Ex-situ Thermally Enhanced Coal Tar Recovery – A Low Carbon Option

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Abstract
National Grid is one of the world's largest utility providers and operates extensively across the UK and north-eastern US. The company manages its portfolio of occupied and surplus properties ensuring effective management of the various property issues encountered on such sites. In particular National Grid's goal is to tackle this industrial legacy, reclaim the land and return it to beneficial use, adding value, minimising risk and contributing to brownfield regeneration.

The National Grid property portfolio includes 1430 properties and land holdings on 680 sites throughout the UK. The property consists of offices, depots, houses and land which are used for National Grid's business operations, property let to third parties, or that which is surplus to requirements. The study site detailed in this paper is a former gas manufacturing facility requiring remediation resulting from identified risks to surface waters. The Site is located in South London and currently comprises a vacant parcel of land (the area requiring remediation) adjacent to an active gas holder station, now owned and operated by a third party.

National Grid employs material 're-use' targets to improve and maintain sustainability goals on their remediation and earthworks projects. However, after two decades of undertaking remediation, the characteristics of their remaining sites in addition to various changes in approach (both legislative and procedural) with regards to sustainability mean that 're-use' targets are becoming less relevant and alternative management processes are being developed to encourage sustainable process-based techniques.

Following the identification of unacceptable risks to surface waters from coal tars originating from a historic below ground tar and liquor tank at the site, Atkins Limited (Atkins) and Bilfinger Berger Environment (BBE) were commissioned to develop a remediation solution for National Grid. The remediation design was to be cognisant of the need to provide a robust, cost effective and sustainable solution. The final remediation design was recovery of coal tar using an innovative and efficient thermally enhanced total fluids pumping system. The system used a 'Micro Combined Heat and Power' (CHP) system both as a power source for a total fluids pumping system and a heat source to increase the mobility of the tar.

The process used locally refined biodiesel (recycled cooking oils) as a fuel source, and all recovered tars were recycled. The results of the project have demonstrated that a novel application of heat injection using flow path management powered with a CHP unit can provide a successful, cost effective and potentially carbon positive (approximately 9 tonnes) remediation solution. The combination of a CHP unit powered with recycled cooking oils is an approach that is considered to be potentially applicable to a wide range of remediation projects and other sectors such as construction.

Whilst effective as a measure of energy input, using CO_2 emissions as an indicator may not be the sole measure of remediation sustainability. It nonetheless challenges the notion that there are few

opportunities for carbon-critical thinking on projects for which success is measured by non-negotiable results, in this case the removal of ground contamination to the requisite level.

BACKGROUND

The study site is owned by National Grid and is located in South London (the Site) and forms part of a larger former gasworks site which was operational until the late 1950's. At present the Site is a vacant and secure parcel of land. Much of the wider site has subsequently been developed into high density residential housing. Immediately adjacent to the Site are two active gas holders and associated plant operated by a third party gas company.

The treatment area within the study site is a buried tar tank, a legacy of former operations, which is brick lined and about 20 m in diameter, and 4.5 m deep. It is infilled with demolition debris, soil and silt and is covered with tarmac. Coal tar is present in the tank, originally at depths averaging 3.4 m below ground level (mbgl), but in some parts as shallow as 1.5 mbgl. 'Perched water' within the tank is at around 0.5 m bgl, and outside the tank at between 0.5 to 2.5 m bgl. The ground formation is mostly fill overlying London Clay at between 2 and 5 m bgl.

The tar tank has been breached on one side by the historic construction of a 24inch (60 cm) diameter cast iron gas main. The conceptual site model shows that the breach has potential to allow slow migration of tar along the path of the gas main.

Contaminant

Coal tar is a viscous (typical 50 to 100's Centistokes (Cs)) by-product of historic coal gas manufacture, often formed by a cocktail of aliphatic and aromatic hydrocarbons. In the ground the tar behaves as a dense non-aqueous phase fluid (DNAPL), finding the lowest parts of permeable formations. A particular feature of coal tars is that their ability to adhere to soil particles is quite high. Factors such as wetting angles at the tar-solid interface and the formation of membrane like 'skins' at tar-water interfaces contribute to this as well as the relatively high viscosity.

