APPENDIX 4
CWS WASTE MANAGEMENT OPTIONS SCREENING

A4 CWS WASTE MANAGEMENT OPTIONS SCREENING

A4.1 Introduction

A preliminary screening of possible options for management of the capped waste stockpile was completed to establish a selection of options that were included in the detail management options study. The objective of the options screening was to focus the options study on those options that were most likely to meet the objectives for the management of the wastes. The objective of the CWS management is to render the Hydro site suitable for the proposed future land use whilst providing the optimum net environmental benefit, or reduced net environmental impact, in completing the management option now and in the future.

Options reviewed were identified from a range of sources including Ramboll global experience, various EPA reference documents and published literature on remediation and management methods. The options evaluation considered the waste characteristics, the location of the site, the conceptual site model now and under the proposed future land use.

Options were initially considered in terms of their ability to disrupt the source pathway receptor linkages from the wastes. Those options that either were unable to, or were considered highly unlikely to be able to achieve this were excluded. Options were also considered in terms of critical regulatory requirements and other stakeholders, such as the community. Options that were unlikely to meet regulatory requirements, and were not considered likely to meet regulatory requirements were excluded.

Remaining options were then assessed in terms of their balance between social and environmental net benefit.

The preliminary review has consolidated options in to physical, chemical and biological. It is recognised that a combination of options could be practical in achieving the objective, and this has been discussed in **Volume 2.**

The waste characterisation is described in **Volume 1, Appendix 2** and shows the waste characteristics to be varied however dominated by elevated PAHs, fluoride and asbestos. For the purpose of the management options assessment PAHs are considered to be immobilised as a consequence of the high temperature process at the smelter from which the majority of PAH impacted waste was derived. No further management of PAHs is required. The options evaluation therefore focussed on management of fluoride and asbestos, noting that most options that address fluoride would also address any other inorganic compounds, and most options that address asbestos would also address aesthetic implications of the waste.

A4.2 Physical

A4.2.1 Excavation, Sorting and Recycling

The potential for landfill mining and reclamation is increasingly being explored as resource value of landfill materials increases. There has been an increase in interest in mining across Europe and the US in particular where evidence of the possibilities for resource recovery is greatest. However, at present there are few commercial applications where landfill mining has effectively been achieved. A study completed by the Scottish Government in 2012 found fewer than 60 documented examples of landfill mining have been completed globally, many of these trial projects. The study found that whilst extraction and separation of materials is technically feasible, it is not proven in terms of large scale separation. It was envisaged that separation on a large scale would give rise to challenges associated with blockages (screening clogging, material slippage and clogging), maintenance costs and breakdown. In addition, the health and safety and environmental challenges were identified to be difficult due to the poor knowledge of buried wastes and the risk of uncovering and sorting previously unknown wastes, particularly mention is made of asbestos and the potential for asbestos fibre liberation.

The study also identified that the production of a quality material suitable for recycling was likely to be poor when compared to alterative pre-segregated wastes that could be sourced for the same recycling purpose. Materials won from sorting from heavily mixed wastes were likely to be contaminated by soils, leachate and other wastes to the extent that the value in recycling is substantially reduced. (Waste Management World 2014)

Whilst landfill mining of municipal landfills is theorised and has been trialled, the practical implementation of sorting and extracting recyclable products has inherent and unavoidable complications. Hydro has two recent experiences where excavation and segregation of wastes (one including hazardous wastes) has been attempted.

Hydro Kurri Kurri has excavated a former clay borrow pit at the site and screened concrete, refractory brick and bitumen (inert materials) that were co-placed with soil/clay for the purpose of separating and recovering inert components for reuse. A total of 75,000m^3 was excavated, trucked and screened using a mobile screening plant. The program has been partially completed with further screening postponed due to difficulties in the screening and segregation process. Difficulties arose from the clayey and moist nature of the soils causing screen clogging. In addition, the variability of materials requiring screening meant material types could not be segregated based on size, with the exception of soil. The screening difficulties resulted in program delays which lead to increased water, sediment and erosion requirements.

