Harworth Group Gateway 36 Development Mine Energy Concept Study with Renewable and Low Carbon Solutions

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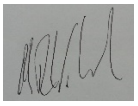
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1 Executive Summary

The coal fields underneath the Gateway 36 development contain sufficient warm water to provide a sustainable heating and cooling resource for the anticipated demand from the development, which is in the order of 5022 MWh p.a. This gives an average of 0.6MW per hour, and an estimated peak required capacity of c. 2MW.

The estimated capex and opex costs for such a mine energy scheme are £4,410,000 and £250,316 per annum respectively.

A small operational profit would be achieved but this would be insufficient to pay back the capital cost within a commercially acceptable timeframe.

As such, it is the considered opinion of Nordic Heat that mine energy would not be viable for Phases 2 and 3 of the Gateway 36 scheme in its current form and timeframe.

The technologies and processes related to capturing, up-grading and distributing mine energy are well known and proven. The main obstacle is to make these solutions affordable compared with existing heat solutions based on gas.

With funding to support the capital cost of the scheme, a viable long term commercial model could be developed, particularly if the remaining phases of the Gateway 36 development are included such as the Hoyland North Masterplan Framework.

Additional commercial, carbon and social value would accrue from supplying the mine energy scheme with renewable energy either generated on-site or purchased via private wire connections to 3rd party electricity generation sites such as wind farms.

The Gateway 36 Development has the potential to have leading low carbon dioxide emissions and energy use compared with similar development built to current Building Regulations.

The Gateway 36 Development is already building an integrated approach for inclusion of Energy Efficiency with Phase 3 Building 2 targeting delivery of a BREEAM Excellent rating. Further consideration of Renewables Decentralised Generation is recommended with a detailed assessment to include Concept Designs, Project Planning and Market Engagement for Investment, EPC delivery and ESCo O&M.

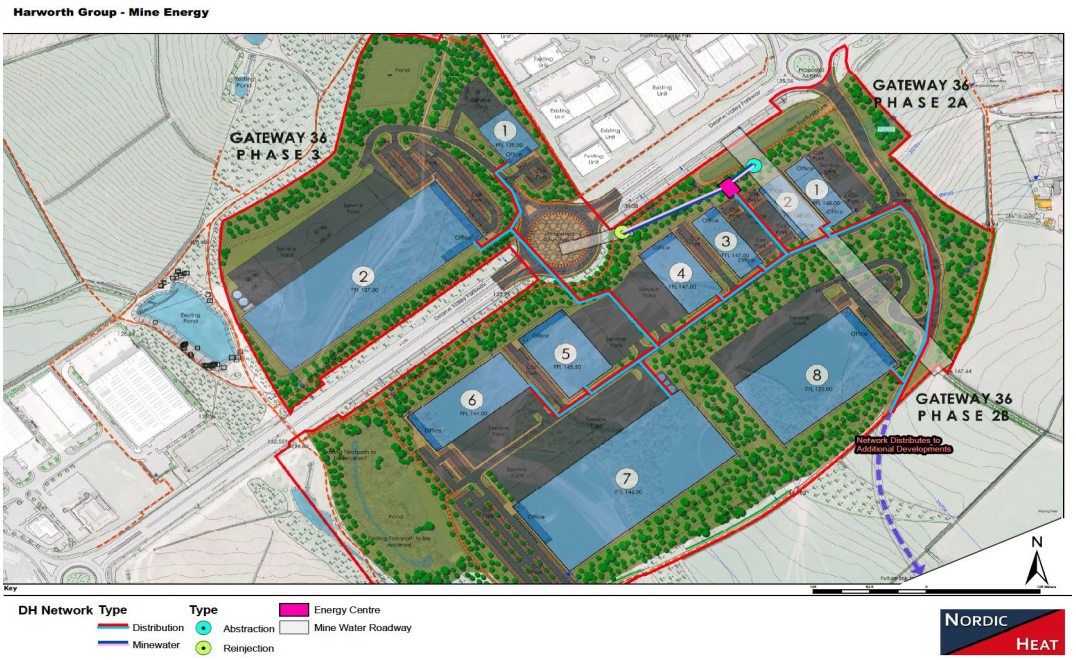
2 Introduction

Harworth Group are committed to exploring mine energy schemes for their developments.

Nordic Heat have prepared this Gateway 36 Development Mine Energy Concept Study with Renewable and Low Carbon Solutions Report to inform Harworth Group of the potential to integrate mine energy with the Gateway 36 Development in response to a Local Planning Authority Planning Permission condition and also to provide a high level strategy for technologies applications that could significantly reduce energy demand and carbon emissions for proposed Development Master Plan buildings.

The Coal Authority indicate that mine water below the Gateway 36 development site (utilising the Top Fenton and Flockton Thick Seams) would be able to provide a peak heat thermal output of up to 2 MWth and an annual heat yield of 5 GWth. The water level is estimated to be approximately 70m from the surface with the 'Seam', and therefore drilling, depths between 100m and 225m. Associated CAPEX and OPEX for such a Project has been estimated at ***£4.41 million*** (see Section 5.4) and ***£250K per annum*** respectively, which taken against potential revenue generation of £312K annually for heat supply to identified Master Plan Buildings would deliver a ***simple payback of 71 years***. An overview extract of the potential scheme is detailed below in Figure 1 and Appendix 10.2 shows full Plan.

Figure 1 – Rockingham Gateway 36 Development – Mines Energy Project Plan with Energy Centre and Building Connections



The payback period indicates that a mine energy scheme for Gateway 36 Phases 2 and 3 will not deliver an economically viable outcome without significant funding for the capital outlay and/or a substantial increase in customer heat loads.

With the imminent closure of the UK government's Renewable Heat Incentive (RHI) and the Heat Network Investment Project (HNIP), immediate public funding options are limited. The Green Heat Network Fund is due to open in January 2022 but this start date does not align with the Gateway 36 Phases 2 and 3 construction programme. It also has specific outputs that the current mine energy scheme for Gateway 36 does not meet.

Of benefit to the scheme would be to spread the capital cost of the project among more customers, thereby also increasing revenues. Significant opportunity therefore lies in considering the deployment of mine energy to homes and other energy users identified in the Hoyland North Masterplan Framework

An optimised commercial approach could be met by:

- Securing grant funding support for the capital investment
- Developing a customer profile for the scheme that is optimal for energy revenues as well as leasing revenues

- Implementing energy efficiency through demand measures and building innovative, high performance, energy efficient buildings.
- Installing on-site renewable and low carbon energy generation assets with additional demand being supplied by off-site carbon offset initiatives such as investing in tree planting schemes

This report also specifies a range of energy efficiency measures that could be implemented and discusses the potential impact that best available technologies could have on the energy demand and carbon emissions of the development recognising that for Phase 3 Building 2 the occupier has indicated delivery of a building that will achieve Building Research Establishment Environmental Assessment Method (BREEAM) Excellent level.

A range of renewable and low carbon technologies are discussed and their initial feasibility for different areas of the development appraised.

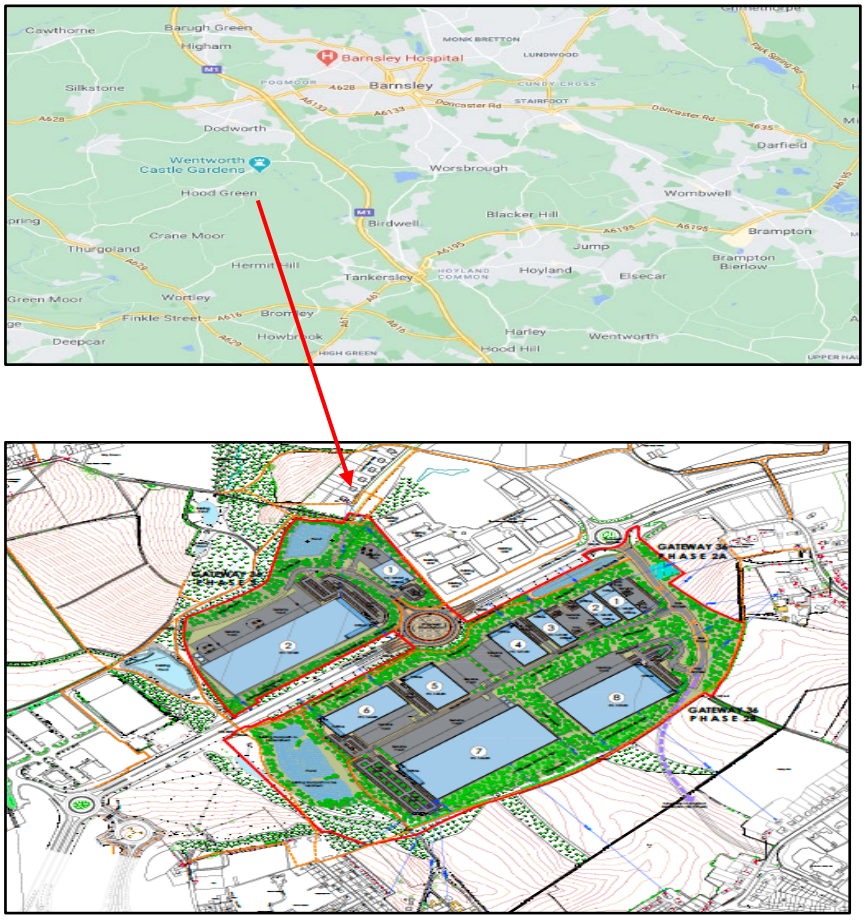
This Report also discusses the commercial potential for Harworth Group to develop an Energy Services company (ESCo) supplying mine energy and other renewable energy for the whole Gateway 36 project including the Hoyland North Master Plan.

3 Gateway 36

The Gateway 36 development is located on the site of the former Rockingham Colliery just off Junction 36 of the M1 near Tankersley Yorkshire. Harworth Group is interested in exploring the potential for using mine energy and potentially other forms of renewable heat and power generation on the site. Reference has been made to master plan drawing number 12006-1-1 10 showing phases 2 and 3 of this development (for 9 and 2 units respectively) giving a total development size of 97,288.2m^2. Location and Master Plan Layout are shown below in Figure 2.

Outline planning permission has been awarded with a condition requiring opportunities for using mine energy to be investigated. Barnsley MBC are particularly interested in developing mine energy schemes, building on the town's distinctive local resources and heritage to provide secure, sustainable, low-cost energy.

Figure 2 – Gateway 36 Development Location and Master Plan



4 Approach and Background

The low and zero carbon design principles for the development take into account current planning policy guidance, such as the Future Homes Standard (31% lower emissions from 2021) aiming to demonstrate the benefits of sustainable development against indicated design horizons. Specifically, Gateway 36 will consider and promote where appropriate, energy efficient buildings; development heating schemes, the use of available mine energy and building embedded renewables. Specifically, a Detailed Mine energy Concept Study has been undertaken with core outputs provided by the Coal Authority Rockingham Colliery Report detailed in Appendix 1 and a technology overview provide in Section 4.

Through an ESCo or other delivery partnership, Harworth Group will seek to generate where possible near or on-site renewable, low carbon electricity and heat for the Gateway 36 development by exploring the use of a range of technologies detailed in this report.

A complementary relationship is planned between energy efficiency measures and renewable energy technology implementation to significantly reduce Target CO_2 Emissions Rates (TER) for carbon dioxide emissions.

This relationship provides a strategic approach to delivering sustainability objectives by displacing grid supplied energy with on-site and localised carbon offset renewable energy generation assets and by minimising;

- embodied energy for construction materials
- construction waste
- energy use for all building services

This Report sets out various measures to improve the energy performance of proposed development buildings through incorporation of passive and active solar techniques, energy efficiency measures associated with the systems within the buildings and general improvements to the thermal performance of the building fabric. As a baseline, a predictive energy demand (PED) for the Gateway 36 identified initial Development Phases has been established and the potential impact of the above measures is estimated. Finally, potential renewable and low carbon energy generation technologies

are discussed, with a focus on Mine Energy in response to LPA paragraph 23 Planning Condition for the Development.

5 Predictive Energy Demand and Carbon Emissions

As discussed above, it is the aspiration of the Gateway 36 Development to implement a leading approach to sustainability.

The baseline PED and associated carbon emissions have been estimated, assuming that the site conforms to Part L2A of the Building Regulations with 2016 Amendments: Conservation of Fuel & Power in New Buildings.

The baseline modelled PED for heating is 5022 MWh/yr, producing approximately 1,009 Tonnes/yr of Carbon emissions from a (business as usual – BAU) gas supply. By using heat pumps running on mine water at Rockingham, the Coal Authority estimates that a CO2 saving of 68.88% can be achieved.

Building and Phase ID	Building Type/Use	Identified Unit Floor Area m^2 (including office area)	Annual estimated Electricity consumption (KWh)	Annual Estimated Heating Consumption (KWh)*	Annual Estimated Cooling Consumption (KWh)**	Annual CO2 Equivalent Emissions Gas Consumption (tonnes/Year)	Annual CO2 Equivalent Emissions Electricity Consumption (tonnes/Year)	Unit Target Emission Rate kg CO2/Year/m2.
Phase 2 Unit 1	Retail	2416	398558	136800	84000	27	20	
Phase 2 Unit 2	Retail	2416	398558	136800	84000	27	20	
Phase 2 Unit 3	Retail	2787	459872	159600	96000	32	22	
Phase 2 Unit 4	Industrial	4274	71795	245100	148000	49	35	
Phase 2 Unit 5	Industrial	5574	93647	319200	192000	64	45	
Phase 2 Unit 6	Industrial	6968	117057	399000	244000	80	57	
Phase 2 Unit 7	Industrial	23690	397997	1350900	824000	271	192	
Phase 2 Unit 8	Industrial	14400	241920	820800	500000	165	117	
Phase 3 Unit 1	Industrial	2323	39020	131100	80000	26	19	
Phase 3 Unit 2	Industrial	23226	390193	1322400	808000	266	188	
Sub Totals (Energy in MWh, CO2e Tonnes)			**2609**	**5022**	**3060**	**1009**	**713**	

Note 1 : Energy Benchmark data breakdown for Heating and Cooling provided by from FHP Consultants February 2021

Note 2 : Energy Benchmark data breakdown for Electricity based on CIBSE TM46:2008 Tables

*Note 3 : * Heating Requirement based on 5700 Hours a year, ** Cooling requirement based on 4000 hours a year*

Note 4 : UK Government BEIS GHG Conversion Factors 2020, Grid Electricity 0.23314 kgCO2e/KWh, NGas 0.20094 kgCO2e/KWh

The baseline scenario anticipates an electricity load (not including the energy demand for heat pumps and mine water pumps) of 2609 MWh at a cost of £298,730.50 (@ £0.1145/kWh) with a total yearly operation carbon emission of 553.7 tonnes per year.

Further cost and CO_2 reductions could be achieved if the electricity supplied could be from renewable sources such as private wire from a wind farm or on-site generation. Based on project experience in another mining area in the UK, it is estimated that a private wire connection to an off-site renewable energy source (such as an adjacent wind or solar farm?) could potentially reduce electricity costs by up to 50%. Further cost and carbon savings could be achieved from on-site renewables generation.

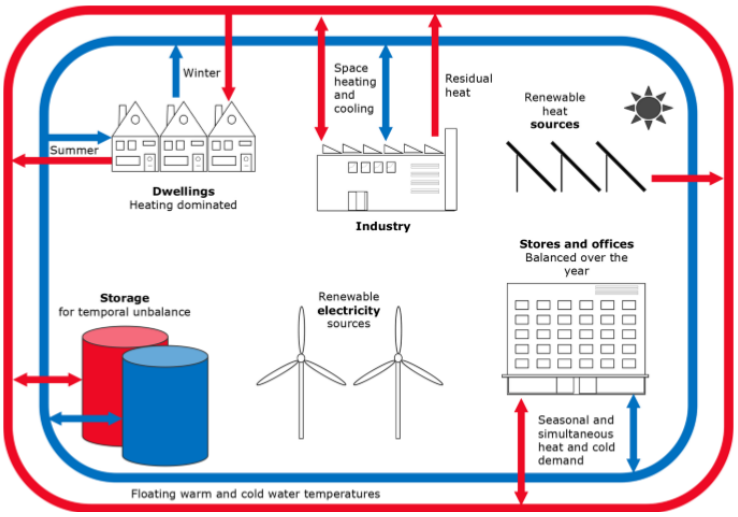
If for the examples above, if an alternative renewable electricity supply with a lower than grid supply cost was available, it would significantly enhance the commercial model for the mine water heating scheme (reducing operational costs significantly).

The potential cooling load has yet to be fully modelled by Nordic Heat. Alongside purchasing lower cost renewable energy for cooling, mine water has the potential to be used to enhance the efficiency of chiller technologies. With a base case electricity demand of 2609 MWh, a saving of £150,000/year on electricity costs could be made if the electricity purchase price was halved (by using electricity from on-site renewable generation or private wire). This would result in further carbon reductions dependant on the technology used.

The requirement to provide a comfortable environment for the building's inhabitants (people and equipment) has resulted in an increased demand to include enhanced cooling facilities within new buildings, to counter the trend in increasing higher ambient temperatures resulting from improved building insulation and global warming.

Fifth Generation District Heating and Cooling (5GDHC) is a proven way of meeting both heating and cooling demands and is particularly compatible with mine energy.

In Heerlen - The Netherlands, for example, 5GDHC enables shallow geothermal energy from flooded former mines to provide both heating and cooling to the town. The central network includes a dual supply of both warm and cool water. If end-users take heat from the warm supply, they return reciprocal cool water to the cool supply. As such all energy flows are kept in the system. Efficiency losses are in the order of 5% instead of 25% for conventional heat grids.



The Concept designer for the Heerlen 5GDHC project, Rene Verhoeven, is a member of the Nordic Heat strategic energy development team.

6 Commercial Modelling

The following tables provide a high-level commercial model for using mine energy to supply Phases 2 and 3 of Gateway 36. Further detailed techno-economic modelling is needed to create a robust business case.

Revenue

Revenue – Heating only	£
Heat Sales per annum	312,500
Total Revenue	**312,500**

Assumptions;

- Heat Demand/Sales = 5,000 MWh
- Price = £62.50/MWh (HNIP modelling)

Capex

Outline Capex

CAPEX	£m
Borehole Abstraction System	0.78
Mine Water Heat Recovery Energy Centre	0.45
Ambient Loop	0.70
Commercial Building customer connections – Heat Pumps	0.88
Sub Total	2.81
Uplifts – Design, PM, Prelims	1.6
Total Capex	**4.41**

Opex

Opex	£ (p/a)
Energy Centre	5,022
Heat Exchanger	1,000
Water Treatment	1,000
Heat Pumps and Mine Pumps inc. Repex	32,000
Network – Fixed Costs	10,000
Network – Variable Costs	10,044
HIU	3,000
Total	**62,066**

Energy Costs for Heating

Assumptions;

- 60m pumping head
- Heat Pump COP = 4
- System COP = 3.46
- Electricity Cost = 11.45p/kWh

Opex - Energy Costs for Heating only (Electricity)	£ (p/a?)
Mine Water Pump	44,500
Heat Pumps	143,750
Total	188,250
Opex Total	**250,316**

Once installed and fully operational, the Mine Energy Centre	£
Revenue	312,500
Opex	250,316
Operating Profit	**62,184**

Options for Enhanced Viability

The commercial viability of using mine energy for the Gateway 36 scheme could be enhanced by 1) increasing the number of customers and 2) changing the nature of the energy demand

Increased Customer Numbers

Gateway 36 is adjacent to the Hoyland North Masterplan area being developed by Barnsley Metropolitan Borough Council (BMBC)

Creating a green, sustainable development for Hoyland North is critical for BMBC;

> "A golden thread running through the Masterplan Framework process is health and well-being principles and sustainability initiatives."
>
> "The green infrastructure will enable connectivity and integration of the new development with existing communities and provide strong, convenient connections to existing services and facilities within Hoyland and to the new employment areas along the Dearne Valley Parkway."

Hoyland North offers significant mine energy supply opportunities;

- 37 hectares of 'employment' land
  - B1(c) – light industrial
  - B2 – general industry
  - B8 – storage and distribution;
- 765 new homes

<u>The Rising Price of Carbon</u>

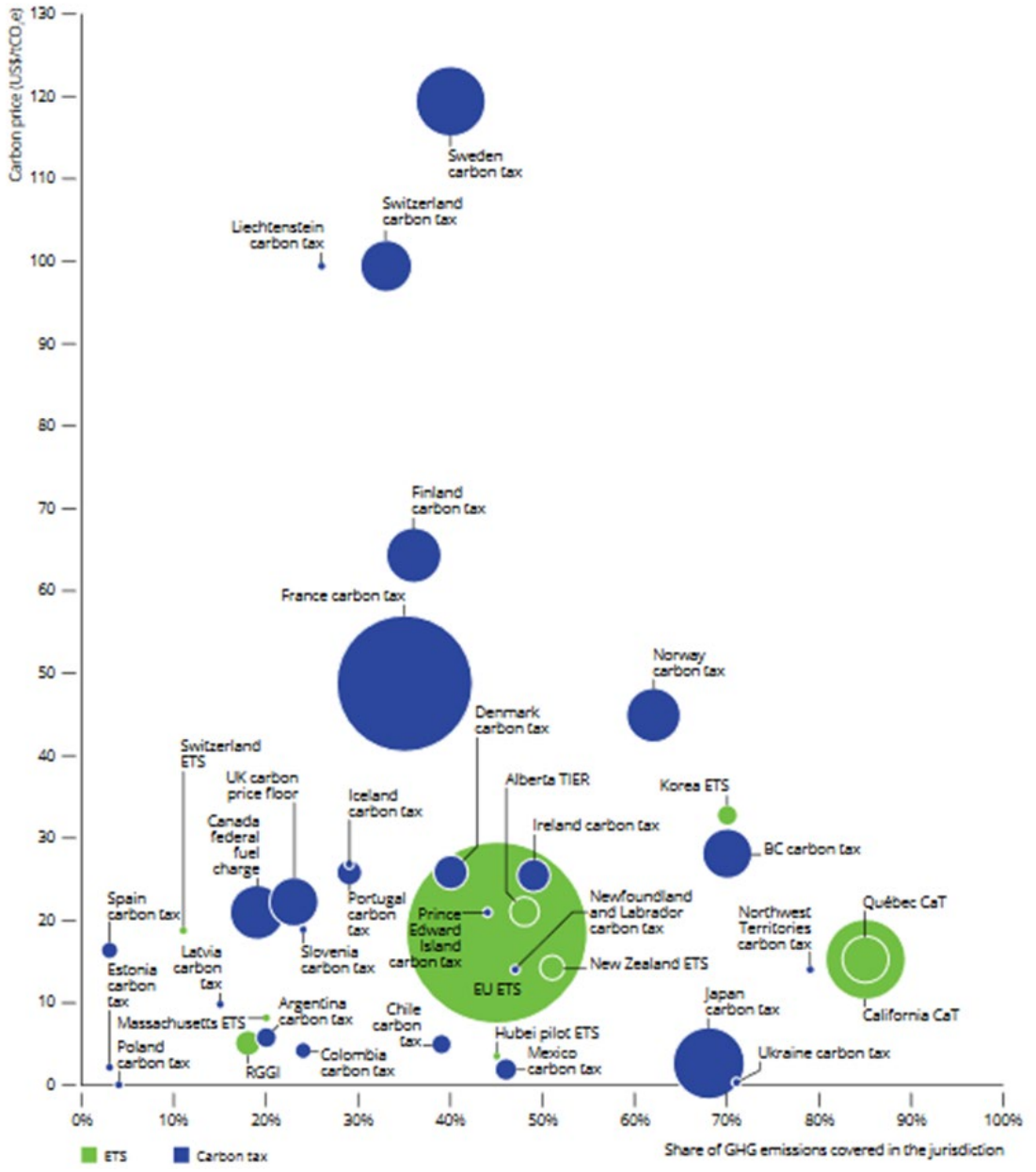
Energy derived from fossil fuels is increasingly costly. This is having a marked impact on business cases for commercial developments, significantly increasing;

- revenue streams for renewable energy schemes
- costs and risks for fossil fuel schemes

As a consequence, mine energy schemes will become increasingly commercially viable.

