CRAIGHALL ENERGY

Frances Colliery Minewater Heat Recovery Scheme

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1 Background

1.1 Background to Frances Colliery

The Frances Colliery area comprises all the Coal Measure mine workings from the outcrop in the west to the deepest undersea workings in the east. The earliest recorded mine workings date from the 12th Century and deep mining finished with the closure of Frances/Seafield Colliery in 1988. However, pumping at Frances and Michael collieries was only abandoned by British Coal in 1995 following an agreement, between the Coal Authority the Scottish Environment Protection Agency, to recommence mine water pumping at a later date in order to prevent surface discharge of mine water. The mine water pumping was to recommence when mine water levels reached 56 metres BOD. This particular level was identified because of the perceived risks of higher levels of contamination and surface discharges associated with allowing recovery above 56 metres BOD.

In 2000 a mine water treatment scheme was constructed at Frances Colliery and a mine water pumping test undertaken. The pumping test showed very poor quality mine water (>400 mg/L total iron and pH <4) which required chemical dosing. Following the test it was agreed with SEPA to allow the mine water levels to recover to approximately 14 metres BOD at Frances then recommence pumping.

In early 2004 mine water pumping recommenced with an improved mine water quality of approximately 50 mg/L of iron and a pH of 6.2 at an abstraction rate of 80 L/s. The mine water recovery at all eight mine water level monitoring sites was controlled and the mine water treated to the required discharge consent level of 5 mg/L of iron without the need for expensive chemical dosing.

In late 2008 the pumping rate was increased to 120 L/s and continued to draw water from a large area of the East Fife Coalfield. However as a result of the increased rate, the total iron in the raw mine water had risen meaning that caustic dosage needed to be considered in order to meet the criteria for discharge.

1.2 Current Risk Profile

The current risks to the Frances Colliery are based on the advice given to the Coal Authority by WYG in its review of the minewater recovery assets in the UK.

The principal risk to the current pumping and treatment scheme at Frances is blockage of flow paths from the northern part of the coalfield resulting in raised mine water levels and surface discharges that could not be controlled by pumping.

The principal long-term risks will be shaft collapse at Frances affecting the pumps and pumping range. At some stage in the future a shallow larger diameter borehole at Frances may be required when the shaft lining finally fails. This would however have a material impact on temperature of pumped water. Any shaft failure is likely to be gradual giving time for remedial actions to be taken. Failure of the shaft lining is not expected to affect the surface stability but at that stage, backfilling of the shaft may need to be considered.

The long-term control of mine water in East Fife is required to prevent significant discharges of mine water to the sea at Dysart and into the River Leven. However, it is anticipated that there will be a gradual decrease in contamination of the mine water over an extended time period (60 to 100 years).

1.3 This Report

This report is an options appraisal which intends to provide answers to the following questions:

- The current flow rate, water quality and temperature of minewater at the Frances Colliery

- The possible heat recovery and heat recovery options from minewater
- The possible utilisation of heat recovered at the Frances site
- The development of renewable energy at the site to support the pumping of minewater, minewater treatment and operation of a heat pump
- The likely process for minewater treatment
- The cost benefits of such a scheme and its carbon benefits

1.4 Note on Stakeholder Engagement

Throughout the process of collating this report, we have endeavoured to engage with stakeholders to acquire data, technical details of plant and costs. The following were contacted several times to establish a relationship:

Heat pumps and heat exchangers – Vailant, Kobelco, Viessman, Star, Johnson Controls, Danfoss

Water treatment – Mott McDonald, Coal Authority, Envirochemie, Aquabio

The responses we received indicated the following issues:

- Lack of staff due to Covid
- Lack of staff due to redundancies
- Unwilling to engage at such an early stage
- Unwilling to provide information without contracting
- Unable to commit to any future relationship (steel prices in particular has led to some mothballing)
- Too many speculative projects in Europe and so unwilling to commit time

As such we have relied largely upon the use of known data and standard equations to develop the options. These form the basis of the works and it is suggested that if a project does proceed that contracted terms would be required to get engagement from these parties.

2 Baseline Information

Based on an information request to the Coal Authority, the following data was acquired on the baseline information on the Frances Colliery which informs the options appraisal.

2.1 Temperature Profile

The graph below shows the temperature profile of the minewater at Frances Colliery since 2016. From this data we can derive that the mean temperature is circa 14 degrees Celsius, with a low of 13.7 degrees and a single point reading of 16 degrees. The median temperature is also 14 degrees Celsius and the coefficient of variation[1] in temperatures is less than 2%. Therefore the temperature profile is considered to be relatively stable at 14 degrees Celsius.

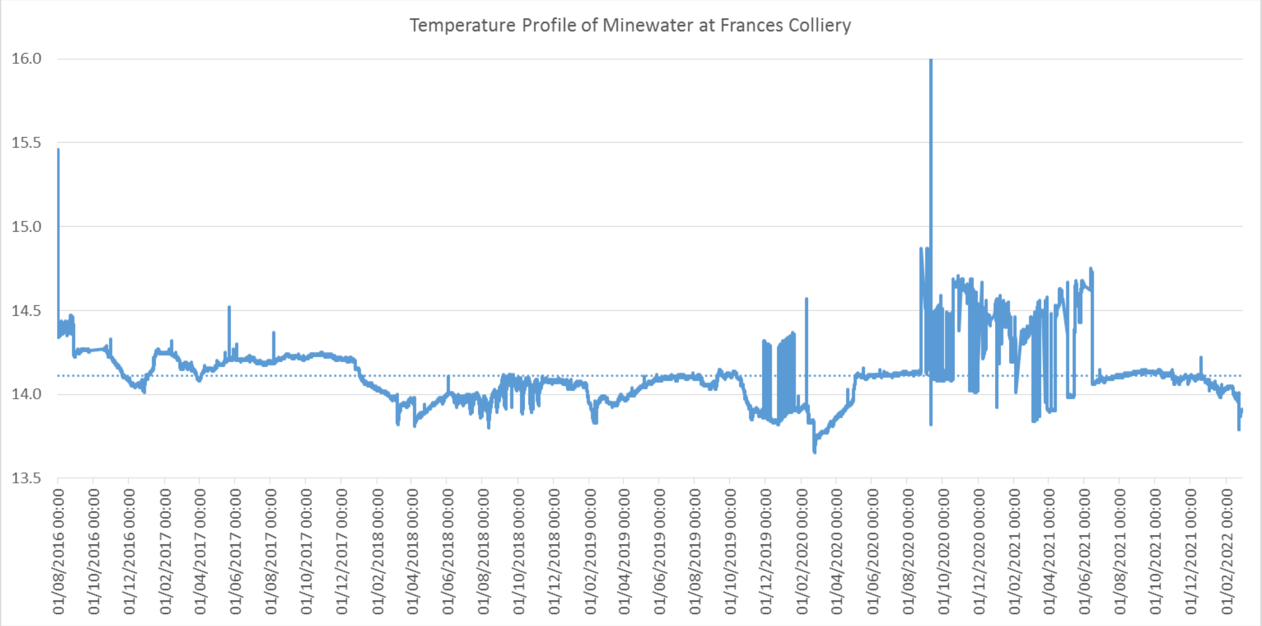

Figure 1 - Temperature profile of minewater at Frances Colliery

2.2 Flow Rate

The flow rate is the rate at which minewater is being pumped from the Frances Colliery. The data related to pumped volumes is problematic since:

- data is not collected on a daily basis
- data used to be collected on a litres per second basis but is now only collected as the totalised volumes pumped by the two pumps
- the totalised volume can relate to more than a single day

As a result, data is retrieved from the last daily readings where readings were taken for more than two days in a row to ascertain the most likely and most recent flow rate data.

As the data in the graph below shows there is:

- An average flow rate of 122L/s
- A maximum flow rate of 210L/s
- A median flow rate of 121L/s

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[1] The coefficient of variation (CV) is a statistical measure of the relative dispersion of data points in a data series around the mean and is used as a measure of volatility in the data.

