THE POTENTIAL FOR ECONOMIC REPROCESSING OF MINE WASTE IN IRELAND

Prepared for: Environmental Protection Agency

SLR Consulting – February 2018

THE POTENTIAL FOR ECONOMIC REPROCESSING OF MINE WASTE IN IRELAND

A Small Scale Study under the STRIVE Programme

Prepared for: Environmental Protection Authority

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CONTENTS

DOCUMENT REFERENCES

TABLES

FIGURES

APPENDICES

1.0 Introduction

Ireland was once ranked as the biggest producer of lead and zinc in Europe, but has dropped down the rankings since the Lisheen and Galmoy mines closed within the last five years. Mine waste, in the form of tailings and spoil, is both a potentially valuable resource, as well as, in some cases, an environmental hazard, and represents an opportunity for Ireland to move its mining industry into a new phase.

The modern history of mining for base metals in Ireland stretches back to the 1960s, when the Tynagh zinc-lead-(copper) Deposit was discovered, in Co. Galway. Since then, the zinc-lead mines of Gortdrum, Silvermines, Tara, Galmoy and Lisheen were developed, leading to Ireland's ranking as Europe's leading zinc producer in the decades to 2014.

Only Tara Mines in Navan is still operational in 2018. There are advanced exploration/resource delineation projects at Pallas Green in Co. Limerick and Kilbricken in Co. Clare. There are no certainties regarding the future of either of these projects due to highly volatile international metal markets. With the decline in production, Ireland is no longer Europe's leading producer of zinc. Zinc and lead are the only major base metals produced in Ireland; all others (e.g. copper, iron/steel, nickel) have to be imported.

While Tara, Galmoy and Lisheen have all operated to the highest international environmental standards in the modern era, those standards were not in place during the lifetimes of the older mines. The technologies and regulations regarding ore processing and disposal of mine waste (tailings) have advanced significantly since the older mines were designed and operated. The use of earlier technologies means that:

- It is likely that significant quantities of metal were not extracted by older processing technologies, and could be won from tailings using modern techniques (Sustainability Pillar) and;
- The older tailings facilities do not meet modern environmental standards, and some have already had a negative effect on the local hydrological environment (Water Pillar).

Furthermore, it is believed that some legacy mine tailings may be valuable sources of commodities on the EU list of Critical Raw Materials (including Ge, In & Sb). Tailings reprocessing has become increasingly common since first used to extract gold in the 1980s. Advances in technology have been steady and the potential value of tailings as a source of raw materials (both critical and non-critical) has been recognised by the EU (e.g. ProMine http://promine.gtk.fi/).

1.1 Scope of the Small-Scale Study

Scant work has been carried out on existing tailings deposits in Ireland, beyond physical stabilisation from an environmental standpoint. This small-scale study pursued two major lines of investigation:

- Ascertain whether there is potential for economically viable tailings reprocessing[1] projects in Ireland, and;
- If the potential does exist, detail the major research avenues to be pursued to fully examine that potential.

[1] In the mining industry, such reprocessing is known as valorisation

1.1.1 Proposed Methodology & Organisation of the Work

The proposed study was broken into eight sections, each with a specific deliverable. The sections and deliverables are summarised in Table 1.1, below.

Table 1.1 Summary of Study Sections and Deliverables

Activity	Output
Desk mapping of sources of mine tailings, collating information from multiple sources	List of mine tailings in Ireland with accompanying location map in GIS
Characterise each source by major commodities and likely minor commodities. For example, it is believed that some rare earth elements (REE) may reside in zinc-lead tailings. Characterise any likely geochemical reactions over time among metal assemblages	Table of major and minor commodities potentially existing in Irish tailings deposits
Identification of international best practice/ case studies in re-processing of base metals tailings	List and description of processing methods/approaches likely to be most suitable for reprocessing of Irish tailings deposits and metal assemblages
Summarise the legal and regulatory framework	Summary of relevant legal and regulatory issues
Summarise potential lines of investigation for identification of likely processing methods	Identify future research topics to find best reprocessing methods
List likely stakeholders for consultation as part of future research	Stakeholder listing
Identify economic issues to be researched	Summary of primary economic factors
Tabulate findings and use to identify the potential tailings sources most likely to be environmentally, economically, technically and legally feasible for recovery of critical metals	'League Table' of best candidate tailings deposits for further investigation.

1.1.2 Critical Raw Materials

Security of supply of raw materials, both metallic and non-metallic, is increasingly of concern. Critical Raw Materials (CRMs) are materials that have been identified by the EU as having high risk to the continuity of their supply, and high importance to the EU economy[2]. To date, the EU has identified 27 CRMs. While it is outside the original scope of this study, the researchers believed it was important to identify, as much as possible, those waste piles which could supply CRMs.

Table 1.2 List of Critical Raw Materials

Antimony	Coking coal	Indium	Phosphorus	Platinum Group Metals
Baryte	Fluorspar	Magnesium	Scandium	Heavy Rare Earth Elements
Beryllium	Gallium	Natural graphite	Silicon metal	Light Rare Earth Elements
Bismuth	Germanium	Natural rubber	Tantalum	
Borate	Hafnium	Niobium	Tungsten	

[2] http://ec.europa.eu/growth/sectors/raw-materials/specific-interest/critical_en

Cobalt	Helium	Phosphate rock	Vanadium	

2.0 Desktop Mapping

Data were collated from multiple sources, mapped using ArcGIS and standardised for easy comparison. A list of mine waste sites was generated, accompanied by a map and GIS data for use by the EPA.

2.1 Sources of data

Data were collated from the following sources:

- ProMine Portal (via Minerals4EU[3]);
- EPA Historic Mines Study (Stanley, et al., 2009), via EPA data portal[4];
- Geological Survey of Ireland (GSI) economic assessment of mine waste (McGrath, 2016); and
- GSI Open Data – Mineral Localities. This dataset was used to confirm localities.

The EPA/GSI Historic Mines Study was the major source of data, while the other sources were used to ensure that no sites of significance had been missed, and to add data or confirm data concerning the sites itemised by the study.