On the next page is an infographic showing the international cost of carbon.

Sweden, for example is now pricing carbon at around £120 per tonne while in the UK it is at £22 per tonne, suggesting that carbon in the UK is substantially underpriced.



All international carbon pricing models indicate substantial rises as the world seeks to meet 2050 carbon reduction targets.

In the UK, the Treasury has published guidance for predicting the future cost of carbon and setting out scenarios on 3 levels – low, central and high.

https://www.gov.uk/government/publications/valuation-of-energy-use-and-greenhouse-gas-emissions-for-appraisal

7 Mine Energy

7.1 Mine Energy

Around a quarter of UK's homes and businesses are located on former coalfields. Since mining ceased, the mine workings have filled with water that is continuously warmed by the natural heat of the earth. The Coal Authority estimates that this renewable source of energy is sufficient to heat all the buildings in former mining areas.

In May 2021, the 'Mine Energy White Paper' was published with the support of BEIS, the Coal Authority and key public and private sector organisations interested in developing mine energy projects. It identifies both opportunities and the challenges of implementing them. See Appendix 3 and the link below.

https://www.northeastlep.co.uk/wp-content/uploads/2021/05/Mine-Energy-White-Paper_FINAL.pdf

The commercial challenges facing a mine energy supply for Gateway 36 are common to mine energy schemes across the UK and are explored in depth in The Mine Energy White Paper. Key factors include;

- Mine energy schemes currently depend on public subsidy and the future subsidy arrangements in the UK are uncertain.
- The price of gas for heating is low and this makes it difficult for mine energy schemes to compete given their relatively high set up and operational costs.
- The Coal Authority has decided to charge for mine energy but has not yet established its charging structure.
- Mine energy schemes are considered high risk which increases costs and deters investors.
- There is a shortage of expertise to deliver mine energy schemes which also increases costs.

7.2 Mine Energy Technology Overview

The UK's Energy Strategy continues to be in transition moving away from its historic core reliance on fossil fuels. A significant proportion of UK energy demand is now met through renewables (>40% in 2019) and key to this continued path will be the incorporation of heat energy from the ground, water and air.

The UK's abandoned mining infrastructure now lies largely derelict and to a certain extent emerging generations have forgotten its existence. Yet, people in former mining towns and villages remain strongly connected to their mining heritage, even though its decline brought hardship and, in some areas, environmental pollution.

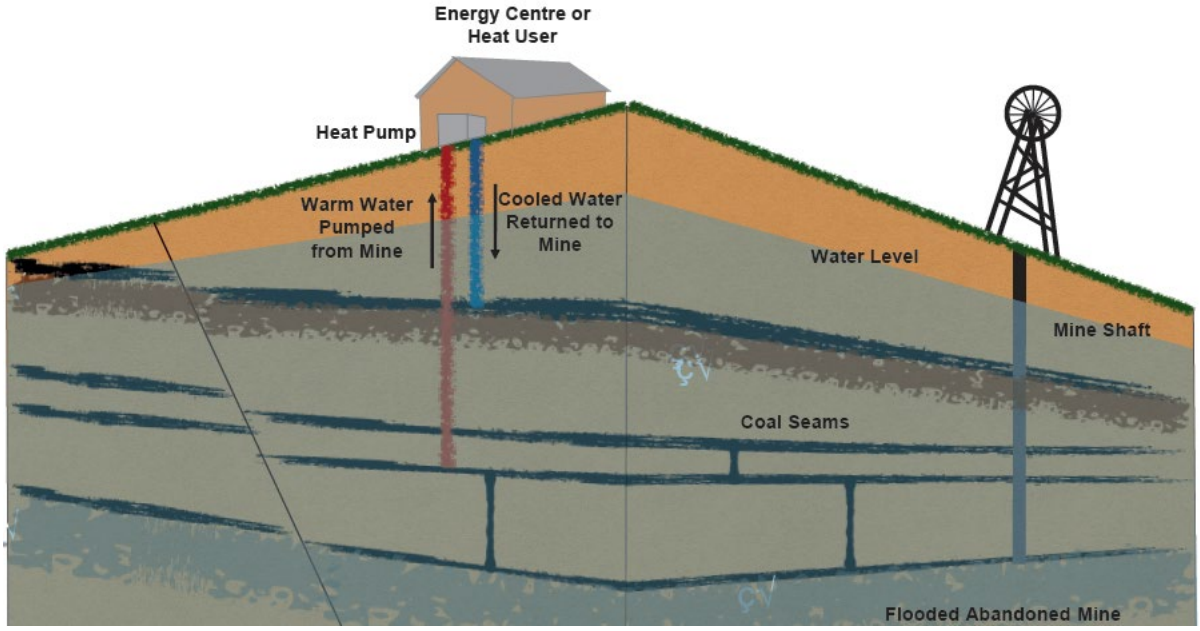
The mining legacy and the associated infrastructure can and is being repurposed and has the potential to be a key future heat energy source for decentralised energy systems deployment. The mine shafts and galleries that are now flooded contain copious volumes of water at 12-20℃. Whilst water at this temperature is not appropriate for everyday LTHW requirements, the integration of heat pumps can boost temperatures to provide hot water and space heating. Heat pumps require an energy input, but because each kW of electrical energy input could be expected to deliver a heat output of 3-4 kW, heat is provided in an energy efficient way.

Mine water is accessed by drilling boreholes into flooded workings and pumping it to the surface, where heat is removed using a heat exchanger. The now-cooled mine water is then returned to the subsurface as detailed in Figure 2 below while the warmed water from the other side of the heat exchanger is boosted using a heat pump to the required space heating temperature.

Using mine water as an energy source compared with individual closed-loop, ground-source heat pumps offers advantages for both buildings and domestic properties. Decreased landscaping and garden size of newer housing stock leads to reduced space for horizontal ground arrays, meaning that boreholes would be required, which are more capital intensive. In addition there can often be dual benefit in reduced mine groundwater management with risks associated with ground stability and flooding both controlled and removed.

Mine-water heat systems are generally operated open-loop, which offers better thermal efficiency than closed loop ground-source heat systems. Finally, mine-water systems offer economies of scale, meaning that clusters of buildings including mixed use development could be served from a single mine and a few boreholes. To deliver this vision requires support in both planning and building control policies that positively encourage the future development of low-temperature energy systems. A detailed appraisal of the heat energy potential from the Gateway 36 Rockingham Colliery site is provided in **Appendix 1** of this Report.

Figure 3 – Mine Energy Technology Concept



7.3 Preliminary Findings for Rockingham Mine Energy opportunity – Coal Authority

- Mine energy is technically feasible at Rockingham with workings in a number of seams below the base of the opencast void.
- The 'lowest' seam extracted was the Swallow Wood. Workings remain in the Flockton Thick (limited, in the central part of the site), and extensive workings in the Top Fenton, Low Fenton, Parkgate, Thorncliffe and Silkstone Seams
- Drilling depths would be less at the western end of the site, increasing as you go east.

  - The estimates in the Table below are based on abstraction boreholes to the Parkgate or Thorncliffe horizons and reinjection to the Top/Low Fenton.
  - Boreholes at the western end abstraction c. 175m to 200m and reinjection 150 to 155m. Cost c. £175k to £300K and £150K to £200K respectively
  - Boreholes at the central area of the site abstraction c. 225m to 250m and reinjection 200 to 205m. Cost c. £225k to £350K and £200K to £280K respectively
  - Boreholes at the eastern end abstraction c. 300m to 350m and reinjection 280 to 285m. Cost c. £300k to £450K and £280K to £400K respectively
  - There may be an opportunity to drill to the Flockton Thick and Top Fenton Seams, which is worked under more limited areas in the central part of the site. This is the shallowest seam which has not been removed by the opencast.
  - Initially any drill would be initially through the opencast backfill.

- Mine water level well understood, many connections between mines and level recovered to within about 60m of surface.
- Based on the information, provided the heat demand for the fully developed site is in the order of 5022 MWh p.a. This gives an average of 0.6MW per hour, and an estimated peak required capacity of c. 2MW.
- This would require a flow of c. 71 l/s with a heat pump COP of 4.
- The table below sets out energy use/costs for a scheme of this capacity against a gas equivalent at 60m .
  - Saving c. 15% on OPEX v natural gas
  - Saving c. 69% on emissions v natural gas.

Input parameters				Emissions factors	
Flow	71.7 l/s	Electricity tariff	11.5 p/KWh	Grid electricity	0.23314
Delta T	5 °C	Gas tariff	3.3 p/KWh	Natural gas	0.18387

RAW (excluding RHI) **Emissions**

Effect of pump head on COP and OPEX cost per hour — 2000 KWth per hour output

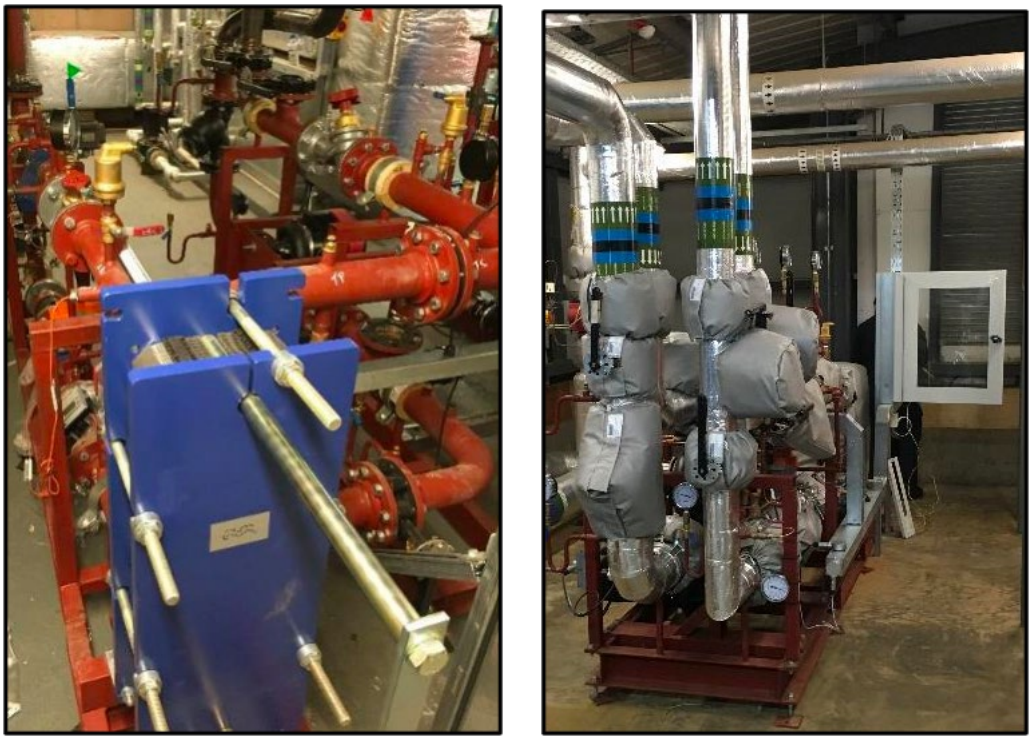
Pumping Head (m)	Pump energy KW	COP Heat pump	System COP	Mine pump cost/hr	Heat pump cost/hr	Overall cost/hr	Cost/hr gas	Mine GSHP Saving /hr	Mine GSHP Saving %	carbon mine energy Kg/h	Carbon gas heating Kg/h	Saving
0	0.0	4	4	£0.00	£57.50	£57.50	£77.65	£20.15	26%	116.6	432.6	-73.06%
20	25.8	4	3.80	£2.97	£57.50	£60.47	£77.65	£17.18	22.1%	122.6	432.6	-71.67%
40	51.6	4	3.63	£5.93	£57.50	£63.43	£77.65	£14.21	18.3%	128.6	432.6	-70.28%
60	77.4	4	3.46	£8.90	£57.50	£66.40	£77.65	£11.25	14.5%	134.6	432.6	-68.88%
80	103.2	4	3.32	£11.87	£57.50	£69.37	£77.65	£8.28	10.7%	140.6	432.6	-67.49%
100	129.0	4	3.18	£14.84	£57.50	£72.34	£77.65	£5.31	6.8%	146.6	432.6	-66.10%
120	154.8	4	3.05	£17.80	£57.50	£75.30	£77.65	£2.34	3.0%	152.7	432.6	-64.71%
140	180.6	4	2.94	£20.77	£57.50	£78.27	£77.65	-£0.62	-0.8%	158.7	432.6	-63.32%
160	206.4	4	2.83	£23.74	£57.50	£81.24	£77.65	-£3.59	-4.6%	164.7	432.6	-61.93%
180	232.2	4	2.73	£26.70	£57.50	£84.20	£77.65	-£6.56	-8.4%	170.7	432.6	-60.54%
200	258.0	4	2.64	£29.67	£57.50	£87.17	£77.65	-£9.52	-12.3%	176.7	432.6	-59.15%
220	283.8	4	2.55	£32.64	£57.50	£90.14	£77.65	-£12.49	-16.1%	182.7	432.6	-57.76%
240	309.6	4	2.47	£35.60	£57.50	£93.10	£77.65	-£15.46	-19.9%	188.8	432.6	-56.37%
260	335.4	4	2.39	£38.57	£57.50	£96.07	£77.65	-£18.42	-23.7%	194.8	432.6	-54.98%
280	361.2	4	2.32	£41.54	£57.50	£99.04	£77.65	-£21.39	-27.5%	200.8	432.6	-53.59%
300	387.0	4	2.25	£44.51	£57.50	£102.01	£77.65	-£24.36	-31.4%	206.8	432.6	-52.20%
320	412.8	4	2.19	£47.47	£57.50	£104.97	£77.65	-£27.33	-35.2%	212.8	432.6	-50.81%
340	438.6	4	2.13	£50.44	£57.50	£107.94	£77.65	-£30.29	-39.0%	218.8	432.6	-49.42%
360	464.4	4	2.07	£53.41	£57.50	£110.91	£77.65	-£33.26	-42.8%	224.8	432.6	-48.03%
380	490.2	4	2.02	£56.37	£57.50	£113.87	£77.65	-£36.23	-46.7%	230.9	432.6	-46.64%
400	516.0	4	1.97	£59.34	£57.50	£116.84	£77.65	-£39.19	-50.5%	236.9	432.6	-45.25%

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7.4 Mine Heat Building Connections

For Mines Heat and or other Ground Source Renewable Heat buildings, connections will typically consist of a non-direct connection via a single plate heat exchanger. A packaged skid similar to Figure 4 below would be installed in building plantrooms, which would contain a plate heat exchanger, 2 port valves, isolation, metering and differential pressure control.

Figure 4 Typical non-domestic skid arrangement for Public Buildings



Naturally, certain connections will require architectural and structural engineering input during detailed design and may be subject to planning approval.

8 Energy Efficiency

A substantial proportion of the potential carbon emissions reductions for the development will come through reducing the energy demand.

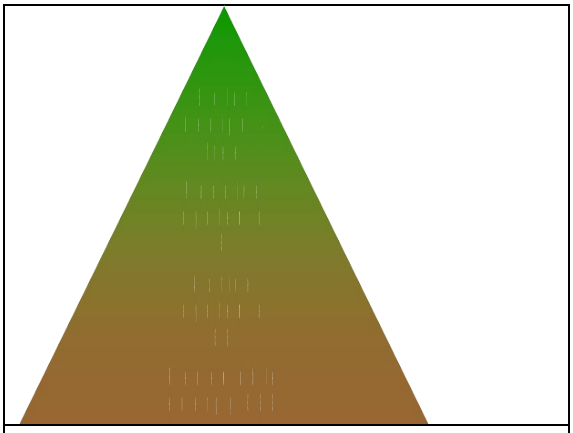


Figure 4 - Carbon Reduction Hierarchy

Gateway 36 and developments of its type take a holistic approach to carbon mitigation based on a hierarchy as detailed in Figure 4 where the most effective measures used to reduce carbon emissions are those that cost the least.

The design of the building and building services should seek to minimise energy consumption and carbon emissions. Taking this into account the following report sections suggest a number of initiatives and possible efficiency deliverables that should be considered by the development project team in order to make Gateway 36 an innovative and energy efficient development.

The key measures that should be considered as a minimum are given below:

- High performance building fabric reducing the heat loss parameter (HLP) and therefore carbon emissions arising from space heating including low U-value building elements and improved air tightness. Further detail is provided in Section 6.1.

- Consideration of innovative passive ventilation systems will be given to enable efficient building heat extraction during warmer months of the year. Alternatively, mechanical ventilation with a low specific fan power and heat recovery could be employed.

- Good access to daylight for all living spaces, particularly kitchens and living rooms, minimising the need for electric lighting.

- Dedicated low energy light fittings should be installed as standard.

- High efficiency lighting installed in all common areas and lighting installed in areas of periodic occupation to have occupancy sensors fitted to ensure that they are only on when required (e.g. waste storage, stair wells and plant rooms).

- External lighting to be high efficiency and installed with timers and/or daylight sensors to ensure they are not operational during the day.

- Individual smart metering for all units, on-display metering where it is felt this might increase awareness of energy efficiency and influence behaviour. Building Energy Management Systems to monitor and target energy use with a view to energy behaviour change.

- High efficiency electric motors installed in central services and included in the enhanced capital allowances list.

8.1 Heat Loss Parameter

Space heating makes up a significant proportion of the energy requirement for a residential dwelling. In order to minimise the energy needed for this purpose the heat losses from the building should be reduced as much as is practical, a key element towards this is to ensure that the building elements are poor conductors of heat or in other words have low U-values.

Another key factor in reducing heat losses from dwellings is the air tightness of the building envelope. The less air lost though uncontrolled ventilation, the more heat is retained within the building. A measure of air-tightness is air permeability; this is defined as the air flow rate required to maintain an excess pressure of 50 Pascals during a pressurisation test.

The fabric U-values and air permeability are key inputs into the calculation of the heat loss parameter (HLP). This in turn is one of the key factors that determine the space heating requirement of the dwelling. In order to meet the carbon reduction targets, the space heating demand must be lowered and so both the fabric U-values and air permeability will have to be significantly improved from current typical specification.

9 Renewable and Low Carbon Technologies

After the consideration and implementation of the efficiency measures above, the next step is further reduction in the CO_2 levels by integration of renewable and low carbon technology generation.

The section below highlights the main renewable and low carbon technology options and discusses their likely suitability for the Gateway 36 Development.

9.1 Combined Heat & Power (CHP)

The Development has an 11 KV grid connection which is limited to 4 MWe, taking this into account and planned additional phases of Gateway 36, the deployment of a CHP installation could provide a valuable asset for baseload power and heat which would also be compatible with inclusion of potential renewable heat sources from Mine, Air and other Ground Sources.

In order to provide sustainable CHP solutions for developments a fuel system using biomass or bio-fuels backed up by natural gas for security of supply should be considered. In addition, long-term Power Purchase Agreement (PPA) should be in place to secure revenue opportunity and project financing. This component is vital if application of CHP with District/Community Heating systems is considered for both initial planned development construction and future loads.

9.2 Heat Pumps

In addition to Mine Heat Energy Heat Pumps, there are a range of other heat pump technology applications that utilise low grade ambient or waste heat and upgrade this via a heat pump to a higher temperature that can be used for space heating or even water heating. Heat pumps are a low carbon renewable technology courtesy of having an efficiency or coefficient of performance above one, usually between two and four depending on the technology and delivered temperature.

9.3 Clearly modern building uses and environment requirements have the potential need for both heating and cooling. In this case Reversible Heat Pumps can be

utilised which work in either direction to provide heating or air conditioning (cooling) to the internal space. Solar Thermal

A solar thermal collector system provides hot water by using the energy present in sunlight to heat a collector. This energy is then transferred to a circulating fluid and used to heat hot water.

This technology could be incorporated into building roofs and on South facing elevations and could provide 40 – 60% of the annual hot water demand providing significant carbon emissions.

9.4 Solar Photovoltaics

Solar photovoltaic (PV) can be integrated into the fabric of the building, as a roof covering or as glazing, or mounted on the building.

PV is ideally suited to building applications due to its low maintenance requirement and visibility. The cost of deployment for this technology type is very competitive, in addition the ability to generate on site decentralised embedded power would be beneficial taking into account grid import connection capacity limitations.

Figure 5 Building PV Application



9.5 Wind Power

Modern wind turbine technology turns the power of the wind into electricity. This would be a useful output for the development which is likely to have a significant electricity demand, and any excess can be easily exported to the grid..

The built up nature of the development will have two detrimental effects on any turbines installed. Firstly, the obstructions will lower the mean wind speed and therefore the energy output. Secondly, they will create turbulence, which can lead to increased maintenance of the turbines.

Other factors including wind-flicker visual impact, noise impact and potential structural strengthening requirements will need quantifying and assessing when micro-wind installation is considered.

9.6 Biomass and Biofuels

Using wood fuel for heating is one of the oldest forms of renewable energy systems. Modern biomass heating uses locally sourced wood chip, or wood pellets, in a specially designed boiler which combusts the wood fuel at high temperature, attaining very high efficiencies, to produce hot water, for space or water heating, with minimal emissions.

The key issues for wood fuel heating are security of fuel supply, delivery, suitable wood fuel handling systems and sufficient space allowance for the increased plant size and fuel storage.

An alternative to woody biomass fuels are biofuels or biodiesel. These fuels are used in place of heating oil and thus have far fewer problems associated with fuel delivery and storage due to the higher energy density.

9.7 Indicative Renewable Energy Technology Capital & Operational Costs

Technology	Capacity kWth / kWe	Development Application	Indicative Deployment CAPEX £K
Solar PV	1000 kWe	Buildings Fabric & Roof Mounted	£550K/MWe Peak
Active Solar Flat Plate Collector	Heat Absorbance U-Value of 5 W/m2	Buildings Fabric & Roof Mounted	£2K/kWth
Biomass CHP (with RCIP or ORC)	1000 kWe, 1500 kWth	Energy Centre for CHP outputs to Buildings	£1500K/MWe

Wind Energy	1000 kWe	Development location	£500K/MWe
GSHP	1000 kWth	Open and Closed Loop Boreholes or Slinky Loop	£600K - 1500K/MW
ASHP	Residential 4kWth to 16kWth, Commercial Buildings application >100 kWth and above	Building or Residential Property Installed Air Source Heat Pumps	£1.5k - £2.5K/kWth

10 Delivery Models

The wider Gateway 36 Development has significant opportunity to build out a sustainable low or zero carbon development but it is recognised that to enable successful delivery a clear delivery model for implementation and operation of energy generation assets and customer interfaces is required. Three initial delivery models could be considered as follows;

- Developer Design Build Own and Operate (DDBOO), whereby the developer identifies and invests in decentralised energy generation assets, manages EPC delivery and then operates and maintains assets for customer connections (including metering and billing).

- External Design Build Own Operate (DBOO) – third party EPC with Energy Services Company (ESCo) skills set provides full turnkey solution with long term lease arrangement with Gateway 36 Development Harworth Group.

- Joint Venture ESCo Special Purpose Vehicle (SPV) – This model would set up a JV SPV between the developer and a EPC/ESCo provider to implement DBOO outcomes. The SPV could accelerate other investors to provide equity into the JV including Local Authorities or Housing Development companies for wider mixed-use developments. It is recognised that Harworth Group do not have a core business for Energy Generation Projects and therefore this option is very likely to be a preferred Delivery Model for a potential Rockingham Gateway 36 Mines Energy and wider Decentralised Energy Generation deployment.

