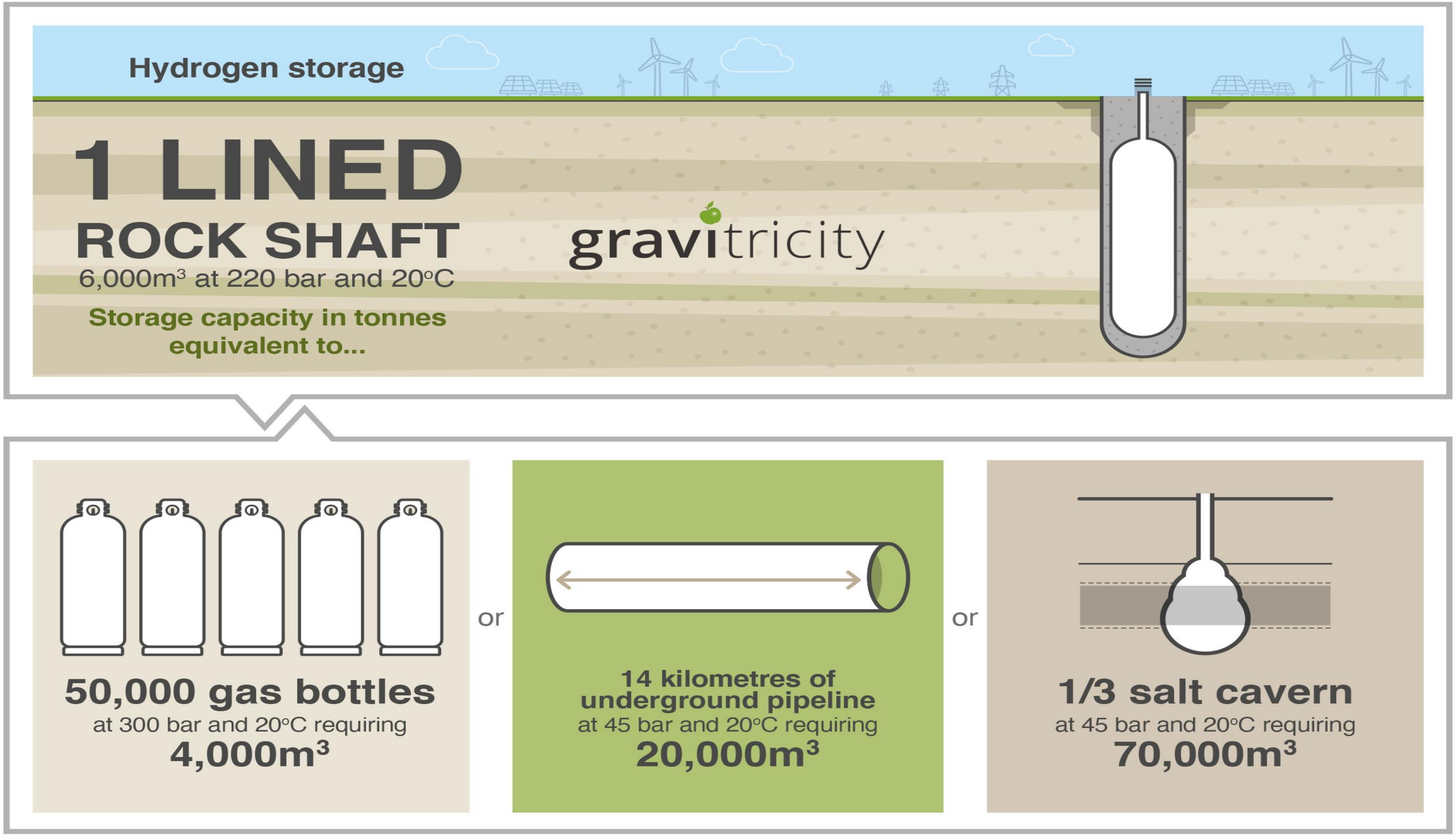
Industrial decarbonisation

Demand drivers

Routes to market

Technical requirements

Our 'mid scale' solution will hold a lot of hydrogen!



Building a delivery partners with world class expertise

Complementary skill sets

Consultant engineers & feasibility

ARUP

Grant Funding

Department for Business, Energy & Industrial Strategy

Pressure vessel specialists

BENDALLS ENGINEERING

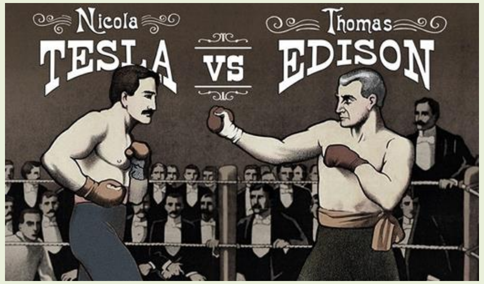
Ground Engineer Specialists

VSL

Is Energy Storage a format war?

