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SCENE

LOST RIVERS

A pathfinder project exploring the potential to harvest heat energy from London's hidden underground rivers

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SCENE

Scene is social enterprise that works with communities to build resilience through local ownership of renewable energy systems. They work across UK and build products for the global 'energy access' market.

10:10 CLIMATE ACTION

10:10 Climate Action is a charity dedicated to inspiring everyone to tackle climate change. Whether we're installing solar panels on schools and community buildings or lobbying for better policy and support for community energy, we're positive, inclusive and dedicated to cutting carbon.

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1 INTRODUCTION

Take a stroll down London's Farringdon Street, and you'll see cars, offices, buses, bikes. But wind the clock back a few hundred years and you'd be traveling down the river Fleet. In centuries past, a myriad of tributaries flowed right through London into the River Thames and River Lea.

They provided water for drinking and cooking, spots for fishing, opportunities for transportation and power for driving mills.[1] As the city grew, many of these tributaries, some of which were major rivers in their own right, were buried into heavily engineered channels and the streets and buildings of London were built over the top.

Some of the rivers still flow over ground. There are a wealth of environmental initiatives to make the most of this 'blue infrastructure' for people and nature.[2] But go underground, and rather less attention is paid to the streams that were once such an important part of the local geography. Of course, there's not a whole lot of wildlife to protect, and not much in the way of fishing, sailing or swimming to be enjoyed. So at the moment, all that these lost rivers are good for is to dilute the surface water and foul drainage which flows into them.

But what if London's lost rivers could be used as a low-carbon source of heating and cooling for the buildings which lie above them? Of course, the water temperature is not warm enough to directly heat buildings. But through a combination of energy efficiency measures and the use of heat pumps, we have an incredible opportunity: lower costs, lower carbon emissions, better air quality, and greater energy resilience. Heat pumps can be cheaper to run than gas boilers, using electricity to deliver heat in a process that is several times more energy efficient than traditional electric heaters. Configured slightly differently, a heat pump can also deliver cooling in an efficient way.

This project sets out the fantastic and inspiring potential of this idea, explaining in simple terms how heat pumps work and why you'd want to install them in places where they can be connected to underground water courses. By highlighting places that are doing it already, describing how other countries are benefitting and presenting the schemes currently under development elsewhere in the UK, we will see how this technology, whilst not new, is certainly timely.

The report gives an overview of a typical development process for a water-source heat pump project, and showcases five sites in London we have prospected where this concept could become a reality. However, many more sites will exist beyond these, and there are huge opportunities for water utilities, local government, commercial developers, property owners and communities to seek out their own projects and make the most of this vastly underused resource.

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DECARBONISING HEAT WITH HEAT PUMPS

THE CHALLENGE

One of the huge challenges in meeting the UK's climate change commitments is decarbonising heat.[3] From the EU Renewable Energy Directive, our target is for 12% of our heat to come from renewable sources by 2020. We are currently on track to miss this. As we move towards 2050, heating and cooling space and water will need to be **completely decarbonised** in order to leave space in carbon budgets for other sectors such as aviation and industry.[4]

Three quarters of London's household energy is used for hot water and heating. The London mayor is aiming for London to be a zero-carbon city by 2050. This will include energy efficient buildings, clean transport and clean energy generation - and a phasing out of gas boilers on a huge scale. One of the mayor's aims for achieving this sustainable future is to trial low carbon technologies like heat pumps, with the vision of city-wide deployment by 2030. In addition, in late 2017 the government launched its Clean Growth Strategy calling for innovations that result in a switch to lower carbon sources of heat.

As we decarbonise the city's heat supply, we must make sure we use London's resources and benefit Londoners. This project seeks to address these twin challenges.

The biggest and first step needed is to dramatically improve the energy efficiency of our buildings. That would reduce overall demand for heat and thereby reduce the scale of the problem. But even with much more thermally efficient buildings, the UK will still need to find low carbon sources for huge amounts of heat energy.

Long term, using electricity to meet heat demand is likely to be the only solution that allows us to meet our UK carbon budgets.[5] This implies a massive increase in the use of heat pumps, electrically-powered devices which can harvest low grade heat from the surrounding environment and use it to heat indoor spaces and water in buildings. Heat pumps can deliver three or four times more heat for every unit of electricity than the plug-in electric heaters or electric boilers commonly found in homes.

As global average temperatures rise and extreme climate impacts become more common, the need for cooling will also become more and more important, particular within urban heat islands like London. In many commercial and industrial buildings, cooling is already a higher energy demand than heating, mainly because a lot of the equipment used in modern workplaces generates heat as a byproduct of its operation. Heat pumps are particularly useful because the same heat pump can operate in two modes, to provide heating in winter and cooling in summer. 'Heat' in this context is slightly misleading, more precisely it's 'thermal energy'.

It's also critically important to consider security of supply from new energy sources. The transition from heavy reliance on imported gas for heat, to heat which is locally generated using electricity - can help to ensure continuity and consistency of supply and protect essential services from geopolitical uncertainties.

WHAT IS A HEAT PUMP?

There are two ways you can warm up a cold room. One is to create heat, as you would by running a traditional electric heater. The other is to move heat into the room from elsewhere, and the most efficient way to do that is by using a heat pump.

Understanding how a heat pump works means remembering two key things from your school physics lessons. The first thing is that pressure affects the boiling point of a liquid. Lowering the pressure means a fluid will turn into a gas at cooler temperatures, while raising the pressure means the fluid must be hotter before it can boil. That's why it's easier to boil water on top of a mountain, where air pressure is low, than it is at sea level.

