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2019 YEAR OF CARBON

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Bryan Lovell Meeting 2019

Role of geological science in the decarbonisation of power production, heat, transport and industry

21-23 January 2019

The Geological Society, Burlington House

Convenors

Mike Stephenson (British GeologicalSurvey)

Dave Schofield (British Geological Survey)

Sebastian Geiger (Heriot-Watt University)

Philip Ringrose (Equinor)

Web:www.geolsoc.org.uk/lovell19

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08.45	**Registration & tea, coffee & refreshments**
09.20	**Welcome -** Mike Stephenson (British Geological Survey) **Day 1 Chair:** Stuart Haszeldine (University of Edinburgh)
09.30	**KEYNOTE: Trends in world energy and decarbonisation** Spencer Dale (BP)
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10.00	**Cool Economy** Toby Peters (University of Birmingham)
10.30	**Energy storage - Compressed Air Energy Storage – a cost-effective enabler for carbon-free energy** Seamus Garvey (University of Nottingham)
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15.30	**Minerals for the energy transition** Karen Hanghøj (EIT RawMaterials)
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10.00	**Geothermal: Hot dry rock** Roy Baria (EGS Energy)
10.30	**Low enthalpy heat and building** Ingo Sass (TU Darmstadt, Germany)
11:00	**Mining for Heat** Charlotte Adams (Durham University)
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12.00	**Geoscience Insights for Developing Superhot Icelandic Geothermal Resources** Thomas Driesner (ETH Zurich, Switzerland)
12.30	**Do we have the right skills for the geoscience decarbonisation future?** John Underhill (Heriot-Watt University)
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14.00	**Is there a role for H_2 in large-scale power production?** James Dawson (NTNU)
14.30	**H21 North of England** Henrik Solgaard Andersen (Equinor)
	Session VI: Critical material resources
15.00	**Clean technology raw materials: Rare Earth Elements** Frances Wall (University of Exeter)
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16:00	**Seabed minerals** Tracy Shimmield (British Geological Survey)

16.30	**Mineral resources in a low carbon future** Lluis Fontbote (University of Geneva)
Session VII: Energy transitions	
17.00	**Social science insights on energy transitions** Ben Sovacool (University of Sussex)
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10.00	**Geological disposal of radioactive waste** Jonathan Turner (RWM)
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11.30	**Role of the Oil and Gas sector in decarbonisation** Phil Ringrose (Equinor)
12.00	**Deep Geothermal: exploration in Italy, from knowledge to deployment in Europe** Adele Manzella (IGG CNR, Italy)
12.30	**UK Networks and projects** Jonathan Pearce (British Geological Survey)
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14.00	**Advancing the Energy Transition** Dominic Emery, BP's Vice President of Group Strategic Planning
The Underground and Decarbonisation: Minding the Gap Between Geoscience, Policy and Progress, chaired by Andrew Miller (tbc)	
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16.30	**Close**

Poster Programme

A new research facility: kick-starting future opportunities in subsurface mine water geothermal heat and heat storage

J.Birkin[1] & K. Shorter [1]
[1]British Geological Society, Keyworth, Nottingham, United Kingdom

Scaled cavern formation by salt dissolution: gas storage in the Permian halite

Katherine A. Daniels[1], Jon F. Harrington[1], Lorraine P. Field[1] and David J. Evans[1]
[1]British Geological Survey, Nicker Hill, Keyworth, Nottinghamshire, NG12 5GG, UK.

Linking Redox Processes and Black Shale Resource Potential

J. Emmings[a,b], S. Poulton[c], G. Jenkin[b], S. Davies[b], C. Vane[a], M. Leng[a,d], M. Stephenson[a], A. Lamb[a], Vicky Moss-Hayes[a]
[a]British Geological Survey, Keyworth, Nottingham, NG12 5GG, UK

Carbon capture and storage on the East Irish Sea Basin

Davide Gamboa[1], John D. O. Williams[2], Michelle Bentham[2], David Schofield[3], Andrew Mitchell[4]
[1] British Geological Survey, Columbus House, Greenmeadow Springs, Tongwynlais, Cardiff, CF15 7NE, UK

Quantifying geological CO_2 storage security to deliver on climate mitigation

Juan Alcalde[a], Stephanie Flude[b,c], Mark Wilkinson[b], Gareth Johnson[b] , Katriona Edlmann[b], Clare E. Bond[a], Vivian Scott[b], Stuart M.V. Gilfillan[b], Xènia Ogaya[d] and R. Stuart Haszeldine[b].*
[a]Geology and Petroleum Geology, University of Aberdeen, School of Geosciences, Kings College, Aberdeen, AB24 3UE, UK

Subsurface capacity for energy storage onshore and offshore UK: CO2, CAES, Hydrogen

Stuart Haszeldine[1], Mark Wilkinson, Stuart Gilfillan, Gareth Johnson, Julien Mouilli-Castillo, Jon Scafidi, Niklas Heinemann, Dimitri Mignard
[1]School Of Geosciences, University Of Edinburgh

Europe's cobalt resource potential for supply to low-carbon vehicles

S. Horn1, E. Petavratzi1, G. Gunn1, R. Shaw1, F. Wall2
[1]British Geological Survey, Nicker Hill, Keyworth, Nottingham, NG12 5GG

Run-of-the-River Micro Hydro Power – Feasibility and Value

M. Johansson[1]
[1]Geode-Energy Ltd, 1-9, Central Square, Cardiff, CF10 1AU, United Kingdom

Assessing the feasibility of the "all-in-one" concept in the UK North Sea: offsetting carbon capture and storage costs with methane and geothermal energy production through reuse of a hydrocarbon field

***Jonathan Scafidi** and Stuart M.V. Gilfillan*
School of GeoSciences, University of Edinburgh, James Hutton Road, Edinburgh, EH9 3FE, UK.

Mine water: a sustainable renewable energy resource?

Fiona Todd, Dr Chris McDermott, Dr Andrew Fraser Harris, Dr Stuart Gilfillan and Dr Alex Bond
[1]University of Edinburgh, Old College, South Bridge, Edinburgh EH8 9YL
[2]Quintessa Ltd, First Floor, West Wing, Videcom House, Newtown Rd, Henley-on-Thames RG9 1HG

Trends in World Energy and decarbonisation

Spencer Dale[1]

[1] *BP plc, 1 St James's Square, London, SW1Y 4PD*

Spencer Dale is group chief economist of BP plc. He manages BP's global economics team, providing economic input into the firm's commercial decisions. BP's economics team also produces the annual Statistical Review of World Energy and Global Energy Outlook.

Spencer Dale joined BP as group chief economist in October 2014. Prior to that, he was executive director for financial stability at the Bank of England and a member of the Financial Policy Committee. Between 2008 and 2014, Spencer was chief economist of the Bank of England and a member of the Monetary Policy Committee. Spencer joined the Bank of England in 1989 and served in numerous roles, including private secretary to Mervyn King and head of economic forecasting. Spencer served as a senior advisor at the US Federal Reserve Board of Governors between 2006 and 2008.

Abstract

The lecture will consider the key forces shaping global energy markets over the next 20 years and assess the progress towards achieving the Paris climate goals. It will also speculate on some of the likely challenges that the global economy will face in the second half of this century as it transitions to a fully decarbonised energy system.

Notes

Clean Cooling

Toby Peters[1]

[1]*University of Birmingham, Engineering and Physical Sciences, Edgbaston, Birmingham, B15 2TT*

Toby Peters is the Professor in Cold Economy and an IGI Fellow at the University of Birmingham, a Senior Research Fellow in Transformational Innovation for Sustainability at Heriot-Watt University and a Visiting Professor to the Global Innovation Centre, Kyushu University in Japan. He is Chair of the Academic Group for CoolignEU, sits on the Technical Review Committee for the Global Cooling Prize and is an advisor on cooling to NGO and international development agencies.

An award-winning technology developer, he is one of the inventors of Liquid Air Energy Storage and the architect of the "Cold Economy". He was joint lead academic on the Doing Cold Smarter Policy Commission in 2015 and researches new system-level approaches around delivering environmentally and economically sustainable cooling and power in both transport and the built environment, and the role "clean cold" has to play in emerging market transformation and sustainably addressing post-harvest food loss in developing economies.

Abstract

Until recently, cooling has been a blind spot in both the energy and development debates; a serious omission.

Cooling is an invisible industry essential to our modern society – from the cold chains that safely deliver our food and vaccines, to the air conditioners that make our workplaces and homes comfortable to cooling servers for our insatiable demand for social media or data.

At the same time more than a billion people are facing risks due to lack of access to cooling for basic needs – lack of access to nutritious food, vaccines essential for health, as well as the ability to find respite from temperatures beyond limits for human survival. Ensuring cooling is affordable and accessible to all who need it is essential to alleviating poverty and achieving global sustainable development goals (SDGs) for 2030.

Demand for cooling is already straining electricity grids and causing high levels of greenhouse gas (GHG) emissions - cooling causes twice the global GHG emissions of shipping and aviation combined.

But global growth projections suggest at least 19 new cooling appliances will be sold every second for the next 30 years. However even at this rate, the world will still not achieve Cooling for All by mid-century; let alone 2030. In fact, our analysis suggests that if we are to deliver access to Cooling for All – and thereby meet the Sustainable Development Goals - by 2050, we could require 14 billion cooling appliances globally; four times as many as are in use today and 4.5 billion more than the current global projections for 2050. This would see the cooling sector consume more than five times the amount of energy it does today.

Without dramatic improvements in the efficiency and ways cooling is provided, supplying the power required for all these new devices will make it impossible to meet the Paris climate goals.

Clean cooling is about the radical reshaping of the cooling landscape. Our work is about (i) enabling informed understanding of the role cooling in an equitable, healthy, productive and sustainable society and (ii) looking at how we must change our approach to cooling,. Specifically pooling demand and understanding the portfolio of free, waste and renewable resources that will allow the re-mapping of processes to achieve efficiencies that would not be available from a single application or sub-system perspective. This will allow us to embrace the full portfolio of technologies at our disposal. Equally, it will enable the new business models to make cooling affordable and accessible to all.

Notes

Compressed Air Energy Storage – a cost-effective enabler for carbon-free energy

Seamus Garvey[1]

[1]Faculty of Engineering, University of Nottingham, university Park, Nottingham United Kingdom, NG2 2RD

Seamus Garvey is Professor of Dynamics in the Faculty of Engineering at University of Nottingham and has held that position since July 2000.

He is Director of the Rolls-Royce University Technology Centre in Gas Turbine Transmission Systems at the University and also serves as academic theme lead for “G-ERA” which represents one-third of the £60M Energy Research Accelerator project funded by Innovate UK and involving the Universities of Aston, Birmingham, Leicester, Loughborough, Nottingham and Warwick along with British Geological Survey. His research portfolio includes a substantial section on energy storage and integrating this with renewables. He is the founder of the “Offshore Energy and Storage” conference which has run annually since 2014 (OSES2019 will be in Brest, France, in July 2019). He is also the founding chairman of the International Compressed Air Energy Storage Alliance which held its inaugural meeting on July 3, 2018 in Ningbo, China.

Notes

High-temperature subsurface heat storage as part of the future urban heat supply

Sebastian Bauer[1] and Andreas Dahmke[1]

[1]Institute of Geosciences, Christian-Albrechts-University Kiel, Ludewig-Meyn-Str. 10, 24118 Kiel, Germany

Prof. Dr. Sebastian Bauer is head of the GeoHydroModelling Group at the Institute of Geosciences at Kiel University, Germany. He and his group have more than ten years' experience developing scientific modelling tools for the simulation of reactive non-isothermal multi-phase multi-component transport in the geological subsurface. Focus in recent years is geotechnical energy storage in the subsurface, quantification and prognosis of induced effects as well as subsurface spatial planning. The technologies investigated are thermal energy storage through open and closed systems at elevated temperatures as well as gas and compressed air energy storage and carbon dioxide sequestration. He coordinates the German ANGUS research project on subsurface energy storage.

Abstract

In Germany, about 50% of total energy demand is due to heating as well as cooling purposes, with only a small fraction stemming from renewable sources so far. As part of the energy transition, a significant increase of renewable heat is therefore required to counter climate change effects. This may be achieved by directly harvesting solar thermal energy, or by indirectly using solar power or other power-to-heat concepts, as well as by utilization of industrial surplus heat or heat from building climatization. Geological heat storage in the urban subsurface has the potential to contribute significantly to the increased usage of these sources, as it allows for a seasonal storage of large amounts of heat directly where it is needed.

Technical options for subsurface heat storage include both aquifer as bell as borehole thermal energy storage, which in principle enable heat storage in most geological subsurface formations. Using higher temperatures up to 90°C allows to increase both storage rates and capacities. To enable the implementation of large scale urban subsurface heat storage, however, methods for dimensioning the storage systems in terms of achievable heat injection and extraction rates as well as storage capacities are required. Also, methods for predicting induced thermal, hydraulic, mechanical and chemical effects by the storage operations need to be at hand to assess the environmental impact of these storage sites. Furthermore, based on these assessments, a concept for the use and management of the subsurface has to be developed. This allows for a sustainable use of the urban subsurface and the harmonization of the different types of subsurface use already present.

We will present the methods and concepts contributing to these topics developed so far, and demonstrate them on examples for both theoretical as well as experimental work. This includes numerical approaches for quantifying storage sizes and storage rates by simulating the governing subsurface processes individually for a specific urban subsurface setting, as well as specifically developed methodologies for geochemical and thus water quality impact

assessment as well as geomechanical effects. We will also present a concept for determining the subsurface space demand from these storage sites, as part of subsurface spatial planning. We thus think that urban subsurface heat storage presents not only an option for increasing the renewable fraction of energy supply, but may also contribute to the resilience of urban areas against climate change and in the longer term provide economic as well as ecologic benefits.