- A coefficient of variation of 19% illustrating that there is a small amount of variation in pumped volumes

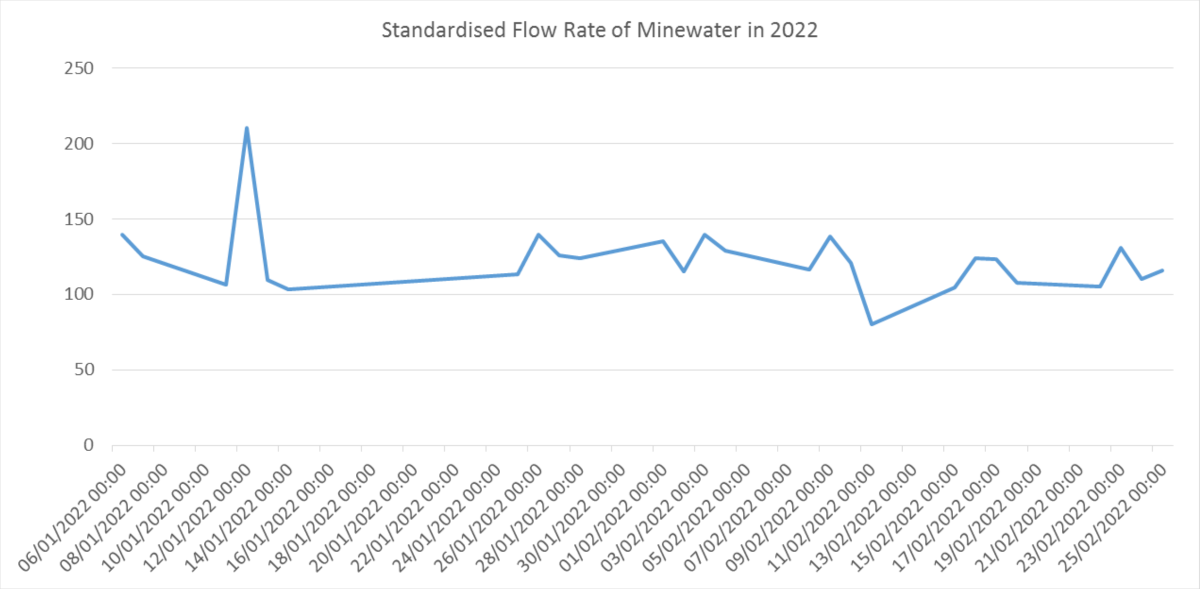

Figure 2 - Standardised flow rate of minewater in 2022

2.3 Water Quality

The quality of minewater has a significant bearing on the type of heat recovery schemes that can be considered and also on the water treatment plant required. The baseline data for water quality is as follows:

	Average	**Max**	**Min**	**Median**
Total Iron Colorimetric	58.4	179	0.3	55
Ferrous Iron	58.0	589	0	54.6
pH	7.0	639	0	6.48
Chloride	733.8	2600	133	601
Sulphate	1515	2980	164	1520
Lab Alkalinity (as CaCO3)	355.6	1440	0	368
Conductivity	4334	11500	439	4178.5
Susp. Solids	80.0	5470	0	67
DissIron	67.0	194	0.01	62.8
Aluminium	0.1	4.07	0.01	0.05
Manganese	5.0	74.5	0.09	4.79
Ammonical Nitrogen (Tot as N)	1.9	34.2	0.3	1.7
Calcium	349	471	43	346
Magnesium	256.5	367	23.3	256

Sodium	410	1700	43	346.5
Potassium	37.8	79	4.44	36
Ion Balance %	1.9	25.8	-79.1	2.1
Total Iron ICP	68.2	187	1.06	65.5
Strontium	1.6	2.47	1.04	1.55
Zinc	0.2	5.36	0.012	0.025
Nickel	0.1	0.1	0.05	0.06
Boron	0.9	2.74	0.6	0.765
Barium	0.0	0.01	0.01	0.01
Calc Metal Acidity (as CaCO3)	116.9	332.0	3.4	92.5
TOC	1.5	5.6	0.23	0.74
Cold Acidity (as CaCO3)	263.6	821	0	265
Lead	0.0	0.02	0.01	0.01
Cadmium	0.0	0.01	0.01	0.01
Copper	0.0	0.02	0.01	0.01
Mercury	0.0	0	0	0
Bromide	2.5	28	0.5	2.1
Nitrate	1.0	1.5	0.5	0.9
Phosphate	0.1	0.15	0.01	0.05
DOC	0.9	4.7	0.38	0.69

Table 1 - Water quality at Frances Colliery (mg/L)

3 Renewable Heat

3.1 Heat Recovery

Heat recovery from minewater happens as a result of the second law of thermodynamics, which states that heat flows naturally from an object at a higher temperature to an object at a lower temperature, and heat doesn't flow in the opposite direction of its own accord.

Heat can be recovered both through the use of heat exchangers and through the use of heat pumps.

Heat Pump

Conventional heat pumps utilise the Rankine cycle, a condensation-evaporation cycle of a fluid with a suitably low boiling point. A compressor forces the fluid to condense, releasing heat energy as it changes state. The condensed fluid flows through an expansion valve before collecting heat energy in the evaporator (a heat exchanger interfaced with the source). This vapour then passes back into the compressor to complete the cycle. In effect, low-grade heat energy from the source is ‘pumped’ up-gradient in order to provide thermal energy at a useable temperature, consuming a proportionately modest amount of electricity.

Heat Exchanger

A heat exchanger is a device that facilitates the process of heat exchange between two fluids that are at different temperatures. Heat is transferred by conduction through the exchanger materials which separate the mediums being used. For example, a shell and tube heat exchanger passes fluids through and over tubes, whereas an air cooled heat exchanger passes cool air through a core of fins to cool a liquid.

Heat pumps and heat exchangers can either be used in a coupled sequence for heat recovery, or, where servicing a heating network (DHN) a heat pump may be used by itself.

3.2 Types of Minewater Geothermal Systems

The type of minewater system employed needs to have consideration of physical and chemical parameters to determine the optimal mode of heat extraction. Open and closed loop systems suit different scenarios depending on parameters including, size of the resource and demand, expected flow rate, water chemistry etc.

The table below shows the different types of system which can be employed:

System	Description	Notes
Open system with water discharge	Minewater is brought to the surface via pumping. A shell-and-tube or plate heat exchanger transfers heat between the minewater flow and a secondary heat transfer fluid serving a thermal demand, often via a heat pump array.	Can offer higher thermal outputs than closed systems. Suitable for systems where water discharge is required.
Open system with reinjection		Requires significant knowledge of the underground dynamics of interconnected workings. Can create thermal depletion of the resource if not appropriately designed. Can be more expensive.
Closed loop system	A secondary heat transfer fluid is circulated through heat exchange pipes submerged in minewater within a shaft, tunnel or borehole, absorbing available heat without	Can be lower maintenance than open systems.

	abstracting the water. The heat transfer fluid is then typically circulated to a heat pump, where the heat is extracted and the newly chilled fluid returned to the submerged heat exchange network.	Only works in situations where pumping is not necessary. Produce limited heat recovery.
Surface closed loop	Pumped discharge or gravity drainage sites, which employ passive minewater treatment, often host aeration cascades and lagoons which facilitate oxidation and precipitation of dissolved minerals. Closed loop heat exchange pipes or panels can be submerged within such treatment lagoons.	Produce limited heat recovery. Can cause issues with regards to lagoon management and removal of accumulated sediment and ochre.

Table 2 - Types of minewater geothermal systems

Given the specific characteristics of the Frances Colliery minewater, it is considered that an **open system with water discharge** is the most suitable, since:

- There is a requirement to continually pump and discharge the minewater
- The water quality is such that it requires treatment prior to discharge due primarily to high iron and salinity
- We require the maximum possible heat recovery to make the project as economically viable as possible
- Reinjection would need to be at a point far enough away so as not to deplete the thermal resource, which may be uneconomic for a scheme of this size. This would require significantly more investigation than the current budget or timescales allow

3.3 Heat Recovery Options

The key considerations in the design of heat recovery options are:

- Ensuring the maximum quantity of heat is captured
- Ensuring that the system used does not have significant downtime due to fouling with poor water quality (ochre formation, furring and clogging of heat exchangers)
- Minimising electricity requirements to reduce costs

Knowledge of the design of heat recovery systems in minewater geothermal projects is limited to those projects which have already been commissioned elsewhere in the UK and across Europe, specifically we have taken evidence from:

Scheme	**Design**	**Issues to Consider**
Shettleston Housing Association	3L/s of mine water passing directly through a 65kW heat pump to heat social housing.	The heat pump system ran for much of its lifespan with few operational challenges. The inline filter required regular cleaning as the water occasionally contained ochre flocs and sediment. The reinjection boreholes and pipework however were regularly blocked.
Markham	Shell and tube heat exchanger connected to a 20kW heat pump to supply heat to a small office complex.	The system has functioned well, with negligible problems of heat exchanger clogging noted (presumably due to the

		reducing, oxygen-free nature of the water)
Dawdon	Initial scheme was only 1L/s using a shell and tube heat exchanger to supply heat to a 12kW heat pump to heat the treatment facility	Throughout the first year of operation, the in-line filter and heat exchanger clogged with ochre deposits which restricted flow and decreased efficiency. The system was reconfigured using the same hardware, but using untreated minewater, with >74 mg/L total iron. This was successful, the use of unaerated, reducing raw minewater prevented dissolved iron from oxidising
Novoshakhtinsk	28L/s directly supplies two 384kW heat pumps to provide hot water at 65 degrees to a DHN.	Temperature drop across the heat pump is only 5-8 degrees.
Mieres	The scheme works at 100L/s, the water passes through shell and tube heat exchangers, heat is then transferred to two 352 kW heat pumps at a university, one 652 kW and two 1.2 MW heat pumps at a hospital and a 100 kW heat pump operating at the Asturian Energy Foundation (FAEN).	The minewater chemistry is relatively mineral-rich (mean total dissolved solids 1200–1400 mg/L), but iron-poor (mean iron 1.1 to 1.6 mg/L depending on depth of pumping), and is consistent throughout the connected mine system. The iron content has caused some minor issues with clogging of the University plate heat exchangers.
Herleen	The Herleen scheme is a large and well developed scheme and as such has an integrated system of heating and cooling, employing a range of heat exchangers and heat pumps to service more than 300 dwellings, a college, a hotel, a sporting centre, and several office buildings, one of which features a datacentre.	The minewater, especially from the hot wells, was potentially corrosive due to its salinity and also contained dissolved iron. Issues with water quality were overcome by excluding contact with oxygen, careful selection of materials and provision of pipeline "pigs" for scale removal.
Caphouse	30L/s scheme using two sets of shell and tube heat exchangers and a single 10.5kW heat pump	This scheme used dual heat exchangers to limit issues arising from ochre. Use of the heat exchanger prior to the heat pump allowed for better control over the variable demand for heat by ensuring the heat pump can operate at part load if required.

Table 3 - Review of minewater geothermal schemes

The outcome of this research in terms of the overall heat recovery design is that:

- Limiting contact with oxygen will ensure a more successful design by reducing the potential for ochre formation, clogging and excess maintenance and repair costs
- Heat recovery can either be single stage via direct use of a heat pump, or two stage by using a separate heat exchanger (nominally shell and tube) prior to a heat pump
- Single stage may be more efficient for heat recovery

- Two stage may offer a more system control in terms of maintenance, repair and ability to modulate heat delivery
- Thermal stores in the DHN to ensure smooth delivery of heat with a fluctuating demand

Other conditions in the heat recovery design that may or may not be considered depending on planning and SEPA consents include:

- Buffer tanks prior to heat recovery to ensure consistent flow rates to heat recovery
- Buffer tanks after heat exchange to ensure consistent flow rates to water treatment
- Filters prior to incoming buffer tank

These elements are included in the schematics, but are only included as an option in the cost appraisal. In particular it is notable that a single day storage in any tank is likely to be circa 10,000m3, and would therefore be sizable and expensive at circa £900k per tank depending on foundation and piling requirements.

3.4 Simplified Schematics

Below we provide the simplified schematics for two options for heat recovery, acknowledging that the recovery of minewater will most likely be through an open system with water discharge. In both scenarios, minewater is untreated prior to heat recovery and is stored in an oxygen free environment under pressure to ensure limited ochre formation.

3.4.1 Two Stage Process

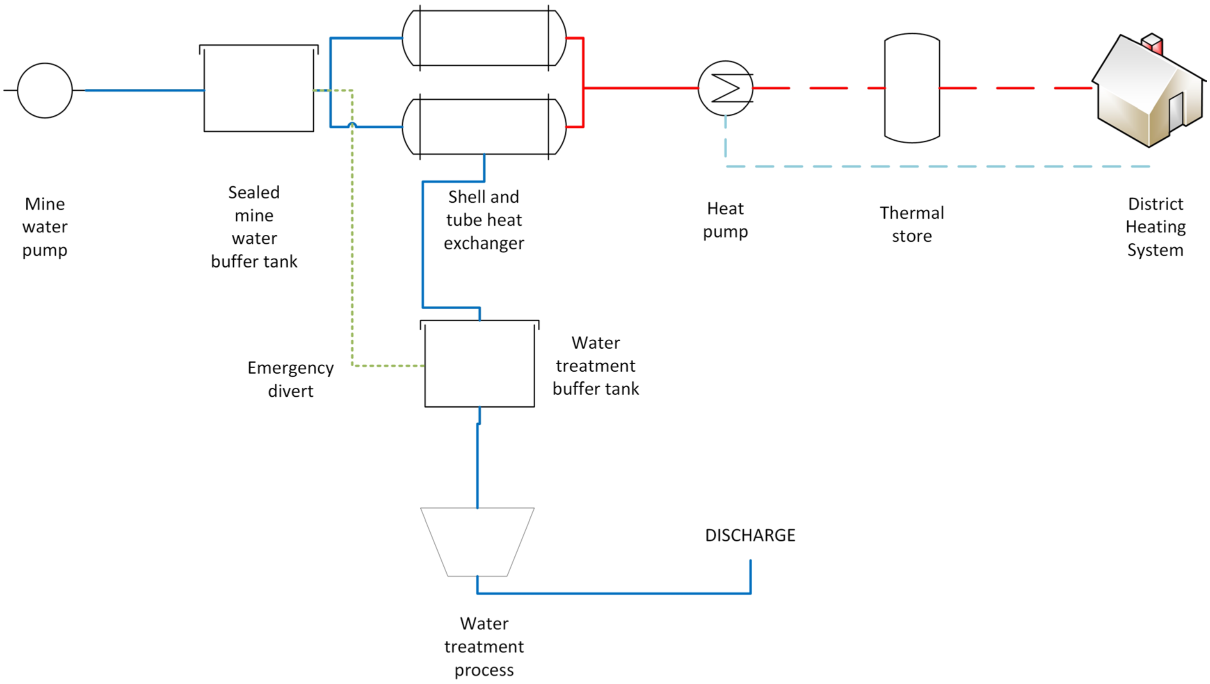

Figure 3 - Schematic of a two stage process

<u>Process</u>

In this two stage process:

- Minewater is pumped to a sealed minewater buffer tank at a rate of 122L/s
- The buffer tank ensures that no oxygen is present in the system and that minewater can be metred at a consistent rate to the shell and tube heat exchangers, at a rate of 122L/s

- Two shell and tube heat exchangers transfer heat to a “clean” circuit (notionally transferring heat from minewater to glycol or similar) a temperature drop of 10 degrees across the heat exchanger sends out the minewater to the water treatment buffer tank at circa 4 degrees[2]
- The water treatment buffer tank stores the minewater prior to the water treatment process and ensures operation at a consistent flow rate
- Water is treated through a process to remove contaminants to the level required by the discharge consent prior to discharge via the current long sea outfall
- The glycol fluid enters the heat pump where it transfers heat through a process of evaporation, compression and condensing of the working fluid (nominally a refrigerant). This heat is then passed to a water which is stored in the heat pump prior to circulation through the heat network
- The thermal store acts as a buffer tank or heat reservoir to service the heat network

Calculations

Stage 1

Heat transfer in heat exchanger is given by ***-(mCpDT)*** η

Where:

m = mass flow rate (kg/s) = 122

Cp = specific heat (j/kgK) = 4200

DT = change in temperature = 10

η = systems efficiency = 90%

In this instance therefore the heat transfer at 100% efficiency is as follows:

122 x 4200 x 10 x 0.9 = 4,611,600watts[3] or 4,612kW

Stage 2

The heat exchanger will deliver approximately 4,612kW to the heat pump. The heat pump system delivery of heat is given as follows:

4,612kW / (1 - 1/COP)

r = density of water = 1000 kg/m3;

c = specific heat capacity = 38700 J/kg/K;

Q = flow rate (m3/s) = 0.122

DT = temperature change at heat pump = 10 degrees

COP = coefficient of performance of heat pump = 4 (estimate)

In this instance:

4,611,600/ 1-(1-0.25) = 6,148,800 watts or 6,148kW

Where 100% of the heat delivered is extracted by the heat pump and the heat pump adds 1,537kW through electrical power.