The second thing is that a gas turning into a liquid will release heat energy and warm the environment, while a liquid turning into a gas does the opposite - sucking in heat energy and cooling the environment. (This is why sweating cools us down, as the liquid sweat evaporates).

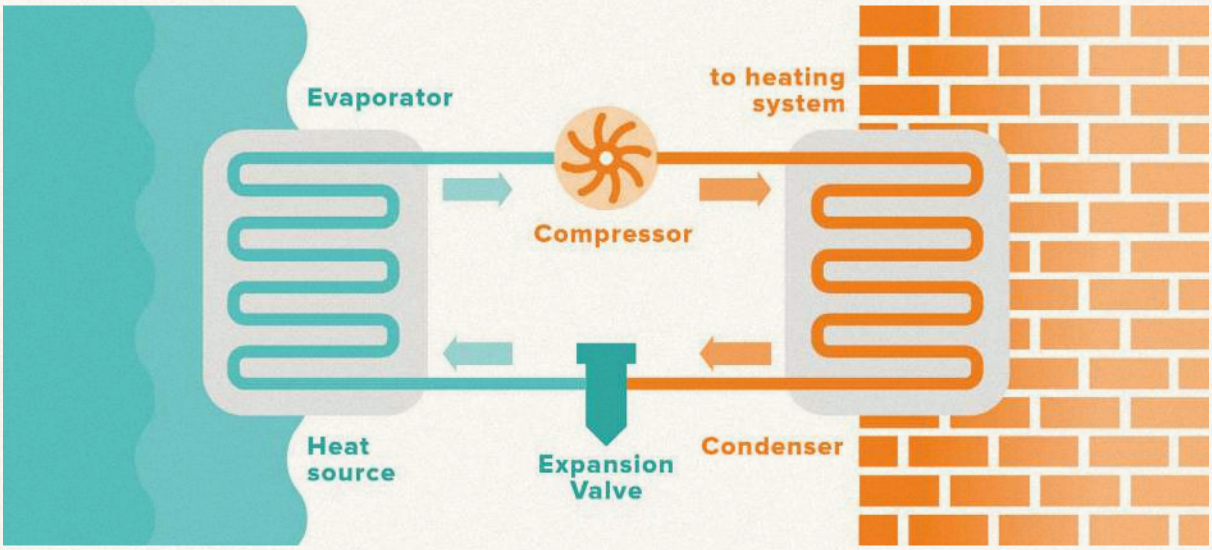
The combination of these two effects means that by controlling the pressure, we can make a liquid turn into a gas, or a gas to a liquid, whenever we want - warming or cooling the environment in the process.

A real-world heat pump is essentially a long loop of sealed tube where this process can take place. Part of the tube is inside the place you want to change the temperature of (ie the place you want to heat up or cool down), and part is outside it. The tube is filled with a refrigerant, which can be any liquid that has the right blend of thermodynamic properties. Those properties will differ depending on the task, but commonly used refrigerants include ammonia, carbon dioxide, isobutane and hydrofluorocarbons.

The refrigerant is circulated around the tube. It enters the compressor in a gaseous state at a lower pressure and temperature. The compressor increases the pressure of the gas. It then goes into the hot side of the tube where, thanks to the high pressure, it turns into a liquid, releasing heat energy into the environment.

The refrigerant is then pushed through an expansion valve, which dramatically lowers the pressure. This drop in pressure begins the process of converting the refrigerant back into a gas, which is completed in the cool side of the tube. The energy it needs to do this is pulled out of the surrounding environment, cooling it. The cool, low-pressure refrigerant then passes back into the compressor, and the cycle starts again.

The cool side can be fairly cool and still contain plentry of 'heat' for the heat pump to



transfer. When in liquid form, the refrigerant is so cold that it absorbs heat from its surroundings – even from air as cold as -15°C! By pumping the refrigerant round the system, the not-very-hot heat from the external environment can be converted into usable heat.

There are lots of ways this technology can be used. In a fridge, or air conditioning unit, heat is moved from inside to the outside. In a heating system, the reverse is true and heat energy is moved from outside to inside. It's possible to build a system that's reversible - releasing heat to the outdoors in the summer and capturing it in the winter.

Either way, harvesting heat energy from the external environment, rather than creating it in place, makes heat pumps one of the most efficient forms of heating available. Putting just one unit of electrical energy in will produce up to five units of heat energy. It's basically magic.

BUILDING HEATING SYSTEMS

Many heating systems in the UK have been designed to be powered by gas or oil burners. As these work by burning fossil fuels at hundreds of degrees celcius, getting the system of pipes and radiators hot isn't an issue! Consequently, pipework is narrow and radiators are small, with water typically leaving the boiler at 80°C and returning at 60°C (flow and return). The fact that most of our buildings are leaky doesn't much compromise the systems' ability to keep us warm – to counteract draughts, you just burn more fuel.

Except, of course, burning more fuel is a problem. It costs more, damages air quality locally, contributes to climate change, and leaves us reliant on distant fuel sources like natural gas.

In theory, the same ambient temperature inside can be achieved using a lot less energy when the system is powered by a heat pump. However, to be most effective, firstly you need to improve the energy efficiency of the building. Just as a fridge only works with the door closed, heat pumps work best in buildings which are well insulated and sealed. This not only reduces overall energy demand, but it also allows the same ambient temperature to be achieved with a lower flow and return temperature in your heating system. Some buildings' pipes and radiators will be able to cope with these altered temperatures without modification, but other buildings will require the installation of systems with larger radiant surface areas (larger radiators or underfloor heating) and, in some cases, larger diameter pipework. Good sealing, insulation and radiator design are easier to achieve in a new build than a retrofit, but nevertheless it is estimated that 38% of London's total heat demand could be met by secondary heat with an operating temperature of 70°C **without the need for significant retrofit.**[6] With ambitious retrofit programmes, that could rise to over 45%.[7]

HEAT SOURCES

AIR SOURCE HEAT PUMPS

Air source heat pumps extract heat from the outside air, in one of two ways:

- Air–air heat pump (transfers heat directly to inside air).
- Air–water heat pump (transfers heat to a heating circuit and a tank of domestic hot water).