The work presented is part of a research project funded by the German Federal Ministry of Economy and Energy "ANGUS II - Impacts of the use of the geological subsurface for thermal, electrical or material energy storage in the context of the transition to renewable energy sources – Integration of subsurface storage technologies into the energy system transformation" (www.angus-projekt.de)

Notes

"*It's all mica schist..*" the role of fracture and fault analysis in the design and routing of tunnels for Hydroelectric Storage schemes

Martin Smith[1]

[1]*British Geological Survey, The Lyell Centre, Research Avenue, Edinburgh, United Kingdom EH14 4BA*

Dr Martin Smith MBE is the Science Director for Global Geoscience at the British Geological Survey (BGS). As a career survey geologist he has extensive experience in UK and African geology, in the implementation of digital and 3D modelling systems and in providing expert technical advice on subsurface geology for major infrastructure projects. From 2011 to 2016 he was employed as a technical expert and witness for the Glendoe Hydroelectric project. Since 2013 he has been engaged in developing BGS expertise internationally and currently leads the BGS Official Development Assistance and DFID programmes which operate across more than 13 countries worldwide.

Abstract

As a form of renewable low carbon energy that is well understood and with low technology risk then Pumped Hydroelectric Schemes (PHSs) are for mountainous countries, a key component of an integrated energy supply. Currently in the UK the four main schemes located in Scotland and North Wales provide a power output of 2.8GW to the UK electrical grid.

The main challenges for any PHS site include the topography, water availability and geology with engineering issues generally not seen as a major risk. Located in areas of predominantly ancient hard crystalline basement or volcanic rock the geology is often assumed to be stable and predictable. Yet, the highest cluster of operating and planned PHSs in the UK are located in the vicinity of the Great Glen Fault Zone, one of the largest, long-lived and complex strike-slip fault systems in the UK. PHS began in this area with the Foyers scheme originally built in 1896 to power an aluminium smelter and was later redeveloped to pump storage in 1969. Recently, there has been renewed interest following commissioning of the Glendoe Hydroelectric Scheme for new PHS sites in the region including Coire Glas, Balmacaan and Dores (Red John) with one achieving planning consent.

The risk of tunnel collapse due to fracturing and faulting and stress release along strike-slip fault with a complex history of reactivation is relatively high and demands a working knowledge of fault rock textures and their fractured damage zones. Construction of the first high pressure and unlined Headrace Tunnel and dam as part of the Glendoe Hydroelctric Scheme encountered three major fault structures. But only one in 2009 resulted in a major failure completely blocking the tunnel, resulting in the construction of a by-pass tunnel and a lengthy court action.

In this talk I will describe the geology at Glendoe and focus on a fracture previously observed and interpreted to be a relatively minor fault that subsequently became the focus of a major tunnel failure.

This study emphasises the importance of an understanding of fault rock textures, processes and features and for the geological community to engage and communicate effectively the language of faulting to PHS planners and tunnel engineers.

Notes

CO_2 Capture

Jon Gibbins[1]

[1]Department of Mechanical Engineering, Sire Fredrik Mappin Building, Mappin Street, Sheffield, S1 3JD

Jon is the Centre Director of the UK Carbon Capture and Storage Research Centre and a member of the Centre's Coordination Group and is the Research Area Champion for Solvent Post-Combustion.

He has worked on coal and biomass gasification and combustion for over 30 years, at Foster Wheeler, Imperial College and the University of Edinburgh and on carbon capture and storage (CCS) since 2002. He is currently Professor of Power Plant Engineering and Carbon Capture at the University of Sheffield and Director of the UK CCS Research Centre. He is involved in a number of other academic, industrial and government initiatives on CCS in the UK and overseas, including the SaskPower CCS Global Consortium Advisory Committee. He was also a member of SaskPower's Clean Coal Project Advisory Panel for their 400MW oxyfuel plant study in 2006-2007, has participated in reports and inquiries on CCS for a range of UK Government and other organisations and has contributed to a number of media pieces and other outreach activities on CCS. He also takes an interest in broader energy system issues, as a member of the DECC Scientific Advisory Group from 2010 to 2014 and through participation in ongoing work on electricity system balancing, economics and regulation.

Notes

The Design of Carbon Dioxide Storage

Martin Blunt[1]

[1]*Department of Earth Science and Engineering, Imperial College London, London, SW7 2AZ*

Professor Blunt's research interests are in multiphase flow in porous media with applications to oil and gas recovery, geological carbon storage and contaminant transport and clean-up in polluted aquifers. He performs experimental, theoretical and numerical research into many aspects of flow and transport in porous systems, including pore-scale modelling of displacement processes, and large-scale simulation using streamline-based methods. He is on the editorial boards of Transport in Porous Media, Water Resources Research and Advances in Water Resources. He was the Chair of the 2006 Gordon Conference on Flow in Permeable Media. He has over 200 scientific publications.

Abstract

An overview of the challenges associated with the design of safe and effective carbon dioxide storage in the subsurface is presented. The physical and chemical processes occurring when carbon dioxide is injected deep underground will be outlined, including pressure build-up and the risk of induced fracturing, buoyant migration, capillary trapping, dissolution and reaction. A combination of analytical and numerical methods to predict plume movement and the long-term fate of carbon dioxide will be outlined, together with a description of experimental work across length and time scales to validate and inform these models. Research on the design of storage, to ensure rapid immobilization of the injected carbon dioxide, will be described.

Safe, long-term storage of carbon dioxide in the subsurface is possible with careful site characterization, injection design and monitoring. If carbon capture and storage is to make a significant impact on mitigating climate change, many Gigatonnes of carbon dioxide need to be injected underground, creating an industry which – in terms of volumes injected – will be as large as the current oil and gas industry. To rise to this challenge an active, engineering design-led approach to storage needs to be employed.

Notes

Biomass energy with CCS: unlocking negative emissions

Clair Gough[1]

[1] *Tyndall Centre for Climate Change Research, University of Manchester*

Dr Clair Gough is a senior research fellow at the Tyndall Centre for Climate Change Research at the University of Manchester. Her research brings together integrated technical and social scientific analyses in the context of energy and climate change. She has many years' experience working on carbon capture and storage (CCS) and biomass energy with CCS (BECCS) and has recently co-edited the first book to be published on BECCS.

Abstract

There is a growing and significant dependence on large scale deployment of biomass energy and carbon capture and storage (BECCS) in the future greenhouse gas emission scenarios analysed by global integrated assessment models. As a result, BECCS has become central to the discourse around achieving the goal of limiting global average temperature rise 1.5ºC agreed in Paris in 2015. This reliance on BECCS hinges on its potential to deliver so-called negative emissions, removing carbon dioxide from the atmosphere in order to maintain a sustainable concentration of CO_2 in a cost-effective manner.

As a young and untested group of technologies, there are many uncertainties associated with BECCS and a there is strong imperative to better understand the conditions for and consequences of pursuing this group of technologies. There is very little practical experience of implementing the technology in commercial applications and, indeed, relatively little research into the conditions for realising its deployment at the potential scale required. The challenges associated with bringing together modern biomass energy systems with CCS at scales large enough to contribute to negative emissions reductions at a global level go well beyond the technical and scientific challenges. This presentation will draw on some recent and ongoing work from across the Tyndall Centre to consider some of the critical challenges and assumptions for the potential for this technology to unlock negative emissions.

Notes

Minerals for the Energy Transition

Karen Hanghøj[1]

[1]*EIT RawMaterials, Tauentzienstr. 11, 10789 Berlin, Germany*

Dr Karen Hanghøj is the CEO and Managing Director of EIT RawMaterials, a Knowledge and Innovation Community supported by the European Institute of Innovation and Technology, a body of the European Union.

Dr Karen Hanghøj holds a PhD in Geology from University of Copenhagen and has worked extensively with research on geological processes in the lower crust and mantle and their associated mineral deposits. Prior to joining EIT RawMaterials Karen was head of the Department of Petrology and Economic Geology at the Geological Survey for Denmark and Greenland (GEUS) and involved in several EU - funded mineral raw materials projects and networks.

Dr Karen Hanghøj is currently a member of the High-level Steering Group of the European Innovation Partnership (EIP) on Raw Materials, a stakeholder group advising the European Commission. She is also a member of advisory Boards for a range of Horizon 2020 projects such as MinFuture and ERAMIN2 as well as being a member of the UNFC Mineral Working Group and of advisory Board CAMM (Center for Advanced Mining and Metallurgy) of Luleå Technical University in Sweden.

Abstract

Raw materials are critically important for society in general, and for the transition to a green economy in particular. They are key for achieving the goals set out in COP21 and several of the United Nations Sustainable Development Goals, for implementing the European *2030 Agenda for Sustainable Development* and for the *European Resource Efficiency Flagship.* Metals, minerals and materials and their sustainable supply and consumption are important in the move towards a Circular Economy.

Emerging energy and mobility technologies create a strong demand for raw materials, and for some critical raw materials this demand will dramatically exceed current production in the next 10-15 years. Limited access to these materials might negatively impact the transition, thus reducing the competitiveness of European actors downstream. From a raw materials value chain perspective, three objectives are key in securing supply for the energy transition: bringing materials into the loop in a sustainable way, keeping materials in the loop for a long as possible, and minimizing waste at all stages. We need to design smarter solutions for the sustainable extraction, processing and use/repairing/recycling of raw materials from both primary and secondary sources. Furthermore, we must ensure that used materials and products find their way into new product lifecycles in an energetically and economically meaningful way. We need to maintain products and materials in the economy as long as possible through waste valorization, industrial symbiosis, reuse, repairing, remanufacturing and recycling. The approach towards the design of solutions must address the whole life

cycle in a systemic way, materials innovation, products, product-service systems, processes, design of products for circularity, new business models, new policy measures, new taxation approaches, and new education and awareness methodologies.

Notes

Siting of Offshore Wind Turbines

[1]*Ingrid Feyling*

[1]*Equinor, Forusbeen 50, 4035 Stavanger, Norway*

Ingrid Feyling is a part of the Wind Energy Technology team within the New Energy Solutions department of Equinor and works with offshore wind resource assessment and energy yield. She has previous experience from the wind industry in Scotland as well as research experience on offshore wind. She holds a MSc degree in Wind Energy Engineering from the Technical University of Denmark (DTU).

Abstract

Equinor has been involved in offshore wind for the last decade and are working determined towards further development within this energy segment. Equinor has activities across the value chain of offshore wind with operatorship, project development, research and technology development.

This presentation will introduce Equinor’s ambitions and goals towards a low-carbon future before touching on the key elements in offshore wind development, siting of wind turbines and wind energy yield assessment.

Notes

Science Policy and Decarbonisation

Chris Stark[1]

[1]*Committee on Climate Change, 7 Holbein Place, London SW1W 8NR*

Chris has been Chief Executive of the Committee on Climate Change since April 2018.

His previous role was Director of Energy and Climate Change in the Scottish Government, leading the development of Scotland's approach to emissions-reduction and the accompanying energy system transition. His team provided advice to Scottish Ministers on all aspects of energy and climate policy – and on licensing and consent decisions for new onshore energy infrastructure. Prior to that Chris headed the Strategy Unit, the Scottish Government's central strategy team, and he has worked in a number of Whitehall departments. He has wide experience of economic policymaking, in the Scottish Government, HM Treasury and the Department for Business, Innovation and Skills.

Notes

Geothermal: Hot Dry Rocks

Roy Baria[1]

[1]*EGS Energy Limited, 13 North Parade,Penzance, Cornwall, TR18 4SL*

Truro resident Roy Baria, former Deputy Director of the first Cornish Hot Rocks project, received a coveted Special Achievement Award at the annual meeting of the Geothermal Resources Council (GRC) in Reno, Nevada, USA, at the end of 2018. It was in recognition of his outstanding work developing deep geothermal systems worldwide.

Roy was a director of the Hot Rocks project in Penryn during the 1980's and then Chief Scientist at the first major European project in Soultz, France. He is now Technical Director of EGS Energy, the company working on development of a deep geothermal system at the Eden Project. Roy says "*I am delighted that deep geothermal has now returned to Cornwall as a viable energy technology. It's gratifying to see groundbreaking projects underway at United Downs and in development at the Eden Project.*"

Dr Andrew Jupe, Director of altcom Limited in Penzance, who also attended the award ceremony in Reno, said

"*It has been great to see Roy receive this award. He is an innovator with the passion and energy to take the technology through from R&D into commercial reality. He has also left a great skills legacy around the world. Our company altcom is one of numerous small hi-tech businesses in the region that emerged from the development of geothermal research and technology in Cornwall. "*

Roy joined the Camborne School of Mines (CSM) Hot Rocks project in 1980 on secondment from the British Geological Survey (BGS) and served initially as head of geophysics and then Deputy Project Director. In 1990, at the request of the European Commission and UK government, he was seconded to the European Project in Soultz-sous-Forêts (near Strasbourg). There he served as one of three project directors, representing the UK alongside France and Germany.

The ground breaking research undertaken at Soultz led to the first fully commercial deep geothermal developments in the world. Roy played a pivotal role commercialising the technology and these projects provided the catalyst for the return of geothermal to Cornwall.

For more information, see: www.egs-energy.com, www.altcom.co.uk and www.microseisgram.com

EGS Energy Limited is a Cornwall-based company leading the commercial exploitation of abundant renewable geothermal resources to produce carbon neutral electricity and heat. EGS Energy's unique access to engineered geothermal system (EGS) technology and know-how makes it a leader in the rapidly growing area of clean, green geothermal energy

The company plans to establish its first electricity generating plant in Cornwall at the Eden Project, using an engineered geothermal system. There are a number of areas on the Cornish granite that the company has identified as optimal for the development of EGS, for the roll-out of further EGS power plants.

The electricity and heat produced by EGS Energy will be:

- from a sustainable resource and emissions free;
- predictable, despatchable and peak load available (95%) over the long term; and
- small in terms of its physical and environmental footprint.

The team has amassed over 70 years' experience analysing, designing and operating deep geothermal reservoirs. The Eden plant will be the first commercial engineered geothermal enterprise in the UK by EGS Energy, which will be the first step in its plan to deliver engineered geothermal power plants throughout Europe.