Norsk Hydro, at Herøya Industrial Park, Porsgrunn Norway, attempted sorting of wastes during excavation and relocation of a former mercury waste deposit. Wastes within the deposit were proposed to be sorted to inert and hazardous components and landfilled appropriately at a commercial landfill. Sorting trials were carried out however were abandoned due to: indistinguishable characteristics of the wastes; elevated and unacceptable health risks resulting from manual sorting and inspection requirements; the length of time that would be required to complete the sorting and inspections; and water management issues that could not be resolved.

The waste management options study additionally contemplated sorting by other more automated means including optical and gravimetric sorting. In both cases, wastes would be crushed. To enable crushing, wastes would require sorting to remove metals and other items unable to pass through a crusher. Wastes would then be crushed to approximately 3mm and passed through either an optical sorter or a gravity sorter resulting in two waste streams that are either light/dark, or light/heavy. These waste streams could then be recycled or treated, for example. An example of a possible sorting method is shown in

Figure **1**.

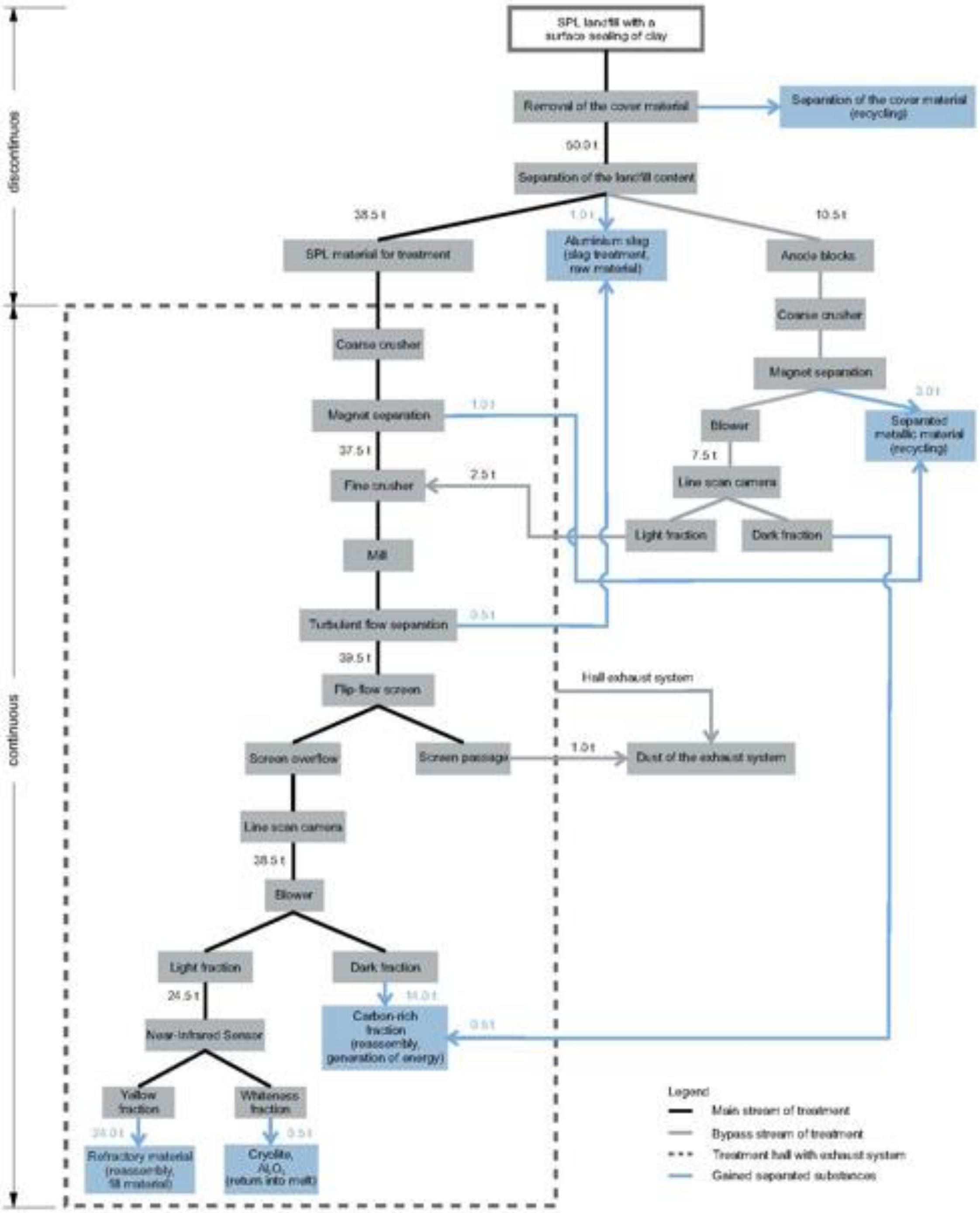

Figure 1 Theoretical Optical Sorting Process

Options for these methods of sorting considered first what could be done with the sorted fractions, assuming the inherent difficulties in sorting by these means could be overcome. The evaluation considered recycling of 'black' and 'white' components for energy, as black would comprise carbon, and white cryolite. The resultant evaluation of the market uptake of these material was determined to be low due to the presence of impurities and asbestos fibres within the samples. Based on Hydro's experience of difficulty in recycling purer forms of carbon it was considered that there is no recycler able to take waste with asbestos content in any form. The gravity separated components were also not expected to produce a recyclable derivative as the range of specific gravities within the wastes would lead to a highly mixed output.

The conclusion of the evaluation was that segregation is theoretically possible by mechanical and manual means and would incorporate high health, safety and environmental risks. However, it was considered almost certain that a recyclable end product would not be achieved. Recycling by any other more automated means to reduce the health, safety and environmental risk was also not likely to produce a product able to be recycled. However, this option, and the inherent uncertainty, has been considered further in the options analysis and involves recycling available materials and treating and disposing of non-recycling components.

A4.2.2 Stabilization/solidification

Stabilization/solidification are methods that allow the waste material to be suitable for long term disposal. Stabilization refers to the conversion of the waste material to a physically and chemically more stable form. This may include treatment processes to reduce the volatility, solubility and reactivity of the material. Solidification is a form of stabilization whereby the waste material is mixed with a solidification agent, leading to a chemical reaction and/or mechanical binding. (Manahan, 1991)