Air source heat pumps, especially the air-to-air versions, are relatively easy and inexpensive to install. Therefore historically they have been the most widely used type of heat pump. However, they're limited by the amount by which the temperature of the outside air can vary. Higher temperature differences between inside and outside (for example during periods of extreme cold) mean the system will work less efficiently.

GROUND SOURCE HEAT PUMPS

All ground source heat pumps use a heat exchanger in contact with the ground to extract or dissipate heat. The system transfers heat from the ground into pipework, typically high-density polyethylene pipe, containing a mixture of water and anti-freeze. Systems can be installed horizontally or vertically – while vertical systems are more efficient, they are also substantially more expensive.

Horizontal ground source heat pumps require digging up large areas to install them - hence they are not very practical in London. Vertical ground source heat pumps can also be difficult to site. Their installation requires the drilling of multiple boreholes, and need to be carefully sited to avoid disturbing or damaging underground features during the construction process.

WATER SOURCE HEAT PUMPS

Closed loop water source heat pumps can use the same principle of heat exchange as ground source heat pumps by installing pipework that runs through a body of water or water course. The heat exchange process can be very efficient due to the flow of water around the pipework. Even in still water like lakes, convection currents help with the heat transfer process. Closed loop systems may be advantageous where poor or corrosive water quality precludes an open loop system or where the heat load is small.

Open loop heat pumps take water directly from the water source and extract the heat through a heat exchanger. Open loop systems need to return the water far enough away from the intake to avoid the colder discharged water from cooling the intake. In the case of the lost rivers, this means downstream. Since this system doesn't control the water chemistry, it may need to be protected from corrosion by using different metals in the heat exchanger and pump. Sedimentation may also foul the system and require periodic cleaning. If the water contains high levels of salt, minerals, iron bacteria or hydrogen sulphide, a closed loop system is usually preferable.

Real world examples exist of heat pumps being delployed in some challenging water sources. The town of Heerlen, in the Netherlands, is progressively expanding a heat network using water from the old abandoned mines - a particularly good source given the higher temperatures deep underground. Sewers too can be warmer than other watercourses, and if the right technology is installed, the suspended solids are no hindrance to providing heat – as highlighted by one of the precedents later in this report!

SIZE

Heat pumps are available in a range of sizes, from small systems that can supply one- or two-person houses to huge machines that can supply entire housing estates, office blocks or shopping centres– and sometimes all of those places! Larger systems usually use several machines to cope with fluctuating demand and provide redundancy in the event of a technical problem.

In general, the larger the heat pump system, the higher the efficiency and therefore the lower the cost of providing each unit of heat. This is one reason why large heat pumps supplying heat networks can make more sense than lots of small heat pumps supplying each individual need. What's more, a good heat source like an area of open ground or an underground river might only be accessible in one specific place. A heat network can make use of one resource to supply lots of users, some of whom might be a few hundred metres away from the site of the heat pump.

HEAT PUMP USE IN THE UK

So, if heat pumps offer so many benefits, why aren't we all using them already?

The reason is partly historical. In the 19th and 20th centuries coal gas, then later natural gas, were abundantly produced in the UK as by-products of coal mining and oil extraction. At the same time that other north European countries such as Denmark and Sweden were investing in heat networks, here in the UK the government invested in the gas grid, which more often than not was piped to each individual user rather than supplying communal or district heating networks. Today, the national gas network continues to provide a low-cost, but potentially deadly and highly combustible gas into most of the homes and businesses in London.

As a consequence, most heating systems currently in place would require replacement or modification to be compatible with energy from a heat pump. And, buildings need high standards of energy efficiency for heat pumps to operate most efficiently. However, networks supplying multiple users do already exist in numerous places across London, and it is common for new developments to incorporate heating networks rather than having individual boilers for every user. Councils are undertaking projects to retrofit heating networks in their housing estates, motivated by the cost and carbon savings they can realise. These existing and future heat networks offer the best prospects for heat pump integration. Networks supplied by heat pumps have been used widely in North America, Scandinavia, Germany and Switzerland for many years, and we can now benefit from a tried and tested technology.

BORDERS COLLEGE: A NEW FRONTIER FOR LOW CARBON HEAT IN THE UK

The Borders college campus at Galashiels is the site of the first sewer-source heat pump unit to be installed in the UK. The system, which has been operational since late 2015, extracts heat from the waste water flowing into a local treatment works, raises the temperature using a heat pump and delivers hot water to the college's space heating and domestic hot water systems via five plant rooms.

At the time of the initial feasibility assessment, the college had already made a number of investments to improve the sustainability of its energy systems, including an energy efficiency retrofit and the installation of solar PV panels. The next area targeted for improvement was the facility's heat supply. Comparing the waste water heat recovery option with that of a new biomass-fired boiler, the college found that the two projects would provide similar greenhouse gas savings. However, the heat recovery system offered some important advantages: the possibility of a more predictable heat price, the avoidance of the cost, complication and space requirements of regular biomass fuel deliveries and the opportunity to avoid an up-front capital investment.

