Programme Area: Energy Storage and Distribution

Project: Heat Storage

Title: Final Report

Abstract:

In the UK overall fuel efficiency of electrical generation is limited by the centralised positioning of power stations in relatively isolated locations and the current inability to use low grade heat. Large scale geological heat storage offers the opportunity to make use of this low grade heat whilst providing some of the flexibility and ability to meet peak loads inherent in the natural gas system linked to seasonal heat demand. Currently electricity demand is relatively constant throughout the year whilst heat demand is seasonally led due to dominant space heating requirements during colder periods. Introducing a storage mechanism to seasonally store heat from power stations provides the potential to balance this seasonal mismatch whilst avoiding excessive investment in peak load plant which is only used on a few days per year.

Context:

Heat is the biggest end use of energy in the UK - most of it is used for heating homes and providing hot water. This research project examined the feasibility of capturing large quantities of waste heat from power stations and industrial processes and then storing it underground for later use in homes and offices. It investigated the cost effectiveness and practicalities of storing large quantities of heat for long periods of time to meet a significant proportion of the UK’s winter heat demand. It evaluated the practical limits for this type of storage, the technology development needs and where in the country large-scale heat storage could be most effectively exploited. International consulting engineers Buro Happold completed the research project in 2011.

ETI Executive Summary

Programme: Energy Storage and Distribution

Project Name: Heat Storage (FRP)

Deliverable: FR/Final Report

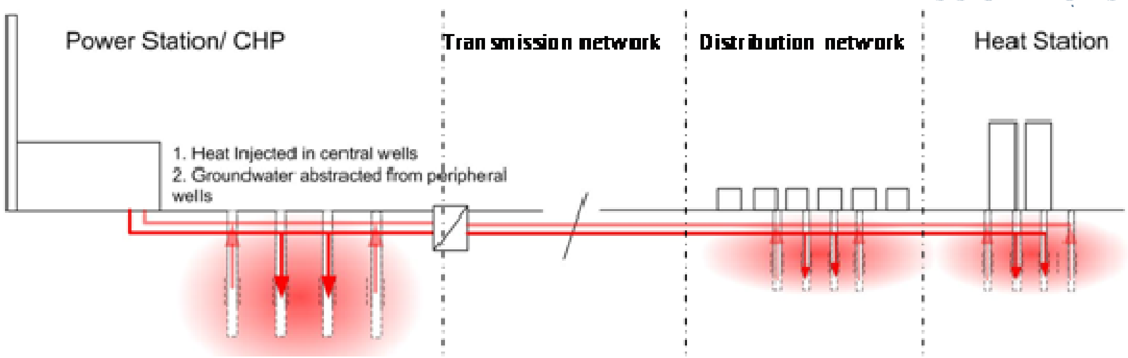
Introduction

In the UK overall fuel efficiency of electrical generation is limited by the centralised positioning of power stations in relatively isolated locations and the current inability to use low grade heat. Displacing the use of high grade fuels, particularly natural gas which is currently widely used, and in future electricity, for space heating by using the low grade heat output from power stations can significantly increase the fuel efficiency of power stations. Large scale geological heat storage offers the opportunity to make use of this low grade heat whilst providing some of the flexibility and ability to meet peak loads inherent in the natural gas system linked to seasonal heat demand.

An important aspect in the context of this study is the electrical and heat demand profiles throughout the year. Currently electricity demand is relatively constant throughout the year whilst heat demand is seasonally led due to dominant space heating requirements during colder periods. Peak space heating demand is estimated to be at least 120,000MW with a seasonal variation of a factor of greater than 5. Introducing a storage mechanism to seasonally store heat from power stations provides the potential to balance this seasonal mismatch whilst avoiding excessive investment in peak load plant which is only used on a few days per year.