2.2 Data Compilation

The data were compiled onto an Excel spreadsheet (available digitally and in Appendix 1). The first step in the compilation of the spreadsheet characterised the mine waste sites according to the following criteria, each acting as a column header in the spreadsheet:

- Mine District – Mineral deposits often occur in clusters of individual deposits, and the cluster or mine district name is often more commonly used than that of the individual deposit or waste pile;
- Mine Name – Individual mine names;
- County – County in which the mine waste is located;
- Townland – the GSI mineral localities data refer to the townland name in most cases and it was considered that it would be useful to retain this information;
- Easting – Six figure coordinate in Irish National Grid (TM65);
- Northing – Six figure coordinate in Irish National Grid (TM65);
- Major Commodities – the commodities (metals) for which the original mine was exploited and/or the commodities recognised as being most abundant or likely to be of economic value in the mine waste;
- Minor Commodities – commodities occurring in minor amounts in the original mineral deposit but which may be extracted economically, or for which a credit may be given by a smelter;
- CRMS – Critical Raw Materials[5] that are or may be present in the mine waste; and
- Penalty Elements – elements present in the mine waste that are considered deleterious in the smelting process and for which a smelter will make a deduction in the payments due to a supplier of concentrate.

2.2.1 Mine Districts

There are 23 mine districts considered, with a strong concentration seen across the midlands (see Figure 2.1), approximately on a curved line stretching from Co. Wicklow, southwest to Gortdrum in Co. Tipperary, then

[3] www.minerals4eu.eu
[4] http://gis.epa.ie/GetData/Download
[5] http://eur-lex.europa.eu/legal-content/EN/ALL/?uri=COM:2017:0490:FIN

northeast to Doolin, in Co. Clare. All of the other districts are relatively isolated and scattered, from Co. Cork to Co. Donegal. The proximity of the midlands mine waste locations to each other may be significant from a logistic/economic standpoint, as it is possible that a central processing plant receiving material shipments from multiple small sites may be more feasible than multiple plants.

2.2.2 Mine Name

In most cases, the name of the mine is given, although in the cases of some clusters, e.g. Leinster Coalfield, there are multiple mine sites; the name in these cases is listed as 'Various'.

2.2.3 Coordinates (Eastings & Northings)

The eastings and northings were principally acquired from the data on the ProMine website. Those that were missing were acquired from the GSI's mineral locations dataset and in some cases, were pinpointed on the map using the author's own knowledge.

Commodities, CRMs and penalty elements are addressed in the Section 3.0.

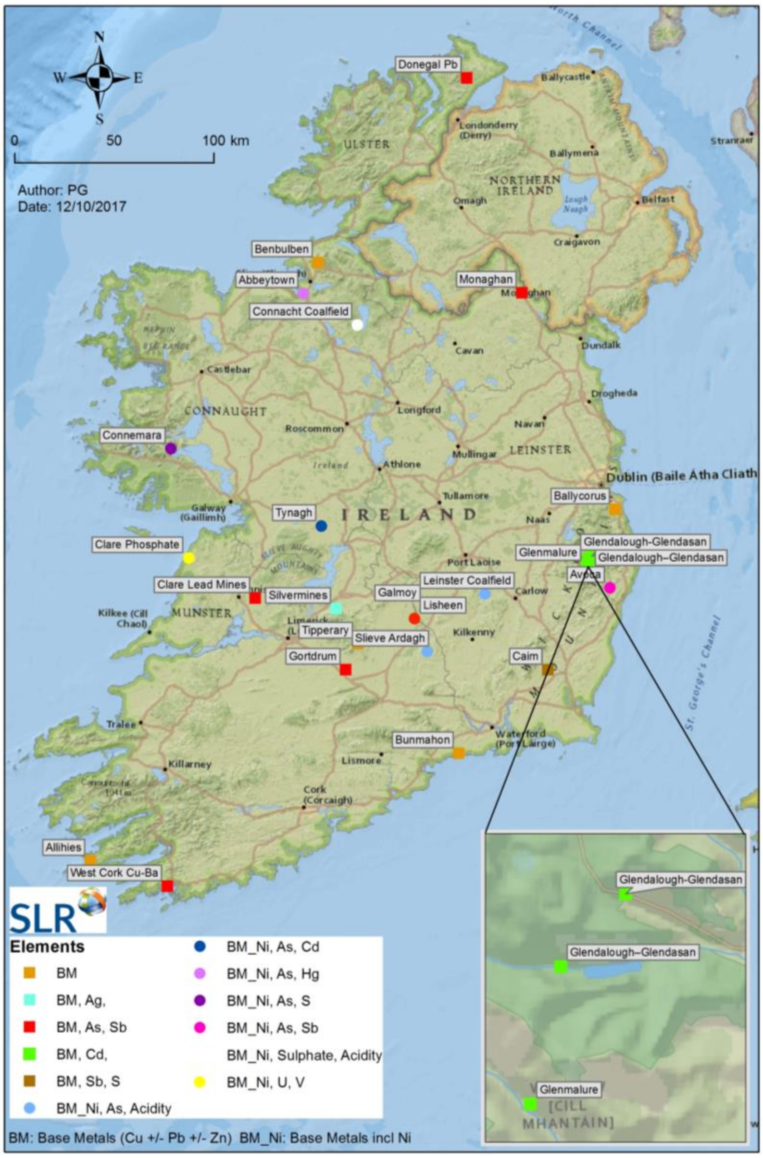

Figure 2.1 Location Map of Mine Waste occurrences considered by the study

3.0 Characterisation of Sites by Commodities

Each site was characterised by its major commodities as well as known minor commodities and potential other commodities which may not yet have been identified. Particular reference was made to the EU Critical Raw Materials list.

Each site has been characterised using three criteria:

- major commodities are the materials for which the mine was originally exploited;
- minor commodities are other materials which were not exploited or are not considered to have had any significance on the economics of the historic mine; and
- CRMs are those critical raw materials which have been identified at that mine site or are known to occur in similar mineral deposits.

3.1 Major Commodities

Seventeen of the thirty five sites considered contain base metals (Cu/Pb/Zn) as their major commodities. Coal was the next most common major commodity, occurring in the Leinster and Connacht coalfields and Slieve Ardagh. The final three major commodities are barite (Benbulben), phosphate (Clare) and gold (Monaghan). Silver is a major commodity at twelve of the sites, albeit a secondary one for most.