The system, comprising a new Energy Centre building, pumping station, sewer interface and interconnecting pipes, took only six months to install and commission. Many of the equipment packages were assembled off-site and brought to the college packaged to simplify the installation. Long term, the college expect the system's two 400kW8 heat pumps to provide 1.8GWh of heat each year which would previously have been supplied by natural gas boilers. They should meet 95% of the college's heating needs (the gas boilers have been left in place as backup). They will save 150 tonnes of greenhouse gas per year.

After 18 months of operation, the college are very pleased with new heating system. In fact, it's performed better than expected. This is partly down to the college's efforts to improve the energy efficiency of their buildings. This meant that the temperature of the hot water supplied to the buildings could be decreased to 55°C from the 63°C originally expected.

The project was delivered through a joint venture between Equitix (channelling capital originating from both the Green Investment Bank and private sources) and SHARC Energy Systems (a subsidiary of International Wastewater Systems Inc.). A 20-year Heat Purchase Agreement was made with Borders college, allowing the facility to pay for the service provided with some of the savings they make on natural gas consumption. A contract with Scottish Water allows for an annual charge for the use of the sewer and technical support. SHARC Energy Systems, who supplied the equipment, also hold a contract to operate and maintain the system for 20 years.

The Borders college project shows the feasibility of installing waste water heat recovery systems as retrofits with minimal disruption to ongoing heating services, even at a site with buildings dating as far back as the 1800s. The success of the project has paved the way for a new programme of related projects in Scotland. Some of these will also harvest heat from waste water while others will use rivers or sea water. Several new projects employing SHARC's technology are scheduled for completion in 2018, including installations in Glasgow (Kelvingrove Museum and the Clyde Gateway development), Campbeltown, Stirling and Pickaquoy, Orkney. These forthcoming projects will also involve variations on the Heat Purchase Agreement and contractual model used for the Borders College project.

STATE MINISTRY BUILDING, STUTTGART: HEAT RECOVERY FROM A LOST RIVER IN GERMANY

In 2012, a new building for the Interior Ministry for the state of Baden-Württemberg was constructed in the heart of the German city of Stuttgart. An ancient stream, the Nesenbach, used to flow down a valley where the building now stands. During the 20th century, the stream bed was progressively built over and inflows diverted, and today what was the stream is now one of the most important sewer lines in the city. In dry weather, the flow rate is some 170 litres per second, but during and after storms the flow rate can rise to several cubic metres per second.

In addition to the Interior Ministry, the building houses parts of several other state government ministries, government and police "situation rooms", conference areas, childcare facilities and a canteen. Around 600 people work inside. The building was designed to meet very high energy efficiency requirements, featuring a thermally optimised building design and high efficiency equipment. The relatively small amounts of thermal energy that are required – for heating in the winter, and for cooling in the summer – are supplied largely from energy extracted from water in the Nesenbach underground canal, which passes directly in front of the building.

In heating mode, the bank of three heat pumps deliver up to 530 kW of heat to the building. In cooling mode, they can extract 580 kW of heat. In heating mode, the heat pumps are backed up by a connection to a separate district heating network which provides extra power during peak periods and redundancy in the event of heat pump downtime. The heating/cooling water circulation system runs through the concrete ceilings and floors of the building. This arrangement provides continuous heat transfer with relatively low temperature differences thanks to the large effective surfaces involved, and uses the mass of the building to regulate the temperature through periods of varying demand.

The heat extraction system was supplied by HUBER Technology and, like the SHARC system installed at Borders college, incorporates specialised equipment to screen the waste water before it enters the heat exchangers in order to prevent clogging. The heat exchangers transfer energy from the waste water into a separate closed-loop circulation system, meaning that the water inside the buildings has never come into contact with the waste water.

Stuttgart's climate is very similar to that of London, although Stuttgart is slightly colder in winter. This fact, and the similarity of the Nesenbach to many of London's lost rivers, mean that we could expect to replicate the performance of the Stuttgart ministry building's heating system in similar settings in London such as the Hammersmith Town Hall case study presented later in this report.

3

DEVELOPMENT PROCESS

This project aims to generate interest and support for this idea, both amongst the wider population and with decision makers. We hope this report will inspire people to initiate projects that tap into the heat resources of subterranean waterways such as culverted rivers and sewer networks. We focused on London's lost rivers for this study, but every city in the UK has a sewer network that could offer a substantial low carbon heat resource to the adventurous developer. In this section we provide an overview of the development process, with extra focus on the early stages, to assist those with a heat pump project idea to make the concept a reality.

We've also prepared GIS mapping as part of this project. This allows you to match the location of the sources of secondary heat from London's lost rivers to potential buildings which could use them. However, in any city that has a sewer system, location data should be available from the companies or public bodies operating the waste water network that would enable a similar matching exercise to be done.

POLICY SUPPORT

There is very strong policy support for the decarbonisation of heat, and the Renewable Heat Incentive (RHI) offers attractive financial incentives to support uptake of locally generated sustainable heat. This policy support is unlikely to go away – after all, the fundamental underlying principles behind locally sourcing energy (security, affordability, and sustainability) aren't going to change. But as renewable heat technologies become mainstream, it is likely that the subsidies will fall - as happened for solar and wind in the last decade. Reductions in support for heat pump deployment have certainly not happened so far – in fact, the subsidies went up at the last review – so it's not a high project risk for projects conceived now. However, the threat of reductions somewhere down the line is an incentive to act now, rather than leave it for a few years.

HOW TO DEVELOP A PROJECT

There are distinct, but interrelated development stages in progressing any heat demand and supply opportunity from inception to operation. These are illustrated in the diagram below.

For the development of heat pump opportunities connecting to subterranean waterways such as culverted rivers and sewer networks, these stages comprise:

DEVELOPMENT

1. Heat Strategy and Mapping:

Identifying and prioritising the strategic drivers for the development of low carbon heat supply, whether for an individual company or organisation, a local council, or city-wide.