For further information on the recent papers and awards of Roy Baria, please visit:

https://www.falmouthpacket.co.uk/news/17333956.truros-roy-baria-awarded-at-geothermal-resources-council-meeting/

https://www.businesscornwall.co.uk/news-by-location/truro-business-news/2019/01/recognition-for-hot-rocks-pioneer/

https://www.thisisthewestcountry.co.uk/news/cornwall_news/17333956.truros-roy-baria-awarded-at-geothermal-resources-council-meeting/

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Low-enthalpy Geothermal Energy for Heating Buildings

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Professor Ingo Sass works for the department of Geothermal Science and Techonolgy Technische Universitat Dartmstadt as full time professor as well as professor for Geothermal Systems and Geothermal Resources Utlization at School for Renewable Energy Science, Universities of Iceland and Akureyri, Iceland. He has worked in the department for Engineering Geology and Geothermal Laboratory at Technische Universität Darmstadt/Germany and has been a member of the Executive Board, CDM Consult AG; responsible for South Germany and International Activities, CDM Consult GmbH. His professional experience also includes Project Manager Geothermal Power Plant, FlowNet Management & Consult GmbH, Managing Director, FlowTex GUT GmbH, Ettlingen/Germany and Project Engineer, Pall Schumacher GmbH, Crailsheim/Germany.

More than a fourth of the total final energy consumption in the EU can be attributed to the production of space heat and hot water. However, the energy transformation in the EU has strongly focused on the electricity sector, so far, while the heating sector lags behind: the share of renewables in the electricity production already reaches 30%. In contrast, renewables only account for approximately 19% of the heating energy (data for 2016, Eurostat 2018). Consequently, there is a huge potential for reducing greenhouse gas emissions in the heating sector.
Thermal energy for space heating and hot water supply is required on comparably low temperature levels. Thus, low-enthalpy geothermal energy is perfectly suited for a replacement of fossil based heating systems. It is virtually everywhere and continuously available, which makes it capable for providing base load heat.
There are several approaches to make use of the thermal energy in the ground. It can for example be extracted in an open-loop system: groundwater is lifted in a production well, cooled down while releasing heat to the heating system and then recycled to the aquifer via an injection well. The underlying advective heat transport enables such well doublet systems to achieve comparably high heat extraction rates. However, their applicability is limited as they require high permeable geologic units and suitable groundwater compositions.
In contrast, closed loop systems are much more site-independent. So called borehole heat exchangers are used to extract heat from the subsurface. These are boreholes, which are equipped with a closed pipe system and usually backfilled with a cement based grout. A heat transfer fluid (usually water or a water-glycol-mixture) is circulated through the pipe system. Heat is transferred from the subsurface to the fluid by conductive heat transport in the grout and pipe materials. The fluid’s temperature gradually raises on its way through the pipe system. Back at the surface, the gained heat is transferred from the fluid to the heating system.

Shallow geothermal installations (up to 400 m in depth) usually require a heat pump to achieve the requested supply temperature level of the heating system. In contrast, medium deep (400 m – 1500 m) to deep systems (> 1500 m) gain higher extraction temperatures due to the elevated ground temperature with increasing depth. Consequently, such systems can induce higher coefficients of performance of the heat pump or completely dispense with a heat pump.

Apart from sheer heat extraction, low-enthalpy geothermal systems also represent heat sinks, which can be used to get rid of excess heat. Consequently, such systems are already in use in cooling applications, which become more and more important in the context of global warming. Furthermore, excess heat from industrial processes, cogeneration power plants or solar thermal collectors can be transferred to the subsurface during the summer months and then be extracted in the winter for heating purposes (Figure 1). Such seasonal storage systems are especially efficient when applied on a district heating level.

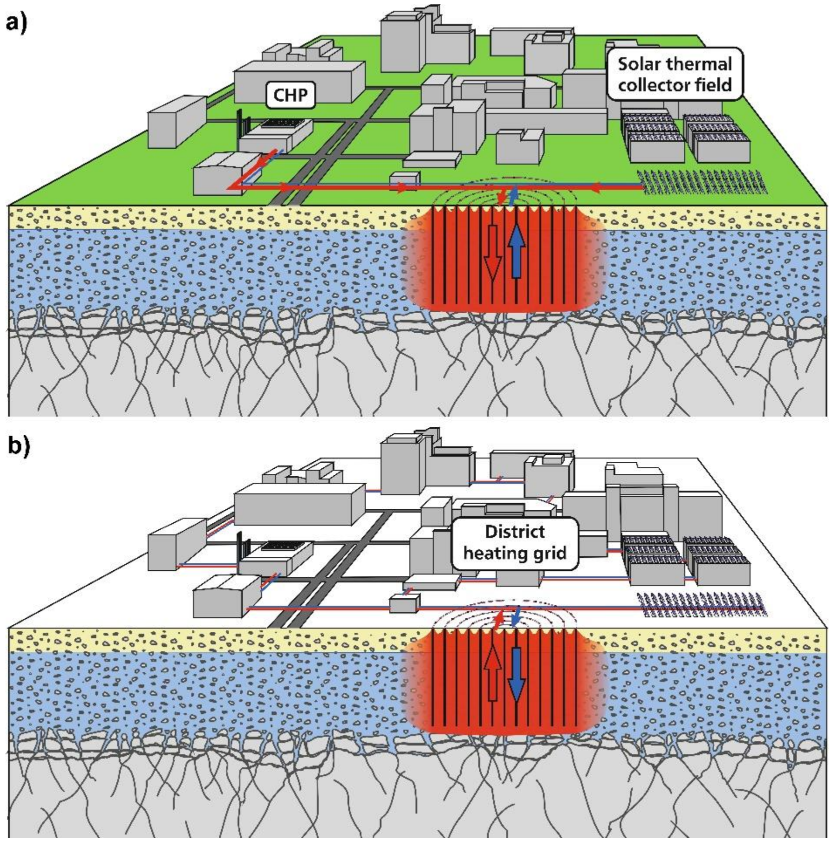

Figure 1: Borehole heat exchanger array used as a seasonal heat storage system in a district heating grid in a) summer operation and b) winter operation. CHP = combined heat and power plant. (Welsch 2018).

Current research focuses for example on medium deep borehole heat exchanger systems. In particular the storage of heat in deeper formations promises a much wider application of the technology since shallow groundwater resources can be protected from significant thermal impacts. Another important research branch deals with the improvement of borehole heat exchanger materials with regard to the hydraulic integrity of these systems.

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Notes

Mining for Heat

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Charlotte Adams is an Assistant Professor at Durham University. She trained as a hydrogeologist specialising in minewater treatment and her PhD (Newcastle University 1999) focused upon the removal of zinc from metal mine drainage. Charlotte subsequently worked for five years in the renewable energy industry and has undertaken multidisciplinary academic research on sustainable energy and water systems since joining Durham University in 2009. Working with abandoned mines gave Charlotte a thorough understanding of the huge geothermal potential of these and other resources in the UK and she now manages the BritGeothermal research partnership which is a research collaboration between the universities of Newcastle, Glasgow, Durham and the British Geological Survey. This partnership was established to promote the UK's geothermal resources as a secure source of low carbon heat and also led drilling of the 3 most recent deep geothermal wells in the UK. Currently, Charlotte is leading work at Durham on the potential of abandoned mines to provide energy storage and a low carbon source of heat and cooling for the UK. She is also a Fellow of the Durham Energy Institute and a member of the University’s Carbon Management Team. In 2018 Charlotte was awarded the Aberconway Medal from the Geological Society to recognise distinction in the practice of geology with special reference to work in industry.

Abstract

The application of geological science to prospect for and exploit of coal reserves has delivered wealth and industrial growth for the UK over several centuries. In the past century alone, over 15 billion tonnes of coal were extracted from UK coalfields. However, times have changed, coal is now considered a dirty fuel and is being phased out of our power generation mix. In April 2017, the UK power generation sector celebrated its first coal-free day. Over the past decade, there has been much progress in decarbonizing electricity supplies with increased uptake of renewables and nuclear, but far less progress has been made with decarbonising heat. Finding low carbon alternatives to heat is important, half of UK energy demand is for heat and this is predominantly supplied by gas. Continuity and security of UK gas supplies are threatened by our limited gas storage and the fact that the UK has been a net importer of gas for over a decade, leaving us to face an uncertain future.

Back in the mining era, the 1872 Coal Mines Regulation Act and Metalliferous Mines Regulation Act required that detailed plans of underground workings were deposited with the then Ministry of Fuel and Power when mines were abandoned. The purpose of this being to indicate where areas of underground workings exist that may affect future developments. The surveyors working back then to produce these plans would have had little appreciation of their value today yet this information is crucial as we again look to our mining infrastructure as an energy source for the future.

The mining legacy remaining from over two centuries of intensive mining, has left a flooded underground asset that is estimated to contain some 2.2 million GWh of available geothermal heat. Just over one quarter of UK homes overlie worked coalfields and could access this source of geothermal energy. Where heat demand exceeds the developed geothermal reserve capacity there also exists potential to augment the energy stored in water within mines. This top-up energy could be derived from; energy from waste, sewage, industry and renewables. Benefits of such energy storage include; balancing the electricity grid, providing seasonal storage at a scale that is uneconomical through other means and a near zero carbon heat source, particularly when heat pumps used to upgrade the heat are powered through renewable energy.

The Coal Authority is the UK government agency established to both manage abandoned mine sites and obtain best value from the legacy potential. Following abandonment mine pumps were switched off and the network of roadways, shafts and worked seams were flooded by ground water rebounding to pre-mining levels. Where rising mine water would detrimentally affect aquifers or watercourses this is intercepted by the Coal Authority and treated. These treatment schemes release around 80 MW of geothermal heat to atmosphere on a continuous basis. There are a few examples of flooded mines being used for geothermal heat abstraction and for heat storage yet the potential for the UK and other mining regions is huge. This paper will demonstrate the geoscience techniques used to examine the nationwide potential for stored heat in flooded coal mines.

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Geoscience Insights for Developing Superhot Icelandic Geothermal Resources

Thomas Driesner[1]

Institute of Geochemistry and Petrology, ETH Zürich, and Swiss Competence Centre on Energy Research SCCER-SoE

Thomas Driesner is a senior reseracher/adjunct professor at the Department of Earth Sciences at ETH Zurich. His research interests cover numerous facets of the role of hot fluids in the earth's crust: from molecular-scale thermodynamics to crustal-scale fluid flow, and with a particular focus on hydrothermal systems in the context of ore formation and geothermal resources.

Abstract

Geothermal power production is almost exclusively based on natural waters heated by magma bodies that lie at a few km depth. Typical geothermal production temperatures are between 250° and 300°C, from wells drilled to 1 to 2 km. Further increase of water temperature is limited by the so-called "boiling curve with depth", which strongly steepens at these depths. This constellation limits power output per well to values in the order of 3 to 5 MW.

The magma bodies that heat the water, however, are much hotter, i.e., 750° to even more than 1000°C and very hot water should be expected at greater depths where pressures are in excess of ca. 220 bar and the boiling curve terminates and water becomes "supercritical". Such considerations gave rise to the Island Deep Drilling Project IDDP (www.iddp.is) to explore if such extremely hot water can indeed be found and utilized.

So far, IDDP has drilled two wells and indeed encountered "superhot" geothermal resources. The IDDP-1 well in the Krafla geothermal system found one at just 2 km depth, immediately above a magma body, and the well discharged superheated steam reaching 450°C and 140 bar at the wellhead. Tests showed that producing the resource might increase power output by almost an order of magnitude up to 35 MW per well. The IDDP-2 well, drilled 2016 to 4.6 km depth into the Reykjanes system, encountered temperatures possibly much in excess of 430°C but damage to the casing has hampered accurate tests up to now. Cores recovered from near the bottom seem to indicate much higher geothermal reservoir temperatures.

While industry considers conventionally operated geothermal systems mostly an engineering exercise and rather little geoscience is involved, the new superhot resources are terra incognita: modelling reservoir processes under these extreme conditions or designing sustainable and safe production scenarios is out of range for current industry concepts, workflows and tools. Therefore, there is growing interest in geoscience input for understanding the nature of these resources and assessing if and how they can possibly be utilized. A variety of geosciences can provide invaluable input: *hydrothermal geochemistry* to understand the chemical properties of these waters, *magmatic petrology* to understand the

nature of the heat source, *rock mechanics* to understand permeability and rock stability in and around crystallizing magma bodies, and *numerical modelling* of fluid flow to understand the possible state and dynamics of reservoir materials and processes.

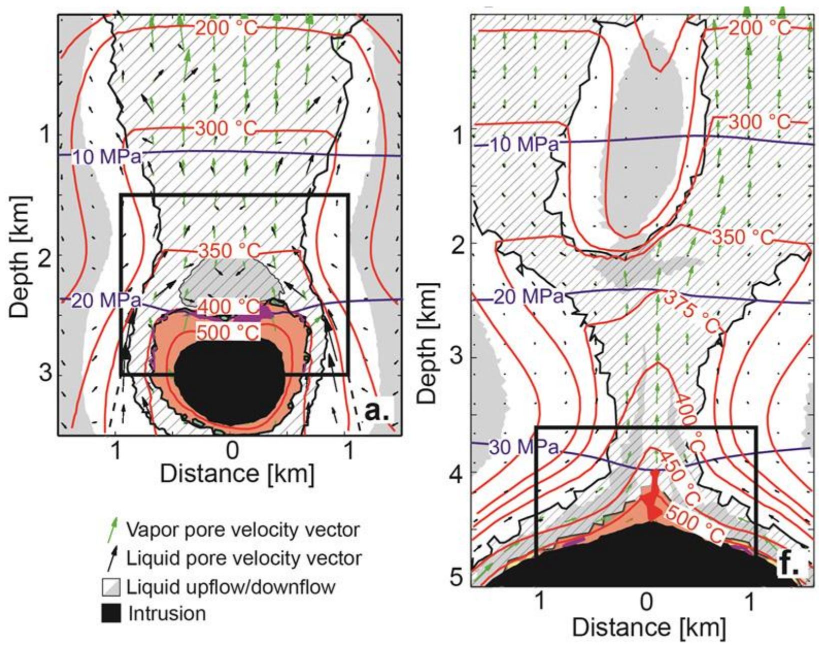

Figure 2. Numerical simulation of superhot geothermal resources (orange) around and a magma body (black) as a function of intrusion depth. Hatched areas show liquid water +steam zones, white and grey areas zones of up-/downflowing liquid water. After Scott et al. (2017).

