I·M3
Institute of Materials, Minerals & Mining

Conference 2021

Mining Technology
I·M3

LEGACIES OF MINERAL EXTRACTION AND SUSTAINABILITY OPPORTUNITIES

Organised by Mining Technology technical community as a Celebration of the Reopening of Neville Hall, Newcastle-upon-Tyne, Home of North of England Institute of Mining and Mechanical Engineers and The Common Room

10-11 November 2021

Record of Proceedings

IOM3 CONFERENCE 2021 - LEGACIES OF MINERAL EXTRACTION AND SUSTAINABILITY OPPORTUNITIES

Organisations donating to the conference

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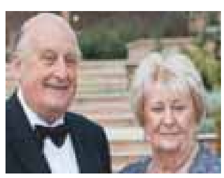

Sir John and Lady Mae Hall

Forward

The north of England has had an enormous influence on the development of the world through the Industrial Revolution – coal that powered Britain's global reach, the development of the railways, modern industry…yet among the grime and poverty of coal miners, a group of mining engineers, colliery owners and other stakeholders decided to do something about the horrendous accident rate and appalling conditions underground.

Quoting from the Institute, at a meeting of "colliery owners, viewers, and others interested in the Coal Trade" on 3 July 1852, it was proposed to form a society to discuss the ventilation of coalmines, prevention of accidents and other items connected with the general working of coalmines. It was to be called "The North of England Society for the Prevention of Accidents and for other purposes connected with mining".

It is my pleasure to write the forward for a set of papers on such diverse topics as coal mine reclamation, environmentalism and sustainability, renewable energy, mine planning and mine safety. Although the mining industry has shrunk to a handful of mines, the UK's mining professionals and research institutes remain in the vanguard of the world-wide mining industry. The Conference is a celebration of the reopening of the historic Neville Hall following a complete refurbishment of the building with the aid of Heritage Lottery and public funding. The building and assets are now being protected by a newly created charity: The Common Room of the Great North Limited. The North of England Institute of Mining and Mechanical Engineers (NEIMME), which celebrates its 170th anniversary in 2022, will retain its office and use of facilities in the building. The event demonstrates how sustainability can be achieved by modernistic thinking and cooperation in this case IOM3, local society (NEIMME) and the Common Room Team working together with a common theme.

The UK Government wants the country to be a world leader in a green revolution especially in renewable energy, and aims for it to be carbon-neutral by 2050. It may seem at first counter-intuitive, but it is good news for the mining industry. For instance, storage batteries, essential for electric vehicles and renewable energy, require lithium, copper, nickel and cobalt, and according to the World Bank, the demand for lithium is predicted to be five times the current level by the middle of the century. From industry sources, the construction of an individual commercial 3 MW wind turbine uses around five tonnes of copper, three tonnes of aluminium and 300 tonnes of steel, complex plastic resins for the blades, and over 1,000 tonnes of concrete for the base.

Most new mines take over 15 years to come onstream, and hence the downside is that mines may struggle to match demand - then metal prices will rise. In time the industry will expand to meet demand and the danger then is increasing environmental damage and a rise in greenhouse gas emissions as more metals are mined. Mining must meet the challenge by improving its environmental performance, reduce its dependence on fossil fuels, and to fully develop its sustainability programmes – and to action them.

Mining is only one part of the supply chain from the producer to the landfill. Product life cycles must be improved by redesign, re-use and increased efficiency of recycling, which for most metals is well below 10 percent.

Legislators and regulators must also raise their game to allow minerals to be mined to drive the green revolution. All too many mines are refused permits to operate.

Christine A Blackmore BSc MSc CEnv CSci FIMMM
IOM3 Vice President and Mining Technology Group Chairman

Day One Programme (10 November)

09:00 – 10:00	Registration & tea/coffee
10:00 – 10:10	Welcome
Christine Blackmore, Chair, Mining Technology Board	
10:10 – 10:30	Opening Address
Darryn Quayle, Mining Specialist, Department of International Trade, UK Government	
10:30 – 11:00	Keynote Presentation: Mine Energy Task Force
Andrew Clark, Energy Programme Lead, North East Local Enterprise Partnership	
11:00 – 11:30	Tea/Coffee Break
11:30 – 13:00	Session 1: New life for old mine sites (1)

Chair: Paul Bradley, Mining Technology Board

	Presentations	Author(s)
A	Making the most of abandoned mines: the Ecton Mine Educational Trust	J Barnatt, S Henley, P Kennett & R Shaw
B	The use of void space created by mining activity for beneficial purposes	S Reece
C	Circular Economy: Bates Clean Energy Terminal	M Lawlor, J Gluyas, C Lambert, C Adams, T Chaplin & N Jackson

13:00 – 14:00	Buffet Lunch
14:00 – 15:30	Session 2: New life for old mine sites (2)

Chair: Alan Auld, Mining Technology Board

	Presentations	Author(s)
D	Energy storage for mining legacies: Facilitating the green revolution	C Yendell
E	Carbon Capture, Use and Storage: UK potential	J Gluyas, S Daniels & V Hunn
F	Integrated mine planning leading to sustainable post-mining transition	R Schmitz, M Dusar & D Habisch

15:30 – 16:00	Tea/Coffee Break
16:00 – 17:45	Session 3: An international commentary

Chair: Liz Mayes, Chief Executive, The Common Room

	Presentations	Author(s)
G	Managing legal risks in mining projects: Lessons learned from the International Arbitration of Disputed Mining Projects	L de Germiny & E McConaughey
H	Legacies of mining in community perception: Recognition and reconstruction in mine reopening	A Cisneros
I	Developing and sustaining competence in safety critical roles	K Sabin
J	Sustainable nickel for a low carbon future	A Oxley

19:00	Buffet Supper & Entertainment (Ashington Colliery Brass Band) Compère: Norman Jackson

Day Two Programme (11 November)

08:00 – 08:45	Registration & tea/coffee
08:45 – 08:50	Welcome
David Seath, Mining Technology Board	
08:50 – 09:10	J F Tunnicliffe Medal
John Tunnicliffe, Past President, IMinE	
09:10 – 10:40	Session 4: Mine water management

Chair: Jon Gluyas, Executive Director, Durham Energy Institute

	Presentations	Author(s)
K	Mine Water: A potentially important heat source	N Jackson & C Adams
L	Research and innovation opportunities for mine water and heat storage at the UK Geoenergy Observatory in Glasgow	A Monaghan, V Starcher, H Barron, F Fordyce, H Taylor-Curran, R Luckett, K Shorter, K Walker-Verkuil, J Elsome, O Kuras, C Abesser, R Dearden & M Spence
M	Coal mine water management: Improving approaches through evidence and experience	A Mellor, L Wyatt, A Moorhouse, C Satterley & I Watson

10:40 – 11:10	Tea/Coffee Break
11:10 – 12:40	Session 5: New life for old mine sites (3)

Chair: Charlotte Adams, Commercial Manager, The Coal Authority

	Presentations	Author(s)
N	Glenmuckloch Energy Project	A Wilson
O	The changing societal and environmental expectations: Implications and impacts for the mining industry	P Bradley
P	Breathing new life into abandoned mines: The Robominers Project	L Lopes, B Bodo, C Rossi, G Stasi, S Henley, V Correia, A Kot-Niewiadomska, J Aaltonen, N Sifferlinger, N Zajzon, G Zibret & M Kruusma

12:40 – 13:30	Buffet Lunch
13:30 – 15:15	Session 6: Impact of mining legacy on surface development

Chair: Steve Martin, President, NEIMME

	Presentations	Author(s)
Q	The Coal Authority's role in facilitating redevelopment of sites impacted by coal mining and the promotion of a safe, assured and sustainable future	L Sharpe, M Lindsley & C Adams
R	Identifying challenging ground hazards for remediation and land development: A Case Study of a site affected by over 300 closely spaced bell pits, NW Leicestershire	R Hurcombe & A Brown
S	The challenges of managing access to the Coal Authority underground mine and mineral property portfolio	D Hurst, C Adams, S Leeming, S Walker & K Deeming
T	Our mining history: Assessing the risk to our national infrastructure	S O'Neill

15:15 – 15:30	Session 7: Closing Remarks

Christine Blackmore, Chair, Mining Technology Board

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MAKING THE MOST OF ABANDONED MINES: THE ECTON MINE EDUCATIONAL TRUST

John Barnatt, Stephen Henley, Peter Kennett and Richard Shaw (Ecton Mine Educational Trust)

Abstract

The Ecton mines, in the south-west part of the Peak District National Park, were major producers of copper and lead in the 18th and early 19th centuries, with zinc also produced later in the 19th century. Underground mining had ceased by 1890 and the workings have long been flooded to river level, but with still accessible passages above here. The late Geoff and Elizabeth Cox developed Deep Ecton mine as an educational resource in the late 20th century, and generously bequeathed it to a charitable trust (EMET) which has continued and expanded this role.

Deep Ecton mine is designated by Historic England as a Scheduled Monument and it is a geological SSSI, while the surrounding hillside is an SSSI for its ecology. The Ecton mines are now the focus for a wide range of educational and research activities, including:

- Formal education, mostly led by volunteers in EMET's sister organisation the Ecton Hill Field Studies Association: one-day field courses (surface and underground) at primary, secondary (GCSE and A-level), and university levels, for applied geology and chemistry
- Informal education: U3A, National Trust, and other organisations
- Archaeological studies in and around Ecton Hill exploring the date and character of the mine workings
- Provision of research facilities: recent projects have included geology, ground-penetrating radar, isotope geochemistry, laser profiling, and microseismic
- Joint EU projects: UNEXMIN, UNEXUP: submersible robot exploration of flooded sections of the mine; follow-up work at Keele University
- Activities: supervised access for caving groups and mine history societies, always with a significant educational component

EMET maintains a well-equipped study centre, land around the mine portals, the main underground mines themselves, and also has safety obligations (at least 40 known shafts and adits, many within the Trust's mineral ownership). All work by the Trust is provided by volunteers, including several active minerals industry professionals, providing on-going links with the industry and professional institutions including IOM3.

Introduction

The Ecton mines, comprising a group of mines and exploration on a high ridge to one side of the valley of the River Manifold, within Staffordshire, in the south-west of the Peak District area underlain by Lower Carboniferous limestones, were exploited for copper, lead and zinc. Maximum production rates were achieved during the second half of the 18th century, but working had ceased altogether by the late 19th Century

By far the most important of these mines, in terms of mineral production, was Deep Ecton Mine, in the northern part of Ecton Hill (Figure 1). Although this mine produced large tonnages of several metallic ores, it was its copper production that was economically the most important and Deep Ecton is commonly referred to as a copper mine.

Deep Ecton was mined to a depth of over 300 metres (1000 feet) below the main adit level, but flooded to river level after cessation of most production in the 1850s. However, some upper workings remain accessible and two levels are regularly entered. The upper one of these, Salts Level, is now used as an integral asset in teaching programmes for schools and universities as well as educational visits by the National Trust and other organisations.

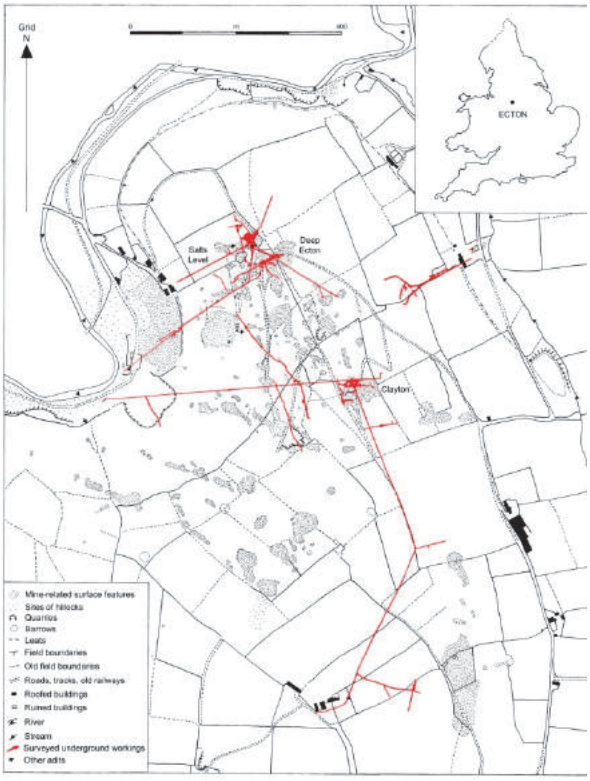

Figure 1: Ecton Hill and the location of the main underground workings at river level, and also of Salts Level *c.* 35m above Deep Ecton Adit.

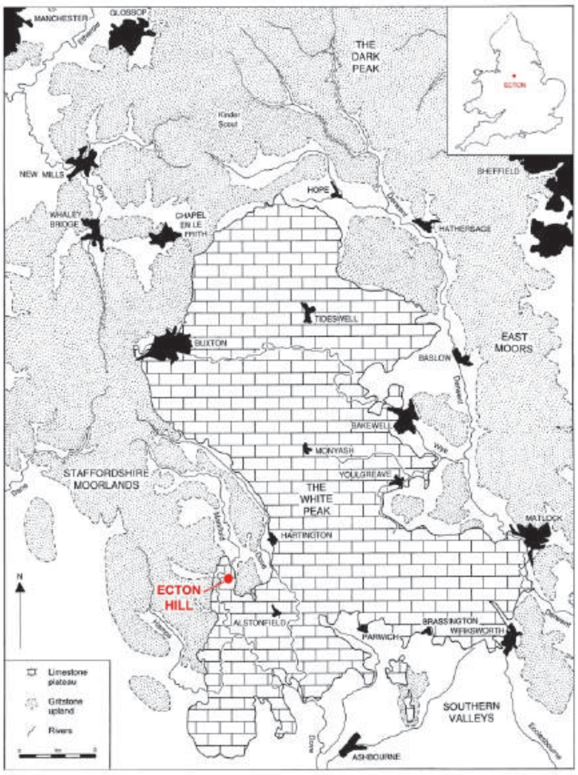

Figure 2: Location of Ecton Hill relative to the 'White Peak' Lower Carboniferous limestone inlier.

The presence of a large proportion of copper ore is very unusual for a mine within the south Pennines region of "Mississippi Valley" type lead-zinc mineralisation, and combined with tectonic deformation which is unusually intense for rocks of this age in central England, makes Ecton a particularly interesting target for geological research.

The Deep Ecton adit, at river level, 35 metres below Salts Level, is important for its range of accessible geological and mining technology features. The workings at this level are considerably more extensive than in Salts Level, and access is normally restricted to *bona fide* researchers. The two levels are connected underground by a ladderway within the 'pipe' workings in the steeply dipping ore body which originally hosted most of the mineralisation, and which extended to the full depth of the mine.

Geology

The Ecton Mines are located to the south-west of a Lower Carboniferous limestone inlier in central England (Figure 2), sometimes called the 'Derbyshire Dome' which represents a shallow-water lagoon surrounded by a ring of reefs. Ecton lies outside the lagoon and is hosted by limestones and shales of a deeper water facies.

The geology is documented in detail by Ford (2000), and Porter (2004) and has been reviewed recently (Shaw 2020). The primary mineral deposit consisted of copper and other metal sulphides in a near vertical 'pipe' and associated fracture-filling veins, within a Lower Carboniferous deep-water (predominantly) limestone sequence. The mine was a major producer of copper, as well as lead and zinc, in the second half of the 18th century, with production at lower volumes continuing until the 1850s. The deeper parts of the mine were abandoned and the pumps were stopped in 1855, and the mine had flooded to river level by 1858.

The Deep Ecton Mine is situated within Ecton Hill which comprises a sequence of mainly limestone strata of Dinantian (Lower Carboniferous) age.

In the Ecton area the Dinantian limestones are divided into four units (Aitkenhead et al, 2002):

- Mixon Limestones with Shales (Brigantian)
- Ecton Limestones (Asbian)
- Milldale Limestones (Chadian and Arundian)
- Rue Hill Dolomites and Red House Sandstones (Courceyan)

The oldest of these beds, the Rue Hill Dolomites/Red House Sandstones, are only exposed several kilometres to the south of Ecton but are probably present at depth beneath Ecton Hill. It is unlikely that they were reached by the Deep Ecton or Clayton Mine pipe workings both of which went for 300m below river level.

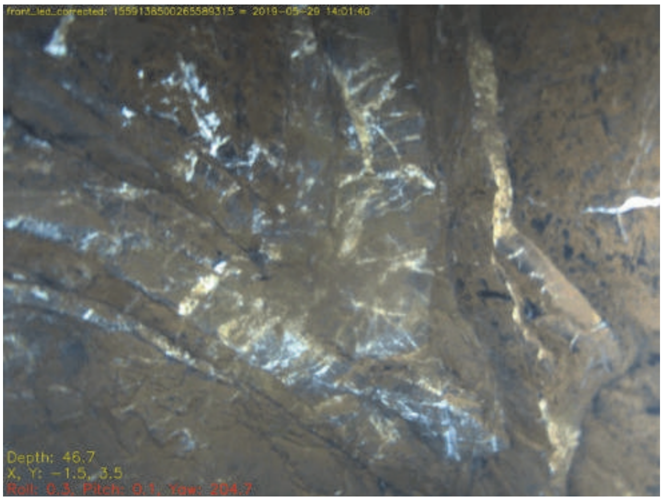

Figure 3: Tight syncline in limestone at 46m depth below water level in the Ecton winding shaft

On the macro scale, Ecton Hill is an asymmetric anticline that plunges to the north with a steep dipping eastern limb and a more gently dipping western limb.

Tight small scale folding (Figure 3) is a feature of Ecton within the more thinly bedded beds, particularly around the anticlinal crest zone, and such folds are well exposed at Apes Tor at the north end of the hill, as well as within the underground mines. The miners referred to these small folds as ‘huckle saddles’ (anticlines) and ‘trough saddles’ (synclines) (Watson; 1860).

Ford (2000) describes three types of mineral deposit at Ecton. These are:

- Lodes – steeply dipping to near vertical fissure veins perhaps occupying faults;
- Saddles – Ores deposited in the limbs and joints of the smaller scale fold structures;
- Pipes – The main ore deposits at Ecton are more or less cylindrical features, steeply inclined and cutting through the strata.

The principal metallic minerals at Ecton are chalcopyrite, galena and sphalerite with some pyrite. The major gangue minerals are calcite, fluorite and barite. There are a large number of minor primary and secondary minerals present, including malachite and azurite. These are described by Ford (2000).

The mineral assemblage and the tectonic setting make Ecton an unusual mine for what is otherwise a typical Mississippi Valley mineral province typified by lead, zinc, fluorite and barite mineralisation within veins and paleokarst cavities in weakly deformed limestone. Even though there is now almost no copper (or any other metallic ore) to be seen after the mine was stripped of all visible ore during the 19th century, the geological evidence that remains is still of great value to researchers, and is key to interpreting the regional geological history.

History and archaeology

Deep Ecton Mine was one of the most important copper mines in Britain in the 18th century. Here there are large flooded workings that extend down to over -300m below river level (Meads, 1858; Figure 4). These had not been seen since the later 1850s after the mine pumps were turned off, until the UNEXMIN project provided information on some of the flooded workings by the use of robot submersibles (see below). The accessible underground passages above the water, and the surface remains, are of national importance as archaeological features that tell of the long history of mining at Ecton and the then ‘state of the art’ mine developed for the Duke of Devonshire in 1760-90.

The history of the Ecton Mines and what survives today have been described in detail by Porter and Robey (2000), Porter (2004) and Barnatt (2013; 2020b). We now know that copper mining here started just under 4000 years ago in the Bronze Age (Timberlake 2014). Lead was mined at small scale in medieval times and miners again became interested in the copper in the 17th century AD. With the dewatering of the 'pipe' deposits in the 1720s-30s by a company of 'Adventurers', who drove the Deep Ecton Level from next to the River Manifold, exceptionally rich mineral deposits at the heart of the hill were first discovered. The Duke of Devonshire took the mining 'in-house' in 1760 and for the next 30 years earned a small fortune. By 1790 the 'pipe deposits had been followed vertically downwards to about 220m, where they 'failed' at depth; below here they were significantly more constricted and became uneconomic. In the first two decades of the 19th century an adjacent deposit, at Clayton Mine, was also followed down to depth. The rest of the nineteenth century was a period when a series of private mining companies tried their luck at Ecton, with funding from investors who knew of Ecton's profitable past history. These were all short-lived ventures that were wound up once shareholders' money was gone.

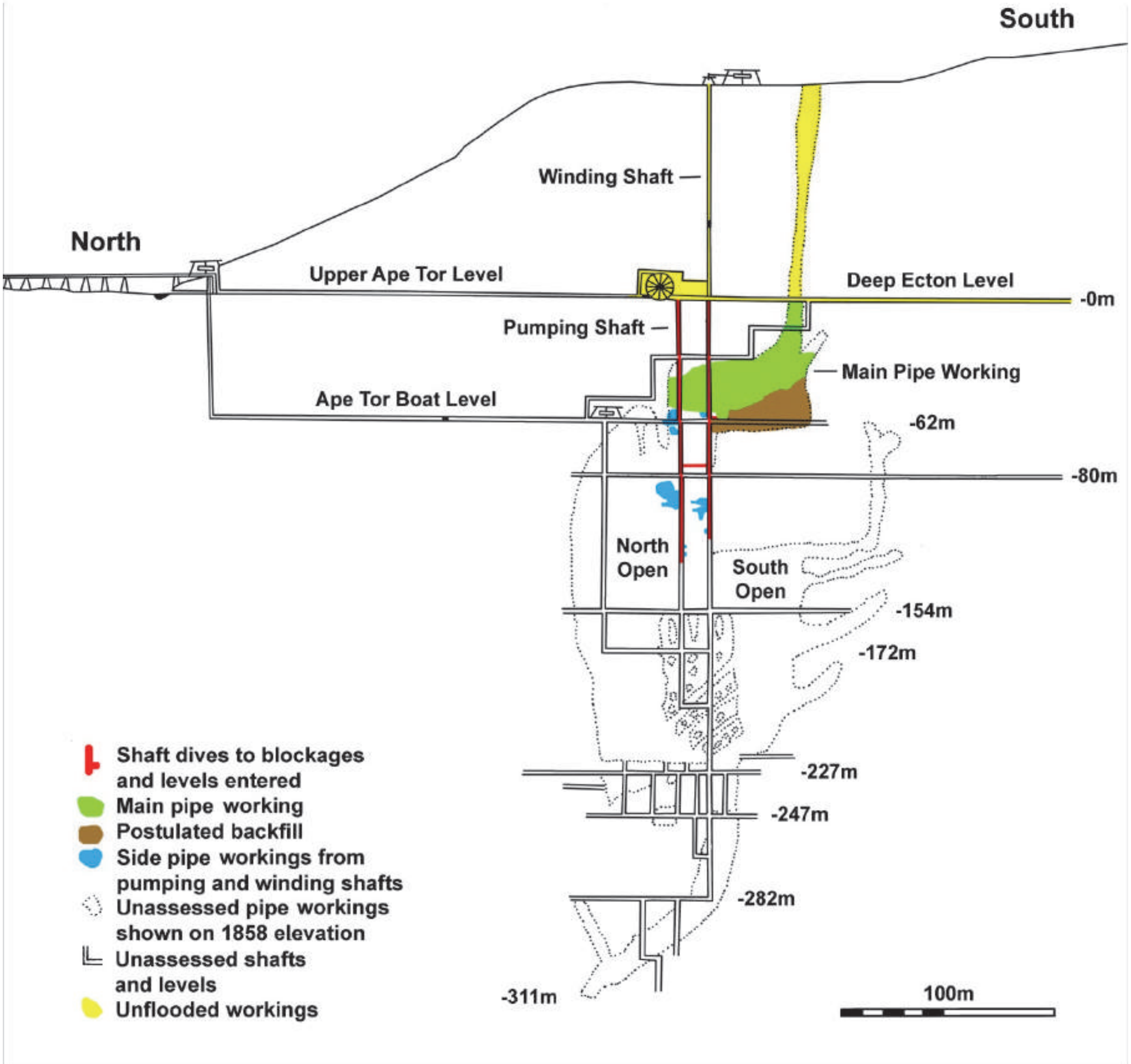

Figure 4: The approximate extent of passages explored during the UNEXMIN dives undertaken in May 2019 at Deep Ecton Mine, with these superimposed on the schematic 1858 mine elevation drawn by Meads, with feature names and recorded depths and a scale added.

Important archaeological remains at Ecton survive both at surface and underground. High on the ridge there is the 1788 Boulton and Watt steam winding engine house. This is now owned by the National Trust and is thought to be the oldest mine winding engine house in the world that survives in good condition. The shaft here was the deepest in Britain in the 1780s and James Watt designed the first tapered ropes used in the world to bring up the ores here. There are mine hillocks across the ridgetop, dating from the Bronze Age to the 19th century AD, together with entrances to adits, shafts and 'pipe workings'. The main Deep Ecton dressing floors lie part way up the hillside, on top of a massive waste hillock, and here a high 1880s dressing shed wall with ore bins behind has been restored (Barnatt 2017). Nearby there is a well preserved powder house.

In small dangerous workings on the ridgetop there are distinctive shotholes that show Ecton was one of the first places in Britain where gunpowder blasting was employed, using a continental technique, here by a Dutchman Jacob Mumma in 1665-68.

Salts Level, which from 1807 was used to bring ore out to surface, enters the mine at dressing floor level close to the education centre. It runs through competent rock to the main winding shaft and then the 'pipe deposit'. This allows education centre groups to easily view a small part of the workings. For many this is their first chance to enter a mine and look down a deep shaft and view impressive mineral workings. There are also important details dating to 1804-07 to see, such as gunpowder shotholes and stone sleeper blocks for an iron plateway that was laid for mine tubs.

Deep Ecton Level, with a fine arched entrance tunnel restored in 2018 (Barnatt 2020a), gives access to the 'pipe workings' and for over 150 years was the main way into the mine. Here infrastructure was installed to facilitate mining at depth. From 1773 until 1807 ore from below was unloaded here from the winding shaft for transport to surface. Nearby there are two large 1780s chambers where water was pumped out of the workings using water-powered machines, and items such as tubs and pipes were lowered down using a horse- and man-powered capstan. It is thought the main level was converted to an underground ore canal, used between 1773 and 1784, and we know from documentation that there was a second one at just over 60m down into the now flooded workings.

Site recognition and conservation

Ecton Hill, including the mines, lies entirely within the Peak District National Park and is subject to the National Park planning regulations and constraints imposed by designation. It is heavily visited by walkers and those with an interest in our industrial past.

Most of Ecton Hill is within the Hamps and Manifold Valleys Site of Special Scientific Interest (SSSI), and Deep Ecton Mine is itself an underground SSSI for its geology.

The archaeological importance of the Ecton Mines is also recognised by a Historic England listing[1] as a Scheduled Monument.

All of these might be seen in the mining industry as unwelcome constraints on its activities, but as far as EMET is concerned, in the context of using Deep Ecton Mine as an educational and research resource, they are positive. There is an informal "partnership" arrangement between EMET, EHFSA, and the various statutory and regulatory bodies, for whom education is seen as a positive and even an integral part of their function. As owner of some of the land around the adit portals, and of the mineral rights across much of the hill, EMET itself has a role to play in ensuring safety for the general public, especially as half of Ecton Hill is designated as Access Land, and its fulfilment of this role in maintenance of secured mine entrances is particularly appreciated by the County and National Park authorities - who recognise that this can usefully be funded through EMET's educational and research activities.

[1] https://historicengland.org.uk/listing/the-list/list-entry/1021175

EMET and the Geoffrey Cox study centre

Geoffrey Cox was the director of the Minerals Industry Manpower and Careers Unit (MIMCU) at Imperial College, London. In 1972 he was invited by the Duke of Devonshire to purchase Deep Ecton Mine for educational use. He organised a group of teachers from various schools in the region to run day and weekend courses. It was Geoff's intention to set up a Trust and had initially wanted the mine to be donated to the Institute of Materials, Metallurgy and Mining (IOM3). After IOM3 had declined to take on the responsibility of ownership of the mine, an independent Trust was proposed as the way forward. Starting in 2003, negotiations with a number of interested parties including John Bramley and Tony Brewis (both Fellows of IOM3), Graham Woodrow (deputy CEO of IOM3), and Eileen Barrett (Geoff Cox's former PA), led eventually to formation of the Ecton Mine Educational Trust on 6th September 2005, sadly delayed by the death of Geoff Cox in November 2003.

The principal aim of the Ecton Mine Educational Trust (EMET) was the use of the mine to promote education in applied geology, mining and mineral extraction. Thanks to the generosity of the late Mrs Elizabeth Cox, Geoff's widow, the Trust is the owner of the relevant mineral rights on Ecton Hill, the study centre, and the main mines here.

The Trust provides the facilities for school and university teachers to run one-day or two-day field courses that introduce young people to subjects relevant to the minerals industry.

The G A Cox Study Centre (Figure 5) can be used as a meeting place, a lecture room (with a capacity of 25) or a laboratory (with all the equipment required for the EHFSA courses and more). There is also a changing room containing the necessary safety equipment for underground visits.

An outdoor meeting place/lecture area (Figure 6) provides a pleasant alternative for fine weather activities.

Figure 5: Group preparing for an underground visit into Salts Level, in the GA Cox study centre lamp room.

Figure 6: The outdoor classroom in use for an applied chemistry lesson

Education

EMET's sister organisation, the Ecton Hill Field Studies Association (EHFSA), runs formal educational courses for schools, colleges, universities, and U3A and other groups studying Geology, Science or History of Science/Technology (Figure 7). Activities generally include an underground visit to see the mineralisation, and to understand how the miners were able to make the mine such a profitable enterprise. Most activities include a hill walk to see evidence of past mining techniques and the 1788 Boulton and Watt steam engine house.

Figure 7: Teaching mineral processing in the G A Cox study centre

Curriculum-related Activities are structured events lasting a full day. A Level Chemistry Activity Days and KS4 Chemistry Activity Days also include some practical Chemistry, relating to the minerals occurring in the Ecton ore body. The A Level Geology Activity Days generally concentrate on field work techniques, mineralisation and engineering geology appropriate to the specifications of both the OCR (Oxford, Cambridge and RSA) and WJEC (Welsh Joint Education Committee) awarding bodies.

Other School Activities for KS2 pupils upwards can be arranged for general interest with the opportunity to undertake Science/Geology-based activities or with an emphasis on specific aspects of the history and geology of the Ecton Mine. These school activities cover many aspects of the National Curriculum at KS2, although the programme is more flexible than the structured Curriculum Activity days and the day is usually of shorter duration.

Activities for General or Special Interest groups are available for any type of group of adults, or adults with children. Visitors can enjoy an underground visit, hear the fascinating story of the historic Ecton mines, and how science was developed and applied to the winning of an important metal – copper. These activities are tailored to suit the interests of the visiting group.

Several University Level groups regularly visit Ecton to add a new dimension to their programmes. The site provides obvious interest for Chemistry, Geology, Mining and Minerals Processing groups. PGCE (postgraduate certificate of education) Tutors have used Ecton for their students to plan an off-site visit for school students and to appreciate the importance of fieldwork in motivating children and improving learning in Science. University Tutors can either leave the leadership of such courses to the EHFSA tutors or take the lead themselves.

It is hoped that in the future educational activities at university level can be broadened to better cover the historical and archaeological aspects of Ecton Hill.

Research

Ecton Mine is now becoming a centre for scientific research. Apart from EMET involvement in the Horizon2020 UNEXMIN project[2], Ecton Mine has participated in a number of university-based and industry-sponsored projects as well as archaeological and historical research in partnership with The National Trust, Historic England, and the Peak District National Park. Some of these projects include:

- Archaeology and history of the Boulton & Watt engine house
- Archaeology and restoration of the back wall and mineral hoppers at the Ecton dressing-floor (Figure 8)
- Study of 'clumped isotopes' by the University of East Anglia to use the isotopic composition of calcite to determine temperatures of hydrothermal mineralising fluids

[2] https://www.unexmin.eu/

- Test of microseismic technology for locating moving objects within the mine
- Considered as a location for study of muon flux detectors (Durham and Sheffield Universities)
- Tests of new gravimeters with potential for detection of ore bodies or voids (Glasgow University)
- LIDAR mapping of the adits and pipe workings above water level (Figure 9)
- ground-penetrating radar to assist archaeological interpretation on Ecton Hill

Figure 8: Restoration of the Ecton Mine dressing floor wall following detailed archaeological investigations, as restored in 2016 with financial support from Historic England

Figure 9: High resolution laser scanner point cloud from a survey of Salts Level sponsored by Arcelor Mittal.

EMET was a participant in the UNEXMIN project which was funded by the European Commission and ran for 45 months from February 2016 to October 2019. This project involved the development and testing of submersible robots for surveying and exploration of flooded underground mines. During May 2019, there were a total of ten dives by two of these robots, from three launch locations: the pumping shaft (Figure 10), the winding shaft, and the pipe workings. These dives reached a maximum depth of 125 metres and allowed exploration of about 10% of the recorded extent of the historic mine workings. Geological structures discovered included tight folding similar to that seen on surface at Ape Tor (on the northern flank of Ecton Hill) as well as indications of multi-phase mineralisation events. Archaeological evidence discovered included proof of linkage (cross-cuts) between the two shafts as well as between the winding shaft and the pipe workings, together with discovery of pipe workings additional to those marked in the schematic cross section by Meads (1858), and possible location of the Ape Tor boat level (Figure 11). A number of locations were identified for further robotic exploration at a later date - at depths and in situations where it would be unsafe for human divers to access.

Figure 10: The launch platform, and the adjacent work station, at the pumping shaft, photographed as their installation was being completed

Figure 11: The carefully-built wall across a passage intersected by the pumping shaft at 65m below water level, with what appears to be clay in the interstices, appears to have been built as a dam to hold water back. Possibly the passage behind led to the Ape Tor boat level

Conclusions

Deep Ecton was closed in the latter years of the 19th century after 100 years of decline from its peak metal production in the 1780s-1790s. However, what still remains both underground and at the surface provide a great opportunity for both education and research: an opportunity that was recognised by the late Geoffrey Cox whose work is now continued by the Ecton Mine Educational Trust and Ecton Hill Field Studies Association. Rather than leaving things to decay, re-working or bulldozing the surface remains, and blocking or infilling the underground workings, what is left of the mine is put to good use, giving many students their first (and often only) direct contact with industrial history, mining geology, and applied chemistry. The Trust is also actively developing and promoting the use of the mine as a research facility about which more information is available with every passing year.

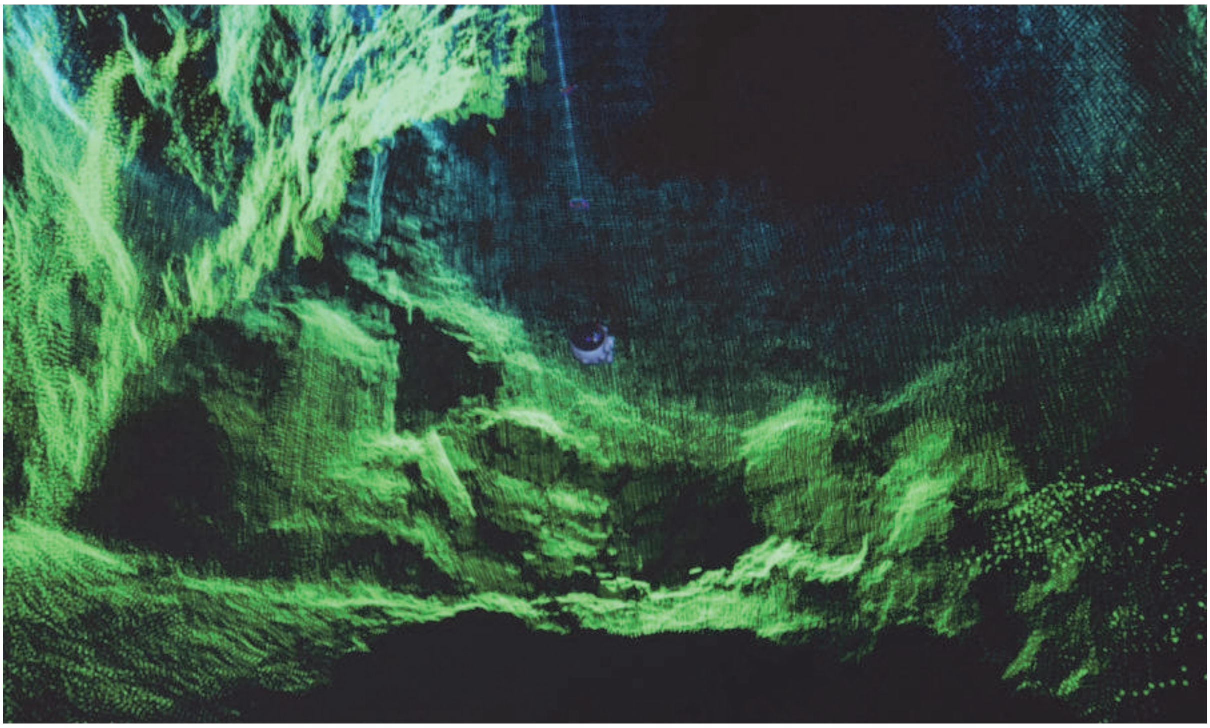

Figure 12: A sonar point-cloud image photographed from one of the dive monitors in the UNEXMIN control room in the G A Cox study centre, in late May 2019, showing part of the second chamber down in the 'main pipe workings' centred at about -35m below water level, showing the scale of the working and examples of side passages that have yet to be explored (the submersible at the centre is a graphic that allows its size and location to be identified). The submersible is approximately spherical, 60cm in diameter.

References

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CAPTIONS TO FIGURES

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THE USE OF VOID SPACE CREATED BY MINING ACTIVITY FOR BENEFICIAL PURPOSES

Steve Reece CEng FIMMM

The views, thoughts, and opinions expressed in this paper are those of the author acting in a personal capacity and are not necessarily those of the author's current or previous employers or any other group or individual.

Abstract

Abandoned mines can often pose significant issues, ranging from subsidence and ground movement to the hazards associated with unmapped voids, contamination, gas emission and water discharges. One of the legacies of large scale underground mineral extraction is the creation of significant volumes of void space. Through a series of case studies, it is demonstrated, that when managed correctly, underground void space can actually be a valuable asset and can create significant safety and environmental benefits and generate enduring socio-economic benefits for the communities that host such facilities.

The use of underground voids has been shown to be able to successfully isolate and contain hazardous materials from the biosphere protecting people and the environment for very long periods of time. They can also act as storage space for materials often warehoused in surface buildings and by doing so, reduce reliance on valuable surface land that can be put to other beneficial use. The underground environment often has stable conditions which can also be beneficial for the material being stored or disposed of and can reduce energy and construction materials consumption. Safety and security are often enhanced by undertaking activities deep underground.

New businesses created from the re-use of underground voids provide valuable and often long-term employment opportunities with the chance of people gaining new skills and other associated socio-economic benefits such employment brings. However, undertaking new activities in the underground environment does create risks that need to be thoroughly assessed and appropriately managed if the benefits are to be realised in a safe and sustainable manner.

1. Introduction

There are estimated to be over a million abandoned mines around the world[1]. Regardless of where these abandoned mines are located, they can often pose significant issues, ranging from subsidence and ground movement to the hazards associated with unmapped voids, through to contamination, gas emission and water discharges. One of the legacies of large scale underground mineral extraction is the creation of significant volumes of void space. This void space once created can however also present significant opportunities to contribute to sustainable development.

To provide some scale to the opportunity it is estimated that as much as 500 million cubic metres of void space may be created globally by non-ferrous metals, precious metals and industrial minerals extraction each year[2]. The author estimates that during his own career he has been involved in the creation of in excess of 10 million cubic metres of void space in the UK alone. Clearly not all of this void space can be used for beneficial purposes and it is incumbent on policy makers, mine operators and regulators to continue to consider the implications of the creation of such large volumes of underground space particularly where it cannot be used for beneficial purposes.

There are examples from around the world where underground mines have been repurposed for uses such as mushroom farming, growing specialised pharmaceutical plants, secure military operations centres and digital or cloud storage facilities. The Sanford Underground Research Facility for example

[1] https://www.mining.com/web/innovative-ways-to-repurpose-old-mines/
[2] https://www.world-mining-data.info/?World_Mining_Data___Data_Section, 2018 data point

is built in an old gold mine in South Dakota. This underground physics lab is home to studies about subatomic particles and dark matter as well as an assortment of biology, engineering, and geology experiments. The Comfort Inn in Coober Pedy in remote South Australia is an old opal mine which is now a hotel, and salt mines in Europe and South America have been turned into underground cathedrals. A company in Romania has even built an underground theme park in a salt mine and a 17th century salt mine in Transylvania has been transformed into an amusement park.

Through the use of a series of case studies from projects the author has been directly involved in, this paper sets out to demonstrate that when managed correctly underground void space can actually be an extremely valuable asset and can create significant safety and environmental benefits and generate enduring socio-economic benefits for the communities that host such facilities.

Although primarily focused on the use of mining void space for the management of intractable wastes, the paper also explains how high-quality stable underground void space can be used for the long-term storage of material which requires regular access and may need to be retrieved at some point. Using an example from a UK rock salt mine some of the unique challenges and benefits created by the development of a significant document storage business are set out. Projects in the UK and Australia are presented as case studies to explain how the geology surrounding void space contributes to the development of a barrier which is part of an overall disposal system to safely manage intractable waste streams over the long term.

The case studies demonstrate that positive impacts can be delivered by such projects. For example, valuable space that would otherwise be required on the surface can be released for other uses and environmental benefits are often realised by removing materials that would be hazardous if stored or disposed of on the surface. Energy efficiency can be improved, and construction material consumption reduced. Additionally, projects to develop underground storage and disposal facilities create opportunities for skills development, competence building and long-term employment.

2. Geological storage of documents and archive materials

The characteristics of stable underground void space make them inherently suitable for a wide variety of storage and archival purposes, however they also introduce risks which become even more pertinent in the underground environment. The first pre-requisite is for a stable underground void and the fundamentals of ground control need to be considered. Whether the roof and sides are self-supporting or require supplementary support, it is essential that the any ground stabilisation works that are required are undertaken at the outset as remediation becomes increasingly difficult once archives are introduced. If a stable void can be achieved, it eliminates the need for surface structures to be built. Depending on the geothermal gradient, steady all year-round temperatures and humidity ranges can be achieved by utilising the mine ventilation system and the inherent conditions which make them attractive for document storage. The absence of ultraviolet light, vermin and the additional security provided by being underground are also positive attributes.

Introducing significant amounts of flammable material into an underground environment can however be counter intuitive and the potential safety issues this introduces to people working below ground must be properly mitigated. The basic principles of fire risk assessment must be applied including consideration of fire loading, fire detection systems and firefighting backed up with effective evacuation and emergency arrangements as necessary. The selection of the location of such facilities relative to other activities in the mine are also highly important. The UK Health and Safety Executive, working in conjunction with mine operators has produced helpful guidance on this topic: *Guidance on the prevention and control of fire and explosion at mines used for storage and other purposes* [3]

[3] https://www.hse.gov.uk/mining/festorage.pdf

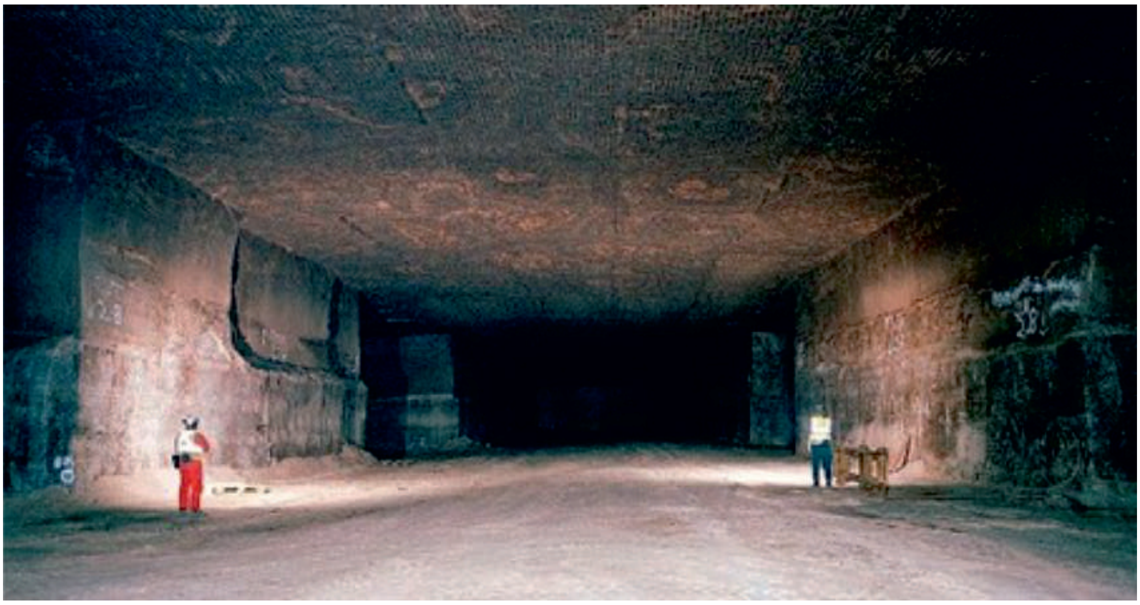
Case Study 1 – Document archive storage in a UK rock salt mine

Winsford Rock Salt Mine located in Cheshire is Britain's oldest working mine. The Rock salt at Winsford was formed around 220 million years ago and lies around 200 - 300 metres under the Cheshire Plain. Mining commenced in 1844 when rock salt was discovered whilst prospecting for coal and has been mined almost continuously ever since. Today the mine remains of strategic national importance providing the majority of the UK's annual salt requirements for de-icing roads during winter.

The Winsford mine, which is now operated by Compass Minerals UK, has created over 25 million cubic metres of high-quality void space, primarily by traditional drilling and blasting methods using a large-scale room and pillar mining system. In 2002 the mine operators Salt Union Ltd transitioned from drilling and blasting to continuous mining.

To continue with the proven largescale room and pillar method of mining a cutting sequence was developed to maximise extraction but minimise unnecessary set-up and movement of the continuous miner. In order to achieve the desired room height of around 9 metres the continuous miner is deployed in two lifts first removing the rock in the upper 4.6 metres of the mining horizon. Pillars are created by cutting cross cuts at right angles to the main roadway but due to the machine reach when coupled to the conveyor system the pillar forming sequence only becomes complete once the cross cuts are from the adjoining tunnel are joined up. The second stage of extraction involves the removal of the lower section of rock salt. The excavation sequence results in high quality rooms that are nearly 9m high and 20 m wide as shown in **Figure 1**, with variable pillar dimensions depending on the depth of the mining horizon.

Figure 1: Rooms created by continuous miner at Winsford



© Personal photograph taken by Paul Deakin

A feasibility study was undertaken in 1996 to identify alternative mine uses to leverage the large volume of high-quality void space that had been created by many years of mining activity at Winsford. Whilst the core business was to remain mining for de-icing road salt, the underground conditions which provide a consistent temperature of around 14 Celsius and are naturally free from ultraviolet light, vermin and flooding were identified as being suitable for two potential uses: archival storage of high value assets such as historical records, architectural models and critical data as well as storage and disposal of specific types of hazardous waste. A series of detailed risk and impact assessments then followed for both potential projects. The waste disposal project is discussed in case study 2.

In 1998 DeepStore was established to reuse the underground void space by providing archival document storage. Security, compliance and cost are of importance to organisations who store large volumes of documents and the Winsford mine void presents a sustainable alternative to above-ground facilities. DeepStore offer services across a broad range of areas including document storage solutions, digital services, secure destruction and project management. Today the facility at Winsford has more than 1.8 million square metres of storage space and holds several million archive boxes. **Figure 2** shows the racking systems installed inside one of the storage rooms being filled with archive boxes.

The implementation of the DeepStore project has utilised a significant portion of the underground void space at Winsford Mine for beneficial purposes that are commensurate with sustainable development objectives. The use of the underground space has meant that a highly energy efficient solution has been found which leverages the geothermal gradient of the mine to produce a steady all year-round temperature and humidity range which is one of the requirements for successful document archiving. In doing so this has eliminated the need for significant on surface development with its associated impacts. The business has also created employment opportunities for local people and is a highly complementary business partner to the seasonal deicing business.

Figure 2: Racking being filled with archive boxes in underground storage room

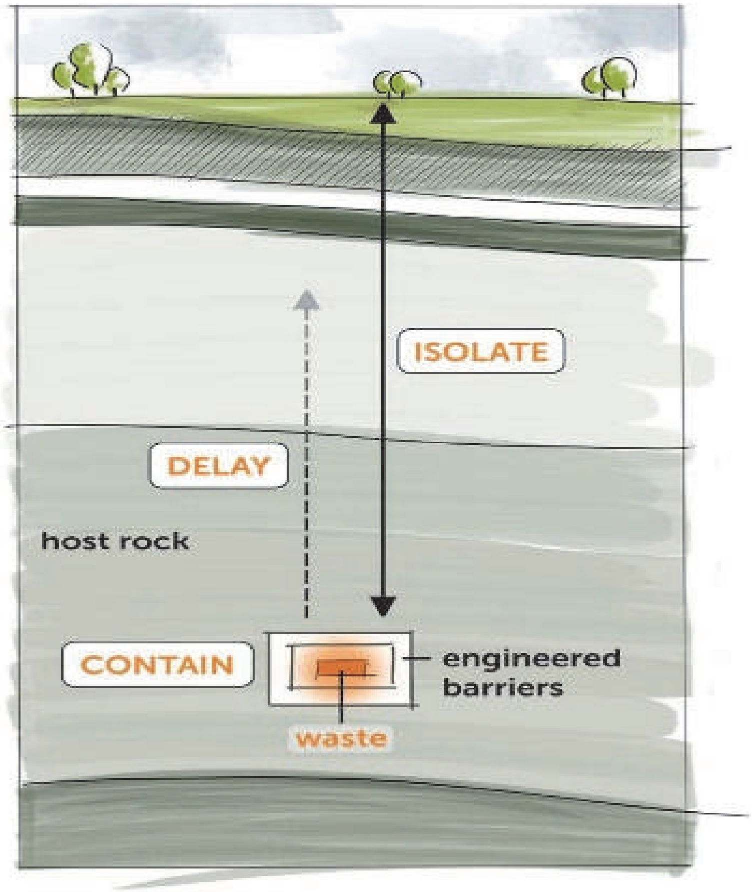
© Personal photograph

3. Deep geological disposal of hazardous wastes

Highly toxic and radioactive waste that cannot be further recycled must be managed safely and securely to avoid contamination of air, ground and underground water. Deep geological repositories can provide long-term storage or disposal that isolates waste in geological structures that are expected to be stable for millions of years, by using a number of natural and engineered barriers working together in a “multi-barrier system”. The multi-barrier system uses a combination of the conditioned waste form, waste packaging, engineered seals and geology that are designed to create an overall disposal system to provide long-term isolation and containment of materials from the biosphere without future maintenance or intervention being required. **Figure 3** presents a simple schematic of the multi barrier system of containment and how it provides the safety functions of contain, delay, and isolate.