For higher-level initiatives, undertaking baseline assessments to define heat maps and locate generation opportunities.

At a single-site level, gathering information about the location of possible heat sources and heat users and the characteristics of existing heating systems.

2. Masterplanning:

Undertaking opportunity assessments with the aim of selecting one or two candidate projects for which to invest in a feasibility study.

3. Feasibility study for single projects.

4. Detailed project development.

COMMERCIALISATION

5. Procurement, financing and contractual agreements.

DELIVERY

6. Construction.

7. Testing and commissioning.

8. Operation and Maintenance.

Below we set out further detail on stages 2, 3 and 4 in the context of London, to explain how potential opportunities could be developed into investment ready business proposals.

MASTERPLANNING - HEAT DEMAND AND HEAT SUPPLY APPRAISAL

KEY TASKS

For development at borough or city-wide level:

Review London's heat map data and where possible obtain additional hourly and half hourly energy consumption data for the buildings above or adjacent to culverted rivers or sewer networks which could provide secondary heat.

Consider planned developments as well as existing buildings. Large single energy users with single ownership are likely to be easier to deliver than smaller energy users in multiple ownership.

FOR DEVELOPMENT AT A SINGLE SITE

Review site heat consumption data, using half hourly or hourly data if possible, to establish average, maximum and minimum heat loads.

Obtain topographical information and measurements of flow rates and temperatures in the underground heat source. Currently, Thames Water holds only modelled information for the whole network, which can provide a helpful indication of the potential resource. However, to develop an investment case in-situ monitoring will be required, preferably over a period of several months or longer. This can be a complex undertaking and requires specialist equipment and contractors approved by Thames Water.

Engage with relevant people to establish technical details of the building's existing heating system arrangements: in particular, energy supply equipment locations, heating flow temperatures, and existence of any refurbishment programmes.

As gas boilers tend to be replaced on a 15-year cycle, a proposal to replace the system with a heat pump is more likely to be seriously considered if they are reaching the end of that 15 years, than if a new system has just been installed.

Engage with relevant people to establish the approximate extent and timing of site expansions or energy efficiency works that might affect heat loads in the future.

FOR ALL DEVELOPMENTS

Analyse data on flows and temperatures of lost rivers and sewer networks in conjunction with heat or fuel consumption data. Is at least 100kWth available from the source(s)? Do the existing or forecast heat demands match or exceed the availability from the source(s)? Are the distances between the source and the energy centres, or the connections to the heat network, less than 200m (unless a particularly large system is being considered)?[9]

Identify key stakeholders and gauge their level of interest and influence. At a borough or city-wide level, this could include local government, utilities, waterways management groups, environmental organisations, major property developers and construction companies. At single-site level, this could cover owners, tenants, users, and energy system managers. Wider community interest and involvement should also be considered at this stage.

This process provides the baseline for an initial options appraisal to shortlist development options.

FEASIBILITY STUDY - HEAT DEMAND AND HEAT SUPPLY APPRAISAL

KEY TASKS

Review and analyse site heat consumption data in more detail, including load duration curves if available. If not already done, obtain measurements of flow rates and temperatures in the underground heat source over a longer period – preferably a whole year in order to cover a range of climatic conditions.

Consider at a high level the technical feasibility of options for tie-ins to existing systems and space requirements for new equipment. Identify whether any equipment would need to be installed on land currently owned by a third party.

Although environmental impacts on hydrology and ecology are unlikely to occur when connecting to London's lost rivers or underground sewer networks,[10] you may need to consider noise or visual impacts, particularly where new energy centres are required. However, these are likely to be favourable when compared with gas alternatives – particularly considering other areas like air quality.

Develop broad cost estimates for the project, focusing on the major line items such as the heat pump itself, any new heat exchangers, pipework and electrical and civil work if required. Obtain up-to-date information about site energy costs and rates for incentives like the RHI. Estimate any changes in non-energy costs that would occur, such as maintenance and staffing. Calculate an estimate of annual cost savings and payback or return on investment. Estimated carbon savings can be calculated in parallel.

At the feasibility stage, it is also important to consider the delivery structures involved to design, build, operate and maintain the project. It is not necessary for a building owner to secure and invest the capital upfront to deliver a low carbon energy supply. Partnerships, or long-term supply agreements, may be attractive to bring in technical or financial delivery and operation expertise to ensure the long-term success of the project.

SYSTEM DESIGN AND MODELLING

There are a number of variables – energy efficiency, heat supply and storage - which interact and need to be considered in terms of technical, financial and operational impact to identify the preferred solution. You can then compare the optimum operational strategy and plant size to the business as usual scenario based on typical existing heating systems using gas boilers. Then you can assess the avoided heat generation costs and also the avoided carbon emissions and the associated financial savings achieved. The avoided cost of heat includes avoided fuel, avoided costs of carbon credits, operations and maintenance and plant reinvestment costs over the life of the project. The variability in electricity costs needs to be accounted for as this has a large influence on the plant sizing and run hours.

At this stage, engineering design will need to consider the sizing of other elements of the system beyond the heat pump itself and produce lists of the equipment that needs to be procured. Locations for large equipment and routes for new pipework should be planned. Control systems and safety features should be specified, and the practicalities of installation considered.

The preferred project delivery structure will also need to be confirmed as part of developing the system design to underpin any business case. As far as possible, the agreement between development partners and heat customers should be progressed, through Memoranda of Understanding and Heads of Terms as necessary, working towards full agreement.

4

SEARCHING FOR HEAT IN LONDON'S LOST RIVERS

This project aims to generate interest and London's lost rivers offer a huge opportunity for low cost, low carbon heating and cooling. Here are five prospects we explored for making this happen.