Because of this, *in-situ* schemes typically will only remove a moderate proportion of the total mass of DNAPL. For this project, enhancements were proposed to increase the recovery by reducing the viscosity of the tar (e.g. by heating) to temporarily increase the mobile fraction. This would reduce the remedial programme and give greater certainty that mobilisation into the adjacent pathway would be reduced following project closure.

SCOPE OF WORKS

The scope of works for the project was to reduce the identified risks to surface waters as far as reasonably practicable. This was to be achieved by the utilisation of a robust yet innovative technique considering sustainable approaches (in line with Atkins Carbon Critical Design (CCD) philosophy and National Grid re-use criteria and wider sustainability policies) and cost effectiveness.

The treatment areas were to be focused on the tar tank and where possible in areas proximal to the tank (where tars are understood to have escaped from the tank via a wall breach).

Consultations with the Environmental Agency and Local Authority Contaminated Land Officer were undertaken with the Remediation Objective agreed for the project. The remediation works undertaken at the site were not measurable against risk-based criteria due to the nature of the impacts (gross contamination of free phase coal tars). Instead remediation was to be undertaken considering environmental betterment with objectives measured against lines of evidence (as agreed with the regulators).

REMEDIAL TECHNIQUE SELECTION

A detailed remediation performance specification was drafted by Atkins**,** in line with National Grid's remediation guidance, prior to tendering. This outlined the various requirements for the project to prospective Contractors. The project team decided that the performance specification should not be prescriptive, to allow prospective Contractors room to be innovative.

A number of limitations exist at the site which limited the potential options available for treatment of coal tar contamination:

- the presence of live gas mains immediately adjacent to the treatment area meant that completely dewatering or excavating the tank were not practical options as ground heave and/or settlement would present unacceptable risks to the owner of the gas mains (movement thresholds for the main were specified as zero);
- the gas main is of cast iron construction so the use of chemical or oxidation methods to enhance a total fluids pumping process were also ruled out at the design stage as these may risk corrosion or generation of potentially explosive ground gases; and
- the use of high temperature heat to decompose or modify the tar was also considered an unacceptable risk to the gas main. It also provided concerns regarding its affect on the tars (bench scale tests indicated that the tars on the site would fractionate and form LNAPLs at higher temperatures potentially creating new and more complex contaminant migration issues).

The site is also in close proximity to a high street, adjacent to a main road, public footpath and important buried utilities and close to a number of residential properties. The remedial options appraisal considered the site setting, its constraints, the impact of managing tar disposal to landfill and the NGPLs goal to promote safe operations and economic and sustainable alternatives to landfill. Offsite disposal to landfill was rejected on a number of grounds; unsustainable technique, tar contaminated material would have required considerable pre-treatment due to waste acceptance criteria (WAC) constraints, and excavation was considered to involve an unacceptable risk to the adjacent gas mains.

Based on the limitations on site and Atkins' performance specification Bilfinger Berger Environmental (BBE's) tender proposed the use of total fluids pumping with flow path management enhanced with *ex-situ* thermal heating (heating of waters above ground prior to

recirculation via flow paths within the treatment area). BBE's tender was both in line with the key elements of the specification and offered notable innovation, specifically relating to sustainability principles at the core of Atkins Carbon Critical Design (CCD) philosophy and National Grid's re-use goals and wider environmental position.

GUIDING SUSTAINABILITY PRINCIPLES

CCD is Atkins' philosophy of challenging designers, not just of infrastructure and buildings but of all of our services, to deliver projects for which GHG emissions are as fundamental a consideration as cost, quality and timescale.

National Grid encourages technical innovation and waste reduction across its portfolio of operations. One of the most important mechanisms to achieve this was the use of internal 're-use' targets. These were, and still are, a key performance indicator, and by default have led to a substantial reduction of material disposed to landfill.