A number of chemo-toxic waste repositories to manage wastes such as mercury, cyanide and arsenic are operating worldwide. Spent nuclear fuel and high-level reprocessing and plutonium wastes require containment for periods ranging from tens of thousands to a million years, to contain radioactivity from reaching into the environment in harmful amounts. Safeguards are also required to ensure that neither plutonium nor highly enriched uranium is diverted to weapon use. There is general international agreement that placing radioactive wastes in deep geological repositories hundreds of metres below the surface is safer and more sustainable than indefinite storage on the surface.

Figure 3: Multi-barrier concept used in deep geological disposal systems



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Case Study 2 – Chemo-toxic waste disposal in a UK rock salt mine

The second alternative mine use to utilise the high-quality void space at the Winsford mine is a waste disposal facility operated by Veolia. This is known as the Minosus facility. It is the only underground storage and disposal facility for hazardous chemo-toxic waste operating in the UK.

The ultra-low permeability rock surrounding the waste storage area means that the environment of the mine is dry with no water ingress. Due to the strict waste acceptance criteria applied at the facility there are no gases or leachate produced from the wastes unlike above ground landfills which are exposed to rainfall and require gas and leachate management systems to appropriately treat them. All waste is contained within double lined high specification intermediate bulk containers or drums and placed within partitioned rooms within the mine enabling complete traceability of wastes at the level of individual containers and ensures complete containment of the waste with no credible pathway to the biosphere. There are no issues with dust or odour as all offloading and handling of wastes takes place within an enclosed area on the mine surface. The majority of the land above the Minosus operation is used for agricultural purposes such as dairy farming.

The final closure plan for the facility consists of a series of specially designed hydraulic barriers to isolate the waste disposal area from the rest of the mine when disposal operations are complete.

Figure 4 shows an image of intermediate bulk containers being unloaded from the transit containers used to transport the waste from the mine surface and stacked in the disposal room.

Figure 4: Waste being unloaded and placed in position in an underground room

Case Study 3 - Chemo-toxic waste disposal in Australia

Australia is one of the highest producers of hazardous waste per capita. However, currently there is insufficient infrastructure nationally to manage the rapidly growing problem from legacy, production and emerging hazardous waste types. Tellus Holdings, headquartered in Sydney, are developing a portfolio of both near surface and deep geological disposal facilities to manage hazardous wastes.

The company already has one operational near surface facility at Sandy Ridge in Western Australia. The post closure safety case is based on a suitable near surface host geological environment which also displays many of the characteristics required for deep geological disposal facilities, coupled with a favourable arid climate. The location of the development envelope was specifically chosen for its natural characteristics which are consistent with International Atomic Energy Agency (IAEA) site selection requirements and international best practice standards for near surface geological repositories.

To support the operational phase safety case Tellus deploys one of the largest temporary coverings in Australia over the active kaolin clay hosted disposal pit. This prevents rain ingress during the very infrequent rain events that are experienced in the area and also provides containment in the event of a spill during placement of wastes. **Figure 5** shows an illustration of the temporary covering positioned over the disposal pit.

Figure 5: Temporary covering positioned over a disposal pit at Sandy Ridge

Tellus is also developing the Chandler Project which is located in regional central Australia approximately 120 km south of Alice Springs in the Northern Territory. The Chandler Project is Australia's first proposed underground salt mine and deep geological waste repository and will be operated in a 500-million-year-old stable halite bed. The location of the proposed development envelope was specifically chosen based on internationally recognised requirements for a deep geological repository for hazardous waste storage and permanent isolation.

The Chandler Project although in a very remote location is located near the Central Australian Railway and the sealed Stuart Highway that connects Adelaide to Darwin. Tellus has completed a Pre-feasibility Study and is currently progressing the project to Bankable Feasibility Study stage. Once operational the project will be licenced for an initial 25-year period, but with the potential for approval extension it could become a multi-generational project. **Figure 6** shows the author during one of the rounds of exploratory drilling.

The project has already received approval to mine up to 750,000 tonnes per annum (tpa) of salt and will use a room and pillar mining system capable of receiving up to 400,000 tpa of hazardous waste at the facility subject to licence conditions. The company also plans to build a circular economy park at Chandler to recover any residual valuable materials in the waste streams. The technologies used will be dependent on the waste received and the technical and economic viability. Hazardous waste from a broad spectrum of industrial sectors, including mining, oil and gas, contaminated site remediation, and utilities is anticipated and although the facility will not accept any nuclear materials it will accept Naturally Occurring Radioactive Material (NORM). The Chandler Facility will also be designated as an Emergency Services facility that can take diverse waste types from man-made and natural disasters.

As part of the development of the safety case an independent international technical review of Chandler by Quintessa (UK) studied the potential for groundwater contamination. A quantified operational and post closure risk assessment was undertaken and the report concluded that there were no plausible risks to the overlying groundwater resource. About 270 jobs will be created during the construction phase of the project and between 150 to 180 permanent jobs during the operation phase of the project.

Figure 6: Exploratory Drilling at the Chandler Site

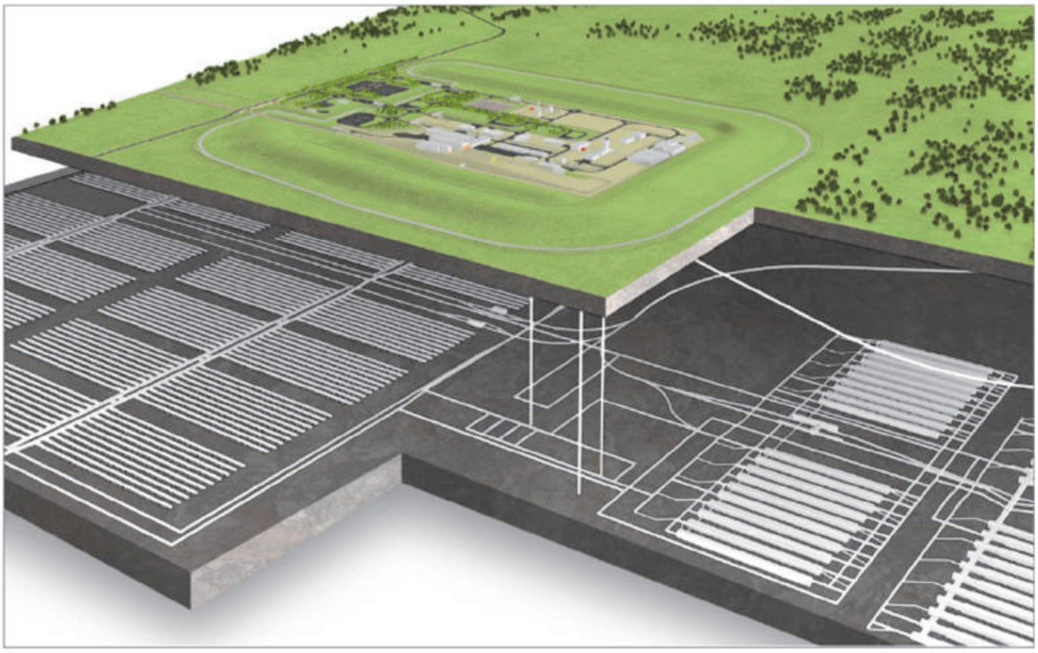
Case Study 4 - Radioactive waste disposal in the United Kingdom

Nuclear power provides one fifth of the UK's electricity, and has been a part of the energy mix of the UK for more than 60 years. The UK has also been a pioneer of nuclear technology, from military to medical research, to industrial uses, and as a result has accumulated a legacy of higher activity radioactive waste and nuclear material. More waste will be produced as existing power stations reach the end of their lifetime and are decommissioned and cleaned up, and through the operation and subsequent decommissioning of new nuclear power stations once they are built and have come on line.

There is international consensus that isolating radioactive waste deep underground in solid rock is the best permanent solution for the management of higher activity radioactive waste. Higher activity waste is currently stored on an interim basis above ground where it is secure and safe, but this is not a sustainable long-term solution. Geological disposal using a multibarrier system is already the chosen approach in many countries internationally and is widely regarded as the responsible solution for the protection of future generations and the environment.

The wastes that will be disposed of in a Geological Disposal Facility (GDF) are referred to as the "inventory for disposal". The types and amounts of waste that make up this inventory are important because the layout and design of any GDF will need to be tailored to them, and also because it is recognised that communities considering hosting a GDF will want to be clear about what wastes are destined for it. There are some radioactive materials that are not currently classified as waste, but would, if it were decided at some point that they had no further use, need to be managed as wastes through geological disposal. These currently include spent fuel, plutonium and uranium. A GDF will be a National Significant Infrastructure Project (NSIP). The majority of the facility will be up to 1,000 metres underground. On the surface, the GDF will require a land area of about one square kilometre. An image of what a GDF could look like is presented at **Figure 7**.

Figure 7: Illustration of what a UK Geological Disposal facility could look like



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A GDF is a highly engineered facility that will use multiple barriers to ensure that hazardous materials are kept away from people and the environment. It does this by isolating and containing the waste for the time required for the radioactivity associated with it to reduce naturally. This is already the chosen approach in many other countries including Canada[4], Finland[5], France[6], Sweden[7] and Switzerland[8]. These countries are well on their way in developing their own facilities.

The multi barrier approach requires solid radioactive waste to be packaged in secure engineered containers, typically made of metal or concrete, and then placed in a stable rock formation hundreds of metres below the surface, with the containers surrounded by buffer and backfill materials, very often clay or cement or replaced host rock material in the case of evaporites. Once operations have ceased, the GDF will be permanently sealed to provide safety without the need for further action. In the very long term, a GDF requires no ongoing maintenance, protecting the waste from natural processes such as climate change.

The UK Government's Working with Communities policy establishes a consent based approach for Radioactive Waste Management Ltd[9], who are a wholly owned subsidiary of the Nuclear Decommissioning Authority, to engage and work in partnership with communities and relevant

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4 www.nwmo.ca
5 http://www.posiva.fi/en
6 www.andra.fr
7 www.skb.com
8 www.nagra.ch/en
9 https://www.gov.uk/government/organisations/radioactive-waste-management/about

principal local authorities in England to identify suitable sites with a willing community for the development, operation and eventual closure of a GDF.

The process of finding and confirming the suitability of a site is expected to take several years. The relevant development consents and permissions from the independent regulators, that need to be obtained before construction of a GDF can start, can only be applied for following a positive "Test of Public Support" in the host community. The UK Government is currently proceeding on the assumption that only one GDF will be necessary.

Investment will flow into a community that hosts a GDF. There will be hundreds of well paid direct jobs for over a century. Local projects will benefit from community investment funding and public facilities and infrastructure will be improved over the longer term. Finding a site for a GDF will be the first community consent-based process to be undertaken in the UK for a project of this size. A GDF cannot be built without the consent of a community.

4. Conclusion

The use of voids created by mining have been shown in many parts of the world to be able to successfully isolate and contain hazardous materials from the biosphere protecting people and the environment for very long periods of time. By doing so it reduces reliance on valuable surface land that can be put to other beneficial uses. The underground environment often has stable conditions which can be beneficial for the material being stored or disposed of and can reduce energy and construction materials consumption. Safety and Security is often enhanced by undertaking activities deep underground.

New businesses created from the reuse of underground voids provide valuable and often long-term employment opportunities with the chance of people gaining new skills and other associated socio-economic benefits such employment brings.

However, the underground environment does create risks that need to be thoroughly assessed and appropriately mitigated if the benefits are to be realised in a safe and sustainable manner.

5. References

All sources cited as footnotes

CIRCULAR ECONOMY: BATES CLEAN ENERGY TERMINAL

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Abstract

In line with the theme of the conference the authors have chosen the site of the former Bates Colliery at the Port of Blyth as a complete example of the circular economy working in practice. Mining and the port have been intimately linked for hundreds of years. We document the major events that have occurred beginning with an outline of mining in the township until closure of the Bates Mine in 1986. Following closure, monitoring of the rising mine water and its subsequent treatment and management are examined. The rise and fall of coal mining were mirrored by shipbuilding and the development of the port including for coal shipments along with that of general cargos. As coal mining ceased and other sectors declined the Port of Blyth has developed many other income streams, principally opportunities in supplying the offshore energy sector. The importance of this is substantial and is now reflected in the rebranding of Port of Blyth as Energy Central.

Bates Colliery site and ship loading facilities have undergone many significant changes and developments over the years and we provide a comprehensive review of the sustainable opportunities that are being exploited. The paper comprises three distinct parts:

- The history and development of mining in the Blyth area leading up to closure and the after effects.
- The Port of Blyth, the importance of the port to North East England and the management of the huge changes in activities since the closing of local coal mines, including the transition from carbon based to renewable energy related trade.
- Proposals to exploit a potential heat source, the huge quantity of warm water now contained in the abandoned mine.

1. Location and Background

The Port of Blyth and the former Bates Colliery are situated in the South East of the County of Northumberland UK (Figure1).

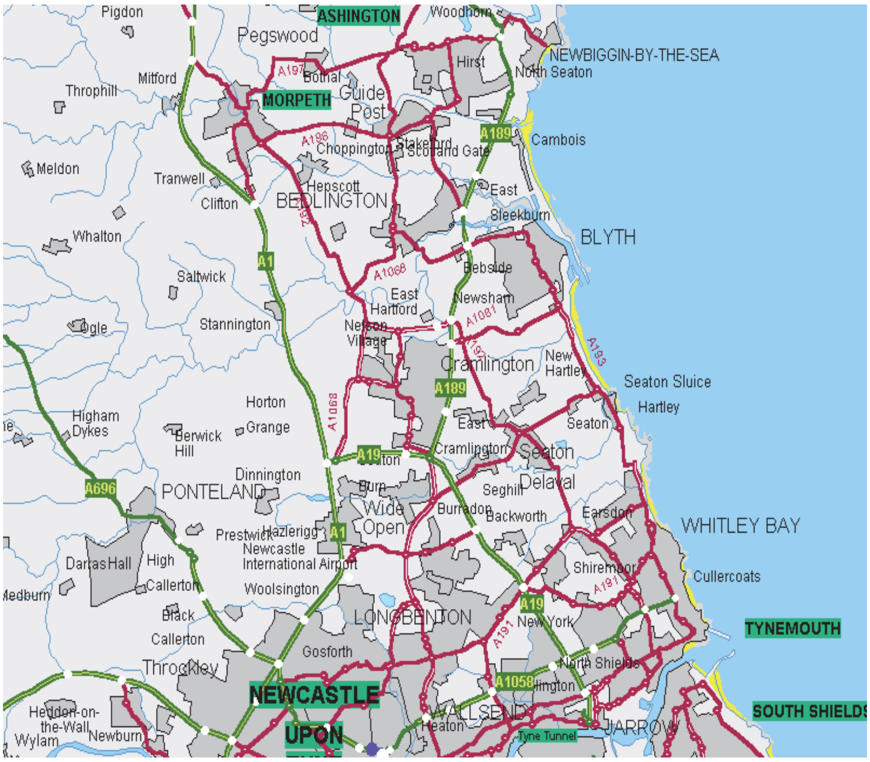

Figure 1 Location Plan

The coal mining area described in this paper is contained between two major geological features, the Stakeford Dyke (fault) to the North and the Ninety Fathom Dyke (fault) to the South which separates this zone from the rest of the Great North Coalfield. Mining in the area of Northumberland, South of the Stakeford Dyke has been carried out since Roman times with records of workings existing in 1236 in the town of Blyth (Hodgson, 1840).

The mining activity began exploiting the shallower coal seams principally near outcrops but as shaft sinking methods and better ventilation were developed the exploitation of reserves expanded rapidly. Between the late 1700s and mid 1850s the Blyth Valley became a vast mining area serviced by a complex system of wagon ways and with the emergence of rail, extensive links were established between the mines and shipping transport at the developing Port of Blyth (Smailes, 1935). Figure 2 illustrates the early history of Coal mining in the locality however there were huge numbers of other small mining concerns many of which were not recorded.

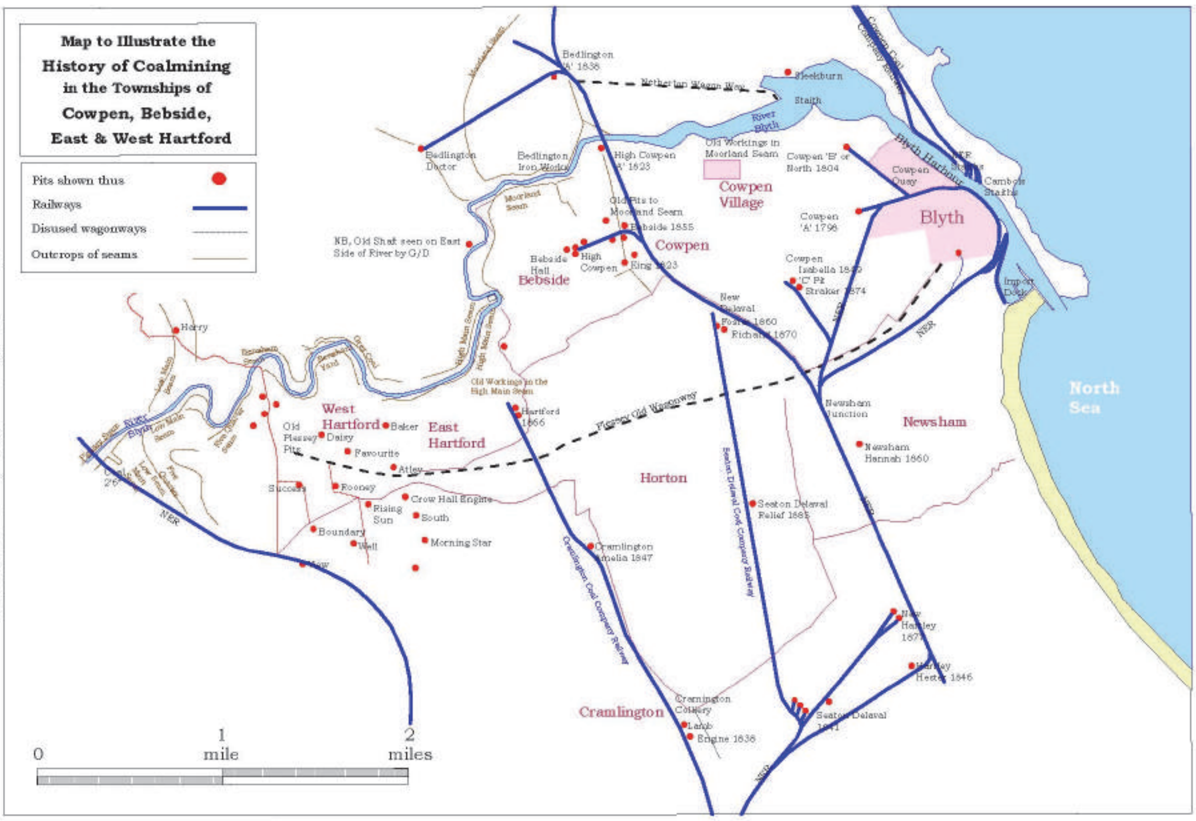

Figure 2 History of coal mining in the Blyth area

In 1965/66 the South Northumberland area composed of 22 operating Collieries and 8 pumping stations with an annual coal output of 5.1M tonnes. The majority of these Collieries were interconnected either deliberately or by geological faults.

By 1970, rapid closures of pits reduced this number to only eleven, with the mines mainly concentrated in the coastal strip where undersea mining was well advanced. Over the following years, mines in the Blyth Valley and surrounding area continued to close due to exhaustion of reserves or economics leaving Bates Colliery as the only survivor until its closure in 1986.

In relative terms Bates Colliery was considered a newer mine with shafts sunk in Blyth in 1932 and 1952 from which an undersea reserve of coal, unworked by the neighbouring Mill and Cambois Collieries, was exploited. During the latter years of its life, safe working was ensured by pumping stations at the closed mines ensuring mine water was kept at a level to prevent possibility of inrush.

From 1952 to the early 1960s the mine underwent a major reorganisation to the shaft access and the surface with a new screen plant and complete surface reorganisation including improved ship loading facilities for coal and mine shale facilities for disposal to sea tipping. The mine became the major operator in the locality exploiting reserves up to some 5Km offshore. The following photograph and plan are indicative of the surface reorganisation (Figures 3 and 4; North and Jeffrey, 1996; NCB, 1966).

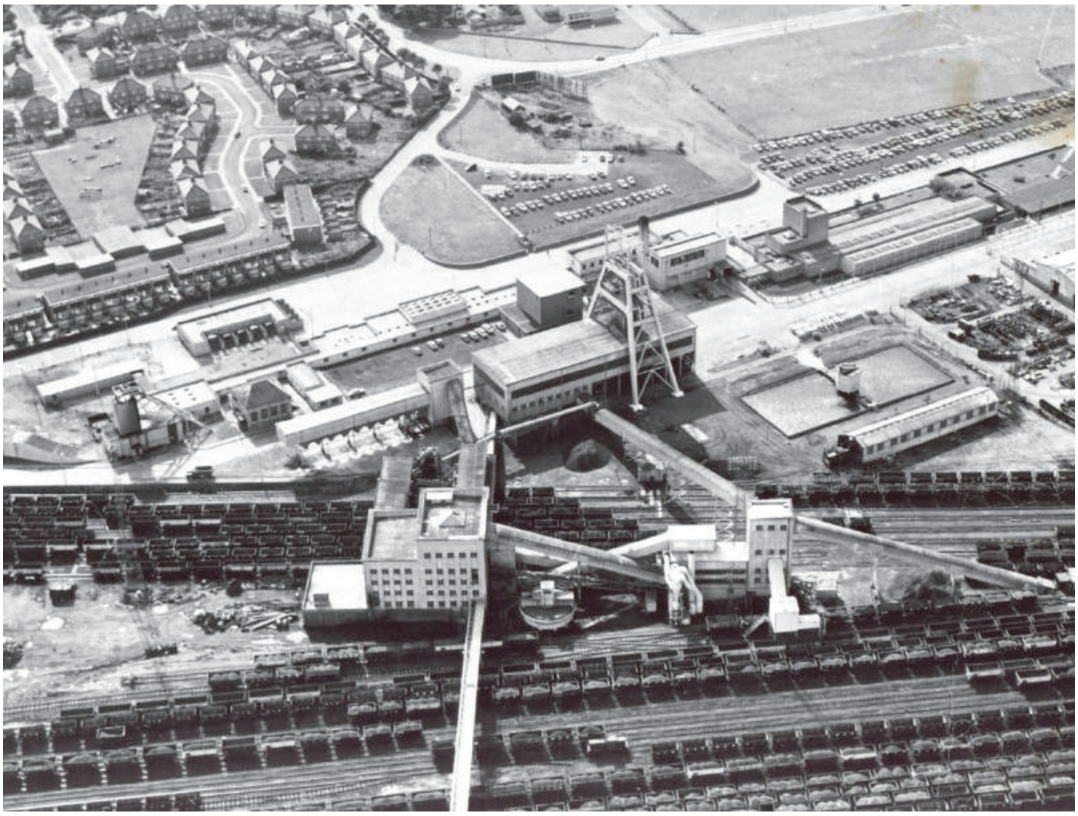

Figure 3 Arial View of Bates Colliery 1964

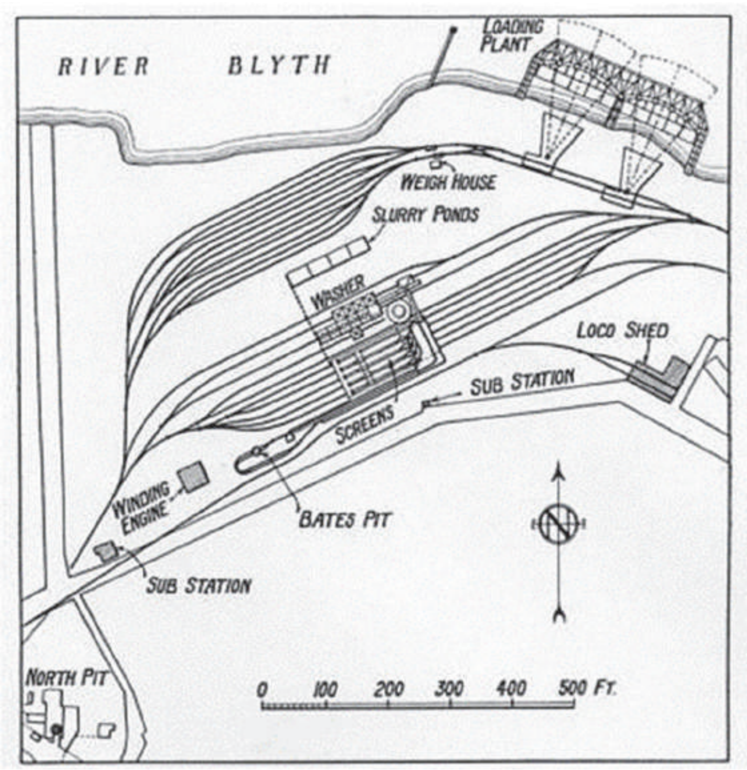

Figure 4 Pictorial View of Bates Colliery Surface Arrangements 1964

Between the 1960s and its closure, Bates Colliery operated successfully, becoming fully mechanised with substantial reorganisations underground including efficient transport arrangements for men and materials ensuring that safe working could be carried out over long distances. However major industrial disputes in 1972, 1974 and 1984 together with deterioration in economic returns caused by increased pumping and rising general costs meant that an economic decision was made to close the mine. Thus, all mining and water pumping at Bates and the outlying pumping stations ceased in 1986.

2. Mine water recovery following Bates Colliery Closure

Managing mine water is a key consideration for the safe working of any mine. It is a hazard that can cause serious disruption to operations and has been well documented over the years (Vutukuri and Singh, 1995), causing, in some cases, major loss of life. Over the years, a series of regulations were designed to mitigate the threat and risks posed by mine water ingress. Mines operating beneath the sea bed were also subject to additional specific precautions.

During the latter part of 20th Century a comprehensive mine water management and monitoring scheme was established to deal with the possible consequences that may be attributable to the recovery of ground waters in South East Northumberland following the cessation of deep coal mining.

This programme was initially managed by British Coal but in 1994 following privatisation of the coal industry, responsibility was transferred to the Coal Authority. Management of existing discharges and prevention and treatment of future discharges from former mines is now one of the Authority’s key activity areas.

On all these matters, The Coal Authority works closely with the regulator which is the Environment Agency and in 1999 an enhanced Memorandum of Understanding was established.

At the cessation of mining in South Northumberland in 1986 the total mine water pumped to the surface, including 8 pumping stations was at a rate of 378 l/sec (5,000 gallons per minute.)

Decisions taken by the former NCB/British Coal and subsequently The Coal Authority had always indicated that Bates should be earmarked as the solution to prevention of uncontrolled surface mine water discharges. As a result, when all adjacent pumping operations were stopped it was planned that the monitoring stations would check the theory that the water within the interconnected colliery workings would form a substantial subsurface mine water pond covering an area of some 350km^2 that could effectively be dealt with at River Blyth Estuary thereby preventing uncontrolled discharge over a large area (North and Jeffrey, 1996).

Between Bates closure in 1986 and 1995 water levels at each of the outlying monitoring stations and the Bates Shafts were monitored and as suspected it was proved that the bodies of water were combining as the mine water levels rose. Subsequently as indicated by the graph in Figure 5, a time frame for remedial action was established based upon the projected level when preventative action would be required (Jackson and Purvis, 2001). This action required not only dealing with water but also any associated emissions of mine gas, possible ground movement and subsidence.

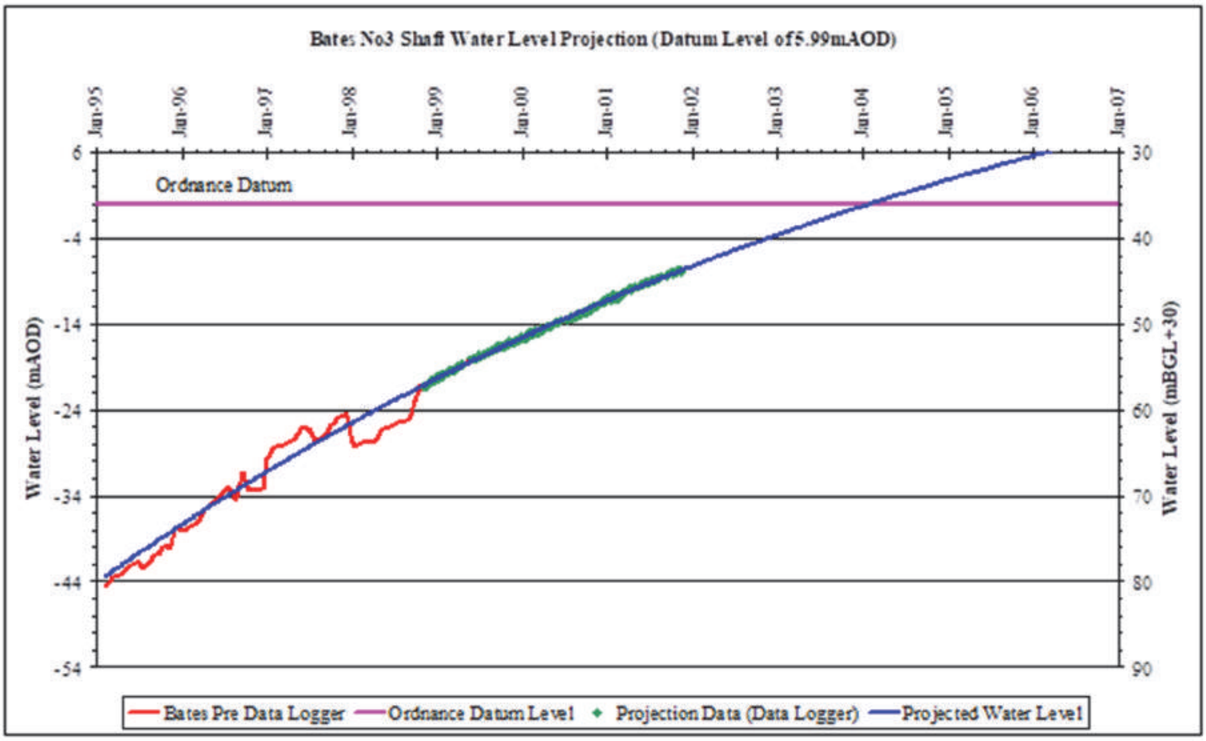

Figure 5 Water level recovery at Bates Shaft. The date on which the blue line crosses the x axis represents the expected date of emergence

3. Rising Mine Water Management

Between 1994 and 2001 the Coal Authority finalised its strategy for dealing with the rising mine water and designed the passive treatment system which is still operational today. A major part of the preparatory works was the need to purchase land from the Port of Blyth and to have easements and wayleaves in place which would be required in order to build the scheme and maintain it potentially in perpetuity (Figure 6). The purchase price was in the order of £600,000.

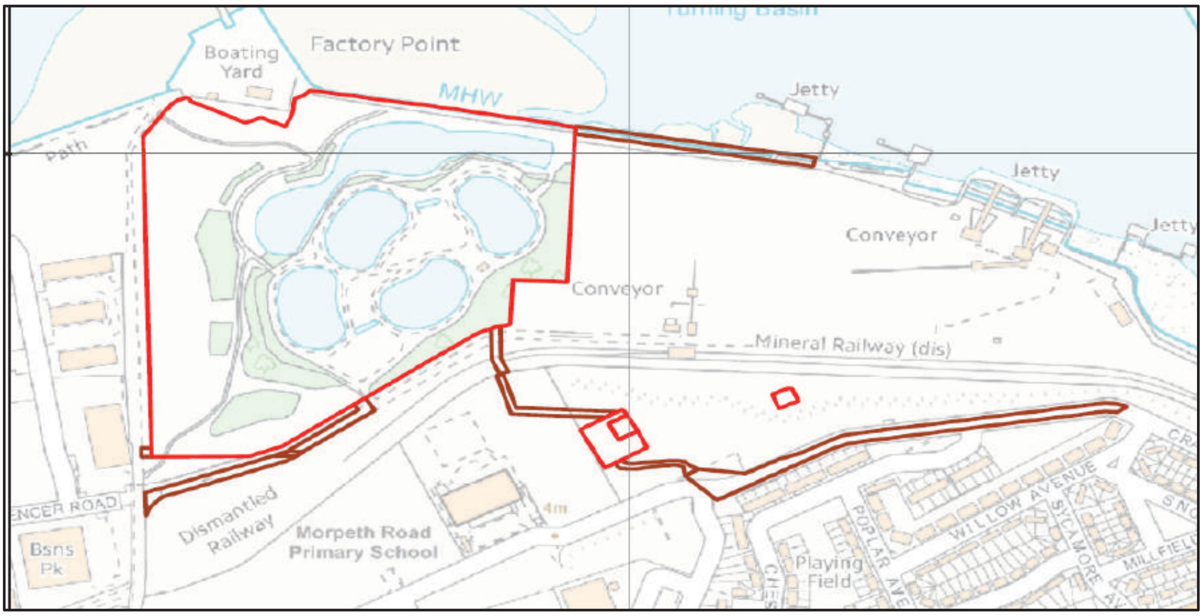

Figure 6 Plan showing The Coal Authorities Land acquisition in 2002 (Red) and Easements secured (Brown)

Construction commenced in 2001 within existing land ownership boundaries and proceeded fully following the additional land purchase in January 2002.

Figure 7a Pump Installation 2001 **Figure 7b** Lagoon Construction 2002

The scheme design required the installation of a submersible electric pump in No.3 Mine Shaft to facilitate mine water pumping from the shaft head in twin 200mm diameter rising mains, across a 3rd Party land to the Water Treatment Area (Figures 7a and b, Figure 8).

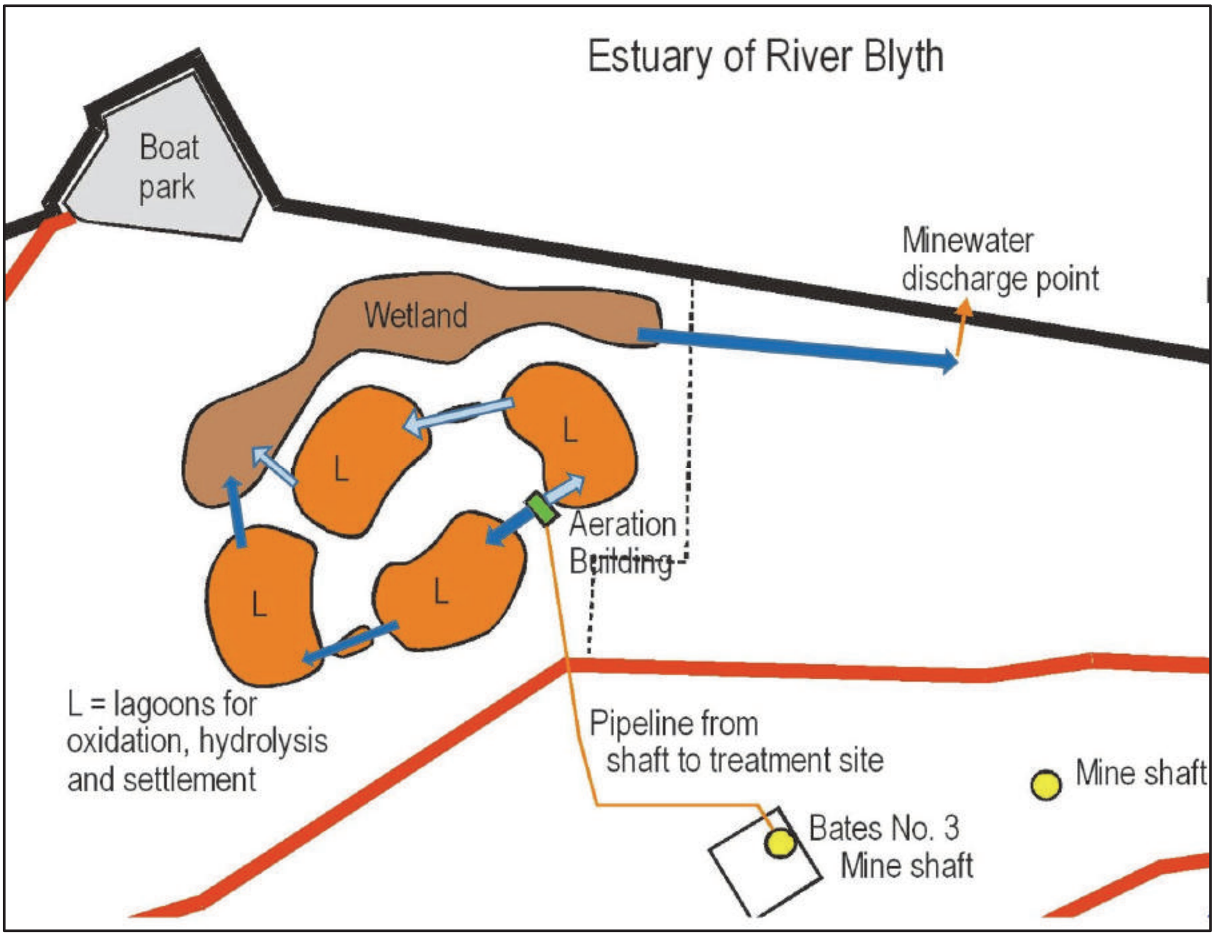

Figure 8 Treatment Scheme Layout

The pumped mine water had iron concentrations initially in the region of 60mg/l, was chemically reducing in nature and contained hydrogen sulphide, therefore the early introduction of oxygen was essential. Oxygenation is achieved by discharging the pumped mine water from the rising mains at the aeration cascade building.

The oxygenated mine water is then split into two streams. Each stream of mine water flows through a series of two aerobic lagoons (4 in total, of combined area 11,400 m^2 and 25,000 m^3 volume), where oxygen reacts with the dissolved ferrous iron. The ferrous iron is oxidised to ferric iron. At circum-neutral pH, the ferric iron is rather insoluble and precipitates out as a sludge of ferric oxyhydroxide (Figure 9).

When the mine water exits the final lagoon, the two streams of water are recombined and it then enters a final polishing wetland or ‘reed bed’ covering an area of 8,000 m^2. Further oxidation and settlement occur in the wetland, where any remaining particles of ferric oxyhydroxide are trapped by the reeds and rushes growing in the wetland. One of the early major challenges was to find species of reeds that would survive given the high salinity of the Mine Water. Following its passage through the wetland, the water is discharged to the River Blyth and whilst the efficiency of iron removal can reduce at times due to the effects of adverse weather conditions etc., the water discharged has always comfortably met the consented limit 10 mg/l of iron.

The Initial pumping rate was 76 l/s; however, this proved to be insufficient to control the rising mine water and by stages the pumping rate was increased, until by 2010 the flow rate was 60% above the design rate of 100 l/sec. This was achieved without compromising the discharge quality due to a reduction in iron concentrations of the mine water by around 50% since pumping started. At this stage the pumping rate had reached the discharge consent limit of 162 l/s.

In 2017 the Discharge Permit was varied by increasing the maximum flow rate to 250 l/s and adding a maximum daily iron loading of 140kg whilst the instantaneous limit for iron remained at 10mg/l. This allowed the pumping rate to further increase to its current level of circa. 220 l/s.

Figure 9 Treatment Area working at capacity in 2020

The treatment systems performance is closely monitored in order to ensure environmental compliance at all times and in general there is a requirement to de-silt 1 of the 4 Lagoons each year. In 2020 after almost 20 years of service, the reeds in the wetlands needed replacing and the entire area was dug out and new reeds planted. During the reed bed refurbishment, the wetland area was put off line and chemical dosing introduced to ensure pumping rates could be maintained at normal levels.

4. Reclamation of the Bates Colliery Site

By the end of 2008 Banks Developments had taken ownership of the major section of the former Bates Colliery Site and secured planning permission to construct 310 residential properties and a new primary School (Figure 10).

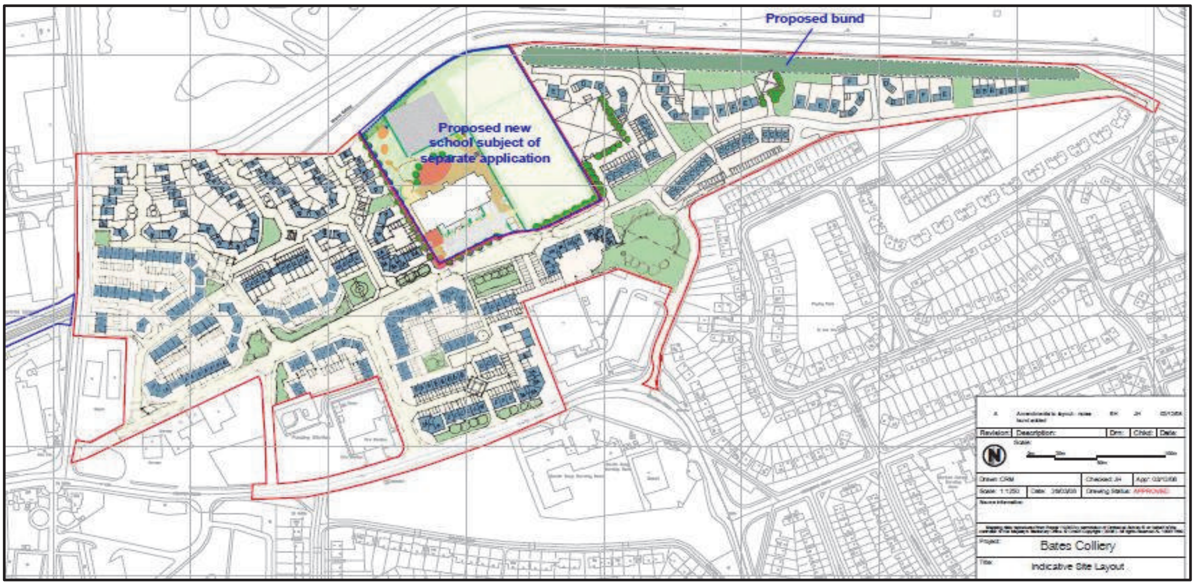

Figure 10 Bates Colliery Re-Development Masterplan

To prepare the site for development the significant below ground concrete obstructions needed to be removed (Figure 11a and b) along with pockets of contaminated made ground which would have posed a Human Health risk to the occupiers of the new properties if it remained. Additionally, the existing bund which had been constructed to provide noise attenuation from the Port Activities for the properties on Crawford Street at the Eastern end of the site needed to be relocated to the Northern boundary of the new development to provide noise attenuation for the new properties.

Figure 11a Concrete foundations removed within the School Plot

Figure 11b Crushing operations - over 12,000t processed and re-used within the new Development Platform

A summary of the tasks required was as follows: Excavation of existing bund and made ground (total 200,000m^3), processing and removal of all unsuitable material and placement as compacted fill to a high geotechnical specification for the new development. Off-site disposals were as follows: Hazardous Waste – 1,200tonnes; Non-hazardous Waste – 400tonnes.

Following the removal of the 3m of made ground, it was discovered that the original (pre- colliery build) topsoil and subsoil was still in place. As these organic materials were unsuitable for formation of the development platform they had to be removed and stored in stockpile for use by the future developer. This resulted in a shortfall of circa. 18,000 m^3 of fill material to achieve the development platform level. The shortfall was addressed by importing 8,000 m^3 of suitable material and leaving a void of 10,000 m^3 for the developer's foundation arisings rather than having to dispose of them off-site.

One of the last activities on site was to divert the rising mains around the new School's proposed playing field in order to mitigate constraints to its use.

5. Waste Minimisation and Recycling

The ochre (Hydrous Ferrous Oxide or HFO) that collects in treatment lagoons is classified as a waste and had always been disposed of at licensed non-hazardous landfills at significant cost.

In 2012 the first of a new design of drying bed was constructed at Bates to allow the annual de-silting to be carried out more efficiently and cost effectively (Figure 12). The emptying of a Lagoon can now be achieved by pumping its contents to the drying bed, then allowing it to settle before removing water via the underdrainage and surface water management systems. This resulted in a reduction in the moisture content of the Ochre of over 50% with reduced tonnages therefore going to landfill.

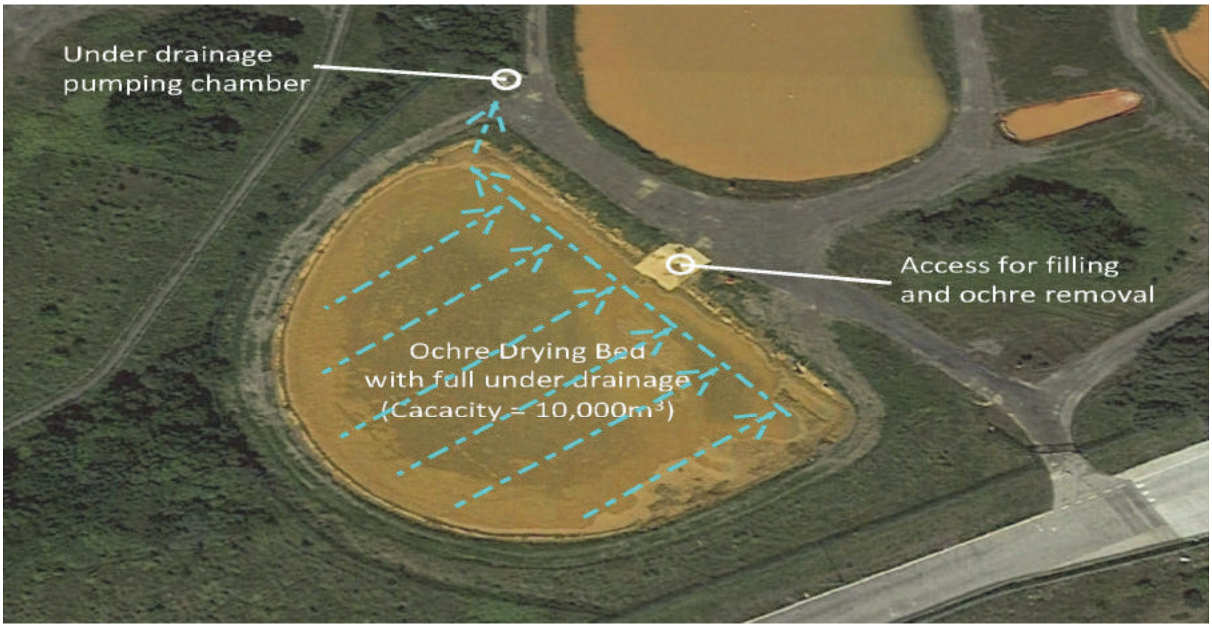

Figure 12 New drying bed constructed in 2012

The sorption properties of HFO means it has been used for many years for the removal of phosphate and arsenic from waste water. It can also be used for remediating metals in contaminated soils, legacy industrial wastes and in energy from waste processes.

In 2016 following an enquiry for the provision of HFO for a land remediation project, an ochre conditioning area was constructed near the cascade building to allow material from the drying bed to be further de-hydrated and stored in preparation for sale. In the following year The Coal Authority supplied 5,000 tonnes of HFO to Merseylink to remediate and allow the re-use of 9,000 m^3 of heavily contaminated soils for the Mersey Gateway Project; with a significant proportion being sourced from Bates (Figure 13a and b). The remediation targets and engineering specification were fully met and achieved estimated cost savings in the region of £2 million. As a result, the project was awarded first prize in the 2020 Brownfield Briefing Awards for best re-use of materials in 2020.

Figure 13a Incorporating HFO with contaminated soils

Figure 13b The new Mersey Gateway Bridge

At the time of use at Mersey Gateway the use of HFO required incorporation within a Bespoke Environmental Permit (as it had the ‘waste’ status); however, the Coal Authority are progressing End of Waste status with the Environment Agency which will allow HFO to be easily marketed as a product thereby allowing it to be being sustainably re-used rather than being discarded and filling up valuable landfill space.

6. **Low Carbon Energy**

The Coal Authority has made a commitment to invest in the use of renewable energy technologies and set-up an Innovation team to implement the use of solar electricity generation wherever viable to reduce the power consumption from the Grid. This would assist in mitigating spiralling electricity costs associated with water pumping whilst at the same time replacing grid electricity with zero carbon renewable energy. All operational pumping stations were considered with the decision process taking account of the size of land holding (or land purchase opportunity), the capacity of the local electricity grid, the amount of energy being consumed by the pumps on site, predicted construction costs, planning success likelihood and finally the return on investment profile.

Bates would be the seventh and largest Coal Authority Solar scheme to be built and following intensive ground investigations the construction began in the autumn of 2018 (Figure 14).