BUCKINGHAM PALACE: A GREENER UPGRADE FOR THE ROYAL RESIDENCE

In 2017, Buckingham Palace began a ten year refurbishment programme to ensure that the building remains fit for purpose and is preserved for future generations. Large parts of the palace's plumbing, electrical cabling and heating systems have not been updated for 60 years. They require urgent replacement in order to avoid the real risk of significant fire, flood, health and safety incidents and potential loss or damage to the works of art in the Royal Collection. Furthermore, the palace needs to be modernised so that it's a healthy and comfortable place to live and work for hundreds of resident and non-resident staff and the royal occupants. The refurbishment, which will require £369M of funding through the Treasury, also has an objective to increase the energy efficiency of the palace and reduce carbon emissions by 40%.[11]

The River Tyburn originates on the high ground of Hampstead and proceeds to flow under Regent's Park, crossing Oxford Street and charting a course below Mayfair to enter a conduit known as King's Scholars' Pond Sewer. The water of the Tyburn then proceeds to pass under Green Park towards the forecourt of Buckingham Palace. However, these days under normal conditions very little flow actually passes by the Palace, but rather is intercepted at a point 250m to the north in Green Park to flow towards wastewater treatment facilities.

As part of the Buckingham Palace refurbishment, the building's old natural gas boilers and Combined Heat and Power (CHP) system will be replaced, as will 32 kilometres of heating pipework, to prevent failures and boost energy efficiency. The programme includes plans to install a biogas system to produce renewable fuel that can be burned to supply heating and hot water. However, this sustainable technology will provide less than 5% of the palace's energy needs, meaning the vast majority of heating will be provided by burning fossil fuels. Solar thermal panels and ground source heat pumps are among the technologies that could be deployed in the future, but do not feature in the existing plans.

One sustainable heat technology currently not featured in the options appraisal for the refurbishment is a water source heat pump, with the lost river as a heat source. A system designed to extract heat from the Tyburn just before or just after it leaves its natural north-south route could be tapping into a resource of as much as 10 megawatts, far more than the palace uses even on the coldest day. Models produced by Thames Water predict average flow rates of almost 1 cubic metre per second, with relatively little variation over the course of a day. This would be ideal for the successful integration of a heat pump system without adversely affecting the temperature of the water downstream of the palace.

In fact, the Queen's residence would not be the first palace to have its heating needs supplied by this technology. In 2012, two buildings of the Presidential Palace (Palais d'Elysée) in Paris were connected to a new heat pump system installed by GDF Suez that extracts 240 kW of heat from nearby sewers![12]