In this contribution I highlight how geoscience-generated insights may add significant value for the development of this new type of resources from exploration concepts to resource assessment and reservoir engineering. For example, an interplay between the fluid properties as a function of temperature, pressure and salinity and flow physics dictates that systems with saline geothermal waters should be much more economic if the magma body is located at a depth greater than ca. 4 km. I review how geochemistry of "supercritical" water determines the corrosion and scaling potential, and how the behavior of permeability with temperature influences the size of the superhot resource.

Notes

Do we have the right skills for the geoscience decarbonisation future?

John Underhill[1]

[1]*Chief Scientist at Heriot-Watt University and Academic Director of the NERC Centre for Doctoral Training (CDT) in Oil & Gas*

John Underhill is Chief Scientist at Heriot-Watt University, a leadership and advocacy role informing the strategic direction of the university. He also holds the position of Chair of Exploration Geoscience and is the Academic Director of the Natural Environmental Research Council (NERC) Centre for Doctoral Training (CDT) in Oil and Gas. He studied Geology at Bristol University and was awarded a PhD from the University of Wales. He worked for Shell in The Hague and London as an exploration geoscientist. He was appointed as Lecturer in the Grant Institute of Geology before becoming their Professor of Stratigraphy. Whilst at Edinburgh, he spent sabbaticals in BP and Norsk Hydro. He was elected to the Board of the European Association of Geoscientists & Engineers (EAGE), an organisation that he led as their President in 2011-12. In 2012, he was awarded the Geological Society's Petroleum Group's top award, The Silver Medal, and the Edinburgh Geological Society's Clough Medal. Other awards include the American Association of Petroleum Geologists (AAPG) Distinguished Educator Award, and the Lyell Medal in 2016. Member of the Royal Society of Edinburgh (RSE) Scotland's Energy Future Inquiry (2017-19). Member of the UK Energy Minister's Technology Leadership Board (2015-18) and Exploration Task Force (2018-19). Member of the Natural Environment Research Council (NERC) UK GeoEnergy Observatories (UKGEOS) project's GeoScientific Advisory Group (GSAG) 2015-19. He was also a well-respected football referee in the Scottish Premier League until reaching the mandatory retiral age and was on the FIFA panel of referees, officiating in European and International matches.

Abstract

The drive to decarbonise the energy system places a responsibility upon academic trainers, educators and researchers to equip the next generation of geoscientists with the right technical skill sets needed to address the global challenge the issue presents. Whilst the need to change and evolve our geoscience provision may be perceived as a threat to well-established and long running courses, it also represents a new opportunity to tailor undergraduate and postgraduate training to address the increasing need. The skills that the graduates will need to address many of the key issues demand wider synergies with disciplines that geoscientists have not traditionally engaged with (e.g. economists and social scientists) as well as engineers in order to articulate the message and deliver pre-requisite outcomes efficiently. Fortunately, changes in the political and research funding landscape, which has seen the instigation of a Global Challenge Research Fund (GCRF), the development of a new industrial strategy, launch of the National Productivity Investment Fund (NPIF) and cross-Research Council initiatives under the umbrella of UK Research & Innovation (UKRI), all face this challenge. New undergraduate and MSc courses and modules are already springing up in many Universities but arguably, in an *ad hoc,* case-by-

case and competitive manner befitting the local need rather than tackling the national or global one, which demands a more strategic national approach to training.

The success of the NERC Centre for Doctoral Training (CDT) in Oil & Gas, a partnership between 17 Universities, 2 Research Centres and 8 industry partners shows how a perceived demand or need can be addressed through collaboration. Now in its fifth year, the CDT has over 120 PhD students enrolled, the first of whom are graduating and moving to jobs over the past year. The students have not only been doing bespoke doctoral research on their chosen topic but importantly, also undertaking a 20-week training program alongside, consisting of a mix of mandatory and optional modules. Such has been the success of the scheme that students have been obtaining internships and going into employment directly thereafter. Whilst the CDT has been led and managed by Heriot-Watt University, the PhDs are split equitably and undertaken at all of the 17 degree-awarding Higher Education Institutes (HEIs). The training aspect is provided by academic and industry practitioners. Its success has led to the CDT receiving the prestigious Geological Society's Accreditation meaning that students that complete the program receive a diploma recognising their added training. The CDT has a number of committees that undertake quality assurance and provide important feedback including a Research Committee that vets and approves PhD topics, a Training Committee that oversees the taught elements, a Graduate Committee that provides student feedback and an Industry Advisory Board, who advise on their skill needs. The CDT was ascribed four themes by NERC in the original tender: Extending the Life of Mature Basins; Exploration in Challenging Environments; Unconventionals; and Environmental Impact and Regulation. The program has evolved to include Carbon Storage and decommissioning in its remit and has also been expanding to cover other geoscience-based energy applications such as hydrothermal, particularly where that is tied to the (re)use of depleted oil and gas fields. The opportunity therefore exists to build upon, reframe and expand the remit of the CDT to cover sustainable low-carbon geo-energy research and training and in so doing, provide the right skill sets to address decarbonisation.

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Is there a role for H_2 in large-scale power production?

James Dawson[1]

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James Dawson is professor at the Norwegian Institute of Science and Technology in the department of Energy Processing and Engineering. His research areas include fluid mechanics and combustion.

Abstract

In this talk, I will discuss how hydrogen can potentially play a significant role in a large-scale, zero-carbon power generation by replacing the combustion of natural gas with hydrogen or a suitable hydrogen rich fuel in gas turbines. Current combined cycle gas turbine plants operating on natural gas can provide up to 350MW per unit with over 60% efficiency. In, principle, they could produce heat and power with near zero CO_2 emissions utilizing carbon-free fuels such as hydrogen or hydrogen rich blends through careful modifications of the combustion system and minimal changes to other hardware components of the engine. However, significant differences between the combustion properties of hydrogen and natural gas, such as flame speed and ignition delay times, pose significant technical challenges that need to be overcome. This talk will focus on the main technical challenges of burning hydrogen and hydrogen rich fuels, emphasize the importance of scale with the aim of demonstrating that, alongside the growth of renewable energy sources, hydrogen fired gas turbines can play a crucial role in global CO_2 reductions and help provide a stable energy supply infrastructure.

Notes

H21 North of England

Henrik Solgaard Andersen[1]

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Henrik Solgaard Andersen is R&D Manager at Statoil,currently working on the proposal to use hydrogen to decarbonise homs in northern England

Abstract

H21 North of England (H21 NoE) presents a detailed engineering solution for converting the gas networks across the North of England to hydrogen between 2028 and 2035. This would provide deep decarbonising of 14% of UK heat and be the world's largest CO2 emission reduction project achieving 12.5 million tonnes per year of CO2 avoided to the atmosphere. The project also sets out how to decarbonise 70% of all UK meter-points by 2050 using a six-phase regional hydrogen rollout strategy. Based on credible, proven at scale technology and a strong industry supply chain, H21 has the potential to replace all UK natural gas with hydrogen for deep decarbonisation of residential, commercial and industrial heat, power generation and transport by 2050

Key technical aspects of H21 NoE:

Conversion of 3.7 million meter points equivalent to 85 TWh of annual demand (14% of all UK heat) and circa 17% of total UK domestic meter connections;

A 12.15GW natural gas based hydrogen production facility), delivering low carbon heat for West Yorkshire (Leeds, Bradford, Wakefield, Huddersfield), York, Hull, Liverpool, Manchester, Teesside and Newcastle;

8 TWh of inter-seasonal underground hydrogen storage based 56 caverns of 300,000 m3

A 125 GW capacity Hydrogen Transmission System;

A CO_2 transport and storage infrastructure with the capacity to sequest up to 20 million tonnes of CO2 per annum by 2035 in deep saline formations in the Southern North Sea

Notes

Clean technology raw materials: Rare Earth Elements

Frances Wall*[1]*, *Rob Pell, Xiaoyu Yan*

[1]*Camborne School of Mines, University of Exeter, Penryn Campus, Penryn, Cornwall, TR10*

Frances Wall is Professor of Applied Mineralogy at Camborne School of Mines (CSM), University of Exeter, UK. She has a BSc in Geochemistry and PhD from the University of London and worked at the Natural History Museum, London before joining CSM in 2007. Her research interests include the geology, processing, and responsible sourcing of critical raw materials. Frances currently leads two large international projects: SoS RARE (www.sosrare.org) and HiTech AlkCarb (www.carbonatites.eu), was Head of CSM from 2008-2014, and has recently joined the British Geological Survey Science Advisory Committee.

Abstract

Clean technologies need raw materials to build them. Even with the best efforts to recycle, we will need to mine greater quantities of raw materials, and a greater range of elements, than ever before in order to build low carbon technologies. Solar cells, wind turbines, electric cars, lithium batteries, fuel cells and nuclear power stations are all complex technologies with equally complex raw materials needs. It takes 44 different elements just to make one computer chip. This costs carbon as well as money. Despite their necessity, clean technology raw materials are often only required in small quantities and are quite cheap to buy. Having only a few mines worldwide might be sufficient – but these are vulnerable to supply disruption. The family of seventeen rare earth elements (REE) are perhaps the epitome of these *critical* raw materials, they are used in wind turbines, direct drive motors in electric vehicles, low energy lighting, all computers, and many other applications all around us.

Finding secure and environmentally-friendly supplies of REE is a challenge for geologists. Potential supplies are diverse – ranging from high grade igneous rocks to low concentrations in clays, mud on the sea floor and by-products from fertilizer and aluminium production. Right from the first stages of exploration, geologists can be thinking not only about the size of an ore deposit but about how it will perform when processed, how to mine with minimum energy and water, and what waste will be generated. Geologists can also be responsible for incorporating environmental tools such as life cycle assessment into their exploration routines so that the mines of the future are designed right from the start to keep carbon emissions low.

Notes

Seabed Minerals

Tracy Shimmield[1]

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Tracy Shimmield is the Co-Director for the Lyell Centre, a purpose-built £21 m facility, which will enable the British Geological Survey (BGS) and Heriot-Watt University (HWU) to build on their individual and combined interdisciplinary expertise in land and marine conservation, geology and geoscience. Tracy has over 30 years' experience in environmental geochemistry. She obtained an MSc. From Strathclyde University and a Ph.D. from Edinburgh University. Her research interests include the investigation and assessment of human impacts on the marine environment through the monitoring of pollutants and the study of biogeochemical processes involved in their redistribution. She is interested in how science and innovation can come together to realise societal benefit and economic growth and was a member of the Scotland Can Do Forum set up by the Scotland's Deputy First Minister. She also works with the Scottish CENSIS Innovation Centre.

Notes

Mineral resources in a low carbon future

Lluis Fontboté[1]

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Lluís Fontboté (M.Sc., University of Granada, Spain; Ph.D., Heidelberg University, Germany). Since 1990, he has been a full professor at the University of Geneva, Switzerland, where he leads a research group on ore deposits that is active worldwide. His main area of expertise is epithermal polymetallic deposits linked to porphyry systems, iron oxide copper gold deposits, and MVT zinc-lead deposits. In collaboration with his students and coworkers, Lluís has also published work focusing on VHMS and orogenic gold deposits, on acid mining drainage and on the future of global mineral resources. He has worked in exploration for several commodities, mainly in the Andes.

Abstract

Recycling is important and essential, but is not enough to meet the strong growth in demand, in particular from developing countries. Rapid evolution of technologies and society will eventually reduce our need for mineral raw materials, but at the same time, these new technologies are creating new needs for metals, such as many of the 60 elements that make up every smart phone. Climate-friendly technologies will add pressure to the growing demand on mineral raw materials. According reports several, meeting a 2°C global temperature warming scenario would imply important added annual consummation of several metals including lithium, indium, neodymium, copper, cobalt, silver, zinc, lead, molybdenum, iron, and aluminum.

In contrast to articles announcing that deposits of mineral raw materials will be exhausted within a few decades, geological evidence indicates that the resources of most mineral commodities are sufficient to supply countless future generation as long as there is a major effort in exploration (e.g. Arndt et al., 2017). Confusion between the terms mineral resources and reserves is the main reason of the widespread misconception of a rapid exhaustion of mineral resources.

Large regions of the Earth are underexplored and it must be taken in account that the vast majority of mined deposits have been discovered at the surface or in the uppermost 300 meters of the crust. Geological evidence shows that deposits are also present at greater depths. Mining technology is ready for mining at depths of 3000 m and more. In addition, price increases can render economically viable deposits with grades too low to be mined today.

However, there is potential for temporary future shortages of certain mineral raw materials. The shortages may result from other reasons than from physical exhaustion. Insufficient exploration effort and efficiency may be a reason. The cyclic nature of mining economy does

not facilitate the task, neither the small size of certain metal markets and, frequently, their vertical integration and consequently lack of transparence. Difficulties in obtaining the social license to operate is a factor that compromises land access to exploration and mining projects. Despite recent important advances and modern technologies that mitigate impact, mining is still linked to a long history of environmental degradation. Society needs to be aware that (1) recycling is not enough to meet the increasing demand of metals; (2) that, therefore, search and exploitation of new ore deposits is necessary; and (3) that technical solutions exist to minimize the impacts associated to mining activities. This is a complex endeavour and requires technical improvement but also of a communication effort from the involved stakeholders.

Finding deposits at greater depth is possible but requires full application of our knowledge on mineral systems and further development of it. Formation and occurrence of the main ore deposits is nowadays reasonably well understood. New exploration methods based on extensive use of automatized mineralogical core logging and trace element and isotopic composition of magmatic, alteration, and ore minerals provide new vectoring tools. Combination of zircon composition and zircon geochronology helps identifying geological environments adequate for giant magmatic-hydrothermal deposits. Developments of electromagnetic and seismic and 3D imagery as well as the use of "big data" and machine learning approaches and identification of large crustal structures offer new opportunities. The big challenge there is to form geologists able to cope with the generated data wealth. This includes solid knowledge in Earth science basics including mineralogy, petrology, structural geology, geochemistry, and fieldwork skills, analytical and synthesis capacity, and at the same time, ability to collaborate with specialists in other fields.