The possibility of using heat from power stations has been considered previously but this report develops a more detailed assessment of the technical and economic feasibility. This report differentiates from previous waste power station heat projects due to its consideration of:

1. The utilisation of large scale geological heat storage to address seasonal imbalances in supply and demand for heat
2. The "quality" of heat - its temperature and the marginal reduction in the electrical efficiency of power stations in order to generate useful heat output
3. The heat network design from power stations to local distribution (see diagram below)



Schematic of Heat Network System

4. The density of heat demand required to make heat networks economically viable.

Results summary

This feasibility study assesses the potential for large scale geological heat storage (sometimes termed heat capture and storage) in the UK and has been commissioned by the Energy Technologies Institute (ETI). The results of the study suggest that large scale geological heat storage is technically feasible, and depending on future energy prices can be economically viable. The main benefits of such storage lie in the potential to help improve thermal efficiency of existing and future power stations (currently around 35-55%) by enabling the practical and viable use of their waste heat output. This could increase the overall system efficiency to approximately 80%. By decoupling electricity and heat generation it can provide flexibility to deal with variations in supply and seasonal demand. In the longer term it can provide low or zero carbon heat when climate change targets mean using natural gas is not longer acceptable. Additional benefits include reducing demand on the electricity system by reducing the amount of heat demand switched from natural gas to electrically driven heat pumps.

Under ideal conditions the unit cost of heat delivered in bulk to a city centre has been shown to be less than £100/MWh, and in some cases as low as £20/MWh where the transmission pipe work to high demand areas is relatively short. Without storage the equivalent direct heat unit cost range is only reduced by 2-12% as the dominating cost is the district heating transmission pipework and peripheral plant. The indicative capital cost (including the heat storage system, primary district heating pipework, backup heating plant, pumps etc.) is between £0.99million/MW for a 10km district heating main, and £2.25million/MW for 100km. This is based on a nominal average daily peak load of 250MW and extracting heat from a power station at 120℃. It does not include the heat take off plant at the power station, district heating distribution and building connections within the respective town or city. Ideal conditions are where:

1. The available annual heat off-take from the power station and the heat demand are balanced on an annual basis (i.e. the available heat supply does not outstrip the demand

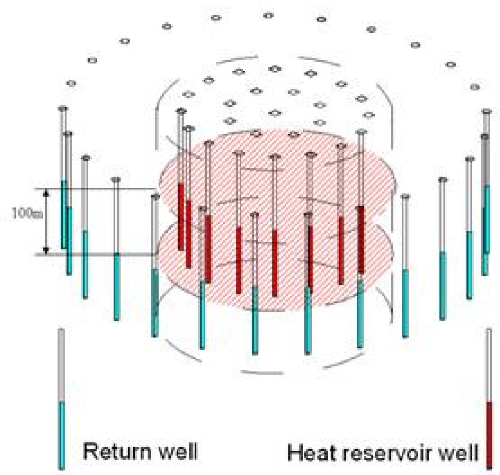
at all points in time, in which case direct heat provision without storage would be economically and practically preferable and vice versa).

2. The power station from which the heat energy is taken off is not far from the demand centres (<25km). Beyond this distance the capital cost of the heat network represents more than 50% of the total capital cost. Extensive existing heat networks must be present in order to make use of the large quantities of heat available and to provide an acceptable unit cost of heat. Where heat networks are not present a policy framework is required to drive the further development and take up of district heating in suitably high density areas.
3. The area is underlain by conditions suitable for geological storage, namely rapidly water/heat transmitting aquifers located >200-300m below ground level (bgl). Aquifers at this depth allow higher storage temperatures (1208C) due to their separation from potable water aquifers and ability to contain relatively high pressures.