There are many methods of solidification for solidification including: sorption into a solid matrix; thermoplastics; vitrification; solidification in cement; solidification in silicates; and encapsulation (Manahan, 1991).

Sorption is generally suited to liquids, leachates, sludges, and emulsions of hazardous material, where a solid sorbent material is used to fix the hazardous constituents. Some typical examples of sorbent materials are activated carbon, fly ash, and clays. Sorption may be by mechanical, physical or chemical means. Sorbents may be used to improve a materials suitability for solidification by other means, such as with cement or silicates. (Manahan, 1991)

Thermoplastics are substances that become liquid at elevated temperatures, and can be mixed with the hazardous materials as liquids, allowing the hazardous material to be solidified in the thermoplastic material when it cools. Examples of thermoplastic materials are asphalt, polyethylene, and other organic polymers. The hydrophobic nature of organic thermoplastics can be used to reduce the leaching potential of the hazardous material mixed therein. Typical applications of solidification in thermoplastics are for immobilizing and containing heavy metal waste. Organic polymers can be used to bind solid waste material within the polymer matrix. (Manahan, 1991)

Vitrification of a waste material is a form of solidification and involves imbedding waste material within glass using thermal treatment. Glass, or the raw materials used for glass, may be heated and mixed with the waste material to produce a chemically inert vitrified material (Manahan, 1991). In some applications the thermal treatment, for example, plasma arc gasification, is a form of thermal waste destruction, and the glass serves to immobilise hazardous constituents in the waste ash. In-situ vitrification would involve downhole plasma torching of the CWS to produce an inert slag in the subsurface. Ex-situ vitrification would involve excavating the CWS and feeding the material through a vitrification plant, to produce an inert slag. The plasma arc gasification process is generally complex and costly, in part due to the high energy input required to sustain the reactions. Ex-situ, onsite vitrification has been included in the Options Study as Option 7.

Portland cement is one of the most widely used methods for solidification of hazardous waste materials. The mechanism of solidification with cement may include physical isolation within the cement matrix and/or stabilisation by chemical reaction, reducing leachability. Cement is most effective for solidification of heavy metal sludges where heavy metal ions form insoluble compounds with hydroxides and carbonates under basic conditions. Some hazardous materials may affect the curing process of cement and also lead to deterioration over time. As mentioned above, this may be avoided or mitigated by an additional sorption step for some hazardous wastes, and the sorbent and waste can in turn be solidified in cement for disposal. (Manahan, 1991)

Possible end uses for the material in solidification with Portland cement include use as a concrete fill, or use as filler in concrete panels.