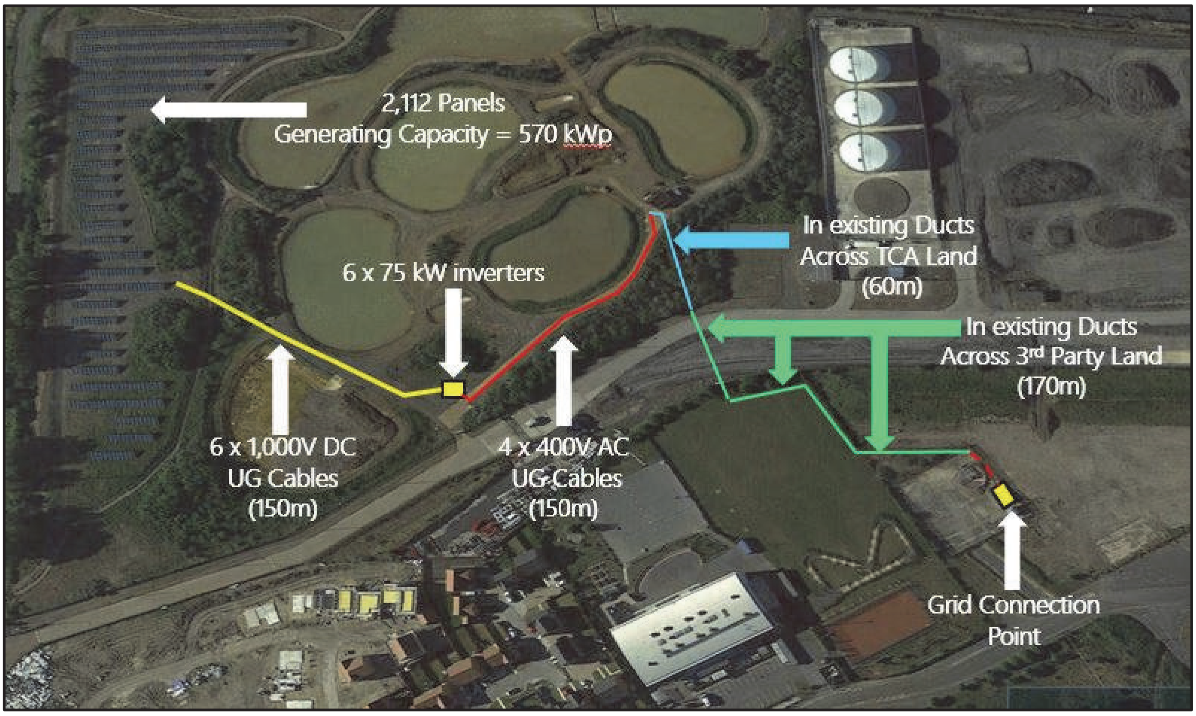

Figure 14 Solar Scheme Layout

As the solar arrays were to be installed on part of the former colliery arising stockpile, to the west of the treatment area, the panel frames had to be secured to driven piles to protect against the substantial wind loading due to the exposed location.

The major obstacle to overcome during the construction phase was installation of the 4 No. 60mm Ø 400V cables (each 380 m in length) through the existing 110mm Ø ducts which lie alongside the rising mains. It was essential to install the cables without any joints and the additional bends installed on the Morpeth Academy School grounds made the task significantly more difficult given the lack of flexibility of the armoured aluminium 3 phase cables in the prevailing winter temperatures (Figures 14 a and b).


Figure 14a 400V DC cable shown within the 110mm Ø duct

Figure 14b Typical cable routing at changes of direction

The installation consists of 2,112 solar panels which at its peak generates 570kW of electricity at 1,000V DC, this being converted to 450V AC by the 6no. 75kW inverters, before being fed to the grid connection point (Figure 15).

Figure 15 A view of the northern section of the solar arrays

Although the mine water treatment pumping operation only requires 200,000kWh each year during solar operating hours, the scheme was purposely designed to produce 550,000kWh, the limit being determined by the maximum instantaneous grid acceptance of 475kWh at the connection point. This means that 350,000kWh is available annually for supply locally or to power heat pumps that could take advantage of the mine water opportunity; with the balance at any time being exported to grid (Figure 16).

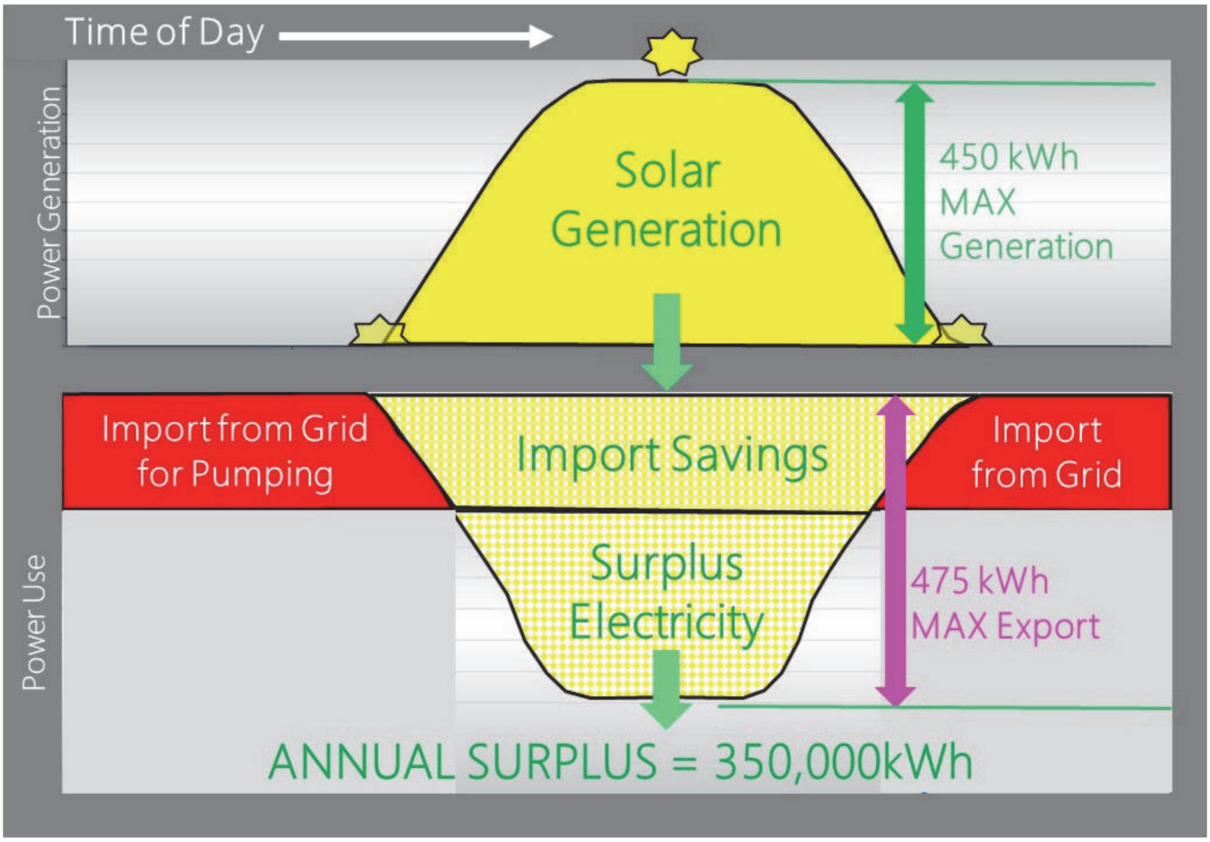

Figure 16 Graphs showing relationship between solar generation, reduced use of electricity from Grid and surplus electricity to pumping requirements

7. Port of Blyth and Bates Staithes. Past, Present, Future

The Port of Blyth (Figure 17) is the port operating division of Blyth Harbour Commission, an independent statutory trust. The port is operated for the benefit of stakeholders including all port users, employees, the local community and wider sub-region, the Commission is overseen by a Board of Commissioners and a management team of Directors. A key feature of Trust Port status is that all surpluses are re-invested into improving the facilities and services offered by the Port, with all activities undertaken to provide benefits to a group of stakeholders which includes staff, customers, port users, the local community and the wider regional economy.

Figure 17 Port of Blyth

Given that the shipment of coal from Blyth began during the 14th century, with mines recorded nearby at Cowpen and Bebside by the late 16th century, it is safe to say that coal was the driving force behind the continued establishment and development of the port throughout the following centuries.

Evidence of the port's first "major" commercial quay on the River Blyth was first recorded in 1682, while the advent of railways saw another step change. The Tyne and Blyth Junction Railway built the first rail linked staiths on the south side of the river in 1849 and coal shipments grew rapidly over the next few years to around 200,000 tons per annum.

This growth highlighted a clear need for major investment in the port and as a result the Blyth Harbour Commission was formed by an act of Parliament in 1882.

By the 1930s Blyth was exporting 5.5 million tonnes of coal per annum and subsequently became the largest coal exporting port in Europe when the trade reached its peak in the early 1960s at over 6 million tonnes per year.

A period of decline ensued during the late 1960's with coal trade reducing significantly as local mines began to close, together with the last remaining shipyard, the Blyth Shipbuilding Company, which ceased operation in 1966.

The 1970s saw a reversal of this trend with Alcan establishing a major aluminium smelter 5 miles north of the Port as well as an import terminal on the river to handle large volumes of bulk raw materials. At the same time Blyth started to expand its paper import trade from Finland which grew to a peak of over 0.5 million tonnes in 1998, making the Port one of the major paper terminals in the UK.

The loss of a large proportion of this paper trade in 2000 was a major blow but the Port re-invented itself again, rapidly expanding into container handling, plywood, project cargo and dry bulk commodities. The Port's wholly owned subsidiary Transped was established during this period to drive forward opportunities in container transportation and logistics.

While the closure of the RioTinto aluminium smelter up the coast at Lynemouth in 2012 was a further setback, the level and diversity of trade growth meant that the effects of the closure were minimised - with a record turnover being produced the following year.

The Port's location on the North East of England coast meant it was ideally positioned to support new customers in the offshore energy sector who found the service and flexibility on offer in Blyth a real attractant. Not only did the port emerge as gateway for thousands of onshore wind turbine components destined for projects in northern England and southern Scotland, but it was also the location for the first offshore wind turbines in UK waters.

The Blyth wind farm comprised of two turbines and was installed in 2000, these operated for nearly 25 years, producing renewable energy for the UK grid. Interestingly, once the turbines had come to the end of their serviceable life, they were then notable for being the first turbines in UK waters to be decommissioned.

Now a leading offshore energy hub, the Port of Blyth is home to a number of major tenants operating in the offshore energy sector and regularly hosts key operations and maintenance activities and internationally significant engineering projects.

In recent years, the port has worked in close collaboration with Offshore Renewable Energy Catapult, Northumberland County Council and Advance Northumberland to establish the influential "Energy Central" partnership, which operates to attract inward investment from the offshore energy sector into Blyth.

With approximately 75% of the port's trade now related to offshore energy, and growth in both container movements (including continued high performance from logistics subsidiary Transped) and dry bulks, the port's medium to long term future is secure. In addition, a number of exciting new developments should ensure that the port not only survives but prospers.

Figure 18 Artists impression of Port of Blyth's Bates Clean Energy Terminal on the site of the former Bates pit. Proposed pipeline for mine water heating scheme can be seen in red

The recent launch of the Bates Clean Energy Terminal, following multi-million pound redevelopment works, provides an ideal opportunity for growth (Figure 18). The revamped terminal will soon feature a raft of low carbon initiatives alongside the potential mine water heating scheme, including solar power, electric plant and machinery and R&D of new low carbon fuels and other innovations. These initiatives and the prime quayside land available for redevelopment on site will no doubt appeal to operators in the renewable sector looking for locations to base themselves to make the most of the huge development in offshore wind in the North Sea in the coming years.

The mobilisation of component parts for those wind farms currently under construction or those at the planning stage provides a good opportunity for growth at well positioned and flexible east coast UK ports such as Blyth, while the Crown Estate's Offshore Wind Leasing Round 4 will offer yet more opportunities. The port also intends to monitor potential revenue streams from innovations in offshore wind such as floating turbines as well as new renewable sources such as tidal power.

As a Trust Port, the Port of Blyth is pleased that all these developments will provide significant opportunities for all of our stakeholders, both locally and regionally, from individuals in our community looking for improved career options all the way through to established, multinational tenant companies.

The growth over the last 20 years in offshore energy trade has allowed the Port of Blyth to develop into a thoroughly modern Trust Port, with as many as 500 people now employed on port land around the estuary with thousands more in the related supply chain supported every day.

Given that the port consistently grew as a result of coal exports over several centuries, it is interesting to note that while times change, the Port of Blyth is *still* an energy port after all these years. Of equal interest is that another legacy of coal related activity in Blyth will soon provide a unique opportunity - through the mine water heating scheme at the Bates Clean Energy Terminal - to drive trade forward at the port with those operating in the renewables sector.

8. The mine energy opportunity

The Coal extracted from the Great North Coalfield has long since been mined, traded and burned yet the water that has flowed into the voids and replaced it can be used again and again to provide a sustainable source of geothermal heat. The temperature of water within abandoned mines generally lies in the range 12-20°C. Abandoned mines offer significant potential to supply low carbon geothermal heat at scale in former mining areas (Adams *et al*., 2019). The coalfields underlie around one quarter of the built environment and there are around 23,000 abandoned mines across the UK. In addition to this, the Coal Authority operate over 80 mine water treatment systems where mine water is either pumped or flows by gravity to surface and is treated prior to discharge to surface waters. These alone collectively produce around 100MW of heat which currently dissipates to atmosphere.

These existing discharges are currently being investigated by the Coal Authority and Durham University as sources of heat supply for adjacent new and existing developments. One such opportunity is the Seaham Garden Village scheme that will use water pumped from the former Dawdon Colliery in County Durham to supply heat to a new development of 1500 homes via a heat network. The mine water pumped from the former Bates Colliery shaft in Blyth also provides a further opportunity. The passive mine water treatment system at Blyth pumps and treats around 220 l/s at a temperature of around 15°C, equivalent to a heat output of just over 4MW (assuming a temperature drop, caused by the heat extraction, of 5°C). Clearly temperatures of 15°C are not sufficient to provide direct heating and therefore a heat pump is required to increase the temperature. The heat pump should produce around 4-5 kW of heat output per kW of electrical input leading to a 75% reduction in CO_2 emissions compared with the gas counterfactual and with the greening of the electricity network over time emissions will continue to decline. The production of surplus electricity by the Coal Authority's Bates solar array offers the potential to use this surplus for heat pumps that could take advantage of the available mine energy resource to provide heating and cooling leading to a very low carbon scheme.

The mine water is at relatively shallow depths in the Blyth area and several seams were mined meaning that depending on the distance of the end user from the resource and the complexity of running heat networks through developed areas there might be potential to drill boreholes to access the mine water should accessing the pumped discharge not be appropriate. Figure 19 shows how this could be configured. The key principle is to identify separate targets for abstraction and re-injection to avoid short circuiting. Generally, the deeper seams where temperatures are slightly higher are used for abstract with re-injection taking place to a shallower seam.

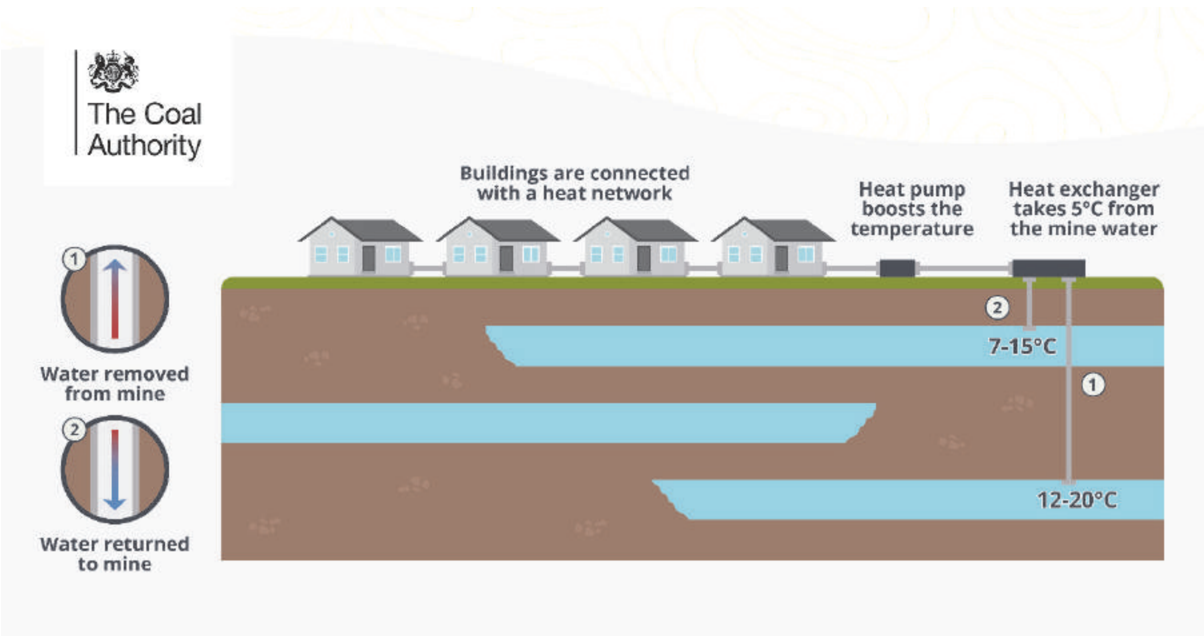

Figure 19 Schematic showing mine energy deployment using boreholes

Development land to the south of the treatment scheme has been acquired by the Port of Blyth and presents an opportunity to use the mine water to provide heating and cooling. It is understood that the school adjacent to the mine water treatment lagoons already has an underfloor heating system so there exists an opportunity to retrofit this building with a heat pump running off the mine energy.

Many local authorities are leading the way by exploring and progressing opportunities to develop mine energy systems in their areas as one response to the climate emergencies that have been declared across the UK and also to prepare for the 2025 moratorium on new domestic gas connections. This interest is being supported by the UK government's Heat Network Delivery Unit and Heat Network Investment Project (to be followed by the Green Heat Network Fund) which aims to increase heat network uptake. Heat does not travel well therefore the benefits of these schemes will be realised locally presenting opportunities for regeneration in mining areas. This has happened in the Netherlands at Heerlen where a mine energy scheme has been operating for over a decade supplying heating and cooling to a range of new and retrofit buildings via an ambient loop heat network (Verhoeven *et al.*, 2014). In addition to delivering heating and cooling, the mine energy scheme has brought economic gains and other social benefits to a formerly deprived mining area.

9. Conclusions

This paper tells a story of adaptation and diversification that has had a strong connection with energy supply and innovation and is now coming full circle. Industries associated with coal mining, shipbuilding and transportation by sea and rail have had a symbiotic relationship and have long shaped the economic development this part of Northumberland. This was reflected in the establishment of the port's major commercial quay in the 1600s and subsequent growth paralleled by the expansion of mining activity in the area. The closure of the last shipyard at Blyth in 1966 and the abandonment of Bates Colliery in 1986 were key drivers for change.

As coal mining ceased and other sectors declined, the Port of Blyth diversified into new business areas including taking delivery of raw materials for the Alcan smelter at Lynemouth and paper and timber shipments. When these markets dwindled, the port became a first mover responding to the UK's increasing appetite for wind energy by hosting the first 2 offshore wind turbines in UK waters and building opportunities around the offshore energy sector supply chain. Now a leading offshore energy hub, the Port of Blyth is home to a number of major tenants operating in the offshore energy sector and regularly hosts key operations and maintenance activities and internationally significant engineering projects. In recent years, the port has worked in close collaboration with the Offshore Renewable Energy Catapult and there is now an opportunity for the mine and port to be linked once again through businesses engaged in the renewable energy supply chain to access heating and cooling from the sustainable heat source at Bates mine water treatment scheme.

In the intervening two decades after the closure of Bates Colliery, the former colliery site was redeveloped and the water that had silently been re-filling the mine reached the predicted point where pumping and treatment became necessary. This pumping station is now crucial for controlling regional water levels over an area of 350 km^2 of the coalfield. Just like the port, the mine has had a renaissance that has precipitated new opportunities. The water pumped from the mine has potential as a source of geothermal heat and markets have been developed for the ochre that accumulates as part of the mine water treatment process following an R&D programme that recognised the significant value of the ochre as an agent for land and water treatment. This avoids significant volumes of waste going to landfill. Offsetting the electricity demand and associated carbon emissions linked to continuous mine water pumping with the installation of a large PV array provides a further opportunity that in addition generates surplus electricity.

Over the years both the mine and the port have maximised the opportunities to benefit from change and will continue to innovate and adapt. The Energy Central initiative engages with the low carbon energy future whilst building on a long history of energy innovation in the area.

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ENERGY STORAGE FOR MINING LEGACIES: FACILITATING THE GREEN REVOLUTION

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January 2021

The global energy mix is changing, and rapidly. As the world becomes more electrified, the demand for renewable energy sources has increased, thus creating a growing need for electrical energy storage[1]. Mitigation of Climate Change demands decisive action, meaning that many coal mines for power generation across the world are likely to become stranded assets. Gravitricity is working on an R&D project to develop a technology offering which will address these dual issues by re-purposing disused or soon to close mine shafts into long-term energy storage solutions, with a low-levelised cost of storage, enabling the assets to support local intermittent renewables, such as solar PV and wind. This novel technology uses gravity to store energy in weights via a mechanical system and unlike Lion batteries (which degrade over a few years) provides a long term solution lasting 25 years or more.

Gravitricity is currently building a first of a kind mechanical demonstrator system (above ground) which will be connected to the electricity grid in Edinburgh ahead of developing full scale system technology for use in mineshafts across the UK, Europe and further afield. The fact that so many mines in the UK have been closed for many years means that there are a number of additional constraints to be resolved (compared to operational mines) before safe access can be made. This report seeks to identify and explore some of the challenges that Gravitricity are planning for when repurposing disused mineshafts in the UK, and other regions.

Background

Technology

The Gravitricity system suspends weights of 500 - 5000 tonnes in a deep shaft by a number of cables, each of which is engaged with a drum hoist capable of lifting its share of the weight. Electrical power is then absorbed or generated by raising or lowering the weight, using the same electric motor for motoring and generating. The hoist system can be accurately controlled through the electrical drives to keep the weight stable in the hole.

Gravitricity technology has a unique combination of characteristics:

- 25+ year design life – with no cycle limit or degradation;
- Cost effective – levelised costs well below lithium batteries;
- Response time – zero to full power in less than one second;
- Efficiency – between 80 and 90 percent;
- Versatile – can run slowly at low power or fast at high power;
- Simple – easy to construct near networks;

Each unit can be configured to produce between 1 and 20MW peak power, with output duration from 15 minutes to 8 hours.

Mineshaft Integration

Traditionally, when a mineshaft reaches the end of its service life, a decommissioning plan must be prepared and executed in order to leave the infrastructure in a safe state[2]. In the case of Gravitricity's technology proposal, a new service life can be given to a mining asset and in doing so, an innovative repurposing strategy along with a novel mine maintenance plan must be realised. At the time of writing, work is ongoing to define and optimise new processes for the integration of such technology into existing mineshafts. Whilst not the focus of this paper, it should be noted that Gravitricity also intends to sink purpose-built shafts in future to facilitate Energy Storage Projects in specific locations where they are required.

Gravitricity has investigated shafts at several different points in their lifecycle, ranging from shafts that have ceased operation, been closed and filled, right through to (in some cases) shafts of 1000m or more that were newly sunk and never used. In the determination of preferred sites for a first of kind prototype demonstration it has become apparent that certain scenarios will be more favourable than others. For example, capped closures from some time ago (typically 20 years or more), of which many exist in the UK, introduce additional required steps prior to commencing detailed site works. An overview of some specific site requirements and shaft repurposing tasks is provided in the next sections with a summary of the areas identified for innovation activity within our ongoing R&D Programme.

Available mineshaft cross section

The energy available in any shaft is related to the depth of the shaft and the mass of the weight(s) installed. When utilising existing shafts, Gravitricity technology will seek to use the largest possible cross-sectional area that can be made available in a mineshaft and this will be determined through the site investigation process.

When refurbishing an existing mineshaft, considerations will be given to the best ways to optimise the available cross-sectional area. This could include consideration of clearance distance from existing infrastructure or ensuring sufficient remaining cross-sectional area to allow ventilation activity to be maintained (if needed). It is important to note that weights can be tailored to fit specific shaft dimensions.

As an example, considering the design of a 500 T weight to be installed in a 7.5 m diameter shaft. If the shaft had a single conveyance compartment, with existing furnishing requiring a 1.0 m clearance between the weight and the shaft lining then the weight may be designed to have a maximum diameter of 5.5 m and a height of 4 m.

Foundations

Due to the large masses involved, Gravitricity installations will require significant civil supports. The load will be passed to foundations via hoist support frames. It is expected that the high ground loads seen during shaft sinking will have required substantial foundations to be implemented. Preliminary internal investigations have concluded that the additional loads required for Gravitricity's technology will likely require additional re-enforcement of some level. This is one of a number of aspects that will generally be confirmed on a site-to-site basis. Research carried out to date by Gravitricity has confirmed that sufficient foundations can be achieved with relative ease using well established, existing piling techniques.

Shaft furnishings

Existing furnishings in a shaft can have a major impact on the cost of re-adapting the shaft for a Gravitricity installation. Service pipes, buntons, stairways, multiple compartment layouts and other features can all limit the shaft cross section available for weight installation. In deep shafts this may not have a significant impact on the energy capacity (as a small increase in weight height to compensate for lost cross section will have a very small marginal impact on the available travel of the weight and the resulting Energy storage capacity). However, furnishings may present barriers to hoist configurations (by limiting reeving systems) and offer significant cost barriers if they are in poor condition and need to be removed or repaired. An internal review conducted by Wardell Armstrong in

2019 on behalf of Gravitricity found that the scrap value available from removal of steel infrastructure will offset a significant proportion of the cost associated with its removal. The development of a repeatable process for removal of shaft furnishings has been identified as one of a number of core activities in the next phase of Gravitricity's R&D plan.

Headgear

Headgear in existence at mining sites will be assessed on a site by site basis prior to the implementation of Gravitricity systems. Typically, the loading capability of mining headgear structures will not be sufficient to hold the loads required for full scale Gravitricity systems. Whilst Gravitricity aims to implement purpose built hoisting equipment, it is also the case that existing operational winders can play a very useful role in the refurbishment of mineshafts, prior to new system installation.

Shaft Environment

Knowledge of shaft specific environments is essential to feed into system design requirements[3] for future shaft uses. An example of some shaft environment parameters being considered is given in this section.

Water and Hydrogeology

Information on any existing water ingress and pumping at a site must be determined as well as the expected duration of these pumping activities in relation to ongoing mining operations or prevention of aquifer contamination form mine waters. Potential environmental impacts associated with local hydrogeology[4] must also be understood. In the case of Gravitricity system deployments, it is important to understand how water ingress affects shafts and how future levels may change over the lifetime of the project. Interaction with local hydrogeology and possible alternative uses for existing water has been identified as an area to be further researched as part of Gravitricity's ongoing R&D activity.

Mineshaft Gas

Mineshaft gas compositions can vary significantly across different sites. Constraints resulting from mineshaft gas affect health and safety requirements of a system and require substantial attention to ensure safe working conditions[5].

Gas issues will require substantial consideration for coal mines but are not expected to be a major constraint in other mineral mines such as gold mines. Possible effects from different minerals will require to be evaluated.

The operation of Gravitricity systems in close proximity to harmful (to humans or the atmosphere) gases is a core area which is being considered as part of Gravitricity's ongoing mineshaft R&D activity.

Temperature, Moisture and Humidity

Temperature levels within mines has the potential to affect equipment and must be clearly understood. Thermal expansion can affect system operation so a clear understanding of impacts on the system resulting from temperature changes in specific mine sites must be gained. This can be of particular concern in deep shafts where mineshaft temperatures vary considerably between seasons or between day and night.

Shaft Maintenance and Ongoing Shaft Inspection

It is of great importance to achieve high safety standards for gravity based energy storage systems in mine shafts. Given the novel nature of this technology, which has some fundamental differences to typical mine operations (i.e. unmanned operation) it is expected safety protocols may take a different form to those which exist for current mining operations. As a result, possible amendments to policy or use of alternative, more appropriate standards will be explored with local safety bodies and policy makers.

Regular shaft inspections are required for operational Gravitricity systems as is the case in more traditional mining environments. There may be a strong argument for the introduction of more remote sensing and recording equipment to be used to carry out planned shaft inspections and this is an example of the type of activity which may differ from more common practices in today's mining industry.

Identification of areas for Future Innovation

In the case of this novel technology development, it is important to acknowledge that there are sub systems which are already well established through other industries and there are other areas that require more detailed innovation activity to validate a solution. Figures 1 and 2 summarise the key focus areas identified for Gravitricity's ongoing mineshaft R&D programme.

Figure 1: Example of Technical considerations in Gravitricity mineshaft R&D programme

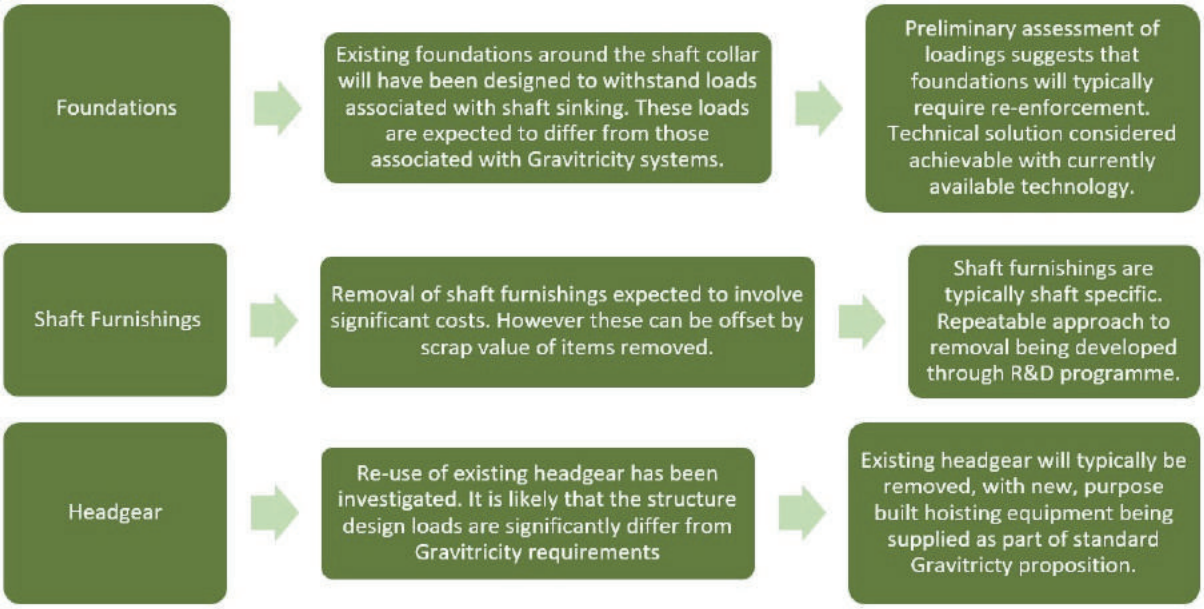
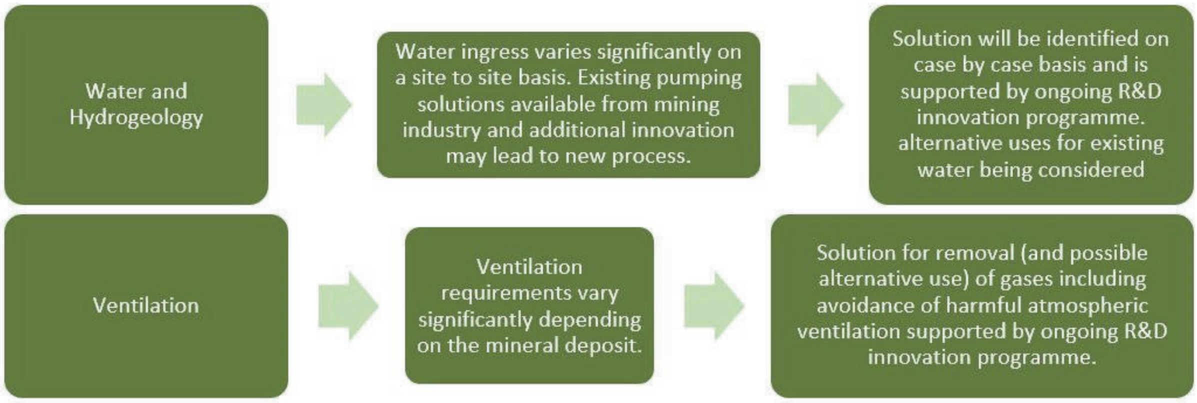


Figure 2: Example of environmental considerations in Gravitricity mineshaft R&D programme



Closing Remarks

As set out in this paper, Gravitricity has identified several key opportunity areas for innovation which will be focused on as part of planned R&D activity feeding into the company's first full scale deployment. As summarised in Figures 1 and 2 above, key areas of innovation are anticipated to include consideration of shaft furnishings plus the safe handling of environmental factors such as water ingress and ventilation.

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CARBON CAPTURE, USE AND STORAGE: UK POTENTIAL

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Abstract

Carbon capture, use and storage is a critical technology that will enable the UK to successfully undergo the energy transition process and deliver a future in which we are net-zero emissions of greenhouse gases. Carbon dioxide can be captured from fossil fuel power station flue gases, from the waste product of hydrogen manufacture and as a necessary but unwanted by-product of many large-scale industrial processes.

For almost two decades UK governments have shied away from a firm commitment to capture carbon and permanently bury it, despite the desire of many large industries to deliver the technology. Research collaborations between UK academia and UK-based industry have demonstrated both the viability of the technology, operational elsewhere in the world, and evaluated the massive storage volume potential that exists in depleted petroleum fields and associated saline aquifers beneath the UK continental shelf.

Now is the time for the UK to deliver operational CCUS if it is to meet its greenhouse gas emissions targets.

Introduction - UK and global emissions of greenhouse gases and climate change.

In common with all other nations the UK has, since the beginning of the Industrial Revolution, built its economy using the energy released from fossil fuels combustion. The UK was one of the early-movers in developing its coal resources at an industrial scale in the 18th and 19th centuries. Coal production peaked early in the 20th century at around 300 million tonnes mined per annum. The UK also proved to be rich in natural gas and oil, with development of the North Sea and other parts of the UK continental shelf to become a globally significant petroleum province. Emissions of CO_2 from the UK are highest in the industrial cities and areas of the country (Figure 1).

Combustion of coal, oil and gas releases CO_2, a powerful greenhouse gas, into the atmosphere. Fossil fuel powered industrialisation, combined with industrial scale agriculture and deforestation has increased the quantity of carbon dioxide emitted from around 5 Gt CO_2pa in 1900 to over 35 Gt CO_2pa, causing CO_2 concentrations in the atmosphere to rise from around 280 ppm to over 400 ppm (Figure 2), causing ocean acidification, and global temperatures to rise by an estimated 1 degree centigrade. It is widely recognised that continued use of fossil fuels is unsustainable and it is the impact of fossil fuel combustion on climate change and ocean acidification rather than paucity of coal, oil and gas which is the limiting factor. The United Nations formed the Intergovernmental Panel on Climate Change (IPCC) in 1988. Its aim was to provide policy makers with regular scientific assessments on the current state of knowledge on climate change. Recent modelling by the IPCC indicates that without stringent and rapid mitigation of GHG emissions, global surface temperatures can be expected to rise by around 4°C by 2100 (Figure 3).

The IPCC advocates a suite of processes and policies which need to be adopted by society rapidly and at scale to dramatically reduce emission of greenhouse gases. Carbon Capture and Storage (CCS) is the only industrial scale process which enables continued use of fossil fuels but does not release carbon dioxide into the atmosphere. As such it is seen as a transition technology for a society constructed around fossil fuel combustion. The technology is proven and widely tested at demonstration scale but is not widely adopted because it adds cost and modest complexity to the use of fossil fuels. The opportunities for use of CO_2 are many but, volumetrically, most are trivial when compared with the quantities emitted.

UK governments have in the last two decades failed on three occasions to take the opportunity to adopt CCS. Most spectacularly this occurred in November 2015 on the eve of the United Nations Framework Convention on Climate Change, Conference of the Parties meeting in Paris, December 2015 (COP21) when all £1 billion of manifesto committed funding was removed at the last minute from the then CCS competition at the point when two industrial consortia were about to go operational. However, of late the political narrative in the UK has changed with the inclusion of hydrogen manufacture which requires carbon capture and the use of the acronym, CCUS where 'U' stands for use. Consequently, more recent commitments by the UK government to fund £1 billion to activate CCUS in the UK look set to work, given the broader commitments by government to meet the climate emergency requirements to reduce GHG emissions and reach net-zero emissions by 2050.

The aim of this paper is to examine the component technologies of CCUS, storage opportunities in the UK, potential large-scale use of carbon dioxide and the timeline for delivery of CCS/CCUS in the UK.

Capture

Capture of carbon dioxide can occur directly from the atmosphere, immediately post-combustion of the fossil fuels or on release from other industrial processes such as methanol reforming for hydrogen production. Here we consider carbon capture associated with industrial processes.

A major use of fossils fuels in the UK is for power generation. The progressive closure of coal fired power stations in the UK in the last decade means it is unlikely that carbon capture will be retrofitted to coal fired power stations but such capture plants could be deployed on gas fired power plants and newly commissioned biomass power plants. If fitted to biomass plants, carbon capture should make such plants carbon negative.

Post combustion capture typically involves exposing the flue gases to an ammonium bearing solution. Carbon dioxide in the flue gas is removed by the ammonium solution cascading through the emerging flue gas. The CO_2 bearing solution is isolated and heated whereby the CO_2 is desorbed and captured while the ammonium solution is cooled and returns to the cascade to interact with more of the evolved flue gases. The captured CO_2 is then piped or transported by tanker to the storage site. CO_2 can also be captured as near pure, gas from oxy-fuel and pre-combustion power plants although no such plants operate in the UK.

Carbon dioxide is also emitted in a suite of large scale industrial processes such as calcining limestone for cement manufacture and ammonia production as well as any process that involves burning fossil fuels, for example glass and steel manufacture. In all these instances the carbon dioxide could be captured as it is emitted.

Finally, what was a modest scale industry, that of hydrogen manufacture, is set to grow rapidly as hydrogen has been tagged as the low-carbon gaseous fuel for the future. Hydrogen produces only water vapour when burned and could, with modification of the national gas grid distribution system, be piped to homes and industry. However, at present the only commercially viable and large-scale production method is methanol reforming, a by-product of which is carbon dioxide which must be captured if the low-carbon benefits of using hydrogen are to be realised.

Just as with the CO_2 captured post combustion from power generation, so too the carbon dioxide from industry and hydrogen manufacture is contaminated with other gases in small to trace quantities. Both the transport and storage processes can be affected by the contaminants.

Transport

Capture plants, whether clustered together or dispersed, are commonly located at some distance from suitable storage sites (typically for the UK the most appraised storage sites are offshore, e.g[1]). The captured CO_2 needs a secure and cost-efficient delivery system to reach the storage site. Shipping, pipeline, road and rail can all be used to transport CO_2.

Pipelines have long been used to deliver oil, gas and water both on and offshore. There are already over 6000km of pipelines transporting CO_2 mainly in the US and Canada[2]. Although there are currently no operational CO_2 pipelines in the UK nor specific legislation for the transportation of CO_2, the White Rose (Drax in 2015) project successfully navigated the permitting process proving it can be done safely[3]. Onshore pipelines typically operate with CO_2 in gas phase, whilst offshore pipelines are planned for CO_2 in either gaseous or dense phase, depending on storage reservoir conditions. Both offshore and onshore pipelines will have sensitivity to impurities within the stream of CO_2, which can affect both the chemical and physical properties of CO_2 flow[4]. For example the presence of free water could prompt hydrate formation within the pipeline, limiting flow. Impurities could also affect the conditions of the phase change of CO_2, the pipeline transport process, pipeline capacity, crack propagation within the pipeline, and corrosion.

There is complexity regarding international regulatory frameworks for shipping CO_2 (see also[3]). Shipping of CO_2 has been undertaken for more than 30 years for food and beverage industry supplies, however larger ships are required for transportation of CO_2 for subsurface storage. Global experience in shipping CO_2 in large volumes is limited. There are several large tankers in existence that have been reconditioned that can reportedly carry up to 10,000m^3 [3]and there are plans to build two dedicated tankers associated with the Norwegian CCUS[5]. Ports have restrictions on the specifics of ship traffic, including maximum ship length, which would constrain early projects but in the long term could be accommodated. Finally, with effective and comprehensive international regulations there will be opportunity for international trade in CO_2 associated with CCUS projects.

Transport of CO_2 via road and rail will be necessary to some extent, especially for dispersed CO_2 capture plants, however they tend to be more expensive transport solutions. Road trucks are limited to 26t per truck and rail to 60t per wagon, with rail transport subject to additional limitations due to high passenger demand (pre-CoVid19). Short term storage would be necessary at capture site and could be a limiting factor if space is limited.

Perhaps unsurprisingly, costs modelled for different locations of capture sites identified highest transport costs associated with truly dispersed sites, with capture sites located in a cluster close to major ports having lowest transport costs[6]. The carbon footprint of the transport solution also needs consideration to be minimal.

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Use of CO_2

Carbon dioxide is thermodynamically stable and, for the most part, if it is to be transformed to something else (useful), energy needs to be applied to drive the reaction to the desired products. To go ‘carbon negative’ or at least carbon neutral, the source of the applied energy cannot be from direct or indirect use of fossil fuels. The one common process which consumes carbon dioxide is in its reaction with alkali earths to produce carbonate mineral. This is how the Earth has moderated high CO_2 levels in the geological past by precipitation of limestones and other carbonates. Humans though, lack the luxury of geological time spans to effect atmospheric and oceanic carbon dioxide and hydroxide reduction. There are a few instances where natural carbonatisation occurs and can be speeded up. Industrial waste such as that from steel manufacture, will react with dissolved CO_2 in rainwater and become mineralized[7]. Dobrzanski[7] demonstrated how this process could be enhanced using dense phase CO_2. Similarly, injection of dense phase CO_2 into subsurface pore fluids rich in calcium will also lead to near instantaneous sequestration of CO_2[8].

Although these processes can be locally important in removing CO_2, they are by comparison with the quantity of CO_2 released each year, trivial. Nonetheless, there are large industrial processes which can use carbon dioxide, making the most of either its solvent properties or heat capacity.

Enhanced oil and gas recovery

Dense phase carbon dioxide is soluble in oil and can be used for enhanced oil recovery via miscible flood. CO_2 injected into the flanks of an oilfield or in a multi-spot pattern will sweep the oil away from the injection well and at the same time dissolve into the oil. The CO_2-charged oil expands enabling the CO_2 injection process to reach parts of the oilfield pore spaces that other secondary and tertiary recovery processes cannot. Empirical evidence indicates that for each tonne of CO_2 injected an additional 2 to 5 barrels (6.29 barrels = 1 m^3) of oil can be recovered[9]. Enhanced oil recovery using CO_2 was first trialed in Hungary in the 1950s before taking-off in Texas in the 1970s where anthropogenic CO_2 was used to improve recovery. Unfortunately, most of the CO_2-EOR projects today use carbon dioxide produced from natural CO_2 deposits not from anthropogenic CO_2. Injection of CO_2 into gas reservoirs could also be used to improve recovery of methane although application of this technology remains little developed [9, 10].

CO_2 plume geothermal (CPG)

A very promising but as yet undeveloped technology could see deep subsurface CO_2 storage sites being turned into geothermal power stations with the CO_2 being used as the power fluid. In conventional low-enthalpy geothermal systems hot water is produced from the subsurface and either used as a heat source directly or it can, in conjunction with a heat engine (organic Rankine or Kalina cycle), be used to make electricity, albeit at low efficiency. Such systems have been promoted for

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partial decarbonisation of producing oilfields[11]. Auld *et al*[11] examined many aging North Sea fields with copious hot water production, 10 or 20 times greater than the oil volume produced. Such fields are typically at about 3 km burial depth and temperature of around 100 ºC, compared with a uniform sea temperature of around 4 ºC. Despite the temperature difference, the quantity of electricity that can be generated is about half that needed to pump the water into the ground for secondary recovery of the oil.

Substitution of the water in the system with dense phase CO_2 removes the power shortfall. The parasitic load of the pumps to push water into the ground is not required for CO_2. CO_2 plume geothermal (CPG) is a viable way of harvesting geothermal heat and producing power[12]. The system depends upon establishment of a thermal siphon in which dense phase CO_2 rises up a production well to drive a turbine and produce electricity. The cooling of the CO_2 then results in an increased density yielding sufficient head for it to self-reinject into the reservoir interval from which it came, so starting the cycle again. Typically, the reservoir needs to be permeable and at a temperature of about 100 ºC or above for the system to work and although the heat capacity of CO_2 is lower than that of water, the low viscosity of dense phase CO_2 means that it can be transmitted through the reservoir from return well to production well more easily. Demonstration scale systems are yet to be built and there are several technical hurdles to overcome but the promise of CPG to become a large-scale use of CO_2 is an exciting one.

Storage

Storage sites

The Earth's sub-surface offers a variety of possible permanent storage sites for CO_2. Depleted petroleum fields and deep saline aquifers are the most preferred sites. Here the CO_2 is stored within the pore spaces as dense phase fluids. The characteristics of the sites are similar to those that are responsible for trapping petroleum. The reservoir needs to be porous and permeable and be overlain by a seal. Most of the sites chosen to date have an identifiable trap geometry as well although in very large saline aquifers entrapment can occur via residual gas trapping and in all settings the CO_2 will eventually dissolve into the connate water resulting in (dis)solution trapping.

One project in Iceland has injection of CO_2 released from geothermal fluids reinjected into porous basalt where it reacts with calcium and magnesium to precipitate as carbonate minerals[13].

Storage volumes

The UK's national CO_2 storage database, CO2Stored, provides information on over 500 potential storage units in the UK offshore with storage capacity between 10 and 1000 MT, the units are recognised as saline aquifers (open or confined) or depleted fields (Figure 4). The estimated P50 capacity of theoretical storage capacity for the UKCS is 75Gt across the NNS (14Gt), CNS (40Gt), SNS (15Gt) and EIS (6Gt), when stores with a P50 theoretical volume of less than 20 Mt are screened out[14]. The dominant capacity is held within sandstone saline aquifers (60Gt). The potential storage units can be co-located geographically, with vertical stacking of multiple storage units, or co-located stratigraphically, within the same formation. Globally 12,267 Gt of storage resources are

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recognised, classified against the Storage Resource Management System (SRMS), with 98% of storage projected to be within saline aquifers[15].

Storage monitoring

A critical part of the CCUS chain is to accurately allocate the volumes of CO_2 that have been captured, transported, injected into and kept securely within the storage site. Any losses along the network need to be identified and would have a fiscal significance. Within a CCUS chain, the contribution of individual emitters needs to be logged. The composition of the CO_2 will also need monitoring, such that any CO_2 streams that are out of specifications and could cause damage to pipeline or storage site can be identified and suspended if necessary. The combined CO_2 stream on entering the transport and storage network is also likely to be metered, to account for any losses during transport. Whilst accurate mass flow metering is critical, it remains a challenge, especially for multi-phase flows[16]. Research into accurate, cost-efficient and scalable metering technology is ongoing (see [17]for a review of flow meter technology). Monitoring volumes injected into the storage reservoir will be the final part of metering.

Monitoring the storage reservoir is necessary to ascertain whether the CO_2 is behaving as expected and to detect leakage. A baseline survey against which any future comparisons are made is required in advance of injection operations. The storage site and the environs are monitored during injection at a frequency and with technologies that will be defined prior to awarding the carbon storage permit, according to the risks of the site. Monitoring must continue for at least 20 years after cessation of injection (and closure of the storage site) to prove that the injected CO_2 is permanently contained prior to handover of the storage site to the Competent Authority (CA). Handover is only to occur after conformance is demonstrated, so post-handover monitoring is, by design, likely to be minimal, without any corrective measures foreseen.

Monitoring techniques can have a deep or shallow focus. Monitoring of the storage reservoir and deeper overburden can be undertaken with 4D seismic surveys, and downhole temperature and pressure gauges. The CO_2 plume can be located using 4D seismic methods, as has been demonstrated to great effect for injection into the Utsira Formation at the Sleipner Field, Norway[18]. Shallow focused monitoring techniques include monitoring the seabed, the near-seabed, and the water column using automated underwater vehicles and mini-Remote Operated Vehicles (mini-ROVs).

UK timeline to CO_2 storage

The deployment of CCUS at scale is essential to reduce the CO_2 emissions from energy intensive industries and to enable production of clean hydrogen. The UK Government ‘Ten Point Plan[19] for a Green Industrial Revolution’ published in November 2020, and the subsequent Energy White Paper

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'Powering our Net Zero Future' published in December 2020[20] both highlight that the government expects CCUS to play a critical role in helping to achieve the UK's climate change targets and reduce greenhouse gas emissions to net-zero by 2050. The government has set a target to capture up to 10 Mt CO_2 per year by 2030, and with the creation of a £1billion CCUS Infrastructure Fund aims to establish two CCUS industrial clusters by the mid 2020s, and four by 2030 (including at least one power project). These CCUS clusters will be developed alongside low carbon hydrogen to form industrial 'SuperPlaces' in areas such as Teesside and the Humber, the North West, Scotland and Wales, with the aim of at least one of these clusters becoming net-zero by 2040.

The government ambition is to capture and store up to 10 Mt CO_2pa by 2030, however individually a number of the CCUS industrial clusters are already aiming to be operational by the mid-2020s with far more ambitious capture targets, which when combined have the potential to greatly exceed the 10 Mt CO_2pa by 2030 target. For example, the Acorn project[21, 22] is planning to begin injection operations in 2024, capturing over 6 Mt CO_2pa from a variety of sources by 2027. The HyNet project[23] is aiming to be operational in 2025 with a capture volume of up to 10 Mt CO_2pa by 2030, and Zero Carbon Humber[24] plans to be operational in 2026 and capturing up to 17 Mt CO_2pa by the mid 2030s.

The 6th Carbon Budget published by the Committee for Climate Change in December 2020[25] also favours a more ambitious capture target, proposing that to achieve net-zero by 2050 the UK needs to remove around 58 Mt CO_2pa with greenhouse gas removal technologies such as bioenergy with CCS (BECCS) and direct air capture with CCS (DACCS) playing a more significant role from the mid-2030s onwards. The knowledge gained from the deployment of CCUS and the development of a transport and storage network will be critical for the rapid future deployment of these negative emissions technologies.