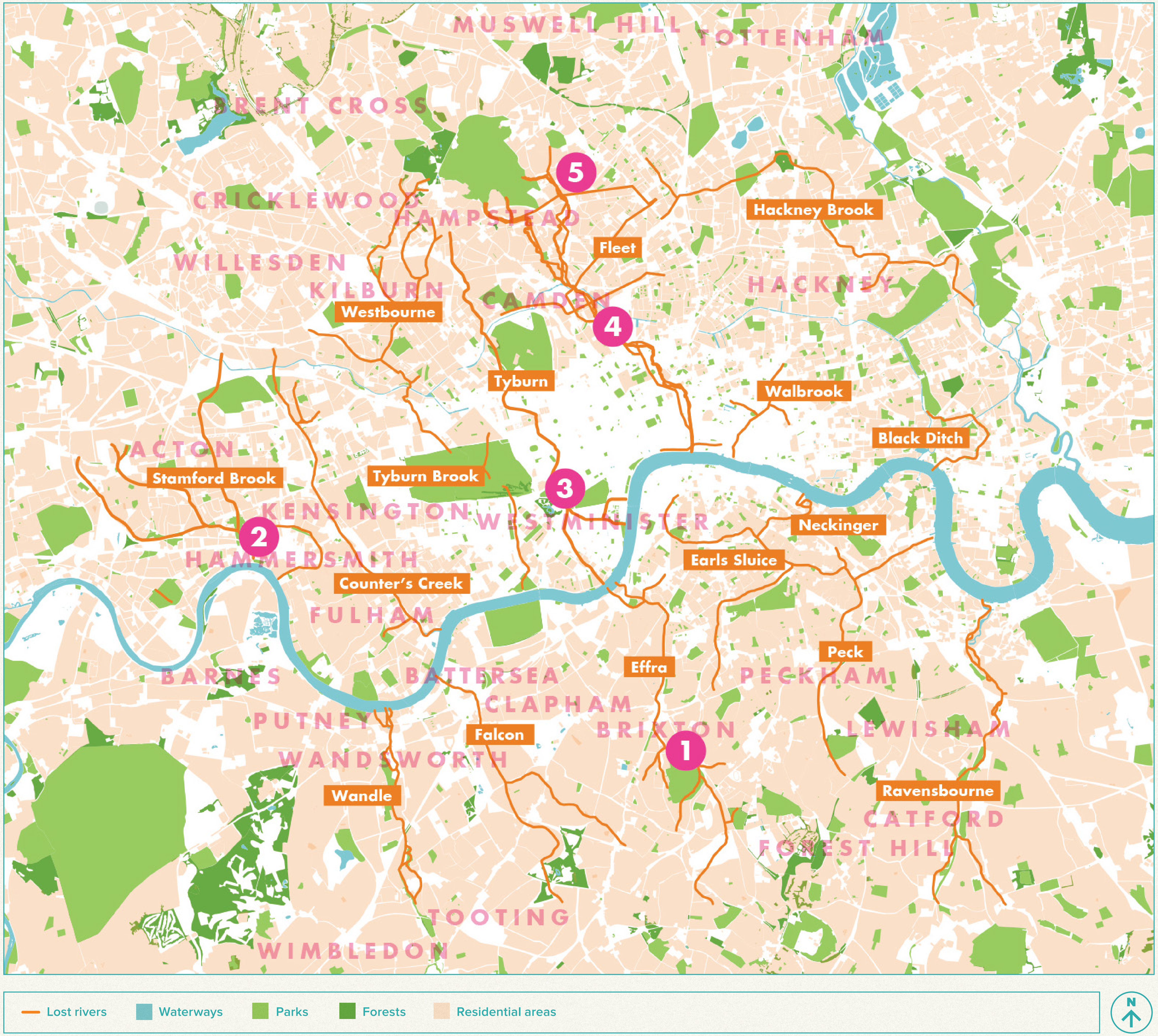
HAMMERSMITH TOWN HALL: REDEVELOPMENT WITH SUSTAINABILITY BUILT-IN

The seat of Hammersmith & Fulham Council and Register Offices, Hammersmith Town Hall is also a concert venue and location for community events. The original 1930s building is Grade II listed in recognition of its architectural and historic interest. The building was extended in the 1970s, but the brutalist design of the extension is not widely loved. Architects have produced designs for a renovation of the older part of the building and replacement of the extension with a new, mixed-use development on its footprint and surrounding land. Pending planning approval, the new development will feature housing, a cinema, retail space, office space, arts venues and a public plaza.[13]

Stamford Brook, like the Tyburn, runs almost entirely underground and parts of its course are used to carry waste water and surface runoff. The brook is formed of three streams from the Acton and Wormwood Scrubs areas, which come together at Ravenscourt Park. Until the early 19th century the lower part of the stream (known as Hammersmith Creek) was navigable and barges used to sail from the Thames up the creek to unload at Cromwell Brewery, located where the town hall now stands.[14]

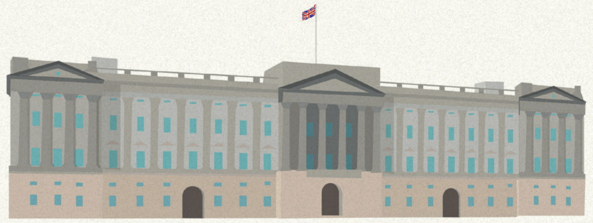
Although the area on the surface has changed beyond recognition, water from Stamford Brook still flows directly underneath the town hall. This flow represents a sizeable resource for heat extraction – cooling 20 litres per second by 5 degrees centigrade gives a yield in excess of 400 kilowatts. But, even more heat could be extracted from a point some 50 metres south of the building where the brook's water is augmented by flow from a wastewater interceptor pipe. This flow varies over the course of the day, but at least 700 kW is available at all times. During daytime hours the heat available rises above 1 megawatt, and would be further increased during times of rain when greater amounts are flowing through the brook and other water courses.

The redevelopment of the Kings Street area surrounding the Town Hall provides an opportunity for sustainable energy to be incorporated into the design of new services. The concentration of public, commercial and domestic energy users would mean that piping and other mechanical engineering costs for a heating network would be kept relatively low. At the same time the system would have the opportunity to achieve high operational efficiency. The council and developers investigated the feasibility of including a heat pump of around 1MW thermal capacity to meet some of the network's needs, but are unlikely to pursue this option.



1 BROCKWELL LIDO

2 HAMMERSMITH TOWN HALL



3 BUCKINGHAM PALACE

4 SOMERS TOWN HEAT NETWORK

5 ACLAND BURGHLEY SCHOOL

ACLAND BURGHLEY SCHOOL: NEXT-GENERATION HEATING FROM THE RIVER FLEET

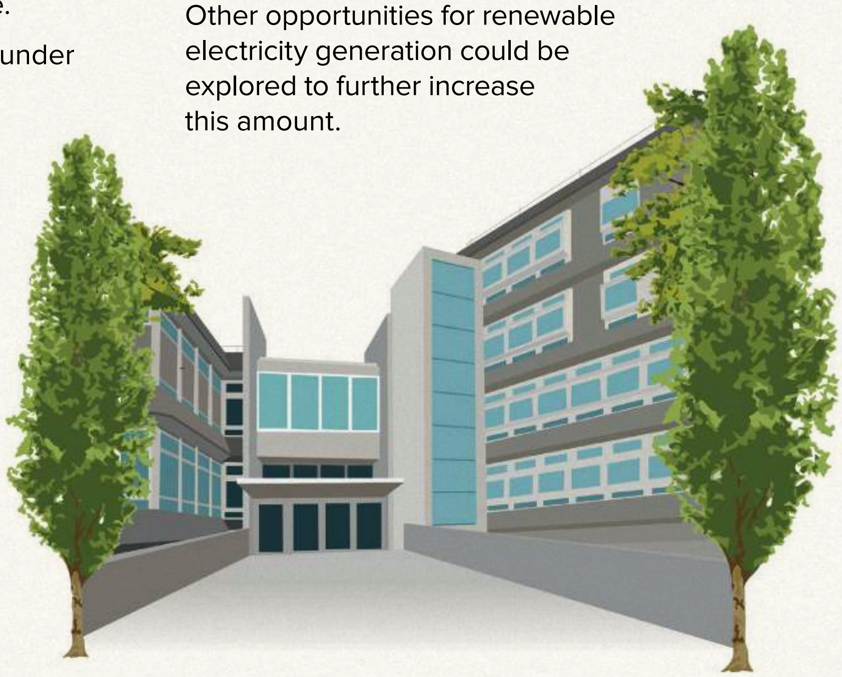
Acland Burghley School is a mixed comprehensive secondary school with around 1000 pupils aged 11 to 19, located in the Tufnell Park area. There's much to be gained from reducing energy costs while improving sustainability in schools: the Carbon Trust estimates that space heating and hot water account for 73% of a typical school's energy use and 55% of its energy costs.[15] Gas consumption data from Acland Burghley indicates that between November and March the school uses around 500 kW of heat during opening hours. The use of this fossil fuel results in around 100 tonnes of CO2 emissions each year, and an annual cost to the school running into the tens of thousands.