However, much of National Grid's work is moving to smaller more technology-led projects due to the nature of the remaining sites requiring remediation which make bulk volume 're-use' of materials on site less applicable. Implementation of the European Landfill Directive has also made excavation and disposal more expensive, and less practical, for wastes exceeding WAC thresholds. This change in legislation encourages *in-situ* remediation over excavation and disposal.

PROJECT DESIGN

The selection of the remedial technique (total fluids pumping with flow path management and *ex-situ* heat enhancements), as discussed above, was driven to a large extent by the physical limitations presented by the site's layout, size, location and former use. However, the detailed design of the system and the manner in which the system would be powered (considered to represent the majority of the GHG emissions from the project) were cognisant of the guiding sustainability principles held by both Atkins and National Grid.

Based on these principles a less formal 'sustainability' target approach was adopted i.e. "reduce GHG emissions and disposal of wastes off site as far as reasonably practicable". The key goals for the project were therefore to:

- deliver the remediation to a successful endpoint with agreement from key stakeholders (Environment Agency and Local Authority) using a robust remedial design;
- deliver the remediation in a cost effective manner;
- deliver the remediation in a way as to minimise emissions of GHGs and reduce the volume of waste disposed off site as far as reasonably practicable; and
- deliver the remediation in a way as to minimise impact to the local community and environment (e.g. noise, dust, odours).
- An overarching corporate goal set by National Grid to which these project goals aspire, is to provide world class solutions representative of best practice, innovation and sustainability.

REMEDIATION METHODOLOGY

Based on the various limitations and design requirements, the selected method of remediation was developed and implemented. The total fluids pumping with flow path management required a high density of wells across the treatment area to facilitate successful development of flow paths within the ground. A total of 43 wells were installed across the tar tank based on a 3 m spacing. Wells were designed to act as both water injection and abstraction wells.

Well point abstraction of tar and tank water would then be undertaken using peristaltic pumps (11 in total) with the tar and water being separated and the water treated in an above ground treatment plant. Abstracted water (post granular activated carbon (GAC) treatment) would then be heated to a moderate temperature of 50-60˚C and re-infiltrated so that a mean temperature of 30˚C was achieved inside the tar tank. The tar would be collected for transport off site to be blended into recycled fuel oil (RFO).

The purpose of the heating was to reduce viscosity and increase mobility of the tar *in-situ*. BBE obtained data from the literature, other suppliers and on-site field tests that the viscosity of coal tar shows a significant decrease over a temperature increase from an ambient 12-15˚C to a moderate 30˚C. This change is typically from 100's Cs to 10's Cs.

In practical terms, the viscosity was reduced from that resembling an olive oil-like fluid, to that of a water-like fluid. This was designed to increase mobility and recoverability.

The key advantage of this process of 'ex-situ water heating' compared to other 'in-ground' heating methods is that the heat is delivered directly into the flow path of the infiltrated water and through to the abstraction well. This enabled good heat delivery into the areas where tar mobilisation is occurring, as well as transfer by conduction and convection into peripheral zones. The effectiveness of this delivery can be judged by the effectiveness of the tar recovery itself.

Heat enhanced remedial schemes typically have a high energy burden. In the design process BBE sought to reduce this burden as far as possible. Selection of the heating method was the most important part of this and BBE chose to use an off the shelf 'Micro Combined Heat and Power System' (CHP) to provide the heating.

Micro CHP is an established technology across Europe to provide heating for medium sized commercial and public buildings. In this case, the CHP itself consisted of:

- an internal combustion engine providing 17 kW of electrical power via a generator (giving a load for the engine to work against), and 26 kW of heat via the engine coolant water;
- a primary heat exchanger which transferred 97% of the coolant heat at 70˚C into a secondary heating circuit to provide hot water to the process at around 65˚C;
- a microprocessor control system; and
- an automatic by-pass radiator so that excess coolant heat can be lost to atmosphere in the event that heat cannot be delivered to the process water.

