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Energy Test-Beds Role in Providing Safe and Sustainable Energy from the Subsurface

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ABSTRACT

Scientists, policymakers, industry leaders and the public urgently need to understand how the Earth responds to new and emerging subsurface energy technologies. These energy technologies will make a major contribution to the economy, to jobs, and to energy security, but are largely untried, unproven, and untested. Without a better understanding of this, nascent energy industries are likely to be arrested in their development, investments at best delayed and potentially unrealised, and economic dividends lost in the face of uncertainties related to technical feasibility and environmental impact, and this may result in more public scepticism and opposition. These Energy Test-Beds (ETB) facilitate real-time, open access observations of the effects of subsurface energy applications (such as shale gas extraction, CCS and geothermal power generation) on groundwater, seismic activity and surface atmospheric emissions. They enable world-class understanding of subsurface energy applications leading to better management, regulation and environmental security assurance. Furthermore, they provide a platform for the development and commercialisation of a range of new low-carbon technologies and the development of innovative, exportable local technology and expertise in energy technologies using the subsurface. The UK will develop the UK geo-energy observatories (UKGEOS) as a national facility, open to global science projects with a focus on shallow geothermal energy from mine workings in a Glasgow regeneration area, and on deeper energy systems for extraction and storage at a site in northern England. The KTB KraflaTestbed will develop high-enthalpy geothermal energy at the magma - rock interface and will also allow testing of novel monitoring systems for volcanic hazards. Other testbeds across the EU and globally are focussed on geothermal energy and carbon capture and storage. This paper focuses on describing the need for these ETB, their planning and early outcomes and underlines the future requirements globally.

1. INTRODUCTION

Scientists, policymakers, industry leaders and the public urgently need to understand how the Earth responds to new and emerging subsurface energy technologies. These energy technologies will make a major contribution to the economy, to jobs, and to energy security, but are largely untried, unproven, and untested within complex global geological conditions. Without a better understanding of this, nascent energy industries are likely to be arrested in their development, investments at best delayed and potentially unrealised, and economic dividends lost in the face of uncertainties related to technical feasibility and environmental impact, and this may result in more public scepticism and opposition. Energy Test Beds (ETB) must be national/international facilities, open to global science projects, which will:

- **facilitate** real-time, open access observations of the effects of subsurface energy applications (such as shale gas extraction, CCS and geothermal power generation) on groundwater, seismic activity and surface atmospheric emissions;
- **enable** world-class understanding of subsurface energy applications leading to better management, regulations and environmental security assurance;
- **provide** a platform for the development and commercialisation of a range of new low-carbon technologies; and
- **develop** innovative, exportable technology and expertise in energy technologies using the subsurface.

2. BACKGROUND AND RESEARCH OPPORTUNITY

The top few metres to kilometres of the subsurface are increasingly utilised by humanity, not just for the extraction of raw materials but also for energy transformation (heat and cool), storage, containment of waste and in transport and infrastructure. It also holds a significant percentage of the world's potable water (UNESCO, 2012).

Our ability to measure in the subsurface is undergoing a revolution via the use of new technology, high precision and transient (e.g. Raspberry Pie-type) sensors, high performance computing, edge cloud computing, visualisation and artificial intelligence (AI).

Nonetheless, the engineering conditions in the subsurface are challenging. Despite this, a number of the identified low-carbon technologies required to decarbonise the planet need us to work in the subsurface and significantly change the way we observe and monitor systems in these environments.

We are at a point in time where we can imagine the environmental monitoring and engineering for a number of subsurface conditions, some in deep, extreme conditions of temperature, pressure and chemical state (e.g. saline, acidic or biofilm).

It is proposed here that governments, research and industry globally should invest in a number of pilots for research and technology in these environments in which fundamental and translational science can help solve societal problems. The science proposed crosscuts disciplines, recognising that earth and environmental scientists will work with engineers, bio- and socioeconomic scientists.

2.1 Timeliness

We are at a point where data transmission, sensor technology and visualisation of sub-seafloor and sub-land surface technology is going to make a step change possible in our ability to future-proof the economic and social use of this space. New technologies and approaches for high-precision modelling and simulation, including the necessary data integration, will engender a new way of using and interacting with this space.