Arndt, N.T., Fontboté, L., Hedenquist, J.W., Kesler, S.E., Thompson, J.F.H., and Wood, D.G., 2017, Future Global Mineral Resources: Geochemical Perspectives, v. 6, no. 1, p. 1-171

Notes

Social science insights on energy transitions

Benjamin Sovacool[1]

[1] *School of Business, Management and Economics, University of Sussex*

Dr. Benjamin K. Sovacool is Professor of Energy Policy at the Science Policy Research Unit (SPRU) at the School of Business, Management, and Economics, part of the University of Sussex in the United Kingdom. There he serves as Director of the Sussex Energy Group and Director of the Center on Innovation and Energy Demand which involves the University of Oxford and University of Manchester. Professor Sovacool works as a researcher and consultant on issues pertaining to energy policy, energy security, climate change mitigation, and climate change adaptation.

More specifically, his research focuses on renewable energy and energy efficiency, the politics of large-scale energy infrastructure, designing public policy to improve energy security and access to electricity, and building adaptive capacity to the consequences of climate change. He is a Lead Author of the Intergovernmental Panel on Climate Change's Sixth Assessment Report (AR6), due to be published in 2022, and an Advisor on Energy to the European Commission's Directorate General for Research and Innovation in Brussels, Belgium.

Professor Sovacool is the author of numerous academic articles, book chapters, and reports, including solely authored pieces in *Nature* and *Science,* and the author, coauthor, editor, or coeditor of 20 books on energy and climate change topics. His books have been endorsed by U.S. President Bill Clinton, the Prime Minister of Norway Gro Harlem Brundtland, and the late Nobel Laureate Elinor Ostrom. He is also the recipient of 20 national and international awards and honors, including the 2015 "Dedication to Justice Award" given by the American Bar Association and a 2014 "Distinguished Visiting Energy Professorship" at the Environmental Law Center at Vermont Law School.

Abstract

Transitioning away from our current global energy system is of paramount importance. The speed at which a transition can take place is a critical element of consideration. This presentation therefore investigates the issue of time in global and national energy transitions by asking: What does the mainstream academic literature, often drawing from historical evidence, suggest about the time scale of energy transitions? Additionally, what does some of the more recent empirical data related to transitions say, or challenge, about conventional views? In answering these questions, the article presents a "mainstream" view of energy transitions as long, protracted affairs, often taking decades to centuries to occur. However, the article then offers some empirical evidence that the predominant view of timing may not always be supported by the evidence, and that accelerated transitions are possible under the right circumstances.

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Public Views of Geoscience Decarbonisation Options

Nick Pidgeon[1]

[1]*Understanding Risk Research Group and FLEXIS Project, School of Psychology, Cardiff University*

Nick is Professor of Environmental Psychology and Director of the Understanding Risk Research Group within the School. He works on risk, risk perception, and risk communication and as such his research is interdisciplinary at the interface of social psychology, environmental sciences and geography, and science and technology studies. He is currently researching public responses to energy technologies, climate change risks, nanotechnologies and climate geoengineering. He has in the past led numerous policy oriented projects on issues of public responses to environmental and technological risk issues and on 'science in society' for UK Government Departments, the Research Councils, the Royal Society, and Charities. He currently serves as a social sciences adviser to the UK Department of Environment, Food and Rural Affairs and to the Department of Energy and Climate Change. He was awarded an Honorary Fellowship of the British Science Association in 2011, and an MBE in the 2014 Queen's Birthday Honours for services to climate change awareness and energy security policy.

Abstract

The growing low-carbon energy transition, and with it the requirement to meet the Paris accord target of net-zero carbon emissions by the latter half of this century, will bring with it a need for a range of technologies which depend, one way or another, upon the development and use of the subsurface. This paper will outline what we know about public views on exploitation of 'the underground' for energy applications – starting with the lessons learned from earlier unsuccessful attempts to site radioactive waste repositories in many countries that have tried. Radioactive waste remains the paradigm case in risk facility siting failure, and highlights the importance of taking seriously public and societal acceptability over and above simply technological or economic factors. In more recent times some of these lessons can be seen to apply to technologies such as geological carbon capture, large-scale energy storage, geo-thermal energy, and bioenergy with carbon capture or BECCS. The paper argues that we should not attempt to reinvent the wheel, and hence also reviews implications for public attitudes toward some of these newer technologies. Not only are process and distributional equity issues important for getting siting issues right, but people need to be convinced that any technological option represents a genuine and sustainable transition away from dependence upon fossil fuels. I also argue that how people conceptualise the deep underground itself has received less attention. Here, views on resources, risk and the deep underground raise important societal questions about how people perceive the desirability and viability of subterranean interventions, and broader questions about the use, identification and value of natural resources. To understand this we will need a fully-developed social science of the subsurface.

Notes

Geological disposal of radioactive waste

Jonathan P Turner[1]

[1] *Radioactive Waste Management LTD., Birmingham West Midlands, United Kingdom*

Jonathan Turner is a Chartered Geologist who has spent most of his career in oil and gas exploration, both in industry (Shell, BG Group) and academia (University of Birmingham). He has published widely on applications of structural geology and geomechanics, and at BG Group was Deputy Chief Geologist during delivery of the major Santos basin (Brazil) and Surat basin (Queensland) development projects. Through his work with the Geological Society and as a visiting professor at the University of Manchester, Jonathan particularly enjoys working with early-career geoscientists.

Abstract

Preparations for undertaking one of Britain's largest ever environmental projects are advancing rapidly. Radioactive Waste Management is a public sector delivery body tasked with disposing of Britain's higher activity radioactive waste. A complex 60-year legacy of waste needs to be managed to protect people and the environment from its harmful properties. The safest and most sustainable way to deal with higher activity waste is to emplace it in a geological disposal facility (GDF). Geological disposal combines engineered and natural barriers *working together* to isolate a GDF from humans and surface processes, and to prevent migration of radionuclides to the surface environment.

GDF delivery requires a suitable site – not the 'perfect' geology – and a willing community. Among major infrastructure programmes, it is possibly uniquely challenged by the need for public consent and the very long timescales of both GDF programme duration and the geological length of the post-closure safety period (>100k.y.).

Geoscientific expertise will play a central role in overcoming many of the key challenges of delivering a GDF safely, including:

- Obtaining the 'social licence to operate' – public perception, effective communication of controversial subsurface projects;
- Modelling the geosphere response to environmental change e.g. predicting behaviour of groundwater systems in glacial periods;
- Modelling near-field response of the geosphere to a GDF e.g. excavation damage zones, effect of heat flux, extent of rock desaturation during the GDF operational period.

Notes

Assessing Geohazards for UK Nuclear New Builds

Bob Holdsworth[1]

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Currently Chair of Structural Geology at the Department of Earth Sciences, Durham University. With over 30 years of research experience, he has broad expertise covering fault reactivation and weakening processes, fractured basement reservoirs and continental tectonics. He has extensive experience working at the industry-academic interface and was awarded a successful NERC Knowledge Exchange Fellowship (2009-12). My work with the Clair JVG (BP, Shell, Chevron, ConocoPhillips) and Hurricane Exploration has generated new data and understanding of fractured basement reservoirs that has underpinned the appraisal and drilling of the UK's first basement-hosted oilfields along the Rona Ridge, west of Shetland.

He is one of three UK academics who sit on the Office of Nuclear Regulation (ONR) Expert Panel for Seismic Hazard. As the expert in structural geology and UK regional geology, he provides expert review of materials that impact directly on permissioning decisions made by the ONR during the planning and construction of multi-billion pound nuclear facilities of fundamental long-term strategic importance to the UK energy supply. He has contributed to the written sections of the technical guidance (TAG) documents for ONR and contributed to an Expert Panel Paper on Seismic Hazard which is consulted by both the nuclear industry and regulators worldwide. I also leads on the technical review of geological aspects of documents related to the development of a UK Geological Disposal Facility, one of the largest and most technically challenging infrastructure projects ever attempted.
With two other colleagues, he launched (in 2006) a spin-out company Geospatial Research Ltd (GRL) (www.geospatial-research.com) based in Durham. The company has created 30 new highly skilled jobs for graduate and post PhD-level geoscientists and has provided consultancy services based on Durham structural geology research to 41 companies worldwide.

Abstract

New nuclear has been promoted as a relatively low carbon way to help the looming energy gap as the UK phases out coal-fired power stations and as existing nuclear installations reach the end of their operational lives. An ambitious programme of new builds has suffered and continues to suffer a range of setbacks, but at least some plants are currently being constructed or planned. A number of safety cases are complete or in preparation and are assessed by the Office for Nuclear Regulation (ONR), with technical advice from its Expert Panel on Natural Hazards where appropriate.

Seismic hazard represents one of the most "geological" external hazards that needs to be considered when developing a new Nuclear Power Plant (NPP). It is a particularly significant

issue for the nuclear industry as it is a major common cause fault initiator, affecting all parts of the site simultaneously. It can also generate secondary hazards such as fires and flood and is, by its very nature, unpredictable. The primary hazard and main cause of damage to structures and plant is strong shaking of the ground caused by the passage of seismic waves radiating from the earthquake source. This may be amplified by the local presence of unconsolidated sediments and can also trigger secondary hazards such as liquefaction or landslides. The characterisation of strong ground motion is usually carried out via a Probabilistic Seismic Hazard Analysis (PSHA). If a fault rupture extends to the ground surface then the relative displacements, whether vertical or horizontal, can also present a serious threat to any structure or facility that traverses the fault trace. Whilst surface breaking 'capable faults' (CF) are rare in intraplate settings like the UK, it is necessary to carry out a careful study of the location, character and movement history of all faults on, or near to a site in order to screen out this exclusionary hazard.

The UK lies in the interior of the Eurasian continental plate and is located approximately equidistant from the northern end of the Mid-Atlantic ridge to the NW and the Eurasia-Africa convergence zone to the SE. Over the last six to eight million years, the interaction of these far-field plate boundaries has generated a first order NW-SE compressional stress regime, which in the last two million years has been perturbed by second-order stresses generated by loading and unloading of the crust by British and Fennoscandian ice sheets. The intraplate location of the UK means that it is a region of low tectonic activity. Historical and instrumental seismicity records point to a complex pattern of earthquakes that is neither purely random nor uniform. There appears to be a poor correlation between seismicity and well documented ancient faults mapped at the surface in the UK. There is no compelling evidence for temporal clustering of UK earthquakes, other than aftershock sequences that are clearly apparent for some significant UK events. Thus significant earthquakes in the UK that might challenge nuclear safety are assumed to follow a Poisson process or model. This implies that events occur randomly with no memory of the time, size or location of the preceding event and with a stationary underlying frequency-magnitude distribution.

CF/PSHA studies have been carried out and assessed for two UK new nuclear sites, and are in progress for two others – all have informed and will continue to inform the contents of the ONR Technical Assessment Guide (TAG) 13 for External Hazards*. A global revolution is occurring in the way that NPP seismic hazard assessments are carried out making them more robust and transparent, following the protocols set out by the Senior Seismic Hazard Assessment Committee (SSHAC). There is also much being learnt about the subsurface geology and geological evolution of the British Isles which is being enabled by significant scientific advances such as the application of new dating techniques for fault rocks and fracture fills. The use of multifaceted GIS-based models that incorporate fully georeferenced geological and geophysical datasets into a single viewing platform is allowing previously unparalleled insights into the 3D geology below a site. This represents a geologically-led revolution in the civil engineering field akin to the effect of 3D seismic in improving petroleum exploration.

* to download, go to: http://www.onr.org.uk/operational/tech_asst_guides/ns-tast-gd-013.htm

Notes

The role of the oil and gas sector in decarbonisation

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Philip Ringrose is Adjunct Professor in CO2 Storage at the Norwegian University of Science and Technology (NTNU) and Specialist in Geoscience at the Equinor Research Centre in Trondheim, Norway.

He has BSc and PhD degrees in geology from Universities of Edinburgh and Strathclyde, Scotland, UK. He has published widely on reservoir geoscience and flow in rock media, and has recently published a textbook on *Reservoir Model Design* together with Mark Bentley. He is Chief Editor for the journal *Petroleum Geoscience* and was elected as the 2014-2015 President of the European Association of Geoscientists and Engineers (EAGE).

Abstract

Starting from the perspective of the historical growth in energy demand during the industrial and petroleum ages ~1800 to ~2020, we note that provision of energy and industrial activity in human society are closely coupled. Over the last 100 years, oil and gas companies have come to dominate the energy sector. Their business model is essentially to produce subsurface hydrocarbons to meet the global demand for energy and for a wide range of industrial activities, with global oil production reaching nearly 100 million barrels per day in 2018. As we now enter the age of low-carbon energy, it is natural to ask who will dominate the energy sector and how might it work?

A modified oil and gas energy sector is most likely to play a significant role for several fundamental reasons:

- The energy sector will still require the ability to develop large projects (with the associated investment, construction, operation and distribution work streams) in both the renewable energy sectors and in the decarbonised fossil-fuel sectors;
- Decarbonisation will fundamentally require CO_2 disposal at industrial scales, using the same rock formations exploited for oil and gas resources;
- Gigatonne-scale geological storage of CO_2, along with seasonal storage of energy and gas, will require the well technologies and subsurface resource management tools which have been developed in the oil and gas sector.

We can also view this from the perspective of pressure management – the petroleum age required skills in pressure management during a process of gradual depletion of the earth's subsurface hydrocarbon resources, while decarbonisation will require new forms of pressure management associated with the accumulation of CO_2 molecules derived from power-sector combustion and other industrial processes. An approach to basin-scale pressure management to enable this transition is proposed.

Notes

Deep Geothermal: exploration in Italy, from knowledge to deployment in Europe

*Francesco Baccarin[1], Massimo Luchini[1], **Adele Manzella**[2] and the IMAGE and DESCRAMBLE Project Teams*

Author affiliation(s): [1]Enel Green Power (EGP), Italy;[2] National Research Council (CNR), Italy;

Adele Manzella is Senior Scientist and works as a geophysicist in geothermal exploration to conduct field and theoretical investigations of geothermal systems in Italy and abroad.

She received her M.Sc. at Padua University on 1985, and took graduate courses in geophysics at University of Berkeley, USA, on 1986-1987. She worked in seismology, numerical modeling for seismic and electromagnetism. Her main fields of activities have been: magnetotelluric surveys in tectonically active regions of Italy (CROP crustal projects, Vesuvius and Etna volcanoes) and Bohemia (Czech Republic); groundwater exploration using electromagnetic methods in Tuscany and Sardinia (Italy); geothermal exploration as a geophysicist, conducting magnetotelluric surveys and theoretical investigation of geothermal systems in Italy, Tibet, Iceland, Australia, Sri Lanka; integration of different geothermal exploration methods for reservoir characterization, and feasibility studies for geothermal plants. On 2006 she won the G.W. Hohmann Award, for “outstanding application of electrical and electromagnetic methods to the study of geothermal resources”. On 2018 she won the Patricius Medal for “providing geothermal knowledge for accelerating the deployment of geothermal energy”.