Silicates, or pozzolanic substances, containing oxyanionic silicon (e.g. SiO_3^{2-}), such as fly ash, pulverised slag, calcium silicate, and clays, can be used in conjunction with a setting agent (Portland cement or gypsum, for example) for solidification. The resulting stabilised material may be granular, or form a bulk solid. Admixtures can be also used to adjust the properties of the material. Care should be taken in the selection of the silicate material as fly ashes and slags may inherently contain leachable constituents of concern. (Manahan, 1991)

Encapsulation is the process of surrounding a hazardous material in an impervious material that prevents contact between the hazardous material and the environment. Typically encapsulation utilises heated thermoplastic materials, to surround the waste, encapsulating it once cooled. (Manahan, 1991)

van Jaarsveld and van Deventer (1996) investigated the potential for geopolymeric materials ('alkali-activated alumino silicate binders') to immobilise toxic metals. It was noted that many waste materials such as contaminated soils and tailings already contain large quantities of silica and alumina which could contribute to geopolymerisation reactions. The geopolymerisation reactions require an alkali medium to dissolve some of the silica and alumina and hydrolyse surface particles, and it is the surface reactions that binds and immobilises heavy metals. It was also noted that geopolymerisation was not thought to immobilise metals solely by encapsulation, but also by adsorption of metal ions into the geopolymer structure.

For the waste materials in the CWS the presence of asbestos within any stabilised product means that there is no beneficial end product that can be reused as regulations do not permit the reuse of asbestos containing materials. Solidification for later emplacement within a containment cell was considered possible using Portland cement and was considered to be similar to chemical treatment with lime, which is discussed below and included as Option 4.

A4.2.3 In-situ retention with cut-off wall, or similar onsite containment or treatment mechanism

In-situ retention involves the isolation or containment of the waste material from mobilisation of contaminants through various mechanisms, for example through surface infiltration of rainwater transporting contaminants into groundwater (Pearlman, 1999). A cut-off wall is a subsurface barrier of impermeable material to contain a waste from the outside environment or manipulate the flow of groundwater, which may transport contaminants. Cut-off walls can be used in conjunction with impermeable surface capping and other subsurface barriers for complete retention.

In-situ retention may be employed in cases where removal of the waste presents hazards, high costs, or the technology for treatment of the waste is not currently viable (FRTR, 2007). Types of subsurface barrier technologies include (Pearlman, 1999):

- Slurry walls – an accepted form of containment for hazardous waste, which may involve the excavation of a trench that is filled with a slurry of impermeable material (including soil-bentonite, cement-bentonite, plastic concrete)
- Sheet piling – constructed by pile-driving vertical sheets of steel, precast concrete, aluminium or wood into the soil. Sheets may be joined to form a continuous wall.
- In-situ soil mixing – additives are added to soil and mixed or blended in place to ultimately form an impermeable barrier
- Composite walls – geomembrane material is used to line a trench excavated for the purpose of the installation of a slurry wall, forming a composite cut-off wall
- Grout curtains – involves the injection of grout into the subsurface in a staged fashion (usually at high pressure through boreholes), ultimately filling pore spaces in the soil or fractures in rock and constructing an impermeable barrier
- Vitrification – electrodes apply heat to the soil at temperatures capable of melting the soil constituents and form a vitrified glass material

- Permeable reactive barriers - Turner (2003) assessed the potential of calcite to remove fluoride (and cyanide) from contaminated groundwater in a permeable reactive barrier. It was found that, as well as the production of calcium fluoride in precipitate, the surface area of the calcite provided fluoride removal by sorption.

The installation of a cut-off barrier, subsurface lining, containment layer installed post landfill construction is theoretically possible however the difficulty and likelihood of failure increases when these barriers are installed post landfill creation. Methods would be required to demonstrate that any installation has met the design criteria and would likely include remote instrumentation. Visual quality assurance would not be possible, and uncertainty around geological conditions would remain.

In-situ treatment by a permeable reactive barrier nominated in Turner 2003 was identified to have high consumable and labour input and was prone to failure due to other constituents, such as salt precipitation, present within the leachate. The in-situ barrier would be required in combination with another mechanism to control leachate flow and generation, such as a barrier liner. The long term monitoring and active maintenance of the system would be required, as would extraction and replacement over time. Other options were preferred as simpler and more cost effective and therefore this option was not preferred.