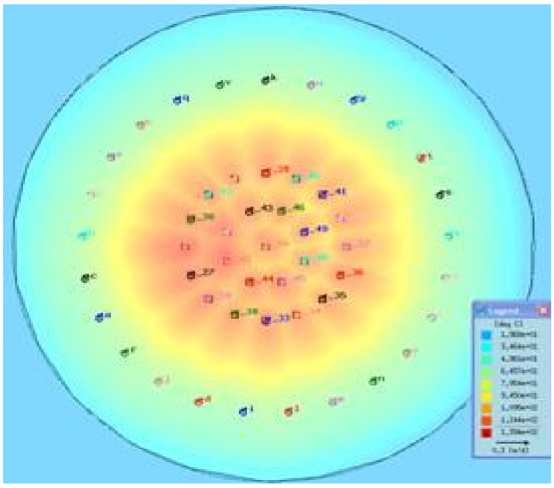
Key findings

- There are numerous examples of heat storage in Europe and Northern America although these systems are generally at a relatively low temperature and at a smaller building or community scale. Examples of storage systems operating at temperatures >50□C are limited.
- The preferred storage media are deep (200m-300m bgl) aquifers. The is because these deep aquifers are mostly brackish in nature and not as sensitive or regulated as shallow freshwater aquifers utilised for potable water supply.
- Ground stores are likely to operate with a heat storage efficiency of 60-85%, depending on the storage temperature and hydrogeological conditions. A period of 4-6 years is required to reach steady state conditions in the large aquifer stores which were modelled. During these initial years losses can be higher.
- The main considerations for designing ground stores include: accurate injection/abstraction profiling, geological and hydrogeological analysis, determining suitable water treatment, assessing efficiency and groundwater flow, and determining a regulatory regime.
- The most important operational aspects are: water treatment, monitoring, heat injection, consumer heat use (which must match design assumptions), maximising efficiency and ensuring ongoing regulatory compliance.
- Analytical and numerical modelling techniques to support the design and operation of below ground storage systems are well developed. Based on the modelling completed a heat storage design should be based on the optimum combination of a number of key parameters, including: the aquifer thickness, aquifer permeability and temperature differentials.

- Closed loop borehole thermal energy stores (BTES) systems can be deployed in all regions of the UK. Open loop aquifer thermal energy stores(ATES) is limited to areas with suitable hydrogeological conditions, but data on deeper strata most suitable for these systems is limited. ATES systems are estimated to be feasible in 20-40% of the UK, but further ground investigation data is required to determine this more accurately.

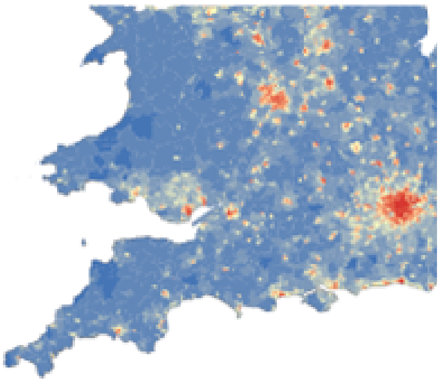


Baseline Aquifer Thermal Energy Storage (ATES) System

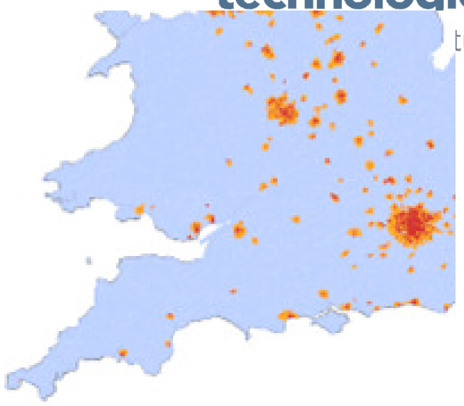


Plan View Thermal Modelling

- The economic viability of district heating is a limiting factor to the applicability of large scale heat storage. Only a certain proportion of the UK has a sufficiently dense demand for heat to make heat networks viable. Spatial gas use data from DECC was used to formulate heat density maps for Great Britain with further supporting information for Northern Ireland. Using typical economic thresholds for district heating around 10% of the current UK gas fired heat demand is deemed economically viable, consistent with previous studies commissioned by DECC. A further 44% deemed potentially viable in the future should energy prices increase, but this would require the extension of heat networks to low density suburban areas where other technologies may provide lower cost heat.