The heat from the secondary heating circuit was past through a ‘tube in tube’ heat exchanger through which the treated site process water flows immediately prior to re-injection.

The generated electricity was sufficient to power all the systems on the plant and abstraction. There was also additional capacity to power three 3 kW immersion heating elements which also added heat to the site process water once it has passed through the processes heat exchanger.

The CHP itself delivered 27 kW of heat energy into the primary heat exchanger, though this is probably reduced to about 25 kW in the process heat exchanger. Therefore a total of 34 kW (including 9kW of electrical heating element) of primary heat energy was available to heat the process water. Any surplus electrical energy remaining was exported to the National Electricity Grid via an import-export meter on a 60 amp three phase connection.

Internal combustion engines are typically 30-40% efficient in terms of mechanical power delivered. The use of the engine coolant ‘waste’ heat in the CHP to provide heating energy captures almost all of the balance of energy from the engine. The manufactures literature claims that 97% of all energy is captured. Compared to a system powered by a standard site generator, the entire heating ‘enhancement’ was available effectively at no extra operational cost.

To further drive down GHG emissions, the system was designed to use B100 grade biodiesel as the fuel for the CHP instead of diesel. The biodiesel was sourced from UK supplied recycled and primary vegetable oils (rather than more controversial imported sources) and was 100% vegetable oil with no fossil fuel blended into it. Biodiesel use reduces the requirement for fossil fuel, which the design team viewed of key benefit to a sustainable scheme. The use of recycled vegetable oils effectively obviated the requirement for this material to be disposed of as waste.

Tar and tank water was abstracted using surface mounted peristaltic pumps with a combined abstraction capability of 20 m^3/day and from 10 of the 43 wells at any one time.

Treated and heated water was returned by gravity infiltration into four wells. The location of the abstraction and infiltration wells was selected and changed on an ongoing basis providing good flow path management and delivery of heat based on observed site data.

The above ground treatment plant consisted of a bespoke tar collection hopper, from which tar was drained into industrial bulk containers (IBC) for storage and transport. Process water was then gravity fed through a secondary tar collection tank, an LNAPL separator, then into a transfer tank. GAC completed the process, with treated water then either re-routed into the process or directed to foul sewer under a discharge licence.

Operation was by two staff visiting on a twice weekly basis. A relatively sophisticated telemetry and control system allowed remote viewing and a high level of automated control. This helped to diagnose faults and optimise the system by giving real-time information on flow rates, temperatures and pressures.

RESULTS

The results of the project have been broken down into three sections to allow for a clear appraisal of the various outputs considered important in assessing the success of a sustainable solution. The sections are as follows:

- physical results (did the remediation meet the objectives?);
- carbon quantification results (did the remediation technique provide a sustainable solution?); and
- cost effectiveness (did the remediation provide a commercially competitive solution?).

PHYSICAL RESULTS

The physical results relate to the performance of the remediation system over the duration of the project in terms of achieving the remediation objectives. A key aspect of the results was whether the novel approach of heating extracted (and treated) water *ex-situ* and re-injecting it via flow paths was successful in reducing the tar viscosity across the treatment area and therefore successful in increasing recovery rates and cumulative yields.

Table 1 below details the temperature results obtained during the project.

Table 1 - Temperature Results for the Project

Item	Result
Injection temperature achieved	55˚C (once stabilised)
Ambient shallow perched groundwater temperature	12˚C (starting in winter) 17˚C (mid summer)
Measured tar tank in-situ temperature during remediation	30˚C (once stabilised) (measured at a fixed point at 2 m depth)

Table 2 below presents the relationship of tar viscosity with temperature during the project. It is clear that tar viscosities obtained from the tank have reduced by a factor of approximately 10. At the viscosities recorded (approximately 10 cS) within the tar tank at 30°C, coal tars have a consistency similar to water. As such, recovery potential was greatly increased.