Whilst in-situ retention is theoretically possible it has not been considered in the Options Study as it is not consistent with the redevelopment objectives of the site. This option was also considered to have a high risk of failure in a sensitive groundwater environment.

A4.2.4 Offsite disposal

Offsite disposal of waste is a proven and implementable technology involving the excavation and transportation of the waste material to an appropriate disposal facility. Generally pretreatment of the waste material is required in order to meet disposal requirements. (FRTR, 2007)

Considerations in the offsite disposal process include (FRTR, 2007):

- All ex-situ treatments of buried waste require excavation as the first stage of the process
- The distance to the disposal facility can present risk and increased cost of disposal and environmental and societal considerations
- There may be limited disposal options for certain hazardous wastes (including aluminum smelter wastes in Australia)
- Operation and maintenance of the offsite facility must continue indefinitely

Offsite disposal of the CWS waste would involve the emplacement of the material in a facility that allowed for the management of leachate that may be generated through a leachate collection system, as well as management of gases through a gas collection system.

Offsite disposal of the CWS waste has been included in the Options Study as Option 5, crushing and treatment with lime followed by offsite containment. The offsite containment cell would be designed with best practice engineering in an EPA approved location.

A4.2.5 Containment on site

Onsite containment, as opposed to in-situ containment or retention, involves the long term management of the waste material on site in an appropriately constructed containment facility. The waste is required to be excavated and disposed of in a specifically designed containment cell onsite, typically incorporating an impermeable lining, a leachate drainage collection and management system, a gas management system, an impermeable capping layer, all specifically designed in consideration of the contaminants of concern, the composition and volume of the waste material.

Onsite containment of the CWS waste, in an engineered containment cell has been considered in the options study as Option 2.

A4.2.6 Salt mine landfilling, similar to that used in Europe for radioactive waste disposal

Salt mine landfilling sites characteristically provide an impermeable, dry, well isolated environment for long term disposal of waste that poses a high risk of leachability. Natural boundaries and features can be augmented by man-made engineered boundaries. (Bertin Technologies, 2000).

Özarslan (2001) reviewed the underground disposal of hazardous wastes in Germany, including disposal in former rock salt mine workings. Underground disposal was identified as a possible option for wastes that cannot be treated by chemical, physical, biological, or by incineration, and which also present a high degree of leachable material and heavy metals. Germany was noted to be one of the world leaders in research and development for underground disposal of radioactive wastes. Özarslan (2001) describes the concept of 'complete enclosure' for the disposal of hazardous wastes, whereby the material is permanently isolated from groundwater and other intrusions by multiple natural and engineered barriers.

Disposal of CWS waste in an underground salt mine disposal facility has been included in the Options Study as Option 6.

A4.2.7 Deep Ocean Repository

Deep ocean repository of waste materials has been undertaken around the globe, particularly for the disposal of mine tailings. Dold (2014) carried out a review of submarine tailings disposal practices currently in use in various parts of the world. Some identified advantages for submarine disposal, which may be applicable to other hazardous waste materials of a similar nature, were as follows: deep sea conditions provide a constant reducing environment which may be beneficial for stabilizing some contaminants; the risk of failure of a landfill or waste cell on land and impacts from rainfall are eliminated; less maintenance is required in comparison with other disposal options; and less land surface area is consumed, in comparison with above ground containment or disposal. Conversely, the following were identified as disadvantages of submarine disposal: ecological effects on habitat and organisms on the sea bed; risk of contaminants being mobilised in the seawater; bioaccumulation of metals in food chains, ultimately affecting humans through the consumption of fish; the surface area for disposal on the sea bed would be much greater than that for above ground disposal; currents and upwelling in the ocean could transport fines.

The London Convention (Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter 1972) and the subsequent London Protocol (1996), which came into effect in 2006, ratified by 48 signatories, including Australia, aims to control the all sources of marine pollution. The Protocol provides a list of waste materials that may be considered for ocean dumping includes: "inert, inorganic geological material; and bulky items primarily comprising iron, steel, concrete and similarly unharmful materials for which the concern is physical impact, and limited to those circumstances where such wastes are generated at locations, such as small islands with isolated communities, having no practicable access to disposal options other than dumping" (UN IMO, 2006).