She coordinated for CNR the Italian geothermal evaluation projects VIGOR and Geothermal Atlas of Southern Italy, and led the participation of CNR and was WP leader in most EU projects dedicated to geothermal energy of CNR, regarding exploration methods development, coordination of research efforts and geothermal networking, and promotion and support for the development of geothermal energy.

She participates to the Steering Committee of the European Technology & Innovation Platform of Deep Geothermal energy (ETIP DG) and its Secretariat, coordinating the preparation of strategic documents, the first being its Vision published on March 2018. She represents CNR within the SET-PLAN European Energy Research Alliance-Joint Program Geothermal Energy (EERA-JPGE), the European Geothermal Energy Council (EGEC) and the International Geothermal Association (IGA). Author and co-author of publications on national and international scientific journals and proceedings of conferences/workshop, convener at national and international conferences, lecturer in international geothermal courses, conferences, schools and workshops, and reviewer for many international journals in geophysics and geothermal exploration research.

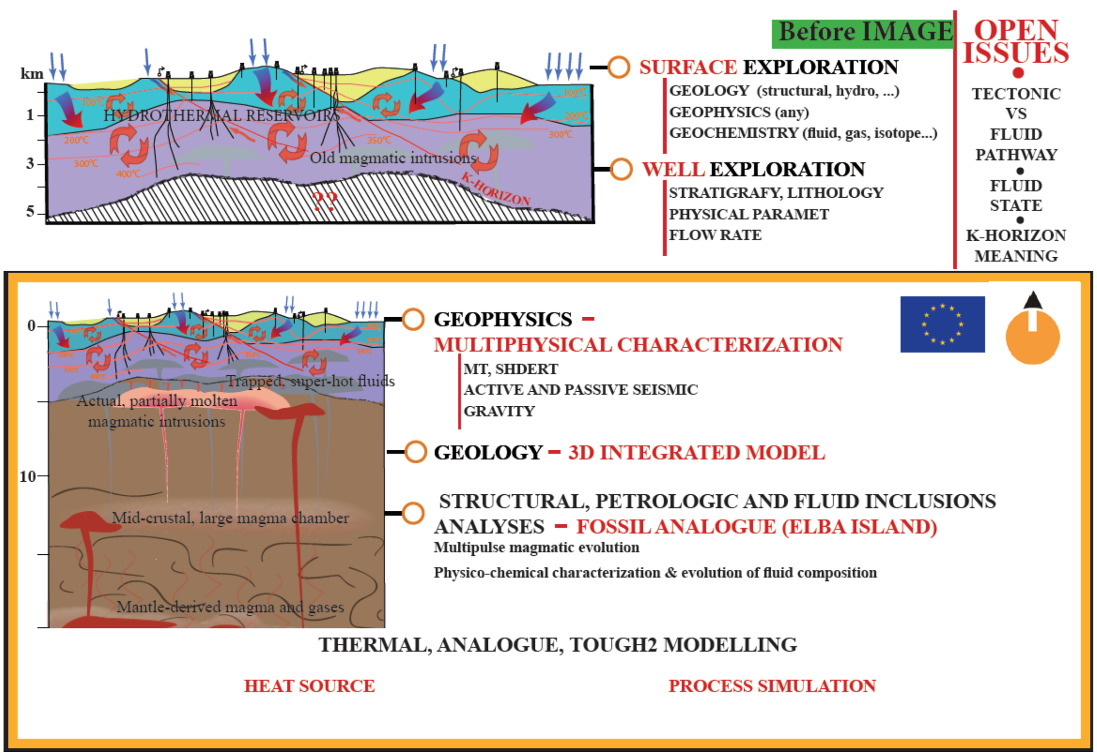
Abstract

Very high-temperature geothermal reservoirs are an attractive target for future geothermal development, for their potential of boosting the output of geothermal plants and improving the

role already played by the geothermal sector for the decarbonization of power and heat production. Two European projects were the occasion for refining knowledge of deep chemical-physical conditions in an area characterized by high heat flow anomalies and hosting one of the most productive hydrothermal systems in the world: the Larderello field in Tuscany, Italy. The combination of shallow depth for super-critical conditions and the possibility to deepen an existing well have been the main criteria for the choice of the test site.

The area was first surveyed and a conceptual model of the deep roots of the dry-steam hydrothermal reservoir and of shallow magma emplacement was defined. Then, a drilling experiment aimed at testing geothermal resources at extremely high temperature in continental-crust condition for demonstrating novel drilling techniques and the control of gas emissions was performed. The test site was an existing dry well that was deepened from the original 2.1 km to about 3 km depth. At this depth a temperature exceeding 500 °C and of pressure of about 300 bar were recorded. An integrated exploration approach, joining geological and geophysical data, combined to direct, in-situ information resulted in a novel perspective of deep geothermal resources.

The research leading to these results has received funding from the European Union's FP7 and Horizon2020 Research and Innovation Programs under grant agreements No. 608553 (Project IMAGE) and No. 640573 (Project DESCRAMBLE).



The **"Vision for Deep Geothermal"** looks at future development of deep geothermal energy and highlights the great potential of untapped geothermal resources across Europe. The Vision is designed to trigger a debate about how best to achieve a future for geothermal energy in Europe that is secure, affordable and carbon free, and which has the least impact on nature.

For more information on the Vision for Deep Geothermal please visit:

https://www.etip-dg.eu/publication/vision-for-deep-geothermal/

For more information on geothermal energy and it's role in long term decarbonisation of the European economy, please visit:

https://www.etip-dg.eu/publication/fact-sheet-geothermal-energy-in-the-long-term-perspective-of-a-decarbonised-european-economy/

Notes

UK Networks and Projects

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Jonathon Pearce is the principle geochemist at the British Geological Survey, in Keyworth. He is working ona number of projects and collaborations relating to CO_2 storage research including SiteChar, ULTimateCO2, CRIOS, RISCS, SAfeCCS and ECCSEL. He has been a member of the CO_2 storage scheme since its creation in 2000 and has particular research interests in the monitoring strategies for CO_2 storage, especially for risk mitigation.

Notes

Advancing the Energy Transition

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Dr Dominic Emery is VP, Group Strategic Planning for BP, responsible for strategy development, long-term planning and policy.

Dominic is a geology graduate and has worked for BP since 1986. He has held positions in BP's Exploration and Production Division, in Asia and the Middle East, and also in the UK North Sea. Dominic has led Gas and Power business development in Europe, as well as running power and utility assets at BP industrial sites. He joined BP Alternative Energy in 2007, ran Emerging Business & Corporate Ventures in 2012 and moved to his current role in 2013.

In addition to his BP role, Dominic was the founding CEO of OGCI Climate Investments, a $1bn fund set up by oil and gas companies to invest in technologies and projects to reduce carbon emissions. He is also on the Board of the EITI (Extractive Industries Transparency Initiative) and alternate on the Board of the ETI (UK Energy Technologies Institute).

Abstract

The challenge facing society is the need to reduce emissions by around 50% by 2040 to be on track for the Paris goals, whilst growing energy demand to the world by between 20 and 30% over the same time period.

The approach that we have taken at BP is to develop a set of strategic priorities that will allow us to be both resilient and flexible to a range of emissions and energy outcomes for this changing world. These are:

Growing gas and advantaged oil in the Upstream

Market-led growth in the Downstream

Venturing and low-carbon across multiple fronts

Modernizing the whole Group

Supporting these priorities is a framework we call 'Reduce-Improve-Create', or RIC. This means i) reducing emissions in our operations, with a set of clear targets, ii) improving our products, including liquids, gas, renewables and customer offers, and iii) creating new businesses, through ventures, pilots and technology commercialisation

We believe that this approach will allow us to continue to deliver the energy the world needs, whilst decarbonising across a broad front, involving all our people, and collaborating widely across the energy industry.

Notes

Poster Programme

A new research facility: kick-starting future opportunities in subsurface mine water geothermal heat and heat storage

J.Birkin[1] & K. Shorter [1]
[1]British Geological Society, Keyworth, Nottingham, United Kingdom

Scaled cavern formation by salt dissolution: gas storage in the Permian halite

Katherine A. Daniels[1], Jon F. Harrington[1], Lorraine P. Field[1] and David J. Evans[1]
[1]British Geological Survey, Nicker Hill, Keyworth, Nottinghamshire, NG12 5GG, UK.

Linking Redox Processes and Black Shale Resource Potential

J. Emmings[a,b], S. Poulton[c], G. Jenkin[b], S. Davies[b], C. Vane[a], M. Leng[a,d], M. Stephenson[a], A. Lamb[a], Vicky Moss-Hayes[a]
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Carbon capture and storage on the East Irish Sea Basin

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Quantifying geological CO_2 storage security to deliver on climate mitigation

Juan Alcalde[a], Stephanie Flude[b,c], Mark Wilkinson[b], Gareth Johnson[b] , Katriona Edlmann[b], Clare E. Bond[a], Vivian Scott[b], Stuart M.V. Gilfillan[b], Xènia Ogaya[d] and R. Stuart Haszeldine[b].*
[a]Geology and Petroleum Geology, University of Aberdeen, School of Geosciences, Kings College, Aberdeen, AB24 3UE, UK

Subsurface capacity for energy storage onshore and offshore UK: CO2, CAES, Hydrogen

Stuart Haszeldine[1], Mark Wilkinson, Stuart Gilfillan, Gareth Johnson, Julien Mouilli-Castillo, Jon Scafidi, Niklas Heinemann, Dimitri Mignard
[1]School Of Geosciences, University Of Edinburgh

Europe's cobalt resource potential for supply to low-carbon vehicles

S. Horn1, E. Petavratzi1, G. Gunn1, R. Shaw1, F. Wall2
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Run-of-the-River Micro Hydro Power – Feasibility and Value

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Assessing the feasibility of the "all-in-one" concept in the UK North Sea: offsetting carbon capture and storage costs with methane and geothermal energy production through reuse of a hydrocarbon field

***Jonathan Scafidi** and Stuart M.V. Gilfillan*
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Mine water: a sustainable renewable energy resource?

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A new research facility: kick-starting future opportunities in subsurface mine water geothermal heat and heat storage

J.Birkin[1] & K. Shorter [1]

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A geothermal energy research observatory is being constructed to investigate the potential and impact of exploiting heat from groundwater within abandoned underground coal mines. This UK Geoenergy Observatory (UKGEOS) facility will be a subsurface laboratory for shallow, low-enthalpy geothermal systems and their use in heat generation and storage.

This Glasgow Geothermal Energy Research Field Site sits above and within seven coal seams which were mined to approximately 220 m below ground level. When mining ceased in the 1930s, the groundwater rebounded back to natural levels flooding the network of mine shafts, drives, and tunnels. This groundwater system has the potential to provide low-carbon district heating.

However, the geological and environmental impacts of mine water geothermal heat have not yet been the focus of research. For example hydrogeochemical changes in the groundwater or the influence of different types of underground workings. The subsurface observatory will include a range of continuous surface and subsurface monitoring and research boreholes, and provide open access data, to address research questions including:

1. A complex, heterogeneous and evolving rock mass,
2. Multiphase fluid flow in heterogeneous media,
3. Mechanical responses to artificial perturbations,
4. Biogeochemical responses to artificial perturbations, and
5. Surface-subsurface interactions and impacts.

There are three phases to this project:

- Phase 1: drilling boreholes, environmental baseline monitoring of the surface and subsurface, and geological characterisation of the site,
- Phase 2: geothermal infrastructure and monitoring, and
- Phase 3: research facility open to the science community.

Phase 1 is currently underway, with the first borehole being drilled in winter 2018/2019.

The UKGEOS Glasgow project is the first of its kind to monitor in unprecedented detail the environmental and subsurface impacts of mine water heat extraction and heat storage. Low enthalpy geothermal heating is widely viewed as a route to decarbonising. Understanding what happens in the subsurface as a result of heat extraction and storage will allow better planning for safety, sustainability and governance.

Notes

Scaled cavern formation by salt dissolution: gas storage in the Permian halite

Katherine A. Daniels[1], Jon F. Harrington[1], Lorraine P. Field[1] and David J. Evans[1]

[1]British Geological Survey, Nicker Hill, Keyworth, Nottinghamshire, NG12 5GG, UK.

Renewable energies provide a clean alternative to power generation in the UK. However, the resultant supply varies on daily, weekly and seasonal cycles. Security of energy supply coupled with a transition towards greater production and use of renewable energy in the UK, and globally, will necessitate an increase in both energy and grid-scale storage. The successful operation of underground natural gas storage has proven the high-pressure geological gas storage technologies. Potential storage sites for compressed gas include energy bags anchored to the sea bed[1], and underground geological storage; these can be solution-mined salt caverns, porous rock (including aquifers and depleted oil and gas fields) and lined and un-lined rock caverns[2,3,4,5]. Such technologies thus represent viable options for the storage of hydrogen or compressed air energy (CAES) at high pressures, to enable renewable energy generation to be less time- and condition-dependent[6]. CAES systems store large volumes of compressed air using excess energy generated at off-peak times (for example wind energy available at night), which is then released to drive turbines, generating electricity during periods of increased demand [7]. Using energy storage to increase both the use of renewables and the security of supply has important implications for the UK Government's commitment to reduce CO_2 emissions[8].