Targeted investment in pilot demonstrators and test facilities would place researchers in leading roles globally in the energy transition. One would fully expect national funders to join this activity, creating a global network that will underpin future energy use, engineering resource planning and urban development.

2.2 The concept

Global energy security throughout the next century will continue to depend significantly on fossil fuel and nuclear energy whilst unlocking the potential of renewables as well as unconventional energy sources. The UK government's Industrial Strategy (Department for Business, Energy & Industrial Strategy, 2017) highlights the importance of continuing support for the oil and gas and nuclear sectors. Furthermore, within the 8 Great Technologies, it is clear that 'big data' represents an opportunity for the UK to gain competitive advantage in a range of industry sectors. The proposed test bed will generate data-driven opportunities to address the challenges and opportunities of the energy sector.

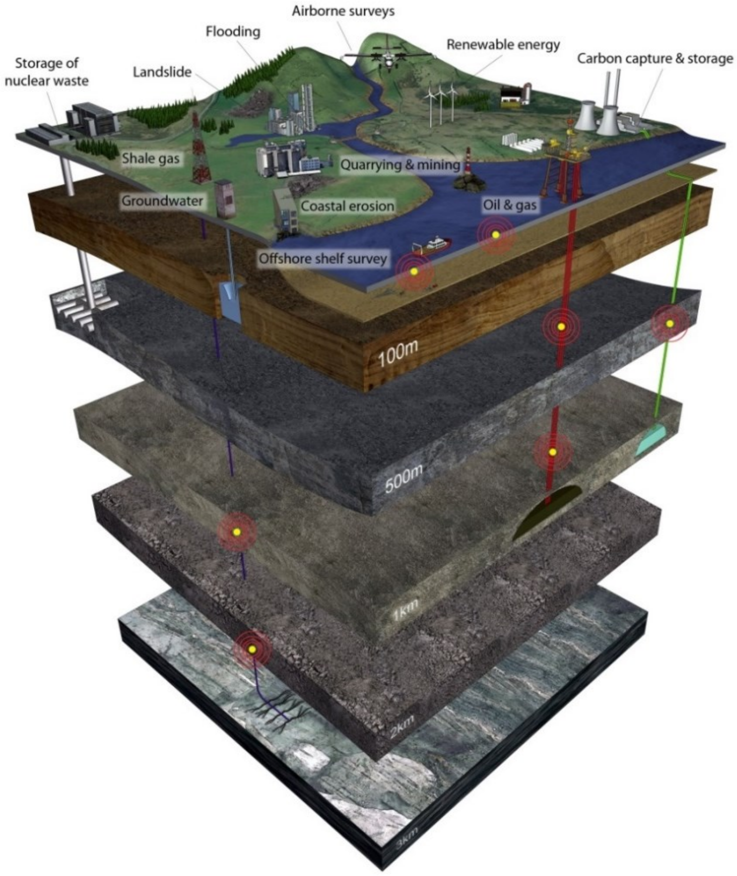

Figure 1: Schematic illustration of a network of observational and real-time monitoring infrastructures to underpin energy systems

Figure 1 schematically illustrates a connected network of infrastructures that will allow the subsurface to be monitored at time scales that are consistent with our use of the subsurface, to increase efficiency and environmental sustainability but also to act as a catalyst to stimulate investment and speed new technology energy options to commercialisation.

It will thus act as a bridge from ideas to application and would attract support and possible co-funding from oil and gas companies, utilities and energy and environment consultancies

2.3 Objectives

Our future use of the subsurface, particularly for energy (subsurface gas storage, compressed air energy storage, shale gas, coal bed methane, underground coal gasification, enhanced oil recovery, geothermal) and waste disposal relating to energy (carbon capture and storage, radioactive waste) depends on a much greater understanding of subsurface flow and processes. This is particularly pertinent to low-carbon energy because the feasibility of three low carbon energy solutions rely on understanding of subsurface geological containment or flow: carbon capture and storage (CCS), shale gas and radwaste. Lack of understanding and uncertainty feeds through to lack of confidence amongst policy makers and industrial investors, and most of all to lack of public confidence. The latter might be a show stopper for much low carbon technology where subsurface management is needed (Stephenson, 2012).