Issues and opportunities

A BEIS report published in 2018 (The UK CCUS deployment pathway: An Action Plan[26]) states that the main barriers to deployment of CCUS at scale are no longer technical, but that a lack of effective commercial and regulatory frameworks has hindered the development of industrial scale CCUS, a view echoed in the more recently published Climate Change Committee report 'Reducing UK Emissions: Progress Report to Parliament' from June 2020[27]. In response, the UK Government announced plans to publish an Industrial Decarbonisation Strategy in spring 2021[28], and that new commercial frameworks and CCUS business models for both CCUS and low carbon hydrogen would

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[27] Climate Change Committee "Reducing UK Emissions: Progress Report to Parliament" June 2020; https://www.theccc.org.uk/publication/reducing-uk-emissions-2020-progress-report-to-parliament/

[28] HM Government; "The Government Response to the Committee on Climate Change's 2020 Progress Report to Parliament: Reducing UK emissions" Oct 2020 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/928005/government-response-to-ccc-progress-report-2020.pdf

be finalised and in place by 2022 to facilitate progress towards the CCUS cluster and capture targets discussed above[29].

Even with an ambitious domestic net-zero by 2050 target, UK emissions account for only around 1% of the global total, highlighting that climate change is a global issue. To achieve the goals set in the Paris Agreement, global greenhouse gas emissions need to halve over the next decade, a target that will not be met through current global emission reduction commitments[30]. The UK will hold both the G7 and COP26 Presidencies in 2021 and therefore has a unique and timely opportunity to show leadership and encourage other nations to adopt similar net-zero targets. The newly established COP26 Energy Transition Council[31] can play a key role in initiating the knowledge sharing partnerships and international cooperation that will be essential to drive rapid global deployment of CCUS and other emission reduction technologies.

Conclusions

Deployment of carbon capture, (some) use and storage is a critical step in the energy transition for the UK and many other nations around the globe. The technology enables decarbonisation of fossil fueled power plants, industrial processes and the development of manufactured hydrogen as a replacement fuel for natural gas (methane). It is a tidy-up process in which carbon dioxide is not released to the atmosphere but instead stored indefinitely deep underground. This means that there is a cost to CCUS rather than it being a revenue stream. Initially, this can only be covered by fiscal devices such as carbon (emissions) taxation.

The UK is very well placed to store carbon dioxide in depleted petroleum fields and associated saline aquifers beneath the North Sea and other parts of the continental shelf, with capacity such that the UK could offer storage to other nations. This could turn what for the UK is a cost of storing carbon into revenue generation for storing other's carbon. There are also opportunities for utilizing the stored carbon in some storage sites for power generation with CO_2 plume geothermal technology.

Two decades have lapsed since the first UK project was formulated to capture and store carbon dioxide. As of yet not a single molecule of carbon dioxide has been put into geostorage in the UK. The current UK government initiative to create CCUS must deliver if we to have any chance of meeting our emissions target obligations.

[29] BEIS "Carbon Capture, Usage and Storage: A Government Response on potential business models for Carbon Capture, Usage and Storage" Aug 2020 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/909706/CCUS-government-response-business-models.pdf

[30] IPCC, 2018; https://www.ipcc.ch/site/assets/uploads/sites/2/2018/07/SR15_SPM_version_stand_alone_LR.pdf

[31] UKCOP26.org, 2021, https://ukcop26.org/uk-presidency/campaigns/

Figures

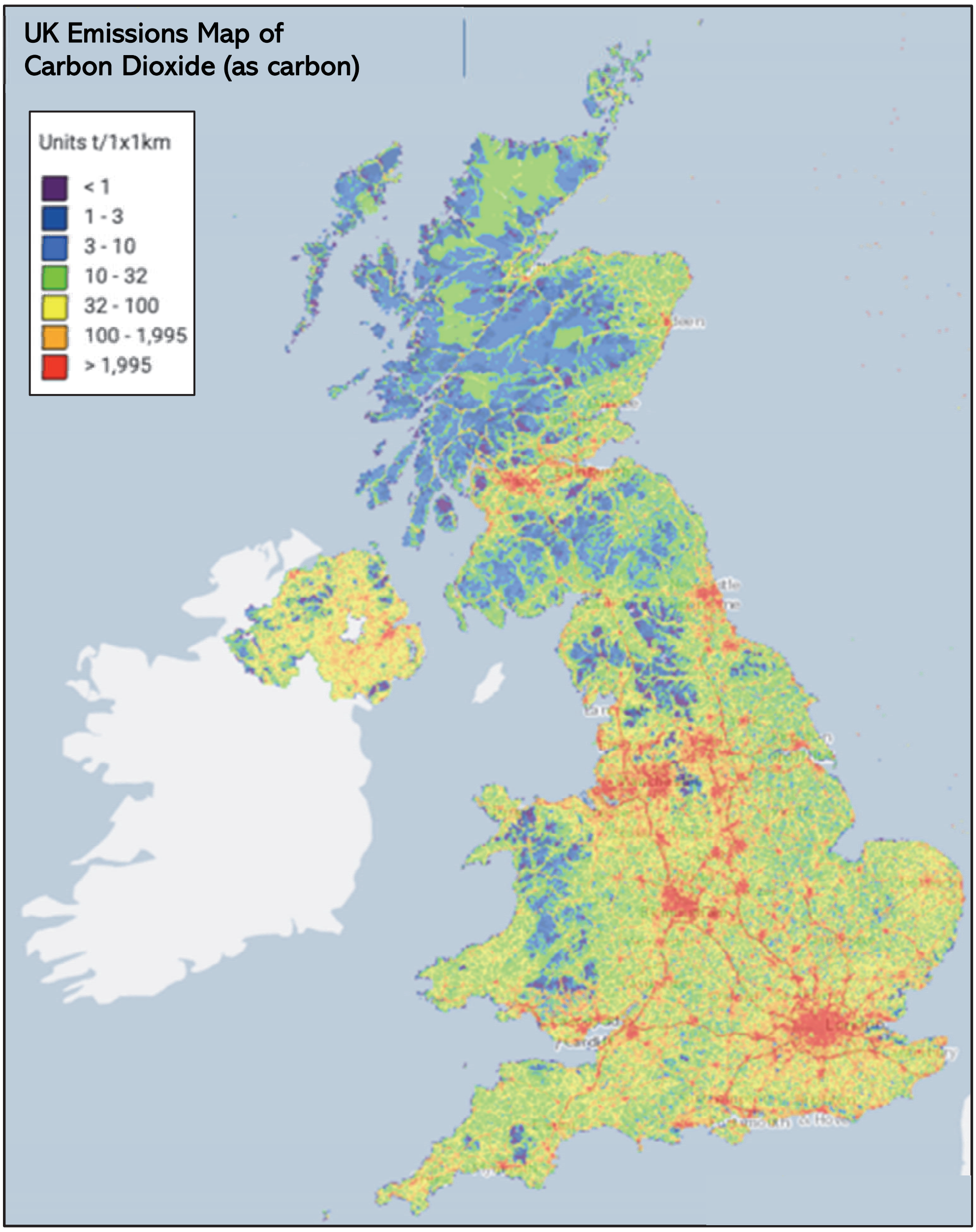

Figure 1 Total CO_2 emissions as carbon, UK 2018. The data includes emissions form industry, transport and domestic centers. Both point source emissions and distributed emission are concentrated in areas such as London, northern industrial cities and the central belt of Scotland. Map downloaded and modified from https://naei.beis.gov.uk/emissionsapp/

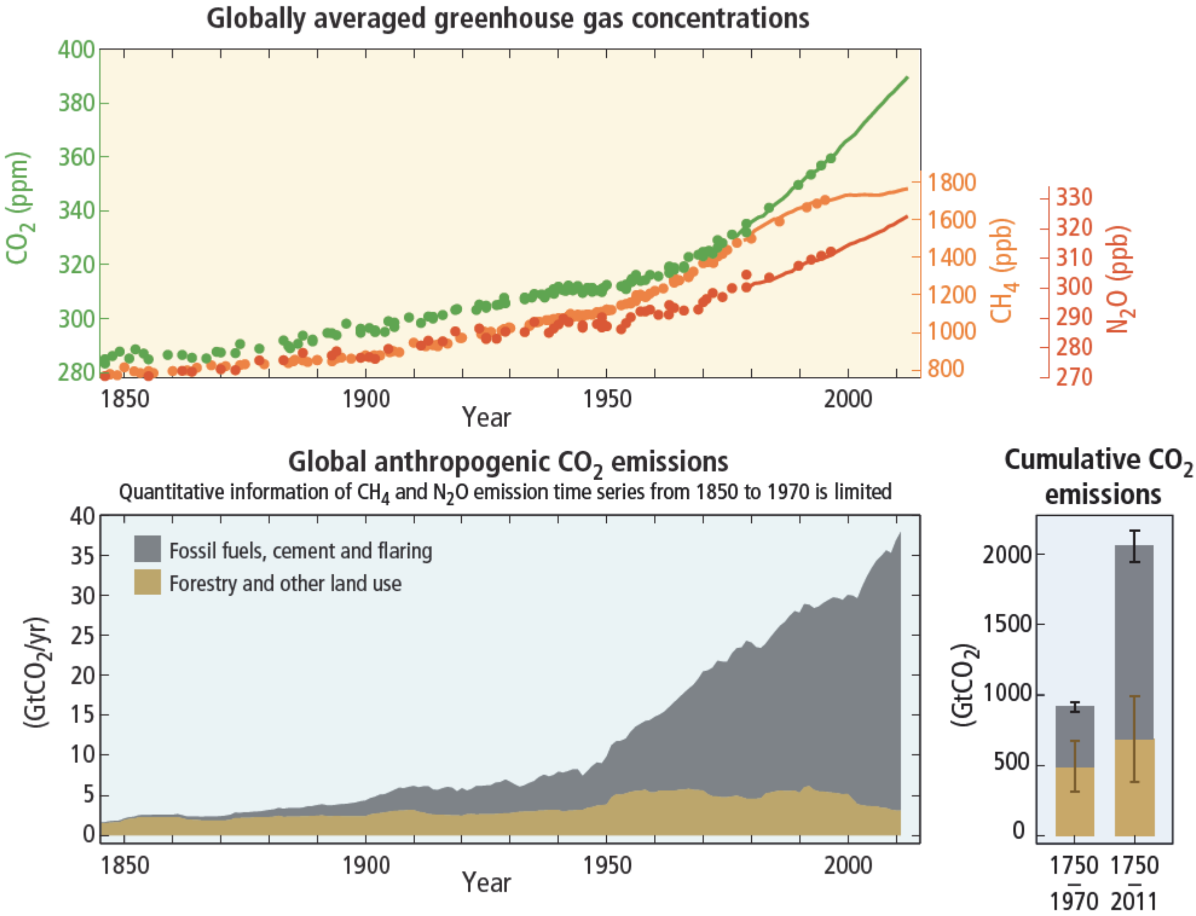

Figure 2 Top: Atmospheric concentrations of the greenhouse gases CO_2 (green), CH_4 (orange) and N_2O (red) determined from ice core data (dots) and direct atmospheric measurements (lines). Bottom: Global anthropogenic CO_2 emissions from forestry and other land uses as well as from burning fossil fuel, cement production and flaring, along with cumulative emissions and their uncertainties (taken from IPCC Climate Change 2014: Synthesis Report, 2014[32])

[32] IPCC"Climate Change 2014: Synthesis Report" (2014) Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. IPCC, Geneva, Switzerland.

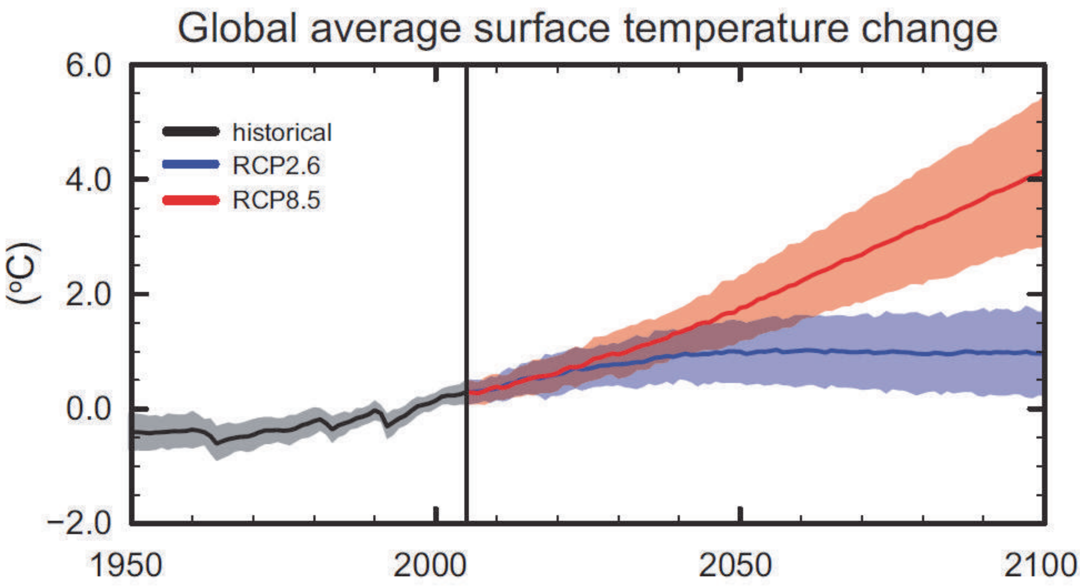

Figure 3 Model simulated time series from 1950-2100 of the change in global annual mean surface temperature relative to 1986-2005 for different scenarios. Projections and a measure of uncertainty (shading) are shown for historical emissions (black), model RCP2.6 (blue), where stringent mitigation of GHG emissions is adopted, and model RCP8.5 (red), where high levels of GHG emissions continue. (modified from Figure SPM.7, IPCC 2013 Summary for Policymakers)[33]

[33] IPCC, 2013:Summary for Policymakers In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_SPM_FINAL.pdf

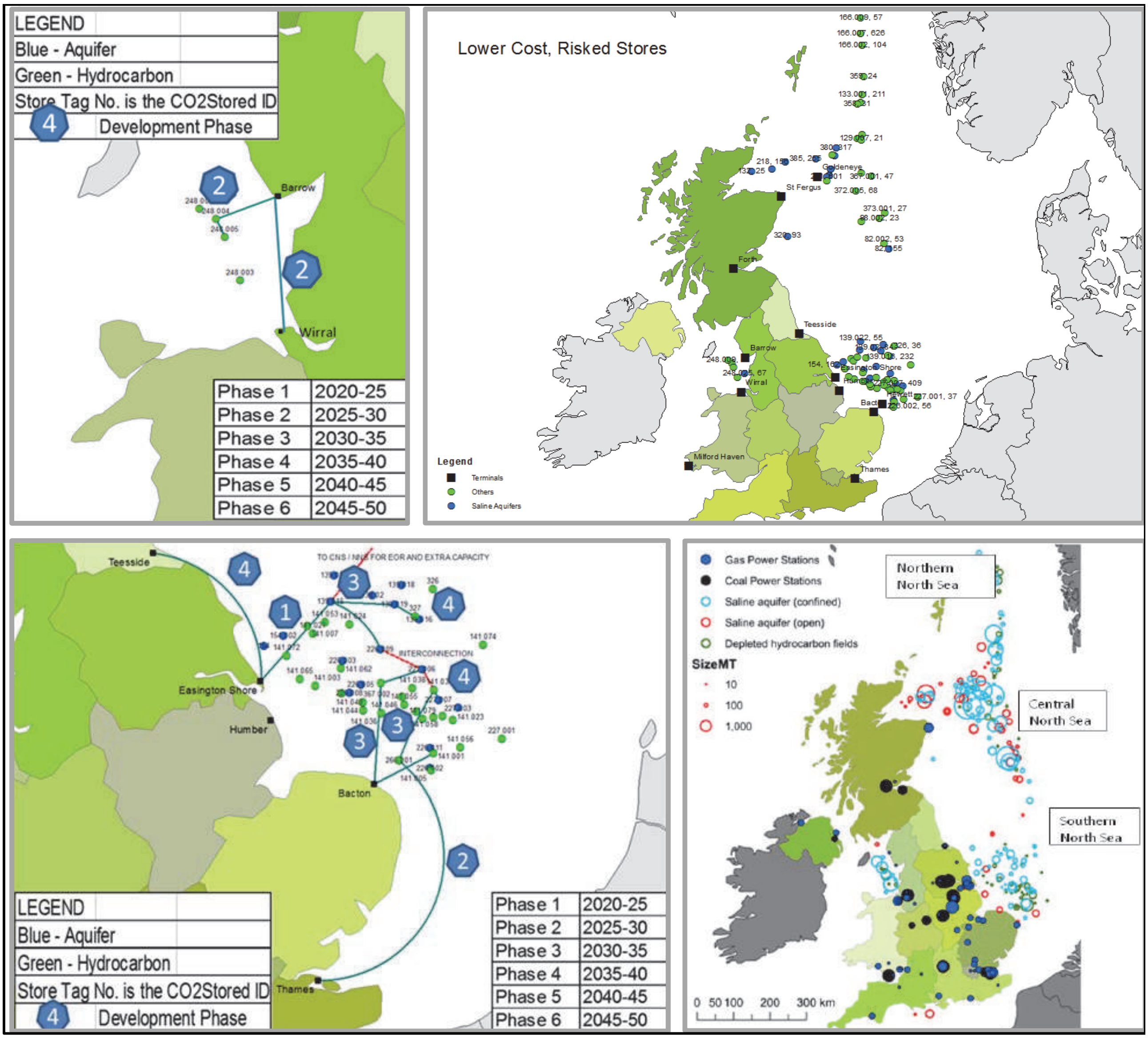

Figure 4 Potential CO_2 storage sites on the UK continental shelf (from https://s3-eu-west-1.amazonaws.com/assets.eti.co.uk/legacyUploads/2014/03/A_Picture_of_Carbon_Dioxide_Storage_in_the_UKUPDATED1.pdf Information taken from the UK CCS Storage Appraisal project, commissioned by the ETI. Further outputs are publically available via www.co2stored.co.uk).

INTEGRATED MINE PLANNING LEADING TO SUSTAINABLE POST-MINING TRANSITION

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Abstract.

Minerals are extracted by hard rock underground and surface mining, in clay and sand pits, and in dredging operations, thereby changing the local landscape and ecological relationships. However, after mining has remodelled the local topography, it can create more diverse ecosystems, even biodiversity hotspots. Many natural reserves owe their origin to former mineral extraction operations but even nature conservationists are often unaware of this mining legacy. In this contribution, we discuss the rehabilitation of mining sites which could lead to environmentally and socially accepted post-mining. What society expects from completed mining operations has changed considerably over time. Up until the 1980s the public desire was to restore mining operations back to their previous use. Since the 2000s the concept developed to leave the mines as they are (of course with considerations for general slope stability, measures to reduce acid rock drainage, etc.) and to promote biodiversity. This evolution shows that the "wishes" for post-mining use might change quite significantly and quickly. Such changes are very fast when seen in the context of the long mine planning processes and operations. Mining companies should - to ensure acceptance of mining - take into account such desired post-mining outcomes. There are, however, limits to variations in mine extraction by mining laws and limits set by mining technology, properties of the backfill and geotechnical stability and mining costs. Modern industrial mineral mining companies use an integrated mining process in which reclamation is not done after mining but in parallel with mining. Reclamation is divided into terrain remodelling during mining and reclamation that can take place mostly after mining. Terrain modelling focusses on stabilising slopes and also on post-mining use by limiting e.g. future subsidence where this is not desired, or by creating stable terrain high points and low points. Terrain modelling is followed by restoration in the direct sense. Reclamation has become an integral part of a continuous mine planning process.

This contribution has three parts. Part 1 discusses examples of old mining, where a planned reclamation and recultivation did not take place. Many sites have developed an extraordinary biodiversity and neither the public nor conservationists recognise these areas as old mining sites. Part 2 discusses the large-scale reclamation and recultivation of very large mining regions where the prime goal is to restore the land to its pre-mining state. Such large mining areas are currently not in development in Europe. Part 3 discusses the contemporary reclamation used for small industrial mining sites where nature is allowed to develop freely. The mine planning and geotechnical engineering of such contemporary reclamation is discussed in detail.

Part 1 Old Mining

Evaluation of post mining areas: is there a conflict between mining and recultivation / rehabilitation?

In Belgium, as well as in other Western countries, public resistance to extraction of minerals is seriously complicating quarry operations; particularly opening new quarries or extending existing quarries is a considerable challenge and a long time endeavour. Both the public and authorities have different motivations to oppose the mineral industry, from irrational fears to more rational objections to loss of biodiversity, ecosystem destruction, downgrading property value. Ecologists are often among the hardliners opposing mineral extraction, whereas geoscientists and mining engineers rely on geodiversity for supplying commodities, necessitating human interference with the subsurface. However, practically all (semi-)natural ecosystems and associated biodiversity in Western Europe are geogenic and man-made, and the result of changes in land use due to past agricultural practices and mineral extraction. Particularly abandoned extraction sites provide environments for rare species of plants and animals. Geodiversity creates ecological anomalies and biodiversity hotspots.

Example 1: As illustration for this principle, we can refer to a steep-sloped pasture in Moelingen (province of Belgian Limburg), famous as an outstanding nature reserve, the richest in western Europe for waxcap fungi, moreover considered as belonging to different ecological niches and all found in spatially separated associations on a rather small surface (see figure 1) (Lenaerts et al., 2011). As motivation for developing this site as a nature reserve, biologists stated that the pasture must have been undisturbed (except by grazers) for ‘many hundreds of years’. Such consideration was not based on hard facts but on the seemingly logical assumption that rich biodiversity must be opposed to human interference. Although it cannot be denied that human disturbance was indeed minimal during the last century the nature reserve is due north of a former lead mine, exploited during the early 19th century. The surface of the nature reserve is marked by traces of former trenches and spoil heaps connected to the lead mine and by a former chalk excavation. The subsoil consists of patches of a Cretaceous paleo soil on Devonian dolomite and shale, in faulted contact with Carboniferous silicates and covered by Cretaceous chalk or Pleistocene fluviatile gravels, where no mature soils could develop. The waxcaps associations are linked to these different subsoil lithologies and to grades of disturbance. It is a good example of natural recovery after all mining or extraction activities have ceased, responding with biodiversity anomalies to changes in the subsoil conditions, that remain obscured to non-geoscientists (figure 2) (Dusar et al., 2011).

The Moelingen nature reserve is a fine example of a clash of paradigms with different interpretation of conditions for nature conservation by geoscientists and conservationists. Taking a time perspective, it is safe to say that active quarries of today will provide the best nature reserves of tomorrow (figure 3). Biologists tend to emphasise continuity in land use as a condition for preservation of biodiversity whilst geoscientists tend to focus on the anomalies in the distribution of minerals as sources of geodiversity; both may have a discussion about the same territory which could make them allies, but they apply different paradigms making them adversaries. A dialogue between ecologists and mineral producers seems hard to realise but could be productive and of mutual benefit.

Figure 1. The first impression of this nature reserve in Moelingen, Beligum, the number 1 in Europe for waxcap fungi, is that this is apparently a natural landscape that has been undisturbed for hundreds of years.

Figure 2. The site that seems to show a pristine nature in figure 1 has been a site of different types of mining/quarrying, which influenced development of a unique biodiversity hotspot for this region.

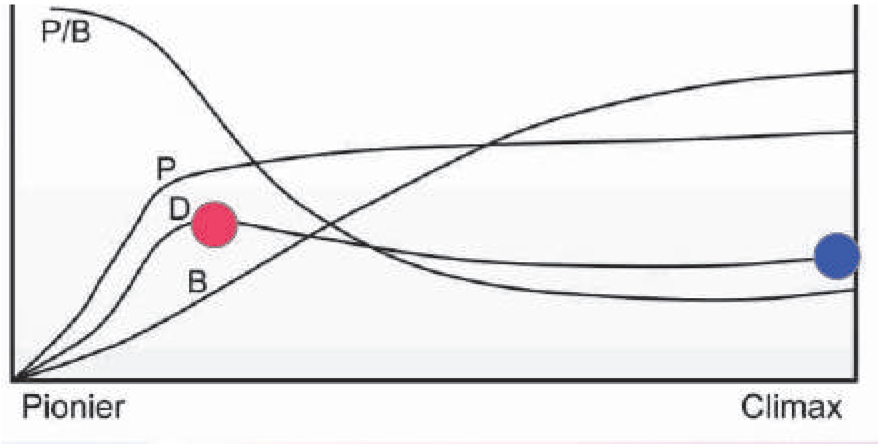

Figure 3. Transect of biological parameters along growth line from pioneer to climax vegetation, from minimal to maximal ecological stability (P: biomass production; B: biomass volume; D: biodiversity; P/B: biomass productivity), after Odum (1971). Biodiversity peaking at transitional situation (red dot). Biodiversity anomalies (corresponding to the red dot) react to serious disturbance of the soil, without difference between man-made and natural disturbances. The blue dot represents reclaimed lands (e.g. reforested) after mining.

Example 2: The Altenberg (Vieille Montagne) lead and zinc deposit in Eastern Belgium has been intensively exploited in the past, especially at the onset of the Industrial Revolution in the 19th century. It was one of the most important European mining areas and the object of political tensions at the origin of the creation of the neutral territory of Moresnet. In spite of this importance, no attention has been given to its geological and mining legacy after closure of the metal mines. Today, traces of the former mining exploitations have nearly completely disappeared from the landscape. Calaminarian grasslands are the most visible remnants of past mining operations, sheltering an anomalous metallophyte flora. They constitute remarkable ecosystems that are now the subject of particular protection. However, the Calaminarian grasslands due to ancient pollution of the soils downstream of the mine workings are now in sharp decline as a result of green management of the valleys (Dejonghe, 2020).

The purpose of these examples in Part 1 (Moelingen and Altenberg) is to show how valuable non-reclaimed mining areas can become in course of time. It is not the purpose to advocate this procedure for any contemporary mining activity since this is not best practice. However, the concept can be applied for certain areas within contemporary mine closure (see point 4) if risks are excluded (unstable slopes: should not be acceptable for public access, areas next to artificial lakes should be stable, no environmental risk from leachates).

Part 2 The period of very large surface mines

For large mining sites (100 km^2), typically for copper ore mines or mining districts for energy minerals such as lignite, surface coal and tar sand, the areas affected by mining are too large to leave the mined-out areas to nature only. Prior land use must be restored. In such mining districts the mines tend to be large (25 km^2) and mines will become very old (>100 years per mine). For such mines, the permits were issued in a period when the focus was on land consolidation and upscaling of agricultural equipment and when society required an agro-industrial optimum. Mining companies learned to recreate prime agricultural land. Examples are e.g. the large lignite mining districts in Germany (Rhenish, middle German and Lusatian lignite mining areas) and other lignite mining areas in Poland, Czech Republic etc. Good agricultural and forestial reclamation has taken place, leading to the same crop yield as prior to mining: Research has shown that surface mining can be a "short-term land use that may be followed by productive farmland, if reclamation is done correctly" (Darmody et al 2001).

In the Rhenish lignite mining district 315 km^2 have been affected by mining of which more than 220 km^2 have been recultivated. 118 km^2 of agricultural terrain and 84 km^2 of forest have been recreated (RWE 2013). Critical to such success are "selection of the best available soil materials used in soil construction and a material handling method that minimizes soil compaction" (Darmody et al 2001), and selection of after mine land surface forms that are suitable for the intended land use. Producing terrains with just enough slope is required to provide for adequate surface drainage without undue erosion (Jansen 1981).

In country development, Manning (1995) recognised a trend away from such large-scale operations as discussed above to smaller scale industrial minerals mining. This affects the type of post mining land use as well. Citing Manning (1995): "As industrial development proceeds the country's need for industrial minerals in support of domestic manufacturing industry increases, eventually overtaking metals (author’s note: or energy minerals) in terms of their value." Manning (1995) shows examples for Spain where industrial minerals overtook metallic mining in the 1970s. Recent figures (SME 2021) for the United States show the same trend. In 2020 the USA produced $82 billion worth of minerals (industrial minerals, natural aggregates, ferrous and nonferrous metals) compared with $55 billion for industrial minerals. What is the consequence? Industrial minerals mines are smaller than copper or open cast coal mines because of geological reasons (the industrial minerals' industry only has a limited degree of processing and therefore higher demands on the in situ quality of the commodity), the gross margin is often smaller and therefore the mining operations tend to be smaller. Since the value of the industrial mineral itself is low, the transport distance (except when they are ship bound) need to be short and close to where the users are. As a consequence, industrial minerals operational sites are smaller but there are many. Permits are in general quite recent and were provided in a time when other land use (urban, nature protection zones, infrastructure) was well developed (compared to the situation 50 or more years ago) and the public view is at present not favourable towards large scale industrial agriculture. Therefore, the contemporary reclamation of such small mines allows for "more nature" and more creativity. How this is handled in mine planning terms is discussed in part 3.

Part 3 Contemporary small scale industrial mineral mines

Potential of mining/quarrying for industrial minerals sites for biodiversity increase

In order to maintain mineral extraction activity for the future it is essential to engage in a dialogue with other stakeholders. As many former extraction sites have spontaneously developed into biodiversity hotspots there should be great potential for ongoing extraction activities as well. However, this requires that all parties concerned must be aware of the processes and time spans involved.

Geological anomalies are the purpose of exploration and extraction. They also create habitats of an anomalous nature, characterised by species that are rare outside the quarry sites. Living nature thereby does not differentiate between natural or human-induced habitats (e.g. natural rock or quarry wall or tower).

Biodiversity implications should be included in all operations through the major phases of a quarry lifetime (permitting, extraction, rehabilitation). This represents a move from either quarrying or nature conservation to quarrying and nature conservation, i.e. the life cycle of a quarry generally allows that unique biotopes will be created within the quarry area, already during quarry operation. The challenge is that spontaneous new habitats may be in the way of further operations, in which case displacement of habitat and removal of species can be an option.

There is no uniform procedure for valuing biodiversity, meaning that authorities responsible for licensing may use other criteria than those following up the operations (e.g. between the regional administrations for natural resources and for nature conservation), thereby increasing the number of conflicts between the extractive industry and the authorities and an increased rejection rate of their plans.

Fixation on species is good for visibility and public attention but managing the physical basis of ecosystems is better for sustained biodiversity. There is ample evidence that this works better in the long-term. The transient character of quarrying means that any given place could be in a phase of complete destruction of the original ecosystem whereas other places recreate nature. The overall effect should be considered, bearing in mind that all new biodiversity hotspots have been cleared of their original biological content before.

A major challenge is that legal protection of nature tends to be fixistic. It considers nature under threat of attack, thereby preventing change. This is completely opposed to quarrying practice. The mineral extraction industry creates evolving landscapes, ultimately leading to different but generally more diverse biodiversity. This process is not in line with the legal framework for the protection of nature. Good cooperation between the mineral extraction industry and the authorities or conservationists is a matter of education, for both parties. However, current post-mining reclamation plans increasingly aim at creating favourable conditions for even better biodiversity. The same processes as applied in mine reclamation also find their way into building codes such as e.g. BS 8683, a new standard on processes for designing and implementing biodiversity (BS 2021).

The mine planning process and reclamation

The time frame of a quarry is frightening for authorities and the citizens and is comparable to the human life span. In our governance culture, long-term planning and evolution are not accepted any more. The present must be maintained, instead of seeing the present as a transitory stage between past and future.

The different phases in more detail:

A) Mining and ecology during extraction. This phase deals with aspects such as “temporary nature”. During past workshops Ecology and Mining experts representing the mining industry and authorities in Belgium explained how they handle the advantages of subjects such as temporary nature and what potential drawbacks there are for the extractive industry to promote "temporary nature on extractions sites" (BLUG / Geological Belgica 2015).

B) Mining and ecology directly after the extraction activities on a site have ceased (short-term after mining): “speed up colonisation” and “early accessibility of extraction sites as soon as possible after extraction stopped". Nature and people should be given opportunities directly after extraction to use again the former extraction sites.

C) Mining and ecology after the extraction activities on a site has ceased (long-term after mining).

Traditional operations, as the Moelingen example in Part 1, refer to case C, but ongoing operations tend to be managed increasingly according to case A.

In mine planning there is a difference between terrain remodelling and reclamation / rehabilitation. In order to extract minerals, the minerals themselves and the layers above (overburden) need to be removed. Depending on the ratio between minerals and the overburden (the stripping ratio) and the type of rock or soil, the overburden can be put back into the area where the mineral has been taken out. This is important in order to reconstruct the original or the new topography. This part is called terrain remodelling. Since vegetation or agricultural post-mining are only influenced by the top few meters the terrain remodelling can be planned even if the end-use has not been defined by e.g. the mine planning authorities. Because, as stated above, the time frame associated with mining and quarrying is long and frightening for planning authorities and since in this period the destination of the terrain might change and since only the top few meters need to be adapted for most post-mining there is no conflict as long as the terrain remodelling itself is fixed from the start. In this way the mine or quarry operator can stack the overburden material in the right spot so that material transport, cost and ecological footprint associated with this mining activity is minimised. Another advantage is that early terrain remodelling allows for B in the scheme above: Mining and ecology directly after the extraction activities on a site have ceased (short-term after mining).

The difference in timing and associated material movement with terrain remodelling and recultivation / rehabilitation is explained in figure 4.

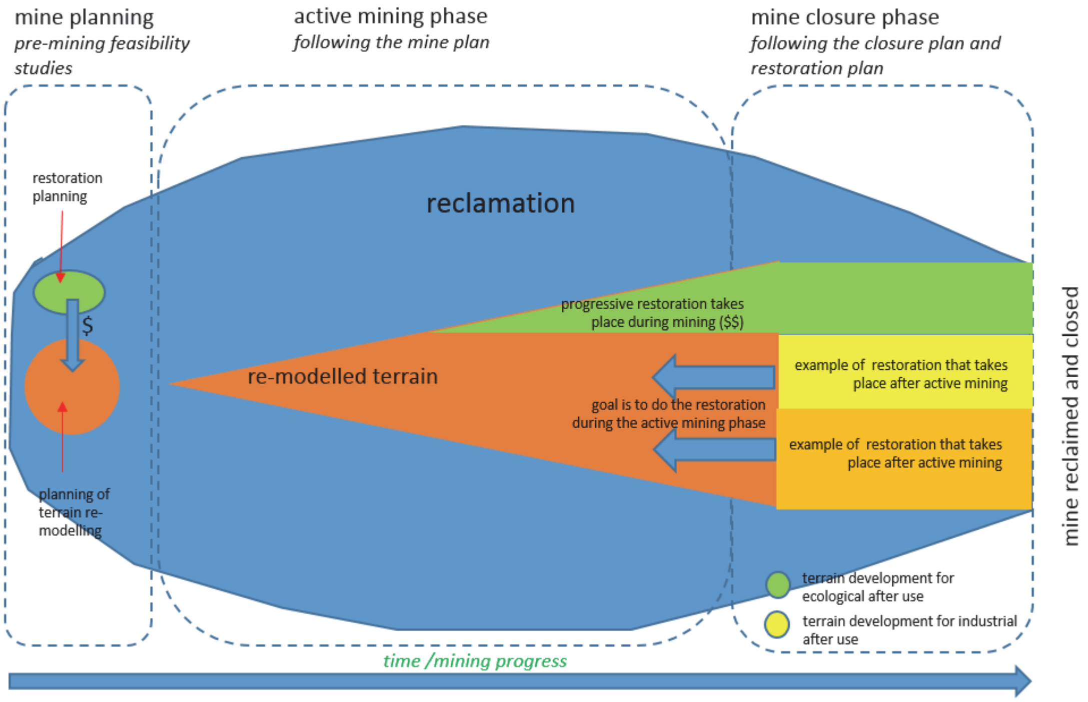

Figure 4. Mine reclamation phases. $) terrain modelling (planning process) requires input from the reclamation plan; $$) only remodelled terrains can be reclaimed. Note that the post-mining use influences the restoration process while mining. E.g. a housing development as post-mining sets limits to the maximum amount of subsidence that can take place on the backfilled mining area. Note that rehabilitation is a special form of restoration whereby the terrain and vegetation are restored to the original state. The vertical axis represents cost and or mass movement involved in mine reclamation.

Geotechnical engineering aspects associated with terrain remodelling

Certain aspects need to be respected:

Example1: Steep slopes are often requested by authorities as final topography for plants and animals especially in regions where there is no steep topography by nature (loose sedimentary deposits). Such slopes are only possible to a limited extent in areas where there are no steep slopes by nature since the mechanical properties of the material do not allow stable steep slopes in the long term. Cliffs or canyons in sand will be stable - depending on the amount of rain and the drainage and vegetation - for only a few years, and might collapse suddenly, thus constituting a hazard. Steep slopes in mixed sand / gravel in non-cemented formations will be subjected to deep erosion gullies and require costly maintenance or engineered erosion resistant bedding liners. Terrains steeper than those geological processes produced are not stable without constant "terrain management" and should not be the goal of terrain modelling.

Example 2: In active hard rock mines or quarries there can be non-productive tranquil areas where exploitation ceased long ago. If there are benches with rock outcrops that are stable and old and have become covered by e.g. lichens and if such rocks have been providing habitat to animals and insects, these should not be destroyed upon mine closure. Such outcrops should be preserved since a geological window will remain open, protective catchments for rocks higher up and valuable habitat (water will not drip out of the outcrops) will remain intact. If such benches are levelled out upon mine closure the outcrops as well as slow growing lichens will be destroyed and water will run under the muck and is thereby not accessible to most pioneer species). Levelled out outcrops and benches do not provide catchment and rocks will travel down and will remain an unnecessary and permanent risk to all post mining use.

Example 3: In some cases such as the hard rock uranium mining in East Germany (Wismut 1999), the open cast mines have been completely reclaimed since 1990 to agricultural terrain to avoid further exposure of the environment to nucleotides (example on early reclamation of such sites: Whittington (1974)).

Although virtually any vegetation or ecological development is possible on mined-out terrains by only adapting the upper few meters (and therefore can be decided later on when the mine is active - as long as the terrain modelling does not change), this does not hold true for infrastructural development. If the after mine use is housing, industrial or line infrastructure (highways, railways) this post-mining destination must be included from the start in the terrain modelling phase because there are strict requirements with respect to allowable subsidence and sub surface stability and these require a planned placement of overburden layers in the mine. I.e. a detailed terrain remodelling to allow for such special post-mining is required.

Conclusions

Mined out terrains are sites of either
- high ecological value
- prime agricultural terrains with high crop yield
- areas of high wood production value
- areas of high recreational value (e.g. Sint Pietersberg (2021), The Netherlands, Sophienhoehe (2021) Germany, https://www.tourismus.kreis-dueren.de/wandern/sophienhoehe, Zilvermeer (2021) Belgium https://www.zilvermeer.be/over-het-zilvermeer.html).

The mine or quarry life spans are long and might be in presumed conflict with urban or environmental planning processes. This is not necessarily the case. As long as the type of terrain modelling is agreed upon and this decision is maintained the post-mining can still be adapted to suit future demands, that may only arise later in the quarry or mine life. That is why in the mine planning processes terrain remodelling and recultivation / rehabilitation constitute two distinct phases.

In order to avoid the high maintenance cost of the reclaimed or rehabilitated terrains the following aspects must be accepted:
1) If desired by local communities or planning authorities, mines can quickly develop into biodiversity hotspots, whose uniqueness depends on local geological anomalies and type of exposure. However,

these areas might evolve into local climax ecosystems. This may be, from a conservationist ecology point of view, undesirable but can only be stopped by maintenance of human intervention (e.g. targeted animal grazing).
2) The mass balance of the mine must be right to reach the desired topography and must be fixed and unaltered during the mine or quarry permitting process.
3) Not all forms of end topography are possible in all terrains. Depositional basins filled with loose sediments cannot be - on the long term - redeveloped into areas with steep cliffs or valleys. They will be subjected to natural geomorphological processes and be prone to extensive erosion and terrain remodelling by nature.

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MANAGING LEGAL RISKS IN MINING PROJECTS:

LESSONS LEARNED FROM THE INTERNATIONAL ARBITRATION OF DISPUTED MINING PROJECTS

LORRAINE DE GERMINY
EMILIE MCCONAUGHEY

Abstract

Many major disputes arising out of mining projects have been addressed in recent years through international arbitration, with investors (mining companies) filing cases against the states where their mining projects are located (host states). Most of these disputes were triggered by changes in the legal framework of the host state, delays in the permitting process and social opposition to the project. To mitigate risks, investors should perform and document adequately political, legal, environmental, and social risk assessments as well as seek assurances from the relevant authorities and engage early on and regularly with affected local communities. Should a dispute nevertheless arise, an investor can bring different types of claims under international law against the host state.

Introduction

In just the last thirty years, over 120 disputes in the mining sector have given rise to international investment arbitration proceedings, more than two-thirds of which were initiated in the last ten years. These are instances where a mining company or investor (hereinafter referred to as a foreign investor) has filed proceedings against a foreign state where it claims to have invested in a mining project and to have suffered harm at the hands of the foreign "host" state in question. These proceedings are necessarily against the foreign state – not a private company, subcontractor, or service provider – and involve allegations of misconduct generally by the government, a state-owned mining company, a central or local authority, and/or the courts of that country. By their very nature, these are also cases filed by the foreign investor against the host state and not *vice versa*.[1]

The projects at issue have involved all types of minerals (gold, silver, copper, salt, uranium, tar-sands, iron ore, steel, zinc, coal, aluminium, etc.). The number of cases involving gold mining projects appears to have followed the gold price evolution, with many cases initiated shortly after the 2011-2012 spike in gold prices.[2]

The projects are located on all continents, with over 50 states appearing as respondent. The states most frequently sued have been Venezuela (ten cases), Colombia and Kyrgyzstan (six cases), and the Democratic Republic of Congo and Tanzania (five cases). All types of mining projects have gone to arbitration: some had advanced significantly into operations when the arbitral process was started (half of the disputes relate to producing mines), while others were still in the exploration phase or merely projects on paper.[3]

A foreign investor may file proceedings based on an investment agreement with the host state or an international investment treaty between its home state and the host state. Investment treaties and agreements invariably provide that, should a dispute arise and should certain conditions be met, the

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[1] In some limited circumstances, states may be able to file in the arbitration counterclaims against the foreign investor.

[2] T Duarte-Silva and L M Velarde Saffer, "Investment Disputes Involving Mineral Assets: Relevant Statistics & Trends" (July 2020) TDM, p. 13 (Fig. 9) ("Duarte-Silva/Velarde Saffer").

[3] T Duarte-Silva/Velarde Saffer, pp. 15-16.

foreign investor will have the right to file arbitration proceedings against the host state to seek redress. Most arbitration proceedings involving mining disputes to date have been administered by the World Bank Group's International Center for Settlement of Investment Disputes ("**ICSID**") and the Permanent Court of Arbitration based in the Hague ("**PCA**"), while some were administered by the London Court of International Arbitration ("**LCIA**"), the arbitral institutions of the chambers of commerce of Stockholm ("**SCC"**) or Moscow ("**MCCI"**), or were *ad hoc* arbitration proceedings.

Over a third of the known investment arbitration proceedings involving mining disputes are pending.[4] Close to 90 proceedings have already concluded, some resulting in a final arbitral award, others resulting in a (confidential) settlement agreement and still others being discontinued for other reasons.[5]

Mining companies have filed claims ranging from millions to billions of dollars. Two of the largest investment arbitration awards ever rendered to date arose out of mining projects. One gave rise to an award in 2016 of over US$ 1.2 billion to the mining company Crystallex (against Venezuela) and the other, an award in 2019 of over US$ 4 billion to the mining company Tethyan Copper (against Pakistan).[6]

This article provides an overview of the main types of mining disputes that have given rise to international investment arbitration proceedings (**Section 1**). Understanding the problems encountered by mining companies in foreign countries and how their disputes were resolved can help mining companies anticipate and prevent similar problems occurring in the future (**Section 2**). When a dispute with a foreign country cannot be prevented or resolved, the mining company may be able to seek redress against the host State based on an investment agreement or treaty (**Section 3**).

Section 1: Mining disputes that give rise to investment arbitration proceedings

Three types of scenarios have triggered the bulk of the arbitration proceedings to date: changes in the legal framework, permitting delays, and social opposition.

Other disputes have involved claims that state authorities unlawfully interfered with or acted in retaliation against the investment or the investor, adversely modified the applicable fiscal regime, and/or took improper administrative or judicial action against the investor.[7]

[4] An exhaustive assessment of all mining disputes having gone to arbitration is not possible because some arbitral awards/disputes are confidential.

[5] Among the close to 90 arbitration proceedings reviewed, 47 cases ended in a publicly available award. In 14 cases, the award is not publicly available but its existence and, in some cases, the tribunal's findings are at least partially public. In 28 cases, the proceedings resulted in a (confidential) settlement agreement or were discontinued for other reasons.

[6] *Crystallex v. Venezuela*, ICSID Case No. ARB(AF)/11/2, Award, 4 April 2016, p. 263; *Tethyan Copper v. Pakistan*, ICSID Case No. ARB/12/1, Award, 12 July 2019, p. 620. As noted below, these awards are respectively the subject of enforcement and of annulment proceedings.

[7] *Eg, CEAC v. Montenegro*, ICSID Case No. ARB/14/8, Award, 26 July 2016; *Adel A Hamadi Al Tamimi v. Sultanate of Oman*, ICSID Case No. ARB/11/33, Award, 3 November 2015; *Glencore v. Colombia* (I), ICSID Case No. ARB/16/6, Award, 27 August 2019.

Cases involving changes in the legal framework

Mining companies shape their mining projects not only in light of technical and economic elements (such as resources and reserves and market price fluctuations), but also the legal framework that is set to govern the project. Mining codes, environmental, tax, and labour laws will affect the way a mining company may design and implement a project and its expectations of returns on investments. Sudden and/or dramatic changes in the legislative or regulatory framework can have dire consequences on those returns and run counter to the company's reasonable expectations.

The case of *Glamis Gold v. USA* arose from a change in the legal framework. Glamis Gold alleged that the adoption of various federal and state measures rendered its Imperial Valley gold mining project (which at that time was several million dollars into the exploration phase) uneconomical. These measures introduced backfilling requirements for open pit mines to mitigate the environmental impact of the mining activity and to preserve Native American sacred land. The tribunal accepted that these measures reduced the value of the project but did not consider that they had caused a substantial deprivation of the investment and therefore rejected Glamis Gold's expropriation claim. The tribunal also found that the State had not failed to grant fair and equitable treatment to Glamis Gold and its investments.[8]

In *Rusoro v. Venezuela*, the foreign investor claimed that changes to the Venezuelan legal regime in 2009 and 2010 to regulate the sale and export of gold and to close the swap market, and a nationalization decree in 2011, amounted to an expropriation of its investment. In its 2016 award, the tribunal agreed that the nationalization decree constituted a direct expropriation of Rusoro's investments given the absence of payment of prompt, adequate and effective compensation. The 2010 legal reform of the gold sector, however, was not found to be "part of a premeditated plan … to nationalize the gold sector" and thus did not constitute an indirect expropriation.[9] The tribunal deemed the changes in the legal framework to be "legitimate sovereign measures, adopted according to the established procedure, within the framework of the general exchange control regime already in force when Rusoro entered the Venezuelan gold market".[10] The tribunal awarded Rusoro a total of over US$ 960 million in damages, plus interest.

Rusoro successfully had the award recognized in the United States and Canada,[11] and is now carrying out enforcement proceedings in these two countries. Venezuela appealed the US decision[12] and also filed for annulment before the French courts. In January 2019, the Paris Court of Appeal annulled the portion of the award relating to the quantification of the compensation,[13] but the French Supreme Court overturned this decision and reinstated the award (now worth some US$ 1.6 billion, including interest) in March 2021.[14] Venezuela filed a new challenge before the Paris Court of Appeal in June 2021. Pending resolution of the French proceedings, Venezuela requested that the proceedings in the United States be temporarily held in abeyance.[15]

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[8] *Glamis Gold v. USA*, UNCITRAL, Award, 8 June 2009, paras 166, 441, 536, 828 and 829.

[9] The tribunal did not examine the claims based on the 2009 measures because they were time-barred. *Rusoro v. Venezuela*, ICSID Case No. ARB(AF)/12/5, Award, 22 August 2016, paras. 428-429 and 892.

[10] *Rusoro v. Venezuela*, paras. 360-361, 400-403, 410, 433-438, 891-892, and 895.

[11] Judgment of the Ontario Superior Court of Justice, CV-17-1167, 25 April 2017; Order of the United States Court for the District of Columbia, Civil Case No. 16-cv-02020 (RJL), 2 March 2018.

[12] US Court of Appeals for the District of Columbia, Case 18-7044, 5 April 2018, Notice of appeal.

[13] Decision of the Paris Court of Appeal, N° RG 16/20822, 29 January 2019, p. 9.

[14] Decision of the French Supreme Court, Civ. 1re, No. 19-11.551, 31 March 2021.

[15] US Court of Appeals for the District of Columbia, Civil Action No. 16 cv-2020, Reply in Support of Motion to Hold Case in Abeyance Pending Resolution of Foreign Proceedings, 7 June 2021.

Cases involving permitting delays

Many disputes start because of a state's alleged failure or delay in issuing permits, even though the mining company claims to have met all requirements. Recent cases highlight the need for states to act transparently and in a non-discriminatory fashion during the permitting process and to timely issue and properly motivate permitting decisions in accordance with domestic and international law. They otherwise face the risk of liability under investment treaties for their failure or delay in issuing or renewing the relevant permits, licenses or concessions.

In *Pac Rim v. El Salvador*, the investor had acquired exploration licenses relating to gold deposits but the State refused to grant mining exploitation concessions (on the basis that the application did not meet the requirements of the mining law) and an environmental permit. In the arbitration, the State and *amici curiae* explained in part that the Ministry of Environment had refused to issue the environmental permit because of concerns that the mine would contaminate local drinking water and because of the project's lack of a social license to operate. The tribunal found in favor of the State and dismissed the claim in the amount of US$ 284 million.[16]

Foreign investors may have legitimate expectations based on promises or representations made by state officials in connection with their possible investments in that state. In some instances, they may rely on those representations in making the investment.