Like the Tyburn, the River Fleet begins its journey on the Hampstead-Highgate massif and is partly fed from the Hampstead and Highgate Ponds. A few centuries ago, the Fleet was the largest and the most important of all the (what we now call) lost rivers. It once carried boats and powered mills.[16] Covering over the river started from the 1730s and it was completely covered by the 1870s, by which time several connections to the sewer network had been made.

One of the tributary streams flows under the Overground railway line near to Acland Burghley School. This could provide a source of thermal energy for a heat pump installation that could reduce the load on the school's gas boilers during the winter months and shoulder seasons. Models produced by Thames Water predict average dry-weather flow rates of 116 litres per second, rising to a peak of 167 litres per second at certain times of the day. The amount of heat that could be extracted from the water here is several times greater than the amount that the school requires.

It is normal to need to modify and refurbish some of the heating system before a heat pump can be successfully integrated. Typically, the size of radiators in some rooms will need to be increased, larger pipework be installed and new control systems implemented to allow the heat pump to operate successfully in parallel with existing gas boilers. Having said that, the lower temperatures at which heat pump-connected systems have to run can offer benefits too. Having warm rather than hot radiators and pipework reduces the risk of accidental scalding, which is especially important in schools.

Although water source heat pumps are capable of extracting large quantities of renewable heat from underground rivers like the Fleet, they can only be considered a 100%-renewable technology if the electricity which the heat pumps use is itself delivered from renewable sources. The 48kW of solar panels installed on the roof of Acland Burghley provide an opportunity for the school to meet up to half of its heating demands with truly renewable heat. Other opportunities for renewable electricity generation could be explored to further increase this amount.



SOMERS TOWN HEAT NETWORK: A PLUG-AND-PLAY OPPORTUNITY?

Downstream of Acland Burghley School, the Fleet continues its southwards journey towards the City of London. On its way, it passes right by the western side of St Pancras station and the state-of-the-art biomedical research facility, the Francis Crick Institute. Across the road from the Crick Institute, a former ground-level car park below a mixed-use building houses the three 1.3 megawatt gas boilers that currently power the Somers Town Heat Network.

This decentralised heat network delivers heat to four nearby housing estates via highly insulated buried pipes, with heat exchangers transferring energy into the communal heating systems in each block. This replaces the old gas boilers that used to serve each building. A Combined Heat and Power (CHP) unit has been delivered to the site and is being installed in summer 2018. The CHP will generate electricity alongside an additional quantity of heat that will supply a further 184 homes, a school and a mixed-use community centre that are to be connected later in 2018. These developments will increase the load on the network above the current 6.5 million kilowatt-hours per year usage (with a corresponding increase above the current 1.5-megawatt peak heat load). The network has been designed to be compatible with different low-carbon technologies when the CHP system reaches the end of its life, or should Camden council decide to switch to a renewable energy source.

Although the Somers Town network delivers carbon savings relative to the systems it replaced, it is powered by natural gas – a stop-gap energy source which councils should be working towards phasing out as renewable energy options become more viable. The renewable heat resource represented by the buried River Fleet is around 500 kilowatts in the vicinity of the energy centre, or 3 megawatts at an interceptor connection about 600 metres upstream. This resource offers one way for Camden Council to reduce the fossil fuel consumption of some of its housing estates, especially given that the Somers Town Heat Network is partially ready to accept heat from a water source heat pump. In practice, the integration of a lower-temperature heat source would not quite be a case of "plug-and-play". Some of the pipework and radiator systems in individual flats might need to be upgraded, and extra insulation installed to improve buildings' thermal efficiency. However, the forward-thinking approach that was taken to the design of the heat network's communal systems means that substantially less work – and cost – would be involved than if heat from the Fleet was to be harvested in a different context.

BROCKWELL LIDO: WARMER SWIMS THANKS TO THE EFFRA?

Brockwell Lido is a 50-metre open-air swimming pool in Brockwell Park, south London. The lido is not currently heated, and in winter the water temperature can be as low as 2 or 3°C – although that does not stop groups of hardy swimmers from using the pool year-round!

The lido is located right next to Dulwich Road in Herne Hill, under which the lost River Effra flows. The Effra, which used to be one of the largest rivers in London after the Thames, traces a route from its source in the Norwood area to its outflow at Vauxhall Bridge via Dulwich, Herne Hill and Brixton. Urban legend has it that Elizabeth I and King Cnut both once travelled up the Effra.

The Effra by Brockwell Park carries a sizeable flow – some 180 litres per second on average, rising to 250 litres per second at peak times – which represents a heat resource of around 3 megawatts. Tapping into just a tenth of this resource could allow the lido to be kept at a comfortable temperature for swimming in the cooler spring and autumn months. By extracting a bit more heat in winter, it would even be feasible to heat the lido year-round to the 25°C! This temperature is achieved by a similar-sized outdoor pool in Hackney, the London Fields Lido.

If the electricity required by a heat pump was sourced from zero-carbon generation, this enormous amount of heat could be provided without a carbon cost – a great example of how renewable energy can go beyond just replacing the use of fossil fuels.

5

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