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[2] The minimum temperature for discharge is likely to be 3-4 degrees and therefore the maximum heat removal will be circa 10 degrees – in practice min water heat recovery has been lower at 3-5 degrees, but we have used 10 degrees here as a target

[3] 1 watt being equal to 1 joule per second

3.4.2 Single Stage Process

Process

In this single stage process:

- Minewater is pumped to a sealed minewater buffer tank at a rate of 122L/s
- The buffer tank ensures that no oxygen is present in the system and that minewater can be metred at a consistent rate to the heat pump at a rate of 122L/s
- The minewater enters the heat pump where it transfers heat through a process of evaporation, compression and condensing of a working fluid (nominally a refrigerant). This heat is then passed to a water which is stored in the heat pump prior to circulation through the heat network. The minewater is discharged to the water treatment buffer tank.
- The water treatment buffer tank stores the minewater prior to the water treatment process and ensures operation at a consistent flow rate
- Water is treated through a process to remove contaminants to the level required by the discharge consent prior to discharge via the current long sea outfall
- The thermal store acts as a buffer tank or heat reservoir to service the heat network

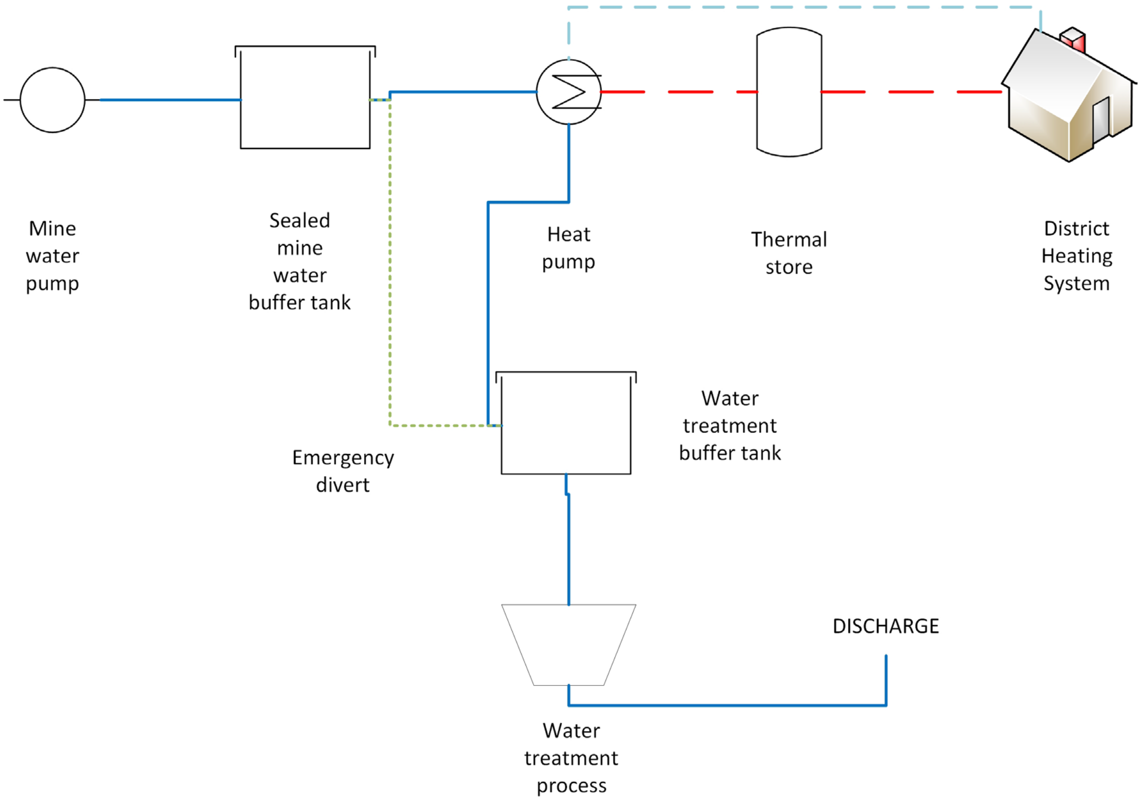


Figure 4 - Schematic of a single stage process

Calculations

The heat delivered by a minewater heat pump system is given by:

H = DT x c x r x Q / (1 - 1/COP)

r = density of water = 1000 kg/m3;

c = specific heat capacity = 4200 J/kg/K;

Q = flow rate (m3/s) = 0.122

DT = temperature change at heat pump = 10 degrees

COP = coefficient of performance of heat pump = 4 (estimate)

In this instance:

$$10 \times 4200 \times 1000 \times 0.122 / 1 - (1 - 0.25) = 6{,}832{,}000 \text{ watts or } 6{,}832\text{kW}$$

At 100% efficiency of delta T in the heat pump where the heat pump adds 1,708kW through electrical power.

3.4.3 Process Option

Both the two stage and single stage processes have advantages and disadvantages as presented below:

Option	**Advantages**	**Disadvantages**
Single Stage Process	Increases the quantity of heat that can be recovered Reduces capital cost and land required Is not dependent on the efficiency or availability of the heat exchangers Can be designed to increase pump rates or be made modular to account for scheme expansions	Can be a bottleneck in the system if a single unit is deployed Expensive compared to heat exchangers and so less ability to have duty/standby operation Less data available on propensity to fouling Little data available on direct use for minewater
Two Stage Process	More data available on direct use with minewater Less expensive plant and so more likely to be able to have multiple units on duty/standby operation Technically easier to service without system interruption	In practice it is unlikely that the heat exchanger will operate at 100% efficiency and so some heat loss will occur Does add cost to the overall system May be sizeable units to cope with design flows and temperatures

Table 4 - Process option advantages and disadvantages

It is considered that whilst the two stage process may offer benefits in operational robustness and ability to have simpler servicing and maintenance, the overall scheme incurs heat losses which could generate in excess of £500k per annum, and is therefore considered to be too financially prohibitive.

As a result we have chosen the **single stage proces**s to proceed to utilisation and cost.

4 Heat Utilisation Options

Heat utilisation options to be explored in this options appraisal were as follows:

- Development of large scale commercial greenhousing
- Servicing of existing and new housing
- A blend of housing and greenhousing

Key issues that emerge from the heat utilisation options are:

- The heat use profile of housing means that decisions are required as to whether to size housing to peak loads or to an average load with supplementary gas use and/or thermal store use
- The scale of commercial greenhousing has a significant effect on the heat demand
- The heat use profile (i.e. seasonal pattern) of greenhousing is not well understood at this stage

4.1 Baseline Data

The baseline data used in the heat utilisation options appraisal is as follows.

Housing has best practice and typical gas use throughout a year depending on what type of housing is being considered. We use the following from CIBSE benchmarks.

	Good Practice	**Typical**	**Unit**
Detached House (gas)	18,811	24,879	kWh/annum
Semi Detached (gas)	11,743	15,471	kWh/annum
Terraced House (gas)	8,673	11,729	kWh/annum
Flat (gas)	5,349	7,852	kWh/annum
Average	11,144	14,983	kWh/annum

Table 5 - Baseline data household gas use

Commercial greenhousing has no current universal standards applied for heat use, although at required circulation temperatures it is considered that the minimum heat requirement will be circa 80W/m2.

4.2 Options and Considerations

Development of large scale commercial greenhousing

Based on a heat requirement of circa 80W/m2 of heated greenhouse floor space, and a total heat availability of 6.8MWth, over 100,000 m2 of greenhousing space could be developed. In this calculation we assume that only 70% of the greenhouse space is actively warmed. We note that this volume of growing space works well with the requirements of potential partners such as Craigmarloch Nurseries and P3P – both of whom have expressed interest in developing commercial greenhousing of circa 100,000m2.

Servicing of existing and/or new housing

The volume of heat that may be available from the Frances site could service a significant amount of housing, whether that be new or existing housing. It may be possible to service the 250 home Kingslaw Gait development to the North West of the site in addition to the development of new housing on the site.

Nevertheless it should be noted that using heat for the development of heat networks purely for domestic housing can incur significant expenditure due to the cost of pipe and pipe laying. The maximum number of properties that *could* be serviced is shown below.