In *Crystallex v. Venezuela*, the claimant had concluded a mining operation contract ("**MOC**") in 2002 with the state-run corporation responsible for the development of the Las Cristinas deposits. Crystallex was required to obtain various permits and authorizations, including the approval of an environmental impact study and the permit for the exploitation of the deposit. The Ministry of Environment, however, refused to issue the requested approval, due to concerns for the environment and the indigenous peoples of the Imataca Forest Reserve. In turn, the exploitation permit was denied in 2008. Crystallex appealed this decision and submitted an adjusted proposal. In 2011, the MOC was rescinded and Venezuela regained control of the mine. The claimant argued in the arbitration that it had received assurances from high-level Venezuelan officials and had therefore legitimately expected to receive the authorisations and permits.

In its 2016 award, the tribunal found that some of these assurances, including statements from state officials regarding the status of the permitting or their support for the project, were too general and indeterminate to give rise to legitimate expectations. However, it found that a letter sent to the investor containing positive representations from ministry officials that the exploitation permit would be issued, followed by a request to pay environmental taxes, could give rise to legitimate expectations on the part of the investor. The tribunal concluded that the state had breached the fair and equitable treatment standard and expropriated Crystallex's investments without providing prompt, adequate, and effective compensation. The tribunal awarded Crystallex US$ 1.202 billion in damages (of the US$ 3.16 billion claimed)[17] – an award which was recognized by the U.S. and Canadian courts,[18] and which Crystallex is now seeking to collect in the U.S.[19]

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[16] *Pac Rim v. El Salvador*, ICSID Case No. ARB/09/12, Award, 14 October 2016, paras. 4.5-4.6 and 10.4-10.6; Counter-Memorial on the Merits,10 January 2014, paras. 206-211 and 237-245.

[17] *Crystallex v. Bolivia*, Award, 4 April 2016, paras. 15-58, 623, 718 and 916-918.

[18] Endorsement of the Ontario Superior Court of Justice on Recognition and Enforcement of the Award, CV-16-11340-OOCL, 20 July 2016; Judgment of the US Court of Appeals for the District of Columbia, No. 17-7068, 14 February 2019.

[19]See *e.g.* Opinion of the US District Court for the District of Delaware, C.A. No. 17-mc-151-LPS, 14 January 2021 (granting in part Crystallex's motion to set the procedures for the sale of shares held by Venezuela's state-owned oil company Petróleos de Venezuela, SA (PDVSA) in it's wholy-owned subsidiary PDV Holding, Inc.).

In *Tethyan Copper v. Pakistan*, the authorities had taken over the project after denying the claimant's application for a mining lease, thereby depriving the claimant of the value of its investments. In a 2017 award, the tribunal accepted the claimant's argument that it had legitimately expected to receive the lease after successfully completing the exploration works on the basis of the contractual framework between the parties and of direct assurances from government officials. The tribunal also considered the reasons invoked to deny the lease as a pretext for the authorities to themselves develop the project, amounting to an abuse of sovereign power.[20] The tribunal separately assessed in 2019 the damages owed to Tethyan Copper at over US$ 4 billion.

An *ad hoc* committee is currently hearing Pakistan's annulment request filed in November 2019.In parallel to the annulment proceedings, Tethyan Copper is seeking to enforce the award in the British Virgin Islands and in the U.S.[21]

Cases involving social opposition to the mining project

Several mining disputes have arisen because of, or in a context of, strong social opposition to the mining project at issue. The social license to operate a project (or SLO), defined as the "level of tolerance, acceptance, or approval of an organization's activities by the stakeholders with the greatest concern about the activity", can lead to the success or failure of a mining project.[22] The SLO concept is today considered one of the key risk factors within the mining industry[23] and has been taken into account by tribunals in making their factual and legal determinations.[24]

One of the first cases to address in detail the concept of the SLO was *Bear Creek Mining v. Peru*. Social unrest, violent strikes and marches led the Peruvian government to revoke the decree issued in 2007 allowing the claimant to own and operate the mining concession, thereby effectively preventing the claimant from going forward with the Santa Ana project. The tribunal assessed whether the State could legally require the claimant to carry out further community outreach than it had done, and whether the company's failure to do so "caused or contributed to the social unrest, so as to justify [the revocation decree]". The tribunal considered that it would have been "possible and feasible" for the claimant to do more, but that the respondent had always been aware and approving of the claimant's community outreach program, such that the social unrest did not justify the revocation decree. The tribunal concluded that the revocation decree indirectly expropriated the claimant's investment. However, the tribunal considered that the lack of social license diminished the prospect of the project proceeding to operation "even assuming it had received all necessary environmental and

[20] *Tethyan Copper v. Pakistan*, Decision on jurisdiction and liability, 10 November 2017, paras. 556, 899-916, 943-958, 1159, 1264, and 1329.

[21] Judgment of the High Court of Justice of the British Virgin Islands, Claim No. BVIHC (COM) 2020/0196, 25 May 2021; United States District Court for the District of Columbia, Civil Action No. 1:19-cv-02424 (TNM), 23 March 2021, Joint Status Report.

[22] R Boutilier and I Thomson, *The Social License: The story of the San Cristobal Mine* (1st edn, 2018), pp. 41-42.

[23] *Eg,* Deloitte study, "The top 10 issues transforming the future of mining", 2019, p. 28 ("Mining companies have long recognized the imperative of earning a social license to operate."); E&Y study, "10 business risks facing mining and metals", 2018, pp. 2 and 5 (qualifying the SLO as a top risk and noting that "Underestimating the power of each and every single stakeholder would be a mistake.").

[24] In addition to the cases described in this section, see *eg, Copper Mesa v. Ecuador*, Award, PCA Case No. 2012-2, 15 March 2016, paras. 2.16 and 6.77-6.79 (the company could not complete the environmental permitting of the project and develop the concessions because of the social resistance); *Glamis Gold. v. USA*, UNCITRAL, Award, 8 June 2009, paras. 126-127.

other permits", and only awarded the sunk costs in the amount of US$ 18 million (instead of the US$ 500 million sought in lost profits).[25]

The relevance of the social license to the development of the mining project is critical. In legal terms, the lack of a social license can render the project unfeasible or too uncertain and thus torpedo a claim that, but for the state's allegedly wrongful actions, the mining project would have been profitable. Social opposition can also contribute to delays or issues in the permitting process. In *SAS v. Bolivia*, the investor envisaged the extraction of precious metals (including indium, gallium and silver) in an area which comprised a mountain deemed sacred by indigenous communities. The local communities voiced strong opposition, including through marches and demonstrations, against the project. The State revoked the mining concessions, referring to the indigenous communities' right to self-determination and self-government and their right to preserve and protect the environment in their territories. The tribunal found that the revocation of the concessions was a direct expropriation but only awarded the investor US$ 18.7 million in compensation of the exploration costs incurred (instead of the US$ 385.7 million claimed in lost profits).[26]

Section 2: Risk mitigation and Lessons learned

At the outset, it is crucial for foreign investors to study the host state's regulatory framework and to assess the political and legal risk in connection with a possible investment in that country. It is advisable for investors to secure specific written assurances from the relevant authorities regarding their project and the legal framework. Should there then be a material and unforeseeable change in the legal framework, which is detrimental to the investment and contrary to the investor's legitimate expectations, it may be able to invoke those written assurances in arbitration proceedings.

Mining companies also need to address environmental and social risks. As early as possible, they should identify and engage with the relevant stakeholders, including possible indigenous communities, to secure and maintain their acceptance, if not approval, of the project, *i.e.,* to obtain the SLO as noted above.[27] The relevant stakeholders include all the persons and organizations which have the ability to impact the project. While engaging with these stakeholders may be legally required as part of an Environmental and Social Impact Assessment (or "ESIA"), this requirement may arise after the exploration license or sometimes even an exploitation license has already been obtained. It is nevertheless highly advisable to consult the affected communities as early as possible, regardless of the legal requirements. Mining companies should consign the results of these efforts in well-documented due diligence and risk assessments as early as possible in a project's life.[28] Insofar as mining companies can demonstrate to the public that they exceed the legal requirements and meet best available techniques (or "BAT") and practices relating to environmental protection, this may assist in securing the SLO (and of course it may also help to secure financing).

[25] *Bear Creek v. Peru*, ICSID Case No. ARB/14/21, Award, 30 November 2017, paras. 149, 170-203, 380, 408-416, 598-600 and 656-668 and 738.

[26] *South American Silver v. Bolivia*, Award, PCA Case No. 2013-15, Award, 22 November 2018, paras. 559-567, 576-578, 610, 823 and 872.

[27] *E.g.,* https://socialicense.com/definition.html.

[28] *E.g.,* 2019 Dutch Model BIT (Art. 7(3)) ("The Contracting parties reaffirm the importance of investors conducting a due diligence process to identify, prevent, mitigate and account for environmental and social risks and impacts of its investment").

Section 3: Claims before an international arbitration panel

Once a dispute arises between a foreign investor and the host state, the investor may decide to commence arbitration proceedings. This is usually done by first sending a notice of dispute to the state, triggering a "cooling-off period" allowing both sides to try to seek an amicable solution. Should these efforts fail, the investor may then file a notice of arbitration.

A claimant's first hurdle is to show that it falls under the scope of protection of the relevant investment treaty. It must show for instance that the mining company lawfully made an investment in the host state. Some claims that have arisen out of disputes where the investments had been made through corruption or in breach of domestic law were then dismissed by tribunals because they fell outside the treaty's scope of protection. In approximately one-third of the over 60 awards reviewed to prepare this paper, tribunals did not examine the merits of the case but found that they lacked jurisdiction, including because the investor or its investment were not protected by the treaty.

If the claimant successfully shows that the tribunal has jurisdiction, it may then bring claims that the state failed to provide the protections included in that treaty. Most investment treaties protect investors from expropriation, *i.e.,* the total and irreparable loss (or substantial deprivation as noted above) of the investment without prompt and adequate compensation.

Another frequently invoked breach in mining disputes is a claim that the state irreparably prejudiced the investment in breach of the fair and equitable standard or acted in a discriminatory way as compared to the treatment proffered to nationals of that state pursuant to national treatment clauses. In such cases, foreign investors often allege that their legitimate expectations regarding the project were frustrated, as illustrated above with the Crystallex case.

Other substantive protections include the obligation for states to assure full protection and security and to refrain from taking arbitrary, unreasonable and discriminatory measures. The treaty may also extend protections granted to investors from other jurisdictions through the most favourite nation clause and may also cover claims arising out of contract violations.

If a tribunal finds that the state's breach caused harm to the investor, it will then quantify the amount of damages due, if any. According to a fundamental international law principle, compensation should only be granted when there is a "sufficient degree of certainty" or where "in all probability" the damage or loss would otherwise have been averted.[29] This may be more difficult to prove in cases where the mining project was still in the exploration phase. In such an early stage of the project, there is no track record of mining activities, no historic cash flows, based on which the loss can be assessed with sufficient certainty. For instance, the tribunal in *Bilcon v. Canada* found that the Government had wrongfully rejected the project for a quarry and marine terminal after a negative environmental impact assessment. When assessing the quantum of the damages owed as a result of this breach, the tribunal found that the claimants had not proven how probably they would have obtained the environmental approval (the permitting risk) and, noting the project's uncertain long-term future profitability, refused the claimants' lost profits claim. The tribunal only awarded compensation for the value of the lost opportunity (awarding US$ 7 million of the over US$ 400 million sought).

A recent study of investment mining disputes shows that, in cases in which compensation was awarded, the amount of compensation was on average less than a third of the amount claimed, ranging between one and 56 percent of the amount claimed.[30]

Tribunals have also considered the behaviour of the foreign investor when assessing damages, by applying the doctrine of "unclean hands" or the principle of contributory fault. For instance, in *Copper*

[29] *Bilcon v. Canada*, PCA Case No. 2009-04, Award on Damages, 10 January 2019, paras. 114 and 168.

[30] Duarte-Silva/Velarde Saffer, pp. 13-14.

Mesa v. Ecuador, the tribunal found that the State had breached the applicable investment treaty by terminating the mining concessions with neither compensation nor due process. However, it also considered the investor's involvement in the social conflict surrounding the mining project and accordingly reduced the amount of damages awarded to US$ 20 million (of the claimed US$ 70 million).[31]

In *Bear Creak Mining v. Peru*, the tribunal considered that the project was still at an early stage and had little chance of obtaining a social license, it therefore did not accept the discounted cash flow (DCF) valuation method presented by the claimant, which is based on the project's expected profitability.[32] Rather, the tribunal ordered Peru to compensate the claimant for its sunk costs (incurred between 2007 and 2011).[33] The tribunal then discussed whether the damages should be reduced on the basis of the claimant's contributory negligence or fault. The majority of the tribunal refused to do so, while the dissenting arbitrator considered that the claimant's damages should be reduced by 50% because it had contributed to the social unrest giving rise to that dispute.[34]

Conclusion

Arbitration proceedings relating to mining projects turn on the specific factual and legal circumstances. However, review of the tribunals' decisions in these cases (where they are publicly available) reveals certain trends and commonalities which can assist mining companies in anticipating and addressing legal, political, social and environmental risks.

Some of the lessons learned for mining companies include:

- the need to diligently study the host state's regulatory framework and to secure from State authorities, where possible, specific assurances regarding the project and the legal framework;
- the need to engage effectively with all relevant stakeholders as early on in the project as possible; and,
- the need to consign all such efforts in proper due diligence reports, highlighting any instance where the companies have met or exceeded legal requirements or even met best available techniques, notably in relation with social and environmental protections.

When a dispute with the host State arises and if certain conditions are met (including with regard to the manner in which the investment was structured), the mining company may be able to file claims in arbitration under an international investment treaty.

[31] *Copper Mesa v. Ecuador*, paras. 6.97-6.102.

[32] *Bear Creek v. Peru*, paras. 597-604 and 656.

[33] *Bear Creek v. Peru*, paras. 604 and 656-661.

[34] *Bear Creek v. Peru*, paras. 662-668.

LEGACIES OF MINING IN COMMUNITY PERCEPTION: RECOGNITION AND RECONSTRUCTION IN MINE REOPENING

Alex Cisneros, Wardell Armstrong International Ltd

Abstract

Community perceptions of mining are shaped before, during and after the mine life. As an increasingly large number of mines are being reopened due to technological advances in the industry, acknowledging the legacy of mining in the social perception is a key aspect to the sustainability of projects and the well-being of people. This presentation discusses how historic mine closure can impact the Social License to Operate for a new mine reopening, or mine waste reworking, and the essential role of proactive, holistic approaches to community engagement.

Using real case studies to outline a common industry issue, we present community engagement experiences and insights to better understand and deal with legacy perceptions. The recognition of historic concerns and unmanaged grievances is more than an opportunity to re-establish engagement. It is a strategic step for projects to reconstruct relations based in trust, participatory parity and common agreements with communities. In addition, it may act as a precondition for communities to recover from legacy impacts and better prepare for new developments.

Societal transformations and the evolution of public involvement in the extractive industry require, in addition to the technological and legal advances, a meaningful implementation of new advances in social practice to establish more sustainable relations.

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DEVELOPING AND SUSTAINING COMPETENCE IN SAFETY CRITICAL ROLES

Kevin Sabin, TSA Ltd

Abstract

This paper explores the issue of competence legacy of coal mining and how we have nurtured that legacy and developed it to deliver a sustainable opportunity in mineral extraction. We consider how mining competence has survived the mass closure of UK coal mines and how the basic process of defining, developing and assessing competence has become best practice enabling international deployment of specialist mining personnel both into and out of the UK.

The 28-step route to competence has been refined and underpinned by robust modern training programmes and a best-in-class Competence Management System (CMS). This CMS is currently supporting the largest mine construction in Europe and provides a proven case study enabling the development and sustainability of competence in safety critical roles across the wider mineral extraction fraternity and ultimately the general construction sector.

This focus on competence has become the backbone of our international strategy to support the further development and application of technology through people, sharing and building upon the inheritance of UK mining. Current examples of this are our ongoing project supporting the introduction of roof bolting underground at Bogdanka in Poland, Europe's largest coal mine and support to the Indian mining sector facilitating the introduction of mass production technology.

The CMS is an integral component of a Safe Management system at a mine and as the digital mine transformation continues at pace, driving asset lifecycle improvements, performance enhancements and optimum utilisation it is critical to apply the same priority to the competence of mine personnel just as we do our equipment if we are to truly realise safer, increased production at reduced costs through the digital mine transformation.

A Competent workforce is by far our greatest asset and this approach to the development of people through a robust structured CMS enables sustainable development of that asset focussing primarily on Safety Critical roles.

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MINE WATER: A POTENTIALLY IMPORTANT HEAT SOURCE

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Abstract

The demise of deep coal mining leaves the UK with a legacy of over 23,000 abandoned deep coal mines which lie beneath one quarter of our built environment. Apart from a number of small enterprises and some prospects looking at exploiting specialist fuel the industry is effectively closed. With mine abandonment comes the cessation of pumping and coalfields have subsequently steadily refilled (recovered) with water. It is essential that mine water recovery which generally takes place over a period of several decades is managed in a controlled manner. This has been undertaken by British Coal and subsequently the Coal Authority.

Though the coal mined has long since been extracted, traded and burned, the remaining water filled voids can be used over for geothermal energy. The Coal Authority has calculated that the constantly replenishing water within these mines meets the heating requirements for the buildings located on the coalfields.

Using well established heat pump technology, a major thrust to use the geothermal potential of water within abandoned mines as a low carbon source of heat is underway across the UK. This is being led by the Coal Authority and IOM3 alongside a range of other stakeholders such as Local Authorities and the UK Government through their heat network delivery unit resulting in a substantial number of projects being developed.

This paper will discuss the background and approach to managing coalfield abandonment including the importance of monitoring mine water recovery and changes in chemical composition. Existing and developing mine energy projects will feature, describing methods, important factors to maximise success and the need for regulatory regimes to cover the process. The lessons learnt form a key element of the discussion highlighting possible applications for other mineral mines and could inform closure procedures that may be applicable to optimize future energy recovery opportunities.

1.Introduction to Heat Pumps

The first heat pump was built by Peter Von Rittinger in 1856[1]. Von Rittinger recognised the principle of the heat pump while conducting experiments on the use of water vapour's latent heat for the evaporation of salt brine. The first large scale heat pump in the UK was developed by John Sumner in 1945 on the doorstep of Finn Geotherm in Norwich[2]. Norwich City Council had built new premises in Norwich at Duke Street, on the bank of the River Wensum. The office was originally intended to be heated by a heat pump, but the wartime austerity prevented resources being available to focus on such an innovative project. After the war however John Sumner, who was the City Electrical Engineer for Norwich, devised a system from salvaged components based on a SO_2 refrigerant. The system is reputed to have achieved a seasonal efficiency ratio of 3.42. The system ran at an average thermal delivery of 147kW and had a peak output of 234kW. It was designed to circulate water around the building's heat emitter systems at 50-55°C. Despite the efficiency and effectiveness of the system it was not widely adopted in the UK because of the relative cheapness of fossil fuels such as coal and later North Sea oil and gas.

As is so often the case however, UK technical advances were adopted and developed overseas. In 1948 a large scale heat pump was installed in Oregon in the United States[3]. Following the OPEC oil crisis of the 1970s the development and adoption of heat pumps gathered pace[1]. During this period closed loop polythene systems became the norm, with vertical closed loop systems being developed in Germany, Switzerland and in Finland.

The development of heat pump technology is still continuing with advances in compressor and controls technology and refrigerants enabling systems to be more efficient and easier to control. Heat pumps have proven themselves to be reliable, effective, and efficient, in the words of Gordon Cook (1948):

"There can be no doubt that in the heat pump we have a machine that is to play an outstanding part in the industrial future of our country."

2. Accuracy of Mining Information

One of the key issues in any mining project is the need to have accurate and up to date information. In the case of an old coalfield, such as discussed in this paper, records of the multi seam workings are important in deciding optimal access points for drilling into suitable voids. Prior to 1875, there was no requirement for mine owners to submit their records. The Coal Mines Regulation Acts 1887 and 1896 required more details to be added to the Abandonment Plans including the position of the workings with respect to the surface[4]. It was not until the Coal Mines Act 1911, however, that the Abandonment Plan had to show variations of level on the mine roadways[5]. Thus, when dealing with a complicated mining situation, it must be remembered that those plans available in the Mining Records Office, particularly for older workings, might not form a complete nor accurate record.

Obviously, these and subsequently prepared plans and reports are key factors when considering utilisation of heat sources particularly where access by borehole is required.

Figure 1: The Great North Coalfield – A major potential heat source

Located in the North East of UK, the Great North Coalfield underlies most of the Counties of Northumberland and Durham stretching almost to the Scottish border (Figure 1)[6]. Over the past 200 years it was a significant contributor to UK energy demands and a major player in the Industrial Revolution. The Former Great North Coalfield is an excellent international example of a major potential energy source. Mining of Coal has been carried out since Roman times in many and varied forms, thus it demonstrates multi seam working in a wide variety of strata. With all mines now closed following the abandonment of Ellington in 2005, mine water recovery has been managed and monitored initially by British Coal but since 1994 by the Coal Authority.

Figure 2 indicates the broad geological structure of the Great North Coalfield which also includes large areas of undersea workings. The strata dip gently to the east, reflected by early mining being concentrated in the shallower areas to the west, but overtime workings extended eastwards and deepened with the most recent phase of mining concentrated at the coastal areas until final closure. In the south eastern parts of the area the coalfield is concealed beneath the Permian deposits.

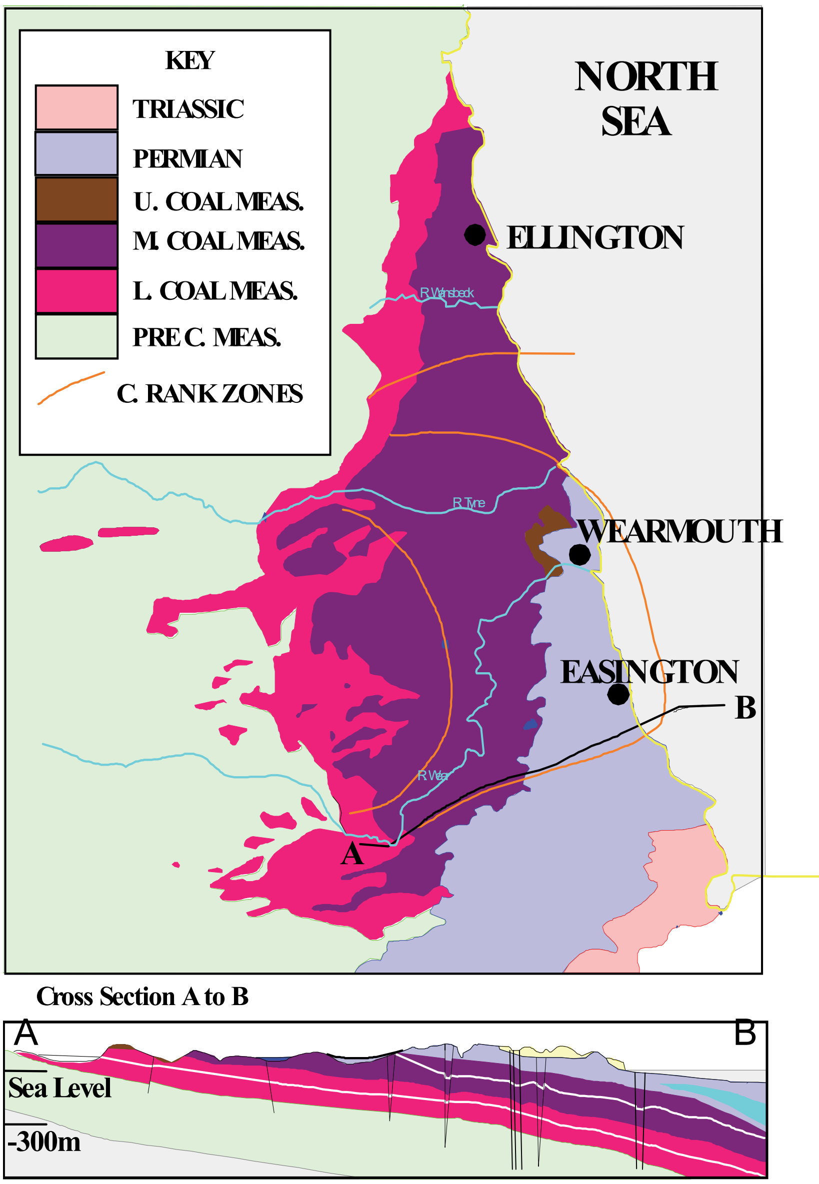


Figure 2: Geological Structure of The Great North Coalfield

The underground water has recovered to its current levels creating a series of vast underground mine ponds which are controlled at acceptable levels by a combination of pumping or gravity discharges and passive and active treatment systems[7]. The regulatory bodies managing these operations are the Coal Authority together with the Environment Agency who cooperate under a Memorandum of Understanding to prevent uncontrolled discharges of mine water and protection of water supply aquifers. The latter principally applies to the Durham County which is an area overlain by Permian limestone.

Within the Great North Coalfield area there are currently 15 mine water treatment sites operated by the Coal Authority which collectively dissipate around 35MW of low-grade heat to atmosphere providing a glimpse of the wider opportunity that exists.

3. Low carbon aspirations

Heating accounts for 45% of energy use in England and Wales, and 55% in Scotland with 85% of this heat being derived from fossil fuels[8]. It is estimated to produce 32% of the UK's air pollutants. Using the geothermal energy stored within abandoned mines provides an alternative source of heat which is a low carbon, local and low-cost, well suited to district heating, commercial space heating, industrial process pre-heating and horticulture. It is scalable, flexible and dispatchable and can also incorporate cooling.

The UK has a target for 43% of heat be supplied using heat networks by 2050, currently around 2% of heat is supplied in this way[9]. The government is currently supporting heat network development and uptake through the Heat Network Delivery Unit. Heat networks have traditionally run at high temperatures (greater than 80°C) and have included centralised heat generation plant (often CHP or biomass). There are many reasons to reduce operating temperatures which include lower system losses and the ability to use non-metal pipework which significantly reduces capital and installation costs.

Boreholes to access mine energy need to be drilled where subsurface conditions are most suitable. This could be at the energy centre in a centralised system or at any point around the heat network for a decentralised system. There are no fuel transport requirements for a mine energy heat network and no local carbon emissions, the heat pumps can be located in building basements or underground.

4. Social and economic benefits

Mining in the UK built an industrial power base in the coalfield communities creating the highest population density outside of London. Nine out of ten of our largest urban areas (by geographical size) are located on the coalfield. Many former mining communities have been disadvantaged following mine abandonment. Compared with non-mining regions this manifests itself in shorter life expectancies and more health issues, fewer opportunities for employment, increased demands on public services combined with an increased incidence of fuel poverty[10].

Developing mine energy systems for low carbon energy supply could assist in reversing these issues by offering reduced heat pricing to tackle fuel poverty, improving air quality, providing opportunities for investment whilst creating employment. The fact that money spent on energy can be retained within the region helps to deliver economic improvement and the sense of local pride can be rejuvenated through increasing the links between communities and their industrial heritage.

5. Where does the heat come from?

Water within the mines is heated by carbon neutral geological processes within the earth with temperatures varying from 10-20°C close to surface to over to 40°C in deeper seams. Water temperatures are not affected by seasonal variations or climate change and are recharged through geological processes. This is distinct from ground source heat which is sourced from the Sun’s energy and stored within a few tens of metres of the surface[11].

When mines are abandoned, pumps are switched off and over a period of several decades the mine begins to fill with water. Water levels within abandoned mine workings vary significantly from hundreds of meters below surface level to within a few metres of surface. For a mine energy scheme, depth to the water table is a key criterion for system viability because the electricity requirement in pumping water from the mine should not offset the overall system performance. Even though a seam may be several hundred metres deep, because the mine system is flooded the mine water may be relatively close to surface, meaning that abstracting warmer water from deeper levels requires minimal additional energy use.

Typically water is abstracted from deeper seams, heat removed, and the cooled mine water reinjected back into shallower seams to provide a long return path, giving the water time to heat up again (Figure 3).

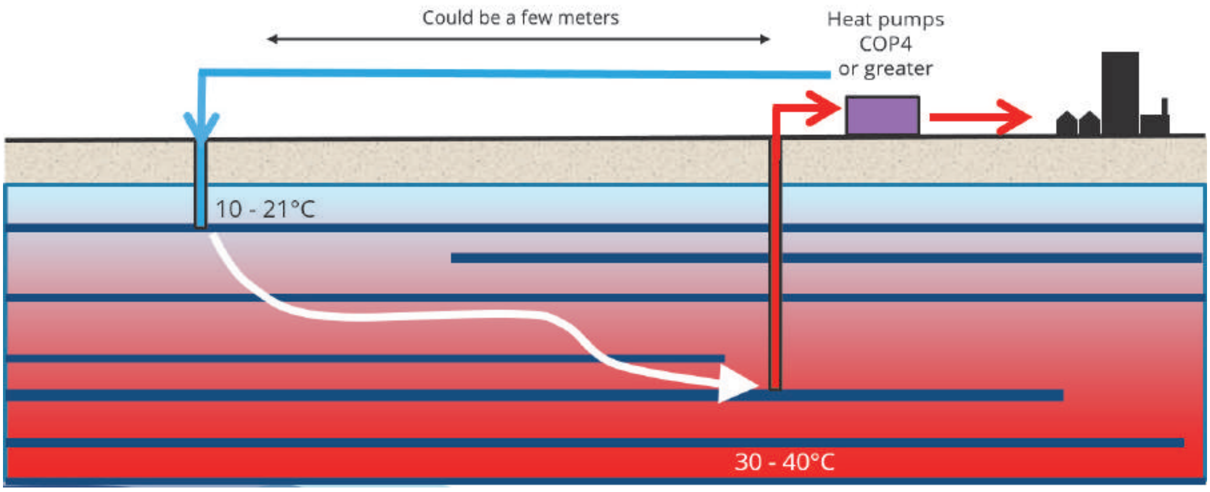


Figure 3: Schematic diagram of a mine energy system

To manage water levels across the coalfield and continue to protect surface and groundwaters, the Coal Authority pumps and treats minewater to control water levels at strategic points across the Great North Coalfield.

This comprises a total heat output of over 36MW. It is planned to link these sites with heat demands where possible. The Coal Authority is working with Durham County Council and Tolent Construction to demonstrate the use of pumped mine water to provide district scale heating for a development of 1400 homes at Seaham Garden Village, County Durham using water pumped from the former Dawdon Colliery (see case studies).

Globally there are over 30 mine energy projects ranging from a few kW to several MW meeting both domestic, municipal and commercial heat demands for both retrofit and new-build projects. The diversity in the range of projects makes mine energy a very versatile energy source but each project is unique, making it difficult to adopt a one size fits all approach. There has been a mine energy heat network operating at Heerlen in the Netherlands for the past decade. This supplies heat to around 200,000m^2 of new and retrofit buildings and has delivered economic improvements for the area because money spent on energy is retained within the region.

6. Requirements for a mine energy project

The abandoned mine infrastructure is extensive and complex, often comprising multiple worked coal seams connected by horizontally or inclined roadways and adits, as well as through mining related fractures and rock porosity. There are also vertical connections via shafts and boreholes and at larger scale through interconnectivity between collieries extending in some cases considerable distances. Understanding subsurface configuration and flow pathways is key to developing mine energy schemes and is a specialism of the Coal Authority who monitor water recovery behaviour but are also custodian of the National Abandoned Coal Mine Plan Archive.

The Coal Authority has 800 monitoring points and over 200 boreholes intercepting mine workings across the coalfields. Their hydrogeologists monitor mine water rebound across interconnected workings and take measures to protect the environment from mine water pollution.

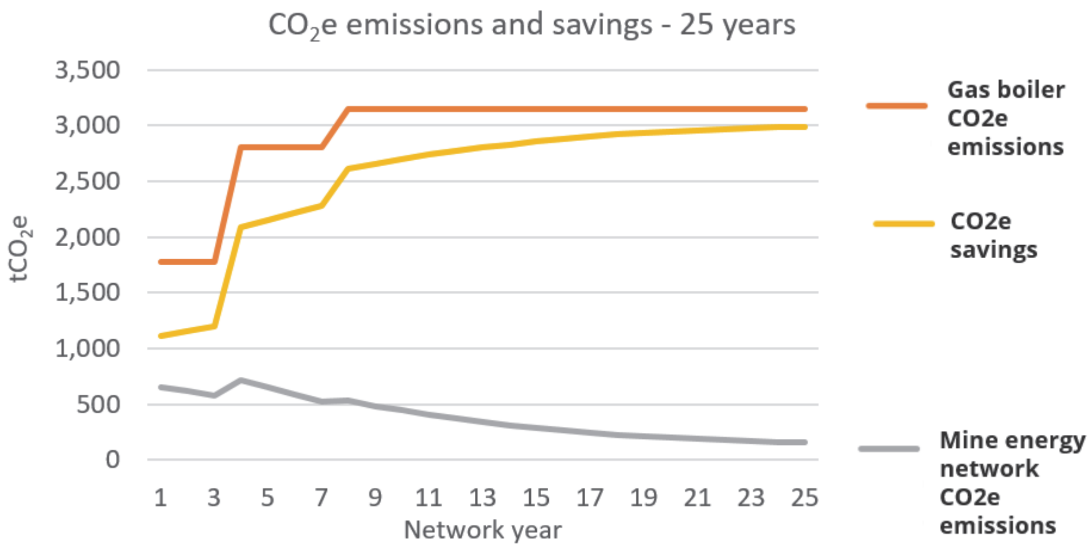
When drilling boreholes to access mine energy, it is crucial to ensure that they intercept suitable targets underground to achieve mine water flow. Key considerations are depth to mine water, as discussed earlier. Another consideration is the presence of more than one seam so that there are separate targets from which to abstract the mine water and return it following heat extraction. Re-injecting water should prolong the life of the system, but care must be taken at the planning stage to ensure an adequate length of pathway between abstraction and reinjection points to avoid short circuiting and cooling the source.

Mine water quality varies across the coalfields. It can be close to the quality of typical river water or have a higher salinity than sea water[12]. The main pollutants are iron and salinity with the mine water quality often being related to coal composition, host geology and mine connectivity. Should the mine have a low pH and/or high salinity, it may be corrosive to system components and appropriate materials should be specified. On exposure to air, the iron in solution can oxidise and precipitate from solution as ochre. This can potentially block heat exchangers and pipework. By designing pumping to avoid aeration, and keeping pipelines under positive pressure, iron remains in solution and iron furring issues are eliminated.

It is also important to consider resilience and flexibility when planning a mine energy scheme to ensure continuous heat supply. This could involve having duty pumps, multiple heat exchangers and multiple borehole configurations, for example, two abstraction wells and one recharge well. This means that both wells could be used for abstraction at peak times with one supplying baseload and one well resting which provides an opportunity for maintenance.

7. Case studies

7.1 Seaham Garden Village



The Seaham Garden Village project is being developed in partnership with Durham County Council and the Coal Authority[13]. Tolent Construction are developing an exemplary Garden Village at Seaham, County Durham that will consist of 750 affordable homes, 750 private homes, a school, shops, and medical and innovation centres. The development is to be built immediately adjacent to the Coal Authority's Dawdon mine water treatment scheme. This scheme protects vital drinking water abstraction from Durham Magnesian Limestone, and pumps 100 to 150 litres of mine water per second to the surface for treatment. This development has the potential to make Seaham Garden Village the first large scale mine energy district heating scheme in the UK.

This mine water is warmed by geothermal processes to provide a continuous supply of water at 18 to 20°C. In the case of a district heating network, this energy can be transferred to a pipe network using a heat exchanger, and then distributed to nearby homes. With mine water temperatures unaffected by seasonal variations, there is a potential 6MW of low cost, low

Figure 4: Projected CO_2 emissions for the Seaham Garden Village mine energy scheme

carbon sustainable energy available for local space heating use from the Dawdon treatment scheme all through the year. The scheme is also unusual in that it does not use metal pipes, due to the lower temperatures involved. The method of delivery is much cheaper than district heating schemes that use higher temperatures, where metal piping is essential and greater temperature losses are encountered, making networks such as Seaham Garden Village much more efficient and economically viable than some other district heating schemes. In addition, as illustrated in Figure 4, the carbon emissions associated with using a heat pump are far less than from using an equivalent gas boiler and will decrease further as the carbon content of grid electricity decreases as more low carbon generation supports our electricity mix. This also leads to an improvement in local air quality.

This kind of low carbon energy technology could help to present coalfield areas as more attractive to investors, which could breathe life back into some areas of the UK where it is most needed. It could also provide a low carbon solution to Britain's future low carbon energy needs. Many local authorities have already declared a 'climate emergency', with pledges to become carbon neutral in the coming years.

7.2 Gateshead Mine Energy Scheme

Gateshead Council has been awarded a grant of £5.9M from the UK government Heat Network Investment Project. This will be used to double the size of its existing heat network in Gateshead Town Centre[14]. This project will differ from Seaham Garden Village because there is no mine water available at surface and boreholes will be drilled to a depth of around 150m to access the mine water. The council-owned Gateshead Energy Company plans to install 5.5km of new heating pipes to the east of Gateshead Town Centre. This will supply heat to up to 1,250 new private homes, a care home, Gateshead International Stadium and other Council-owned buildings in the area. A 6MW water source heat pump will be used to upgrade the heat to supply temperature. The Council is working closely with the Coal Authority who manage all the disused mine workings under Gateshead to ensure the success of the project. Gateshead Energy Company, which is wholly owned by Gateshead Council, already operates a successful heat network which supplies hundreds of homes and businesses in Gateshead town centre with low cost, low carbon heat and power using a gas-fired Combined Heat and Power (CHP) plant. The proposed mine water heat pump system will enable the Gateshead Energy Company to reduce its reliance on combined heat and power, further reducing the council's carbon footprint. As well as hundreds of homes in Gateshead's town centre, prestigious buildings such as Gateshead Civic Centre, Gateshead College, Sage Gateshead and BALTIC also receive heat and power via the network.

8. Stakeholders and Partnerships for Delivery

There are many stakeholders working together to help deliver mine energy within the Great Northern Coalfield. A Local Enterprise Partnership (LEP) is a voluntary partnership between local authorities and businesses. Over 50% of LEP Board Members are business leaders putting the voice of business at the heart of local economic growth. There are 38 LEPs across the UK that have a central role in deciding and delivering local economic priorities with the aim of stimulating economic growth and create local jobs. LEPs have also been allocated money from the Growing Places Fund to be spent on infrastructure and have been given responsibility for delivering part of the EU Structural and Investment Funds for 2014-2020.

The North East LEP which covers the whole of the Great Northern Coalfield recognises the potential of mine water as an important heat source with a contribution to assisting the green economy and promoting new jobs and skills. To this end they have established a Mine Energy

Task force of interested stakeholders. The Coal Authority is also a member of this task force as they are a key to the successful delivery of the mine water heat source by permitting access to the workings infrastructure that they own. Local Authorities, environmental and mining consultants, universities, the Environment Agency and equipment manufacturers are also key members of this group.

Building on the work of the mine energy taskforce, Consultants have been commissioned to explore and synthesise what is known about the opportunities associated with the development of mine energy in the UK and England in particular. This will inform a 'White Paper' which will make the case for mine energy, identify the current barriers to a more widespread exploitation (particularly associated with redundant coal mines) and describe what actions are required to unlock this resource. Ultimately this work will lead to a complete legislative document satisfying all parties and ensure deliverance of an important energy source.

9. Legislation and Control

Any activity involving possible changes to the underground status quo must be fully controlled. Alteration of mine water levels can have many implications such as affecting mine gas emissions and where the water provides hydraulic support can trigger subsidence events. Though mine energy schemes that reinject mine water following heat recovery should not cause widespread changes in water level, it is crucial that mine energy projects are appropriately licensed and developed to prevent damage to the subsurface or the environment and manage potential interactions between adjacent projects thereby protecting the heat resource.

The Coal Authority has established an innovation team in anticipation of the huge potential demand for mine energy schemes in the coalfields. They also have a licensing team who permit access to the abandoned mine infrastructure for the purposes of heat recovery through their heat access agreements. Their role will be to provide advice, expertise and permission to proceed to all interested parties. In addition to applying for a heat access agreement, it is necessary to apply to the Environment Agency for an abstraction license and discharge consent when mine water is being abstracted from and returned to the subsurface.

10. Conclusion

Heat accounts for half of UK energy demands, with most currently derived from gas. However, government targets state that by 2025 there will be no gas connections in new build houses and businesses. Technology-ready alternatives, such as mine energy, are sure to play a huge role in supplying Britain's energy needs for years to come. Whilst it is early in the process of establishing what the benefits of this energy source is to the UK as a whole, initial indications from the project work being undertaken are extremely encouraging. The UK resource is now considered an asset of strategic importance. The case studies outlined are typical of some thirty or so projects under development. Obviously, the viability and contribution each will make will take time to become apparent but as part of the UK drive to reduce carbon emissions then it should be pursued with vigour. Whilst not applicable in the UK coal mining context as underground coal mining has ceased, elsewhere the concept should be considered how mine water can be used as a heating or cooling source as a by-product of the mining operation. Should there be consideration in the mine closure plans to enable ultimate easy access to a possible asset?

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RESEARCH AND INNOVATION OPPORTUNITIES FOR MINE WATER HEAT AND HEAT STORAGE AT THE UK GEOENERGY OBSERVATORY IN GLASGOW

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Abstract

Net-Zero carbon emissions targets require significant progress to be made in the decarbonisation of heat. Utilisation of the warm water in flooded, abandoned coal mines beneath many of the UK's towns and cities could offer a substantial opportunity for decarbonised heating using a technology that is proved, but not widely realised.

The UK Geoenergy Observatory in Glasgow is an at-scale 'underground laboratory' of 12 boreholes, surface monitoring equipment and open data for investigating shallow, low-temperature mine water heat energy, heat storage potential and environmental change. The Observatory has started to enable a range of research and innovation - increasing the evidence base to underpin resource, operational and environmental management, policy and regulation, and to drive cost and risk reduction of these technologies.

Introduction

Over the last 15 years, UK and devolved Government policy has shifted towards enabling decarbonisation of our energy supplies to reduce carbon emissions and reach Net-Zero emissions targets by 2050 or earlier (e.g. HM Government 2017, 2018; Scottish Government 2017; CCC, 2019). Whilst significant progress has been made in the decarbonisation of electricity, decarbonisation of heat presents a more difficult policy and technology challenge. Geothermal energy and subsurface heat storage have significant potential for delivering low-carbon heat, with low enthalpy 'shallow geothermal' heat recovery from and seasonal thermal storage in abandoned coal mines offering one such opportunity.

Many of the UK's towns and cities are underlain by abandoned coal mines. Upon closure and with the cessation of dewatering, the mines have become naturally flooded with warm groundwater. The man-made workings and rock mass surrounding them have a higher permeability compared to unmined rock due to still-open and partially-collapsed mined voids and collapse-related fractures forming an 'anthropogenically-enhanced aquifer'. This warm mine water can be abstracted through a borehole and passed through a heat pump to provide space heating for homes and businesses, before being returned within a sealed loop to a different part of the mine system via a second borehole. Flooded mine workings can act as a thermal reservoir, with the potential to provide both heat recovery and heat storage, as required. The legacy of coal mining can thus be turned into a sustainability opportunity for low-carbon heating.

Small numbers of successfully-operating mine water geothermal and heat storage schemes have proved the concept of using this decarbonised energy source for space heating and cooling (e.g. UK, Banks *et al* 2017; Heerlen Netherlands, Verhoeven *et al* 2014; Asturias Spain, Loredo *et al* 2016; Springhill Canada, Jessop 1995). An increasing number of mine water energy schemes are in exploration and operational stages in the UK (e.g. Athresh *et al* 2015; Banks *et al* 2017; Brabham *et al* 2019; Coal Authority 2020). However, the very large resource potential (e.g. Gillespie *et al* 2013; Preene and Younger 2014; Ramos *et al* 2015; Bailey *et al* 2016; Farr *et al* 2016, Gluyas *et al* 2019) has yet to be widely exploited. Commercial demonstration of mine-water heat technology is critical in breaking economic, regulatory, awareness and acceptance barriers to this widespread utilisation (e.g. NERC *et al* 2019). Underpinning geoscientific research and innovation is essential also, for enhancing process understanding, providing an open evidence base towards social acceptance, cost and risk-reduction (e.g. NERC *et al* 2019). As one of a growing number of underground laboratories worldwide, the UK Geoenergy Observatory in Glasgow is a unique mine water facility for investigating shallow, low-temperature mine water thermal energy resources in abandoned and flooded workings at depths of around 50-90 m.

Background to the UK Geoenergy Observatory in Glasgow

The Glasgow Observatory is an at-scale infrastructure of 12 boreholes and surface monitoring equipment to provide open data for research into the subsurface environment and how natural resources can be used responsibly and sustainably. Available for use by the commercial and academic communities, the Glasgow Observatory is operated by the British Geological Survey (BGS) on behalf of the Natural Environment Research Council with funding from the UK Government Department for Business, Energy and Industrial Strategy.

The Glasgow site was chosen due to its commonalities with other parts of the UK and beyond, in terms of its coal mining history, geology and legacy of industrial land use. Testing, monitoring and calibration at the Observatory will provide an evidence base to inform topics such as resource characterisation and long-term utilisation. This interdisciplinary research is likely to underpin environmental management, influence policy and regulation, and drive a focus on cost and risk reduction.

The Glasgow Observatory is representative of an urban setting, close to demand and is at the scale of small mine energy schemes. It is equipped with downhole sensors that are designed to measure changes in temperature, water levels, water chemistry etc. on measurable (research) timescales. With a lifetime of 15+years, it will provide a growing body of integrated open data. As a research infrastructure, it offers flexibility for interdisciplinary research and enables the testing of the system's responses to induced physical changes (e.g. flow/heat), which would not be possible within commercial schemes.

Geology and mining history

The Glasgow Observatory is located on the western side of the Central Coalfield of the Midland Valley of Scotland. The area is underlain by the Carboniferous Scottish Upper, Middle and Lower Coal Measures formations, comprising cyclical sedimentary sequences of sandstone, siltstone, mudstone and coal. Recorded coal mine workings in the immediate vicinity were active from 1810–1934, with total extraction and 'stoop and room' (pillar and stall) workings of up to seven coal seams shown on abandonment plans. The bedrock succession is overlain by up to 40 m of glacial and post-glacial Quaternary deposits and widespread made ground relating to a variety of prior industrial land use, which in some places is 10-15 m thick.

Whilst the setting of the Observatory cannot encompass all coal mine typologies and mine water hydrogeology, it is believed to be representative of many central Scotland and UK coalfields.

Construction and testing timeline

Following design and permitting in 2017–2018, borehole drilling, testing and construction of research compounds was carried out in 2018–2020 (Figures 1, 2). Environmental baseline monitoring commenced prior to borehole drilling.

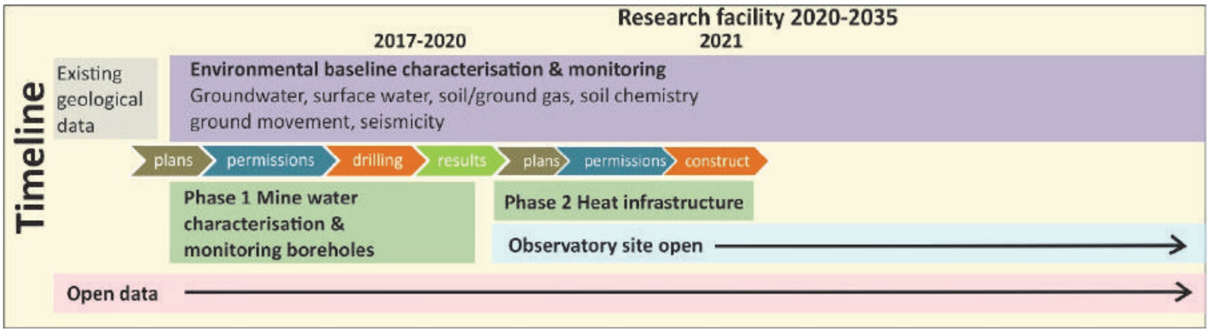

Figure 1: Summary timeline for the Glasgow Observatory

Figure 2: (a) Drilling of the cored borehole GGC01 (b) Installation of uPVC casing screen to mine water borehole GGA08, with pre-glued gravel pack and electrical resistivity sensor cable being attached (red sensors). Photos ©BGS/UKRI 2020.

Permanent infrastructure for heat abstraction / injection, heat transport and heat storage research is planned to be installed at the Glasgow Observatory in 2021, subject to approval of a planning application. Currently at the design stage, the infrastructure is planned to comprise a sealed, open loop abstraction and re-injection doublet (or doublets) in two or more of the mine water boreholes from the Glasgow Main Coal and Glasgow Upper Coal mine workings.

Research and innovation infrastructure

In the Cuningar Loop, Rutherglen (Figure 3, Table 1), five boreholes are screened across the Glasgow Upper or Glasgow Main coal mine working (e.g. Figure 4). The boreholes are screened across a variety of mine working types including open voids (Figure 4), waste-filled mine workings, coal pillars and the fractured rock mass, meaning research can be conducted on heat abstraction and heat storage in different types of mine working. The boreholes are arranged in a triangle to characterise depth and spatial variability over 10-100's m (Figure 3), at a scale representative of small mine water schemes.

The boreholes are equipped with sensors to give a four-dimensional picture of the subsurface. Downhole electrical resistivity tomography sensors (Figure 2b), fibre-optic cables for distributed temperature sensing (DTS) and hydrogeological data loggers enable time-series monitoring to characterise physical, chemical and flow heterogeneities.