Coal in waste heaps is unlikely to be of any value, as the volumes and quality available are unlikely to result in a product that is competitive on the global market. The development of a barite-reprocessing project at Benbulben is likely to encounter significant objections and restrictions due to its proximity to an iconic part of Ireland's cultural and natural landscape. However, barite is on the CRM list and should possibly be considered further rather than being dismissed from the outset.

The author has not visited the Clare phosphate site, but is aware, anecdotally, that the waste at the site consists mainly of scattered boulders rather than a single heap or concentration of mine waste or tailings. The gold in Monaghan is associated with the Clontibret deposit, which is currently at a resource definition stage, and any gold remaining in waste may be processed by the planned mine at Clontibret.

The seventeen sites containing base metals as their major commodities are the most likely to be economically viable from a valorisation standpoint.

3.2 Minor Commodities

The major base metals (Cu, Pb & Zn) make up most of the minor commodities as well as the major commodities. Given that those base metals have relatively low values as commodities, their occurrence in minor amounts means that they are highly unlikely to make an economic contribution to any potential valorisation projects. The most interesting potential minor commodities are gold and, in one case, selenium. Gold is known to have occurred at Avoca, and in the 1990s, Feltrim Mining attempted to win gold from the spoil heaps, without success (Schaffalitzky, 1992).

3.3 Critical Raw Materials

Antimony and barite were the most commonly identified CRMs, with some sites having the potential for Rare Earth Elements (REEs). Avoca is the only site to have been analysed for REEs (McGrath, 2016), to best of the researchers' knowledge. It is thought that the grades of barite at most, if not all, sites are likely to be below an economically feasible level. Due to the relatively high density of barite, it is possible that an operation utilising gravity or density methods could produce it as a by-product.

4.0 Potential Processing Methods

International literature, author knowledge and current research topics were researched to identify the best potential methods for processing the mine waste identified in the earlier parts of the study.

Given the small footprint of most of the mine waste dumps considered by this study (<1.5km^2), and the legacy environmental and community issues associated with many of them, it is thought that any proposed processing system should have the following characteristics:

- low environmental impact;
- small footprint;
- flexible; and
- scalable.

The existing industry knowledge of the authors and subsequent research has identified the following mine processing methods in use globally:

- conventional flotation (either on- or off-site);
- heap leach;
- microbial extraction; and
- gravity/density methods

4.1 Conventional Flotation

Conventional flotation is the most commonly-used processing method for modern base metal deposits. It is the method used at Tara Mines, and at the recently-closed Lisheen and Galmoy mines.

The method requires that material is crushed and ground to a fine particle size (c. 20µm-300µm), before being added to large vats containing water, flocculants and reagents. The mixture is agitated to form a froth of air bubbles surrounded by liquid containing high concentrations of metal. The froth is skimmed off the surface and dried to form a powdered metal concentrate. Different reagents are used for each metal, so a polymetallic feed requires a separate process, or circuit, for each metal. See Figure 4.1 for a schematic diagram of the flotation process. The pros and cons of the method are summarised in Table 4.1, below.

The method is very effective, with generally high recovery rates. It is well-established, with many laboratories capable of conducting studies to optimise recovery using flotation. The requirement of multiple circuits for polymetallic feeds can lead to a relatively large footprint, lack of flexibility and high capital expenditure.

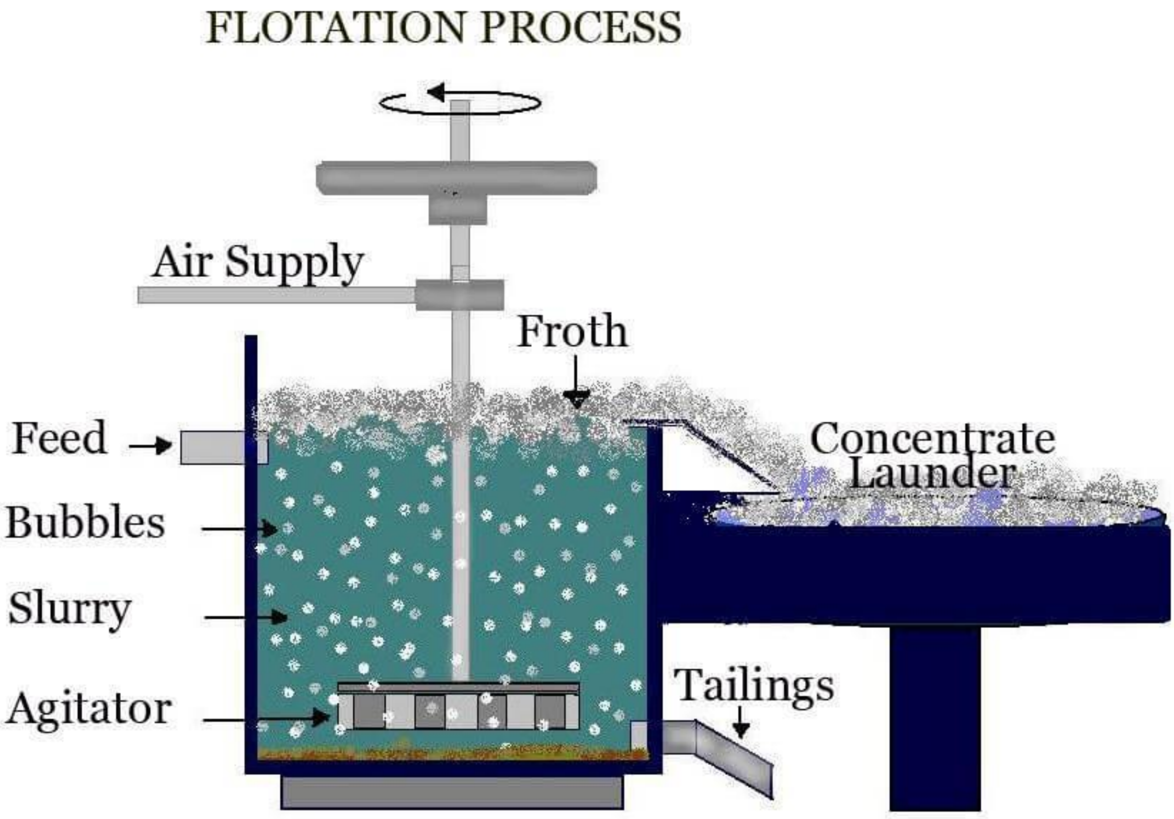

Figure 4.1 Schematic diagram showing principles of flotation. (Source: 911 Metallurgist[6])

The high capital expenditure requirements mean that flotation is likely to be too costly to use on most of the waste dumps in this study.