Halite (salt) formations are ideally suited to the development of compressed gas facilities as halite is a low permeability, self-healing (visco-plastic) material that can be solution-mined to produce custom-made storage caverns; the halite formations in the UK are both onshore and offshore and were deposited during Upper Permian and mid-late Triassic times[3,5]. Gas or compressed air storage in salt caverns requires halite deposits to be sufficiently deep and thick to adequately store the gases at high pressures without cavern collapse, and sufficiently pure that their construction is not disadvantaged by the accumulation of insoluble impurities in the sump. Shallower caverns will necessarily have lower storage and operational pressures than deeper caverns, and the target formation needs to be sufficiently large in its lateral extent to accommodate multiple caverns with adequate intra-cavern spacing. The UK has operational onshore natural gas storage salt caverns in East Yorkshire, Teesside and Cheshire, as well as other planned and consented storage sites in Cheshire, NW England and the East Irish Sea. Although UK halite deposits represent a large natural resource for energy storage, a detailed knowledge of the coupling between mechanics, chemistry and geological properties of salts of varying quality and stress state will enable improvements to be made in cavern shape, operating pressure limits and cycling frequency, optimising storage potential and economic feasibility.

The effect of irregularities due to differential dissolution rates, the presence of insoluble impurities that can affect dissolution and the 'growth' of the cavern, and the impact of stress on cavern geometry and integrity have previously been considered to be key questions in the development of geological energy storage. To that end, much work has recently been focussed on the dissolution behaviour of the Triassic halites in the Cheshire basin through the EPSRC-funded IMAGES project. The project also assessed potential onshore cavern locations[9] and initial exergy estimates for CAES using a gas storage caverns in the Upper Permian Z2 halites of eastern England as an example[10]. The Upper Permian (Z2) halite deposits under the North Sea represent an opportunity to create an integrated energy solution with offshore windfarms sited above geological energy storage sites. In this study, three dissolution tests on the Upper Permian Boulby halite from Boulby Mine, North Yorkshire, have been conducted. The first test was a flow through test, whilst the second and third tests simulated scaled cavern formation with the saline fluid both entering and leaving through the same hole in the top of the halite sample (Figure 1). The three tests, conducted at atmospheric pressure and temperature, investigated different salt concentrations in the dissolving fluid to examine the role of salt saturation on the shape of the cavern produced. The results from these tests have been compared with observations made from dissolution tests conducted on Triassic halites from Cheshire[6,11]. As was also observed in the Triassic halites, impurities and textural heterogeneities within the Upper Permian halite samples were found to have a strong control on the shape of the cavern produced, as were impurities such as clay within the salt matrix and the salinity of the dissolving fluid[6]. These experiments provide insight from the small-scale to inform large-scale processes, and enable a direct comparison between the two different halite resources available for energy storage within the UK.

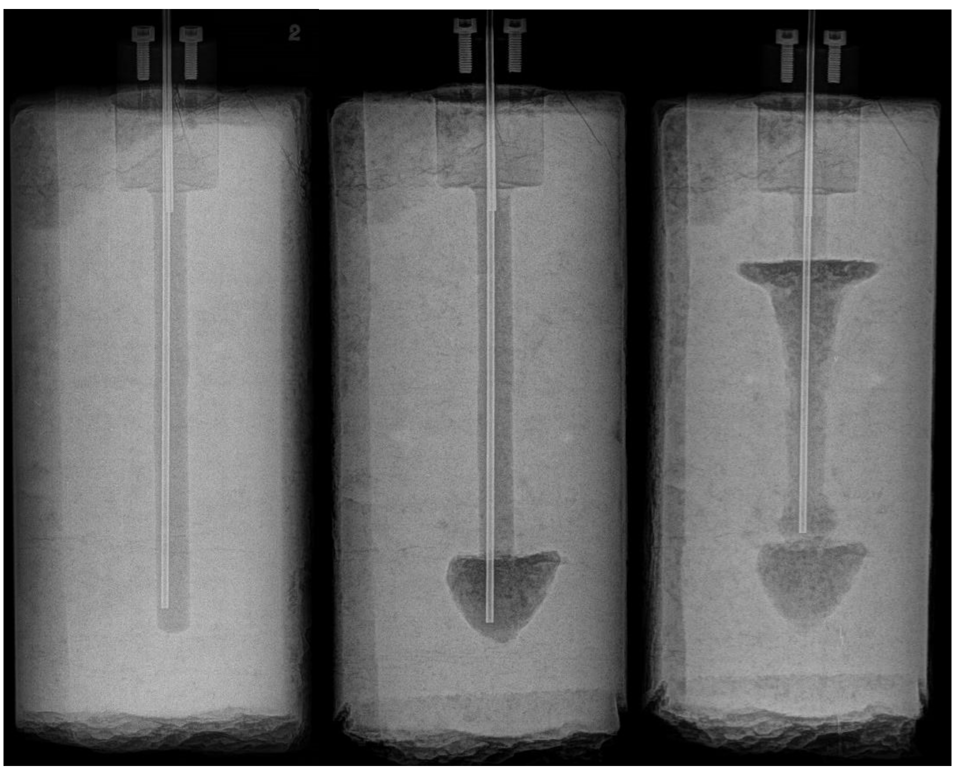

Figure 1: Time-lapse photographs of a laboratory-based dissolution test of host material from Boulby Mine, giving insight into the solution mining process.

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Notes

Linking Redox Processes and Black Shale Resource Potential

***J. Emmings*[a,b]*, S. Poulton*[c]*, G. Jenkin*[b]*, S. Davies*[b]*, C. Vane*[a]*, M. Leng*[a,d]*, M. Stephenson*[a]*, A. Lamb*[a]*, Vicky Moss-Hayes*[a]

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Black shales, such as the Mississippian (~330 Ma) Bowland Shale Formation, are targets for unconventional hydrocarbon exploration in the UK and in equivalents across Europe. Despite this interest, global decarbonisation, by definition, will either require; (1) complete replacement of natural gas with renewables and nuclear power generation, or; (2) moderate to limited natural gas use globally or locally, for example as a 'bridge fuel', as a source for hydrogen via steam reformation, or coupled to carbon capture and storage (CCS) technology. Any of these scenarios will increase the demand for transition metals such as V, Co and Ni, key elements used for energy storage and as catalysts in steam reformation. Black shales in general can host ore-grade enrichments in these metals, although the exact resource potential of UK Mississippian black shales remains unresolved.

We integrate comprehensive sedimentological and geochemical data from three sections through the Bowland Shale in the Craven Basin (Lancashire, UK) to explore the links between controls on hydrocarbon and metal prospectivity. The Bowland Shale at these sites is a highly heterogeneous and complex ~120 m thick succession comprising carbonate-rich, siliceous and siliciclastic, argillaceous mudstones. These sedimentary facies developed in response to a combination of high-frequency (~111 kyr) sea level changes, fault activity at the basin margins and linkage with the nearby prograding Pendle delta system.

Palaeoredox proxies such as Fe-speciation, redox-sensitive trace elements and S isotope analysis from extracted pyrite ($\delta^{34}S_{py}$) demonstrate intervals associated with metal enrichment were deposited under anoxic and at least intermittently euxinic (sulphidic) bottom water conditions. Trace element enrichment 'V scores' (sum of V+Mo+Se+Ni+Zn in ppm) indicate the greatest enrichments in these key transition metals and non-metals are associated with deposition under strongly sulphidic conditions during marine transgressions. V scores in these intervals are often >400 ppm and sometimes >1000 ppm. These bulk enrichments are comparable to stratiform low-grade ores such as the Upper Mudstone Member of the Devonian Popovich Formation (Nevada, USA). Hosts for these metals likely include solid sulphides such as pyrite, organic matter and possibly phosphates or carbonates.

Critically, a process of switching between ferruginous and euxinic conditions in anoxic porewaters, termed 'redox oscillation', is recognised by a distinctive redox-sensitive trace element enrichment pattern, particularly competition between V and Ni metalation. Redox oscillation operated during periods of reduced sea level, where an increased supply of reactive Fe to the basin promoted development of intermittently ferruginous conditions in bottom waters and early diagenetic porewaters. Therefore the distribution of many redox-sensitive elements through the Bowland Shale is predictable. If these elements can be efficiently extracted from the mineral or organic hosts, UK Mississippian black shales may represent a significant resource. This work also improves understanding of the potential for co-extraction of metals during hydraulic fracturing, or during remediation of waste water. Future work will seek to understand which minerals or organic compounds host these redox-sensitive trace elements.

Notes

Carbon capture and storage on the East Irish Sea Basin

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Carbon Capture and Storage (CCS) is a key technology towards a low-carbon energy future and will have an important role on the economic future of the UK Continental Shelf (UKCS). The East Irish Sea Basin (EISB) is a prospective area for CCS in the western UKCS, with a CO_2 storage potential to store over 1.7 Gt. 3D seismic data and borehole information from the EISB were used in this study to characterise the structural network of the EISB, carbon storage sites and potential CO_2 leakage risks associated with them. Two main structural domains are present: a Northern domain with NW-SE faults, and a Southern domain with faults following a N-S orientation. Faults trending E-W are scarce but present in both domains. The basin compartmentalisation is variable. Lower degrees of compartmentalisation occur on the Northern domain where larger, widely spaced faults have developed. The main storage units occur in Triassic strata of the Sherwood Sandstone Formation (SSF), primary aimed at using depleted hydrocarbon reservoirs and with additional storage potential in closures in saline aquifers. These closures occur predominantly at fault-bounded horsts, with adjacent grabens filled by thick sequences of the Triassic Mercia Mudstone Group (MMG), the main caprock for reservoirs in the region composed of alternations of mudstones and evaporites. However, the theoretical storage capacity of the EISB does not regard a secondary storage potential in the lower Permian Collyhurst Sandstone Formation (CSF). On the southern basin domain, numerous fault-bound blocks limit the lateral continuity of the sandstone strata, while on the northern domain the sandstones are intersected by only a few low offset faults. The caprock for the Collyhurst sandstones is variable as the Manchester Marls predominate in the south, transitioning to the St. Bees evaporites towards the north. Collyhurst closures to the north underlie large Triassic storage sites, and the spatial overlap favours storage plans including secondary storage units in the EISB. The 3D fault framework was used for stress modelling and to assess the potential risk of CO_2 leakage in the basin. Stress orientations and magnitudes were obtained from published literature and available borehole data. Calculations derived from well data indicate vertical stresses in the target intervals of interest for CO_2 storage between 18 (Triassic) to 40 MPa (Permian), for pore pressures between 9 and 18 MPa. Under regional stress conditions, easterly-dipping faults show increased slip tendencies, especially within shallower intervals. However, slip tendency values were predominantly below 0.6 (the theoretical value for onset of failure) at depth, suggesting the presence of stable structures in the EISB. Regional stress modelling of faults adjacent show a limited tendency for fault reactivation, capable to retain increase of pressure of 9 to 14 MPa before the onset of slip. The results suggest that leakage risks for CCS operations in the East Irish Sea Basin are limited.

Notes

Quantifying geological CO_2 storage security to deliver on climate mitigation

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Carbon Capture and Storage (CCS) can help nations meet their Paris CO_2 reduction commitments cost-effectively. However, lack of confidence in geologic CO_2 storage security remains a barrier to CCS implementation. Leak rates of 0.01% yr^{-1}, equivalent to 99% retention of the stored CO_2 after 100 years, are referred to by many stakeholders as adequate to ensure the effectiveness of CO_2 storage. Secure storage must allow global average temperature increases, driven by excess CO_2, to remain well below 2°C; these timescales are typically modelled to be 10,000 years. Thus, leakage rates must remain below an average linear rate of 0.01% yr^{-1} for that timespan.

Many studies that assess global industry-wide risk of subsurface gas leakage do not specifically consider subsurface CO_2 retention mechanisms, despite experimental measurements showing that residual trapping may immobilise a significant proportion of the CO_2 almost immediately on injection. The published studies that incorporate subsurface CO_2 retention into their risk assessments are for site-specific, real or hypothetical, hydrogeological models, rather than industry-wide, regional, or global scenarios.

Here, we present a numerical program that calculates CO_2 storage security and leakage to the atmosphere over 10kyr. This links processes of geologically measured CO_2 subsurface retention (residual and dissolution trapping), and CO_2 leakage estimates (based on measured surface fluxes from appropriate analogues). We model 12 $GtCO_2$ of cumulative storage based on the EU's 2050 target, commencing injection in 2020, and calculate CO_2 retention for well-regulated onshore and offshore scenarios, and for a hypothetical onshore, poorly regulated scenario.

The Storage Security Calculator (SSC) is a tool to simulate the long-term (10kyr) security of CO_2 storage at a basin scale. Simulations show that CO_2 storage in regions with moderate abandoned well densities and that are regulated using current best practice will retain 96% of the injected CO_2 over 10,000 years in more than half of cases, with maximum leakage of 9.6% in fewer than 5% of cases. Poorly unregulated storage is less secure, but over 10,000 years, less than 27% of injected CO_2 leaks in half of the simulations; up to 34% leaks in just 5% of cases.

This leakage is primarily through undetected and poorly abandoned legacy wells, and could be reduced through effective leak identification and prompt remediation of leakage. Natural subsurface immobilisation means that this leakage will not continue indefinitely. Regulators can most effectively improve CO_2 storage security by identifying and monitoring abandoned wells, and perform reactive remediation should they leak. Geological storage of CO_2 is a secure, resilient and feasible option for climate mitigation even in overly pessimistic poorly regulated storage scenarios and thus CO_2 storage can effectively contribute to meeting the Paris 2015 target.

Notes

Subsurface capacity for energy storage onshore and offshore UK: CO2, CAES, Hydrogen

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Since the dawn of the Industrial Revolution in the 1600s, and acceleration in the 1700s, the UK has relied upon domestic fossil fuel extraction to power its industry and provide benefits for its citizens. It is now clear that the consequences of carbon emissions from fossil and biological sources are unsustainable, and a Technological and a Just transition to supply electricity heat and transport through different energy vectors is underway. In these same decades, from 2000 to 2050, it is also becoming clear that commercial resources of UK fossil fuels have a rapidly emerging end. That has severe implications for UK energy security, and especially for energy storage on hourly to seasonal timescales, which have never before needed to be solved. We compile here the results of three high-level assessments of the U.K.'s subsurface to host large quantities of energy related fluids.

CO2 disposal in sediments beneath the seas surrounding the UK has been assessed in detail to commercial quality readiness. Most-probable estimates predict about 70 Billion tonnes of CO2 storage capacity. This is predominantly in sandstones which form, and lie between, the well understood hydrocarbon accumulations of the UK offshore. Immense datasets of more than 10,000 boreholes, and dense arrays of seismic reflection data make the UK a uniquely suitable place in the world to undertake accurate and precise assessments of CO2 site performance. Expectations are that the UK could store CO2 produced during the next 100 to 300 years, depending on emissions reductions due to efficiency. 98% of that CO2 will remain securely stored 10,000 years into the future. This has produced a unique database www.CO2stored.com constructed by universities, the British Geological Survey, and energy consultancies.