11 Future Development Strategy

11.1 Best Fit Tenant Sectors

Based on the Gateway 36 location, Master Plan Buildings type and the potential for integrating a range of renewable and low carbon technologies there are a number of sectors which have user requirements with clear synergies to the development. These include;

- Distribution Centres – Distribution and Storage including refrigerated storage and dispatch would benefit from zero and low carbon technologies including a site wide heat network for both heating and cooling loads, integrated PV and waste heat recovery in building designs. In addition the location close to the M1 motorway is a key factor in reducing carbon emissions to rural areas.

- Data Centres – The demand and growth for Data across all sectors of the economy appears to be exponential. DC providers face a clear challenge in meeting this demand whilst delivering sustainable solutions with minimum energy and materials resource use through optimised low Power Use Effectiveness (PUE) and strategic targets to integrate renewable and low carbon technologies. With high cooling loads (up to 10 kW/m2 at the hyperscale level) the use of available renewable power and cooling/heat technologies will be a key factor for DC site selection going forward.

- B1 Light Industrial

- Adjacent Connected Housing Development

12 Appendices

12.1 Appendix 1 – Coal Authority Mine Energy Concept Study Report

12.2 Appendix 2 – Rockingham Gateway 36, Mine Energy Concept Plan with Energy Centre and Connections

12.3 Appendix 3 – Mine Energy White Paper

Appendix 1 – Coal Authority Mine Energy Concept Study Report

The Coal Authority

Rockingham Mine Energy Feasibility Review

May 2021



Disclaimer

This report has been prepared by the Coal Authority for Nordic Heat under Purchase Order 2100 dated 23 January 2021.

Any conclusions or recommendations made are those based on information obtained for the report and our current knowledge and practices. Data used within the report, either obtained by the Coal Authority or 3rd Party, has been cited within the report. Limitations of the data are identified within the report. The Coal Authority does not accept liability for the accuracy of any 3rd party data. Should new data or information become available these results, conclusions and recommendations may require amending.

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Executive Summary

Nordic Heat has commissioned the Coal Authority to carry out a preliminary study to establish the potential for flooded mine workings in the Rockingham area to form part of a low carbon heating network for a proposed development at the site which is situated just to the east of junction 36 of the M1 motorway. The area is located in the South Yorkshire coalfield which was intensively mined from the late 1700s to the mid 1990s.

The site is underlain by the Middle Coal Measures which outcrops some 3Km to the west of the site and dips at approximately 8 to 10 degrees from south west to north east. 13 seams in the area were removed by surface mining which extended to up to 50m below surface and a further 6 seams have been worked beneath the opencast site to depths of up to 380m below surface. The presence of structural discontinuities such as the south east – north west trending Elsecar Fault which runs through the centre of the site means that depth to seams is variable across the site.

Extensive areas of flooded workings underlie the development site and the mine water level lies at approximately 66 to 73m below the surface. A significant number of mine roadways still exist in the locality of the Rockingham Colliery shaft pillar in seams below the opencast site floor which may form suitable good quality targets for abstraction and reinjection boreholes these include the Flockton Thick and the Top Fenton Seams. Other, deeper, seams and associated workings exist too and may also be suitable targets but at increased cost. As seams are shallower to the west of the site this area may provide more cost effective in terms of borehole drilling.

Mine water temperatures are anticipated to be in excess of 15^{o}C and the 'reservoir' available for mine energy purposes is likely to be substantial and, subject to drilling and testing to confirm connectivity, may be able to support a heating (or cooling) system of a scale anticipated for the development in question (up to 2MW peak, 5,000MWh p.a.). Ability to abstract sufficient flow to feed a system of this scale would be subject to drilling boreholes and test pumping and also subject to obtaining the necessary licenses and permits from the Environment Agency (regulator) and The Coal Authority.

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1.0 *Introduction*

Nordic Heat has commissioned the Coal Authority to carry out a preliminary study to establish the potential for flooded mine workings in the Rockingham area to form part of a low carbon heating network for a proposed development at the site which is situated just to the east of junction 36 of the M1 motorway.

Rockingham is located 6km to the south of Barnsley in the South Yorkshire coalfield which was one of the most intense coal mining areas of the UK with many seams worked in the locality from the late 1700s. Virtually all of the collieries were closed by the mid 1990s prior to privatisation of the industry. Most minewater pumping in the locality ceased shortly after this time as the need to protect deeper collieries from flooding diminished.

Nordic Heat has been commissioned by the developer, Harworth Estates, to produce the report required by a condition in the planning consent for the site.

The planning consent for the site includes a condition:

"Prior to the submission of reserved matters a feasibility study shall be undertaken and a report submitted to the LPA for approval in writing. The study and report shall assess the feasibility of using heat from minewater in the development, and shall set out information in a manner which could be used to inform future funding proposals for the use of heat from minewater".

This study is intended to inform the work by Nordic Heat in producing their report to establish the technical and commercial feasibility of developing mine energy to serve the Rockingham development.

The study area is shown in **Figure 1.1**

The purpose of this desk based study is to review data in order to identify the proximity and depth of the mine workings and the mine water levels where known, that might be able to supply heat to the existing district heat scheme. The review focuses on the potential of using mine water as a heat source and includes:

- Extent and depth of mine workings where identifiable
- Inferred and monitored mine water level and quality where data are available
- Areas considered likely to be of good potential for mine energy schemes subject to more detailed feasibility work
- Uncertainties and associated risks in understanding of the mining and mine water regime, and additional works needed to mitigate those uncertainties and risks,
- A note on the regulatory situation with respect to permits and heat access agreements
- At this stage sites for drilling, use of open shafts or other minewater sources have not been considered as these require a more in depth localised study once an area is selected as having good potential and a known heat demand to satisfy.

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The desk study used available mining data; recorded mine workings extent and their elevation; possible extents of unrecorded mine workings; and appropriate local and regional mine water monitoring data. Where applicable, the report highlights limitations and assumptions made with these data.

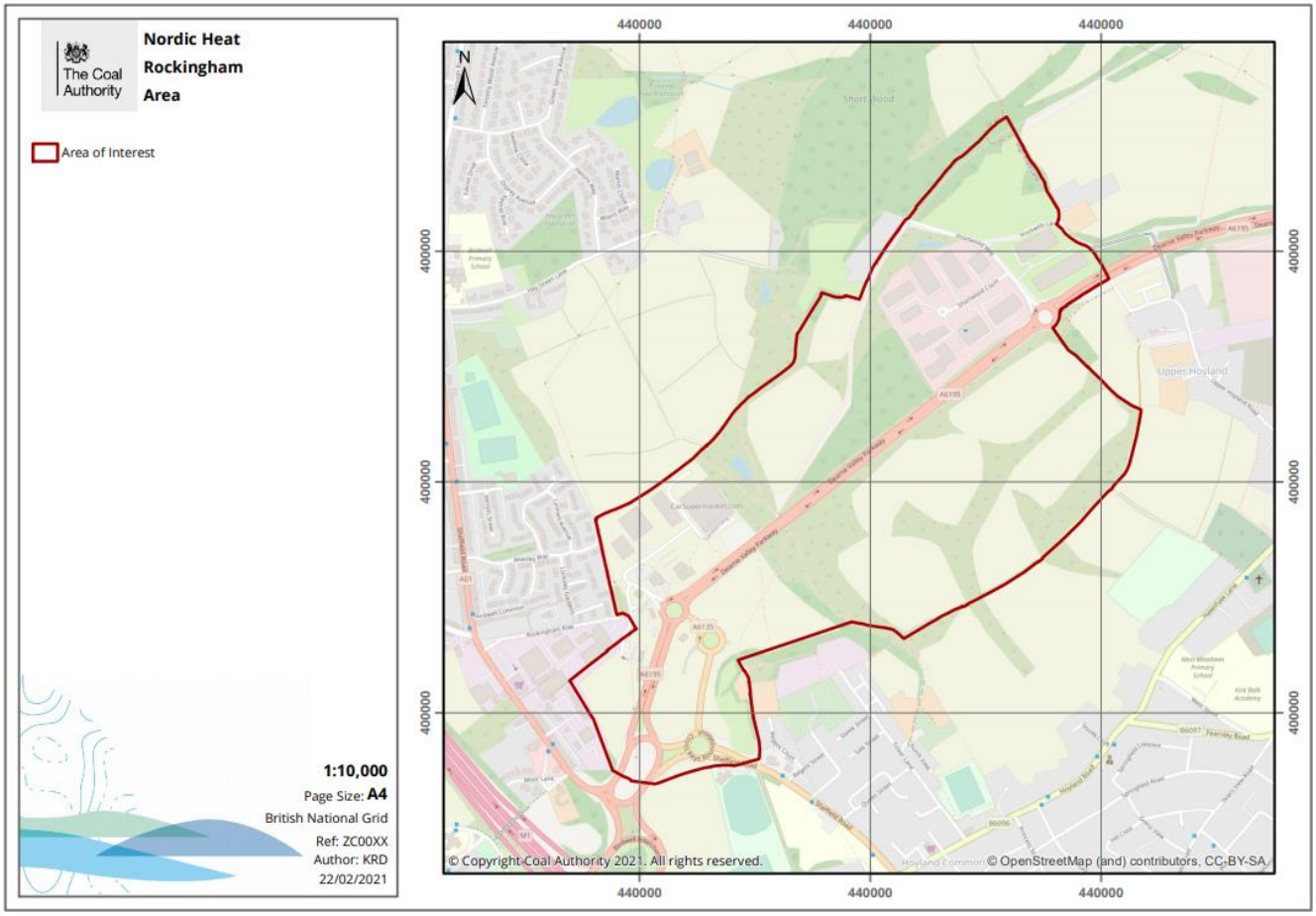


Figure 1.1: Study area

2.0 Geology

2.1 Structural geology

The site is underlain by the Middle Coal Measures which outcrop some 3Km to the west of the site and dip at approximately 8 to 10 degrees from south west to north east. The Lower Coal Measures sit beneath this formation although all seams worked in the locality are within the Middle Coal Measures band.

The solid geology of the area is dominated by three major fault bands which all trend in a south east to north west direction:

- the **Elsecar Fault** runs approximately through the centre of the development site with a downthrow to the north east of approximately 65m.
- the **Tankersley Fault** to the south west of the site boundary with a downthrow to the north east of approximately 50m
- the **Hoyland Fault** to the north east of the site with a downthrow of approximately 20m to the south west.

Two other major faults run perpendicular to the faults described above:

- the **Birdwell Fault** exists approximately 1Km to the north west of the site and the **Worsborough Fault** a further 750m to the north west.

The location of these faults are illustrated in **Figure 2.1**. While these faults represent a significant barrier between worked areas, there are a number of roadway connections across the faults which are likely to provide good hydraulic connectivity between mined areas.

Superficial deposits in the locality and all strata and coal seams down to and including the Swallow Wood Seam have been removed and the void backfilled with the working of the Rockingham surface mine which worked from 1991 to 1995.

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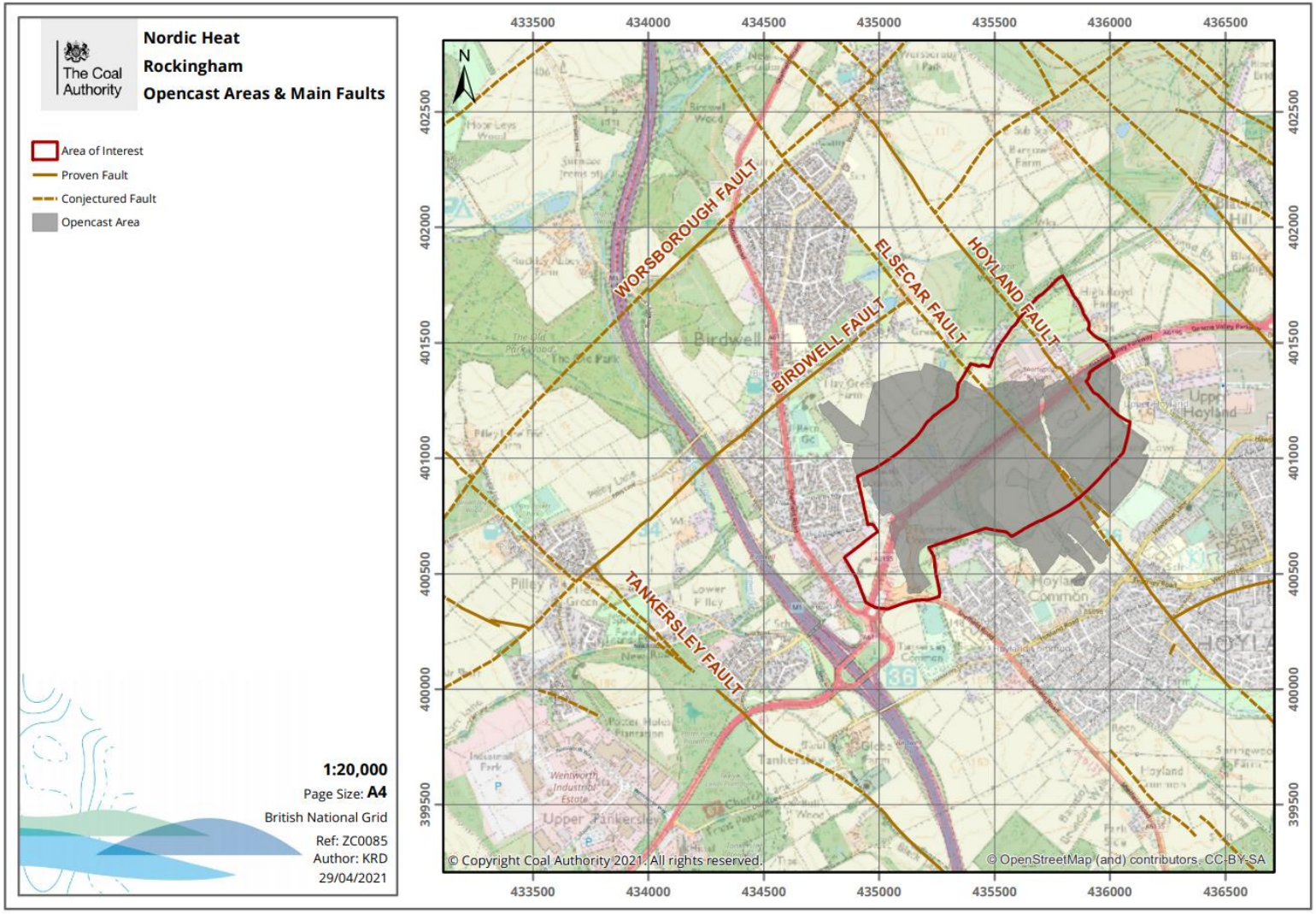


Figure 2.1: Major faulting in the Rockingham locality

Seam/Strata	Estimated thickness		
Superficials	5m		Seams and strata mostly removed by opencast mining
Overlying strata	Variable throughout the site		
Kents Thick Seam		Only present east of Elesecar fault	
	71m		
Barnsley Seam			
	54m		
Swallow Wood Seam		These seams present at Rockingham shaft	
	67m		
Lidgett Seam			
	65m		
Flockton Thin Seam			
	27m		
Flockton Thick Seam			
	24m		
Top Fenton Seam			
	3m		
Low Fenton Seam			
	18m		
Parkgate Seam			
	30m		
Throncliffe Seam			
	52m		
Silkstone Seam			

Table 2.1: Generalised section of strata

3.0 Mining

3.1 Types of mining connections

Typically connections and possible connections in mine workings after the 1940's tend to be better known as mine plans became rationalised. However, occasionally mine water can flow through significant barriers such as dams and strata (e.g. a 70m barrier of unworked coal at Blaenant, South Wales is known to have water flowing through it).

Throughout the coalfield there are a number of different types of mining connection. Each type of connection and each individual connection will have its own hydrogeological properties. Some key types of connections are summarised below:

Roadway: Underground tunnels used to connect various parts of the mine workings. Regularly used for the transport of miners, coal and equipment. Hence, often these are well supported and remain open post abandonment. Roadways can link different areas of mine workings in the same mine or connect adjacent collieries. They can often have high hydraulic conductivity and may provide good flows of water.

Goaf: Is the area of collapsed strata which was left behind after the coal was mined. Goaf can link adjacent mine workings and often has low/medium hydraulic conductivity, although fracturing in the surround strata can increase conductivity.

Shaft: Vertical excavations to access coal. Shafts may be either from the surface, or from one seam or horizon to another underground (usually known as a staple shaft). Shafts are usually of a relatively large diameter (1.5m to 7m) and often access multiple seams potentially providing a significant pathway for water to flow/migrate. Shafts are often filled to varying degrees on mine closure but even a filled shaft may still allow passage of water.

Borehole: Generally vertical or near vertical holes sunk through the strata. Often on completion these were filled or sealed to limit water flow. However, in some instances, dewatering and methane drainage boreholes were drilled to allow flows between mine workings. Dependant on type they are of variable diameter and lengths. They can transmit water between adjacent mine workings, seams and surrounding strata with variable hydraulic conductivity.

Fractures: Can be mining induced or natural (e.g. faults). Fractures around mined strata can allow flow of water with variable hydraulic conductivity.

Barrier: Where collieries mine workings are close together either horizontally or vertically, there may be a barrier of unmined coal. However, during mine water rebound and increased water pressure, mine water can flow through the natural strata. This flow will be variable and depend on the hydrogeological properties of the rocks.

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3.2 Local mining situation

3.2.1 Surface mining

All seams and down to and including the Swallow Wood seam were extracted within the site area by the Rockingham Surface mine operation from 1989 to 1995.
The lowest point of excavation in the surface mine is recorded as 75.64m AOD in the northern part of the site at the line of the Elsecar Fault, approximately 53m below surface level. While recorded workings not removed by the surface mining operation exist outside the surface mine site boundary, it is likely that any major pathways for water migration would have been sealed during the mining operation before backfilling.

A total of 13 seams were removed in the surface mining operation. A number of these were minor 'rider' seams but the following substantive seams were worked:

- Kents Thick
- Barnsley
- Dunsil
- Swallow Wood

A number of mine shafts are recorded in the area of the study. Many have been either completely or part removed by the surface mining operation but those which remain in whole or part may allow passage of mine water between horizons where shaft insets exist.

Shafts which remain below the surface mining floor are
Rockingham Colliery No. 1
Rockingham Colliery No.2
Both of these were partly removed by the surface mining operation but they were both capped at the opencast mining floor approximately 23m below ground level. The remaining length of these shafts connect all of the remaining worked seams down to and including the Silkstone.
The Rockingham Air Shaft which was very close to No's 1 and 2 was completely removed by the opencast operation.

The extent of the surface mining operation is shown in **Figure 3.1**. Workings in six seams remain beneath the base of the former opencast site and are described in the following sections.

3.2.2 Flockton Thick Seam

The Flockton Thick Seam is the uppermost remaining seam below the surface mining floor. It was worked extensively from Rockingham Colliery between the Elsecar and Tankersley Faults in the 1950s. Connections exist through the Elsecar Fault to further Flockton Thick workings to the north east and through the Tankersley Fault to Wharncliffe Silkstone and Tankersley Collieries to the south west.

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The areas were mainly worked by total extraction methods but some roadways, particularly those connecting to the Rockingham Colliery pit bottom area and main connection roadways to other areas exist and may form good targets for mine energy.

The Flockton Thick workings are shallowest at the western extremity of the site at c. 100m dipping to the north east attaining a depth of 175m at the Elsecar Fault. Workings on the eastern side of the fault are c. 230m deep. Remaining roadways in the Rockingham pit bottom area are in the order of 154m deep.

In summary the Flockton Thick workings are fairly extensive and well connected and may present a good 'reservoir' as part of a mine energy scheme (mine water recovery position covered in Section 4)

The Flockton Thick workings are shown in **Figure 3.2**

3.2.3 Top Fenton Seam

The Top Fenton Seam is approximately 50m below the Flockton Thick and was worked extensively both under and adjacent to the site from Rockingham Colliery in the 1920s and 1930's. A significant number of connections exist laterally to workings in this seam from other collieries with Rockingham Colliery Top Fenton workings being contiguous with those from Skiers Spring Colliery to the south east where the Coal Authority has a mine water level monitoring point. Connections also exist by roadway to Wharncliffe, Silkstone and Tankersley collieries to the south west and to Hoyland Silkstone to the north east. Other areas which were worked from Rockingham but separated by the major fault zones detailed in section 2 are also interconnected by roadways.

The Top Fenton workings are shallowest at the western extremity of the site at c. 150m dipping to the north east attaining a depth of 225m at the Elsecar Fault. Workings on the eastern side of the fault are c. 280m deep. Remaining roadways in the Rockingham pit bottom area are in the order of 204m deep.

In summary the Top Fenton workings are very extensive and well connected and may present a good 'reservoir' as part of a mine energy scheme (mine water recovery position covered in Section 4)

The Top Fenton workings are shown in **Figure 3.3**

3.2.4 Low Fenton Seam

The Low Fenton Seam is approximately 3m below the Top Fenton and was also worked extensively in the 1950s and 1960s. The very close proximity of the two seams means that where both have been worked they are likely to behave as a single hydrogeological layer

and should be treated as a single mine energy target. Consequently comments for the Top Fenton connections to other worked areas also apply here.

The Low Fenton workings are shown in **Figure 3.4**

3.2.5 Parkgate Seam

The Parkgate Seam is approximately 20m below the Low Fenton Seam and was worked very extensively in the early 1900s at depths varying from 175m at the western extremity of the site to 250m at the boundary with the Elsecar Fault. Workings to the east of the Elsecar Fault are in excess of 300m deep.

It is likely that mining induced fractures result in some degree of hydraulic connectivity with the overlying Low and Top Fenton workings.

The Parkgate workings are shown in **Figure 3.5**

3.2.6 Thorncliffe Seam

The Thorncliffe Seam is approximately 30m below the Parkgate Seam and was extensively worked by total extraction methods from Rockingham and Wharncliffe Silkstone Collieries in the late 1890s/early 1900s. Further working took place to the east of the Elsecar Fault in the 1930s from Hoyland Silkstone Colliery.

The working depth was 205m at the eastern extremity of the site dipping to 280m at the Elsecar Fault. The Hoyland Silkstone workings to the east of the Elsecar Fault are over 330m deep.

The Thorncliffe Workings are shown in **Figure 3.6**

3.2.7 Silkstone Seam

The Silkstone Seam was extensively worked by total extraction methods in the early 1900s. Workings at the eastern extremity of the site are separated from those in the west by the Elsecar fault. This seam is approximately 50m below the Parkgate and is the lowest/deepest seam worked in this locality.

The depth is c. 250m at the eastern extremity of the site, 320m at the boundary with the Elsecar Fault and 380m deep to the east of the Elsecar Fault.