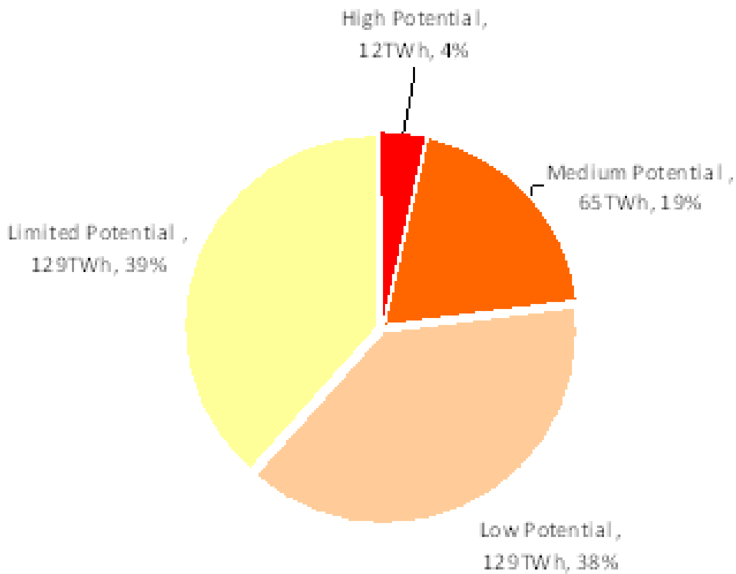
Heat Density Map for the UK



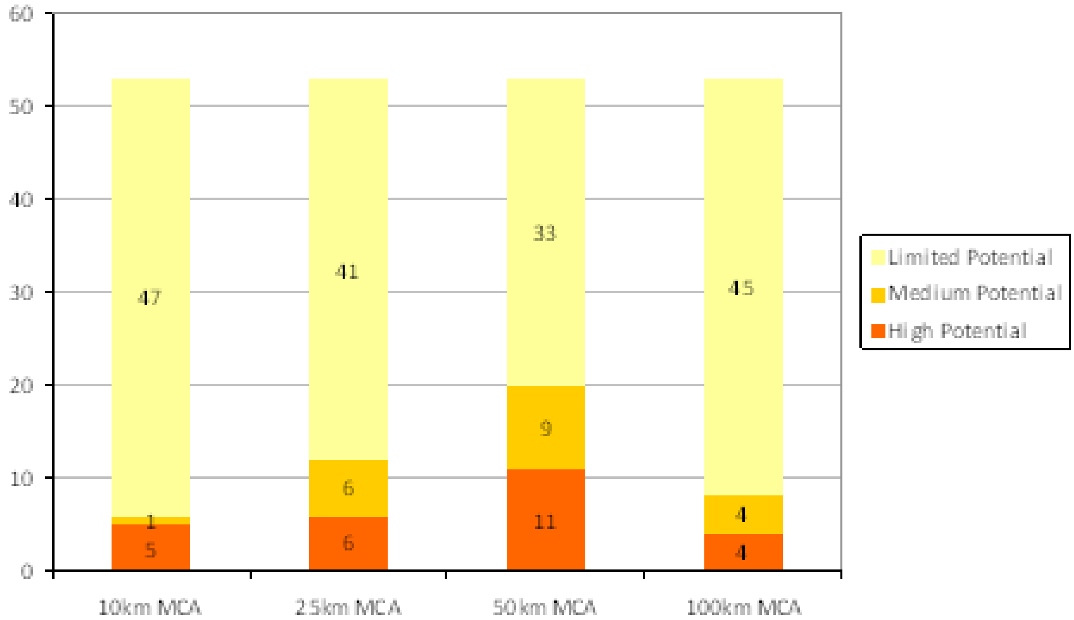
Agglomerated Heat Density using current and future economically viable thresholds