4.2 Heap Leach

Heap leach uses a solvent, usually sulphuric acid, although a cyanide solution is used for gold, to leach metal from the mineralised material. The material is piled on leach pads, the solvent is generated on site and fed on to the top of the heap. The acid containing dissolved metals is drained from the leach pad and processed to remove the metals. As much acid as possible is reused, but 100% recovery is generally not possible. Heap leach is used for a variety of metals, and is most commonly used for gold, although heap leach has also been used for nickel and copper.

Heap leach extraction requires a relatively large footprint; as well as the leach pads, the process also requires an acid-generation plant and a process plant. There are significant environmental and health concerns regarding the use of large volumes of acid and it is likely that community hostility to the method would be widespread. As long as relatively conventional heap leach is being used, the capital costs are not particularly high, but there are operating costs associated with the generation of the acid. See Table 4.1 for a summary of the pros and cons of heap leach extraction.

[6] https://www.911metallurgist.com/blog/wp-content/uploads/2013/09/flotation-separators.jpg

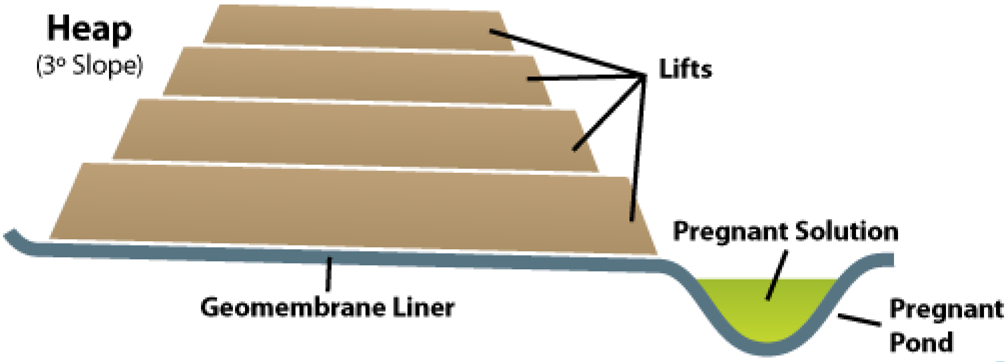

Figure 4.2 Schematic diagram showing heap leach configuration. (Source: OreMax[7])

The large footprint and environmental, health and social concerns associated with heap leach extraction mean that the method is unlikely to be suitable for many of the waste dumps considered by this study.

4.3 Microbial Extraction

Microbial extraction uses bacteria which feed aggressively on the mineralised material. The bacteria are bred in ponds, to which the mineralised material is added. The material is consumed and concentrated by the bacteria, which are then harvested. Complications are introduced if the material is held in different classes of minerals, e.g. sulphides, oxides, carbonates, etc., as each species of bacterium will generally consume only one type of material. If weathering has increased the complexity of the mineral geochemistry, there may be a need for multiple processes to remove all of the metals, similar to the situation with conventional flotation.

Set-up costs are relatively low and the footprint is generally moderate. There are health and environmental risks associated with the method, as the extraction ponds are usually highly toxic to both humans and the environment in general, including groundwater. The method is more suited to small to medium-scale operations than to larger operations, and also more suited to mine influenced water (MIW).

Microbial leaching is relatively flexible, scalable to an extent, and has relatively low capital costs. The health and environmental risks are manageable and it is believed that the method could be applicable to some of the waste deposits included in this study.

4.4 Gravity/Density Methods

The use of gravity or density to separate non-economic waste material from economic minerals is a proven and widely-accepted technique. It generally has low capital and operating costs, uses few or no chemicals that might cause environmental concerns and the recent development of new equipment enhances the range of separations possible.

Efficient gravity/density separation is a function of particle size and specific density differences, i.e. it is easier to separate more dense elements, like gold and lead, from the non-economic material than it is to separate lighter ones. In the case of gold and platinum group elements (PGEs), gravity separation can quickly generate a precious metal concentrate that can be sold direct to refineries. Gravity/density separation can also be used to immediately reject barren waste as an initial pre-concentration step.

Gravity/density can be used to either pre-concentrate material, thus saving on concentrator costs, or as the final method of concentration. The lack of chemical alteration or additives means that the fundamental characteristics of the material do not change.

[7] http://www.ore-max.com/?page=how_it_works

There are two sub-types of gravity/density methods:

- Dense Medium Separation; and
- Gravity or Microgravity Separation.

Dense medium separation uses extremely dense liquids to 'float off' lighter, barren material and generally operates best at medium to coarse grain sizes (1mm-30mm). Gravity and multi gravity separation work best at finer grades (sub-300 microns). The footprint for each method is relatively small. Individual units have a limited capacity, but it possible to add or remove units so that they increase overall capacity by operating in parallel. The overall power consumption of both methods is also relatively low. Both methods could be used in conjunction with each other.

Figure 4.3 Multi Gravity Separator. (Source: Gravity Mining Ltd[8].)

Gravity/density methods have a low environmental impact, are flexible and scalable, as well as having relatively low capital and operating costs, making them a potentially useful method in treating the waste dumps considered by this study.