The CO2 stored database has been used to appraise most feasible offshore sites for CAES, compressed air energy storage. We have taken a probabilistic range of assumptions for performance, linked to engineering design criteria for a range of efficiency in injection and in reproduction of the energies. We find that a substantial resource exists in the UK offshore, but that overall efficiency, and in particular the requirement to co-fire with methane or another energy vector during CAES recovery means that this storage method is less effective than anticipated. Nevertheless a substantial resource exists which can undertake seasonal storage equivalent to the entire UK electricity supply for several months. In particular locations, there are favourable coincidences of suitable CAES close to sites of offshore renewable energy generation. This makes private wire networks feasible, and could improve efficiency, and greatly improve economics.

The CO2 stored database has been used to appraise the most feasible offshore sites for hydrogen storage. Instead of focusing on a restricted geography of suitable salt, we have expanded our search to encompass all porous media, but concentrating on discrete structures. We find that there is an immense capacity for offshore hydrogen storage which could satisfy UK demand for all energy (not just for electricity) for several years. This means that a large optionality is possible in choosing clusters of storage sites to develop. We have also examined onshore settings for hydrogen storage, and find several promising structures which can provide regional storage and heat buffering for days to many weeks.

Clearly, there will be conflicts of use which need to be negotiated between these three options.

Notes

Europe's cobalt resource potential for supply to low-carbon vehicles

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Transport is the largest contributor of greenhouse gas emissions in the UK [1].The decarbonisation of transport is led by electric vehicles (EVs) and their deployment has increased rapidly over the past few years. More than 3 million electric cars are currently in stock globally and an EV year-on-year sale increase of 54% was recorded in 2017 [2]. Several countries are aiming to reduce or ban petrol and diesel vehicles in the future, as a contribution to decarbonisation of the planet [2]. As a consequence there is increasing demand for Li-ion batteries used in EVs, which contain several metals, including lithium, cobalt, nickel and manganese. Hence, the demand for cobalt, which is widely classified as a critical metal, is expected to grow exponentially [2, 3]. More than 50% of world mine production is from the Democratic Republic of Congo (DRC), some of which is linked to human rights abuses [4, 5]. Furthermore, DRC's new mining code, which introduced higher royalties and taxes on raw materials in 2018, has increased the economic concerns of mining companies and threatened future investment in the country [6]. On the contrary, Europe accounts for less than 1% of global cobalt production and is highly dependent on imports [4].

In order to facilitate future cobalt supply for the battery sector and support responsible sourcing new BGS research aims to analyse the supply chain in Europe and identify the future global demand for cobalt with a focus on the EV battery sector. Europe's cobalt potential will be assessed, including both primary resources in nickel and copper deposits, but also in unconventional resources such as shales and waste streams, which can increase the European cobalt resource base and provide important environmental gains.

The project will deliver a dynamic material flow analysis (MFA) model for cobalt in Europe. Mapping of current stocks and flows will help to illustrate the supply chain for cobalt. Subsequently, scenario analysis based on the MFA model will attempt to forecast demand and identify the need for additional sources of supply from primary and secondary raw materials.

Geological investigations will include a review of primary cobalt resources in Europe, such as in nickel-copper sulphide and sediment-hosted copper deposits which are the main global sources of cobalt. Furthermore, the concentration and distribution of cobalt in secondary resources, such as copper slags, will be targeted because improved extraction and recovery technologies have significant potential for reprocessing them [7, 8]. Data from geological investigations will be used to inform the MFA model and scenario analysis.

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Run-of-the-River Micro Hydro Power – Feasibility and Value

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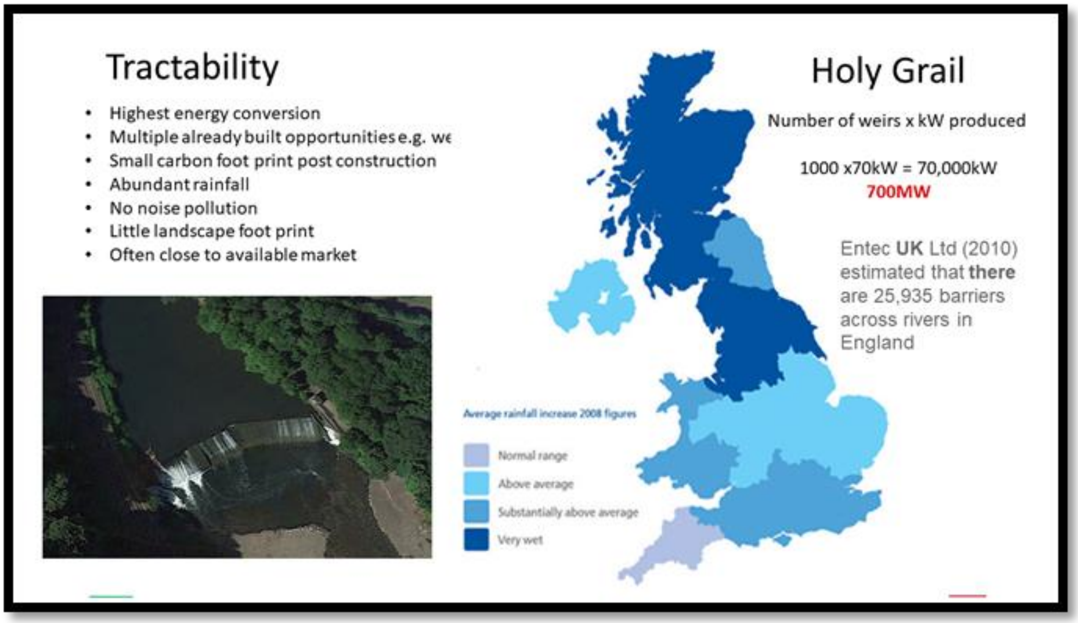
In the past the UK energy system has been dominated by mega power systems with centralized power generated by large coal or nuclear power stations. As the implication for global warming are starting to be realised, together with government supported financial schemes, small scale community energy projects have become a viable option. The UK government is committed to reducing Greenhouse Gases (GHG) by 15% by 2020 and has identified eight technologies capable of delivering more than 90% of renewable energy, one of which is small scale hydroelectric power.

The UK currently (2011) generates 1.5% of its electricity from hydroelectrical power, and although most of Britain's large-scale development potential has been already exhausted, there is much scope for exploiting small scale resource such as run-of-the-river schemes. The technology associated with hydropower is a mature, well established, and a cost-effective way to produce renewable energy and store energy to help balance between demand and supply. This balance will become increasingly important as more energy is produced from fluctuating supplies such as solar and wind. As of 2011, the UK generated 5.9TWh, up 26% on the previous year of its electricity from hydroelectric schemes, with small hydro capacity currently producing 100MW, with an estimated 400MW of potential energy still to be exploited.

Run-of–the-River Hydro electricity generation, utilizes the natural flow of the river. The potential of a river is often described in terms of the head of the river, and this is the vertical distance that the water descends along a slope. The kinetic energy is captured from the extracted water, as it flows from a high point to a micro turbine generator. The energy produced is the most efficient renewable source of electricity, having an energy efficiency of between 80-90%. In small-scale hydro schemes there is little to no water stored, with no need for a dam or a barrage needed to be built especially if small weirs are utilized.

Weirs are common features in UK rivers, and were designed to form a barrier in order to alter the flow characteristics by pooling water behind them, whilst letting the river flow steadily over the top. The purpose of the weir was often to stabilize the river grade, prevent flooding and provide a point in the river to measure river velocities. These well-established structures were often built in the 18th Century and today could provide ideal potential for small hydro schemes around Britain. In general, the Run-of-the-River systems have an installed capacity of between 5kW to 1 MW, and with an efficiency of over 80%, it remains one of the most cost efficient forms of renewable energy. This cheap form of energy generation is believed to be a potential solution to provide off grid energy in urban areas.


Tractability
Highest energy conversion
Multiple already built opportunities e.g. we
Small carbon foot print post construction
Abundant rainfall
No noise pollution
Little landscape foot print
Often close to available market
Holy Grail
Number of weirs x kW produced
1000 x70kW = 70,000kW
700MW
Entec UK Ltd (2010) estimated that there are 25,935 barriers across rivers in England
Average rainfall increase 2008 figures
Normal range
Above average
Substantially above average
Very wet

Notes

Assessing the feasibility of the "all-in-one" concept in the UK North Sea: offsetting carbon capture and storage costs with methane and geothermal energy production through reuse of a hydrocarbon field

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In order to limit anthropogenic warming to 2 °C above pre-industrial levels as per the Paris agreement, carbon capture and storage (CCS) must become a widespread industry by the middle of the century (Azar, Johansson and Mattsson, 2013; Scott *et al.*, 2013; IEA, 2014; IPCC, 2014). However, the initial capital costs of CCS are currently obstructing its development. Offsetting costs through enhanced oil recovery has had some success globally (IEA, 2015) and recent research suggests that the co-production of methane and geothermal energy could also prove financially viable (Bryant and Pope, 2015; Ganjdanesh and Hosseini, 2016). This system produces brine from with methane and geothermal energy are extracted and sold before dissolving captured CO_2 in the brine and reinjecting it into the subsurface where it sinks due to its relatively higher density, providing secure storage.

Here we build on this previous work and investigate an "all-in-one" system with onsite energy production and carbon capture and use Monte Carlo analysis to establish the energy balance of such a system using a depleted hydrocarbon field in the Inner Moray Firth of Scotland. The site was chosen to determine if this system would be viable in an area without the ideal deep, hot, geopressured aquifers proposed in (Bryant and Pope, 2015; Ganjdanesh and Hosseini, 2016) by reusing existing oil & gas infrastructure.

A combination of production data, well logs, end of well reports, and solubility data was investigated to produce a set of different scenarios. Firstly, the potential methane saturation was established by comparing theoretical saturation curves with evidence from oil & gas data. This allowed a calculation of the potential volumes of methane that could be extracted and sold. The second scenario considered using the methane to produce electricity onsite and exporting it to be sold into the UK national grid. The third scenario was for carbon storage only, and calculated the storage potential for the selected site. Finally, a full energy balance was calculated including brine production, electricity production, carbon capture, and carbon injection.

In the methane production scenario we find that when production costs are taken into account, the sale value of methane per m^3 brine is negative, with losses ranging between 2.7 and 1.3 $£_{2017}$. Similar results were found for the electricity production scenario with losses between 2.1 and 0.3 $£_{2017}$. However, when geothermal energy is taken into account alongside carbon capture and storage with produced electricity also used to run the system, the energy balance is positive in almost all cases with the minimum negative at 0.3 and the first quantile positive at 1.6 $£_{2017}$. The production costs used for these calculations were for oil production and so brine production figures are likely to be much lower.

The carbon storage potential for the depleted oilfield was between 18 and 26 million tonnes which would be enough space to store the CO_2 captured from a 500 MW power plant for around 20 years, assuming around 1 million tonnes captured per year. The amount of CO_2

produced by the "all-in-one" system requires less than 10% of the available 'space' in each m^3 of brine which opens up the system to outside sources of CO_2 for disposal for which it could charge.

An "all-in-one" system reusing existing oil & gas infrastructure is highly likely to have a positive overall energy balance with extra space available for disposal of outside sources of CO_2. This re-use of infrastructure and positive energy balance suggest that such a system could overcome the financial barriers to development of a carbon storage industry in the North Sea and would be more cost effective than current plans for decommissioning.

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Mine water: a sustainable renewable energy resource?

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Decarbonisation of the heating sector is one of the major challenges in the drive to meet legally binding climate change targets and to reduce the UK's vulnerability to global environmental or geo-political events. Currently only 5.6% of the UK heat requirement comes from renewable sources[1] which is less than half of the 2020 target of 12%. The main challenge in reaching the target is the limited availability of renewable heat source options.

One of the potential options is geothermal energy; traditionally this has been assumed to mean deep, high enthalpy sources for electricity generation. However, low enthalpy, direct use sources are increasingly being recognised[2], in particular those which are shallower and more accessible from the surface. A study commissioned by the Scottish Government into the geothermal energy potential in Scotland, found that 1/3rd of Scotland's heat requirement could be obtained from shallow sources, specifically abandoned mine workings[3].

Obtaining heat from flooded abandoned mine workings is comparable to a ground source heat system, where the high heat capacity of groundwater is utilised in combination with heat pumps to provide heating or hot water. Historical mining has created reservoirs with enhanced permeability and with a large rock-water interface for heat transfer to produce a sizeable potential heat source[4].

The enhanced permeability and resource availability are not the sole reasons mine workings are attractive as potential energy sources. Abandoned mines are generally located near urban areas and this close proximity, of heat source to user, enhances the efficiency of the resource. Over 60% of Scotland's population live in the central lowlands which is also where the main collieries were situated.

This is not a new concept, existing mine water heat systems have been in use since at least the 1980s[5] with schemes operating in Scotland from 2000[6]. Research into these systems has primarily focussed on the sustainability of the resource, in particular on deep total extraction (longwall) mines. This poster details current research being undertaken into the resource potential of shallow (pillar and stall) mine workings where columns (pillars) of coal maintain stability.

Utilising abandoned mine workings as a renewable energy source will result in changes to the underground flow, pressure and heat regime. These changes could exacerbate pillar deterioration, reducing their capacity to support the overlying strata and ultimately lead to pillar failure.

Results of coupled thermal-mechanical-hydraulic modelling into the effect of heat extraction on the pillars will be presented. The modelling code OpenGeoSys has been used to understand the controls on the geomechanical properties of coal pillars, in particular how different material types can impact the underground stress distribution.

One of the aims of the research is to determine whether the overlying geology influences the risk of surface subsidence from mine water heat schemes. The intention is to create a hazard map which could form an important part of the risk assessment process into the viability of this type of renewable energy scheme, in turn reducing some of the developmental barriers.

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Notes

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Ground Floor Plan of the Geological Society, Burlington House, Piccadilly