Approximately 22 m^3 of coal tars were recovered from the tar tank throughout the six month operational period with recovery rates asymptotic (a key requirement of the remediation objectives) at project closure. Recovery rates ranged from approximately 400 l/day at the beginning of the project, reducing to approximately 10 l/day at project closure.

Due to the low flow recovery approach using peristaltic pumps in addition to the low viscosities achieved from ex-situ heating, tars were abstracted at rates that reduced entrained sediments and facilitated effective settling within the large tar hoppers. As a result, the quality

of tars recovered was of a sufficient standard to allow 100% of recovered tars to be recycled as RFO.

In addition to the volumes recovered, tar levels within the tar tank were also reduced by approximately 1 m. This achieved an important part of the remediation objective, as tar levels were reduced to below the preferential pathways driving the risks to surface waters (i.e. the breach in the tar tank wall).

Table 2 - Viscosity (cS) recorded during field trial

Temp	Range in Viscosity (Cs)
Ambient (approx 15°C)	85 - 120
40 ^{o}C	20 - 60
30 ^{o}C	30 - 1

CARBON QUANTIFICATION RESULTS

Carbon quantification results relating to the project are given below along with estimated result for variations of the technique (and other viable techniques) to provide a relative assessment of the carbon efficiency of the project. While the excavation and disposal option for the site was discounted at an early stage, we have included a CO_2 comparison to highlight the disparity of sustainability in more traditional techniques undertaken within the remediation industry compared to new innovative process-based techniques.

Carbon quantification can become open ended unless boundaries are clearly defined. The scope of parameters evaluated in each treatment scenario simply includes emissions from site plant (including the transportation of plant from depot to site) and of course the equivalent GHG emissions which were obviated by the export of power from the biodiesel generators to the UK electrical grid. GHG emissions from landfilling or worker transportation have been deliberately excluded to manage uncertainty. In order to provide a meaningful calculation and therefore comparison of the projects performance, the table and graph presented below have been derived based on the following:

- calculation for fuel consumption and energy requirements (for process based techniques) are based on those actually used at the site;
- the recycled cooking oils used throughout the project to power the CHP unit produces 0 kg net CO_2;
- it is assumed that 100% of the fuel is converted to CO_2 for all reviewed options;
- CO_2 footprint does not include staff visits, plant construction etc. This is assumed comparable across the different options and is therefore excluded as a constant;
- CO_2 offset by re-direction of unused electricity generated from the CHP generator (22,000 kWh) has been included in the carbon calculation. This calculation is based on the assumption that the 22,000 kWh re-routed back to the local grid (assumed to be produced using a 0 net CO_2 fuel) would be used in place of electricity supplied from UK power stations (0.54 kg CO_2eq per kWh). However, it is noted that further review and assessment is required to understand the true implications of re-routed CHP electricity,

- CO_2 offset by recycling recovered coal tars as RFO fuels has not been included;
- assumes costs for biodiesel and red diesel is comparable at 50p/litre;
- mains electricity supply is estimated at approximately 10p/kWh; and
- the excavation and disposal option accounts for emissions related to plant on site, delivery of plant to and from site and haulage of waste and backfill (assuming waste facilities within 50 miles of the site) for the volume of soils requiring treatment had excavation and disposal been a viable option. Does not include life cycle of the carbon associated with landfilling. Calculations of the carbon footprint for this option were undertaken using Atkins Remediation Options Carbon Calculator (ROCC) www.atkinsrocc.com).

The carbon factors used in quantifying the footprint for the project (except the excavation and disposal option which used ROCC) are based on the Department for Environment, Food and Rural Affairs (Defra) GHG conversion factors published in June 2009 and the suppliers of the biodiesel (GreenerDiesel) and are detailed is Table 3 below.