- At present the regulating authorities in the UK are likely to object to the storage of higher temperature heat in near surface aquifers that are currently used for drinking water, or other uses where there are existing licence holders. There is no clear benefit from using high temperature heat (200oC) outputs from power stations for a district heating network. Medium temperature heat (120oC) is sufficient for the required flow temperatures (80 – 85oC) after losses from the heat store and heat network. Furthermore, cost, technical problems and high electrical power production losses are associated with high temperature systems. There are significant costs associated with low temperature (35oC) systems (i.e. requirements for larger diameter pipework and heat pumps) which do not apply to medium heat systems. Medium temperature systems are recommended due to their lower costs, the existence of well proven heat network systems and the technical feasibility of storing heat below ground at this temperature. However, it should be noted that the geo-chemistry associated with this option is extremely location specific and must be well understood to avoid potential problems from precipitation of minerals.
- Direct heat provision without ground storage is around 10-50% cheaper in capital cost terms than a ground storage system, depending on distance to the heat load. Systems without storage are therefore preferred to storing heat in the ground prior to delivery, due to reduced efficiency, and higher capital and operational costs of the latter. For this reason some locations have no justification for storage although the geological or hydrogeological storage potential is high. In these locations, potential heat supply is much higher than local demand throughout the year so there is no benefit from seasonal storage. Similarly where heat supply is much lower than demand throughout the year some additional form of heat provision is needed either through conventional means (e.g. boilers or heat pumps) or through the strategic development of additional power stations in the area. This dynamic between local heat supply and demand will be a leading factor in decision making for the siting of new heat and power generation.

- A pilot study is required to fully assess the design and operational characteristics for this scale and use of system. Each installation will require an extensive site investigation to develop and prove the potential at each location.
- The multi-criteria analysis (MCA) methodology adopted for the analysis considered the geological potential, nearby heat demand and proximity to a power station. The number of areas in the UK showing either high or medium potential equated to 10% of the UK total heat demand.
- A further MCA was undertaken to assess the availability of preferred geological storage and proximity to power stations located close to areas of high heat demand. At a distance of 25km 12 of the UK's 52 large power stations (>500MW) show high or medium potential for geological heat storage. Increasing the primary heat network length to 50km increases this to 20 large power stations.



Multi-Criteria analysis for MSOAs



Power Station MCA Results

Further work

A pilot study should be undertaken following the selection of a suitable site chosen on the basis of criteria outlined in this report. The ultimate selection of a suitable pilot study, for a suggested 25MW aquifer thermal energy storage (ATES) system should go hand in hand with consideration of the following:

1. Stakeholder consultation with ETI members, power companies, local authorities and government departments (DECC and DEFRA)
2. The practicability and detailed analysis of heat quantities that can be taken off in association with power station operators.
3. An environmental impact assessment (EIA) and risk assessment in consultation with the Environment Agency and the respective local authority as a test case and on the basis and for an actual site.
4. Treatment and mitigation options, post site specific water chemistry and geotechnical testing.
5. “Industrial Capacity” testing by means of main contractor (equipment manufacturer) consultation.
6. Selected sites should be as close as possible to an existing district heating system in the UK, possibilities include:
    - Borehole Storage: Southampton, Sheffield, Nottingham, Leicester
    - Aquifer Storage: Birmingham, Southampton, Manchester,

A phased pilot scheme is suggested with the following indicative costs:

Borehole Pilot Study (not including 1-6 above)

- Phase 1 and 2 (Single borehole development) - £100-150k depending on geological conditions and depth
- Phase 3 (Borehole Array Development) - £400-600k depending on above and array size

Aquifer Pilot Study

- Phase 1 and 2 (Single well development) - £1.5-2m depending on hydrogeological conditions and depth
- Phase 3 (Wellfield Array Development) - £5-7.5m depending on the above and array size