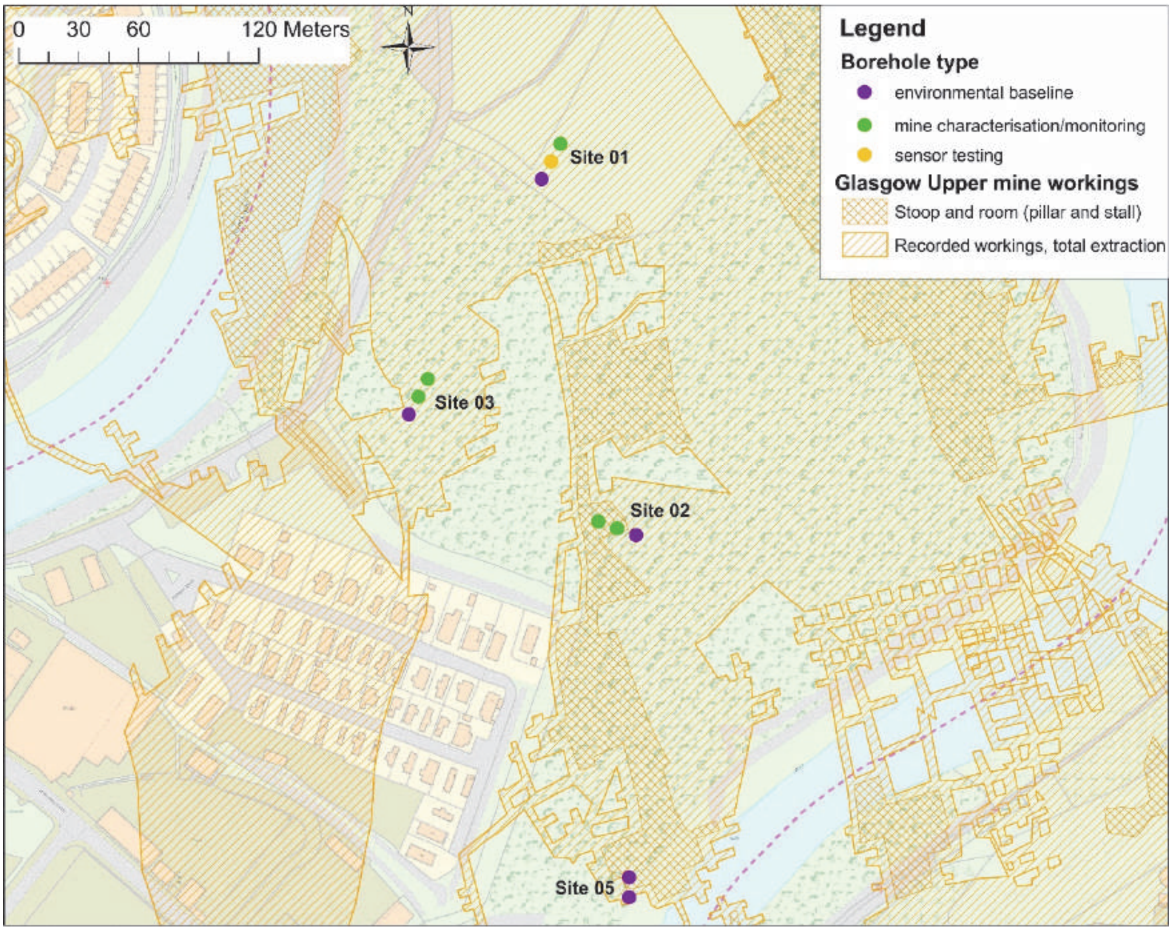

Figure 3: Borehole location map at Cuningar Loop, along with the recorded extent of Glasgow Upper mine workings from BGS interpretation of mine plan records. Contains Ordnance Survey data © Crown copyright and database rights. All rights reserved [2020] Ordnance Survey [100021290 EUL].

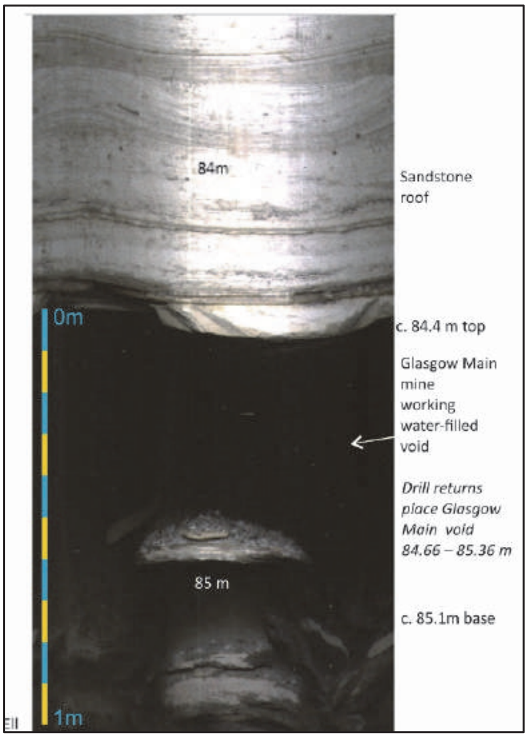

Figure 4: Annotated borehole optical camera image of the Glasgow Main mine working, a water-filled void in borehole GGA05.

Borehole number	Total drill length (metres)	Borehole type
GGA01	52.00	Mine water
GGA02	94.16	Sensor testing
GGA03r	41.72	Environmental monitoring
GGA04	53.63	Mine water
GGA05	88.50	Mine water
GGA06r	16.00	Environmental monitoring
GGA07	56.90	Mine water
GGA08	91.37	Mine water
GGA09r	16.00	Environmental monitoring
GGB04	16.00	Environmental monitoring
GGB05	46.00	Environmental monitoring
GGC01	199.00	Seismic monitoring

Table 1: Summary of the Glasgow Observatory boreholes

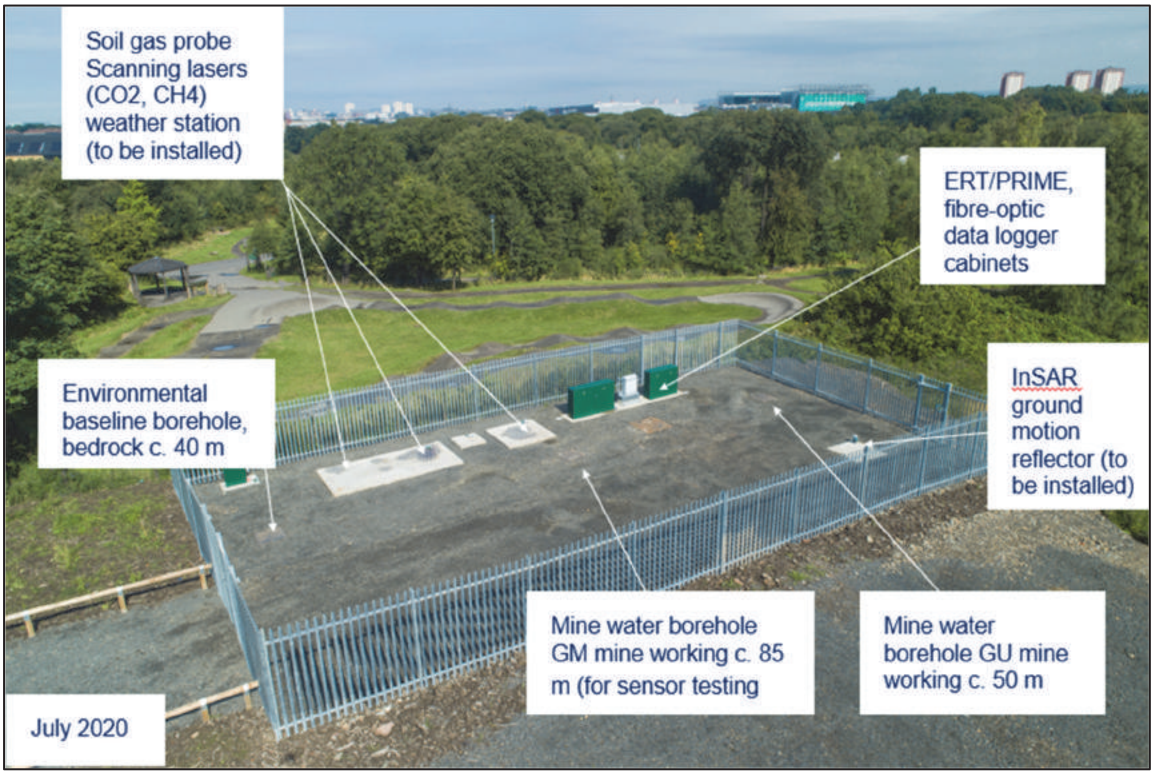

Figure 5: Annotated photo of Site 1 research compound. Photo courtesy of BAM Nuttall.

The characteristics of the hydrogeological system have been examined further by test pumping, regular geochemical sampling, and groundwater data loggers (level, temperature, conductivity). Pumping flow rates of 20 litres/second, with limited drawdown of mine water at around 12°C, were achieved during 5-hour test pumping. Good connectivity within both the Glasgow Upper and Glasgow Main mine workings, and some connectivity between the Glasgow Upper and Glasgow Main mine workings was observed, which is promising for discerning responses during future research.

Five of the boreholes characterise the environmental baseline and monitor any changes in unmined parts of the bedrock and the overlying superficial deposits (Figure 3, Table 1). The boreholes record ongoing baseline environmental change, evidence impacts from pumping mine water and give an opportunity for developing new monitoring technologies. Initial monitoring has recorded variable water levels and variable yields from test pumping.

The boreholes are located in four fenced research compounds that provide space for the handling of borehole equipment and operation of surface monitoring systems (Figure 5).

Environmental monitoring of soil chemistry, soil gas, ground motion and surface waters is also ongoing, to provide a site baseline before any geothermal research takes place. In addition, continuous seismic monitoring is provided by a dedicated monitoring borehole at Dalmarnock (Figure 2a). This 199 m borehole has been cored and geophysically logged and imaged. A new core scanning facility at BGS is being used to give high resolution geophysical, mineralogical, geochemical and optical/X-ray downcore datasets.

Open datasets

A large body of interdisciplinary data and information is already available online via www.ukgeos.ac.uk and will grow over the 15-year project timespan. Observatory users will be able to integrate their data into this evidence base. Examples of open data include:

- Continuous (time-series) monitoring data – e.g. seismic monitoring, groundwater levels, temperature, soil gases
- Static data – e.g. borehole information packs, test pumping results, water chemistry
- Core, rock chip and preserved geomicrobiology samples

Research and innovation opportunities

The Glasgow Observatory provides opportunities for researchers to undertake their own experiments and testing, using the boreholes or research compounds. Multidisciplinary research from across the geosciences, environmental monitoring, geo-engineering and data science is envisaged. Topic areas might include

- resource characterisation and sustainability
- model calibration and validation
- monitoring natural and induced small scale dynamic processes
- long-term operational performance
- environmental change and management
- sensor and tracer testing
- continuous data analytics

A research example might be to develop robust resource estimation methods using the infrastructure to monitor and calibrate rates and processes of heat and flow under thermal perturbation.

Conclusion

The UK Geoenergy Observatory in Glasgow is a new mine water heat and heat storage 'underground laboratory' now accepting access requests from the science community. A wide range of open information and monitoring data is freely accessible already.

These data will help researchers to understand the processes and impacts of extracting and storing heat using abandoned coal mines, as a sustainable way of heating homes and businesses in our towns and cities. The Observatory will provide evidence on utilising the UK's coal mining legacy as part of a decarbonised heat system towards meeting the UK's Net-Zero targets.

Acknowledgements

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COAL MINE WATER MANAGEMENT: IMPROVING APPROACHES THROUGH EVIDENCE AND EXPERIENCE

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Introduction

The Coal Authority has been managing coal mine water across the UK for over 20 years and has constructed or taken responsibility for over 75 mine water treatment schemes that treat 122 billion litres of mine water each year. As coal mines were closed, the pumps that kept mine workings dry ceased. Water levels within workings started to recover, resulting in discharges of iron rich mine water into surface waters. Treatment schemes are designed to remove iron from the mine water before it is discharged into a watercourse or the sea. In some areas, mine water is pumped from workings and treated to prevent this iron-rich water from contaminating aquifers or emerging at surface.

Mine water treatment schemes can be categorised into four types; passive, pumped passive, semi-passive and active. Passive and pumped passive schemes use a combination of cascades to oxidise the iron, lagoons to allow for settlement of iron hydroxides (ochre) and reed beds to filter any remaining iron solids from the mine water. Passive schemes operate for gravity discharges (i.e. adits), whereas pumped passive schemes may pump mine water from below ground (i.e. from within mine workings) or be used to transfer water collected in a sump from an adit to a treatment scheme at a different location. Semi-passive schemes are usually of similar design however require chemical additions in order to achieve treatment. This can take the form of sodium hydroxide to neutralise acidity or hydrogen peroxide to oxidise the water for sites where cascades cannot be built or are insufficient for oxidation. Active treatment schemes currently in operation use the High Density Sludge (HDS) process with addition of lime.

Scheme design has been developed over the previous 20+ years following improved understanding of treatment techniques and the maintenance required to operate these schemes effectively and efficiently. The approach to monitoring mine water and designing treatment schemes has improved significantly and is being used in the development of new schemes as well as the refurbishment of existing schemes.

Operation of mine water treatment schemes

The Coal Authority is responsible for operating and maintaining over 75 mine water treatment schemes across the UK. Some of these have been constructed by the Coal Authority while others were inherited from local councils or the National Coal Board/British Coal. Schemes vary in age with some being over 30 years old. These older schemes often originally served as treatment facilities during the active dewatering of operational coal mines, whilst others were constructed by local authorities. The Coal Authority inherited many of these older schemes from its creation in 1994 to the early 2000’s. Our understanding of the best ways to operate and maintain schemes has evolved over the past 25 years.

Historically, some passive schemes were built and then left with little or no maintenance carried out due to the mistaken belief that natural systems such as wetlands would be largely self-maintaining. It is now understood that in order to maintain treatment, regular maintenance is essential. Such tasks include cleaning cascades and inlet channels to remove ochre build up, desludging ochre from lagoons, cutting reed beds to prevent organic matter build up and periodic dredging and replanting of reed beds. Completing these tasks on a regular basis improves the iron removal across the scheme and can increase the life of the scheme.

For some older schemes where maintenance was not fully considered in the designing and building of the scheme, undertaking these maintenance tasks can be difficult or near impossible to complete while maintaining treatment of the mine water. For a fully passive scheme, flows to the scheme cannot be adjusted. In some cases partial treatment for a set amount of time can be agreed with the environmental regulator. In other cases temporary active treatment (such as chemical dosing) must be bought on site to ensure treatment is continued during the maintenance work.

When maintenance is considered during scheme design, operation of treatment schemes is easier and can be carried out whilst maintaining treatment. Incorporating the requirements for operation and maintenance of the treatment schemes is now central to our design philosophy. One of the key considerations is being able to isolate sections of the treatment scheme whilst maintaining full or partial treatment. Therefore modern schemes are now often designed with ‘treatment trains’ consisting of multiple smaller lagoons or reed beds running in parallel, allowing streams to be isolated for maintenance while maintaining treatment to an acceptable standard. For most maintenance work activities there is a requirement to bypass a lagoon or reed bed to take it offline. Where bypass channels are part of the scheme design this makes maintenance easier and more cost effective, as there is no requirement for over-pumping water.

Developments in sizing of treatment schemes

In 2003 Engineering Guidelines for passive remediation were published by the PIRAMID consortium (2003). This design guidance has formed the basis of many of the treatment schemes that have been built by the Coal Authority. The guidance for the treatment of iron-rich waters was largely based on areal removal rates drawn from the experiences at a limited number of North American treatment schemes, often treating more acidic mine water than is typical in the UK. Further understanding on sizing principles has been developed by the Coal Authority as we have studied how the built schemes in the UK operate under different conditions.

An example of a scheme built using the same principals as detailed in the PIRAMID guidelines is Acomb mine water treatment scheme in Northumberland. There was limited direct operational data available within the UK due to the small number of mine water treatment schemes in operation at the time. Acomb mine water treatment scheme was built in 2002 treating mine water discharged from an abandoned adit. The scheme initially consisted of a cascade, two lagoons that operate in parallel and two reed beds that operate in series (Figure 1). The mine water design parameters were net alkaline water with a flow rate of 13 L/sec and influent iron concentration of 50 mg/L. Availability of suitable land was a significant constraint for development of the scheme and so the provision of additional treatment area significantly beyond the minimum requirements was not possible.

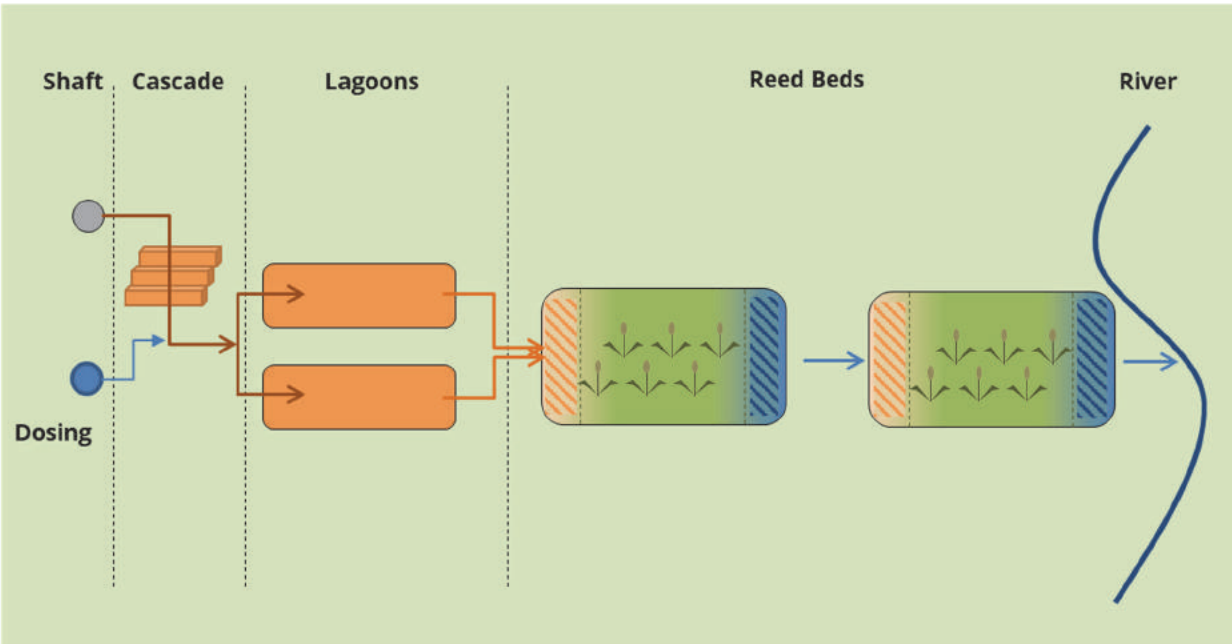

Figure 1: Simplified schematic of Acomb mine water treatment scheme

It was initially hoped the scheme would be able to treat the water as a purely pumped passive scheme. However, the scheme was found to be undersized and sufficient treatment was not possible passively. Therefore, a hydrogen peroxide dosing step was introduced within the first few years of operation. Addition of hydrogen peroxide ensures rapid oxidation of the mine water as it enters the lagoons and effectively increases residence time for the ochre particulates to begin settlement. This has ensured that the scheme has been able to maintain effective treatment of the mine water, but at significant additional operational cost.

In contrast, when the Craig yr Aber mine water treatment scheme, South Wales was constructed in 2015 there was a large amount of data on the operation of treatment schemes as the Coal Authority portfolio had increased in size. Data from across the operational schemes was used to calculate 'average' constant values for similar schemes (i.e. flow rate and iron concentration) using an in house sizing model based on the Tarutis *et. al*. (1999) method for sizing estimation. Like Acomb, suitable land availability was also a significant constraint at Craig yr Aber requiring the design to use minimum treatment areas only. A scheme with a combined area of 5700 m^2 was built in accordance with the minimum sizing outputs of the in-house model. Unlike at Acomb, the Craig yr Aber scheme had a treatment performance that was in-line with the improved model predictions and to date has required no support by chemical dosing, ensuring that operational costs were as expected and providing further confidence in the Coal Authority's treatment model.

The size of the scheme was also designed following the review of how other mine water treatment schemes were operating, identifying challenges in operation at other schemes. The scheme consists of a cascade, two lagoons in parallel and two reed beds in series (Figure 2). The design of this scheme allows the bypassing of each treatment step to enable treatment of the mine water to continue while maintenance is carried out eliminating the need for costly over-pumping.

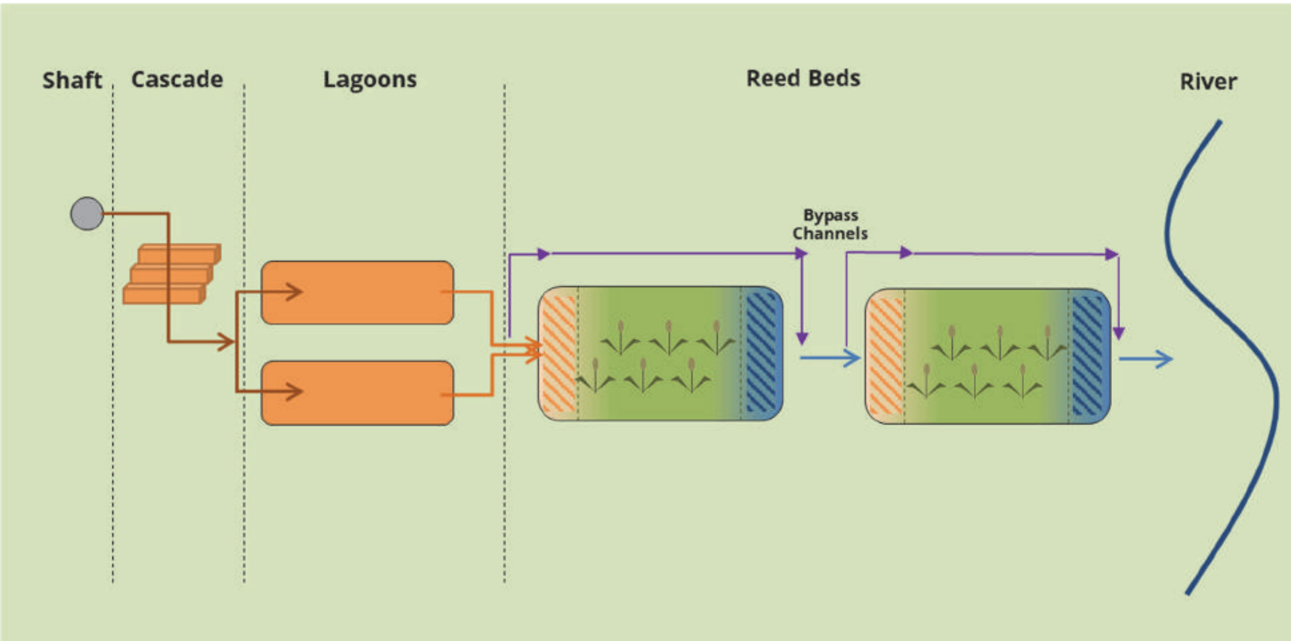

Figure 2: Simplified schematic of Craig yr Aber mine water treatment scheme

Improving scheme design

A number of improvements to our scheme designs are now underway to reduce operating costs and carbon footprint. For new schemes, these are considered during the design phase and incorporated early on. For our existing treatment schemes, these are considered during refurbishment works or where opportunities are specifically identified. Options can include considering the location of the site (to reduce water pumping costs), space for renewable opportunities, reducing the size of the scheme and construction material used.

For new and existing schemes, renewable energy options can be used to reduce energy costs. At Dawdon mine water treatment scheme, an active HDS system in County Durham, heat has been recovered from the mine water for the past 8 – 9 years and used to heat the building that houses the treatment system. We also have nine solar schemes in operation across eight mine water treatment schemes. These solar schemes are saving over £150,000 a year[1] by reducing the power taken from the National Grid and providing additional income through generation and export to the National Grid (Figure 3).

Figure 3: Bates mine water treatment scheme with solar farm (on the left of the image)

Across our schemes we are considering the construction materials that are being used and the potential environmental impact of our schemes. At Craig yr Aber mine water treatment scheme tyre bales were used in the construction of the lagoons and reed beds. The Coal Authority usually aims to achieve a cut/fill balance, reusing all materials on site. However the material present at Craig yr Aber was deemed unsuitable and the local artesian water pressure limited the depth of excavation, which meant material needed to be imported. Tyres bales were chosen as they are cost effective and provide an environmentally friendly option that reuses materials rather than sending them to landfill, and reduces the use of virgin materials.

We are currently investigating the use of baffles across our schemes to increase residence time within our lagoons. Tracer testing at Clough Foot mine water treatment scheme showed that the baffled lagoon had three times the retention time of the un-baffled lagoon, enabling more time for ochre to settle within lagoons. Installation of baffles may enable us to reduce the size of lagoons for future schemes or increase the treatment capacity at existing schemes.

Flow Prediction

Estimating flows required to manage mine water levels and prevent contamination of drinking water aquifers has been a key area of development over the last 20 years. Initially treatment flows were estimated using desk based modelling and short-term pumping tests (days/weeks/months). However the mine systems are often still changing, as water levels within workings continue to recover. In some instances this has led to building treatment schemes where water chemistry or required pumping rates have drastically changed compared to initial scheme design. An example of this is Bates mine water treatment scheme in Northumberland.

Bates was initially designed based on modelled flow rates and mine water chemistry, but with increased hydraulic capacity and with the option to add chemical dosing to the system if required. The design flow of the system was 76 L/s to control the mine water, with initial predicted iron concentrations of 55 mg/L, possibly rising to 100 mg/L. A passive treatment scheme was designed to treat 76 L/s of mine water at 55 mg/L of iron (iron loading of 361 kg/day).

[1] Total power generation was 1.4 million kWh

Bates was being built as a preventative treatment scheme and therefore the mine system wasn't stable before pumping started. The mine water continued to rise during operation of the mine water treatment scheme and the abstraction rate was doubled (76 L/s to 150 L/s) between 2003 and 2005. From 2005 to 2009, an abstraction rate of approximately 150 L/s was adequate to control the mine water level, significantly above the design flow of the constructed treatment system. The iron concentration within the raw mine water also showed an example of first-flush phenomena, with iron initially increasing from 25 to 76 mg/L. This is followed by a decrease in iron to 17 mg/L.

Today, the approach to building preventative schemes relies on monitoring of boreholes, longer duration pumping tests and phased building of schemes to eliminate issues such as those encountered at Bates. At Lynemouth, Northumberland, a treatment scheme has been built in two phases to allow the required pumping flow rates to be calculated more accurately. A first phase, consisting of two cascades and two lagoons in series, was completed in 2015. Operation of this scheme has enabled the long term monitoring of water levels within the mine workings and assessment of the effect of different pumping rates on these water levels. A new flow rate was then used as a basis for the design of a second phase, constructed in 2019. Operation of the first phase also helped in the design of Phase two of the scheme as the inlet iron concentrations could be more accurately predicted.

Prediction of mine water quality and flow rates has proven difficult within complex mine systems in the UK. Modelling of chemistry and mine water flows can provide generic instances of water quality (e.g. high-iron, low-iron, high-salinity). However, extra information from pumping tests and long-term monitoring is required to assess how the mine water changes as well as how the mine water treatment needs to be adapted to these changes.

Amenity and Biodiversity

Mine water treatment schemes exist to perform an important operational role but they can also be managed to provide valuable biodiversity and provide green space for access which is valued by local communities. They provide a rich habitat and their creation can support local and national biodiversity action plans. In 2019 we published our first Biodiversity and Resilience of Ecosystems report for the Welsh Minister for Environment, Energy and Rural Affairs.

Reed beds have been one of the habitats most impacted by habitat loss and it is estimated that there are currently only 5,000 ha of reed beds in the UK (Natural England and RSPB 2014). We have created 35 hectares of reed bed wetland habitat and will increase this as we build further schemes. Evidence from a 2018 PhD research project by a University of Nottingham on some of our sites concluded that biodiversity was similar on both natural and constructed wetlands (Marie Athorn 2018).

Further research was conducted as part of an undergraduate dissertation for Hull University in 2020 considering the bird population on two of our mine water schemes (Jaques 2020). The study identified 31 different species of birds including 4 on the red list and 8 on the amber list for birds of conservation concern (Eaton et al 2015). Other nationally rare animals and birds have also been spotted on our schemes including Marsh Harriers.

Our future biodiversity net gain strategy will include improving our understanding and publishing our evidence and monitoring data. There will be a need to work with other agencies to gain best benefits and this may require us to manage our sites differently and to vary our existing permissions.

Conclusions

The Coal Authority has over 20 years of experience in building, maintaining and operating coal mine water treatment schemes. This experience has led to developments in how schemes are designed, confidence in achieving treatment and changing the way that schemes are built.

Through years of data collection there is more confidence that scheme size estimates will be sufficient to achieve full treatment as shown in the design and operation of Craig yr Aber mine water treatment scheme. Using data from schemes with similar water chemistry allows better prediction of how a mine water treatment scheme will operate.

Scheme design has been developed to improve operation and maintain as well as reduce the carbon footprint of new schemes. This includes installing renewable energy to reduce pumping costs, considering alternative construction materials and investigating ways of increasing the residence time in lagoons (such as baffles).

Challenges in predicting flows in mine water systems that are yet to recover has led to a change in the way that treatment schemes are built. Some new schemes are built in phases to enable long term pumping tests to be carried out, ensuring the schemes are able to treat the mine water long term.

All of these developments in approach and design aid in making the mine water treatment schemes easier and more cost effective to operate, whilst still able to achieve required treatment standards and lower whole life costs.

Looking forwards we will also try to maximise the biodiversity, amenity and heritage benefits of our existing and planned mine water treatment schemes.

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GLENMUCKLOCH ENERGY PROJECT

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Abstract

The project, which will be built on a former opencast coal mining site at Glenmuckloch on the Dumfriesshire and Ayrshire border north of Kirkconnel, would see the development of an energy park, which would also hide the remaining traces on the landscape of previous mining activities.

In 2016, the Scottish Government gave consent for a pumped storage hydro scheme of 210MW on the Glenmuckloch site. Pumped storage hydro stores electricity in times of low demand and releases it on to the National Grid in peak demand periods, providing energy when required and also balancing local constraints on the electricity grid. The Glenmuckloch site already hosts two community-owned wind turbines and planning permission has been received from Dumfries and Galloway Council to build eight 3.2 MW turbines. Renewable energy offers great opportunities for the area and the combination of pumped storage and on-site wind generation are a very natural fit. Viewed together as an integrated system, they would act as a catalyst for economic growth and could form a central plank of a collaborative regional industrial strategy that would generate new jobs and economic growth.

Pumped storage hydro schemes already exist in Scotland but no new projects have been built in over 35 years. It is estimated that the Glenmuckloch project will cost circa £250 m to complete. Once completed, the pumped storage hydro scheme will help provide a means of balancing an energy system increasingly based on renewable energy sources, by storing power during periods of increased generation and releasing stored energy at times of peak demand. The project has the potential to be economically and environmentally transformational and may well provide a blueprint for addressing restoration issues on some of the other former mining sites. Furthermore, the project will demonstrate that the legacies of mineral extraction can present sustainability opportunities.

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THE CHANGING SOCIETAL AND ENVIRONMENTAL EXPECTATIONS: IMPLICATIONS AND IMPACTS FOR THE MINING INDUSTRY

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In today's world there is evermore focus and increasing societal expectation that we pay greater attention to a sustainable future, the circular economy and the environmental effects on our climate. Although our mining and quarrying history is steeped in the industrial successes of providing energy, commodities and vital mineral resources serving cosmopolitan needs, in today's society we must continuously strive for ecological and environmental excellence. Recent MPA reports[1], suggest the current economic values to be as much as 16% of the UK's national economy. With a £15Bn direct turnover and £5Bn Gross Value Added (GVA), culminating in £235Bn GVA when extended to production, manufacturing and other direct markets and it is vitally important. However, the consequences and legacies of mineral extraction and utilisation are the unwanted side-effects of pollution, emissions and waste. Moral obligations, intense societal scrutiny, increasing environmental awareness and ever-changing legislation, means we have to look to the future and determine a path to cleaner and more efficient solutions to these challenges.

Even with state-of-the-art technology and sophisticated engine and exhaust management arrangements integral to modern combustion engines, this is not enough to reduce the known health risks and environmental outputs needed to satisfy the global challenges and targets towards and beyond net zero emissions. As an industry, we have to shape the future, look for and design solutions (as we always have) embracing change towards the increased use of electrically and alternate sources of powered vehicles and the provision of sustainable energy; to minimise the impacts on the population, our workforce and the environment and becoming more efficient and productive.

Recent directives and legislative changes setting lower diesel exhaust emissions, mean we have to accelerate our efforts, act quickly and transition as cost effectively as possible to cleaner modern society demands and expectations. We will have to consider the challenges and impacts, that may arise as a consequence of adopting new technologies and different methods of working.

Mining - benefits to the economy

As described in the annual business survey provisional results for 2018 [2], the approximate gross value added (aGVA) to the UK non-financial business economy was estimated to be £1,285.5 billion. This was an increase of £59.6 billion (4.9%) for the year.

The level of aGVA increased within each of the four main sectors of the economy namely: Production, Construction, Distribution and Non-financial services. The two main components are turnover (income) and purchases, turnover increased by £226.0 billion (5.9%) and purchases increased by £166.6 billion (6.5%). As such the rise in turnover compared to purchases resulted in the gross £59.6 billion increase for the year.

All four of the sectors showed growth in both turnover and purchases, with Distribution experiencing the largest increase of £103.7 billion (7.2%) in income and £94.9 billion (7.8%) in purchases.

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[1] https://www.imeche.org/news/news-article/mineral-extraction-industry-vital-to-uk-economy

[2] https://www.ons.gov.uk/businessindustryandtrade/business/businessservices/methodologies/annualbusinesssurveyabs

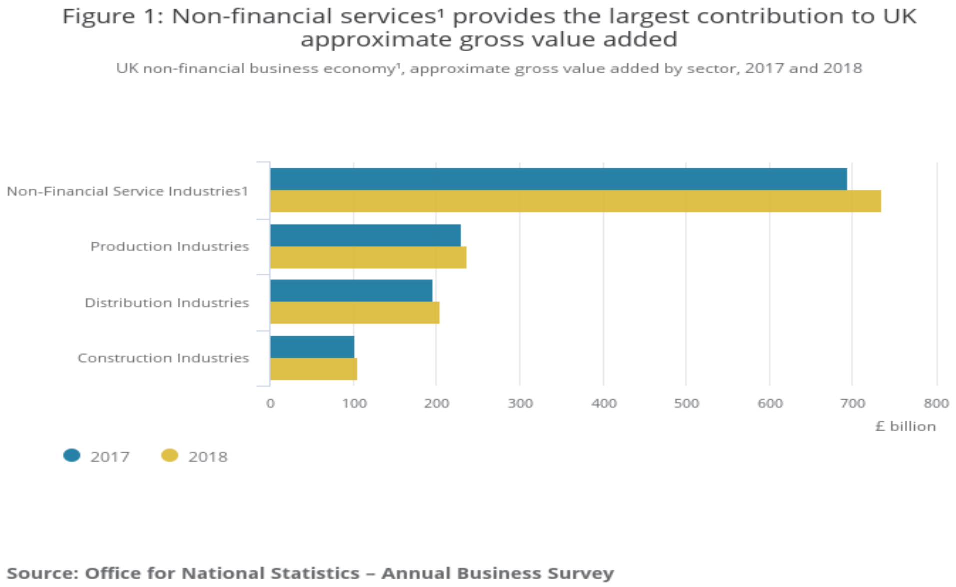

Figure 1: ONS Annual Business Survey

Figure 1 shows that the Non-Financial Services Industries sector was the largest component of the UK non-financial business economy, accounting for £736.0 billion in 2018 (57.3%). This was an increase of £41.2 billion (5.9%) in comparison to 2017.

Extractive industries (Production Industries sector) encompasses mining and quarrying, including oil and gas production. The sector as a whole has made sizeable contributions to the UK economy for many years and remains vitally important, by direct contributions and by supporting substantial added value in the downstream industries and related supply chains.

The largest economic contribution comes predominantly from oil and gas production and in 2018, the total UK extractive industry gross value added (GVA) is estimated to have been a turnover of £20.1 billion. While manufacturing provided the largest contribution, mining and quarrying showed the largest percentage growth, rising by 16.8% year-on-year. This was mainly due to the extraction of crude petroleum and natural gas, which increased by £2.9 billion (23.6%).

Health & Safety Costs

Alongside the benefits from production and extraction industries, there are also downsides and resulting financial costs, not least, the severe impacts on our health, safety and wellbeing that are a direct consequence from workplace activities that result in ill-health and injuries. By the end of 2018/19 work year in Britain, 581,000 workers sustained a non-fatal injury, 4.7 million working days were estimated to have been lost due to nonfatal workplace injuries, 1.4 million workers suffered from work-related ill health (new or long-standing) and 497,000 workers suffered from a new case of work-related ill health, in turn causing 23.5 million working days lost due to work-related ill health. (Labour Force Survey 2018/19) [3]. Also, tragically in 2018/19, 147 workers lost their lives in Britain and there were13,000 deaths estimated to be linked to past exposure at work, primarily due to chemicals or dust.

Whilst Britain is consistently amongst the lowest standardised injury rate figures in Europe (and the lowest number of fatal injuries), these human costs are stark and sobering. The untold pain, grief, suffering and loss of life alone must drive societal change. The monetary valuation given to this suffering is represented in **Figure 2,** it shows this as a total annual cost of £15.0 billion for work related injuries and new cases of ill health, borne by Employers at £3 billion, Government at £3.4

[3] https://www.hse.gov.uk/statistics

billion and Individuals at £8.6 billion (based on 2017/18 and excluding long latency illness such as cancer).

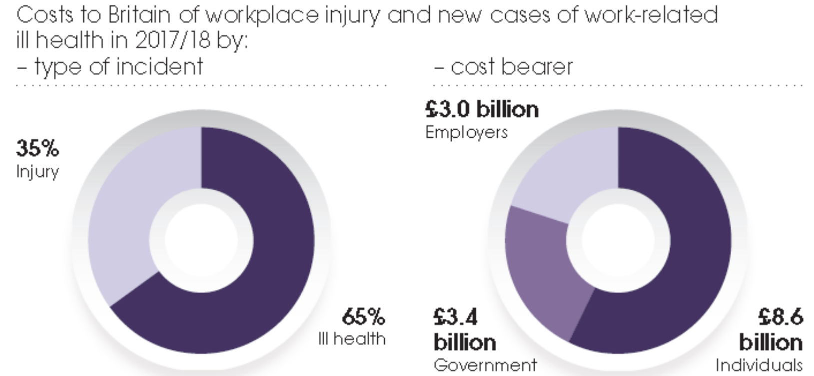

Figure 2: Health & Safety Executive - Annual Statistics Report

Mining Impacts and Implications

On 16th January 2019, exposure limits for Diesel Engine Exhaust Emissions (DEEE) were added to the carcinogen listing for chemical agents for the first time, with implementation required by 2023 [4].

From 21st February 2026, DEEE limits in Mining and Tunnelling will be 0.05 mg/m^3 (measured as Elemental Carbon [EC]). This will mean that operators will have to make some key decisions around their operating models, capital expenditure and vehicle fleets and invest for the future accordingly. Obviously, this was not a surprise to the Production and Extractive Industries sector and continuous improvements to emissions, maintenance and testing regimes are already an integral part of day to day operations. However, these tighter limits could lead to operators replacing older diesel fleets with modern engine vehicles and hybrid variants, or operators even deciding to make the switch and transition to electrical / battery powered vehicles or hybrid combinations.

This is not new technology to the Mining and Tunnelling Industry, as electrically and battery powered equipment is long established and integrated already into operating models and methodology. For example, in 1905 two battery powered locomotives were used on the Great Northern and Piccadilly underground lines. Electrical and diesel locomotives were introduced for underground operation in coal mines in the early 1930s, but their use did not become widespread until after the 1939-1945 war. The first diesel powered locomotive with a flameproof engine was introduced in 1939 following its approval by the Mines Department in conjunction with the Safety in Mines Research Board.

Following nationalisation of the coal industry in 1947 the use of locomotives spread rapidly, doubling in the first year and after 10 years the numbers in use had increased from 90 to 906. In the early years' locomotives were used on existing haulage roadways for transporting supplies, personnel and minerals and materials in and out of the mine. Post nationalisation, construction and reconstruction often involved the horizon mining principle, in which locomotive haulage roadways were driven at gradients of 1 in 400 or 500 (0.25% or 0.20%) in favour of the load. Since the 1970s, rubber tyre battery locomotives then progressively extended to other parts of the mine and to roadways with variable gradients up to the maximum permitted (1 in 10 - rubber tyre) for the particular form of traction and were widespread in use.

Cutting, drilling, bolting and loading operations underground have primarily and for many years, been electrically powered and very successful, but mineral and waste transportation has largely been done either by electrically powered conveyors or diesel-powered vehicles / locomotives because of the energy capacities involved. Current developments and technology improvements and advances though have led to a shift away from diesel vehicles with their exhaust emission and occupational health constraints, to the more extensive use of battery powered and hydrogen powered vehicles. It is probably inevitable that this shift will continue to expand and further displace diesel-engine vehicles, as the major mining and tunnelling equipment suppliers have invested in modern smoother, quieter

[4] https://osha.europa.eu/en/legislation/directive/directive-200437ec-carcinogens-or-mutagens-work

running, efficient battery vehicle solutions and capacity improvements across the sector to give viable options for change with improved occupational health benefits. This change and transition will have to be managed and will need more resources to be mined (and recycled) such as Lithium, Cobalt and Nickel. The expansion in demand for raw materials should provide opportunities for future mining operations to be developed.

In London alone there are currently a total of 165 zero emission buses, with a further 68 electric double decker buses recently added to make it Europe’s largest fleet. London has committed to procuring about 2,000 zero emission buses by 2025 in total in the fleet.

As part of the Mayor's Transport Strategy, Transport for London (TfL) committed to using only the cleanest buses. Ten Low Emission Bus Zones have been introduced, reducing harmful NOx emissions by approximately 90 per cent on some of the capital's busiest roads.

All the buses in the Ultra-Low Emission Zone and 75 per cent of the entire bus fleet already meet the standards, with all buses set to have been upgraded by October 2020. This will make the whole city a Low Emission Bus Zone. Greening transport in the capital will require using a range of clean power sources. Hydrogen buses can for example store more energy on board than equivalent buses, meaning they can be deployed on longer routes. They only need to be refuelled once a day for five minutes, making them much quicker to power up when compared with conventional battery-electric buses.

This is just a small part of the necessary changes seen in one global capital city to meet net zero commitments by 2050 and potentially has far reaching effects across the rest of the world as it leads by example.

Conclusions

In summary there are many benefits to securing these socially licensed changes, both societally and more specifically within the extractive and production industries sector, including in meeting enforced regulatory compliance to the upcoming legal changes and towards a sustainable future. Cleaner, cooler, quieter running and more efficient energy and power sources lead to improved Occupational Health outcomes for the workforce, including reducing long latency impacts, reduced whole-body vibration effects, reduced musculoskeletal disorders and reduced subsequent cost impacts.

The inevitable transition to these newer energy forms, vehicle power sources and ways of working will take time, have to be structured, need capital investment and bring new and different challenges and outcomes, within the extractive and production industry sectors and more widely, for the benefit of future generations.

BREATHING NEW LIFE INTO ABANDONED MINES: THE ROBOMINERS PROJECT

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Abstract

ROBOMINERS[1] is a European Union Horizon2020 collaborative research and innovation funded project (14 organisations from 11 countries) to develop bio-inspired robotic systems that can be used to reopen underground mines which still contain potentially economic minerals. The primary motivation is to secure future sources of important mineral raw materials for European industry.

The project's objectives include

- Constructing a fully functional modular robot miner prototype following a bio-inspired design, capable of operating, navigating, and selective mining in an underground environment
- Designing a mining ecosystem of expected future upstream/downstream raw materials processes via simulations, modelling and virtual prototyping
- Validating all key functions of the robot-miner to Technology Readiness Level (TRL) 4 - ie demonstration of capabilities, not a fully commercial working system
- Using the prototypes to study and advance future research challenges concerning scalability, resilience, re-configurability, self-repair, collective behaviour, operation in harsh environments, selective mining, and production methods as well as for the necessary convergent technologies required for an overall mining ecosystem.

The innovative ROBOMINERS approach combines the creation of a new mining ecosystem with novel ideas from other sectors, in particular with the inclusion of disruptive concepts from robotics. Potential use of the robot miner will be especially relevant for mineral deposits that are small or difficult to access. This includes both abandoned mines that are no longer accessible (or safe) for conventional mining techniques, and deposits that have been explored but whose exploitation has been considered uneconomic because they are too small or too difficult to access. This paper is concerned primarily with applications to abandoned mines, and these are the scenarios in which the prototypes will be tested.

Introduction

There are two main phases in breathing new life into an abandoned mine. The first is to determine whether there is anything worth the cost of exploitation - the second is actually reopening the mine.

Many - maybe most - abandoned underground mines are flooded to water table level, which commonly is the level of their deepest drainage adit. Exploring the potential of these mines requires

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[1] https://robominers.eu/

either very expensive de-watering and potentially dangerous examination by mining engineers and geologists, or investigation by human divers if not too deep, or using remotely operated submersibles carrying a range of instrumentation including cameras, sonar, and laser profilers. An example of such an investigation is described by Barnatt et al. (2021: this conference), using submersible robots developed specifically for this purpose in the EU Horizon2020 UNEXMIN project, and its successor project UNEXUP part-funded by EIT Raw Materials.

If new mineral potential is identified and confirmed by more traditional methods such as drilling from surface, the next stage is de-watering. This can leave mines in an unknown and often dangerous state, after maybe a century or more of degradation of their infrastructure and collapse of parts of the workings.

In old - pre-20th century - mines, extraction was generally by manual methods, and mine openings tend to be limited to the scale of the deposit, thus in narrow-vein deposits typical of many metal mines in the UK, reopening for extraction by mechanical methods, requiring much larger openings, would produce a large proportion of waste, reducing the average mineral grade and impacting the economics of the operation. However, using labour-intensive manual methods would also be uneconomic, as well as being potentially hazardous for the miners: 21st century safety regulations did not apply in the 18th and 19th centuries.

A clear solution to these problems would be to develop a new mining paradigm based on robotics, with small remote-controlled or autonomous mining units able to exploit such deposits with little or no production of waste rock, and no need for human access to an environment with possible and unknown hazards. It is also an advantage if the slow and expensive de-watering process can be avoided. This is the concept that is being developed in the multi-national ROBOMINERS project[2]. The project brings roboticists and geoscientists together to create a small robot-miner prototype as part of a robotic 'ecosystem' for mining difficult to access mineral deposits, which can change the current mining paradigm dominated by humans and conventional large machines.

Drivers

ROBOMINERS offers a solution to wider problems related to assuring sustainable supply of mineral raw materials across the European Union, especially addressing the second pillar of the EU Raw Materials Initiative, which is securing supplies from domestic sources. The ROBOMINERS concept has been constructed based on a number of drivers:

- European dependency on the import of mineral raw materials, especially minerals deemed as critical[3];
- a need to follow EU policy on raw materials, supporting the exploration, re-exploration and mining of resources that were economically or technologically infeasible in the past, or not exploited for other reasons;
- fostering innovation for the mining industry through the entire value chain, including downstream and upstream processes;
- maintenance of the EU's leading position on innovation, especially in the METS (mining equipment, technology and services) and robotics sectors;
- the possibility of technology transfer to other sectors (eg potential for ROBOMINERS-derived applications in space exploration or disaster relief).

The ROBOMINERS vision allows for the reopening of abandoned underground mines, without the need for a full re-commissioning, and minimising workers' exposure to hazards while drastically reducing environmental footprints. As many of them still have valuable amounts of mineral resources ready to be exploited, it will be possible to resume mining exactly where it was abandoned in the past and turn the mine into a profitable business, with reduced environmental footprint and a more socially acceptable operation than could be achieved conventionally. Through design modularity with exchangeability of sensors and tools, the concept is applicable equally to dry, wet (ie with mud or shallow water in the operating mine sections), or flooded mine environments.

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[2] EU Horizon 2020 ROBOMINERS project, grant agreement no. 820971, https://robominers.eu

[3] https://ec.europa.eu/growth/sectors/raw-materials/specific-interest/critical_en

Moreover, though beyond the scope of this paper, it could be a modern and revolutionary solution for extraction of small but high-grade and ultra-depth mineral deposits which are currently uneconomic. The ROMOMINERS approach eliminates the need for developing typical mining infrastructures on the surface, and minimises or even eliminates the need for dumping waste materials at surface.

Objectives and impacts

The ROBOMINERS project consortium has set several goals and targets to determine the success of the project and the approach:

- construction of a fully functional, modular, robot-miner prototype based on a bio-inspired design. The robot will be capable of operating, navigating and performing selective mining in different mining environments;
- design of a new mining system, based on future expected upstream/downstream raw materials processes via simulations, modelling and virtual prototyping;
- validation and demonstration of all key functions of the robot-miner to TRL-4, with the possibility of some components reaching TRL-5, validated in the laboratory and a relevant environment, respectively;
- use of the robot-miner prototype to help in shaping future research programmes on scalability, resilience, re-configurability, robot swarm behaviour, selective mining, production tools and methods.

Linked to these objectives, ROBOMINERS envisages positive impacts in the economy, further research and development in raw materials, social and environmental areas. More specifically, the following potential impacts have been identified:

- creating new exploration scenarios for Europe's domestic mineral resources based on exploitation of any remaining reserves regardless of the size and geometry of the deposit. Reduction in the size of excavations, such as galleries and shafts, improves economic viability which in turn may allow exploitation of smaller deposits;
- positive economic impact in many regions where the potential for developing mining activities exists, fostering competitiveness within the EU minerals industry;
- addressing many of the environmental and social concerns that are associated with conventional mining: smaller underground mines can be made practically "invisible";
- creating potential for research, innovation, new technology and business development, not just in mining, but also in other applications where the use of resilient modular robotics could be important, such as in disaster relief or space research as mentioned above.

In comparison with conventional mining methods and tools, the ROBOMINERS vision shows the following, specific, advantages: 1) no personnel in the mine; 2) less mining waste; 3) reduction of mining infrastructure, earthworks and access routes; 4) cheaper capital cost and quicker set up; 5) reduction in mine rehabilitation problems; 6) known but currently uneconomic resources can also be targeted.