Table 4.1 Summary of pros and cons of a variety of minerals processing methods in relation to mine waste reprocessing

Method	Pros	Cons
Conventional Flotation	Effective Well-established Produces saleable concentrate suitable for smelting	High set-up costs Inflexible High consumption of reagents and flocculants High water consumption Sensitive to geochemistry of material
Heap Leach	Effective Well-established	Moderate to high operating costs Requires acid generation Likely to be receive strong opposition

[8] http://www.gravitymining.com

Method	Pros	Cons
	Produces saleable concentrate suitable for smelting	Only useful for some minerals
Microbial	Flexible Scalable to an extent Relatively low capital and operating costs	Potentially toxic Impractical for large throughputs Slower than most methods
Gravity/density	Effective Well-established Can produce saleable concentrate suitable for smelting Uses few or no chemicals Flexible Scalable	Requires density contrast Not infinitely scalable (probably not relevant for the sites under consideration)

Potential future processing methods that are still being developed, and may provide opportunities for collaborative research/pilot studies are:

- ionic leach;
- ore sorting;
- electrometallurgy;
- ResiduFlex valorisation; and
- RIGaT recovery of indium, germanium and tin

4.5 Ionic Leach

The following is taken from email correspondence from Prof. Gawen Jenkin, of the University of Leicester:

> 'Ores and concentrates often contain enrichments of scarce or critical elements such as Te, Bi and Sb, but there are few financial incentives or competitive technologies that allow their recovery. They may be lost to tailings or roasted off (becoming an environmental liability), or can incur smelter penalties. Even when recovered during smelting and refining, the value may not be returned to the producer. Recovery of these elements, along with the main commodity (Au, Cu, etc.) would add value for producers and secure supply of elements that are key to European infrastructure, industry, and innovation. The University of Leicester has demonstrated the potential of Deep Eutectic Solvent (DES) ionic liquids in the rapid and mineral-specific selective dissolution of gold and sulphide minerals and the subsequent recovery of major metals and by-products from solution. DESs (unlike many ionic liquids) are environmentally benign, chemically stable and the components are already produced in bulk at low cost, potentially making an industrial process feasible. This commitment is to develop this application, optimising by-product recovery so as to achieve a resource- and cost-efficient alternative to current practices. BRIO consortium has estimated that mineral ores amenable to BRIO currently encompass 90% of Cu, Ni, PGE, Pb, Zn, Sn, W worldwide production, which implies that the BRIO potential market for adopting by-product recovery from current identified reserves is up to 240.713 M€/year (current value of products detailed above).
>
> - Tailings are not the material of choice because of low grades (and hence solvent loss on residue), and complex mineralogy if starting to oxidise (oxides and hydroxides less amenable to processing in DES).
>
> - Many of the minor phases that contain potential by-products such as Te, Bi, Sb, Ag, are easily amenable to leaching.'

The method is still in development but it is thought that it might be worth pursuing with collaborative research involving Prof. Jenkins.

4.6 Pre-process Ore Sorting

The SortOre project is based in Trinity College, Dublin, and aims to provide a commercially-viable, automated ore/waste sorting process at either the pre-process stage or as a standalone method (Shvets, 2018 *pers. comm.*). The method is summarised as follows:

- mechanical separation of desirable rocks from waste rocks;
- advanced and highly specialised sensor array analyses the composition of rock; and
- sensors include high power UV sources for fluorescence lifetime spectroscopy, processed by custom machine-learning algorithms.

See Figure 4.4 below for schematic diagram of the SortOre method.

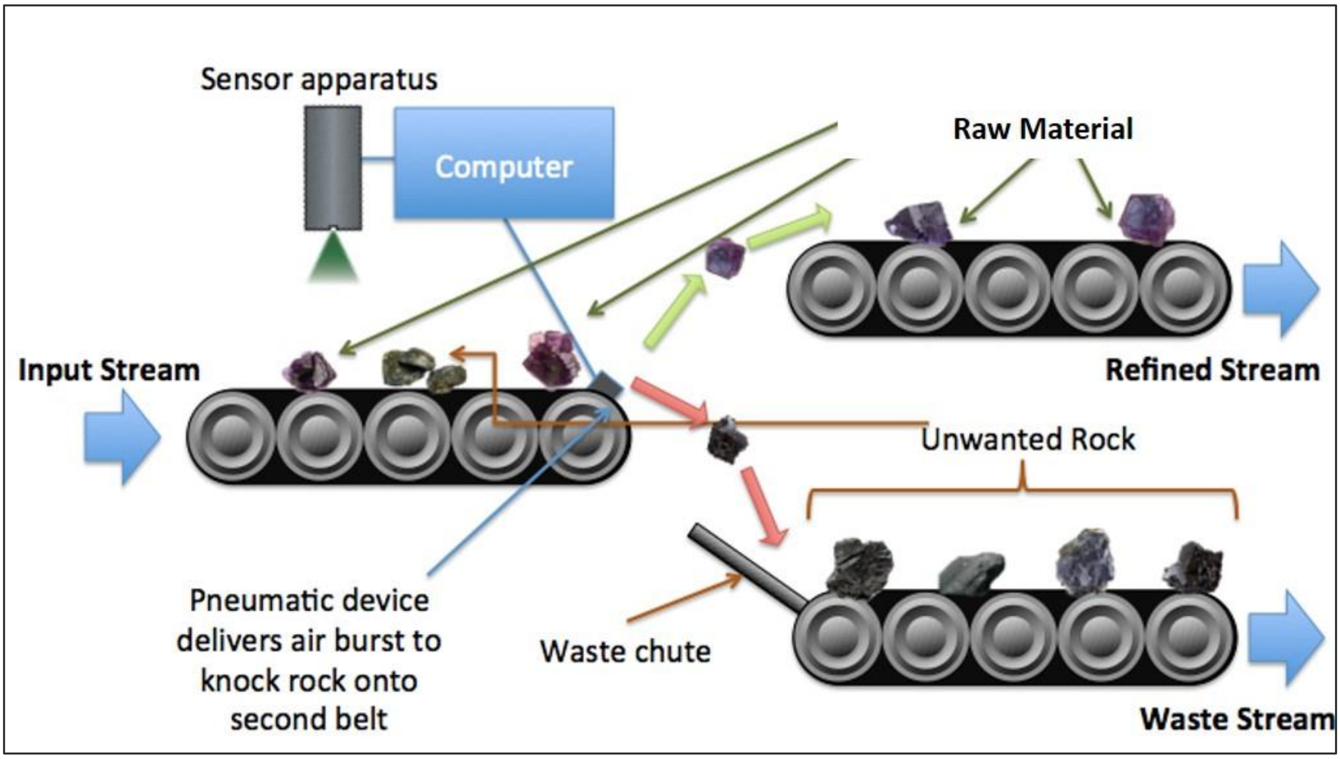

Figure 4.4 Schematic Diagram of SortOre process.