An integrated multicomponent sub-surface monitoring infrastructure linked with the European Plate Observing System (EPOS, https://epos-ip.org/) and the European Carbon Capture and Storage Laboratory Infrastructure (ECCSEL, https://www.eccsel.org/) will allow research into:

1. the impact of deep shale gas drilling and hydraulic fracturing on shallow groundwater and surface water, on seismic activity, and on ground stability and subsidence;
2. processes relating to the containment, confinement, and rates of solution and carbonation of subsurface-stored CO_2 in carbon capture and storage;
3. processes relating to the containment and confinement of subsurface nuclear and other types of waste; movement of fluids (gas, water, solutes);
4. the impact of coal combustion products on the environment both from surface and subsurface operations (e.g. underground coal gasification);
5. the role of biological mediation in the subsurface in shallow to deep environments;
6. processes at basin and reservoir scale in reservoir stimulation and enhanced oil recovery (EOR);
7. ground deformation and induced seismicity associated with enhanced geothermal systems in hot-rock-dry-rock environments.

3. THE UKGEOS PROJECT

The UK is developing a unique package of monitoring capability in the UKGEOS project (https://www.ukgeos.ac.uk/) where monitoring at the surface and in the critical zone will be coupled with deep borehole monitoring of variables such as pressure, temperature, heat flow, seismicity, tilting, strain accumulation, fluid chemistry, pH and biological properties. Monitoring will also include satellite and remotely-sensed data such as InSAR (Interferometric Synthetic Aperture Radar) and gravity, electrical, spectral and magnetic data – this is illustrated in Figure 2.

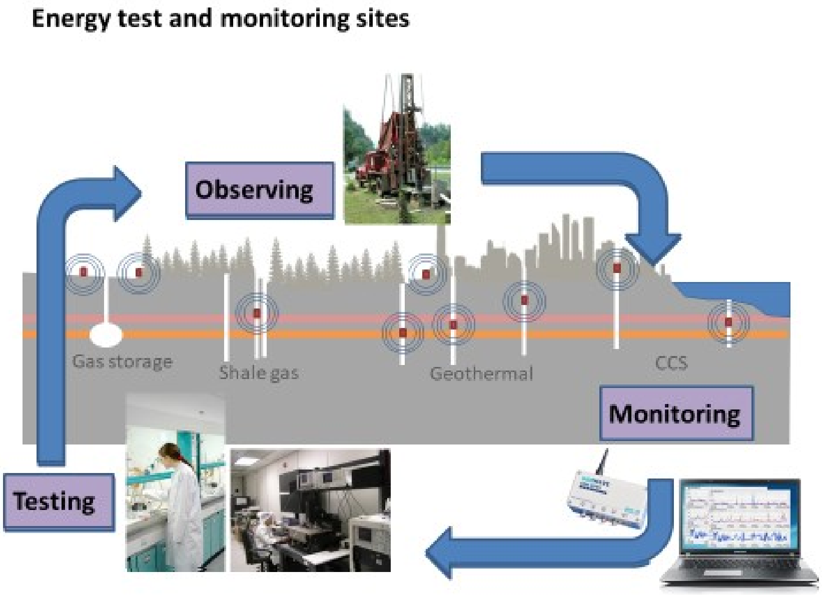

Figure 2: Schematic diagram showing the interaction between monitoring, observing and testing in ETB environments

Infrastructure that underpins research into subsurface activity will make us better at monitoring and managing these new and continuing activities safely and sustainably. Industry would benefit in being able to access state-of-the-art monitoring data to maximise efficiency of extraction and subsurface management, as well as maximising environmental sustainability. This knowhow and data would also stimulate outside investment and speed new technology energy options to commercialisation, for example compressed air energy storage (CAES) and underground coal gasification (UCG). This would become a competitive advantage in developing expertise for use in the British international energy market.

4. THE KRAFLA ENERGY TEST BED

The Krafla energy test bed in Iceland is described elsewhere in this volume, but it will be a key part of an international network of ETB. It is an ambitious, cutting-edge project to create an openly accessible, world-class research facility to advance our knowledge of volcanoes and geothermal research. This first-of-a-kind observatory will enable a step change in monitoring magma, giving us the ability to predict, and potentially control, volcanic eruptions in populated areas. It will help increase human resilience to these hazards.