The Silkstone workings are shown in **Figure 3.7**

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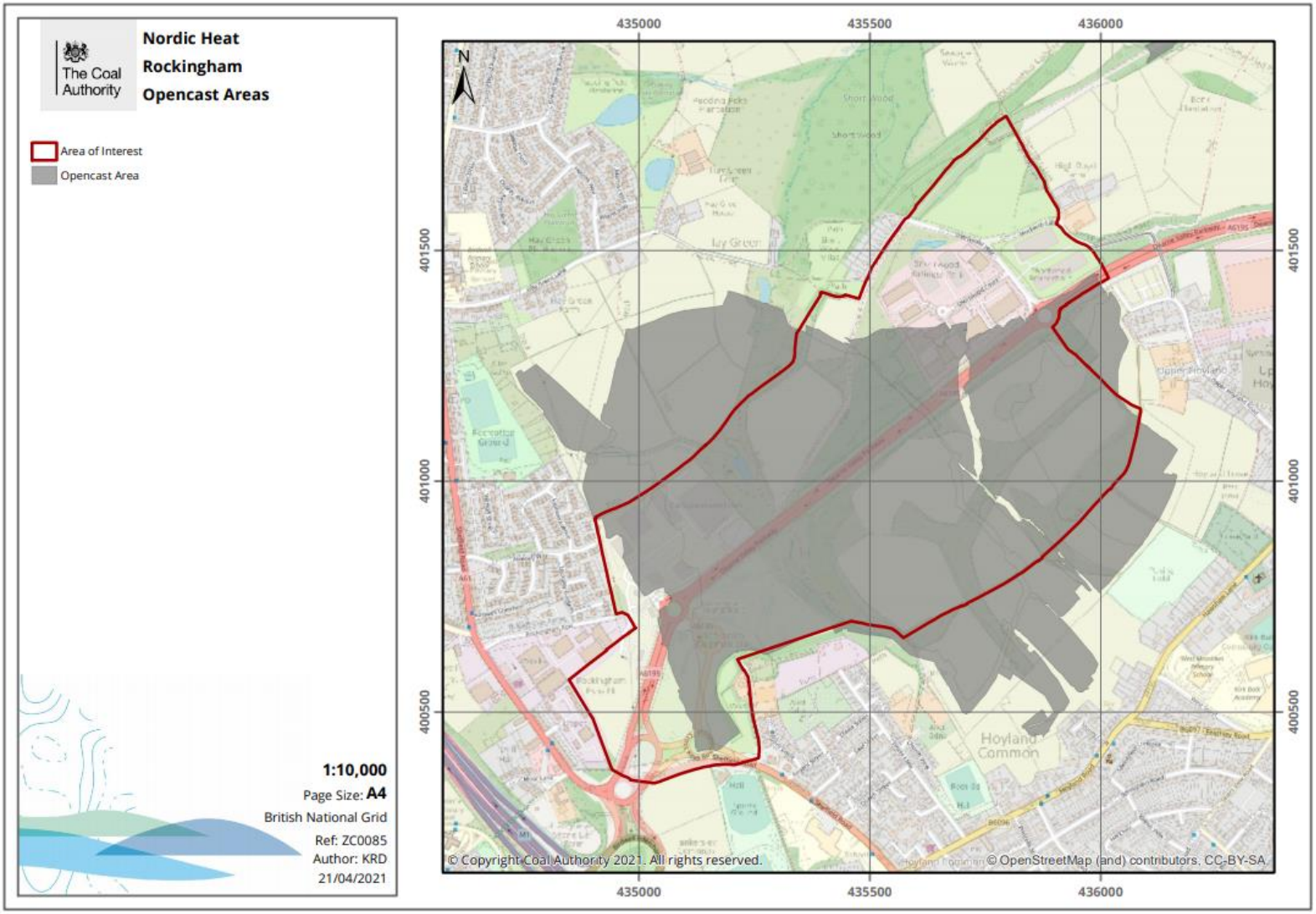


Figure 3.1: Surface (Opencast) mining area

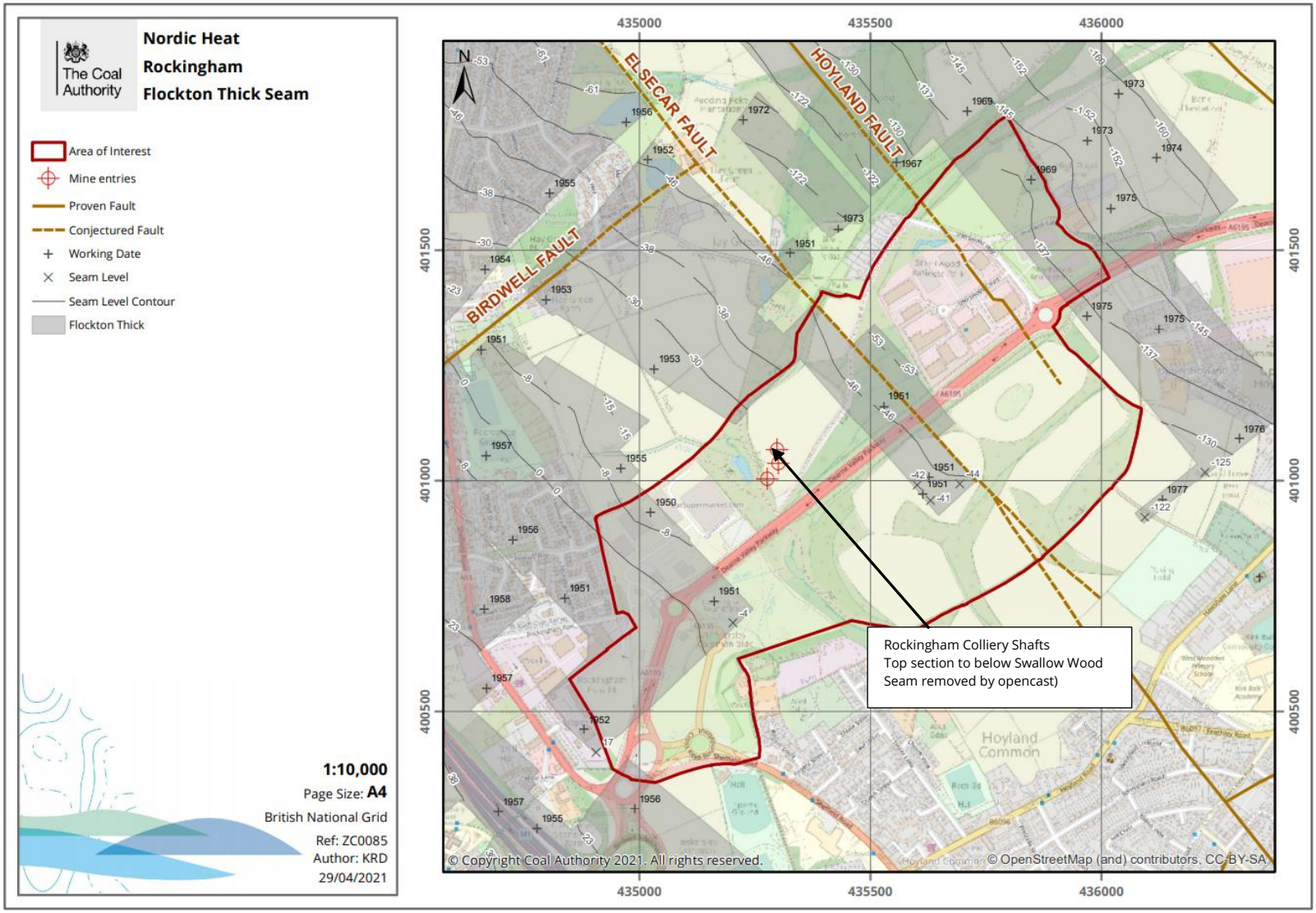


Figure 3.2: Flockton Thick Seam workings

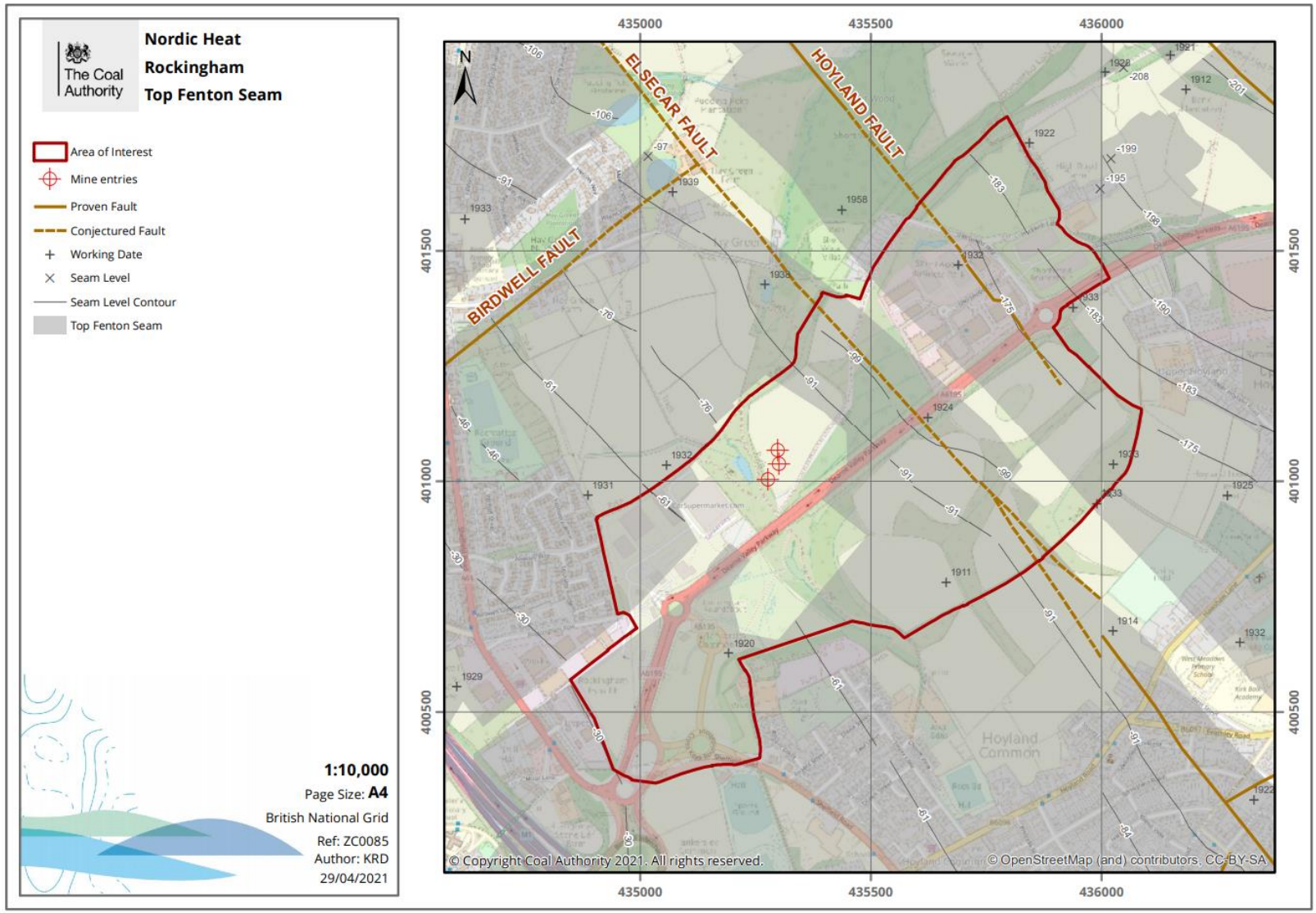


Figure 3.3: Top Fenton Seam workings

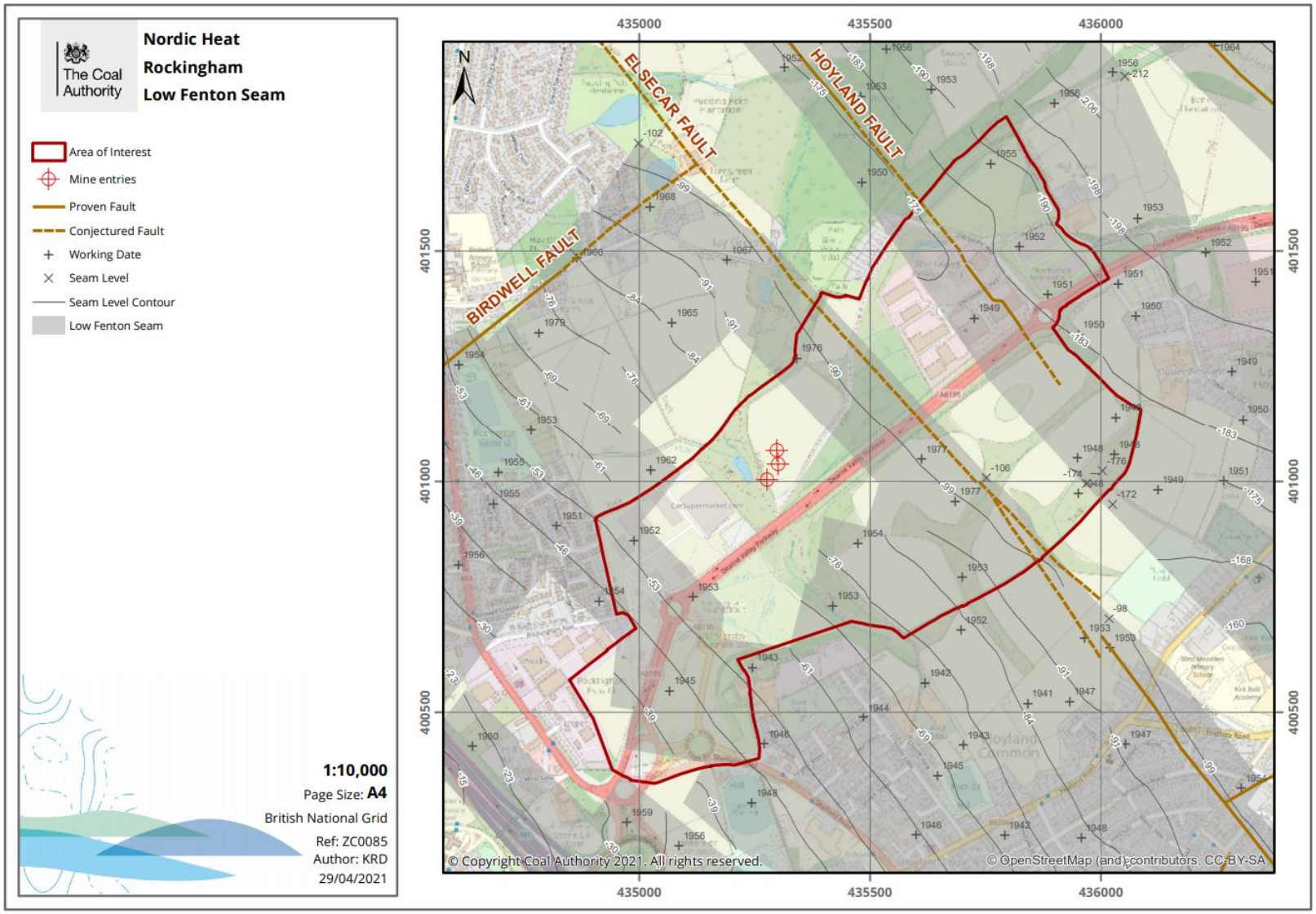


Figure 3.4: Low Fenton Seam workings

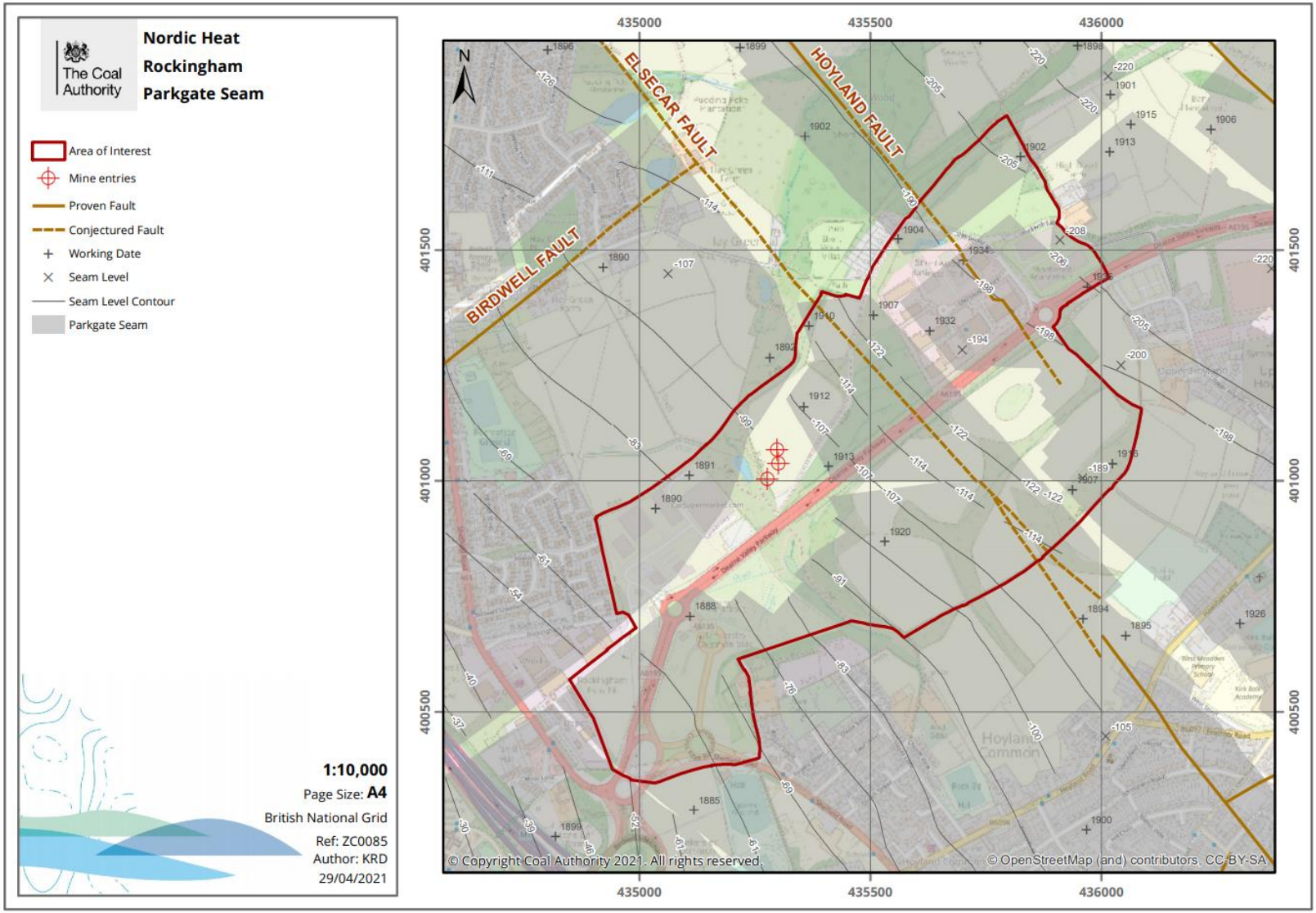


Figure 3.5: Parkgate Seam Workings

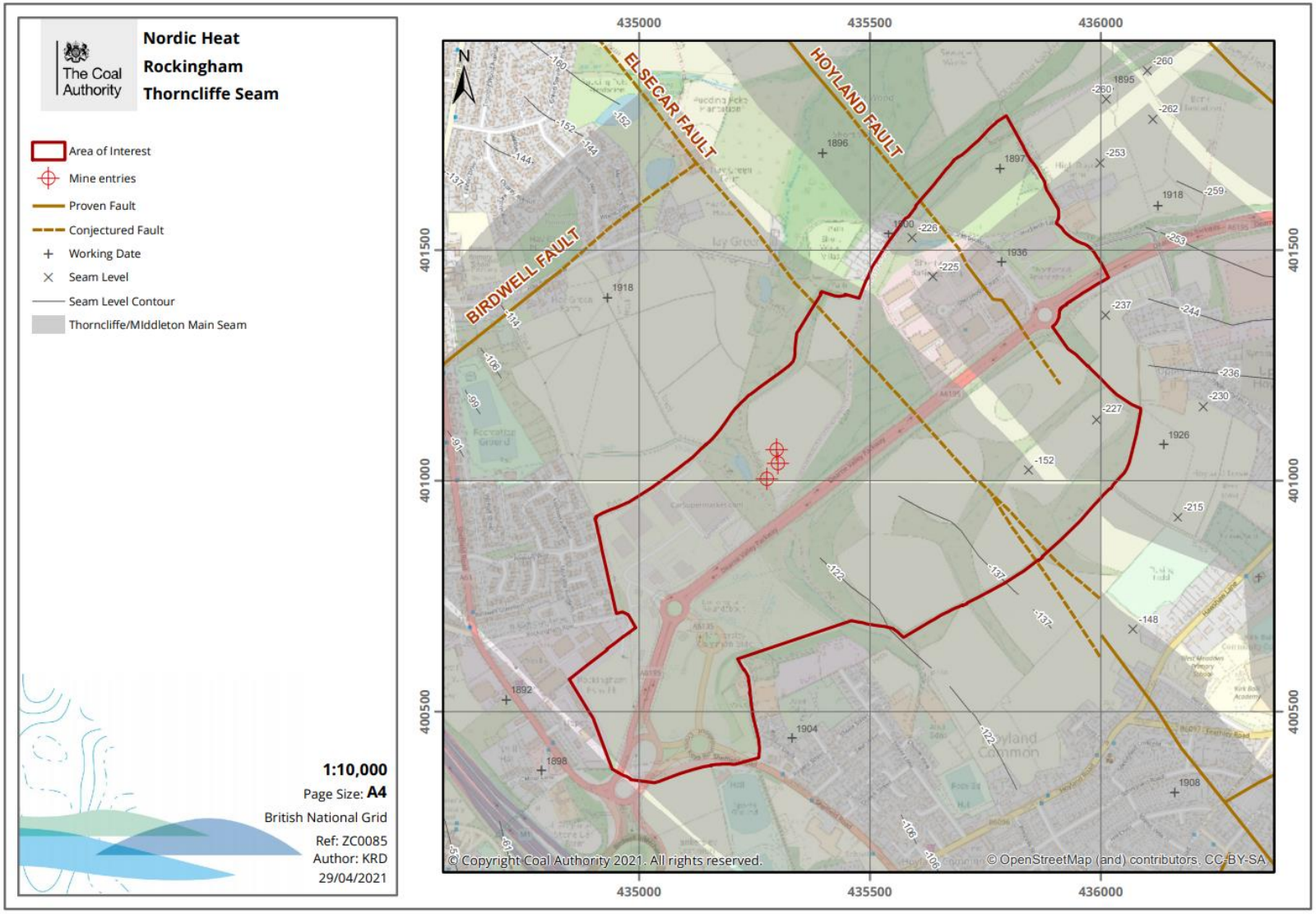


Figure 3.6: Middleton Main/Thorncliffe Seam workings

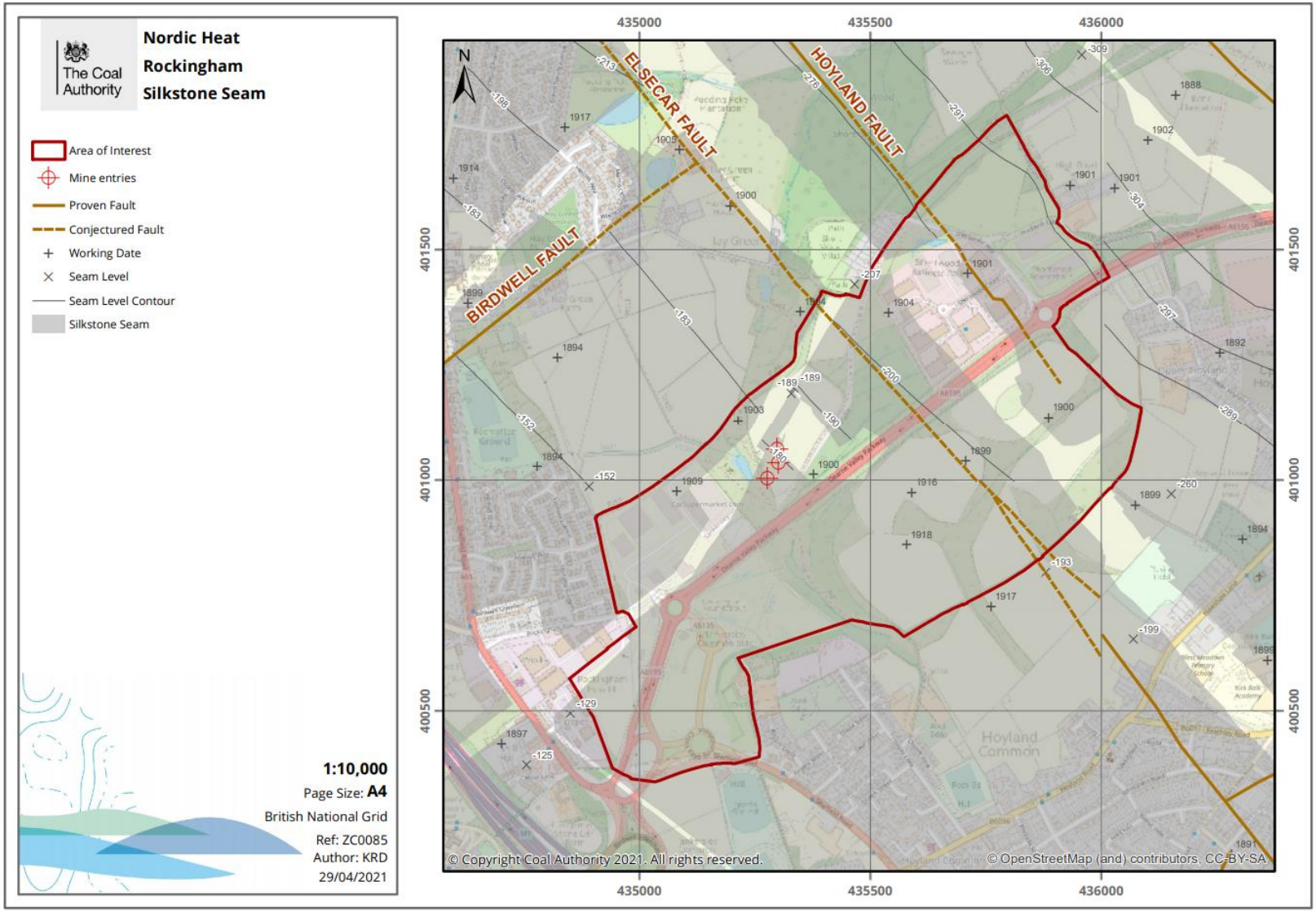


Figure 3.7: Silkstone Seam workings

4.0 Local mine water regime

4.1 Mine water recovery definitions

The mine water status in a particular locality or mining block (or sub-block) is generally described by the following terms:

Recovering (or rising) - where workings are filling with water after the cessation of mining and associated pumping. Water from surface and water table migrates into the deeper workings and gradually fills them up over time. Eventually the mine water will reach a rest (or recovered) level which is often close to the natural water table or lower if some other form of outflow from the workings exists at a lower level. Typically this period is measured in years and may take decades. The Coal Authority has, in some localities, facilities to measure the water rise either at unfilled mine shafts or monitoring boreholes. The recovery over time usually follows an exponential curve with recovery slowing is the level rises towards surface.