	Properties Serviced
Detached House (gas)	2,406
Semi Detached (gas)	3,868
Terraced House (gas)	5,103
Flat (gas)	7,622

Table 6 - Number of households for heat recovery

As an example however, there is an estimated cost of £331 for each kilometre of DHN pipe laid. To service even the first 2,000 homes closest to the site would require almost 25km of pipework to be laid at a cost of £8.2m. A scheme of this size is unlikely to be able to bear such costs, especially where uptake of the scheme is not mandatory. As such, it is considered that existing housing should not be the focus of heat utilisation.

A blend of housing and greenhousing

As such it is considered that a blend of new build domestic housing and new commercial greenhousing is considered to be the optimal use for heat recovered, since:

- A single large scale offtaker such as a new commercial greenhouse provides an 'anchor' baseload client which will underpin the investment case
- New housing developed on site and, if possible, at Kingslaw Gait will act as a heat user but minimises the extent of pipeline to be laid

4.3 Scheme and Operational Regime

It is considered optimal for the scheme to have a main baseload commercial greenhousing heat user of not less than 100,000m2 of total greenhouse space. The remaining heat would be utilised by domestic properties. Domestic properties follow a well-established operational regime in terms of heat use which means that heating schemes need to either be scaled to the lowest end use with gas boilers used as 'top up' heating, or scaled to the peak load with some heat left unused. The following graph shows this more clearly.

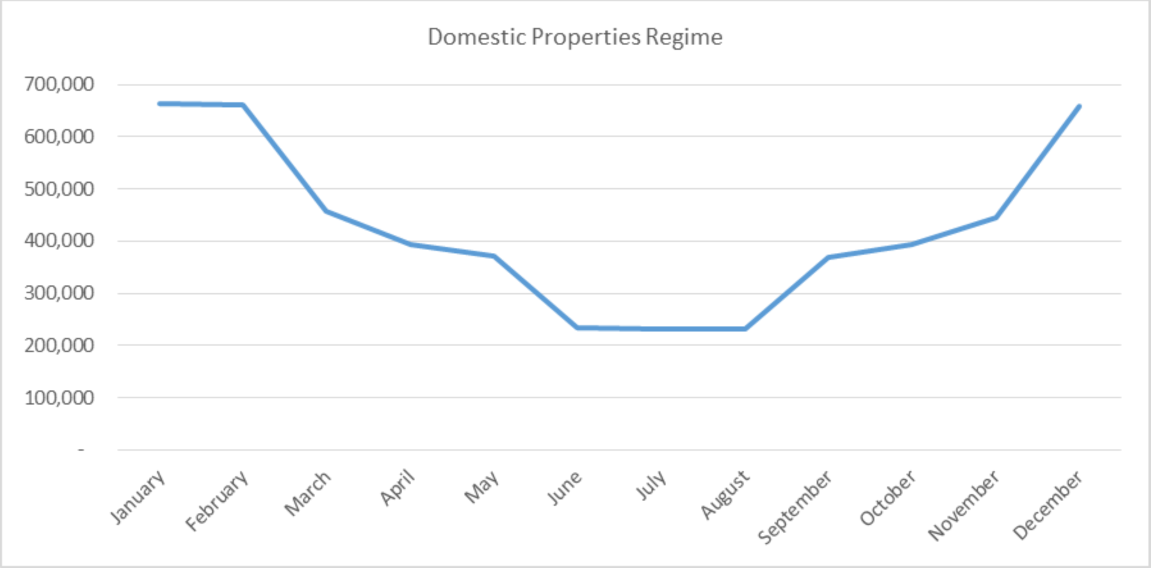


Figure 5 - Domestic properties regime

It is considered that the scheme would be best served in terms of cost and carbon to minimise the use of fossil fuels and for the scheme to be sized for peak domestic property heat use.

As a result the operational regime of heat utilisation would be as follows:

Total Available kWh	56,855,904
Greenhousing Utilisation kWh	49,056,000
Remaining Balance kWh	7,799,904
Maximum Number of Properties to be serviced	341
Total Domestic Heat Used kWh	5,109,118
Total Billable Heat kWh	54,165,118
Total Heat Used and Billed	95.3%

Table 7 - Operational regime and billable heat

This scheme is only possible if the commercial greenhousing is situated at an adjacent site to the Frances scheme. As can be seen below, in the optimal scheme (full layout in section 8) the development of greenhousing to the north of the site allows for >22,000m2 of available land for housing on the Frances site.

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Figure 6 - Housing and commercial greenhousing simple block layout

5 Renewable Electricity Options

This section evaluates the renewable energy options available to provide low carbon and lower cost electricity to the site than using grid electricity. The options evaluated here are not exhaustive, but are considered to be the 'most likely' options which could be pursued in a reasonable timescale for development.

5.1 Electricity Requirement

It is considered likely that the electricity peak load is likely to be circa 2.2MW depending on the CoP of the heat pump, the load required for water treatment plant and the load required for minewater pumping. Assumptions for this are as follows:

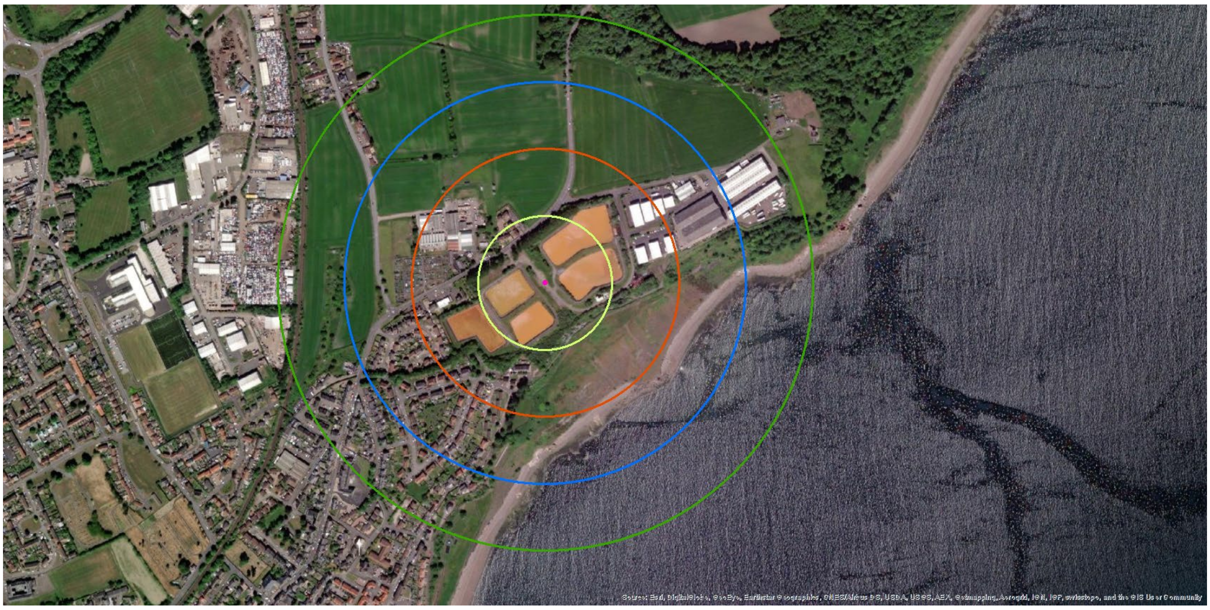
- Mine water pump assumed to be circa 100kW rated
- Water treatment plant assumed electrical load of minimum 250kW
- Heat pump load of 1.7MW

5.2 **Onshore Wind**

The key issue regarding the development of onshore wind at, or close to the Frances site is the proximity of housing. Paragraph 190 of the SPP (Scottish Planning Policy) refers to a guideline separation distance of up to 2km between areas of search for groups of wind turbines and the edge of towns, cities and villages, to reduce visual impact.

However, it is accepted that this 2km separation distance is a guide not a rule and decisions on individual developments should take into account specific local circumstances and geography.

Nevertheless, *as can be seen from the map below*, the site is surrounded to the west and north with housing and to the east with commercial properties. There is housing within the 500m buffer and it is considered that this will be a significant constraint due to the impact of shadow flicker.



Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Figure 7 - Proximity of housing to potential wind turbine - yellow 250m, orange 500m, blue 750m, green 1,000m

Under certain combinations of geographical position, time of day and time of year, the sun may pass behind the rotor and cast a shadow over neighbouring properties. When the blades rotate, the shadow flicks on and off; the effect is known as "shadow flicker". The seasonal duration of this effect can be calculated from the geometry of the machine and the latitude of the potential site.