A number of projects being pursued as part of the European Institute of Innovation and Technology, Raw Materials[9] (EIT Raw Materials) have been identified as being potentially applicable to future valorisation projects in Ireland. Continued and strengthened engagement with the EIT Raw Materials is recommended.

4.7 Electrometallurgy

The MICRO-EOS[10] Horizon 2020 project aims to pre-treat sulphide ores to remove pyrite, thereby reducing cost, energy consumption and reagent use in the processing industry. While the project is aimed at conventional

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[9] https://eitrawmaterials.eu/
[10] https://eitrawmaterials.eu/project/micro-ecos/

flotation, it is likely that the proposed technique would be suitable as a pre-treatment for other processing methods as well.

4.8 ResiduFlex Valorisation

The ResiduFlex[11] Horizon 2020 project aims to consolidate the knowledge of multiple different valorisation techniques, thereby making them more accessible throughout the EU. Interaction with the project could be very beneficial. The University of Limerick is a main partner in the project.

4.9 RIGaT Recovery

The RIGaT[12] Horizon 2020 project is investigating the potential for the extraction of germanium, indium and tin from by-products. The project is of particular interest to Ireland as germanium and indium occur primarily in zinc and lead ores; both are on the EU's critical metals list.

[11] https://eitrawmaterials.eu/project/residuflex/
[12] https://eitrawmaterials.eu/project/rigat/

5.0 Legal and Regulatory Framework

Any future reprocessing project will be treated by the Exploration and Mining Division (EMD) of the Department of Communications, Climate Action and Environment as if it were a normal mining project. A project will require planning permission, an Integrated Pollution Control licence and a mining licence.

5.1 Planning Permission

Planning applications must be made to the relevant local authority. All planning applications for valorisation projects can expect to be treated as standard mining projects and will therefore require an accompanying environmental impact statement (EIS). A baseline environmental study will be required as well as ongoing monitoring. It is possible, or even likely, that the local authority decision will be appealed to An Bord Pleanála. The entire process is likely to take up to five years.

5.2 Integrated Pollution Control

An IPC licence application must be preceded by a public notice in a local newspaper, a site notice and notification to the local authority. Applications are made online, using the EPA's EDEN website[13]. Once all requests have been complied with, the EPA will make a proposed determination within eight weeks. Objections to the proposed determination can be made within 28 days of the proposed determination being issued.

The process of preparing and submitting planning and IPC applications can be carried out at the same time. Similarly, a mining licence application can be submitted to EMD before the planning and IPC determinations have been made, but a mining licence will not be issued until or unless the planning permission and a IPC licence have been granted.

5.3 Prospecting and Mining Licences

The first step in any commercial valorisation project will be to acquire a prospecting licence (PL) that covers the project area in question, or if there is an existing PL, to come to an arrangement with the holder. A mining licence will only be granted by EMD to the holder of a prospecting licence covering the same area, In the event of a commercial discovery.

Mineral ownership in Ireland is, in most cases, vested in the State, although some landowners hold private mineral rights. Mineral exploration is carried out entirely by the private sector, using a permitting system governed by several Minerals Development Acts dating from 1940 to 2017. EMD acts as the agency responsible for the administration of regulatory aspects, including the issuing of PLs.

PLs average approximately 35 km^2 and are issued for a six-year period either on a 'first come, first served' or competitive basis, subject to certain conditions.

5.4 Land Access

The right to explore and the associated access rights are inherent in the terms of a valid prospecting licence. In practice, surface rights are negotiated with individual landowners without the need to invoke the terms of a

[13] www.edenireland.ie

prospecting licence. Land access for exploration and mining development is negotiated with landowners with payment of agreed compensation for access and land/mineral use where minerals are privately owned.

5.5 Royalties

The state takes no shareholding in mining operations, but will require a royalty to be paid. Mining licence terms are negotiated on a project specific basis and generally on a phased schedule. As an example, at the Lisheen zinc-lead mine in County Tipperary, a concessionary royalty of 1.5% to 1.75% (NSR) was levied up to 2007 (from when it commenced operation in 1999) and rose to 3.5% thereafter, until it closed in 2015. At the Galmoy zinc-lead mine, along trend from Lisheen, the royalty rate varied over the life of mine between 1.25% and 2.25%. Applicants for a mining licence are required to obtain planning permission and an integrated pollution Control Licence. From discovery in 1990 to mine production in 1999, Lisheen took nine years to delineate a resource with critical mass, complete feasibility studies, acquire the necessary permits and construct the new mine.

The range of royalty rates allows the state to 'tailor' the royalty, based on the economics of the individual project. Any valorisation project will be, relative to traditional mining, small-scale and likely to be subject to royalties at the low end of the range.

6.0 Future Lines of Investigation

This small-scale study was essentially a scoping process to identify the most likely ways that a successful mine waste reprocessing project could succeed. Included in that are lines of investigation that could be pursued by future research, to be carried out by the EPA or other research bodies.

It is unlikely that there is a single, 'out-of-the-box' valorisation process that will be equally applicable across all the potential valorisation sites in Ireland. The more likely scenario is that a combination of methods will be tailored for each project. The author's opinion is that density/gravity methods will likely play a key part in any valorisation project, due to their scalability, lack of hazardous chemicals and small footprint. (Bell & Donnelly, 2006).

Sections 8 & 9 will demonstrate that the potential for economically viable valorisation projects exists in Ireland. It is not yet clear which site, or what methods will be most successful, however it is recommended that future research concentrates on the following:

- accurate and systematic sampling of the mine waste, particularly at depth;
- widening of the suite of analyses to include gold, REEs and other CRMs;
- carrying out detailed desktop and laboratory-scale or pilot tests on material from the mine sites;

Ideally, in order to efficiently identify the best sites and methods for valorisation projects, future research should be carried out involving a range of sites and methods, with collaboration from a number of the processing methods identified in Section 4.0. It will be necessary to include the following:

- research groups involved in developing processing methods, ideally from within EIT Raw Materials;
- mining or exploration companies that hold the prospecting licences covering the sites of interest; and
- a project coordinator which can deal with both industry and academia, ideally with practical experience of mining and exploration in Ireland.