Recovered – where the infilling of the workings is complete, and there is no longer any change of any significance in the water level. This is often the case when deeper, more isolated collieries flood.

Recovered but rainfall dependant – where the workings have been flooded but there remains seasonal variations in level related to seasonal climatic or rainfall events. This is often the case in shallower workings nearer to the outcrop where water level rises in prolonged wet periods but gradually decreases during drier periods.

Recovered but overflowing – where the mine water level is static, but only so because there is an outfall in the mining block either to surface or to other deeper workings (which may still be recovering separately).

Pumped – where the mine water level is controlled at a predetermined level by means of pumping from a mineshaft or borehole into the workings. Pumping is normally carried out to prevent any uncontrolled outflows of polluting mine water at surface. An example at Strafford some 4Km to the north west of the study area pumps approximately 20-30 l/s.

4.2 Local mining hydrogeology

As outlined in Section 3.2 the locality has been extensively mined in many seams with a likely high degree of hydraulic connectivity between sets of workings both laterally and vertically due to the number of interconnections and in some cases close vertical proximity of workings.

The Coal Authority has undertaken mine water level monitoring in the South Yorkshire coalfield area since its inception in 1994. The coalfield was divided into a number of areas which were considered as containing areas of hydraulically connected workings, the area in question for this study is known as 'Yorkshire Zone 5'. The area contains a significant number of points where mine water levels are monitored, the nearest being adjacent to the Dearne Valley Parkway roundabout at the eastern extremity of the site. In parts of Zone 5, particularly to the west and north west of the

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Rockingham site, mine water recovery was observed as being 'complete' from the late 1990s. Mine water recovery closer to the site was still taking place at ever decreasing rates (due to reducing hydraulic head) until around 2015 when levels stabilised at around 50 to 65m AOD. Some limited mine water pumping and treatment takes place at Strafford, some 4.5Km to the north west of the site to control a historic gravity discharge but this this does not have any significant bearing on the locality of the site where a natural seasonal variation of +/- 3 to 4 m takes place.

The mine water level at the nearest monitoring point in the north eastern part of the site is approximately 55m to 62m AOD (the level varies seasonally with precipitation) which is around 66 to 73m below the surface at the development site.

Coal Authority monitoring points around the area suggest good connectivity between the various points as inferred previously by the review on mining data.

Based on the depths of potential target workings for abstraction boreholes an abstracted mine water temperature in excess of 15°C may be anticipated.

Based on the above findings the 'reservoir' available for mine energy purposes is likely to be substantial and, subject to drilling and testing to confirm connectivity, may be able to support a heating (or cooling) system of a scale anticipated for the development in question (up to 2MW peak, 5,000MWh p.a.). Ability to abstract sufficient flow to feed a system of this scale would be subject to drilling boreholes and test pumping.

4.3 Mine water quality

The nearest point where mine water abstraction currently takes place is at Strafford, some 4.5Km to the north west of the site. An example untreated water analysis from Strafford is shown Table 4.1: Indicative mine water quality

Conductivity (µS/cm @ 25°C)	pH	Chloride (mg/L)	Total Iron (mg/L)	Alkalinity (mg/L as $CaCO_3$)
2080	7.0	74	6.5	585

Table 4.1: Indicative mine water quality

5.0 Mine water for heat use

There are two principal methods for using mine energy from mine water. These are:

Closed-loop systems: typically involved installing the heat exchanger(s) into either boreholes (vertically) or trenches in the ground (horizontally). The heat is taken from the water / ground surrounding the heat exchanger system

Open-loop systems: typically require the mine water to be pumped through a heat exchanger at surface. The pumped water is then discharged back to the ground, or to a surface watercourse. The water may require treating before being discharged to groundwater or a watercourse.

5.1 Open loop heat pump systems

When using an open-loop system, there are a number of issues that may need to be addressed:

The type of open-loop system used will determine environmental permitting and treatment requirements.

If the cooled mine water is reinjected into the mine workings, then this could result in more water available to be pumped. However, it is possible that the cooled water could cool the 'warm' mine water which is being extracted. The extent of this cooling and amount of flow will depend on the volume of mine workings and storage capacity. It may be possible to abstract and reinject to different seams to reduce the risk of short circuiting.

If mine water is discharged to the surface, the amount of water which could be pumped through the heat exchanger will be limited to the recharge of water in the mine workings. Again this will be dependent on the volume of mine workings and storage capacity.

5.2 Using mine water for heating and cooling

To use mine water for mine energy, two key parameters are required; these are available flow rate and temperature of the mine water. At present both of these are unknown within the site. The available flow rate or storage capacity depends on the area and volume of mine workings and connected strata. For coal mine workings, the temperature of the water is typically controlled by average air temperature and depth to the source of the water (i.e. geothermal gradient). In general, the temperature of the water increases with depth; throughout the UK this is an increase of approximately 26°C for every 1km (http://www.bgs.ac.uk/research/energy/geothermal/).

If there is a strong inflow of shallow mine water at the site, then this is likely to be influenced by rainwater, the resultant temperature is likely to be at the lower than expected. Mine water in deeper workings is more likely to be in the higher temperature ranges 16 - 20°C as the ground heat will be greater, the water will be more insulated by the overlying strata, which will also limit cooling from the injection of shallow cooler waters. It is possible to mitigate against this by ensuring boreholes are screened to exclude cooler shallower, groundwater inflows.

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5.3 Uncertainties

Throughout the study, a number of uncertainties regarding potential for mine water as heat source have been identified, these include:

Mine water temperature – The temperature of the mine water under the site is unknown, however reasonable estimates can be made based on underlying geology, mining and similar situations. The temperature of the water may also depend on depth from which is pumped.

Available flow / storage capacity – The amount of water which can be taken out of the mined system is unknown. To determine this, further investigations and tests will be required. Although using data from surrounding mining blocks and the actual location(s) for a pumping borehole(s), maximum possible flows could be estimated.

Mine water level – Although it could be assumed that the mine water level is shallow, this cannot be confirmed without further investigations (suggested pilot boreholes) and tests.

Mine water chemistry – Although there are limited chemistry data for the mine water within the area of interest, similar situations can be used to give indicative possible water quality information. For specific data, additional investigations and tests will be required.

5.4 Risks

Within the information presented in this study and wider aspects of using mine energy there are a number of key risks. These are summarised below:

5.4.1 Risks of data

The temperature data estimates are based on generic information not specific to the area. The predicted water temperature could be different to that expected. Differences in temperature data could impact on the available resource and heat generation.

Mine water chemistry data is based on a pumping site located over 4.5km from the areas of interest, the water chemistry could be different and poorer than is anticipated. Poorer quality water could impact on future test (e.g. pumping test) requirements and the operation of a mine energy system. Poorer quality water could also impact upon any future mine water treatment system. In a system where mine water is re-injected after heat extraction, water quality may be less of an issue.

The area covered by this study has the benefit of a significant amount of data in the form of good quality mine plans and data from mine water monitoring points.

5.4.2 Risks of construction, using mine water and general risks

Drilling a borehole into mine workings will not guarantee a flow, and potential flow rates may be restricted. To avoid or limit this risk, specific drilling targets and / or pilot boreholes could be drilled. The drilling risks for connectivity to mine workings include:

- not adequately contacting mine workings or drilling in to a pillar of unworked coal within the mine workings,
- poor hydraulic connections between the borehole target and the remaining mine workings,

- presence of unexpected areas of unrecorded mine workings and other areas of 'broken ground' impacting on the size, cost and effectiveness of a borehole for pumping or discharging,

- incorrect and / or uncertain target depth may result in a borehole not being deep enough and not intersecting the mine workings

If air is introduced into the mine water before or after it goes through the heat exchanger, iron (and possibly other substances) may start to precipitate out of solution. This could cause fouling and clogging within the heat exchanger and pipework within the ground source heat system, leading to high maintenance costs. This could also result in iron being precipitated and could cause clogging of the pipework and / or the reinjection borehole(s).

Saline and or highly acidic mine water could result in corrosion of pipework and other infrastructure therefore water quality should be determined prior to designing a scheme and appropriate materials used.

The preferred deployment for a mine energy system is to re-inject mine water back to the mine following heat extraction. Reinjection of too much 'cold' water or reinjection in to the wrong location could result in cooling of the pumped water. Potential flow pathways and risk of short-circuiting should be considered prior to design of the scheme.

Any existing mine energy schemes in the locality could limit the amount of water which could be used for ground source heat.

Reinjection of mine water to groundwater or discharge to surface may not be permitted by the Environment Agency. Note that different mine workings (e.g. different depths or seams) could be classed as different groundwater bodies. This could affect options for disposal of mine water following heat recovery and include a requirement for water treatment prior to disposal. The regulatory position should be determined prior to designing a scheme

5.4.3 Mitigation

Throughout the development of a mine energy system, most of the risks above can be mitigated. Typical mitigation could include:

- Undertake investigations and tests to determine the mine water yield, mine water chemistry, mine water temperature and mine water level(s) by drilling a pilot well,

- Use appropriate specialists to advise on drilling into mine workings and associated risks of pumping and construction,

- Potential to sink pilot boreholes prior to installing larger diameter pumping boreholes,

- Assessing the data obtained from tests (e.g. pumping test) to develop an appropriate mine energy system and make decisions about best materials and maintenance of the system,

- Undertake investigations and test pumping to determine most appropriate method(s) and location(s) for potential reinjection or discharge to surface,

- Assess the data from test pumping to confirm if the mine water is viable for a mine energy project and if additional steps (e.g. treatment) are required to use the mine water effectively,
- Early consultation with the Environment Agency would aid decisions about the options for discharging the mine water to groundwater or surface,
- Early consultation with the Coal Authority about drilling into their property, this would aid with permissions and licences needed (e.g. mine water heat access agreements).

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6.0 Regulatory position

The regulatory situation within England will depend on the type of system being installed. At present, for a closed-loop system, other than any planning related permissions, there are no additional environmental permissions required (e.g. from the Environment Agency). However, there are recommendations and guidance in respect to the types of material used within the installation of the system and fluids used within the heat exchanger.

For open-loop systems and most mine energy systems will fall into this category, there are additional consents, permissions and licences required. The types of permissions etc. required will depend on factors such as flow rate and point of discharge. The permissions system for the Environment Agency is set out in their good practice guide. In summary the process includes:

- To drill and test pump a borehole: Consent to investigate a groundwater source (Section 32 of the Water Resources Act),
- If the abstraction rate is greater than 20m^3/day: An abstraction licence will be required from the Environment Agency,
- If the water is returned to groundwater or surface water: An environmental permit (discharge consent) will be required.

If any borehole(s) or trenches intersect the Coal Authority's property, which includes past coal mine workings, unworked coal seams or mine entries (shafts and adits), then prior permission in the form of an Access Agreement will be required from the Coal Authority. Equally, there could other mineral owners which may also need to grant permission. Where any borehole is drilled into past coal mine workings to access mine water for heat recovery, a Mine Water Heat Recovery Access Agreement will be required from the Coal Authority.

Through its heat access agreement which is currently under review, the Coal Authority licence access to former mine workings. It is intended that a charge will be levied for access to the mining infrastructure and an appropriate charging structure is under development (through consultation with early adopters). This is likely to be based upon a price per kWh in addition to the licence annual fee.

The Coal Authority has also indicated that currently only one mine energy scheme can be licensed per mining block. Also the Authority it is not currently accepting any new applications for mine heat access agreements but this is expected to be temporary while the licensing process is reviewed and updated.

In addition to the above, there are also legal requirements in respect of drilling boreholes for the purposes of water investigation. Notifications will need to be provided to the Health and Safety Executive (HSE) of operations to drill a new borehole and abandon a borehole (HSE, 2008. A guide to the Borehole Sites and Operations Regulations 1995, Guidance on Regulations.). The Natural Environment Research Council (NERC) (via the British Geological Survey) is required to be informed of intention to drill any well >15m (or borehole >30m). Records of hydrogeological information are also to be provided to NERC.

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7.0 Borehole options

7.1 Review of site areas

Specific siting of boreholes is beyond the scope of this preliminary study. However it is possible to confirm that the site area is extensively underlain by flooded workings in a number of seams shown shaded grey in Figure 3.2 to Figure 3.7. A significant number of mine roadways still exist in the locality of the Rockingham Colliery shaft pillar in seams below the opencast site floor which may form suitable good quality targets for abstraction and reinjection boreholes.

The table below is based on the uppermost two seams worked in the locality which have not been removed by opencast mining, namely the Flockton Thick and the Top Fenton. Other, deeper, seams and associated workings exist too and may also be suitable targets but at increased cost (typically borehole costs of £1,000 to £1,500 per metre depth are used as a benchmark)

7.2 High Level Borehole Cost Estimates

At this stage the cost of abstraction and reinjection boreholes required can only be general based on estimated depth and anticipated diameter. Normal practice is to abstract from a deeper seam and reinject to a shallower one.

If boreholes can be sited towards the westerly end of the Rockingham site they are likely to be less costly as the workings are shallower. At the eastern end of the site the workings are deeper, considerably so to the east of the Elsecar Fault, meaning that boreholes in these areas would be deeper and more costly.

	West	Central	East
Abstraction Top Fenton Seam	150m (£150K - £225K)	225m (£225K - £340K)	280m (£280K - £420K)
Reinjection Flockton Thick Seam	100m (£100K - £150K)	175m (£175K - £260K)	230m (£230K- £345K)

Table 7.1: Indicative borehole costs

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8.0 General risks of drilling in to mine workings for mine water

When drilling boreholes into mine workings there are two primary groups of risk. These are site specific risks for the possible borehole options and generic risks of drilling to mine workings.

8.1 Risks for possible borehole options

Within each option there are risks, some of which are the same whilst others may depend on the target itself. The risks of drilling in the areas include:

- Missing the underground target location.
- Poor connectivity with the mine workings, which may reduce available yield and or increase drawdown of water during pumping. A pilot borehole may help determine suitable pumping / injection locations. This could increase initial costs (e.g. drilling multiple boreholes) but decrease longer-term operational costs and help reduce project risk by proving the presence or absence of workings (e.g. improved pumping efficiency and reinjection of mine water).
- Drilling through unrecorded workings and recorded workings above the target. This may impact on borehole diameter (and yield) and could increase costs of drilling.

8.2 Generic drilling risks for mine workings

Risks involved when drilling through Coal Measures include, but are not limited to the following:

- Areas of fractured or lost ground – fractured ground is associated with areas where mining has occurred, this can cause issues when drilling as loss of flush can occur, this makes it difficult for drilling to progress. Issues can occur with casing and areas of shallow workings can affect surface stability.
- Coal mine gases – Coal Measures are known to contain various gases within. While gas production declines as mines flood, pockets of gas may be encountered whilst drilling. These gases can cause issues in regards of possible combustion and asphyxiation and a gas risk assessment should be carried out prior to any drilling.
- Groundwater – water within workings can occur in unexpected areas, which can have implications when drilling e.g. cooler groundwater could flow into the workings and reduce source temperatures.

8.3 Probe drilling or pilot boreholes for mine water information

Prior to drilling larger diameter pumping and reinjection wells, it would be advisable to first find a suitable underground target (e.g. roadway). This can be achieved through pilot or probe holes. A summary of pros and cons for each is presented below:

- Probe hole pros
    - Cheaper than a pilot borehole
    - Can be drilled quicker than a pilot borehole
- Probe hole cons
    - Limited use after completion, due to smaller diameter than pilot boreholes

    - Cannot undertake any significant investigations (e.g. chemistry and flow rates)
    - The borehole can deviate more compared to a pilot borehole
- Pilot borehole pros
    - Can be used to investigate mine water hydrogeology and water chemistry
    - Can be used as a pumping or reinjection borehole if borehole diameter allows for a pump to be installed
    - Likely to deviate less than a probe hole
- Pilot borehole cons
    - More expensive than probe holes
    - Take longer to drill than probe holes

Based on the pros and cons of each, and the need to fill in data gaps (e.g. determine water level, flows and chemistry), it would be advised to sink pilot boreholes instead of probe holes for intercepting workings, although probe holes could be used to locate shafts.

9.0 Summary and conclusions

Within the constraints of this high level study the findings are:

Much of the site area was worked by surface (opencast) mining in the 1990's with seams and associated workings down to and including the Swallow Wood Seam being removed and the void backfilled.

Significant areas of flooded mine workings below the Swallow Wood Seam remain within the study area which form a potential target for abstraction and reinjection of mine water to support a mine energy based heating (and cooling) system. The worked areas in each seam are shown shaded grey in **Figure 3.2** to **Figure 3.7.** A significant number of roadways also exist in the former Rockingham Colliery pit bottom area (not shaded) and across fault related barriers between worked areas. These may also represent very good targets for drilling to access mine water.

Any drilling operation to access mine water would have to drill through the opencast backfill which is of variable depth from shallow to approximately 53m depth. Normal practice would be to case off the opencast backfill during drilling to ensure stability of the borehole.

Anticipated drilling depths and costs are set out in **section 7.2.** These costs must be taken along with other techno-economic information provided by others to establish the commercial feasibility of mine energy at this site and proposed development.

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11.0 *Glossary*

Abbreviations

mAOD = elevation in metres above Ordnance Datum

mBOD = elevation in metres below Ordnance Datum

mBGL = depth (typically of water) in metres below ground level

mBDAT = depth (typically of water) in metres below datum level used for the point

L/s = litres per second. A measure of flow rate

m^3/s = metres cubed (cubic metres) per second. A measure of flow rate

mg/L = milligrams per litre. A measure of concentrations

µg/L = micrograms per litre. A measure of concentrations

µS/cm = micro Siemens per centimetre. A measure of electrical conductivity

Terminology definitions (not described in the body of the report)

Mine water = Refers to water that is within the underground mine workings and / or flows through the underground mine workings. In some instances the mine water could be the same as local groundwater.

Mine water level = Refers to the level of the water or the piezometric head of the water in the mine workings. In some instances the mine water level may be hydraulically connected to strata immediately above and / or below the mine workings.

Mining terminology

Adit = A tunnel driven horizontal or near horizontal from the surface to the mine. Used to access the mine workings, but can also be for drainage of water. Also see Level.

Inbye = in an inward direction; i.e. into the mine from the entrance

Level = A tunnel driven horizontal or near horizontal. Can be: access in to the mine; a tunnel between shafts; a tunnel between mine workings; or for drainage of water.

Lode = See Vein

Outbye = in an outward direction; i.e. heading out of the mine to the surface

Shaft = Vertical of near vertical opening used for the working of the mine (mineral extraction, pumping, ventilation)

Sough = A tunnel driven horizontal or near horizontal. Generally used to describe a tunnel driven specifically for draining water

Stope – A section of worked lode or vein

Stoping – To mine or work by stopes

Winze – A shaft or inclined passage leading from one level to another, but not rising to the surface.

Vein = An area of mineralised material within the local host rock. Often referred to as a lode. It is often associated with a fault

12.2 Appendix 2 – Rockingham Gateway 36, Mine Energy Concept Plan with Energy Centre and Connections

Harworth Group - Mine Energy



Key

DH Network Type

- Distribution
- Minewater

Type

- Abstraction
- Reinjection

- Energy Centre
- Mine Water Roadway

NORDIC HEAT

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12.3 Appendix 3 – Mine Energy White Paper

The Case for Mine Energy – unlocking deployment at scale in the UK

A mine energy white paper

Foreword

At the heart of this Government's agenda are three key priorities: the development of new and innovative sources of employment and economic growth, rapid decarbonisation of our society, and levelling up - reducing the inequalities between different parts of the UK. I'm therefore delighted to be able to offer my support to this report, which, perhaps uniquely, involves an approach which has the potential to address all three of these priorities.

Mine energy, the use of the geothermally heated water in abandoned coal mines, is not a new technology, but it is one with the potential to deliver thousands of jobs. One quarter of the UK's homes and businesses are sited on former coalfields. The Coal Authority estimates that there is an estimated 2.2 GWh of heat available – enough to heat all of these homes and businesses, and drive economic growth in some of the most disadvantaged communities in our country. Indeed, this report demonstrates that if we only implement the 42 projects currently on the Coal Authority's books, we will deliver almost 4,500 direct jobs and a further 9-11,000 in the supply chain, at the same time saving 90,000 tonnes of carbon.

The report also identifies a number of issues which need to be addressed to take full advantage of this opportunity; with investment, intelligence, supply chain development, skills and technical support all needing attention. It indicates though that none of these issues are insurmountable and BEIS will therefore work with the Coal Authority, and its partners in the Mine Energy Task Force, to further explore the options for exploiting this zero carbon energy source.

Lord Callanan

Parliamentary Under Secretary of State at the
Department for Business, Energy and Industrial Strategy

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[1] The list includes individual who were interviewed or otherwise involved in the research in a substantive fashion and who gave their permission to be named. Their inclusion should not be taken as evidence of endorsement.