CWS waste cannot be characterised into either of the above categories and therefore it is unlikely to be an acceptable disposal option under Australia's commitments to the London Protocol. Furthermore, disposal of waste at sea is considered environmentally irresponsible and socially unacceptable, and for these reasons it has not been included as part of the Options Study.

A4.3 Chemical

A4.3.1 Chemical fixation

Chemical fixation of hazardous waste involves the conversion, by chemical processes, of hazardous constituents of the waste into less toxic or less mobile forms. As mentioned in Section A4.2.2, chemical fixation can often be concurrent with physical isolation. Common substances used in chemical fixation include inorganic silicates with calcium, to which many metals can be chemically bound. (Manahan, 1991)

Chemical fixation of fluoride in leachate using lime ($Ca(OH)_2$) is included as part of Options 3, 4 and 5 of the Options Study. In this process excess calcium lime is used to precipitate out the fluoride, as follows (Sørlie and Øye, 2010):

$$Ca(OH)_2 + 2F^- = CaF_2 + 2OH^-$$

This produces insoluble calcium fluoride (CaF_2), which precipitates out of solution. Lime solubility (in comparison with other alkali metal hydroxides) improves its availability of cationic species (Ca^{2+}) in leachate, and the resulting calcium fluoride has a solubility of 0.0016 g/100ml water (Weast, 1984). Calcium chloride was previously identified as a superior precipitating agent to lime in the formation of calcium fluoride in fluoride containing effluent, due to its very high solubility (TETRA, 2001). A laboratory study carried out on the treatability of CWS waste however, revealed that calcium chloride was ineffective at reducing the fluoride concentrations in leachate from the CWS waste (Ramboll Environ, 2017).

Chemical fixation as a form of micro-encapsulation is considered a viable option and has been considered further as Option 4 in the review.

A4.3.2 Chemical extraction

Chemical extraction may be used as a method to chemically remove a hazardous constituent of a waste material into solution. This is generally through a leaching process where heavy metal salts are extracted from the material by reacting the salt anions with H^+, provided by an acid, as shown in the following example for lead:

$$PbCO_3 + H^+ = Pb^{2+} + HCO_3^-$$

Chemical leaching with acid, as demonstrated above is often not suitable for wastes that contain cyanides or sulfides, as hydrogen cyanide or hydrogen sulfide can form.

The Alcan gypsum sheathing process for the treatment of spent pot lining uses multiple steps of separate treatments for the two contaminants of concern associated with the material: cyanide and leachable fluoride. Initially the cyanides are removed by the use of superheated steam as follows:

$$CN^- + 2H_2O = NH_3 + HCOO^-$$

With the cyanides eliminated, the fluorides are dissolved into solution using sulphuric acid, which is then in turn neutralized with lime and calcium carbonate to form insoluble CaF_2, as follows (Sørlie and Øye, 2010):

$$H_2SO_4 + 2NaF = Na_2SO_4 + 2HF$$

$$Ca(OH)_2 + 2HF = CaF_2 + 2H_2O$$

$$CaCO_3 + 2HF = CaF_2 + CO_2 + H_2O$$

Ca^+ and SO_4^- also precipitate in solution as follows, to form gypsum:

$$Ca^{2+} + SO_4^{2-} + 2H_2O = CaSO_4.2H_2O$$

The gypsum reduces the leachability of fluoride as a result of its superior solubility, and also provides Ca^+ ions that bond with fluoride to form CaF_2. (Sørlie and Øye, 2010)

Sørlie and Øye (2010) stated that in the context of weathered spent pot lining, as is the spent pot lining contained in the CWS waste, the majority of cyanides are complexed with iron which may be difficult to oxidise and leach out of the waste. Therefore cyanides would likely have to be removed by other means. Additionally, the CWS waste is not solely made up of spent pot lining, which affects the suitability of chemical extraction methods. The size and variability of the waste material adds further complexity to likely success of leaching. Resulting leaching will also require treatment at significant cost. This option is not considered appropriate for the waste material.