Conventional mining is still based on humans operating in the mine environment, with only limited uptake of robotics in exploration, exploitation and processing. Mining occurs either at surface or underground, sometimes in very challenging conditions (e.g., high temperature, deep, remote locations, extraction below water-bearing horizons, and in physically unstable or toxic geological environments). Moreover, in Europe, there are often significant regulatory obstacles to mining as it is widely seen to cause unacceptable surface disturbance and may be prohibited altogether in urban or environmentally sensitive areas. The ROBOMINERS approach to mining replaces conventional mining scenarios which often become uneconomical, technologically infeasible or too dangerous for workers, leading to mine closure. ROBOMINERS could offer a solution to these problems, requiring much lower levels of financing and unlocking new or renewed mining potential in many areas.

The ROBOMINERS mining system

To access a mine, if a suitable shaft or adit does not already exist or cannot safely be used, a borehole needs to be drilled from the surface, large enough for the robot components to pass through (Figure 1). The different modules are then self-assembled underground to make the robot-miner and other service robots as needed. The robot-miner will have high power density, using rechargeable on-board batteries or a power supply cable from surface. Navigation, 'awareness', and sensing are provided by a range of novel body sensors that merge data in real-time with production sensors, allowing optimisation of production rate and selection between different production methods. Depending on the production rate, a generated mineral slurry is passed to a pre-concentrator robot underground, and high-grade slurry pumped to the surface for final processing. The tailings can then be returned to the mine to backfill mined-out areas, together with waste from the pre-concentrator robot.

The ROBOMINERS concept of exploitation calls for a new approach to mining strategy and mine design. The common definition of “mine” (understood as a mining operation with extensive surface and/or underground infrastructure) will change. There will be a new mine environment, where mines are designed as an artificial “ecosystem” with no need for underground human life support nor development of extensive underground or surface infrastructure. This brings health, safety and environmental benefits: tunnels and shafts are minimised in numbers, length and volume. The production of waste rock is also minimised by selective mining and back-filling. With underground pre-processing of the minerals in a mined slurry, the volume of material to be lifted to the surface is also reduced.

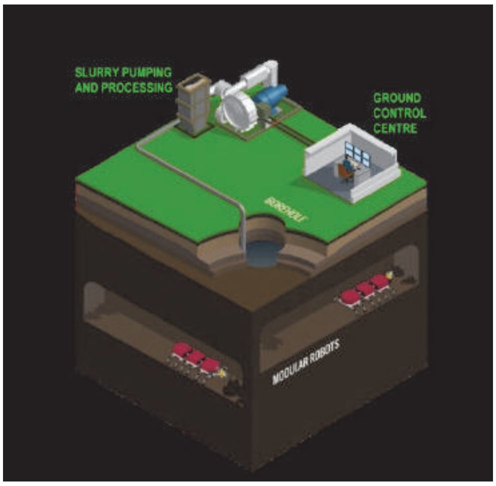

Figure 1: Illustration of the ROBOMINERS concept showing the main elements

The robot-miner

The robot-miner concept needs to be adaptable to the environments in which it will operate. The structure, tools and methods used by the robot are designed to work underground, in dry, wet, or flooded environments, to allow manoeuvrability in 3 dimensions, with different cutting and auxiliary tools, and with exchangeable sensors (applicable in the various operating environments) and artificial intelligence to allow a degree of autonomy. The miner is currently envisaged to have around 1 tonne body weight, with 20-30kW of power capacity, using hydraulic tools where appropriate, and will be attached to an umbilical cable (until the concept is proven). The size of the robot is optimised to allow precision mining, so that it will occupy a different niche to conventional mining machines. From the mining perspective, the robot-miner can be considered small and light, but from the robotics perspective it can be considered as a bigger and much heavier robot than usual (Figure 2).

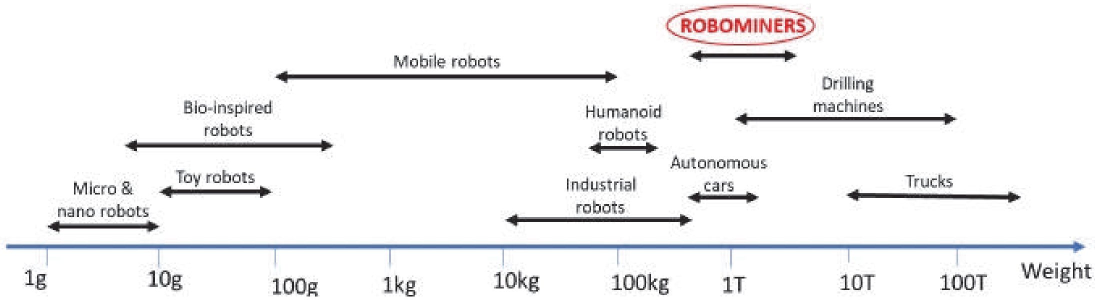

Figure 2: Weight comparison of different robotic systems and mining equipment. The robot-miner lies in the 1 Tonne range, heavier than most common robots, but lighter than most conventional mining equipment

The design and construction of the robot-miner is based on seven principles that together can deliver a complete mining machine:

I. biological inspiration for the robot design: design of the robot-miner takes inspiration from animals that perform in similar conditions. Robots developed by ROBOMINERS will be inspired by legged burrowing insects, with the purpose of emulating their superior underground locomotion capabilities. Some examples include centipede, mole cricket and termites (Figure 3).

Figure 3: Animals as bio-inspiration for the robot-miner concept (centipede, mole cricket and termite)

II. underground perception and localisation: simple but robust perception and localization in underground spaces is required for the robot-miner to operate, as GPS does not work and traditional sensors (e.g. sonar, lidar) are not sufficiently reliable for accurate location in a noisy and potentially dusty or foggy environment underground. Some types of sensor work better above water, others better submerged, in clear or turbid water. To solve this problem, the project will study tactile sensing (seen in some animals), conductivity and flow sensing, and sensing relying on inertial movement, temperature, pressure and other parameters, as well as SLAM (simultaneous localisation and mapping) intelligent software solutions using some or all of the sensor data. The best sensors will be integrated into the prototype.

III. behaviour, navigation and control: navigation and robot control underground will follow the best practices seen in robotics nowadays. One example includes the use of simple behavioural approaches that can be coupled with previous maps of the mines (where these exist), which can reduce uncertainty in decision making processes.

IV. heavy-duty actuation methods: the aim is to employ hydrostatic drive-trains, using either water or oil-based pressure media. This is a well-tried technically feasible solution and offers numerous benefits in terms of improved power density and reduced system volume.

V. modularity: this is a crucial feature of the future miner. The idea is to make it possible to deliver the robot in pieces to the working area through small openings. Reconfigurability will allow fault tolerance and flexibility to adapt the robot's size, power output and reach to a wide range of geological scenarios using standardised components, while alternative replaceable components will provide the same functionality (sensing, mining, analysis, etc) for different mine environments.

VI. autonomy and resilience: The robot's resilience will be shown in four ways, 1) redundancy, 2) physical reconfiguration of individual robots, 3) adaptive behaviour and 4) system reconfiguration. Modularity will make a big contribution. Full autonomy for the system will be studied, but the aim is to have the system work with a degree of autonomy that allows it to perform its tasks without detailed human control. However, during the project, the prototype robot-miner will be developed with an umbilical cable for technical and safety reasons.

VII. selective mining ability: another important feature will be the robot's ability for selective real-time mining. The aim will be to 1) adapt existing methods and sensor strategies and 2) develop new methods that will allow the robot to differentiate between ore and waste rock. The perception sensors will allow the robot-miner to do selective mining by: 1) sensing and following main mineralization directions; 2) applying the concept of "digestive mineralogy", by continuously sampling material produced at the rock face; and 3) dynamic selection and optimization of production tools. Instrumentation strategies for in-stream elemental analysis include high sensitivity solid state XRF[4] spectrometer / LIBS[5] spectrometer and gamma-ray spectrometer, while for molecular analysis can include optical UV-VIS-NIR[6] techniques. Selective mining implies also a more flexible approach to mine layout design. Bio-inspired exploitation strategies (such as worm feeding patterns as seen in some trace fossils), some usable though others impracticable, will be supplemented by simple methods of optimising the extraction of irregular ore deposits (Figure 4).

The robot-miner is currently under design and development, while tools and methods are already being tested with some already selected for inclusion in the future prototype. Laboratory testing is to be followed by real-life on-site tests.

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[4] XRF = X-ray fluorescence spectrometry
[5] LIBS = Laser induced breakdown spectrometry
[6] UV-VIS-NIR = Ultraviolet-visible-near infrared optical spectrometry

Mining scenarios

ROBOMINERS technology can be useful to mine all main types of ore deposits, including magmatic, hydrothermal and sedimentary deposits (Hartai et al., 2020). Targets can include pegmatites, hydrothermal veins, carbonatites, orogenic gold or volcanogenic massive sulphides. The minerals of interest to be extracted include precious metals such as gold, silver and platinum, base metals like copper, iron and nickel, and others, including rare earth elements, lithium, graphite and more. The common factor is that the minerals are of intrinsically high value. Bulk construction and industrial mineral production is not envisaged as an appropriate target.

Abandoned (and operating) mines or sections with known remaining resources are of particular interest. ROBOMINERS presents a solution for reopening many of Europe's abandoned underground mines. The closure of these mines was commonly related to economic and technological challenges (e.g. dewatering costs or collapse of workings) rather than to depletion of mineral resources. There are many thousands of such mines across Europe. These include a large number of metal mines in the UK, with hundreds to thousands of mines in the Cornwall/Devon region alone (Dines, 1956). With the ROBOMINERS concept, perhaps it will be feasible to resume mineral extraction in some of these mines, without major preparatory works.

New mining of small but high-grade mineral deposits and unexplored or explored, hitherto uneconomic, occurrences and ultra depth, inaccessible and hazardous environments are also key targets for the ROBOMINERS technology but are not considered further in this paper.

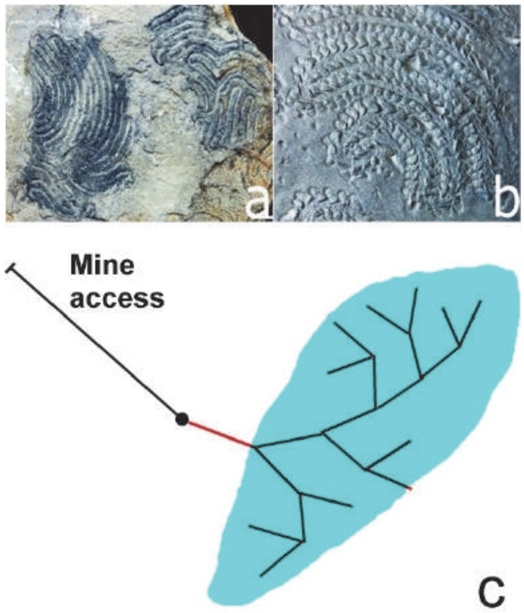

Figure 4: Bio-inspired feeding patterns (a, b) and a new approach (c) to mine layouts for accessing irregular ore deposits, with short drives to minimise cable and slurry pipe lengths

Technology

Different application environments will require different approaches from the robot-miner. This is one of the main reasons for its design to be modular. The possibility of performing different tasks will make the miner adaptable to a range of different conditions. Some of the identified technology needs for mining different mineral deposit types include (Hartai et al., 2020):

- ability to move in different directions coupled with directional drilling (cm to m ahead)
- selection from a set of rock fragmentation and mining production units (cutting / explosive / cavitation / LIBS / water-jet / percussion drilling /...)
- real-time chemical and mineralogical analysis
- first-stage mineral processing to separate a concentrate feed from waste rock
- slurry pumping system to bring mineral concentrates to an underground pre-concentrator robot and thence to surface, and waste rock slurry to backfill in already mined areas
- rock-bolting or other tunnel stabilisation system to maintain structural integrity of the mine
- sensor support such as video camera(s) for hazard detection and for remote control where necessary
- battery recharge system

Future vision

During the project lifetime – up to 2023 – research and development will be based on the robot-miner itself and the mining system, driven by future visions and goals for 2030 and 2050. Efforts correspond to incremental steps in the transfer from design to laboratory to field testing to commercial application (with correspondingly higher TRL levels). Figure 5 summarises the work to be carried out during the project, as well as highlighting also the expected evolution of this technology by 2030 and 2050.

ROBOMINERS development is also driven by current and future trends in mining and robotics related fields and assessed through a continuous foresight process, which includes expert consultation, horizon scanning and roadmapping. Together, these will guarantee that development and ultimately, the vision, of the robot-miner and supporting technology can be tailored to real-life changing conditions.

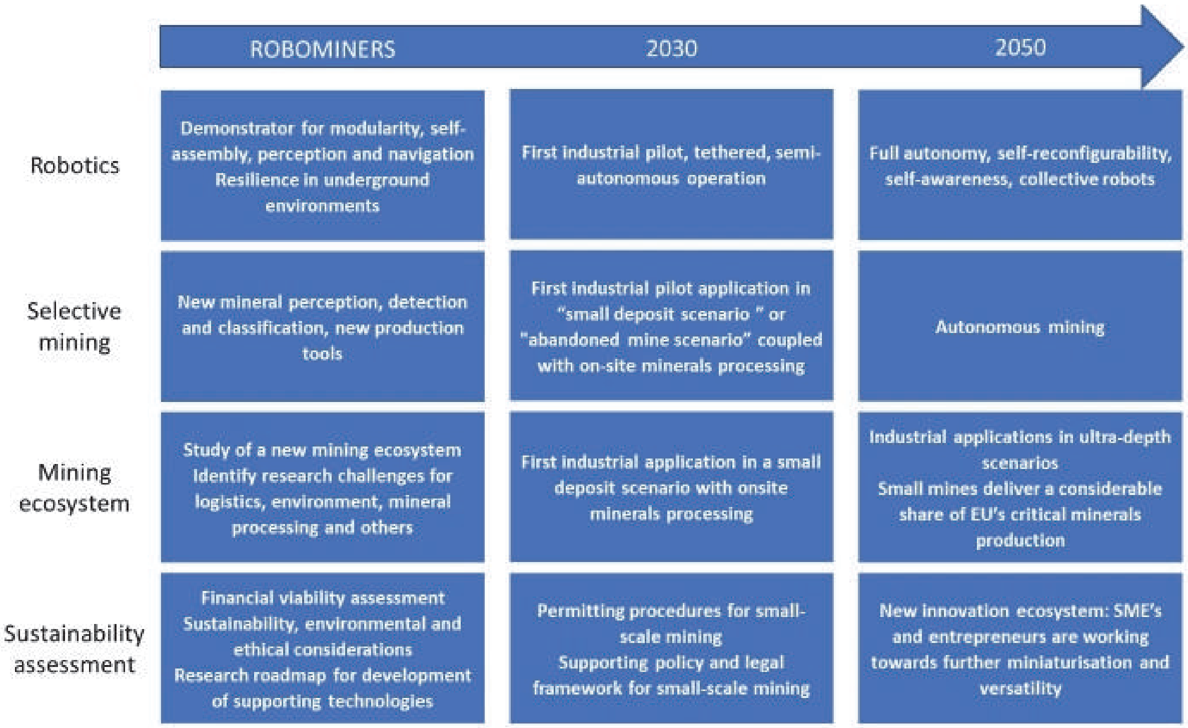

Figure 5: ROBOMINERS 'foresight' visions for the future to 2030 and 2050

Conclusions

The ROBOMINERS project is developing 'proof of concept' technology to exploit small and difficult to access mineral deposits, in a niche where conventional mining cannot operate economically. The vision of ROBOMINERS entails a new mining perspective based on state-of-the-art robotics and mining related technologies, that, when linked, will make mining of specific deposits economically viable while supporting better environmental practices and social acceptance for the mining industry. Definition and design of the systems has started and is driven by 2030 and 2050 targets identified by the ROBOMINERS project. The ROBOMINERS technology will not be a robotic exploitation machine alone; instead, the whole production cycle should undergo serious modifications, creating not merely an upgrade of old established technologies, but a revolutionary new approach. It may be a powerful tool for the resource management industries of tomorrow or even in the more distant future.

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Disclaimer

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THE COAL AUTHORITY'S ROLE IN FACILITATING REDEVELOPMENT OF SITES IMPACTED BY COAL MINING AND THE PROMOTION OF A SAFE, ASSURED AND SUSTAINABLE FUTURE.

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Abstract

The Coal Authority as a statutory body is tasked by BEIS, its sponsoring department, to bring forward and help implement the UK's Growth Strategy. By communicating risks, opening access to its data, improved regulation and publishing best practice guidance, it now equips developers and their advisors, better than ever before, to manage sites impacted by mining legacy.

This paper presents a summary of this work illustrating through recent examples how the Coal Authority's role has shaped research, driven innovation, and by statistics and outcomes, realised intended benefits.

The first study demonstrates how the Coal Authority's new pre-application advice service (PAS) has provided greater financial and technical certainty to two contrasting developments near Newcastle. In the first case a proposed retail park, the PAS provided reassurance to the consultant and developer, during the construction period, after unforeseen complications arose whilst remediating former mine workings. In the second case, the landowner's consultant, through engagement with the PAS, used mining abandonment plans to demonstrate that the remediation of shallow mine workings was not required for a residential development. This resulted in the cost of such remedial works being reapportioned back to the land value and provided the purchasing developer assurance that a planning objection would not be raised on account of that decision.

The second study documents the Coal Authority's own work dealing with a recent significant subsidence event affecting a site in North Tyneside, the sites remediation to a safe and stable condition, the demonstration of that condition, and as landowner, the bringing of the site back into use. Both the elimination of blight and the technical lessons learnt are discussed.

Creating a rich and diverse low carbon energy mix for the future is key to the country's commercial and economic/financial success and to meet carbon reduction targets. The third study examines the potential for society to take advantage of mine water heat recovery as a low-cost deliverable energy alternative in former mining areas by reference to the future South Seaham Garden Village development, Co Durham. The challenges of making schemes both sustainable and economically viable are explored along with the Coal Authority's monitoring network, development of potential resource maps and continuing research.

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Brownfield regeneration a brief background

The policy landscape for brownfield development has changed significantly since the advent of the Coal Authority in 1994. During this time, Government involvement has passed from leading brownfield regeneration by direct funding of agencies such as English Partnerships and Regional Development Agencies, to delivery intervention and private sector incentivisation and enablement by successor bodies, the Homes and Community Agency and since January 2018 by replacement body, Homes England.

The publication of the National Planning Policy Framework, 2012, consolidated and simplified planning guidance in an effort to streamline the planning process and support the development sector. In 2017 legislation (The Town and County Planning (Brownfield Land Register) Regulations 2017) was put in place requiring local planning authorities to prepare, maintain and publish registers of previously developed land, to promote regeneration and support sustainable development. The effects of devolution have introduced some variation, at national and local level, in how the brownfield agenda is implemented, although the overall aim is the same.

The 2017 Industrial Strategy, published by the Department for Business, Energy and Industrial Strategy (BEIS)) noted that its key policies were; ideas, people, infrastructure, business environment and places.
The government agendas for growth and sustainability resulted in the focus being to bring forward research, innovation and initiatives for practical adoption within the industry.

The examples presented in this paper demonstrate how the Coal Authority, an organisation sponsored by BEIS, contributes to the wider implementation strategy to help realise sustainability, economic growth and investment in former mining areas.

General issues

There are huge practical barriers to the realisation of any policy. Research into construction by the industry-led and Institution of Civil Engineers backed Get It Right Initiative (GIRI) [1] revealed that the cost attributable to avoidable errors alone equated to 21% or £21 billion per annum in the UK. The importance of pitching communications that are appropriate to the recipient has never been greater, both to the public to manage perceptions but also the customer, as a risk or uncertainty identified and reported by a consultant does not necessarily mean that it has been acknowledged, accepted and its implications understood by the client.

Management of risk remains a problem, despite recent contractual frameworks embodying early contractor/consultant involvement (ECI). They are not always adopted or followed. Concerns over complacency and the quality of ground investigation data, sampling & reporting are reoccurring, as is the lack of wholesale adoption of the Eurocode Standards to which the BSI are committed irrespective of Brexit. Savings and the overarching policies and initiatives attempting to realise them are being obstructed by commercialisation of data, data solutions and lack of software interoperability. Also, this is from the ownership of that data and realisation of its value through the inability to reuse it. The Coal Authority has licenced data for commercial companies to produce mining reports and related products, and made essential data for risk assessment freely available on-line [2].

Not in the cases mentioned here, but industry wide, the Coal Authority sees a wide and disconcerting variation in the quality of designs submitted to us, particularly for engineering appraisal.
This is despite the publication of improved technical guidance.

The Coal Authority and the planning system

For over ten years the Coal Authority has provided bespoke responses to local planning authorities on planning consultations for development in the defined Development High Risk areas (DHRA's) across England, Wales and Scotland. As a Statutory Consultee in the planning process the Coal Authority's role is as advisor to the local authority, prior to a planning decision being made, on issues of land instability, insofar as they relate to past coal mining activity. It is recognised that not all planning applications require our input and on this basis an exemptions[3] list is published and regularly updated.

The 181 local authorities the Coal Authority deals with receive annual GIS updates to the DHRA, allowing them to review any submitted planning applications against this data.

The National Planning Policy Framework, 2019, paragraphs 178 and 179, make it clear that the onus is on the developer to demonstrate to the local planning authority that the site is 'safe and stabile' for the development proposed. Our statutory remit as 'technical expert' advisor to planning authorities is to review the information provided in support of the planning application against the data we hold and to provide substantive and constructive comments back to the Case Officer at the local authority to inform the decision-making process.

Coal Authority implementation of pre-application advice

Seeking pre-application advice as part of the planning process is encouraged by central government so that identified issues can be resolved prior to a formal planning submission, increasing certainty and reducing time and resources in successful consideration of that application.

Through our statutory role it became apparent that the Coal Authority's technical and planning advice was frequently being sought not only by local authorities, but by applicants, developers and their advisors. In order to assist in providing our knowledge and expertise to those seeking to develop sites in the Development High Risk Areas, particularly sites with complex mining legacy and ground conditions, it was decided to introduce a formalised chargeable Pre-application Advice Service (PAS).

Financial year 2018/2019 saw the formal introduction of PAS by the Coal Authority's Development Team to complement the organisations existing role as a statutory consultee on planning applications. The service provides bespoke planning and technical advice through constructive challenge and review, and uses our experience to identify any omissions or shortcomings, providing advice on addressing the risks from mining legacy to support future planning proposals. It is particularly suited to complex or heavily impacted sites where difficult remediation challenges exist. The benefit and certainty provided by pre-application advice can however only be as good as the accuracy, relevance and completeness of the information presented.

The introduction of PAS has been very successful with a two-fold increase between the first and second years of implementation despite the latter being impacted by the effects of the COVID19 pandemic.

The performance of the PAS has been assessed over the financial year which ended in April 2020. The number of enquiries to instructions equates to a healthy conversion rate of 74% and since repeat business is reflective of the value that customers associate with the service, this has encouragingly accounted for 59.6% of the total workload. In the majority of pre-application instructions where written responses have been provided, 21% have involved a meeting with a customer and or their representatives with approximately a third of those receiving a formal written response.

Comparing the cost of Coal Authority pre-application advice to that offered by local council's data[4] from 2019, the scale of fees proportional to the Ryton case study below (a residential scheme with >250 units) council charges are an order of magnitude higher. So whilst it is appreciated a council will be commenting on several matters of policy, we are confident that Coal Authority PAS fees remains very favourable especially given the financial savings attributable to the matters it considers.

A breakdown of the subject of pre-application advice given over the 2019-2020 financial year is provided in figure 1.

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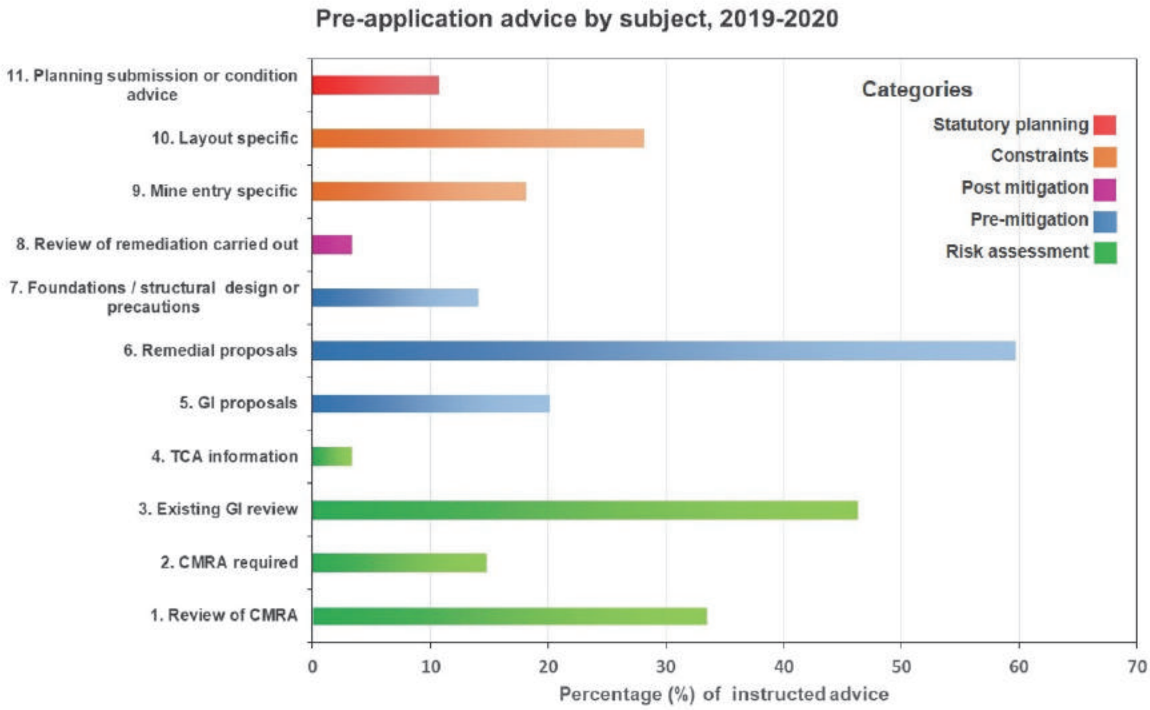


Figure 1: *Breakdown into subject areas of completed pre-application advice.*

The Prudhoe to Ryton A695 route corridor

Two examples of pre-application advice are presented. These were chosen on the basis of their close proximity both to each other and Newcastle, but also because they occurred at the same time, allowing direct comparison. The site at Prudhoe being a mixed retail development and Ryton a proposal for 287 new residential units.

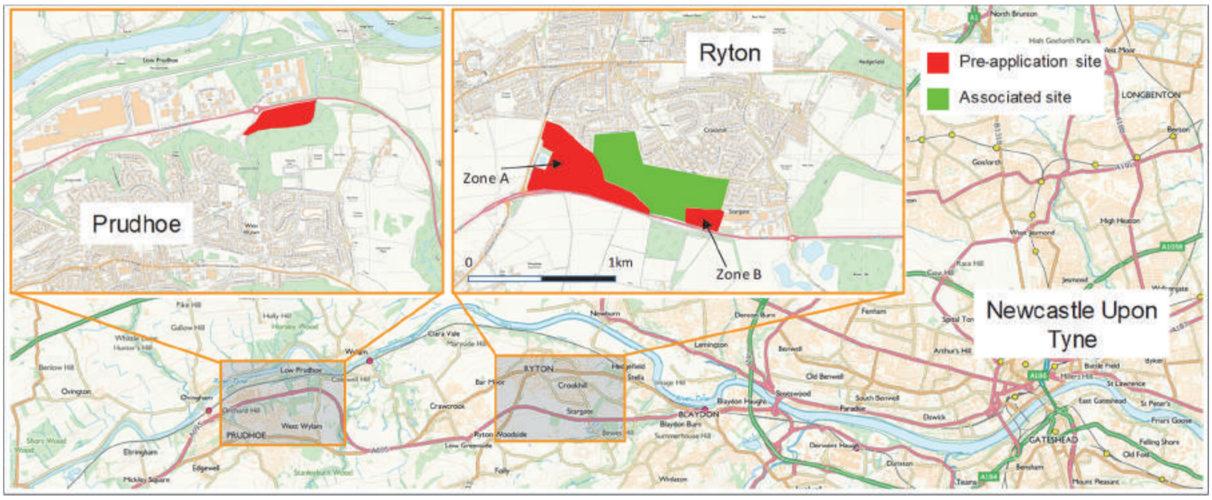


Figure 2: *Site location plan of the Tyneview Retail Park, Prudhoe (inset a) and Ryton growth village (Inset b) within the wider A695 route corridor.*

Tyneview Retail Park (east), Prudhoe, Northumberland

Described as ‘a prominent mixed use retail leisure development with excellent A roadside visibility’ the scheme comprises just under 7,000 sq. m of retail accommodation and is located on the A695

Princess Way north of Prudhoe town 10 miles west of Newcastle. It represents a contract value of £8.6M for the main contractor.

A geo-environmental desk study[5] written in 2016 defined both an initial conceptual site model and the potential geotechnical constraints recommending a programme of ground investigation and testing including rotary drilling to determine the extent of mine workings and extent to which stabilisation might be required. It recognised that besides recorded mine workings, unrecorded mine workings could be detrimental to stability and potential existed for the release of harmful concentrations of mine gas.

Discussions quickly established that advice regarding layout would not be adopted by the Developer since its appearance and the visibility of the site as planned, maximised the client’s chosen layout and was primarily a marketing feature for the development. This they felt could not be compromised. Whilst unconstrained by recorded mine entries (see figure 3) the mining report appeared relatively favourable to development, however drilling quickly identified deep superficial deposits (up to 30m) requiring both deep foundations and deeper drilling for investigation and grouting works beneath proposed structures. Early advice allowed a scaled and proportionate response to the risk to be developed with the consultant. Without this, wholesale grouting on a tightly spaced grid would have been significantly more expensive especially because of the depth of treatment. Treatment extents required beyond the building footprints were assessed relative to the foundations type proposed.

However, it was during the construction phase works that further pre-application advice was sought primarily because the complexities of the mine workings associated with three or more seams resulted in some unusually high grout takes, something not identifiable at the desk study stage. Further drilling identified a zone central to the site which presented notable, uncharacteristic voids. The service responded promptly to findings from site and in discussion with the consultants throughout the remediation works on their proposals, arrived at a mutually agreeable decisions deemed appropriate for the presence and complexity of unrecorded workings encountered.

The benefit of the service provided both a speed of response and flexibility such that late design changes could be considered. The late change affected the proposed restaurant building whose position was moved to accommodate services and a revised road layout at the entrance to the park The pre-application advice ran concurrent and complimentary to the Coal Authority’s permitting regime which allowed inspection of the works and further on site discussions. Positive SHE reports were filed recording the contractor’s adaptation to the site conditions including bespoke screening of the PFA grout mixing operation and safe working in a confined site whilst building construction proceeded in an attempt to stay on programme.

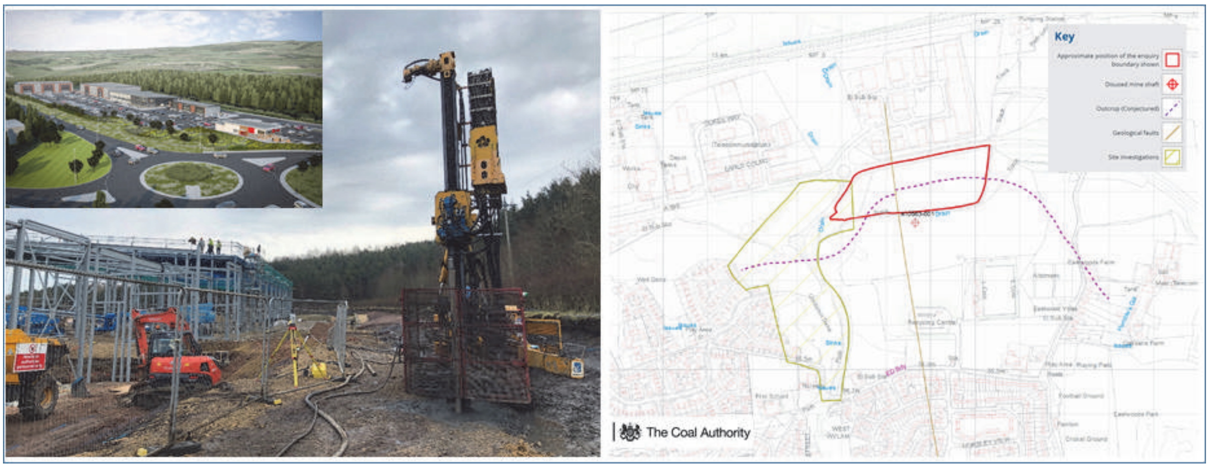


Figure 3: *Tyneview Retail Park, Prudhoe. Grouting works and superstructure construction underway in March 2020 site inspection photo (left) and developers completed scheme visualisation (inset top left). Coal Authority consultants mining report plan extract, September 2018 (right).*

The project represents successful implementation of design that was CIRIA[6] compliant in difficult and unpredictable circumstances. The involvement through the pre-application service allowed a swift acceptance of completion reporting which was provided in June 2020. It resulted in a straightforward recommendation to approve the discharge of the relevant planning conditions in the same month. Whilst the risks and costs had been collaboratively managed the Developer decided to recover programme and costs by delaying implementation of the eastern-most retail unit (Block 4) within the phase 1 works.

Ryton growth village

Similar to the site at Prudhoe the Ryton growth village occupies land formerly undermined by the Stargate Pit or Towneley Main Colliery which was worked from 1800-1826 and subsequently from 1840 to 1961. In more recent times within the site and south of it shallow coal had been exploited as part of a wider surface mining operation which ceased coaling in October 1992. The residential scheme forms part of the 2015 adopted core strategy and urban core plan for Gateshead and Newcastle upon Tyne[7], described as growth village area, GV6.

From a pre-application perspective, Ryton represents a more of a traditional consideration, all advice being sought within the pre-commencement (investigation) phase works. Coal Authority expertise was sought in respect to land acquisition and sale. It was necessary to establish the value as influenced by remediation costs for residential development given uncertainty in both constraints and potential instability arising from the possible presence of shallow mine workings.

Early planning objections had been maintained as a direct result of the mining constraints on layout, namely, the presence of mine shafts and the existence of a residual buried surface mine highwall. Initial pre-application discussions overcame these concerns by the developer adopting a sympathetic layout to those features, part of which included the incorporation of a crescent shaped road layout echoed by the building facades surrounding one of the mine entries in line with Coal Authority published policy[8]. This now forms a distinct and saleable design feature of the development. Internal estate roads associated verges and driveways were aligned to occupy the zone of increased risk associated with the former highwall. As a result, the new proposed layout was quickly agreed through a subsequent statutory planning consultation response.

The extent or even need for remedial grouting within the northern portion of Zone A was a more contentious issue and one which separated the consultants engaged on behalf of the landowner and the developer. Further pre-application advice was requested in a joint attempt to resolve the issue. By detailed examination of the underground mine abandonment plans along with existing comprehensive borehole information, the landowners consultant was able to conclusively demonstrate the risk. By consideration of the method of mining (shortwall total extraction) in the two seams of interest along with their recorded thicknesses and detailed level information shown on the plans, they were able to attribute sufficient confidence to the calculations of cover and cumulative interburden being relied upon and prove its compliance with CIRIA C758D.

As a result within the larger western Zone A area, it was established and agreed at the final pre-application advice meeting that the development could proceed without the need for remedial grouting. The exercise demonstrated the importance of an expert understanding of the information available especially, in this case, the mine plans. These were sufficiently accurate that they called into question, at this specific site, the ability of modern rotary open-hole drilling to consistently and reliably determine, or in this case validate, depths and thicknesses of shallow workings to the required accuracy. There was also a recognition that different mining techniques have an effect over the potential for subsidence at the surface.

At the time of writing the development remains in a pre-commencement phase. The consultant has been advised by the Coal Authority to undertake a review of the separate Zone B area in the east. Then to produce a single updated coal mine risk assessment, CMRA, which will allow the pre-application advice service to provide a formal written response to assist and reassure the developer as they finalise purchase of the land.

Comparison of pre-application advice case studies

At the Prudhoe site unexpected and rather exceptional ground conditions, that could not have been reasonably foreseen from the investigation, were encountered. The value of pre-application advice can be important in such scenarios in managing escalating costs and delays to programme. However as presented in Figure 4, the efficiency of the service when coincident with the construction phase works can be both challenging and resources intensive.

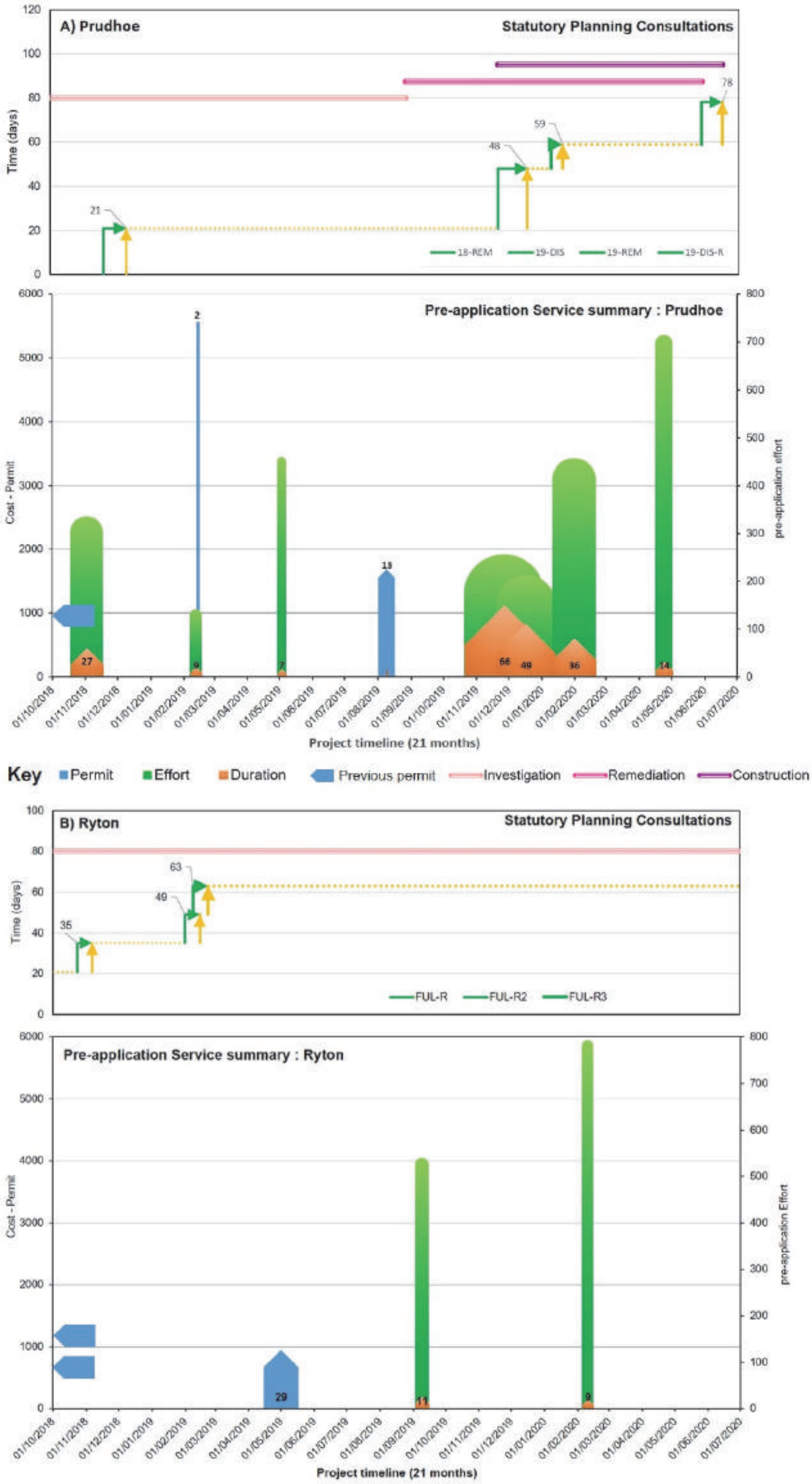


Figure 4: *Comparative assessments of pre-application advice timelines a). Prudhoe and b). Ryton. (Notation - FUL=Full planning, REM=Reserved matters, DIS=Discharge of condition and R=Re-consultation).*

It represents one of the few occasions where the provision of pre-application advice is valid during construction phase works. Advice was provided over more prolonged periods but with much reduced response times reflective of the evolving situation on site. Developers have to accept therefore that the cost of advice given under such conditions will increase proportionally, commensurate with the increased risk and the possibility that a decision might be reversed later when more facts become apparent. The quality, speed and relevance of the information provided and its effective communication becomes important as does the acknowledgement of those risks.

At Ryton early statutory consultation led to pre-application engagement as a result of a maintained objection over layout because of the presence of mine entries and the process was concluded much more efficiently and in a timely manner. The work of the consultant and the negation of grouting meant that following pre-application advice all matters relating to layout pertaining to the western parcel of land had been resolved and agreement reached. This is of course a more typical demonstration of both the pre-application and statutory services working in unison to resolve matters of mining legacy.

Difficulties often result from a series of factors which when combined give rise to significant challenge. At Prudhoe three influences can be discerned. 1 The thickness of superficial materials and need to grout workings at a depth of 40+m 2. Excessive grout takes within the central area of the site. 3. Potential supply issues with materials, particularly PFA, the main constituent of the grout. Any single factors could create a problem, but once excessive grout takes were realised and combined with the depth of drilling, potential supply issues, point 3, then became of critical importance. Thus, combined together, these factors have the potential to result in significant disruption to a development. Given trigger point 2 was unexpected, hindsight might lead to consideration of whether a scheme of trial grouting could or would have led to the prediction of conditions. Perhaps in hindsight a greater use of grouting trials, in the same scenarios, is required in future.

The case studies show that layout changes can produce different results and, not unsurprisingly, any late design change is likely to have an adverse effect. Early consideration where possible however, can create sympathetic design with the potential to enhance a development’s visual appearance with minimal impact for the developer. Clearly the value of pre-application advice can be appropriately realised at different stages in a project to add value, including during the pre-purchase of land. Prudhoe was challenged by local resident’s opposition who cited coal mining as a concern. Pre-application advice can however properly inform all stakeholders on these risks and provide a written response at an early stage with the potential to cease any disingenuous or inappropriate reference to mining legacy by those opposing a development.

The Coal Authority publishes the pre-application advice service as providing the following key benefits[9].

1. Encouraging the frontloading of projects by early contractor/consultant involvement (ECI),
2. Reducing the burden of statutory responses required to reach agreement,
3. Reassurance that all foreseeable mining risks have been identified and that mitigation proposals are unlikely to meet with objection,
4. Technical advice on proposals including appraisal of detailed design, and
5. Identifying layout constraints and agreeing solutions to either avoid or overcome them.

The National Planning Policy Framework makes clear that for pre-application advice to be effective and to make a positive contribution, early engagement in the process is required. Referring back to Figure 1 we see the positive comparison which confirms the service is well understood and that its implementation has been commensurate with the intended aims listed above. The knowledge and understanding gained allows conditions to be recommended which are flexible and align with a developer’s timescales. A recently published technical guidance note[10] now provides designers with information to help them produce compliant submissions required for engineering appraisal.

Examples of all the key benefits 1 through to 5 are identified within the case studies. Research in 2019 defined PAS success as requiring two fundamental criteria i) guaranteed input from specialist professionals, and ii) designed to make the planning application process run more smoothly at later stages, saving the developer time and resources. By presentation of the case studies, it has been our intention to demonstrate the service has and continues to meet these fundamental criteria.

Facilitating brownfield development - Bayfield

The site is located within the West Allotment district east of the A191/B1322 roundabout North Tyneside, the development is known as Bayfield. In March 2016 it became apparent that ground movement was causing damage to residential properties at Bayfield, when an area of subsidence, approximately 150m x 70m, suddenly developed across the site. Whilst the Coal Authority had records of historic mining these showed no coal workings directly under the site. Given the Coal Authority's statutory responsibilities for public safety and subsidence under the Coal Mining Subsidence Act 1991, investigations commenced in May 2016. After two separate phases of ground investigation it was proven that there were extensive unrecorded coal mine workings present beneath the site, dating back 120 years.

Coal Authority records indicated the presence of recorded mine workings in the wider area at depths of between 38m and 257m. Mining at these depths does not generally pose a risk to surface stability, however within the subsidence zone it was found that the coal was intensively worked with coal extraction rates in excess of 70%, whereas normal extraction might only be expected to be c. 45-50%. The intrusive investigations found that the High Main coal seam, had not only been subject to high extraction rates but was also found to range from 2.7m to 3.4m thick, at a depth of between 34m and 43m. Based on the findings of investigations within the subsidence affected area the ratio between the extracted height and the thickness of competent rock cover remaining above the workings was calculated at between 9.7 and 12.3, with industry guidelines recommending a minimum ratio of 10 before remediation is required. Analysis of the recovered drill cores confirmed that the rock above the coal seam was laminated, weathered and fractured and therefore its competency was compromised.

The subsidence event resulted in the demolition of 18 properties with repairs required on a further 19 properties within the affected area, see Figure 5. In order to address the subsidence event the centre and wider affected areas have been subject to a programme of drilling and grouting. The Coal Authority's Engineers and Public Safety and Subsidence teams designed and oversaw the implementation of a drilling-and-grouting based solution to stabilise the ground affected by subsidence.

Figure 5: *a). Effects of the subsidence event and the resulting changes and b). Aerial photograph of the affected area post demolition / remediation and prior to redevelopment (November 2018).*

With permanent presence on site for significant periods the Coal Authority was able to consistently keep the Bayfield community and local planning authority updated, informed and involved in the decision making process. The local community had a substantial influence, with their feedback being instrumental in the decision to facilitate the redevelopment of the site on a like for like basis. The Coal Authority worked closely with North Tyneside Council in order to ensure that the development met national and local standards, with all key stakeholders aware of and supportive of the proposed redevelopment. To support the planning application the Coal Authority commissioned an independent Coal Mining Risk Assessment[11] (dated May 2018) to demonstrate to the planning authority that the site was safe and stable for the proposed redevelopment, as required by the National Planning Policy Framework.

The Coal Authority could have simply remediated the site where the properties had been demolished and left it vacant. This would have been less expensive but contrary to the objectives of sustainable development and housing growth leaving a permanent reminder more likely to result in blight of the surrounding properties. Whilst the Coal Authority is not a housing developer, further to the completion of remediation works and confirmation from an extensive monitoring programme to demonstrate that the site is stable and safe for redevelopment, planning permission for the replacement of the lost dwellings was sought. In this way the Coal Authority not only remediated the site but have facilitated its redevelopment for much needed new homes whilst helping to ensure that those living around the site do not suffer from loss of amenity or environmental degradation. In July 2019 the Coal Authority published technical guidance[12] to the industry highlighting the issues arising from this subsidence event in order that repeat occurrences might be prevented in the future.

Seaham Garden Village – Mine water district heating scheme

The UK has a legacy of over 23,000 abandoned deep coal mines which lie beneath a quarter of our homes, businesses and municipal buildings. Deep coal mining in the UK ended in 2015 with the closure of Kellingley Colliery in Yorkshire. Nine out of ten of our largest cities by geographical area sit above former coal workings. This is not surprising as many of these urban areas grew and prospered on the strength of their coal deposits. Over 17 billion tonnes of coal have been extracted from the subsurface over the past three centuries. This has created voids in the subsurface that in many areas are now filled with water at temperatures of 14 – 20°C and up to 40°C in the deeper mines that extended to depths of 1.4 km below surface[13].

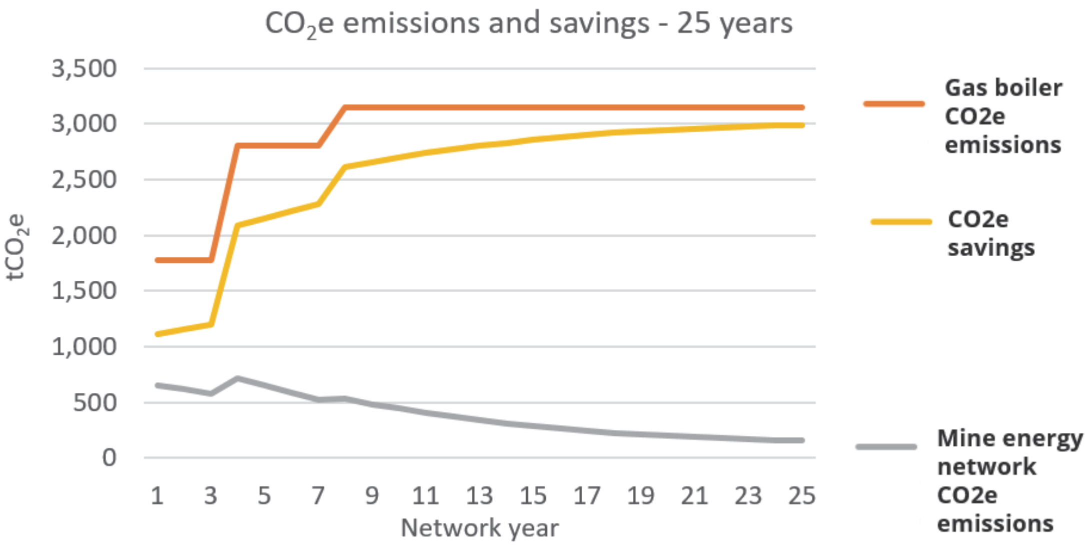
Though the coal has long since been extracted, traded and burned, the remaining water filled voids can be used over and over as a source of geothermal energy. The Coal Authority has calculated that the constantly replenishing water within these mines could provide all of the heating requirements for the buildings located on the coalfields. It could also be used as heat and energy for horticulture, manufacturing, and municipal purposes. The water in these mines is a low carbon, sustainable heat source, which under the right conditions compete with public supply gas prices. The Coal Authority operate around 75 sites across the UK where mine water drains by gravity or is pumped and treated before being discharged to surface waters. It is estimated that a total of around 100MW of heat is available from these sites.

Heat accounts for half of UK energy demands, with most currently derived from gas. However, government targets state that by 2025 there will be no gas connections in new build houses and businesses. Technology-ready alternatives, such as mine energy, are sure to play a huge role in supplying Britain's energy needs for years to come. This case study highlights the potential use of water that is constantly pumped from the abandoned mine as a source of space heating for a new development.