The proposal is to drill down 2 km into a magma body with temperatures of about 900°C. This will potentially help improve resilience for the millions of people worldwide living within 100 km of an active volcano, enable more effective, in situ volcano disaster protections systems and provide more effective geothermal energy production at lower cost, which for example could be made available to the Iceland–European interconnectors.

The project's international consortium includes over 50 research institutes, government agencies and universities from countries including the USA, Canada, France, Germany, New Zealand, Russia, South Korea, Italy and Iceland. It will also leverage other national agency funding.

5. THE GLOBAL NETWORK

There are a number of nascent ETB with various applications and some of these are listed in Table 1 at the end of this paper. They are in various states of development and this is indicated in the table and the reference or website link. In certain cases (e.g. Basel Geothermal) the ETB have been discontinued. This is often in response to public pressure on concerns for the environment and underpins how careful planning and communication are required. In the offshore environment, such as in Sleipner an operational offshore oil and gas facility, CO_2 was injected for 20 years and research results are available but, being a commercial project, there has been no access to the platform itself for research.

The research infrastructures will underpin the energy industry, building on and linking with academic and government institutes and industry and existing distributed research infrastructure such as EPOS[1], ECCSEL[2] , and BritGeothermal[3] in the UK, and GEORG in Iceland.

The economic impact is potentially very large in developing (1) untapped energy resources like shale gas, CBM, UCG, geothermal; (2) methods to sustain fossil fuel reserves e.g. EOR; (3) understanding of storage processes including CCS, gas storage and radioactive waste disposal; and (4) subsurface energy storage such as CAES. Economic value will also stem from management and minimisation of environmental impacts, which will protect the environment, ecosystem services, property and infrastructure.

New energy activities are likely to contribute considerably to the economy. Shale gas could create 5,600 jobs in the UK and an 'Aberdeen Effect' in the northwest of England. CCS may generate £3 to 6.5 billion a year by the late 2020s (Department of Energy and Climate Change, 2012) sustaining more than 30,000 jobs by 2030 (TUC/CCSA, 2013). Coal bed methane and underground coal gasification have been slow to start; analysis indicates that the global UCG market will reach $570m in 2012 with CBM reaching $5.3bn in 2013 (Visiongain, 2012). Estimates suggest that EOR could enable a further three billion barrels of oil from the North Sea worth £190 billion (University of Edinburgh, 2019). Grid scale storage is the key to unlocking renewables because of the need to store energy in periods of low renewable output. A number of energy storage options require geological understanding, including CAES in salt caverns and thermal storage in subsurface aquifers. The value of grid scale geological energy storage could therefore be considerable.

Greater understanding of subsurface processes, if communicated properly, will also allow better public buy-in to subsurface usage and therefore more efficient, streamlined development.

The scientific impact of this new infrastructure will be far reaching, including understanding of subsurface flows, geochemistry and physics of rock matrices, and the interaction of surface carbon and other geochemical cycles and subsurface flows.

The new infrastructure will act as a catalyst for industry both onshore and offshore to stimulate investment and speed new technology options to commercialisation, for example CAES and UCG. It will thus act as a bridge from ideas to application and would attract support and possible co-funding from oil and gas companies, utilities and energy and environment consultancies.

6. GOVERNANCE

The ETB concept involves a suite of activities managed by institutions with a strong history of open management of data and working at the interface of government and industry. As such these could be geological surveys or national energy institutes. They would work closely with academic partners and through research funders and would ensure that there is open competition for access to infrastructure and data sharing. Careful management of the operations is required so that the integrity of the ETB is maintained.

The UK has embarked on the creation of the UKGEOS underground observatories with a focus on energy, which will have significant impact in attracting international specialists (e.g. UKGEOS https://nerc.ukri.org/funding/available/capital/ukgeos/). The sites, which involve ~£40 million in investment, will be operated and managed by the BGS for UK Research and Innovation (UKRI). UKRI will manage open research calls for science to be performed in the ETB.