A4.3.3 Soil flushing or washing

Soil flushing or washing is a similar process to chemical extraction by leaching. Flushing is the process where the soil is left in-situ and water, containing additives to augment the removal of contaminants is pumped in and out of the soil. Washing is the process of removing the soil from where it is and washing it with water and additives to remove contaminants. The flushing or washing fluid consists of acids, bases, surfactants, chelating agents, or reducing agents, depending on the desired contaminant to be extracted. (Manahan, 1991).

Due to the nature of the diverse range of contaminants within the CWS waste material and hydrogeological conditions within the CWS, soil flushing has not been considered as part of the Options Study.

A4.3.4 Chemical oxidation/reduction

Chemical oxidation/reduction of contaminants is a known and widely used process. The principal of oxidation and reduction involves the transfer of electrons from one species to another and can be used to a wide range of organic and inorganic wastes. Oxidation/reduction may be used to convert a species of a contaminant to a more stable form by use of an oxidizing or reducing agent. (Manahan, 1991)

Oxidation processes can be aided or augmented by the use of UV radiation, which has been applied, and considered effective, for the destruction of cyanide complexes from weathered spent pot lining (Sørlie and Øye, 2010). The UV radiation serves to break chemical bonds and increasing the amount of oxidisable species of the contaminants (Manahan, 1991).

A4.3.5 Ion exchange

Ion exchange involves the removal of cations and anions from a solution and into a solid ion exchange resin, which can in turn be treated. The most common use of this process is in removing heavy metals from solution in wastewater, for example in the metal plating industry. Cationic exchangers are used to remove cations as in the following example for cadmium:

$$2H^{+}\{CatExchr\} + Cd^{2+} \rightarrow Cd^{2+}\{CatExchr\}_2 + 2H^{+}$$

A similar mechanism is used by anionic exchanger to remove negative ions for solution. (Manahan, 1991)

Ion exchange is suited to use for wastewater and effluent, and therefore has not been considered in the Options Study for remediation of CWS Waste.

A4.4 Thermal

A4.4.1 Thermal treatment

Thermal treatment of waste material, typically in the form of incineration, can be used to reduce the waste volume, remove volatiles, combustibles, organic material, and destroy pathogens and toxic materials. Incineration is generally carried out at temperatures greater than 900°C, with excess oxygen. The process may be self-sustained by the oxidation of carbon and hydrogen in the waste material, or using supplementary fuel as follows:

$$C_{(organic)} + O_2 \rightarrow CO_2 + heat$$

$$4H_{(organic)} + O_2 \rightarrow 2HO_2 + heat$$

These reactions provide the heat to break other bonds within the waste. If the waste does not contain sufficient calorific value a supplementary fuel such as methane may be added. Due to the associated high operating cost, use of supplementary fuel in incineration would only be employed if there is a particular constituent of the waste that requires elimination by incineration. (Manahan, 1991)

Studies undertaken on the conversion of spent pot lining waste, which forms a part of the CWS waste, to inert and non-leachable material have shown that fluidised bed combustion is the most favourable thermal treatment technology. The studies showed that 99.9% by weight of cyanides could be destroyed and fluorides could be converted to non-leachable species by fluidised bed combustion. Although announced as commercially available since the late 1980s, in 2010 no fluidised bed combustion plant was known to be in operation for the thermal treatment of spent pot lining. (Sørlie and Øye, 2010)

Specific consideration needs to be given to the composition of the flue gas that will be produced during the incineration of hazardous waste materials. The air pollution control can often be the most complex element of an incineration plant (Manahan, 1991). Furthermore, the resulting ash presents a disposal problem, where further treatment may be required. Treatment by thermal methods has been incorporated in Option 6 for the purpose of reducing water reactivity of the spent pot lining component to allow safe disposal in a subterranean cavity however thermal treatment alone will not address the asbestos content of the waste.

A4.4.2 Thermal desorption and Plasma Arc

Thermal desorption or plasma arc treatment are proven remediation technologies, developed since the 1980s, where the hazardous material is heated to temperatures in excess of 6000 °C, either directly or indirectly, in order to volatilise the contaminants within the material, thus desorbing them from the waste.