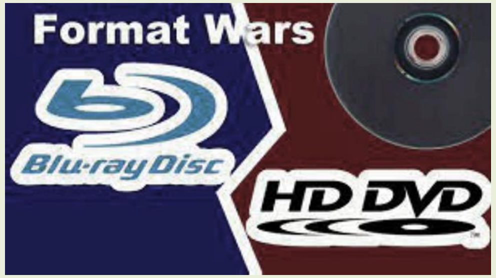
Format wars – one problem, two solutions

1890s



1980s

1990s



Is Energy Storage a format war?

1. At Gravitricity, we don't think so!
2. Identifying characteristic of energy storage is the variance in requirements:
   - **Duration**
   - **Energy & Power**
   - **Location**
   - **Conditions**
   - **High / low cycling**
   - **Importance of efficiency**
   - **Durability and longevity**
   - **Capex vs opex… and more**

Different requirements = different technology solutions

Our crowdfunding page is live!

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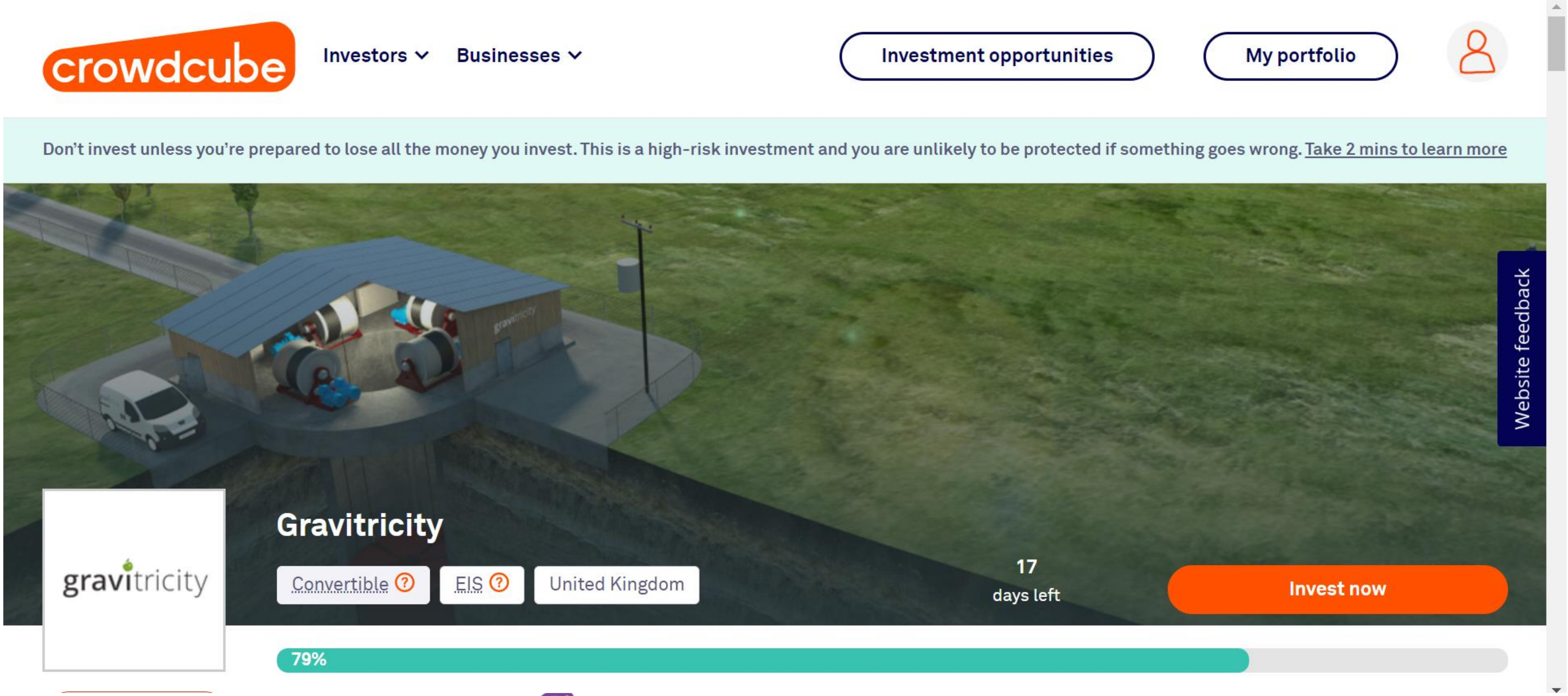

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