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[1]EPOS, The European Plate Observing System (EPOS) is the integrated solid earth sciences research infrastructure (RIs) approved by the European Strategy Forum on Research Infrastructures (ESFRI). EPOS is a long-term integration plan of national existing RIs. The EPOS Preparatory Phase (EPOS PP) is the planning phase of this research infrastructure and e-science for data and observatories on earthquakes, volcanoes, surface dynamics and tectonics.

[2]ECCSEL, This consortium teams up selected Centres of Excellence on Carbon Capture and Storage research (CCS) from 5 countries across Europe. The mission is to develop a European distributed, integrated Research Infrastructure (RI), involving the construction and updating of CCS research facilities.

[3]BritGeothermal: http://www.bgs.ac.uk/research/energy/geothermal/britGeothermal.html

Similarly, it is anticipated that an institution in Iceland that will manage the data and assume the responsibility for the investment will manage Krafla KMT. The Management Board of KMT will involve the major investors and the ETB board will receive advice from a science and technology panel.

All ETB should involve social scientists, innovators, educators and economists, as the biggest challenge of the ETB will be in working with the public to allay fears and to ensure that the ETB are well perceived by the community.

7. CONCLUSION

The challenges posed for the future with respect to decarbonisation are vast but they are manageable. For 2020, the EU committed to cutting emissions to 20% below 1990 levels (Europe 2020 strategy). In the UK, power generation needs sizeable reductions (54 to 68% by 2030 and 93 to 99% by 2050), mainly by increasing surface renewables (wind, tidal and solar), but also by use of CCS, shale gas, nuclear and geothermal power. All of these activities require use of the subsurface in some way. ETB will provide vital research and demonstration platforms that will engender a state of trust between government and industry, with the research and innovation crossing these sectors.

REFERENCES

HM Government : Industrial Strategy Building a Britain Fit For The Future ISBN 978-1-5286-0131-3 (2017)

Energy Live : https://www.energylivenews.com/2012/03/13/decc-launch-20m-ccs-innovations-competition/euro (2012)

European Union : Europe 2020 Strategy https://ec.europa.eu/info/business-economy-eruo/economic-and-fiscal-policy-coordination/eu-economic-governance-monitoring-prevention-correction/european-semester/framework/europe-2020-strategy_en#howisthestrategymonitored (2015)

Stephenson, M H : Are we closing off technology options for a low carbon future? New Statesman https://www.newstatesman.com/energy/perspectives-energy/2012/11/are-we-closing-technology-options-low-carbon-future (2012)

The Trades Union Congress and Carbon Capture and Storage Association, and Orion Innovations (UK) Ltd : UK Vision for Carbon Capture and Storage http://www.ccsassociation.org/press-centre/reports-and-publications/ (2013)

UNESCO : World's groundwater resources are suffering from poor governance, UNESCO Natural Sciences Sector News, Paris, UNESCO (2012)

University of Edinburgh : Oil expertise centre to boost growth https://www.ed.ac.uk/news/all-news/oil-230512 (2019)

Visiongain : The Underground Coal Gasification (UCG) Market 2012-2022 https://www.marketresearch.com/product/sample-7230220.pdf (2012)

Table 1: Examples of Key Energy test beds, links to their websites and a summary of their objectives

ETB Project	COUNTRY	OBJECTIVE	REF / WWW
EPOS ERIC	Pan-European	Geoscientific including geoenergy	www.epos-ip.eu
ECCSEL ERIC	Pan-European	CCS	www.eccsel.org
The Otway CO2CRC project	Australia	CCS	http://www.co2crc.com.au/otway-research-facility-2/
CMC field research station	Canada	CCS	https://cmcghg.com/cami/field-research-station/
Aquistore	Canada	CCS linked to Boundary Dam Demonstration project	http://aquistore.ca/
National Energy Technology Laboratory (NETL)	USA	Coal, oil, (shale) gas, energy technology, fluid migration, wellbore integrity, modelling	https://www.netl.doe.gov
Marcellus Shale Energy and Environment Laboratory	USA	Shale gas	http://mseel.org/
Meuse/Haute-Marne underground research laboratory	France	Radwaste	http://www.andra.fr/international/