Table 3 – Carbon Factors

Fuel type	Carbon Factor	Source	Rationale for use
Biodiesel – Locally derived 100% recycled cooking oils	*0.21 kg CO_2 eq / litre*(92% carbon reduction relative to diesel (assuming the Defra carbon factor of 2.66 kg CO_2 eq))	GreenerDiesel – Fuel supplier for the project	Used on site throughout the project
Diesel – Red diesel –	*2.66 kg CO_2 eq / litre*	2009 Guidelines to Defra / DECC's GHG Conversion Factors for Company Reporting	To provide a comparison against diesel
kWh – UK grid	*0.54 kg CO_2 eq / kWh*		To account for the electricity re-routed to the national grid and to provide a comparison using mains electricity

It should be noted that the carbon factors used in this assessment are not directly comparable as only the biofuel carbon factor is considerate of its lifecycle GHG impact. Diesel fuels and other CO_2 eq values (such as kWh) are only considerate of their carbon emissions and do not account for the embodied carbon associated with the products creation.

On this basis, the relative carbon comparison is actually reasonably conservative (favoured against the CHP) as the carbon factors for diesels and mains supply (kWh) would be expected to be greatly increased. Additionally, our calculations do not account for the carbon offsets from having all recovered coal tars recycled as RFO fuels. This is likely to have a considerable positive effect in terms of offsetting carbon generated across other parts of the project not included within this quantification.

Table 4 below summarises the results of the carbon quantification with the results also presented as a histogram (Figure 1) for ease of reference:

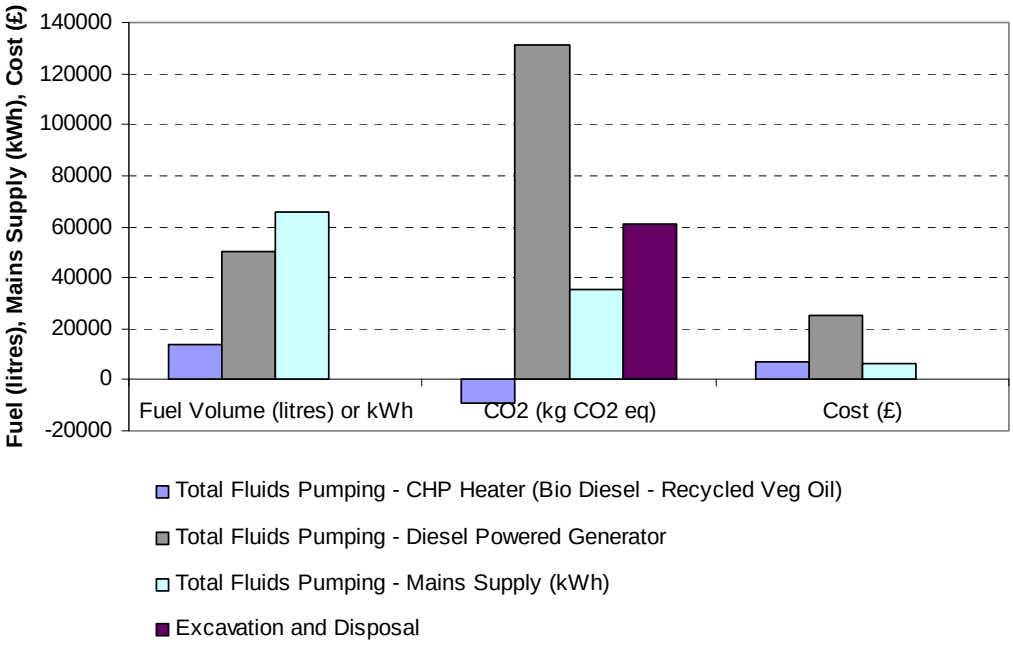
Table 4 - Comparison of Energy Requirements for the Study Sites System against Viable Alternatives.