Typically thermal desorption units are of a rotary kiln type, with direct fired units being where the combustion gas or heat source is applied directly to the waste material inside the kiln. Indirect systems refer to units where the heat source is external to the kiln, used in cases where combustion is not desired. The thermal desorption process produces treated material and off gases which comprise the volatilised contaminants. The off gas is subsequently treated and released to atmosphere. (EPA VIC, 2011)

Plasma arc torches are being used to treat difficult wastes to recover metals by feeding wastes in to a sealed furnace and heating with single or multiple plasma electrodes. The process is to segregate precious metals and destroy hazardous components leaving behind an inert vitrified rock like material.

Neither thermal desorption nor plasma arc has been trialled on materials similar to the CWS and extensive pilot testing would be necessary to verify the technology.

Plasma arc torches have been trialled for *in situ* applications on municipal landfills whereby torches are inserted vertically to within the landfill. The surrounding waste is vitrified and the area 'mined' for inert materials following completion. This method was considered to be highly risk and an emerging technology and *in situ* treatment was not considered further. (Fox 2001)

Thermal desorption and plasma arc is based on the volatilisation of the contaminants and is particularly effective for the elimination of persistent organic compounds, polychlorinated biphenyls and pesticides. It is recognised that thermal desorption or plasma arc may be effective and thermal treatment by plasma arc has been incorporated as Option 7.

A4.4.3 Waste to energy

Waste-to-energy is commonly used in industrial settings where there is a large heating demand, for example, for process steam or preheating of furnaces. Power generation with waste materials is employed for municipal solid waste, hazardous waste, sludge, agricultural, and hospital wastes throughout the world, particularly in Europe (ISWA, 2012).

Sørlie and Øye (2010) reviewed the potential for the carbonaceous (first cut) spent pot lining to be used as a supplementary fuel in a coal fired power plants. It was noted that first cut SPL could be added at up to 8% by weight without any environmental effects. Another study reviewed by Sørlie and Øye (2010) however detected fluoride in flue gases, and due to this risk it was concluded that incineration of first cut SPL for power generation was not desirable.

This option has been discounted due to the nature of the constituents within the CWS waste, and the lack of a local/onsite demand for process heat.

A4.5 Other

A4.5.1 Phytoremediation

Phytoremediation is the use of plants for in-situ degradation, detoxification, removal, or containment of contaminants in soils, sludges, sediments, and water. This method is most suited where contamination is present at low concentrations in shallow soils. However containment of waste in the form of an engineered phyto-cover has proved effective in the Netherlands where peat was used on a hazardous chemical waste as a natural capping material on top of a layer of plastic to form a living peat bog. The plastic is designed to deteriorate over time, and the peat bog ultimately commences phyto-stabilization of the underlying waste. (Öztürk et al, 2015)

Phytoremediation strategies have been employed in Angul, India by the National Aluminum Company Limited for hazardous waste containing spent pot lining. The spent pot lining was placed in landfill, with the cap consisting of an engineered phyto-cover to: minimise infiltration of rainwater; isolate sensitive receptors from the waste; and insulate from temperature changes which may affect toxic or explosive gas production. (Prasad, 2011)

In-situ phytoremediation of the CWS waste, as previously stated, is not consistent with the site development objectives and would not address all contaminants present, such as asbestos.

A4.6 Conclusion

When considering the options considered to be technically feasible, they can broadly be grouped in to options that allow partial recycling; allow reuse; options that treat; and options that dispose. The short list of options includes at least one option in each category. There are permeations of each option that could occur however, a shortlist of six waste management options were identified for further analysis and comparison to a ‘Do Nothing’ option.

The Management Options identified for further analysis are as follows:

Option 2	Onsite containment in a purpose built containment cell. Allows for recycling where feasible to do so.
Option 3	Sorting of the CWS to remove blocks >500mm and steel. Segregation, crushing and washing of steel to allow for recycling of carbon and steel. Crushing remaining materials and treatment through a pug-mill. Placement in containment cell.
Option 4	As for Option 2 but allowing co-placement of lime to reduce fluoride in leachate, should leaching occur.
Option 5	Offsite containment following steel removal and crushing and treating with lime. Allows recycling of steel.
Option 6	Heat treatment to reduce water reactivity, transport and containment in salt mine in the Northern Territory or kaolin clay mine in Western Australia. The salt mine facility has been adopted for the purpose of the assessment. Allows recycling of steel.
Option 7	Onsite treatment by Plasma Arc. May allow carbon capitalisation for the plant use. Allows recycling of steel.

A4.7 References

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