Ketzin	**Germany**	**CCS (completed)**	http://www.co2ketzin.de/?l=1
Hontomiz Technology Development Plant	**Spain**	**CCS**	http://www.enos-project.eu/sites/operational-storage-field-site/hontomin/
Boulby Underground laboratory	**UK**	**Geology/geophysics**	https://www.boulby.stfc.ac.uk/pages/overview-of-the-laboratory.aspx
Frio Brine Pilot site	**USA**	**CCS**	http://www.beg.utexas.edu/gccc/research/fbpexperiment
UKGEOS, Glasgow site	**UK**	**Geothermal**	https://www.ukgeos.ac.uk/
UKGEOS N. Cheshire site	**UK**	**Geology, fluid transport**	https://www.ukgeos.ac.uk/
ukgeos, cardiff	**UK**	**Shallow geothermal**	https://www.ukgeos.ac.uk/
CO_2 Field LAB	**Norway**	**CCS**	https://www.sintef.no/projectweb/co2fieldlab/
SOTACARBO, Sulcis, Sardinia	**Italy**	**CCS**	https://www.sotacarbo.it/
dapwELL	**NL**	**Geothermal**	https://www.tudelft.nl/geothermalwell/
K12B, North Sea	**NL**	**CCS (offshore)**	https://repository.tudelft.nl/view/tno/uuid:68751ab4-9d39-4db6-9f6c-efe082d9d00b operational offshore project, data might be available
Equinor	**Norway**	**CCS (offshore)**	Operational offshore CO_2 storage project run by Equinor
Avalon Borehole Test Facility, Rosemanowes Quarry, Penryn	**UK**	**Seismic, downhole instrumentation**	https://avalonsciences.com/services/avalon-borehole-test-facility/
Schlumberger Training Centre in Livingston	**UK**	**Wireline logging**	http://www.nexttraining.net/courses/details/pp-tc1-nxt17100/practical-wireline-logging-for-geoscientists.aspx?trainingplan=true
Sleipner CO2 injection	**Norway**	**CCS offshore**	Operational offshore O&G facility, injected CO_2 for 20 years, much research and data available. No access to platform itself for research.
Spireslack Quarry, Scotland	**UK**	**SURFACE coal**	http://www.smrtrust.org/what-we-do/success-stories/grasshill-spireslack.aspx
Äspö Hard Rock Laboratory, Sweden	**Sweden**	**Radwaste**	http://www.skb.com/research-and-technology/laboratories/the-aspo-hard-rock-laboratory/
Grimsel Test Site, Switzerland	**CH**	**Radwaste**	http://www.grimsel.com/
Mont Terri, Switzerland	**CH**	**Radwaste, CCS**	https://www.mont-terri.ch/
Soulz sous Forêts, France	**France**	**Geothermal**	https://www.brgm.eu/project/deep-geothermal-energy-soultz-sous-forets-site-has-reached-sustainable-production-phase
Krafla	**Iceland**	**Geothermal**	www.kmt.is

Geoenergy Research Centre (GERC)	**UK**	**CCS**	http://www.gerc.ac.uk/facilities/geoenergy-test-bed/gtb.aspx
Basel	**CH**	**Geothermal**	**Suspended after induced seismicity, no current plans to re-open.**
Gross Schönebeck	**Germany**	**Geothermal**	https://www.gfz-potsdam.de/en/section/geoenergy/infrastructure/geothermal-research-platform-gross-schoenebeck/
Malmberget and Kirunavarra	**Sweden**	**deep mining**	https://www.lkab.com/en/
Outukumpu Mine	**FL**	**Deep mining**	https://www.outokumpu.com/locations/kemimine
Groningen	**NL**	**Gas recovery**	https://www.dnvgl.com/oilgas/laboratories-test-sites/renewable-energy-technology-and-gas-laboratory-dnvgl-labs-groningen.html
Lucania	**Italy**	**Conventional oil recovery**	https://www.eniday.com/en/education_en/largest-oil-field-europe/
jOSEF URL	**CZ**	**Deep mining, geothermal, ccs**	https://ceg.fsv.cvut.cz/en
BEDRETTO	**CH**	**Geothermal**	http://www.bedrettolab.ethz.ch/home/