Method	Power source	Fuel required for Project	Operational CO_2 (tonnes)	Estimated power cost
Total fluids pumping with ex-situ water heating by biodiesel CHP (recycled cooking oil)	17kW generator on 95% load	13,500 litres (6 month programme)	-9.0[1]	£6,750
Total fluids pumping with ex-situ water heating by standard diesel generator, or in-ground electrodes	50kw generator on 95% load	50,000 litres (6 month programme)	131[2]	£25,000
Pump and treat with ex-situ water heating	Mains (3 phase supply)	65,000 kWh (6 month programme)	35[3]	£6,500
Excavate and Dispose	(fuel for plant and machinery)	(N/C) CO_2 generated has been estimated using Atkins ROCC	61[4]	-

1. Calculated using the GreenerDiesel (biodiesel supplier) carbon factor of 0.21 kg CO_2 eg / litre and accounts for the energy re-routed to the grid (22,000 kWh) using the conversion factor for mains electricity (0.54 kg CO_2 eq / kWh) in Annex 3 of the guidance. The 0.21 carbon factor is considered to be inclusive of the embodied and emission GHGs.
2. Calculated using the Defra GHG conversion factor for diesel of 2.66 kg CO_2 / litre. The carbon factor of 2.66 is not inclusive of the embodied carbon and only represents emissions of GHGs.
3. Calculated based on energy consumption of system at the end of the treatment phase using the Defra GHG conversion factor of 0.54 kg CO2 eq per kWh
4. Estimated using Atkins' Remediation Options Carbon Calculator (Atkins ROCC). Accounts for emissions related to plant on site, delivery of plant to and from site and haulage of waste and backfill (assuming waste facilities within 50 miles of the site). Does not include life cycle of the carbon associated with landfilling.

For total fluid pumping technologies, CO_2 footprint does not include staff visits, plant construction etc or carbon offset by recycling recovered coal tars as RFO fuels.

Figure 1 –Comparison of Fuel Volume, Carbon Dioxide and Cost for Total Fluids Pumping with Enhancements and Excavation and Disposal



In addition to the carbon quantification detailed above, the following lists various other considerations for environmental aspects associated with the project:

- all non-hazardous soil arisings (drilling, trench work etc) were re-used on site;
- general refuse was segregated and paper/cardboard etc recycled;
- all abstracted water from tar tank returned to ground following treatment, so no disposal to foul sewer; and
- process plant incorporated headspace extraction to control odours – no public complaints.

COST EFFECTIVENESS

Commercially the project was an economically competitive, although not necessarily the lowest cost, option for the client. Capital investment for the Contractor (purchase of CHP unit) was relatively high, and payback for the Contractor would be over three to four similar projects. The key cost advantage is that energy consumption for a thermally enhanced process is very low.

Table 4 and Figure 1 above illustrate that the CHP and biodiesel combination provides the most economically competitive solution reviewed. This benefit will in the longer term result in cost reductions for similar projects of around 20-30%.

Other aspects of the project that may increase the cost effectiveness that have not yet been fully quantified but do present real opportunity to off set costs include:

- reduced cost for successfully recycled tars as RFO (£300/tonne for RFO compared to £500/tonne for incineration and £700/tonne for landfilling); and
- potential payment from local energy provider for re-directed electricity not required by the CHP unit.

SUMMARY OF RESULTS

Review of the results demonstrates that the technique employed at the site has been successful in achieving the remediation objectives; this has also been completed within the agreed programme and budget. The project has also been able to deliver an economically competitive solution with real potential to reduce in total project cost by up to 30%, within three to four similar projects. The project has demonstrated that significant energy and therefore GHG reduction can be achieved on thermally enhanced remediation projects. In fact, the results indicate that a substantial positive carbon value (estimated at 9 tonnes) has been achieved during operation of the system. Such a result could be used to off set the carbon generated on other aspects of the project for which less control exists (i.e. staff transport, site set up, plant manufacture etc).

APPLICATIONS FOR INDUSTRY

The technique employed at the site has proved to be a successful, cost effective and highly energy efficient system with significant carbon reduction achieved as a result. The authors of this paper recognise that the benefits of the remediation technique used in this project are not limited to the boundaries of the project. Application of the power system (CHP and recycled cooking oils) used at this site could be utilised on a wide range of remediation projects (hydrocarbons, volatiles etc) and potentially the wider construction industry in terms of powering construction sites directly.