Where this could be a problem, developers are required to provide calculations to quantify the effect. In most cases however, where separation is provided between wind turbines and nearby dwellings (as a general rule 10 rotor diameters), "shadow flicker" should not be a problem.

Given the site does not have sufficient space for more than a single large turbine, and that the average diameter of a single 1MW turbine is 54m, **we do not believe that a turbine would be suitable for the site** and would face significant difficulty in achieving planning permission since 10 rotor diameters multiplied by the average diameter creates a buffer zone where a significant amount of housing may suffer from shadow flicker.

5.3 Hydro

Given the high volume of mine water being pumped from the Frances Colliery there is naturally a consideration as to whether this may facilitate the development of some form of hydropower scheme to deliver renewable power to the overall Frances scheme.

There are two main considerations in assessing the viability of a hydro scheme of this nature (i) the characteristics of the site and how these affect likely power generation and (ii) the quality of mine water and how this is likely to behave in the context of a hydropower scheme.

Likely Power Generation

The equation for power generation from a hydro scheme is as follows:

$$P = m \times g \times H_{net} \times \eta$$

Where:

P = power, measured in Watts (W).

m = mass flow rate in kg/s (numerically the same as the flow rate in litres/second because 1 litre of water weighs 1 kg)

g = the gravitational constant, which is 9.81m/s2

Hnet = the net head. This is the gross head physically measured at the site, less any head losses. To keep things simple head losses can be assumed to be 10%, so Hnet=Hgross x 0.9

η = the product of all of the component efficiencies, which are normally the turbine, drive system and generator

For a typical small hydro system the turbine efficiency would be 85%, drive efficiency 95% and generator efficiency 93%, so the overall system efficiency would be 0.85 x 0.95 x 0.93 = 0.75 (i.e. 75%)

The head available on the site within the red line boundary is currently less than 5 metres and so any development would need to secure extra land next to or close to integration with the offshore outfall. The maximum gross head available in this case is calculated to be approximately 45 metres.

As such the predicted amount of power that could be available would be as follows:

190 x 9.81 x 40.5 x 0.75 = 56,615 watts, or 56 kilowatts

As we can see, the power generated would be significantly less than is required and as such **hydro power on the site is unlikely to be a suitable use of capital.**

5.4 Ground Mounted Solar

The formula to estimate the electricity generated in output of a photovoltaic system is:

$$E = A * r * H * PR$$

E = Energy (kWh)

A = Total solar panel Area (m2)

r = solar panel yield (kWp)

H = Annual average solar radiation on tilted panels (shadings not included)

PR = Performance ratio, coefficient for losses (range between 0.5 and 0.9, default value = 0.75)

Although these calculations can be made in principle, in order to be as accurate as possible in determining the optimal scheme we have used optimisation calculations from PVGIS to optimise the tilt of solar panels and ensure that the solar radiation is as accurate as possible to the sites location and orientation. We have also used the land use and planning characteristics of the Middle Balbeggie 5MW solar array to the north west of the Frances site to ensure that our calculations of land requirement for solar are as accurate as possible for the East Fife area.

From the Middle Balbeggie site we acknowledge the following:

- This array has an installed peak power of 42MW
- On a site of 9.8 hectares – so installed peak power per hectare of circa 4.2MW
- The site will produce 5MW - system efficiency of 11.9%
- This is as per the general standard of 2 hectares per MW anticipated power

The electricity requirement for the whole site is likely to be in the order of 2.2MW, as a result it is anticipated that a total installed peak power of 22,000kWp would be required, with a footprint of approximately 5.2 hectares.

The results of an optimised system of this size at the Frances site will produce the following:

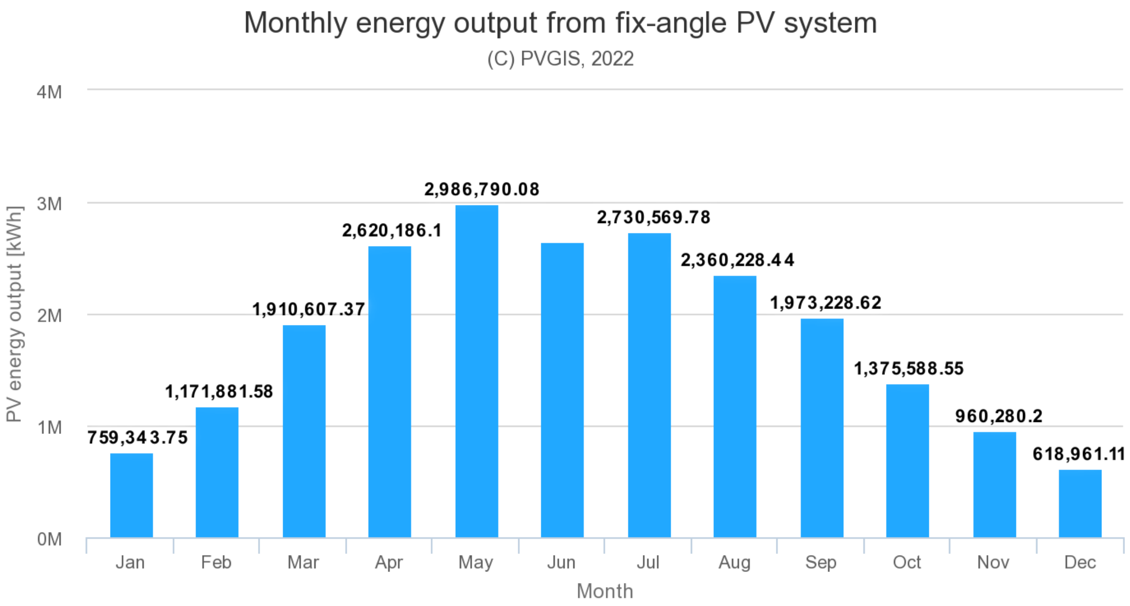


Figure 8 - Monthly kWh output from ground mounted solar at Frances site

- Total annual electricity production of 19,459,142 kWh (slightly large than required to account for pumps etc. not currently calculated)
- A system output size of 2.21MW
- Annual irradiance of 1081 kWh/m2
- System losses of 18.21% due to angle, temperature, low irradiance, system loss

Included in the costs of the system would be battery storage to account for the mismatch between generation and required load and to ensure smooth service during winter months. Grid supply would also be required as aback up to the system, but this has not been modelled in costs currently.

As such, **ground mounted solar is considered to be a suitable use of land** to generate the required power for the site.

Estimated capital costs of ground mounted solar are based on the total kWp of the required installation multiplied by the current cost per kWp in the solar market, which is estimated to be circa £350/kWp installed. This gives a total capital cost of **(22,000 x £350 = £7.7m).**

5.5 **Virtual PPA**

Another option which would be available to the site developers, which would not be constrained by the current site and its suitability or otherwise is the use of a virtual PPA by developing renewable assets elsewhere.

In contrast to the virtual PPA as a financial hedge, the VPPA being described here is basically the purchase of power by the Frances Colliery developers from another renewable development created elsewhere, at an agreed rate.

What this would allow is that the Frances Colliery development would benefit from lower cost renewable energy without necessarily having to have electrons delivered to it from a single on site renewable energy development.

This has some significant benefits to consider, specifically:

- The site has significant housing developments nearby and is therefore susceptible to significant planning risk for renewable development
- The size of the site (and surrounding land opportunities) is unlikely to be sufficient to generate the power requirement of the Frances development, especially given the land required for heat and water treatment developments
- Other sites in Scotland may offer a more expedient route to renewable development and, where elemental renewables are used, may offer a more efficient option for development (i.e. higher wind speeds, greater solar irradiance etc.)
- In addition this offers the developer the opportunity to engage directly, now, with projects in that may already have planning, mitigating risk
- The easing of size and scale restrictions means that the maximum electrical load to be delivered to the site is only limited to the extent of virtual PPAs that can be delivered

It should be considered however, that ownership of the renewable energy generation asset, ground mounted solar for example, may have substantial capital requirements but adds significant benefit to the overall payback period.

Given the options considered we have used ground mounted solar as the renewable electricity option to proceed with to the cost exercise.

6 Mine Water Treatment (MWT) System

6.1 Background

The Frances Colliery site has recently enjoyed upgrades to the mine water treatment system. Specifically in December 2019 there was the installation of new hardstanding, fill point kiosk, storage tanks, pipework, dosing rig, distribution board and control panel, plus improved safety features including a better shower and eye bath.