Executive summary

Introduction

According to the Coal Authority, one quarter of the UK's homes and businesses are sited on former coalfields. Since the cessation of mining much of the underground network of old mine workings has become filled with water which has been warmed by natural geothermal processes. The Coal Authority estimates that there is sufficient energy in this water to heat all of the homes on the coalfields. The exploitation of this resource – mine energy – would make a significant contribution to solving one of the most pressing low carbon challenges facing the country, namely the decarbonisation of heat.

Additionally, owing to the co-location of the resource with often disadvantaged areas, the development of mine energy schemes would directly contribute to the government's 'levelling up' agenda, and could be harnessed to create a powerful narrative of renewal for old coalfield communities. Recent developments in North East England have placed the UK at the forefront of a new generation of mine energy schemes, but the sector is in an early and therefore vulnerable stage of development and requires public support to ensure its continued development. This white paper makes the case for mine energy and provides a series of recommendations, generated through a literature review and extensive stakeholder consultation, intended to help ensure the development of this sector.

The nature of the resource

The Coal Authority estimates that there are 23,000 abandoned deep coal mines around the UK. Following abandonment, the void spaces created by mining fill with water which has been naturally warmed (12–20°C) by sub-surface geological processes and as such is zero carbon. Through the use of heat pumps, some of this heat can be extracted and used to heat fresh water, which can then be used to provide low carbon heating and hot water for use in domestic and commercial buildings via heat networks. The most convenient and cost-effective way of accessing mine water heat is via Coal Authority mine water treatment plants. There are currently 75 of these and they play an important role in protecting water quality. Currently heat from these sites is not utilised, but there is growing interest in this resource. After treatment plants, the next most convenient way of accessing mine water is via old mine shafts; however, many of these were filled and capped when mines were closed, and it is not clear how many could serve for use in mine energy schemes. Drilling boreholes, to tap into known reservoirs of mine water, is the most expensive way of accessing mine energy, but also the most flexible as it allows end users to access the resource close to existing and planned sources of demand.

Provided that heat extraction does not exceed the level of natural heat, recharge mine water heat-based systems are sustainable, as evidenced by a number of long-established schemes in mainland Europe and North America. Recent advances in thinking and practice suggest that the benefits associated with mine energy schemes can be enhanced by using mines to store surplus (waste) or seasonally available (solar thermal) heat sources.

Progress to date

The first known mine energy schemes emerged in the 1980s. One of the earliest, based in Springhill, Nova Scotia, Canada, was established in 1988 and remains in operation to this day. Other notable schemes have been established at Heerlen in the Netherlands and Barredo in Spain. Schemes such as these have helped to develop and refine approaches to mine energy scheme development, but until recently only a limited number of schemes have been developed, with only three small schemes having been established in the UK prior to 2020.

The primary reason for the limited number of developments appears to be the low cost of fossil fuels. However, with the acknowledged need to transition to low-carbon energy sources there has been a renewed interest in mine energy and a new wave of schemes have been commissioned. The UK is currently at the forefront of this wave.

For example, enabled by the Renewable Heat Incentive (RHI), Lanchester Wines, a private company based in North East England, has installed 2.4MW and 1.6 MW mine water-based heating systems. These are currently the largest schemes in the UK, but will shortly be eclipsed by a 6MW scheme led by Gateshead Council and a proposed garden village scheme at Seaham (County Durham), both supported by funding from the Heat Networks Investment Programme (HNIP). Multiple other UK schemes have been subject to some level of investigation and the Coal Authority has suggested that there is currently a potential pipeline of 42 projects.

The benefits of mine energy

Heat decarbonisation

In 2019 the UK committed to becoming a 'net zero' economy by 2050. One of the challenges associated with meeting this ambition is the decarbonisation of heat. A key aspect of the challenge is the limited availability of low carbon heat sources.

Mine water heat is an abundant, widely distributed and naturally occurring low carbon heat source. In comparison, most other low carbon heat sources are subject to higher geographic and scale constraints. Additionally, the mine water heat resource is relatively well understood and is distinguished by several technical characteristics which give it a comparative advantage as a heat source for two of the key heat decarbonisation technologies, namely heat pumps and heat networks. These characteristics are:

- If managed correctly, mine water heat is constantly available at a consistent and elevated temperature. Other heat pump-based systems (water, air and ground) rely on lower temperature heat sources which are at their coolest in the winter months when heat demand is highest.
- Mine water heat is available at scale, relatively widely distributed and often co-located with areas of high heat demand. As low carbon heat sources are in short supply, mine energy is a potentially important enabler of heat network developments and therefore heat decarbonisation. If all of the 42 schemes in the Coal Authority's pipeline were to be built out, this would generate projected carbon savings of 90,500 tonnes per annum.
- Mine water heat is a self-sustaining indigenous resource the use of which increases energy security. In the future, mine energy schemes could play an enhanced role, potentially providing balancing services to local energy systems through the use of mines for thermal energy storage.

Green growth

If the 42 schemes identified by the Coal Authority were to proceed this would create an estimated 4,227 jobs and £293 million gross value added (GVA). An additional 9–11,000 jobs and £400–500 million could be created through indirect and induced economic effects.

Many parts of the coalfields have still not fully recovered from the decline of mining, and such recovery has been experienced is now at risk as a result of the coronavirus pandemic. The development of mine water heat networks would bring immediate and direct economic benefits to coalfield communities and businesses and contribute to the government's 'levelling up' agenda. Beyond the direct impacts associated with the development and operation of mine energy schemes, regeneration agencies would have an opportunity to build on the low carbon credentials of mine water schemes to create a wider narrative of renewal, and through this to attract new businesses to coalfield areas.

Support for mine energy would also contribute to wider clean growth objectives. Currently, the UK has first mover status and has an opportunity to establish new UK-based centres of research and commercial and construction expertise in mine energy; expertise which might subsequently be exported, thereby creating new opportunities for British businesses.

Barriers and constraints

Mine energy offers multiple benefits and enjoys considerable stakeholder support, but the development of the sector is at an early and vulnerable stage as scheme developers face multiple challenges. A summary of the key barriers identified includes:

- The low cost of gas as an alternative heat source. This is the most fundamental challenge for mine energy and one it shares with all forms of low carbon heat.
- Uncertainty regarding the future of existing support schemes for low carbon heat and in particular the HNIP and RHI. A lack of certainty regarding the nature of proposed replacement schemes and the level of support is causing uncertainty in the market and appears likely to cause some schemes to, at the least, be put on hold.
- Uncertainty regarding the Coal Authority's plans regarding a potential charge for access to the mining infrastructure. There are concerns that charging for heat might fatally undermine the business case for mine energy schemes, particularly higher cost schemes such as those that require the drilling of boreholes.
- Perceptions of risk are a major constraint as they deter potential developers and investors and may also undermine public confidence. Specific concerns include:
  - The risk of expensive borehole-based schemes failing to locate a viable and sustainable resource. Drilling is undertaken at the developer's own risk and the possibility of failure can deter more risk-averse investors.
  - The possibility of a decline in the projected heat yield over time or of access to heat being subject to interruption as a result of the collapse of underground workings. Mine water developments are long-term investments; unanticipated declines in heat yield (and therefore income) would undermine the viability of affected schemes.
- Supply chain constraints identified by stakeholders include a lack of information, capacity and capability (skills and expertise):
  - The Coal Authority has developed an interactive mapping tool; however, stakeholders identified a need for enhanced tools to better enable early-stage strategic assessment exercises (e.g. to identify and prioritise potential mine energy projects in a given local authority area).

- The embryonic status of the sector means that there is a lack of expertise, specifically technical consultants, scheme design engineers (borehole and pump system) and drilling contractors.
- In addition to supply-side constraints there is a lack of expertise in relation to mine energy development, and in some cases heat network development as well, among clients and their project managers.
- The Coal Authority hosts a well-regarded mine energy team, but stakeholders reported that this team was becoming overstretched and that a lack of capacity within the Coal Authority was emerging as a constraint on the growth of the mine water heat sector.

Recommendations

The UK has taken a lead in mine energy, but to ensure continued growth, and thereby the associated decarbonisation and socio-economic benefits, requires sustained government support. To accelerate the sector beyond the need for subsidy will require greater levels of collaboration between public, private and academic bodies, supplemented by targeted investments in research and development. A list of more specific recommendations follows.

Recommendation 1 (high priority)

The mine energy sector in the UK is at an early and vulnerable stage in its development and at this point in time is highly dependent upon public subsidy. Successor schemes to the ERDF, HNIP and the RHI should take into account the support needs of the sector and ensure that replacement schemes allow for a sustainable rate of growth.

Recommendation 2 (high priority)

There is a need for policies that reduce the competitive advantage of gas in relation to low carbon heat sources. These need to be accompanied by clear, consistent and unambiguous policy messaging in order to build confidence among developers and heat network investors.

Recommendation 3 (high priority)

Strategic stakeholder bodies should facilitate and support greater ongoing collaboration and knowledge sharing between mine energy scheme designers, developers, regulators and the research community. There is an existing national forum in the shape of the Mine Energy Taskforce. This is well placed to take ownership of several of the recommendations made in this report but would require additional resources to enable it to play a more substantive national role. Participant organisations with an enabling role, such as regulators and licensees, may also need additional resources to enable greater coordination and accelerate progress on the recommendations.

Recommendation 4 (high priority)

The Coal Authority has taken a strong lead on mine energy and is actively supporting and enabling its growth. However, our research identified a need for closer dialogue between the wider mine energy stakeholder community and the Authority to ensure that the development of tools and research programmes relating to mine energy are more closely informed by the emerging market. Two priority stakeholder asks include:

- The development of a GIS tool to enable matching between current and potential heat demand and potential supply. Specific requests included filters that provide indicative drilling and borehole costs, characterisation of the key resource variables (depth, temperature, volume), and the risks associated with site characteristics.
- National sub-surface geotechnical and hydrogeological models to enable characterisation of the sub-surface conditions ahead of site selection and drilling.

Recommendation 5 (high priority)

We found some confusion and uncertainty in the marketplace regarding the role of the Coal Authority in the development of the mine energy sector. Such uncertainty deters potential developers and investors. Stakeholders in the wider market would like clarity around charging for heat access and the Authority's preferred role in new project development.

Recommendation 6 (medium priority)

Funding should be sought and allocated to enable the development of:

- One or more demonstration mine water heat network schemes in smaller coalfield communities. A key focus of such schemes should be the integration of the housing types 'typical' of ex-coalmining settlements (see also Recommendation 13).
- The establishment of one or more inter-seasonal storage demonstrators. These could be new schemes or extensions of existing or proposed schemes.

Recommendation 7 (high priority)

The Coal Authority technical support service is greatly valued but felt to be overstretched. Stakeholders expressed a wish to see the service expanded to enable it to meet increasing demand. Failing that, alternative support mechanisms are required.

Recommendation 8 (high priority)

The Coal Authority is already in discussion with sector bodies about the development of mine energy specific training for the supply chain. Our research suggests that this should include bespoke training for client project managers.

Recommendation 9 (medium priority)

Public sector bodies are leading the development of mine water-based district heating systems. The establishment of a national expert contractors framework would build confidence by providing a level of quality assurance, while streamlining the procurement process.

Recommendation 10 (medium priority)

Public support mechanisms (ERDF, HNDU, HNIP, RHI) have enabled a new, embryonic generation of mine energy schemes, but do not fully take into account the key differences between mine energy and other forms of low carbon heat. To ensure growth, bespoke support measures may be required to address sector-specific barriers. In particular, consideration should be given to the establishment of a loan guarantee (for borehole drilling) and risk insurance (to protect against the possible decline in heat over the operational life of the project).

Recommendation 11 (medium priority)

Most of the previous recommendations should contribute to the improved business case for mine energy, but in addition:

- The sector should focus on identifying opportunities for cost reduction through increased standardisation, for example of contract documentation and procurement specifications, and process optimisation.
- Scheme developers would benefit from having improved access to commercial data to better enable them to compare the relative merits of mine water heat schemes against the main alternatives and to establish cost benchmarks for mine energy schemes.
- Publicly funded schemes should be required to collect and share non-confidential data on the costs of scheme development and on operational issues relating to the sustainable management and operation of mine water energy schemes.

* If resource were to be made available, this recommendation could be taken forward by the Mine Energy Taskforce.

Recommendation 12 (medium priority)

There is a need for research to identify business sectors with high heat/cooling demands (within the range that can be delivered via mine energy schemes) and to examine the technical and commercial case for linking such businesses with actual or potential mine energy schemes.

Recommendation 13 (medium priority)

Desktop studies should be commissioned to consider the relative merits of mine energy, in comparison to whole house retrofit, as a mechanism for decarbonising the types of hard-to-treat properties that characterise many traditional coalfield communities. Such research should include consideration of the relative merits of these options in relation to their delivery of co-benefits, and in particular the alleviation of fuel poverty.

Recommendation 14 (medium priority)

All publicly funded schemes should be required to identify and pursue opportunities to secure social value through the procurement process, such as the use of targeted recruitment and training clauses to create opportunities for specific groups, for example the long-term unemployed.

Introduction

The Industrial Revolution triggered a huge demand for and was enabled by coal, prompting a dramatic increase in mining activity which continued at scale until the early 1980s. At the industry's peak in 1913, a million men worked in 1,600 mines producing almost 300 million tonnes of coal a year. Over 25,000 square kilometres of the UK have been affected by coal mining[2].

Below ground, the legacy of this activity is an extensive range of underground voids (often interconnected), including reinforced underground structures such as mine roadways and shafts, many of which have become naturally flooded as a result of the cessation of pumping activity.

Natural sub-surface processes have elevated the temperature of this water (as such, mine water is considered a geothermal resource), providing a significant and largely untapped low carbon heat resource. According to the Coal Authority, abandoned mines have the potential to meet most of the heat needs of the coalfield communities.

The decarbonisation of heat is one of the principal challenges to the UK's successful pursuit of its net zero ambitions. Addressing this challenge will require the deployment of a range of technologies, among the foremost of which are heat networks. Mine water offers a proven and sustainable source of low carbon heat for heat networks and has several competitive advantages over the existing alternatives.

However, as with all alternative low carbon heat sources, mine water-based schemes require public support if they are to make a material contribution to decarbonisation. Owing to the location of abandoned mine workings, primarily in the north of England and often in areas suffering significant social and economic disadvantage, the provision of such support would contribute to the governments 'levelling up' agenda by providing a direct opportunity to create jobs and stimulate economic regeneration in coalfield areas.

Uniquely, in contrast with alternative sources of low carbon heat, the exploitation of abandoned mine workings as an energy source could be harnessed to create a powerful narrative of renewal. Under the banner of a green future for the coalfields, new mine waterbased heating schemes could be linked to wider regeneration initiatives to attract new businesses, create regional centres of excellence, and stimulate new heat-based business clusters.

This white paper makes the case for targeted public support for the development of mine water heat-based schemes. Its scope focused on the development of mine energy in England, but the recommendations, if implemented, would be expected to support mine energy activity in all parts of the UK.

It describes the benefits and opportunities associated with such developments and the challenges and barriers that currently constrain mine water heat exploitation at scale. Finally, it considers the types of public policy support required to address the identified barriers and makes a series of recommendations for consideration by senior stakeholders and policymakers[3].

[2] Environment Agency (2008) Abandoned mines and the water environment. Available at https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/291482/LIT_8879_df7d5c.pdf [Accessed on 16.10.20].

[3] The research investigated the state of play for mine energy across the UK. We are aware that there are differences in the legal and support frameworks across the devolved administrations. The policy recommendations contained in this report are directed at the UK government and therefore not all will apply to Scotland.

1.1 Origin of the white paper

The white paper was commissioned by the North East Local Enterprise Partnership (North East LEP) on behalf of the Mine Energy Taskforce. The taskforce has been convened by the North East LEP as a national community of interest, via the Department for Business, Energy and Industrial Strategy (BEIS) Energy Hub networks. Funders of the white paper include the North East, Yorkshire and Humber, and Midlands Energy Hubs, BEIS and the MCS Charitable Foundation.

The paper has been produced by CAG Consultants in association with Carbon Alternatives, Geoenergy Durham and Handley Project Solutions. It summarises the key findings of an evidence review report prepared by the project team, which synthesised insights and evidence from a literature review and a series of interviews with over 50 expert stakeholders. The specification for the review asked that the CAG team:

- Outline the high-level UK opportunity in terms of low carbon energy provision and storage
- Summarise existing knowledge, capabilities, expertise and support available across the sector, to enable a more effective connection of expertise across stakeholders
- Collate a high-level understanding of the potential UK project pipeline, based on current stakeholder understanding of where mine energy could potentially be deployed
- Explore up to six case studies of mine energy projects and the factors that enabled these to succeed, or that led to their failure, with insights from these being used to help inform recommendations
- Set out key supply chain capacity that needs to be in place to service a functioning and competitive UK market
- Set out the technical, commercial, regulatory, market, environmental, subsidy and policy failures, barriers or knowledge gaps preventing delivery at scale in the UK.

Findings from the review were shared with a steering group comprised of members of the Mine Energy Taskforce and via online workshops with a wider group of stakeholders. This white paper summarises the key findings of the evidence review, informed by the additional views and insight generated by the steering group and stakeholder feedback.

The exploitation of mine water as a resource

1.2 Introduction

The Coal Authority estimates that there are 23,000 abandoned deep coal mines around the UK. When operational, many mines were pumped to enable mining activity. Following abandonment, mines naturally refill with water which is warmed as a result of sub-surface geological processes. As such, mine water heat is considered as a form of geothermal energy.

1.2.1 Methods for accessing mine water heat

Mine water can be accessed through three main routes: via drilling into old mine workings, via mine shafts, and from mine water treatment plants. The pros and cons of each form of access are summarised in Table 1.

Table 1: Access paths for mine water heat

Heat access method	Summary explanation	Benefits and limitations
Drilling of access borehole	Establishing access to mine water heat typically involves drilling 2-3 boreholes[4]. The process starts with either pilot or exploratory boreholes. Assuming that these are successful in accessing a mine water source, the flow rate and temperature of the water is assessed to determine the likely viability of the scheme. If the tests are positive the initial boreholes may either be increased in size (reamed out) or additional boreholes sunk.	• Allows access to heat near to point of demand • High cost (highly variable, key dependency is depth) • Perceived as high risk as viability of scheme subject can only be confirmed following the drilling of the borehole
Mine shafts	Mine water can be directly accessed via mine shafts. A small-scale example operates at the site of Markham Colliery and larger-scale opportunities are being considered. However, many mine shafts were filled and capped following the closure of the mines. While it may be feasible to open some of these up, it may be impractical for others and in all cases is likely to be costly.	• Where practical, would be expected to be lower cost (easier access) and lower risk than borehole-based schemes • Shafts not always located near to sources of heat demand, or readily accessible when available • Many shafts are unusable or have been filled
Mine water treatment schemes	The Coal Authority currently owns 75 mine water treatment schemes across the UK. These treat over 122 billion litres of mine water every year and are associated with a potential 100MW of available heat energy. Having no immediate use, this is currently simply discharged into the wider environment[5].	• Lowest cost option, as heat can be accessed directly from the outflow • Limited number of pumping stations • Stations not always near to sources of heat demand

[4] Many schemes will require one or two abstraction boreholes to access mine water and a separate re-injection borehole to return water to the mine system.

[5] Farmer, M. (2020) How defunct coal mines could heat UK homes. Mining Technology [online]. Available at: https://www.mining-technology.com/features/mine-heating-water-treatment-coal-authority-uk-heat-pumpseaham-dawdon/ [Accessed on 3.2.21].

1.2.2 Key technologies

The exploitation of mine water is dependent upon two central technologies, namely heat pumps[6] and heat networks, both of which are critical to the decarbonisation of heat in the UK.

1.2.2.1 Heat pumps

Irrespective of the access route, mine water heat schemes are based on the use of heat pumps. Heat pump systems collect ambient heat, usually from the air, ground or water, and then elevate its temperature through compression before releasing it to the end user. Heat pumps are powered by electricity but are regarded as a low carbon technology, as for each unit of electricity used to power the heat pump they are able to generate 2–4 units of heat depending upon the heat source and its temperature.

1.2.2.2 Heat networks

Heat networks (also known as district heating) supply heat from a central source to consumers via a network of underground pipes carrying hot water. Heat networks can cover a large area or even an entire city, or be fairly local, supplying a small cluster of buildings[7].

The Committee for Climate Change (CCC) estimates that heat networks could meet 18% of UK heat needs by 2050[8]. The expansion of heat networks is supported by the government through policy and specifically in terms of funding through the Heat Networks Development Unit (HNDU), the Heat Networks Investment Project (HNIP) and the Renewable Heat Incentive (RHI).

1.3 The development of mine water schemes to date

1.3.1 International developments

The first reported exploitation of mine water as a heat resource was a heating and cooling system installed in a leisure centre in 1981 in Kingston, Pennsylvania, US. This was identified in a review of mine energy schemes undertaken in 2015[9], at which point it was recorded as having run without complications since installation.

Another early installation was undertaken by Ropak Can Am Ltd, a manufacturer of plastic packaging products, at their site in Springhill, Nova Scotia, Canada, in 1988. This site overlies flooded former coal mines containing an estimated 4,000,000m3 of water[10]. An existing oil-based heating system was replaced by one based on heat pumps. Owing to the high cost of oil this installation is reported as having paid for itself within one year[11]. Since the initial installation, a number of other commercial and public buildings in Springhill have also installed mine water heat-based systems.

Despite such projects demonstrating the technical and, in some cases, commercial case for such schemes, only a limited number of additional installations (27), including some non-coal mine based schemes[12], have been established and only a handful (including a new UK site installed by Lanchester Wines, Heerlen in Holland, Springhill in Canada and Barredo in Spain) operate at scale. The primary constraint has been – and in most cases remains – the low cost of alternative, fossil fuel-based, heating systems.

[6] In a mine water heat-based system, heat pump systems use a heat exchanger to transfer heat from mine water (and other sources) to fresh water. It is the latter which is pumped around buildings and not the mine water itself, which is usually returned to the mine.

[7] BEIS (undated) What is a heat network? Available at https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/696273/HNIP_What_is_a_heat_network.pdf [Accessed on 22.11.20].

[8] Committee on Climate Change (2016) Next steps for UK heat policy. Available at https://www.theccc.org.uk/publication/next-steps-for-uk-heat-policy/ [Accessed on20.10.20].

[9] Ramos, P.R., Breede, K., Falcone, G. (2015) Geothermal heat recovery from abandoned mines: a systematic review of projects implemented worldwide and a methodology for screening new projects. Environ Earth Sci 73;6783-6795.

[10] Jessop, A.M., MacDonald, J.K., Spence, H. (1995) Clean energy from abandoned mines at Springhill, Nova Scotia. Energy Sources 17: 93-106. Available at https://www.researchgate.net/publication/255798282_Clean_Energy_from_Abandoned_Mines_at_Springhill_Nova_Scotia [Accessed on 16.10.20].

[11] Ibid.

[12] Gluyas, J. (2020) Email to Bill Kirkup, 15 September.

1.3.2 Mine water scheme developments in the UK

In the UK, the earliest known mine water heat scheme was installed to provide heat to 16 domestic properties (social housing) in Shettleston (Glasgow) in Scotland in 1999. Another Scottish site, Lumphinnans (Fife), was installed in 2001 but has since been decommissioned owing to vandalism of the boreholes. In England, three small schemes have been installed at ex-colliery sites at Markham (2011, Yorkshire), Dawdon (2009, Durham) and Caphouse (2015, Yorkshire).