7.0 Stakeholder Mapping

The researchers drew upon SLR's extensive in-house knowledge of exploration, permitting and operating extractive projects to identify the likely stakeholders for any future mine waste reprocessing project.

The major categories of stakeholders are shown in Figure 7.1 and summarised in Table 7.1.

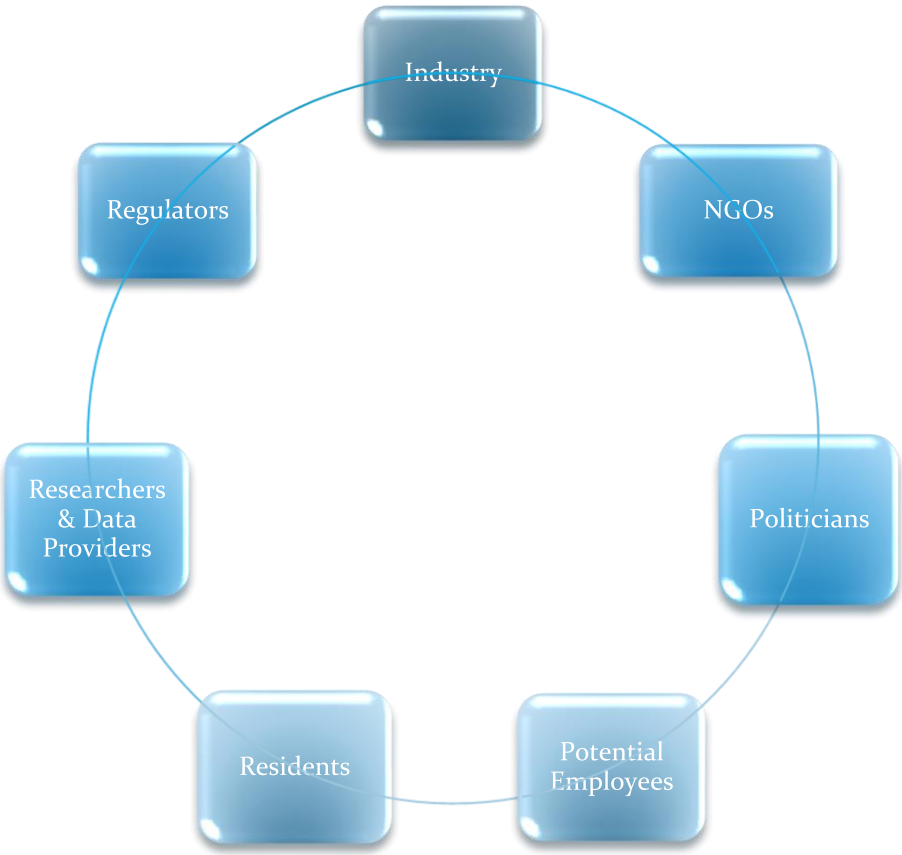

Figure 7.1 Categories of Stakeholder for Future Valorisation Projects

Table 7.1 Summary of Likely Stakeholders

Category	Who	Description of stakeholder
Industry	Mining/exploration companies	Companies established in the mining industry. Maybe PL holders over sites of interest or companies specifically interested in valorisation projects
	Process suppliers	Suppliers of process technology, either conventional mining equipment or innovative valorisation processes.
	Service providers	Consultants to the mining industry. Often have a wide network and act impartially.

Category	Who	Description of stakeholder
Regulators	EPA	Environmental Protection Agency. Issues IPPC licences and enforces environmental regulations.
	EMD	Exploration and Mining Division. Issues mining licences and enforces mining regulations. EMD has already been consulted and has no issue in principal with valorisation projects.
	Local Authorities	County Councils. Issue planning permission and enforce planning and environmental regulations.
Researchers and Data Providers	Geological Survey of Ireland	Providers of high quality geoscience data and data interpretation. Co-authored the Historic Mines Survey. Also commissions geoscience-related research, including the report by McGrath (McGrath, 2016)
	Irish researchers	Primarily UL and TCD (both members of EIT Raw Materials) iCRAG – Irish Centre for Research in Applied Geosciencs, a multi-institutional research centre funded by SFI and industry.
	European researchers	Other EIT Raw Materials researchers
Residents	Local residents.	May have a long history with the area, with both good and bad experiences. Early consultation and involvement is important. Must be managed by people with experience and knowledge in the area of stakeholder engagement.
Potential employees	Some local residents, some from further afield.	There are many trained mine/process workers in Ireland, a substantial proportion of whom have lost their jobs due to mine closures in recent years.
Politicians	Local politicians	Local authority representatives. Must be engaged early to ensure they understand all aspects of the proposed projects. If not, there is a danger of one side leading the narrative.
	National politicians	Representatives in Dail and Seanad. Early engagement also important, as is ministerial backing/involvement, particularly in DCCAE[14].
NGOs	Non-government organisations.	Many NGOs are inherently anti-mining, but they need to be engaged early to emphasise the environmental and economic benefits of valorisation projects. The Mining Heritage Trust of Ireland is also certain to be interested and will likely raise concerns regarding the removal of spoil heaps as they would consider them to be part of Ireland's mining heritage.

[14] Department of Communications, Climate Action and Environment

8.0 Economic Issues

The main thrust of this study was to identify whether the state could realise both economic and environmental benefits from mine waste reprocessing. High-level economic factors have been added to each site's characteristics, to give a general snapshot of the likely *in-situ* value of the materials therein and to serve as a comparator between sites.

8.1 Data Sources

The Aurum report on Mine Waste Characteristics (McGrath, 2016) and the Historic Mine Sites report by the EPA/GSI (Stanley, et al., 2009), were heavily relied upon for the volumes of material at each site and for assayed values. The calculations used a specific gravity value of 2.7 for spoil heaps across all sites; based on the median value given by the US Federal Highway Administration Research and Technology[15]. A value of 2.08 t/m^3 was used for tailings (Quille & O'Kelly, 2010). It is recommended that future studies should include direct measurement of density or specific gravity at each site, as minor variations could result in significant differences in the final values. The *in-situ* values calculated in this study are intended to be an indicative, order-of-magnitude set of figures. The metal values used (see Table 8.1) were based on one-year averages for each metal, from 01/01/2017 to 31/12/2017

The tailings dams at Tara Mines (Co. Meath), Lisheen Mine (Co. Tipperary) and Galmoy Mines (Co. Kilkenny) were not included in the Historic Mine Sites report. A description of the Tara dam is provided in a geotechnical paper from 2010 (Quille & O'Kelly, 2010). Some approximate figures for both Galmoy and Lisheen were provided by Jonathan Talbot (Talbot, *pers. comm.* 2018), who worked at both mines.