Nevertheless the water treatment plant still operates on the basis of passive treatment via large scale lagoons on site which have a significant size.

In order to facilitate the land required for the heat recovery plant, and potentially for the development of ground mounted solar and new housing, it is considered that a new, enclosed water treatment plant will be required.

The key contaminants to be managed by the new water treatment plant relate specifically to total iron, conductivity and pH of the discharge, which is currently to the long sea outfall.

No discharge consent is currently available, but it is considered likely (as per the WYG report) that total iron must be treated to approximately 5mg/L from the inflow average of 58mg/L.

6.2 MWT Option

The most likely treatment system to be employed would be a high density sludge (HDS) active treatment system, similar to the plant currently being operated by the Coal Authority at Dawdon.

The Dawdon system is designed to manage a flow rate of between 100 and 150 litres per second with total iron of 70mg/L and electrical conductivity of 60 mS/cm. The design flows and water quality are therefore considered to be similar enough to the Frances scheme to use Dawdon as a template.

At Dawdon the High Density Sludge (HDS) active treatment system is employed is housed within an industrial steel framed and clad building in order to comply with local planning requirements.

Influent mine water is treated with the addition of lime and a polymer flocculent, in order to reduce in-stream iron concentrations before final discharge to the North Sea. The iron is recovered as an ochreous high density sludge which is disposed of off-site and has potential for reuse in a range of applications. Total iron levels in the raw mine water are typically reduced to <1 mg/L prior to discharge and pH in the neutral range around pH 7.

The scheme includes the following processing plant:

- De-gassing tanks with associated blowers to strip dissolved carbon dioxide from the minewater;
- Stage 1 reactors where recycled sludge is mixed into the influent;
- Stage 2 reactors where lime is dosed to raise the pH levels and the minewater is further aerated;
- In-line polymer dosing to promote flocculation;
- Lamella plate clarifiers/thickeners;
- Sludge holding tanks;
- Filter press for sludge dewatering.
- PLC control to run the plant automatically based on inter-process and final effluent water quality measurement.

The scheme design is as follows (based on the drawings for the Dawdon scheme as built):

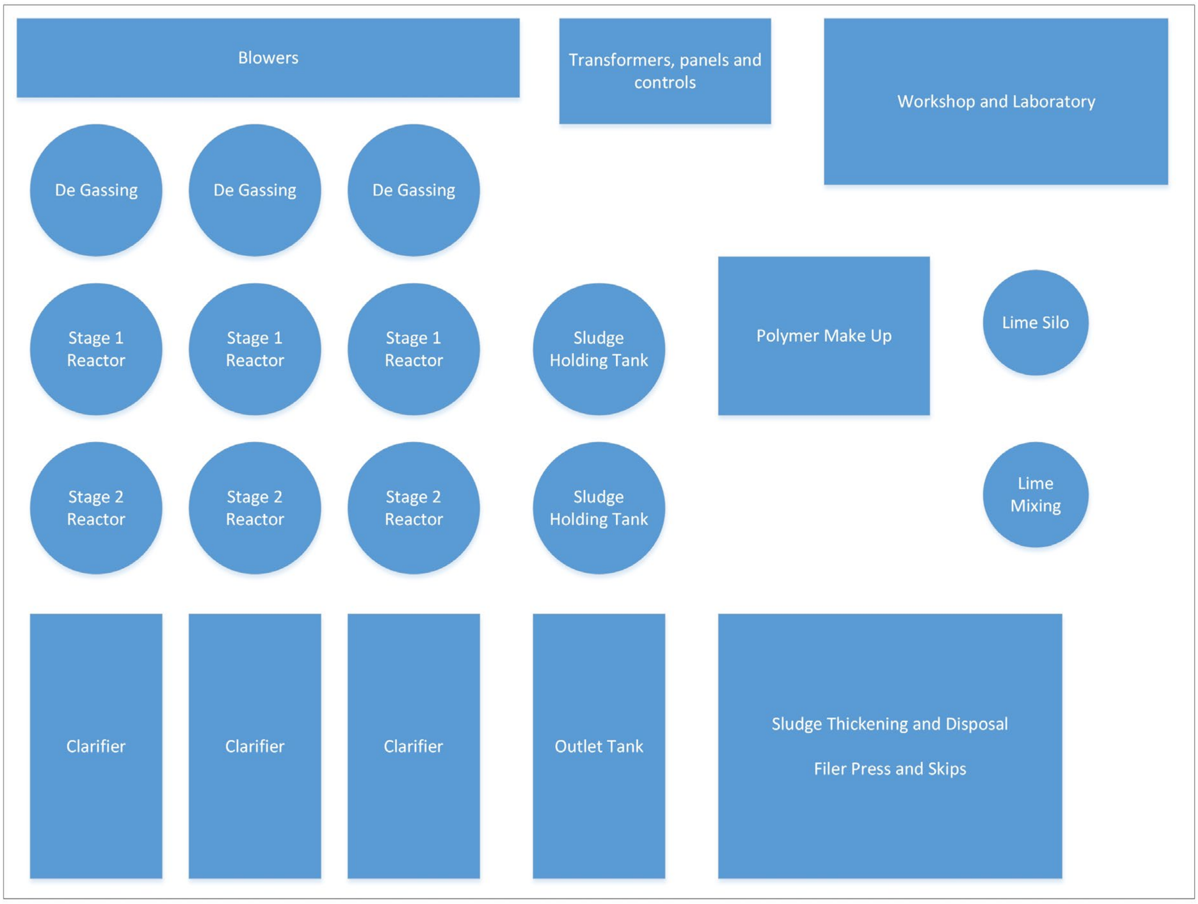


Figure 9 - Process plant and layout at Dawdon minewater treatment scheme

Based on the Dawdon plant we would assume the following will apply to any such development at Frances:

- Building requirement of circa 50m x 40m = 2,000m3
- Based on removing the costs of the building shell and the reinforced slab, the plant and equipment including installation would cost approximately £4.68m

6.3 MWT Option Operational Costs

Although little is known about the actual operational costs associated with the current water treatment system, costs have been estimated below for the operation of the proposed water treatment system.

These costs are estimates and would likely be subject to change as the scheme is further developed, but provides an indicative understanding of the costs associated with a MWT system.

Ochre Disposal

Ochre (hydro ferric oxide) disposal costs are based on the disposal of a dry sludge to a local landfill where the volume of sludge is dictated by the removal requirement of iron to meet discharge consent levels and the volume of minewater pumping.

Item	Data	Notes
Total Iron	58.41	mg/L
Target	5.00	mg/L

Removal	53.41	mg/L
Litres Pumped	10,540,800	litres per day
Iron Removal	562,984,128	mg/day
	0.56	tonnes per day
Tonnes per Annum	205.49	tonnes per annum
Ochre Content of Discharge	51%	Quantifying Ochre Arisings: Output from the UK Coal Authority's Mine Water Treatment Sites
Tonnes for Disposal	402.92	tonnes
Costs of Disposal	£155.00	per tonne based on disposal at Avondale in Polmont
Costs of Haulage	£9.00	per tonne based on disposal at Avondale in Polmont
Total Cost Ochre Disposal	£66,079	

Table 8 - Estimated ochre disposal costs

Chemical Use

Chemical use data is calculated from existing data on the current required volumes for treatment at the Frances site, after the recent 2019 reductions in dosing.

Item	Data	Notes
Annual Use (Estimate)	1,020.00	tonnes per annum
Cost per Tonne (Estimate)	£322.00	per tonne
Annual Cost	**£328,440**	per annum

Table 9 - Estimated chemical use

Staffing

Staffing is based on an estimate of the minimum required staff to adequately manage the minewater treatment scheme.