The Seaham project is being developed in partnership with Durham County Council and the Coal Authority. Tolent Construction are developing an exemplary Garden Village at Seaham, County Durham that will consist of 750 affordable homes, 750 private homes, a school, shops, and medical and innovation centres. The development is to be built immediately adjacent to the Coal Authority's Dawdon mine water treatment scheme. This scheme protects vital drinking water abstraction from Durham Magnesian Limestone, and pumps 100 to 150 litres of mine water per second to the surface for treatment. This development has the potential to make Seaham Garden Village the first large scale mine energy district heating scheme in the UK[14].

This mine water is warmed by geothermal processes to provide a continuous supply of water at 18 to 20°C. In the case of a district heating network, this energy can be transferred to a pipe network using a heat exchanger, and then distributed to nearby homes. With mine water temperatures unaffected by seasonal variations, there is a potential 6MW of low cost, low carbon sustainable energy available for local space heating use from the Dawdon treatment scheme throughout the year.

The scheme is also unusual in that it does not use metal pipes, due to the lower temperatures involved. The method of delivery is much cheaper than district heating schemes that use higher temperatures, where metal piping is essential and has greater temperature losses, making networks such as Seaham Garden Village much more efficient and economically viable than some other district heating schemes. In addition, as illustrated in Figure 6 below, the carbon emissions associated with



using a heat pump are far less than from using an equivalent gas boiler and will decrease further as the carbon content of grid electricity decreases. As more low carbon generation supports our electricity mix, this also leads to an improvement in local air quality.

Figure 6: *Graph showing projected carbon emissions for the Seaham development, the stepped profile relates to subsequent build phases.*

This kind of low carbon energy technology could help to present coalfield areas as more attractive to investors, which could breathe life back into some areas of the UK where it is most needed. It could also provide a low carbon solution to Britain's future renewable energy needs. Many local authorities have already declared a 'climate emergency', with pledges to become carbon neutral in the coming years.

Conclusions

The examples presented have demonstrated how the Coal Authority is acting proactively to support sustainable development and the growth agenda and is using its knowledge and expertise to facilitate redevelopment of sites which have been impacted by past coal mining activity. Engaging in constructive dialogue with the Coal Authority at a project's early stages can provide a greater certainty and confidence in a project realisation and assist in ensuring that issues of coal mining legacy do not place an undue burden on its delivery. Detailed examination of the available mining records can pay significant dividends. The pre-application advice service can help developers and their agents overcome significant mining related challenges, even if these occur during the construction phase works, to arrive at safe and stable development most likely to pass unobstructed through the planning process.

Mine-water systems offer economies of scale, meaning that clusters of hundreds of properties could be served from a single mine and a few boreholes. To deliver this vision requires changes to the way in which energy is traded e.g., consumers will pay for heat rather than gas or electricity. Planning and building control policies could also support the future development of low-temperature energy systems for example by ensuring that new developments in mining areas are assessed for their mine energy potential and by including low temperature distribution systems and thermal storage in new homes where possible.

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IDENTIFYING CHALLENGING GROUND HAZARDS FOR REMEDIATION AND LAND DEVELOPMENT: A CASE STUDY OF A SITE AFFECTED BY OVER 300 CLOSELY SPACED BELL PITS, NW LEICESTERSHIRE.

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Abstract

Backfilled bell pits present significant ground hazards due to their unrecorded, generally random nature and un-compacted fill that has the potential to cause differential settlement if not suitably remediated.

Bell pit mining in the East Midlands is not unusual for coal and fireclay extraction. This paper describes a case study in NW Leicestershire, a greenfield site (on first inspection) earmarked for residential land development. The initial desk study and Phase II ground investigations had not specifically indicated the potential presence of bell pits. Following a report review, suspicions were raised, and additional boreholes, trial pits and a geophysical survey were employed to further confirm the ground conditions associated with bell pit workings. However, the findings of these techniques were not sufficiently conclusive to develop a conceptual ground model with the degree of certainty required for hazard derivation and subsequent risk analyses.

The bell pits were exposed and identified by archaeological trenching, required to satisfy planning conditions, and allowed a subsequent targeted site strip of the affected area to be completed. This revealed over 300, closely spaced bell pits approximately 3.5m in diameter which covered approximately 10% of the entire development site. Aerial drone photography was used to map the bell pit affected area.

The resultant land remediation necessitated bulk removal of the affected area up to 6.5m deep, as over 50% of this ground had been reworked by the bell pit activity. The excavated material was lime stabilised and re-engineered on site, providing consistent ground conditions for the future development and prevented the requirement for grouting, reinforcement or material import, reducing the impact of construction to the local area.

The paper reviews the ground investigation techniques, chronology for this case study and looks at the challenges having followed industry best practice.

History

Bell pits have been used for the extraction of shallow minerals including clay and ironstone but most commonly for coal in South Derbyshire from as early as the 13th Century ('Swadlincote Conservation Area Character Statement', *South Derbyshire District Council Statement*, 2014). The pits are usually encountered up to 1.5m in diameter and due to the nature of their construction are generally no deeper than 12m (D Parry, the Coal Authority, C Chiverrell & CIRIA, *Abandoned Mine Workings Manual,* (2019)). Bell pits were the preferred method for mineral extraction where superficial deposits were at their thinnest and the target mineral seam had a shallow dip allowing for maximum extraction. Centres of bell pits are known to be as little as 2.5m apart (D Parry, the Coal Authority, C Chiverrell & CIRIA, *Abandoned Mine Workings Manual,* (2019)).

Generally, historians tell us that bell pits were excavated, by hand, to the target seam and then mined out radially from the centre of the shaft until the target mineral was exhausted, the pit roof collapsed, influx of groundwater was too great or ventilation was restricted. Once the pit was exhausted it would either be backfilled in an uncontrolled manner or left to collapse, and the exercise repeated a short distance away to work the same mineral assuming the outcrop allowed for this. Their occurrences are often undocumented, with little to no plans indicating their presence. As such, the presence of bell pits can create random areas of 'poor' ground. Due to their construction and backfilling procedures, bell pit affected areas can cause issues for modern engineering projects in the form of low bearing capacity, excessive settlements, being a potential source of ground gas and contributing to localised horizons of groundwater.

Given their age, the location of bell pits tend to be unknown (given the need to record abandoned coal mines wasn't made a requirement until 1872) and can't generally be discovered through Phase 1 desk study alone as this is generally targeted towards contaminated land and relies on records. As such, it is important that local historians and archaeologists are engaged at the desk study stage to help in identifying potential risks associated with the site.

Initial Suspicions

The site in North West Leicestershire (Figure 1) was the subject of a Coal Mining Risk Assessment (CMRA) completed in 2014 and a Phase II Site investigation completed in 2017 by a third party. The CMRA identified three outcrops of coal on site, straddling the Blackfordby Fault. The seams are the Kilburn Seam, to the west of the fault and to the east, the Eureka Seam and Stockings Coal. The seams vary in thickness ranging between 0.8m and 2.4m and although ranging in quality, were reported by the BGS to be commonly worked from outcrop, with recorded workings up to 40m depth. The strata on site dipped at angles ranging between 3^{o} and 4^{o} towards the south west and with strikes offset by local differences in the structural geology.

Figure 1: Site boundary plan

No recorded mine entries were present on site and given the lack of recorded mine entries, the risk from unrecorded mine entries was initially considered to be low. The northern part of the site was a former opencast quarry dating from approximately 1950, which was since backfilled.

The original ground investigation comprised a selection of trial pits, windowless sample boreholes and deeper rotary boreholes. The ground investigation encountered variable natural strata with the south east of the site containing a second material 'type', albeit this was also considered representative of natural material. Water strikes were encountered at various depths within the natural cohesive strata.

GRM were approached by another developer who had acquired the reports of the former investigations and were invited to review the information with an aim to inform the developer's abnormal risks prior to purchase. The anomalous 'natural' material, upon review, was not considered representative for this area. The sporadic nature of the material, along with the occurrence of variable water strikes, suggested to GRM that additional investigation would be beneficial to the developer to try and qualify the variable ground conditions as similar features noted on other sites by GRM had led to bell pits being discovered.

Figure 2: Historic aerial photographic from 1968 highlighting dark patch in south western site area.

Historical aerial shots of the site were also reviewed and identified a much darker patch of ground in the south eastern area of the site suggesting that something more than natural ground was present (Figure 2).

Two Birds, One Stone

As a former opencast quarry was on site, to the north of the main area of interest, a geophysics survey was commissioned to help delineate the former highwall of this feature. In addition, the geophysics survey was also used to gather site-wide data in a relatively short timescale and cost-effective manner to assist with discharging a planning condition applied to the proposed development with respect to archaeology. Magnetic surveys indicated localised anomalies (Figures 3 and 4).

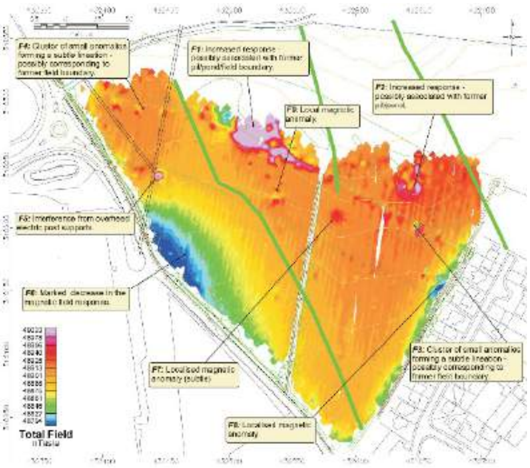

Figure 3: Magnetic Survey Total Field from TerraDat Report ref. JT/5749/1

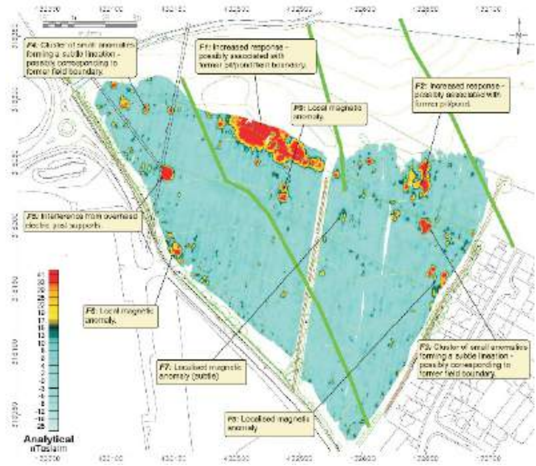

Figure 4: Magnetic Survey Analytical Response from TerraDat Report ref. JT/5749/2

Given the large size of the site, the magnetic techniques used were deemed most suitable. Other techniques, such as gravity surveys which would have potentially identified bell pit features, were considered too time consuming and inefficient given the large scale of the site.

Aside from the former quarry, no clear targets were identified in the south eastern area, however like the aerial photograph, the south eastern area comprised a large anomaly as a result of the ground conductivity survey (Figure 5).

Following the geophysics survey, a trial pitting exercise was completed to investigate the south eastern part of the site. The trial pitting initially identified natural material of firm, orange clay with areas of dark grey clay and mudstone crossing the trial pits. When the pits were extended to investigate these changes further, a clear circular feature was encountered. This was approximately 3.5m in diameter and up to 4.5m in depth (Figure 6).

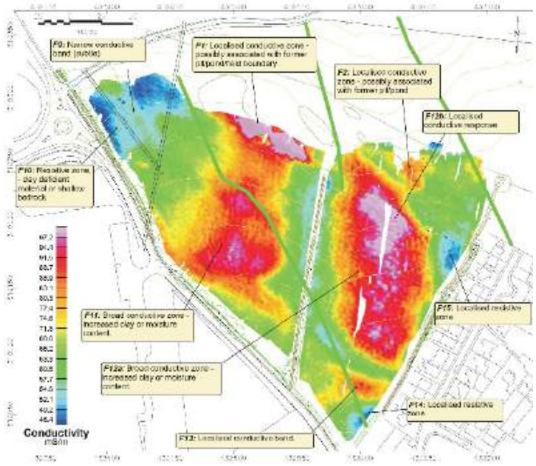

Figure 5: Ground Conductivity Survey from TerraDat Report ref. JT/5749/3

Archaeological Assistance

An archaeological investigation, comprised of shall trenches, was required as part of the planning conditions, and it was decided that while they were open, GRM would inspect the trenches and potentially limit the affected area. The archaeological trenches identified that the south eastern area of the site was the only portion of the site affected by bell pits, and therefore GRM recommended a site strip in this area only to try and establish the full extent of the pits (Figure 7).

An archaeologist was present when the bell pits were excavated to their full depths. No remnant artefacts of archaeological importance were identified within the backfilled bell pits and were therefore not considered archaeologically important at the site. Such was the density of bell pits, the full extent of could still not be established.

Figure 6: GRM photograph of bell pit excavation

Figure 7: GRM photograph of archaeological trench showing bell pit density, the grey material representing bell pits

Scale of the Problem

After identifying an abundance of bell pits in the archaeological trenches, with no definitive area, a full site strip was required to determine the full extent of the affected area. Aerial drone surveys were completed throughout the site strip to enable to scale the issue in hand and help convey the risk to the developer and the groundworkers.

In total, over 300 bell pits were revealed in the south eastern area of the site (Figure 8) covering an area of approximately 7500m^2. The bell pits were mostly backfilled with loose dark grey mudstone gravel and often contained large volumes of water. The pits were also unusually closely spaced and excavated in a grid like pattern, some of which were interconnected with centres ranging between 2m and 5m apart. The natural material surrounding the pits was generally firm orange gravelly clay, considered representative of the weathered coal measures strata. These variable properties would have led to bearing capacity issues for any proposed structures and would result in differential settlement over time had traditional foundations been employed on site.

Figure 8: GRM aerial drone image of site strip taking place, revealing extent of bell pits.

Solution for the Developer

Following the site strip, the bell pits affected an area of approximately 7,500m^2 which required remedial works.

Several solutions were available to the client. Using piled foundations and reinforced gardens would ultimately remove the risk from differential settlement and mitigate against any future collapse. Alternatively, each bell pit could have been grouted and capped. However, although treated, each individual bell pit could potentially be reported as a recorded mine entry by the Coal Authority and may have affected the sale of any future properties.

Due to the density and number of bell pits within the site area, it was considered that treating the bell pits on an individual basis was not feasible. The most cost and time efficient treatment of the area was deemed to be bulk excavation (Figure 9) and treatment with lime before re-compacting the material. Furthermore, this method had the added benefit of being zero risk. No mine entries would be left insitu and therefore would not be of any concern to the Coal Authority. By engineering what was poor variable ground into consistent, engineered material, differential settlement would be minimised and would provide sufficiently competent material to minimise capping material below highways at the site. It also saved on exporting this material to landfill which would reduce the impact of the development on the environment, as well as minimising the impact of this process on the local residents. Based on the remediated area and depth of treatment, an additional 4,000 lorries would be required to remove the material from site.

Geotechnical testing of the excavated material within the bell pits recorded variable moisture contents ranging between 19% and 31% with Optimum Moisture Contents ranging between 9.3% and 17% and was therefore significantly wet and unsuitable for engineering purposes. The site development time scales did not allow for the site won material to be conditioned through natural techniques (eg air drying, wind-rowing, etc) and therefore it was decided to treat the material with lime to improve the characteristics of the soil. Laboratory trials indicated that an average of 0.5% of lime would be sufficient to improve the soils performance.

Figure 9: GRM aerial drone image of large-scale bell pit excavation.

Conclusions and Thoughts

An initial Phase I and Phase II investigation reported variable ground conditions in the south east of the site, which would be problematic for the proposed development as they had poor geotechnical characteristics. A review of the existing information in combination with local knowledge, historical maps and photography, identified areas for concern and recommended additional investigation in the form of geophysical surveys and trenching.

The trial trenching helped refine the data recovered from the magnetic geophysical survey. The geophysical technique primarily reported the high moisture content of the backfill used to fill the bell pits. As such, this technique could not confirm the presence of bell pits on its own merit and should be used in conjunction with other techniques to confirm or deny a hypothesis.

The trenching revealed a number of interesting features regarding the pits, namely the density is greater than that cited within the published guidance by CIRIA, and the pattern doesn't particularly follow what might be expected if one studied the structural form of the local geology. The extraction pattern is one which lends itself to multiple people digging individual pits, rather than a mass extraction process for the same mineral. Although this conclusion is still open to interpretation and makes the case study even more interesting and unique.

Despite being within the CIRIA outlined dimensions, the bell pits identified at this site were unusual given the larger diameters. The bell pits encountered on site terminated at rockhead and no evidence of coal was identified within. GRM therefore consider these features were used to recover fireclay. Notwithstanding the geotechnical properties associated with the material placed within the bell pits, no archaeological artefacts were identified within the pits. As such, the project team opted for bulk insitu improvement and stabilisation scheme with lime to minimise the environmental impact on the local community and provide considerable project savings to the client.

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THE CHALLENGES OF MANAGING ACCESS TO THE COAL AUTHORITY UNDERGROUND MINE AND MINERAL PROPERTY PORTFOLIO

Hurst, D; Adams, C; Leeming, S; Walker, S, & Deeming, K

Abstract

Since 1994, the Coal Authority (CA) has been responsible for the management of coal and coal mine workings within Great Britain on behalf of the state. This includes over 173,000 mine entries and an underground estate the size of Wales by area. The CA regulates access to its underground property estate through a permitting process – mainly to developers. The chief responsibilities under the Coal Industry Act 1994, when considering any grant of access under the permitting process, are to have due regard to public safety and to ensure the effective management of its underground property. There has been an increasing demand for access into coal and coal mine workings in recent years due to the intensive development taking place in coalfield areas. New ways of working have been developed to help all parties gain safe access to the CA's underground property and its mining information data and plans. There are challenges in the correct use of mining information by developers and the public – especially as development proposals need to reflect recent changes in published guidance. These new approaches include: sponsoring the revised technical guidance which will assist developers in achieving best practice; being more proactively involved in large infrastructure projects involving mining legacy; improving the accuracy of our mining data to ensure it is still fit-for-purpose; and continuing consultative stakeholder engagement to inform the public, developers and landowners of the hazards associated with access to our underground estate.

Introduction

Any surface development, whether building homes or improving our road and rail networks, has the potential to disturb, enter or interact with coal and coal workings. These activities were previously dealt with by the former British Coal Corporation (BCC) through developer indemnities, to cover liability under the Coal Mining Subsidence Act 1991. The costs associated with this service were covered by the BCC mining reports service with the 'Area Surveyors' providing any follow-up advice relating to the proposed development.

The CA was formed by the Coal Industry Act 1994 (CIA94) when the UK's coal industry was re-privatised to undertake four key functions:

- Manage coal property
- Licence coal mining
- Manage subsidence claims
- Maintain and provide access to coal mining information

The CA effectively acts as the landowner for the coal property as we are required to coordinate the management of this property and license coal mining operations. We are bound to manage our property to "*secure the safety of members of the public"*. Our responsibility for property is undertaken in various forms: it includes surface parcels of land, mine water treatment schemes, and, of course, our 'underground' property. This includes mine entries, workings (known and unknown), unworked coal, and, in some instances, other minerals at particular locations.

As a non-departmental government body we manage the assets, roles and liabilities that BCC formerly managed. Initially we continued to provide developer indemnities through the CA's Mining Information function. However, the number of applications increased due to the growth in developer rates and the percentage of brownfield development. This increase warranted the formation of an internal Permitting Team in 2004 to work closely with the Mining Information Department to ensure that the management of the 'underground' coal property was, and continues to be, coordinated with its duty to license coal mining operations under the CIA94. The focus of the Permitting Team was to manage all third-party access into the CAs coal and coal workings estate to maintain public safety, the integrity of its underground property, and improve the accuracy of the mining data with 'as-found' information.

Figure 1 shows how the Permit application numbers have increased six-fold in the last 15-years against an ever changing development landscape. This necessitated the new approach in managing our legacy estate.

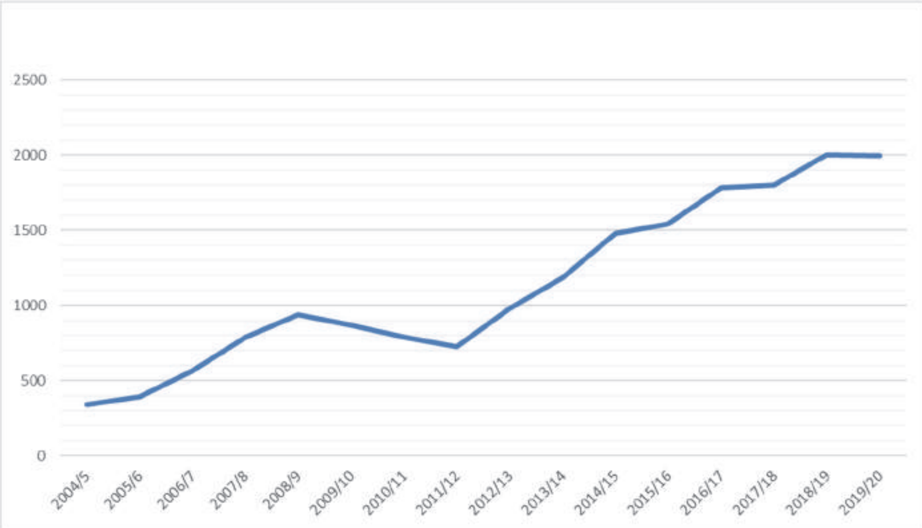

Figure 1: Number of Coal Authority permit applications received per financial year

Discussion

a) Mining information

It is imperative for the CA's internal teams to understand what the mining information does and, more importantly at times, does not tell you. This in-depth knowledge is key in safely and effectively managing the estate and consequently the safety of the public. The CA's Mining Information team is ultimately responsible for managing and updating the national electronic mining database of coal mine entries and workings – the majority of which are based on the original historical plans in our extensive archive. We provide the public an online free-to-access view of some of these datasets using a Coal Authority Interactive Viewer (Figure 2). We manage a complex mining database in certain areas of the country – shown here for the West Midlands.

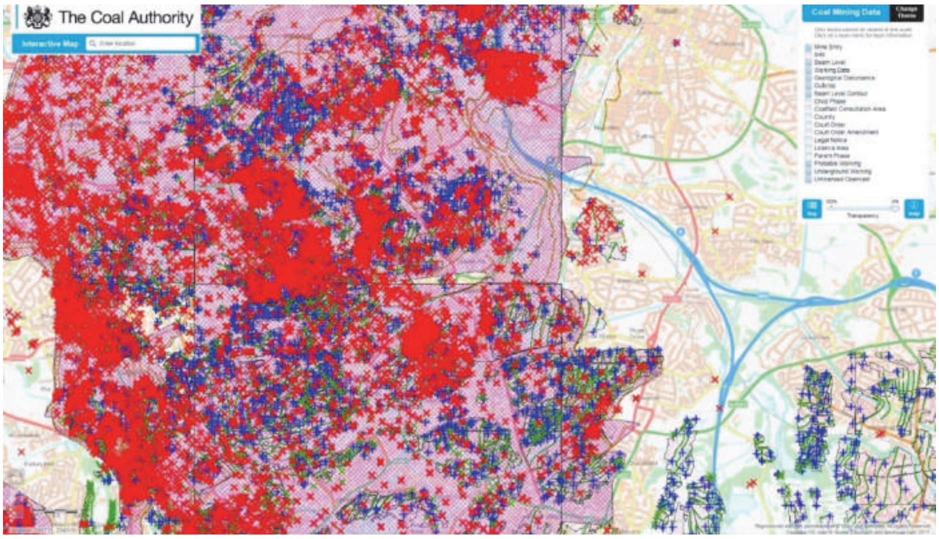

Figure 2: Screenshot of the Coal Authority's free online Interactive Viewer. © Copyright Coal Authority 2020. All rights reserved. Contains OS Data © Crown Copyright and database rights 2020

The Permit Team review a number of data sources when a permit application is received to assess the former mining situation at the given location. This includes: recorded mine entries, shallow workings, coal outcrops, coal fissures, mineral type, and opencast workings all within the context of the geological setting. The importance of such information, particularly in safety terms, is evident in the new *CIRIA* '*Abandoned mine workings manual'* (C758D). This deals with how to address surface instability in mined areas and discusses historical mining extraction and legacy. It also looks at the potential impact on the surface together with peer reviewed remediation strategies. *CIRIA* continues to be the definitive guide for the site investigation industry.

Although, in the first instance, we carry out an in-depth desk study against the CA's in-house Geographical Information System (GIS) system, we still review mining data that is only shown on the original historical abandonment plans. These plans cover both underground and surface coal mining operations. Our archive holds in excess of 120,000 abandonment plans – these are supplemented by the original colliery surveyor's notebooks. As you can appreciate, the plans and the original underground surveys from which the plans as based, are captured to varying and inconsistent standards, quality, accuracy, orientation and size – often the plans are not signed off by the mine surveyor at the time of abandonment. Although these plans are now housed in a state-of-the-art archive, they have suffered varying levels of deterioration due to the age of the plans and previous storage environments. Indeed, some of these plans are secondary copies of an original plan long since lost/destroyed.

BCC started to safeguard these unique plans through a GB-wide photographing/scanning project during the 1980s and 1990s. Every plan went through a '*rationalisatio*n' process. Copies of the original plans were all re-scaled on 2km x 1km sheets to a common scale and orientation – this was Ordnance Survey National Grid and seam levels referenced to Newlyn Mean Sea Level (MSL). Before this, BCC and others used a variety of artificial datum points – including one that was 10,000 feet below MSL so that all levels were positive! A *'rationalised plan'* was produced for each seam throughout the coalfield, so that workings in the same seam, but mined by different collieries, could be seen on one plan. These plans are the foundation of our modern digital coal mining database we use in our GIS today.

It is now CAs standard practice for the Mining Information team to revisit and georeference the original scanned plans rather than view the *rationalised plans*. This is possible by utilising modern techniques and technologies, such as GIS with improved digital surface mapping and tools.

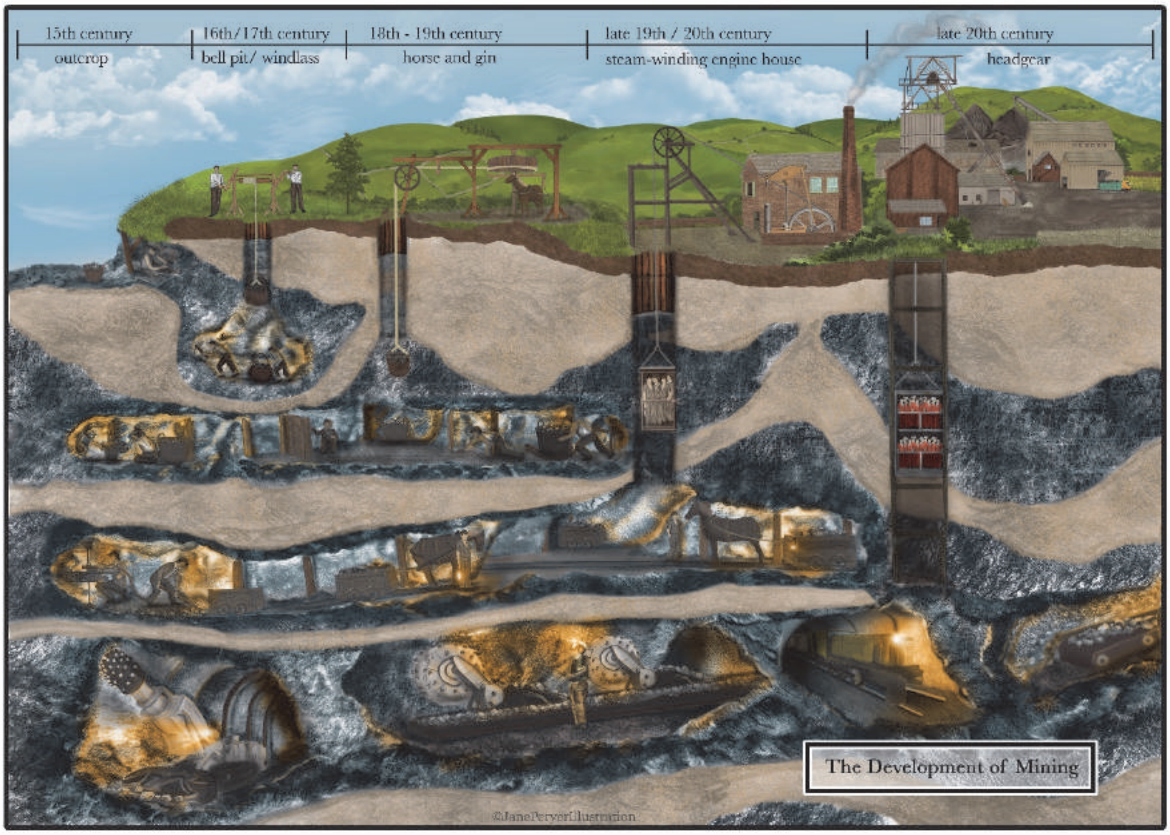

Figure 3: Coal mining techniques © NCMME

It was not until 1872, under the Coal Mines Regulation Act and Metalliferous Mines Regulation Act, that there was a legal requirement for mine plans to be deposited with the Secretary of State upon abandonment. This law came from the increasing number of fatalities from underground mines intersecting into each other unintentionally and resulting in inrushes of gas and water.

Coal mining in some form across Great Britain stretches back to Roman times. Figure 3 shows how these have developed over time. As you can appreciate, the increasing need for coal led to a greater concentration of the underground mines. The graph (Figure 4) shows why we continue to update the mining database upon the discovery of 'new' mining legacy information. Although mining operations pre 1872 were on a small/non-industrialised level, in the form of bell pits or surface extraction operations, they can significantly affect modern development proposals.

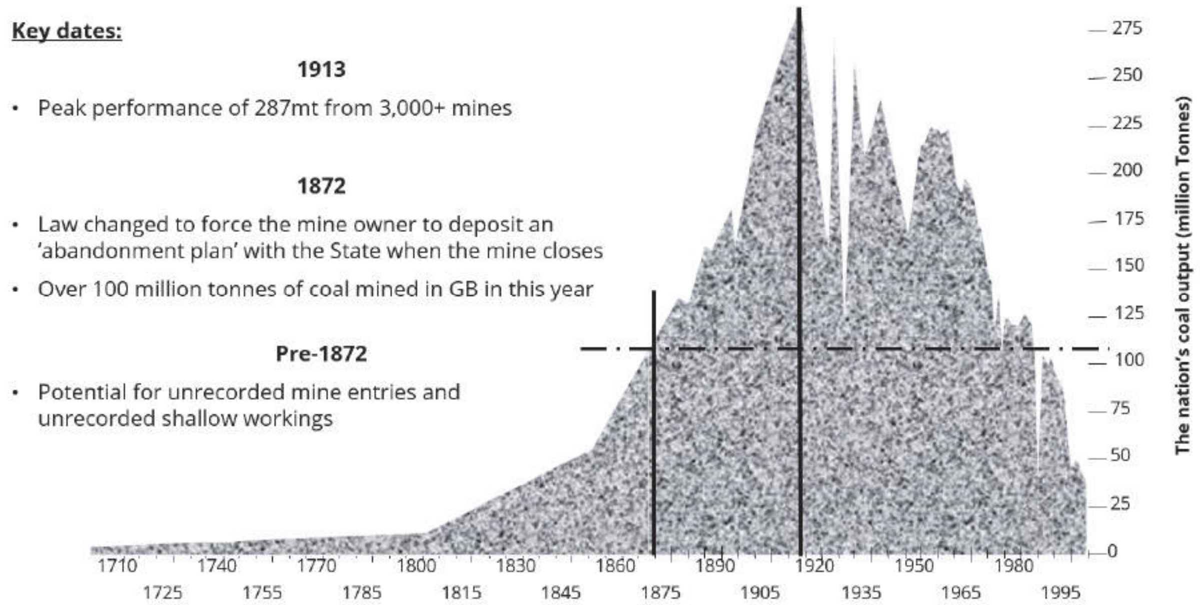

Figure 4: GB coal production with key dates

The CA archive is not definitive though as there are a number of private archives in the UK that hold unique plans and data to which we have no access. It is a requirement for a local archive to send coal mining plans through to the CA if and when they received them. The frequency of such depositions is low with the demise of the coal industry which now leads to an inconsistent approach by local archives across the country. Also, in terms of opencast/surface coal mining completion plans, there was no legal requirement to lodge these centrally and so this dataset is incomplete.

There was a national call for privately owned plans following the *Lofthouse Colliery* disaster in 1973 where a working coal face intersected a flooded coal mine shaft killing seven miners. BCC records suggested that this known shaft did not extend down to the current mining horizon however, records in the public domain proved otherwise.

Another consideration relates to non-coal minerals such as ironstone. It was often the case that such minerals were extracted at the same time as coal. This led to the National Coal Board (NCB), BCC, and now the CA, accepting liability under the Coal (Registration of Ownership) Act 1937. The coal industry was eventually nationalised in 1948 so that the vast majority of coal ownership (including some other minerals) was transferred from private individuals to the newly formed NCB. These original ledgers, that documented the transfers, continue to be used by the Mining Information Department today to cross-check ownership of other minerals.

The location and condition of mine entries is key in assessing a licence application. Georeferencing the appropriate abandonment plans to determine their '*best-plot*' position is the starting point to update the mining database if necessary. By this method, it is often the case that the same mine entry is shown on a number of plans in slightly different locations. This is where experience and a rigorous assessment is required. The team takes into account the age, quality, accuracy, and level of degradation of the plans against other maps and records. Additional sources of information include the Ordnance Survey's modern and historical plan series, British Geological Survey (BGS) geological plans and field slips, and the NCB/BCC original area shaft registers.

The presence of shallow recorded and unrecorded workings is vitally important in assessing surface stability. Mining related features, such as fissures, have been recorded over time but mostly where they have directly caused damage to land or property. New records of such instances are decreasing and are typically related to recent mining activity such as at Thoresby Colliery in Nottinghamshire. New mine plan abandonments from coal mines are now few in parallel with the demise of the industry. Kellingley Colliery in North Yorkshire closed on 18 December 2015 marking the end of deep-pit coal mining in Britain.

The potential for unrecorded historical coal mine workings increases where coal is at, or near to, the surface. The CA and BGS record the locations of coal outcrops i.e., where coal seams 'surface' at the top of the bedrock – not the actual ground surface as some may think. The bedrock is often covered by superficial deposits such as alluvium or clays which can be significant in parts of the country e.g. Lancashire, or made-ground such as in the West Midlands. The BGS maintains the definitive source of coal outcrops although, at times, the CAs records can be more accurate especially around former opencast sites.

The BGS is a great source of information on the mining in wider geological context – whether it be relating to deep (e.g. faulting, rock type and properties) or shallow mining (e.g. surficial and made-ground deposits). The most frequent challenges to our data by far relate to mine entry and coal outcrop positions – often made worse by the lack, and often the unavailability, of some source information for historical mining features.

b) Using mining information to manage risk

The CA's Mining Information Database is dynamic and updated daily by an in-house team. It is not a static, historical archive as some may assume as we continue to review and process new information as it is received. Some of these updates are internal e.g., as the result of a surface hazard or subsidence claim from our Public Safety and Subsidence Department; others come from external customers undertaking their own desktop research and site works. We still receive the odd, albeit infrequent, mine plan often from personal archives or research. However, the most frequent updates we received are through the permitting and planning process – predominately where a site investigation has proven, or otherwise, the existence of a coal mine entry or mine working.

We require all those who want to access our property to do so through a permit application. This application lets us know the what, when, where and how that access will take place – and especially how they will secure the safety of the public during, and after, these works have taken place. Our permit determinations are based on reviewing our mining database (and that of third parties such as the BGS) and using our professional judgement which may include local knowledge/information on potential hazards that may not be flagged in commercial reports. Such reports provide a sound, factual evidence base to allow competent people to conduct an educated assessment. However, the reports do not infer or interpret any risk to development. We will grant a permit if we are satisfied that access is reasonable and that the public safety will remain secured. This is accompanied with a letter outlining the details of recorded mining legacy and any other information that is considered relevant to that access. This helps to ensure applicants, often developers, are well informed of potential hazards to assist them in safely undertaking site risk assessments. This process also helps to secure planning permission and a safe development in terms of mining stability. This is advised by the National Planning Policy Framework in England and Planning Policy Wales via the Local Authority Planning system.

An important part of the permit process is the completion or closure report – this is sent to us when works are concluded. This helps to ensure the mining database is kept up-to-date with as-found information and allows us to check that the work was undertaken in line with the permission granted. The closure reports may include site investigation reports containing:

- the conditions found on site which may indicate previously unrecorded workings or mine entries
- the precise coordinates for recorded mine entries which were previously only estimated from historic plans
- the treatment works that have been undertaken
- reference to the absence of coal or coal mining related features

Such information is critical in ensuring that future mining reports disclose that site investigations have occurred and what, if any, further information we may need to take into account for future application determinations in that area. Furthermore, we often access such site investigation reports within a planning consultation during later stages of the development if necessary. Processing the findings is often an iterative and consultative process with the site investigation company.

The CA is a statutory consultee to Local Planning Authorities (LPA) in the coalfield areas for which we have a dedicated in-house Planning Liaison Team. For ease we have divided the coalfield into two areas as can be seen from Figure 5.

- High Risk Area (red): constitutes approximately 15% of the coalfield and indicates the area where mining is close to the surface or has the potential to affect development
- Low Risk Area (grey): constitutes approximately 85% of the coalfield and represents the remaining coalfield area indicating where mining is likely to be at sufficient depth not to pose a risk to development

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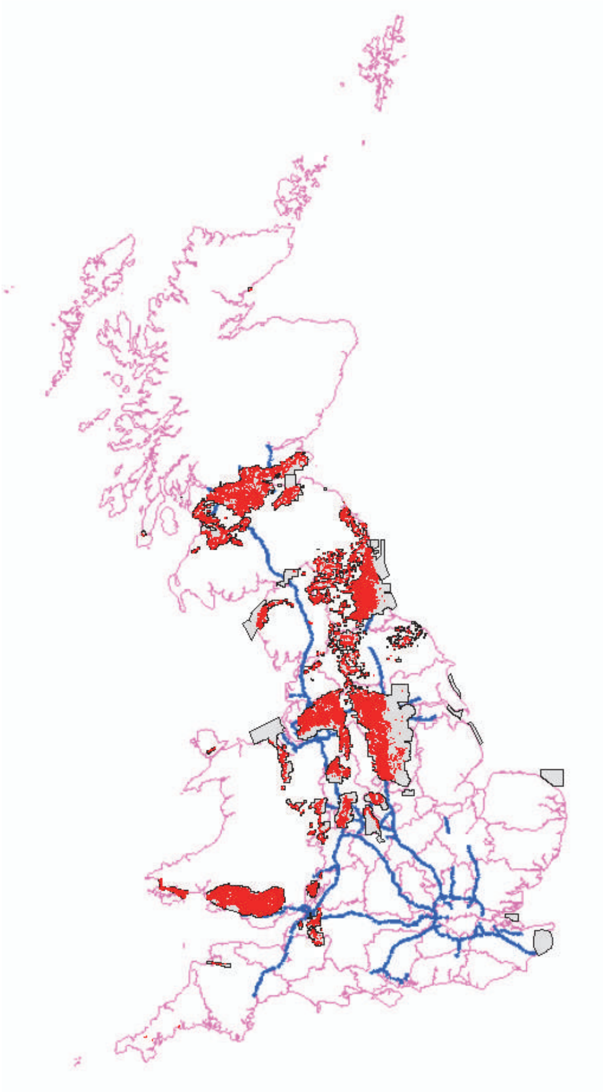

Figure 5: Location of the high risk development area (red) and the low risk development area (grey) within Great Britain © Copyright Coal Authority 2020. All rights reserved. Contains OS Data © Crown Copyright and database rights 2020.

Certain development planning applications within the High Risk Areas will need to be accompanied by a Coal Mining Risk Assessment (CMRA). The LPA then consult with the Coal Authority on its content to ensure it adequately assesses and mitigates any mining risk.

The CMRA is a detailed desktop study completed by a suitably qualified, experienced and competent person. It should examine all available plans and information such as the CA's interactive viewer; obtain/produce a detailed coal mining report; and review source data for specific features eg abandonment plan positions for recorded mine entries and workings. The CMRA needs to present a reasoned assessment of the potential mining risk to a specific development proposal. This may recommend ground investigation be undertaken to further quantify the risk.

The CA's Development Department is made up from the Planning and the Permitting & Licensing Teams. This ensures effective communication to discuss specific sites and coal related hazards. It is important to remember that gaining permission, or acceptance, by one team does not confer or imply it in another – permit applications are often discreet pieces of work on a site, feature or phase of works. The granting of a CA permit therefore reflects our acceptance that the proposed works are reasonable and that public safety remains secure. This is just one aspect of the overall LPA planning permission application process. Similarly, not all developments require the LPA to consult with the CA but they will still need our permission should their proposal have the potential to disturb or intersect our coal property.

c) Using mining information to innovate and serve customers

The CA promotes sustainable and safe development through its permitting and planning processes. We regularly engage with technical experts, developers and the public to raise awareness in terms of the potential hazards from our coal mining heritage – this includes innovative ways to remediate and exploit the mining legacy features.

The *CIRIA Special Publication SP32 (Construction Over Abandoned Mine Workings)* was the go-to guide for the site investigation industry sharing technical guidance in a non-prescriptive approach to identify, assess and mitigate mining legacy based on information gathered over many years. After further research and investigation, a well overdue update was published in 2019 to which the CA was a significant contributor and a principal funder. We were proud that David Parry, in our Mining Information Department, became co-author of the final document. This guidance was relaunched as *CIRIA* C758, *Abandoned Mine Workings Manual* and brings up-to-date the key reference publication for technical experts working to resolve the impacts of coal mining, and to develop new housing and infrastructure in a sustainable way.

There are many mining hazards that need to be assessed when planning a development, apart from the obvious potential for ground instability. These can seriously affect public safety if not properly mitigated. They include mine gases, mine water and spontaneous combustion of the coal. It can be a challenge to effectively assess and mitigate these hazards for the developer. In 2012, the CA published its *Guidance on managing the risk of gas when drilling or piling near coal* to help developers with this challenge. This was a collaborative piece of work with contributions from other public sector organisations, trade bodies and representatives from the UK's drilling companies. This guidance, updated in 2019, brings together information and specialist knowledge along with research into gas generation and pathways when drilling through coal for the purposes of exploration.

We continually engage with the public and developers to ensure they understand how mining legacy may affect their homes, their locality and their own personal safety. We have provided expert advice and support to a series of webinars organised by the CA – notably to outline what the permit service does and the role it plays in public safety. You can view all of our informative webinar series on our dedicated YouTube channel.

The CA has taken further steps to provide authoritative advice by launching a 'pre-application' service. This draws on the advice of the CA in-house teams across Planning, Permits & Licencing, Engineering and Mining Information. This service is discretional and charged on a cost recovery rate. We can only help the industry provide sustainable development through the unique mining information we hold, our internal expertise in interpreting that information, and a willingness of the developer to engage with us.

This crucial public safety role played by the Permit Team was highlighted recently in 2019 when a developer did not wait for their permit to be issued. This was made worse by them not addressing our concerns that a mine entry they were proposing to investigate was potentially beneath a neighbouring house. We needed to see what control measures would be put in place to ensure the safety of the neighbouring resident, but unfortunately they carried on without a permit which led to them being reported to the Health and Safety Executive (HSE) - we considered the issue to be serious enough to warrant this. The HSE completed their investigation and issued the companies involved with 'Fee for Intervention' charge.

A Coal Authority Permit and the accompanying letter of mining circumstance is therefore an essential component of a company's suitable and sufficient risk assessment when undertaking works which may disturb coal property.

d) Case study – Gateshead Mine Energy Scheme

With around 23,000 abandoned mines across the UK, the potential to supply geothermal heat from mine water offers a significant opportunity to decarbonise heat at scale in former mining areas (Adams *et al.*, 2019). The Coal Authority estimate that there is enough resource in place to provide sufficient heat to meet the demands of the buildings located above the coalfields. Many local authorities are taking the opportunity to explore the potential to develop mine energy systems in their areas as one response to the climate emergencies that many have declared. This interest is being supported by the UK government's Heat Network Delivery Unit and Heat Network Investment Project which aim to increase heat network uptake.

Mine energy is very compatible with heat networks because the low temperatures involved mean that pipework costs can be reduced by using non-metal pipes and decentralised ambient loop technology can be deployed. The Coal Authority currently produce around 100MW of heat collectively from their mine water treatment schemes and these are being investigated as possible heat sources for new heat networks at, for example, Seaham Garden Village. Here water is not available at the surface but, subject to the location and nature of the subsurface mining infrastructure, there is an opportunity to drill boreholes to access water from the mine workings and return it following heat extraction as at Gateshead detailed below.

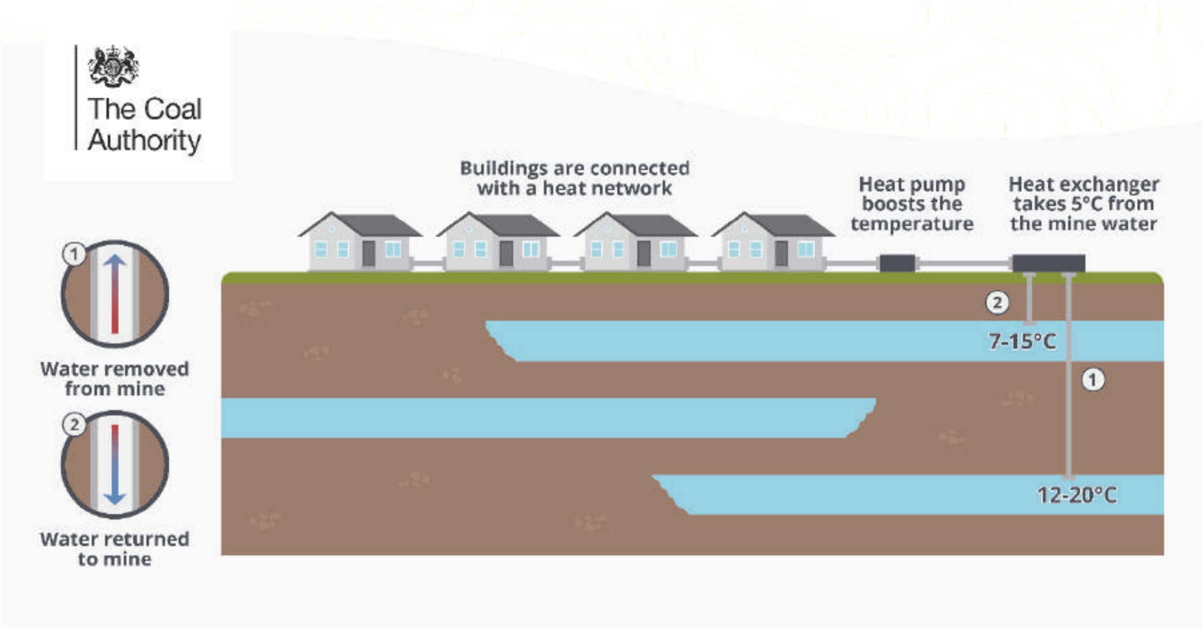

Figure 6 - Schematic diagram of a mine energy scheme

Gateshead Council has recently been awarded a grant of £5.9M via the UK government Heat Network Investment Project giving them the opportunity to double the size of the existing heat network in Gateshead Town Centre. This project will require boreholes to be drilled to a depth of around 150m to access the mine water and return it underground following heat extraction as illustrated in Figure 6. The council-owned Gateshead Energy Company plans to install 5.5km of new heating pipes to the east of Gateshead Town Centre that will supply heat to up to 1,000 new private homes, a care home, Gateshead International Stadium and other Council-owned buildings in the area. A heat exchanger will harvest heat from the mine water and a 6MW water source heat pump will be used to upgrade the temperature from ambient to supply temperature.

The Council is working closely with the Coal Authority who manage all the disused mine working under Gateshead to ensure the success of the project. Gateshead Energy Company, which is wholly owned by Gateshead Council, already operates a successful heat network which supplies hundreds of homes and businesses in Gateshead town centre with low cost, low carbon heat and power using a gas-fired Combined Heat and Power (CHP) plant. The proposed mine energy system will enable the Gateshead Energy Company to reduce its reliance on combined heat and power, further reducing the Council's carbon footprint. As well as hundreds of homes in Gateshead's town centre, prestigious buildings such as Gateshead Civic Centre, Gateshead College, Sage Gateshead and BALTIC also receive heat and power via the network.

Conclusions

The Coal Authority has been responsible for the management of coal and coal mine workings within Great Britain on behalf of the state since its inception in 1994. From this foundation we have grown and adapted our approach to seek out effective, efficient and innovative ways to safely manage our estate – both on the surface and underground. We use our expertise to look at ways to turn potential liabilities into assets such as the use of iron ochre to stabilise arsenic contaminated soils or the use of recovered heat from our coal mines.

We are rising to the challenge to allow greater access into our coal and coal mine workings to keep up with the increasing demand. Our Permit and Planning Teams are now embedded in the development industry and have great working relationships with the coalfield LPAs.. Our teams are at the forefront of bringing new technical guidance to life and making sure it reflects the industry today and our changing customer needs. We seek to make our information and guidance freely available and accessible to all.

Our Mining Information, Permit and Planning Teams are embedded across the wider CA business and markets – we assist the Welsh Government, Network Rail, HS2, and Natural Resources Wales, amongst others, in them understanding the impacts of mining legacy risk. This is only possible by continuing the proactive updates to our dynamic mining information database ensuring our customers gain the most up-to-date and timely information from which all users can make rigorous, evidence-based decisions.

Indeed, blending our historical archive data with modern approaches to data management and delivery paves the way for new and innovative investigations and developments – seen with great success in the access of former mines for heat extraction. This green energy not only benefits the climate but the wider local economies alongside heating homes and businesses.

It is with such a rich history managing this mining legacy that we continue to adapt and evolve to the challenges in an ever-changing modern world.

The Coal Authority – we make a better future for people and the environment in mining areas.

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Permitting Process (YouTube): https://www.youtube.com/watch?v=yXSZSa5A55U

Coal Authority Interactive Viewer: https://mapapps2.bgs.ac.uk/coalauthority/home.html

LEGACIES OF MINERAL EXTRACTION AND SUSTAINABILITY OPPORTUNITIES