More recently (2020), Lanchester Wines, a private company based North East England, has installed 2.4MW and 1.6 MW mine water-based heating systems (currently the largest in the UK) to heat two warehouses in Gateshead. This development is expected to be followed by an even larger scheme, 6MW, led by Gateshead Council, which will use mine water as the heat source for a planned expansion of the Gateshead District Energy Scheme[13] (a wholly council owned business). Another scheme, 3.5 MW (with potential for more), also in North East England, is planned as part of the new Seaham Garden Village development. Both of these schemes have recently been awarded funding through the Heat Networks Investment Programme (HNIP)[14].

Elsewhere in the UK, multiple schemes have been subject to some level of investigation. The Coal Authority, which as the agency responsible for the management of the UK's abandoned mines and owner of the mining infrastructure is engaged in dialogue with multiple potential scheme developers, estimates that there are 42 projects in the UK pipeline[15].

1.3.3 Drivers of interest

It is evident that there has been a step change in the level of interest and activity in relation to mine water energy schemes. The increased prominence and urgency of the climate change agenda is the key driver of interest in the development of mine water-based energy schemes, but an increasingly important driver for LEPs and local authority stakeholders is recognition of the scope for linking decarbonisation initiatives with the pursuit of economic regeneration, i.e. the 'green growth' agenda. These drivers and the associated opportunities are the subject of chapters 3 and 4 of this report.

[13] Gateshead Council (2020) Major grant will connect Gateshead homes to mine water energy scheme. Available at https://www.gateshead.gov.uk/article/15805/Major-grant-will-connect-Gateshead-homes-tomine- water-energy-scheme [Accessed on 16.10.20].

[14] Triplepoint (2020) Successful projects [Online]. Available at https://tp-heatnetworks.org/funded-projects/ [Accessed on 24.1.21].

[15] This figure includes schemes identified as being suitable for development, but which have not as yet been subject to detailed assessment.

The decarbonisation benefits of mine water heat

1.4 Introduction: Meeting the heat decarbonisation challenge

The UK's Climate Change Act (2008) established a legally binding obligation to reduce the net UK carbon account for the year 2050 by at least 80% lower than the 1990 baseline. In 2019 the Climate Change Act was amended to increase this target to 100%, making the UK the first major economy to pass a net zero emissions law[16]. Under the provisions of the Act, carbon emission reductions are phased over a series of five-year carbon budgets, beginning with the period 2008–2012. These budgets set progressively higher targets for decarbonisation.

The UK has made significant progress in decarbonising electricity but has so far made limited progress on 'clean' heat. Indeed, the decarbonisation of heat was identified in the Clean Growth Strategy as "our most difficult policy and technology challenge"[17]. Heat is prominent within the prime minister's 'Ten-Point Plan for a Green Industrial Revolution' and national infrastructure strategy, particularly in relation to objectives around greener buildings. According to CCC figures, heating and hot water account for 40% of UK energy consumption and are responsible for one fifth of UK greenhouse gas emissions[18].

In their most recent progress report[19] to government, the CCC stated that the forthcoming Buildings and Heat Strategy must enable low-carbon heating to move from being a niche solution to being the dominant form of new heating installation in the UK by the 2030s. Currently, the CCC estimates that less than 5% of the energy used for heating homes and buildings is derived from low-carbon sources[20]. The relatively low cost (in comparison to other heat sources) and wide availability of natural gas are barriers to the UK's transition to other energy and technology options, including mine water heat.

1.5 Key benefits of mine water heat as a low carbon energy resource

Mine water heat is an abundant, widely distributed and naturally occurring low carbon heat source. As a resource it is relatively well understood and is distinguished by several technical characteristics which give it a comparative advantage as a heat source for heat pumps and heat networks. These characteristics are:

- If managed correctly, it is constantly available at a consistent and elevated temperature, making it a cost competitive source of low carbon heat
- It is available at scale, widely distributed and often co-located with areas of high heat demand
- If managed correctly, it is a self-sustaining indigenous resource.

The benefits associated with these characteristics are explored in more detail in the following sections.

[16] BEIS (2019) UK becomes first major economy to pass net zero emissions law [online]. Available at https://www.gov.uk/government/news/uk-becomes-first-major-economy-to-pass-net-zero-emissions-law [Accessed on 23.11.20].

[17] HM Government, UK (2017) The Clean Growth Strategy: Leading the way to a low carbon future. Available at https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/700496/clean-growth-strategy-correction-april-2018.pdf [Accessed on 27.1.21].

[18] CCC (2016) Next steps for UK heat policy. Available at https://www.theccc.org.uk/publication/next-steps-for-uk-heat-policy/ [Accessed on [23.11.20].

[19] CCC (2020) Reducing UK emissions: 2020 progress report to Parliament. Available at https://www.theccc.org.uk/publication/reducing-uk-emissions-2020-progress-report-to-parliament/ [Accessed on 23.11.20].

[20] Ibid.

1.5.1 A cost-competitive source of heat

The effectiveness of a heat pump is measured by its coefficient of performance (COP). This represents the ratio between the energy (electrical) used by the heat pump and the energy delivered (as heat). For example, a heat pump with a COP value of 4 means that the use of 1kW of electrical energy releases 4kW of heat.

The COP of a heat pump is determined by the temperature difference between the heat source and that required by the end user. The lower the differential between the source and output temperatures, the higher the COP. The elevated temperature of mine water allows for reported COPs of 4 and above; for example, the aforementioned Lanchester Wines site reports a COP of 6. The high COP attainable through the use of mine water, in comparison with air, water (sea and river) and ground-sourced heat, is one of the key reasons for the attractiveness of mine water heat schemes.

The availability of mine water at a constantly elevated temperature conveys an additional benefit. UK heat demand is highly seasonal but mismatched with some of the main forms of low carbon heat source that operate more efficiently in the warmer months of the year. For example, air and water-based heat pump systems operate at a lower COP in the winter months and may therefore need to be supplemented by gas or electric-based systems. In comparison, the temperature of mine water, if managed correctly, is unaffected by seasonal change (see Table 2). As a result, the COP is also relatively constant, and a heat pump system based on mine water heat will therefore be more cost- and carbon-efficient than those which have to accommodate seasonal temperature variations.

Table 2: Relative COPs of typical heat pump operational scenarios, in comparison with a mine water heat-based scheme[21]

Heat source	Average temperature	Average temperature weighted by heat demand (more heat needed in winter when air and river are colder)	Resultant COP[22] (assumes the same output temperature)
Air (Newcastle)	10.4	8.4	3.5
River (tidal River Tyne)	10.2	8.5	3.6
Mines (300m deep)	17	17	4.4
Open loop heat pump 100m	12	12	3.8

[21] Figures developed for this report by Martin Crane of Carbon Alternatives.

[22] The COPs do not include the pumping energy that needed to get the large volumes of river/mine/ground water to and from the heat pump. These would be expected to reduce the stated COP for mine water heat.

1.5.2 An abundant and widely distributed alternative

As noted in the introduction, the Coal Authority estimates that there are around 23,000 abandoned coal mines around the UK, many of which are flooded with water. Fortuitously, owing in part to the historic importance of coal and the coal mining industry, the mine water resource is often co-located with densely populated urban areas, including nine out of the ten largest (by population) British cities. Overall, the Coal Authority estimates that 25% of UK's built environment is located above former coalfields.

The presence of mine water resources in close proximity to centres of high heat demand, in combination with its potential for high system COP, has attracted considerable attention to mine water as a heat source for heat networks.

Until recently the default option for fuelling new heat network developments has been gas CHP (combined heat and power); however, the case for CHP, from a carbon emissions perspective, is declining[23]. As a result, newer heat network developments are seeking alternative, lower carbon heat sources. This trend has been reinforced where new housing sites are being considered, for example the proposed Seaham Garden Village development, as a result of the proposed Future Homes Standard. If introduced, this will require new build homes to use low carbon heating from 2025.

Other low carbon alternatives to gas CHP for district heating include river source heat pumps, heat from sewers, and energy from waste, biomass and biogas. All have their merits, but all are subject to geographic constraints and larger scale developments, and often lack viable options. The widespread distribution and scale of the mine water resource means that mine water heat provides a valuable alternative and is a potentially important enabler of heat network developments, and therefore heat decarbonisation. Were all 42 schemes in the Coal Authority's pipeline to be built out, this would generate projected carbon savings of 90,500 tonnes per annum.

1.5.2.1 Cultural affinity

An additional potential benefit of mine water heat, as evidenced by stakeholder interviews, is the deep cultural affiliation of ex-mining areas with the coal mining industry. Our research identified examples where this historical affinity has been important in helping to generate support for potential developments among elected members and senior officers. District heat networks are complex and often challenging developments, and such support can be essential in ensuring that projects are taken forward.

To date, consumers, both commercial and domestic, have proven reluctant to engage with heat networks. Linking mine water heat-based developments to a narrative of renewal may also prove useful in 'selling' heat networks to potential customers.

1.5.3 A sustainable and indigenous resource

Mine water heat is a naturally renewable resource as the heat is constantly replenished by geothermal processes. As such, while care is required to not 'over-harvest' the heat, it can be considered a sustainable resource.

As an indigenous resource, its exploitation would enhance national energy security while reducing the 'loss' to the UK economy that is associated with expenditure on imported energy sources.

[23] CCC (2016) Next steps for UK heat policy. Available at https://www.theccc.org.uk/publication/next-steps-for-uk-heat-policy/ [Accessed on 20.10.20].

1.6 Emerging opportunities

1.6.1 Thermal storage

If the UK meets 14–20% of its overall heat demand with heat networks by 2030, it could deliver 32–46GWh of thermal energy storage annually. 46GWh of thermal storage is the equivalent of 4 hours of space heating and hot water demand in wintertime for a million households (i.e. with a 12kW thermal load)[24].

It is usual to include some level of thermal storage in heat networks to provide a short-term balancing function. Doing so provides operators with increased flexibility and can improve the economics and carbon reduction benefits of heat networks. For example, heat can be generated and stored during periods of low demand for release during peak demand periods. This allows for the installation of a smaller plant while enabling it to be utilised in the most efficient manner.

Beyond this, large-scale storage systems can be used for inter-seasonal storage where surplus heat and/or seasonal heat sources, e.g. solar thermal arrays, provide heat during warmer periods of the year for release during the colder months. Such systems offer exciting opportunities to integrate heat networks into the wider energy system. For example, surplus renewable energy can be used to heat water during periods of low electricity demand and released as demand increases, thereby enabling heat networks to play a role in balancing out the natural fluctuations associated with the supply and demand of heat and renewable electricity.

The construction of large-scale thermal storage systems is, however, expensive and can take up considerable space. A more space-efficient alternative, widely and successfully used in the Netherlands and increasingly other countries (e.g. Sweden, Germany, Belgium) is to store heat (and 'cold') in natural aquifers – Aquifer Thermal Energy Storage (ATES). In the UK, ATES is a relatively immature technology but has been deployed on several sites in London, for example the Riverlight development. A 2016 report produced by Delta Energy[25] suggests that suitable geological conditions for ATES exist in the South East England, Birmingham, Liverpool and East Anglia.

Mine shafts and galleries provide a potential alternative, although one less well explored, to the construction of large-scale thermal storage systems and ATES and are present in several parts of the UK where aquifer-based solutions are unavailable. No such schemes have yet been developed in the UK, but building on their aforementioned demonstration facility a mine-based inter-seasonal storage scheme has been established at Heerlen in the Netherlands. The experience here demonstrates that the use of mines for thermal storage is technically feasible and that mine-based systems could provide a significant tool for localised energy system balancing schemes. Multiple uncertainties remain, but if the UK develops mine water heat systems at scale then it has an opportunity to develop a new tool for balancing local energy systems while establishing itself as a leader in this area. However, to do so will require significant research and investment in demonstration sites.

[24] ADE (2018) Market report: Heat networks in the UK. Available at https://www.theade.co.uk/assets/docs/resources/Heat%20Networks%20in%20the%20UK_v5%20web%20single%20pages.pdf [Accessed on 24.1.21].

[25] Delta Energy & Environment (2016) Evidence gathering: Thermal energy storage (TES) technologies. BEIS. Available at https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/545249/DELTA_EE_DECC_TES_Final__1_.pdf [Accessed on 26.11.20].

1.6.2 Cooling

The focus of this paper is the use of mine water-based schemes to deliver heat, particularly through the mechanism of heat networks, but mine water schemes can also deliver cooling.

For example, a proposed scheme in South West Virginia, US, Project Oasis, is exploring the possibility of establishing a mine water-based cooling scheme to attract data centres as part of an area-based regeneration initiative. A recently published feasibility study[26] for this project suggests that a mine water-based system could reduce electricity use by 90%.

To date, the focus of the UK heat network sector, and in particular operators dealing with district scale schemes, has been on the provision of heat. This is largely owing to the relative lack of demand for cooling, and in particular low demand for district-wide schemes. However, there is increasing recognition that demand for cooling services is likely to grow in response to rising temperatures, and the next generation of heat networks (the fifth) are expected to provide both heat and cooling. So-called fifth generation district heating and cooling (5DHC) schemes are being trialled at several sites in mainland Europe, including the latest evolution of the Heerlen scheme. In the UK, an aquifer-based city centre scheme is being considered by Plymouth City Council, while one small mine-based pilot scheme is being developed in Nottingham[27].

In the eyes of some industry stakeholders, the natural evolution of heat networks would lead to the establishment of an intranet of heat, whereby heating and cooling loads are automatically shifted (both across geographic areas and seasons) around a network of pipes shared by multiple users.

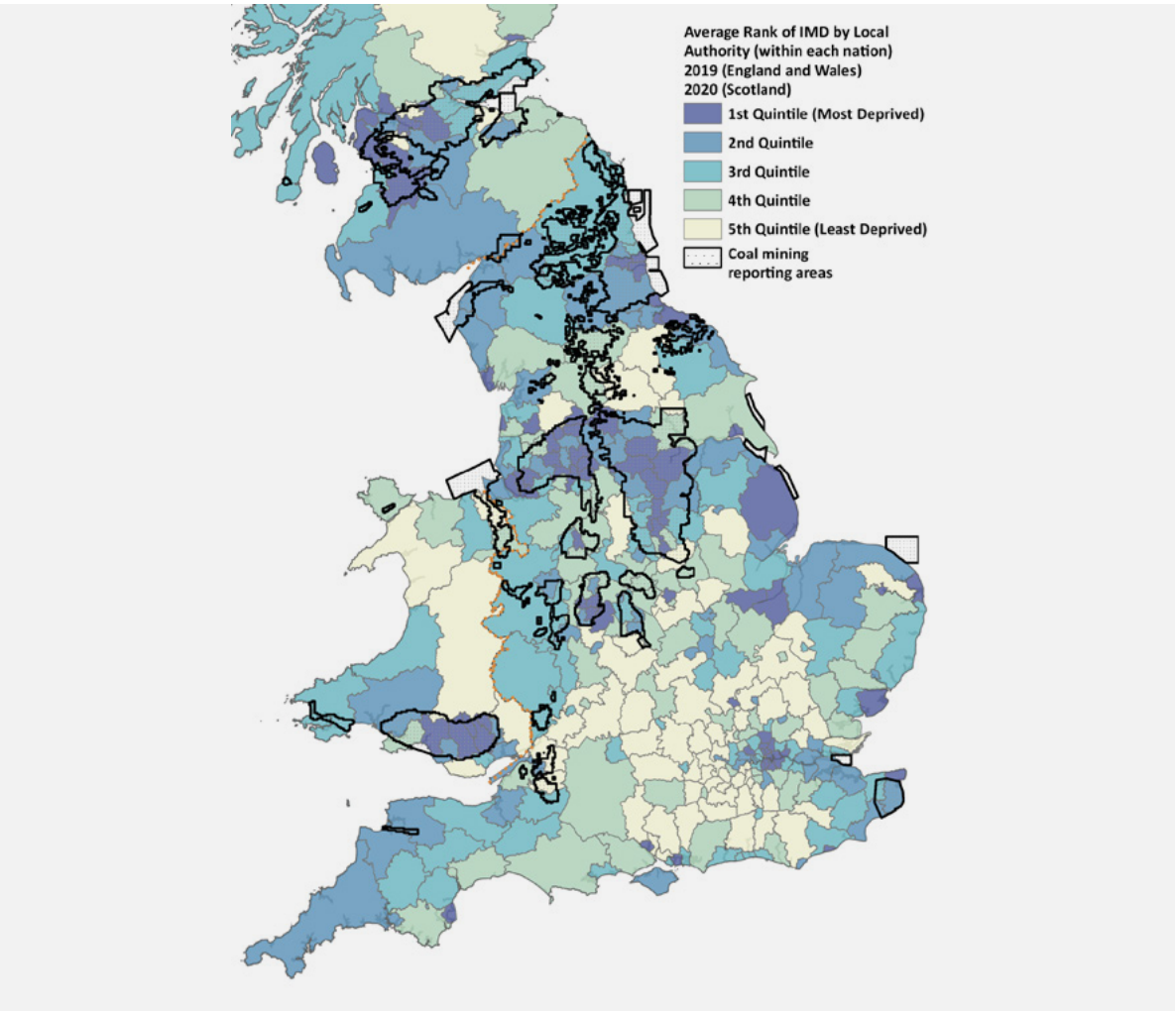
[26] OnPoint Development Strategies (2020) Project Oasis: Market analysis for data centre investment in Southwest Virginia. Available at https://static1.squarespace.com/static/5f0a2bd5c3354d1c75ad855e/t/5f78a1c787afb65ed3150ff1/1601741260417/Project+Oasis+Final+Report+10-01-20.pdf [Accessed on 17.10.20].

[27] D2Grids Communication (2020) [D2Grids] Discover 5 pilots implementing 5th generation heating and cooling networks. Available at https://www.construction21.org/articles/h/D2GRIDS-project-discover-five-pilots-implementing-5GDHC-heating-and-cooling.html [Accessed on 25.11.20].

Green growth: The socio-economic benefits of mine energy

The loss of the coal mining industry means that many coalfield communities have experienced significant economic and social decline. Many communities have not yet fully recovered and, as illustrated by Figure 3; many are located within areas identified as being among the most deprived in the UK. The Coalfields Trust, which was established to support ex-coal mining communities in the towns and villages within the coalfields, estimates the population of coalfield areas at 5.7million. A recent 'State of the Coalfields' (2019)[28] report suggests that if the coalfield areas constituted a region, it would be likely to rank as the most deprived region in the UK.

Figure 1: Average ranking of Indices of Multiple Deprivation (IMDs) by UK local authority area (2019 for England and Wales and 2020 for Scotland)



The development of mine water heat networks would bring immediate and direct economic benefits to coalfield communities and businesses, but also provides an opportunity to attract new businesses and in the process contribute to the government's 'levelling up' agenda.

[28] Beatty, C., Fothergill, S., Gore, T. (2019) The State of the Coalfields 2019 – Economic and social conditions in the former coalfields of England, Scotland and Wales. The Coalfields Regeneration Trust. Available at https://www.coalfields-regen.org.uk/wp-content/uploads/2019/10/The-State-of-the-Coalfields-2019.pdf [Accessed on 22.10.20].

1.7 Economic benefits associated with mine water energy schemes

1.7.1 Green job creation

The construction phase of mine water-based heat network schemes is associated with significant and immediate employment opportunities – opportunities which, given the association of abandoned mines with economically disadvantaged areas, would directly support the government's 'levelling up' agenda.

If the 42 schemes identified by the Coal Authority were to proceed, this would create an estimated 4,227 jobs directly. This is associated with an estimated £293 million gross value added (GVA). An additional 9–11,000 jobs would be created once the indirect and induced economic effects are accounted for, although many of the latter would depend upon the ability of the UK supply chain to fully capture the supply chain opportunities. Applying the same composite multipliers as set out above for jobs, this generates an estimated additional GVA of between £400–500 million.

While the construction of each individual site is largely associated with short-term employment opportunities, expansion and the development of new heat networks would be expected to create longer term, sustainable employment opportunities. Additionally, new heat network schemes, both mine water-based and otherwise, will need to be integrated with other low carbon solutions, for example solar thermal, if the decarbonisation potential of this technology is to be realised and national heat decarbonisation targets attained. Such additional developments would also create ongoing 'green collar' employment and supply chain opportunities, for example in operations and maintenance roles.

Importantly, where such schemes are being procured by public sector bodies, they present an opportunity to create training and job opportunities for disadvantaged groups through the use of 'targeted training and recruitment' clauses[29].

1.7.2 Mine water heat schemes as a driver of local and regional economic regeneration

Increasing acknowledgement of the challenge of climate change, the growth of public support for action and the evolution of an ever more focused policy environment is driving many businesses to seek opportunities to reduce their carbon footprint. For organisations with high heat costs, mine water-based schemes, where cost-competitive, provide an attractive option.

For example, the Lanchester Group, a bottling, packaging and wine development company, has invested over £8 million in renewable heat and energy generation at its sites in North East England. This investment includes an expenditure of more than £3 million on the development of the UK's biggest commercial mine water heating scheme at its warehouse facilities in Gateshead. The group sees a demonstrable commitment to sustainability as being a key point of difference for their business and something that has brought them a tangible competitive advantage.

Regeneration agencies have an opportunity to build on the low carbon credentials of mine water schemes to create a wider narrative of renewal in the coalfields. Mine energy alone will not address the economic and social disadvantage experienced by many coalfield communities, but as a source of low carbon heat it may, when supported by other incentives, enable agencies such as LEPs to attract new businesses to an area.

In the Netherlands, the City of Heerlen operates a wide-ranging regeneration programme and its acclaimed mine energy development forms an important component of its low carbon transition planning, with the scheme also playing a central role in a regional initiative, the PArkstad Limburg Energy Transition (PALET) project[30]. The scheme has reportedly been important in enabling the retention of existing businesses and in attracting new enterprises, to an area that has suffered significant decline as a result of the closure of local coal mines.

[29] Public sector bodies could include requirements for targeted recruitment and training via the procurement process. For further information see https://www.jrf.org.uk/report/tackling-poverty-through-public-procurement

[30] Brummer, N., Bongers, J. (2019) Mijnwater Heerlen: Roadmap to 2040. Interreg NWE. Available at https://www.mdpi.com/2071-1050/8/4/382 [Accessed on 23.10.20].

1.7.2.1 An opportunity to establish new business clusters

Our research identified considerable interest in the possibility of establishing new businesses adjacent to mine energy schemes, particularly mine water treatment plants, where the costs of mine water heat would generally expected to be at their lowest.

The following industry sectors were identified as having high heat demands and therefore as being potential beneficiaries of affordable low carbon heat.

- Pharmaceutical companies
- Storage and distribution centres
- Horticultural glass house production units
- Aquaculture systems.

However, more research is required in order to determine whether and on what basis business decisions in any of these sectors might be informed or influenced by access to mine water heat.

1.7.3 An opportunity for the UK to assume first mover status

A number of industry and academic stakeholders noted that the development of mine energy schemes provided an opportunity to establish new UK-based centres of research and commercial expertise, and thereby create new export opportunities for UK businesses.

A 2016 report by the Carbon Trust[31] estimates that the global heat market will be worth £121–416 billion by 2050. The report notes that the heat market is dominated by non-UK countries but suggests that the UK could capture up to 2% of the market and that this would be worth circa £25 billion in GVA by 2050, while supporting circa 88,000 jobs.

The report does not address mine energy specifically, but many countries have a significant mining heritage. Should the UK take a lead in this area, this would be expected to provide associated businesses with a competitive advantage in what has the potential to be a significant market niche.

1.8 Socio-economic benefits

Jobs and growth, particularly green growth, delivers a range of socio-economic benefits, lifting people out of poverty and creating opportunity. However, mine energy developments also offer opportunities to deliver other forms of social benefit. The expansion of district heating in the UK's major population centres will, it is hoped, over time deliver tangible benefits to domestic consumers in the form of more affordable lower carbon heat. Achieving similar outcomes in smaller communities, for example old colliery towns and villages, may prove more challenging.