	Number	Rate	On Costs	Total
Operational Manager	1.00	45,000.00	18%	£ 53,100
Shift Workers	2.00	24,000.00	18%	£ 56,640
Total				£ 109,740

Table 10 - Estimated staffing costs

7 Optimal Solution

7.1 Optimal Solution

Based on the information provided and the most deliverable development options, it is considered that the optimal solution for the site is as follows:

Scheme Element	**Option Chosen**	**Reason**
Minewater system	Open system with discharge	Required to ensure no oxygenation of water, continuation of pumping and without any additional data reinjection could not be considered
Heat recovery	Single stage system with 6.8MW heat pump	Whilst the two stage option may have better operationally more robust, the potential reduction in revenue is significant at circa £530k per annum
Heat utilisation	Mixed use with new housing and new greenhousing	It is considered that a large anchor load in a new greenhousing development will ensure the schemes viability, whilst the development of new housing on site increases heat use without the associated costs and barriers to servicing existing housing
Electricity generation	Development of a 2.2MW ground mounted solar farm at the site	Solar is the only renewable likely to be able to achieve planning on the site and can be accommodated without the need for land from other parties
Water treatment	An active high density sludge treatment system similar to the process at Dawdon	There are limited options for water treatment, and the Dawdon site is the only active water treatment system for minewater where design data exists

Table 11 - Optimal solution options

7.2 Optimal Solution Site Layout

Based on the optimal solution, an indicative block site layout is provided below to establish that the site has the capacity to host all the components required.

We include here the construction of two 10,000m3 buffer tanks which may or may not be part of the final design based on planning and SEPA permitting processes. These tanks have been situated in an existing lagoon as this will likely reduce costs of bunding which would be required. These tanks are not currently included in the costs but can be added if required by SEPA in order to allow the development to go ahead.

Figure 10 - Optimal site solution layout

8 Project Development Stages

8.1 Preliminary Requirements

Should any project be developed, it is envisaged that some preliminary works will be required as follows:

- **Mine water heat recovery access agreement** – as per the Coal Authority requirements, any scheme would need to explore first a mine water heat recovery access agreement with the Coal Authority. This will require the proposed programme of operations, details of the scheme and some engineering information to be known prior to application
- **Engagement with commercial greenhousing developers** – as the central anchor load for heat, an outline agreement would likely be required with developers to ensure that the scheme had anchor tenants prior to significant development expenditure
- **Engagement with design and engineering contractors** – as detailed earlier in this report, it has been difficult to acquire any design information or plant specifications without contracting. It would therefore be likely that in order to develop an overall design for the scheme, engagement with contractors would be required
- **Engagement with Scottish Power and SGN** – whilst the project is based on the development of renewable heat and power, supplementary and emergency gas and electricity will still be required. Early engagement with stakeholders is required to establish if there are any specific site constraints
- **Outline design for planning** – any proposal of application notice to planning to establish the scope of a planning application would require an outline design to be complete.
- **PAN** - A Proposal of Application Notice (PAN) is submitted by the developer to the Council. It is not a planning application but a notice to the Council advising of how the developer intends to engage with the community about their proposal
- **PAC** - The Pre-Application Consultation sees the developer carrying out the community engagement as per their PAN. The PAC allows the local community to learn about the proposed development and submit any comments directly to the developer prior to the developer finalising their proposal and submitting their planning application

8.2 Standard Project Development Stages

After these preliminary works the project would be capable of development in line with the main stages of a renewable development, as follows:

Project Stage	**Details**
Start Up	Development of risk register, project programme, contract strategy, budgets and contractor shortlisting
Utilities	Engagement with SEPA, development of discharge consent, liaison with gas and electricity DNO’s, finalise design and apply for grid connections and gas network connections
Technical Specifications	Finalisation of civil engineering specification, finalise design and specification of all plant and equipment, finalise heat export data and water abstraction design data, finalise all

	mechanical and electrical specifications, finalise all building specification
Planning	Architects drawings, EIA where required, Planning application preparation and submission, management of planning and conditions
Permitting	Management of abstraction licence, discharge consent, scoping on permitting of water treatment plant and heat pump, environmental permit preparation and submission
Contracts	Management and delivery of competitive tender and contracting for civil engineering, plant equipment supply and installation, electrical installations, etc. Additional contracts may be required for land leases and offtake agreements
Construction	Management of construction, budgets, delivery, testing, takeover and sign off of the assets.

Table 122 - Standard project development stages

9 Determining Benefit

9.1 Carbon Benefit

The carbon benefits of the heat recovery scheme are largely based on the replacement of natural gas as a heating source. The basic calculation of this is as follows:

Item	Data	Notes
Gas Boiler Efficiency	90%	indicative
Energy Replaced	54,165,118	kWh
Natural Gas Required	60,183,464	kWh
GHG emissions Natural Gas	0.185	kg CO2eq/kWh
Carbon saving	11,133,941	kg CO2eq

Table 13 - Carbon benefits

As a result, the replacement of natural gas as a form of heating in a scheme of this size has the capacity to save 11,134 tonnes CO2eq per annum.

9.2 Economic Benefit

Our economic impact assessment is based on the Scottish Government methodology for assessing the economic impacts of development and the multiplier effects of economic development on the wider economy.

The economic impact of our proposed project can be measured as follows. If there is an increase in final demand for a particular industry output, we can assume that there will be an increase in the output of that industry, as producers react to meet the increased demand; this is the direct effect. As these producers increase their output, there will also be an increase in demand on their suppliers and so on down the supply chain; this is the indirect effect. As a result of the direct and indirect effects the level of household income throughout the economy will increase as a result of increased employment. A proportion of this increased income will be re-spent on final goods and services: this is the induced effect.

These are assessed below. We have used the Scottish Government Type 1 and Type 2 multipliers, Type I multipliers sum together direct and indirect effects while Type II multipliers also include induced effects. Our baseline scenario for this economic impact assessment is the development of the full commercial plastic to diesel facility with multipliers taken from SIC code “Water and sewerage”

Metric	**Description**	**Type 1 Multipliers**	**Type 2 Multipliers**
Income Multiplier	The increase in income from employment (IfE) throughout the Scottish economy that results from a change of £1 of income from employment	1.4	1.5
GVA Multiplier	The increase in GVA throughout the Scottish economy that results from a change of £1 of GVA in each industry	1.2	1.3

Table 1414 - Economic benefit multipliers

Based on the employment estimate and using post tax profit as a proxy for GVA at this stage, we can determine that the total economic impact of this development to be as follows:

Economic Benefit	**Type 1**	**Type 2**
Income Multiplier	£ 153,636	£ 164,610
GVA Multiplier	£ 1,581,102	£ 1,712,861

Table 15 - Economic impacts

9.3 Stakeholder Benefits

It is noted that a scheme of this type is likely to bring wider stakeholder benefits. These are presented below.

Stakeholder	**Benefit**
Fife Council	Depending on whether new housing is delivered as part of the scheme Fife Council benefits from the development of new housing and the additional Council Tax that this will bring. The development of renewables and renewable heat will also contribute to the new Fife Climate Action Plan and the Councils ambition to be carbon neutral by 2045.
Local economy	The local economy is likely to benefit where the scheme facilitates the development of commercial greenhousing as this will likely create new employment and will also facilitate new logistics and distribution opportunities from the greenhouse produce.
Local environment	In addition to the carbon savings brought by the new scheme, it is likely that the local environment will benefit from a higher quality of minewater discharge which will minimise impacts on the aquatic environment, and may reduce the impact on local amenities such as the Fife Coastal Path.
Existing householders	Existing householders are likely to enjoy some improvement to visual amenity from the removal of the current treatment lagoons.

New householders	New householders, should housing form part of the overall scheme, will benefit from stable priced, renewable heat without the inflation risk currently seen in the fossil fuel markets.

Table 16 - Stakeholder benefits

10 Conclusions

From the analysis undertaken, we have formed the following conclusions:

Topic	**Conclusion**
Heat recovery	Heat recovery is possible from the minewater, and based on assumptions this could provide in excess of 6MW of heat. Much will depend on the ability to match the energy recovery with design temperatures. Design temperatures would form part of the engineering design.
Renewable electricity	Given the constraints of the site the only real viable solution would be a ground mounted solar array.
Water treatment	A water treatment system to manage the flows and the current water quality is possible. A HDS water system similar to the one operated by the Coal Authority at Dawdon in County Durham would be of a scale similar to Frances.
Heat utilisation	There are various options open for the utilisation of heat. We have shown that the use of a large anchor load of commercial greenhousing does not preclude heat use by housing. However, the costs of pipe are a limiting factor and the development of new housing on site would be a more creative option.
Site use	We have illustrated that the size of the site is such that the heat recovery, water treatment and ground mounted solar could be accommodated on site and still have some land remaining for housing development. This would necessitate that commercial greenhousing is constructed at an adjacent site on existing farmland.
Payback period	Based only on the calculation of gross operational margins the payback period is 22.1 years where service revenues are not included in the calculation and 13.7 years where service revenues are included in the calculations.

Table 17 - Table of conclusions