Conventional wisdom suggests that household heat pumps provide a more cost-effective solution for smaller communities than heat networks. However, the nature of the original housing in many coalfield settlements makes it difficult to deliver the thermal efficiency required (in a cost-effective manner) to enable household heat pumps to provide an effective solution.

Some sector experts have suggested that the inefficiency of the housing stock means that, at a certain scale, district heating may offer a partial solution to the challenge of decarbonising smaller, low income coalfield communities. Where heat could be offered at a discounted rate, an additional benefit would be the opportunity for scheme operators to directly address fuel poverty in areas of high deprivation, thereby delivering against multiple government policy objectives. Given the intractable nature of the challenge, more consideration of the opportunities for small-scale heat networks, particularly mine water-based, is needed.

[31] Carbon Trust (2016) Technology Innovation Needs Assessment (TINA) – Heat summary report. Low Carbon Innovation Coordination Group. Available at https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/593456/Refreshed_Heat_TINA_Refresh_Summary_Report_March216.pdf [Accessed on 23.10.20].

Barriers and constraints

While awareness of the benefits of mine water energy is growing and schemes are being developed, there are multiple barriers which currently constrain the 'mainstreaming' of mine energy schemes. Some of these are sector specific; others apply to all forms of low carbon heat. The following section explores the main barriers and constraints. Potential responses are described and discussed in the final 'Conclusion and recommendations' section of the report.

1.9 Commercial barriers

1.9.1 Low cost of gas the key challenge

Industry stakeholders reported that the most fundamental barrier to the development of mine water heat schemes is the low cost of gas. This challenge is common to all low carbon heat options currently used in heat networks.

We spoke to a number of organisations involved in the development of business cases for mine water heat schemes. Those who reported that they had a viable business case were all reliant upon one or more forms of public support. Capital support is being accessed via the Heat Network Investment Programme (HNIP) or the European Regional Development Fund (ERDF), and revenue support via the renewable heat incentive (RHI)[32]. All of these schemes are due to end in the near future, and while each is expected to be replaced, the final details of successor schemes have not been determined. This is causing uncertainty in the marketplace and is likely to at least cause delays to some potential projects.

There is considerable concern that successor schemes will offer reduced levels of support and that this will render many potential schemes uneconomic.

1.9.2 How much will the heat cost?

1.9.2.1 Charges for heat from mine water treatment plants

There is some confusion in the market about whether the Coal Authority plans to charge for access to heat. It is understood that the Authority expects to charge for access to the mining infrastructure, which is likely to be based on a price per KWh.

Some stakeholders questioned whether the Coal Authority should charge for access to heat. We were informed that the business case, even for schemes drawing heat from mine water treatment plants (the most economically favourable option), were marginal and that heat charging might render them uneconomic. Stakeholders questioned the logic of developers being subsidised via the public purse, only to then repay some of this subsidy to a public agency.

[32] State Aid Rules preclude organisations receiving both capital and revenue funding for the same asset, but splitting the asset by function, i.e. using capital funding for pipework and revenue for heat generating assets, is allowable.

1.10 Risk

The risk profile of mine water-based schemes, particularly the perception of risk by potential funders and developers, and to a lesser extent local communities, was identified as one of the main barriers to scheme development. Specific concerns raised by stakeholders are listed below.

1.10.1 Risk of negative perceptions from investors and local communities

A number of expert stakeholders expressed concern about the potential for resistance from local communities to emerge if care is not taken to clearly communicate the potential risks and disruption associated with a mine water development (this relates primarily to borehole-based schemes). While early indications suggest that communities respond favourably to mine energy schemes in principal, this can change rapidly should schemes create significant disruption, or potential opponents of a scheme inflate community perceptions of risk.

Some industry stakeholder interviewees felt that there was insufficient awareness and acknowledgment of the actual potential risks associated with mine energy schemes. One proposed solution was the development of practitioner guidance, something which the Coal Authority is known to be developing.

1.10.2 Risk of not finding an economically viable resource after exploratory drilling

For borehole-based schemes, a key concern for investors is the cost of pilot/exploratory boreholes and the lack of surety that these will identify viable resources. The cost of pilot and exploratory boreholes varies widely and is determined by the nature of the substrata and the depth of drilling. Shallower mine workings are easier to access and reported pilot costs fall within the range of £30–90,000 (for depths of 70–150 metres). By comparison, one site, requiring exploratory drilling to 500+ metres, reported receiving cost estimates of £800,000– £1 million.

The high cost of boreholes can be a barrier in and of itself, as in most cases it is not covered by existing support schemes. However, of greater concern to developers is that all drilling is done at risk – there being no guarantee that they will locate a viable connection with the mine. While such risks can be mitigated, the uncertainty associated with this stage of scheme development is unattractive to investors. For example, local authorities, a key player in this market, reported that it is difficult to secure support for 'at risk' expenditure, and noted that there is no reason to assume that this will change.

1.10.3 Risk of heat depletion

While mine water heat is naturally replenished, there is a lack of understanding as to what might constitute a sustainable annual heat yield. The size of the resource being tapped into means that this may not be a concern for the first wave of schemes. However, as schemes are expanded and additional schemes developed drawing on the same mine system, interactions could impact the heat resource, causing degradation over time. There is a clear need to develop a better understanding of the sustainability of the mine water resource. The Coal Authority is known to have funded modelling work to investigate this matter.

1.10.4 Risk of disruption of access to heat

An additional concern is that collapses in underground workings, potentially triggered by mine water heat extraction, might affect the movement of mine water, leading to reductions in flow rates and available heat. However, most of those interviewed for our research suggested that the risk to scheme developers is low and can be mitigated.

The reasons for this include:

- Collapses in mine workings are to be expected, irrespective of mine water heat harvesting. Depending upon the mining method, collapsed mines would still be expected to retain 20–50% of the void space and to remain highly permeable to water[33].
- The interconnected nature of the mines and the scale of the resource means that even if a localised collapse causes some level of disruption it would not be expected to affect the sustainability of a given scheme. The interconnections are well understood, in some areas at least, and so the dangers of the mine water supply being compromised could, to some level, be assessed and mitigated during the project planning stage.

In addition, existing schemes, many of which are long running, are not known to have been affected by mine collapse.

1.10.5 Risk mitigation measures

Geologists classify the warm water within abandoned mines as a form of geothermal energy. The UK has significant geothermal resources – for example, in the granites of Devon and Cornwall, and the more widespread sedimentary basins and buried limestone karst – but their exploitation is in its infancy.

While different forms of geothermal resource are associated with their own set of technical challenges, some of the barriers and constraints (commercial and risk-related) identified in this paper are held in common with mine energy, and lessons may be learned from countries with more mature geothermal sectors. For example, various forms of mitigation measure have been developed to address investor concerns about the risk profile of geothermal projects, including[34]:

- Grants for surface studies
- Cost-sharing of exploration drilling
- Government-led exploration drilling
- Development grants
- Loan guarantees.
- Subsidies paid per unit of heat production.
- Risk insurance – this insures the operator against declines in the future production levels of the well.

The UK currently provides grants for surface studies (through the HNDU), development grants (through HNIP) and subsidies (through RHI), although, as previously reported, the HNIP and RHI schemes are currently under review and due to be replaced. Industry stakeholders suggested that, in addition to these more general support schemes, consideration should be given to the development of mine energy specific measures, including cost-sharing of exploration drilling and risk insurance.

[33] Adams, C.A., Monaghan, A., Gluyas, J.G. (2019) Mining for heat. Geoscientist 29 (4): 10–15. Available at https://www.geolsoc.org.uk/~/media/shared/documents/Geoscientist/About%20Geoscientist/Feature%201_May%202019.pdf?la=en [Accessed on 8.2.21].

[34] World Bank Group (2016) Comparative Analysis of Approaches to Geothermal Resource Risk Mitigation: A Global Survey. ESMAP Knowledge Series;024/16. World Bank. Available at https://openknowledge.worldbank.org/handle/10986/24277 [Accessed on 24.10.20].

1.11 Supply chain constraints

1.11.1 Lack of information to enable effective early decision-making and targeting of schemes

There is a clear desire among industry stakeholders for more detailed and accessible information regarding the mine water heat resource, for example via a GIS mapping tool. Better information, at an area rather than site-specific level, is felt to be necessary to enable the prioritisation and strategic development of mine water resources. This would, for example, be useful in informing land allocation decisions by local authorities. More specifically, stakeholders expressed a wish to be able to match current and potential heat demand against supply; a filter that provides indicative drilling and borehole costs; information on the characteristics of the resource (depth, temperature, volume); and identification of likely risks associated with a given set of resource/mine characteristics.

The Coal Authority website hosts an interactive map viewer[35] which contains a range of useful data, including a recently developed temperature mapping function. However, the tool does not provide the range of functionality identified by industry stakeholders.

1.11.2 Lack of expertise

Stakeholder interviewees of all types highlighted that the mine water heat sector is constrained by a lack of expert capacity. Specifically, there are concerns about technical consultants, scheme design engineers (borehole and pump system) and drilling contractors.

Lack of experienced consultancies

Some stakeholders reported that they had difficulty in sourcing relevant expertise and suggested that some consultants were learning on the job. For example, one developer reported that the involvement of inexperienced (in terms of mine water heat) consultants on their project had come at a considerable cost in terms of time and loss of RHI income.

Other interviewees identified concerns that less experienced design consultants were 'gold plating' specifications for borehole drilling and that this was raising costs and undermining already relatively weak business cases. In some instances, it was reported that experienced drillers were being deterred from bidding for contracts as they felt that the associated conditions were too onerous.

Shortage of drilling contractors

Interviewee feedback suggests that there are only a small number of drilling companies (no more than five in the UK) with experience of drilling into abandoned coal mines. Although there is interest in engaging in the mine energy field from drilling companies who traditionally operate in the oil and gas sector , there are concerns that their lack of experience introduces additional risk to the development process.

Lack of experience among scheme development leads

In addition to supply chain constraints, there is a lack of expertise among clients and their project managers in relation to mine energy development and also, in some cases, heat network development. This increases both actual and perceived risk.

[35] Available at https://mapapps2.bgs.ac.uk/coalauthority/home.html

1.11.3 External support needs

The Coal Authority has developed a mine energy team to support the establishment of new schemes and this is a highly regarded and trusted source of advice. A number of stakeholders recommended that new developers engage with the Coal Authority as early as possible; this was identified as a mechanism for addressing gaps in expertise and de-risking projects. Where the Coal Authority have been involved in a consultancy role their most valued contributions include:

- The provision of initial opportunity assessments
- Supporting the drafting of procurement specifications
- Acting as a critical friend in the procurement process and beyond.

The Authority charges a commercial rate for delivering such services. This was not identified as a barrier, but stakeholders reported that the mine energy team was becoming overstretched and that a lack of capacity within the Coal Authority was emerging as a constraint on the growth of the mine water heat sector.

1.12 Regulation

Mine water can be contaminated with a range of pollutants and its release into the environment is recognised as posing a significant threat to freshwater resources[36], flood risk, and general management of groundwater resource. Whilst recognising the potential for harm and the need for early engagement with the relevant environmental regulator to ensure site specific risk mitigation and regulatory compliance, the research identified little evidence of stakeholder concern with respect to environmental issues. This may, however, reflect the fact that the majority of developments are at an early stage in the development cycle.

1.13 Technical risks

Interviewees are aware that there are technical issues associated with the quality of mine water and that this has implications for the design and operation of their schemes. Identified issues included:

- Ochre deposition can cause pipe furring and clog heat pumps if air is not excluded from the system.
- High levels of dissolved minerals can foul heat exchangers. One interviewee, a heat pump manufacturer, noted that they specify heat exchanger materials to account for differences in water quality between schemes.
- Seasonal variations in water quality, e.g., chloride. For example, one developer reported that their sensors need to be replaced more frequently than expected.
- Dissolved H2S can create a corrosive environment for sensors and other forms of equipment.

Interviewees who mentioned these matters did not view them as major concerns and suggested that the issues associated with the use of mine water are well understood and manageable.

1.14 District heating related constraints

Ultimately, the exploitation of mine water heat at scale and the delivery of the identified benefits are dependent upon the expansion of district heating in the UK. The heat network market is itself relatively immature and dependent upon government support. Barriers to the expansion of district heating are therefore, by default, barriers to the expansion of mine water energy schemes. These barriers are well understood and detailed elsewhere but are not addressed in this paper.

[36] Environment Agency (2009) Abandoned mines and t he water environment. Available at https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/291482/LIT_8879_df7d5c.pdf [Accessed on the 21.3.21]

Conclusion and recommendations

1.15 Introduction

Mine water heat is a nationally significant low carbon heat resource and a potentially important enabler of low carbon heat networks – a key technology for addressing the pressing challenge of heat decarbonisation.

Enabled by public subsidy, a new generation of mine water-based networks are emerging and starting to deliver against the UK's new net zero carbon target. In the medium term, such schemes could play an even more significant role in heat decarbonisation and in the evolution of low carbon energy systems more generally, by enabling thermal storage at a city scale.

Additionally, owing to the co-location of the resource with often disadvantaged areas, the development of mine energy schemes supports the government's 'levelling up' agenda. The cultural significance of mining means that, in many communities, the development of mine energy schemes would be a powerful symbol of renewal and could serve as a focal point and symbol for wider economic and social regeneration initiatives.

The mine energy sector is at an early and therefore vulnerable stage. To secure these identified benefits, mine energy, in common with all current low carbon heat sources, requires government support to stimulate growth and to de-risk developments in the eyes of potential developers and investors. To accelerate the sector beyond the need for subsidy will require greater levels of collaboration between public, private and academic bodies, supplemented by targeted investments in research and development. This will also reduce the chance of missteps and help to maintain investor and public confidence.

In this final section of the report, we present a series of recommendations, designed to address the identified challenges and constraints, and to thereby unlock the commercial, social and environmental potential for mine energy in the UK. The recommendations originate from the stakeholder engagement processes (formal interviews, consultations and workshops) that were undertaken to inform this white paper, and are presented under the following headings.

- Ensuring an enabling policy environment
- Delivering sector specific support
- Improving the commercial case
- Securing wider benefits.

1.16 Ensuring an enabling policy environment

1.16.1 Ensuring the continuation of financial support mechanisms

Mine energy schemes currently have access to a range of support mechanisms including:

- European Rural Development Funds (ERDF) - grant support (capital)
- Heat Network Investment Programme (HNIP) - grant support (capital)
- Heat Networks Development Unit (HNDU) – grant support (revenue)
- Renewable Heat Incentive (RHI) – subsidy schemes, paid per unit of heat.

Aside from the HNDU all these support schemes are scheduled to be replaced within the next 1-3 years, by as yet undefined successors. Given the reliance of mine water projects on public subsidy it is essential to ensure that replacement schemes provide sufficient support to enable the continued development of the sector.

Recommendation 1 (high priority)

The mine energy sector in the UK is at an early and vulnerable stage in its development and at this point in time is highly dependent upon public subsidy. Successor schemes to the ERDF, HNIP and the RHI should take into account the support needs of the sector and ensure that replacement schemes allow for a sustainable rate of growth.

1.16.2 Reducing the competitive advantage of natural gas

The low cost of gas undermines the business case for all low carbon heat sources, including mine water heat schemes. The UK government proposes to launch a heat and building strategy in early 2021 and has previously announced a Future Homes Standard which will mean that from 2025 new homes will not be able to use fossil fuel for heating. Some stakeholders noted the prospect of the Future Homes Standard had increased interest in mine water heat schemes. Others, however, reported that some developers believe that the government might yet abandon or delay the commitment to exclude fossil fuel-based heating.

Recommendation 2 (high priority)

There is a need for policies that reduce the competitive advantage of gas in relation to low carbon heat sources. These need to be accompanied by clear, consistent and unambiguous policy messaging in order to build confidence among developers and heat network investors.

1.17 Delivering sector-specific support

Beyond the national policy framework, there are several specific interventions that would directly benefit the future expansion of the UK mine energy sector.

1.17.1 Provision of information, tools and resources

Stakeholder consultation identified a widespread desire for more information, tools, and resources and for better (and cheaper) access to such materials to facilitate site selection for mine energy projects. Specific asks included:

- The development of an enhanced GIS tool to better enable the identification and prioritisation of potential mine energy schemes
- The development of national sub-surface geotechnical and hydrogeological models to enable characterisation of the sub-surface conditions ahead of site selection and drilling[37].

Recommendation 3 (high priority)

Strategic stakeholder bodies should facilitate and support greater ongoing collaboration and knowledge sharing between mine energy scheme designers, developers, regulators and the research community. There is an existing national forum in the shape of the Mine Energy Taskforce. This is well placed to take ownership of several of the recommendations made in this report but would require additional resources to enable it to play a more substantive national role. Participant organisations with an enabling role, such as regulators and licensees, may also need additional resources to enable greater coordination and accelerate progress on the recommendations.

Recommendation 4 (high priority)

The Coal Authority has taken a strong lead on mine energy and is actively supporting and enabling its growth. However, our research identified a need for closer dialogue between the wider mine energy stakeholder community and the Authority to ensure that the development of tools and research programmes relating to mine energy are more closely informed by the emerging market. Two priority stakeholder asks include:

- The development of a GIS tool to enable matching between current and potential heat demand and potential supply. Specific requests included filters that provide indicative drilling and borehole costs, characterisation of the key resource variables (depth, temperature, volume), and the risks associated with site characteristics.
- National sub-surface geotechnical and hydrogeological models to enable characterisation of the sub-surface conditions ahead of site selection and drilling.

Recommendation 5 (high priority)

We found some confusion and uncertainty in the marketplace regarding the role of the Coal Authority in the development of the mine energy sector. Such uncertainty deters potential developers and investors. Stakeholders in the wider market would like clarity around charging for heat access and the Authority's preferred role in new project development.

[37] The Coal Authority have commissioned modelling work, but it is not clear to what extent this will meet the need identified by stakeholders involved in this research.

1.17.2 Establish national demonstration sites

Stakeholders expressed strong support for national mine energy demonstration sites. Arguably the imperative for this will reduce as new schemes come online and information and insight are shared, but a case will remain for successful demonstration sites to test and prove the concept of mine water schemes in different operational contexts and to assess the potential of future developments such as inter-seasonal heat storage.

Recommendation 6 (medium priority)

Funding should be sought and allocated to enable the development of:

- One or more demonstration mine water heat network schemes in smaller coalfield communities. A key focus of such schemes should be the integration of the housing types 'typical' of ex-coalmining settlements (see also Recommendation 13).
- The establishment of one or more inter-seasonal storage demonstrators. These could be new schemes or extensions of existing or proposed schemes.

1.17.3 Strengthen supply chain capacity

There is considerable expertise within the mine energy sector and the supply chain specifically, but it is concentrated in a very small pool of expert contractors. There is a need to invest in the development of expertise to ease current market constraints and as part of a wider approach to risk management, and to enable deployment at scale.

Recommendation 7 (high priority)

The Coal Authority technical support service is greatly valued but felt to be overstretched. Stakeholders expressed a wish to see the service expanded to enable it to meet increasing demand. Failing that, alternative support mechanisms are required.

Recommendation 8 (high priority)

The Coal Authority is already in discussion with sector bodies about the development of mine energy specific training for the supply chain. Our research suggests that this should include bespoke training for client project managers.

Scheme developers and potential developers, many of whom are public sector bodies, noted that they would benefit from better signposting to expert suppliers.

Recommendation 9 (medium priority)

Public sector bodies are leading the development of mine water-based district heating systems. The establishment of a national expert contractors framework would build confidence by providing a level of quality assurance, while streamlining the procurement process.

1.17.4 De-risking mine energy

Investor and public perceptions of risk, particularly in relation to drilling, represent both a barrier and a threat to the development of the mine energy sector. Several of the measures outlined above will contribute to risk reduction, but there is a need for further action to address specific concerns.

Recommendation 10 (medium priority)

Public support mechanisms (ERDF, HNDU, HNIP, RHI) have enabled a new, embryonic generation of mine energy schemes, but do not fully take into account the key differences between mine energy and other forms of low carbon heat. To ensure growth, bespoke support measures may be required to address sector-specific barriers. In particular, consideration should be given to the establishment of a loan guarantee (for borehole drilling) and risk insurance (to protect against the possible decline in heat over the operational life of the project).

1.18 Improving the commercial case

While there is a need for continued public support to stimulate the early development of the mine energy sector, there should be a focus on reducing the costs of all aspects of mine water-based schemes.

Recommendation 11 (medium priority)

Most of the previous recommendations should contribute to the improved business case for mine energy, but in addition:

- The sector should focus on identifying opportunities for cost reduction through increased standardisation, for example of contract documentation and procurement specifications, and process optimisation.
- Scheme developers would benefit from having improved access to commercial data to better enable them to compare the relative merits of mine water heat schemes against the main alternatives and to establish cost benchmarks for mine energy schemes.
- Publicly funded schemes should be required to collect and share non-confidential data on the costs of scheme development and on operational issues relating to the sustainable management and operation of mine water energy schemes.

* If resource were to be made available, this recommendation could be taken forward by the Mine Energy Taskforce.

1.19 Securing wider benefits

1.19.1 Economic benefits

Where cost-competitive, mine energy schemes can help to attract new development and businesses to regeneration zones by offering a secure and sustainable source of low carbon heat. Beyond this, many stakeholders believe that such schemes could help to foster the development of new high heat (and potentially cooling) demand business clusters, for example horticultural enterprises. The commercial case for such clusters is not yet understood, however and further research is required.

Recommendation 12 (medium priority)

There is a need for research to identify business sectors with high heat/cooling demands (within the range that can be delivered via mine energy schemes) and to examine the technical and commercial case for linking such businesses with actual or potential mine energy schemes.

1.19.2 Social benefits

There is a tendency to associate district heating with large urban conurbations, but some stakeholders expressed considerable interest in the development of small-scale networks as a cost-effective mechanism for decarbonising smaller coalfield communities and addressing the negative health and social impacts of fuel poverty. Further work is required to establish the business case for such developments.

Recommendation 13 (medium priority)

Desktop studies should be commissioned to consider the relative merits of mine energy, in comparison to whole house retrofit, as a mechanism for decarbonising the types of hard-to-treat properties that characterise many traditional coalfield communities. Such research should include consideration of the relative merits of these options in relation to their delivery of co-benefits, and in particular the alleviation of fuel poverty.

The development of mine energy schemes delivers a direct and indirect boost to local economies, but this could be enhanced by provisions to ensure that the construction of new developments is tied to the delivery of social value outcomes.

Recommendation 14 (medium priority)

All publicly funded schemes should be required to identify and pursue opportunities to secure social value through the procurement process, such as the use of targeted recruitment and training clauses[38] to create opportunities for specific groups, for example the long-term unemployed.

[38] Targeted recruitment and training' is the terminology used to describe job opportunities and training that are only open to certain groups of individuals, e.g. those who are long-term unemployed.

1.20 Beyond mine energy

While the focus of this white paper is on the exploitation of abandoned coal mines, the UK hosts multiple other forms of geothermal energy. Mine energy is the most accessible of these and as explained in this document has a number of characteristics that recommend it as a development priority, most notably its proximity to centres of population.

Supporting the development of mine energy through the implementation of the recommendations would, however, be expected to build awareness and capabilities that might better enable the development of other forms of resource, particularly in areas outside of the coalfield areas. ATES is already attracting growing attention, but as yet unexploited options such as the co-production of water from onshore petroleum fields and potentially more novel opportunities, such as the exploitation of the water resource associated with buried karst limestones, might also benefit from an expansion of interest in and exploitation of the UK's geothermal resource[39].

[39] Adams et al (2020) Unlocking the UK Geothermal Resource Base. Proceedings World Geothermal Congress 2020. Reykjavik, Iceland, April 26 – May 2, 2020.