Table 8.1 Average Commodity Prices 2017

Category	Commodity	2017 Average Price USD	2017 Average Price EUR	Unit
Base Metals	**Copper**[16]	5454	4826	t
	Lead[11]	2054	1817	t
	Nickel[11]	9215	8155	t
	Zinc[11]	2561	2266	t
Precious Metals	**Gold**[17]	39101	34602	g
	Silver[12]	0.547	0.484	g
Other Commodities	**Antimony**[18]	8841	7823	t
	Barite[19]	170	150	t
	Selenium[20]	23810	21071	t

[15] https://www.fhwa.dot.gov/publications/research/infrastructure/structures/97148/mwst1.cfm
[16] London Metal Exchange; www.lme.com
[17] www.kitco.com
[18] US Geological Survey https://minerals.usgs.gov/minerals/pubs/commodity/antimony/mcs-2018-antim.pdf
[19] US Geological Survey https://minerals.usgs.gov/minerals/pubs/commodity/barite/mcs-2018-barit.pdf
[20] US Geological Survey https://minerals.usgs.gov/minerals/pubs/commodity/selenium/mcs-2018-selen.pdf

The average EUR/USD exchange rate of 1.13 was used[21]

8.2 Method

The volume of material at each site and the median measured X-ray fluorescence (XRF) values were entered into an MS Excel spreadsheet. Some sites, e.g. Tynagh, have sufficient quantities of tailings material to justify reporting tailings and spoil separately. Some sites had no recorded solid waste and the various coal sites were ignored as being of no likely economic value.

The recorded volumes were converted into tonnages, using the appropriate density or specific gravity values (see Section 8.1). The next step derived the quantity of each commodity at the site, using the recorded concentrations and overall tonnage at each site, and multiplied the weight by the appropriate price, to give an economic value for each commodity at each site. Finally, all commodity values were summed to give an overall value for each site.

It is important to note that the values recorded for each site came from the analysis of 'grab' samples; they are surface samples only, so the spoil heaps have not been sampled at depth. A further caveat is that no gold analysis was carried out. While it is unlikely that the lead-zinc mines will contain significant gold, any site with elevated copper should be analysed for gold, similarly, some of the lead vein-hosted mines could be prospective for gold. A report by Crowe, Schaffalitzky and Associates (CSA) in 1992 (Schaffalitzky, 1992) indicated the presence of gold at Avoca, with average values of c. 1g/t. This was borne out in sampling carried out by Aurum (McGrath, 2016). The precise locations and analysis results are not available for the sampling and the gold values have therefore been excluded from this model. Silver was not recorded on a systematic basis, although it is believed that some silver is likely to occur at most of the base metal sites.

Phosphate gangue is a potential source of REEs (Robinson, *pers. comm*. 2016), so it is recommended that the Doolin site be analysed for the presence of REEs. Some of the other sites may also contain REEs, as suggested in the Aurum report (McGrath, 2016), particularly at Avoca.

A major economic factor when assessing mine waste is that significantly lower values are economic than for conventional operations, as the material has already been extracted and undergone comminution.

8.3 Results and Discussion

The results of the economic assessment of the mine sites are presented in Table 8.2, below. The full spreadsheet, including grades, is given in Appendix 1.

8.3.1 Overall value

The most valuable sites in terms of total metal value are Silvermines tailings, Tara Mines tailings, Tynagh spoil, Tynagh tailings and Galmoy tailings. However, total metal value is not the only consideration from a technical and economic standpoint. The proportion, or grade, of each metal is at least as important; there is a well-known saying in the mining industry that 'grade is king'. A higher-grade deposit can produce the same amount of metal for lower costs than a lower grade deposit, as the operation at the higher-grade deposit will need to remove and process less material.

Silvermines and Tara are approximately equal, and given the level of uncertainty involved in this summary, the difference between the two is negligible. It is considered more likely by this researcher that Silvermines has greater overall value for a number of reasons:

[21] https://www.statista.com/statistics/412794/euro-to-u-s-dollar-annual-average-exchange-rate/

- it has higher zinc grade;
- it contains lead at even higher grades than zinc; and
- the model has not considered silver due to lack of data and it is considered likely that there is silver in both the tailings and the spoil heaps.

Similarly, the Avoca tailings at Shelton Abbey has scored highly, but that is due to a high overall volume; the grades are quite low. Galmoy and Lisheen are both based on very approximate guesswork, but given their size, both warrant follow-up.

The *in-situ* value of the metals at each site will be a factor in indicating which processing methods are most likely to be successful from an economic standpoint. A method with high capital costs will not be economically feasible at a site with a modest *in-situ* value. The top five mine waste sites are all of sufficient size to make it likely that a wide range of processing options is available.

The *in-situ* values given in Table 8.2 do not account for recovery rates, losses during excavation or any capital or operating costs, including transport and smelter costs (if applicable).

8.3.2 Relative value

In the middle part of the range of overall values, Caim, the Clare lead mines and Ballycorus are all worthy of closer attention, with values in millions of euros, but with relatively low tonnages. When considered in terms of relative value, i.e. value per tonne of material, they score much more highly (see Figure 8.1 and Table 8.3), with high overall values per tonne. It is possible that a low-cost operation could economically extract metals from those sites. It is likely that the addition of gold values to the Avoca spoil would move it further up the chart in Table 8.3. Both the Avoca tailings and Navan tailings drop into the bottom half of the table when considered by relative value. Avoca tailings, with a value of only €4/tonne, is unlikely to be commercially viable.

Other than Navan and Avoca tailings, the bottom half of Table 8.3 contains mine sites with very low overall tonnages and low values per tonne, so it is believed that they can all be discounted in terms of potentially commercial reprocessing operations, unless significant additional funding was available, or an extremely cost-effective, mobile and efficient valorisation process was developed.

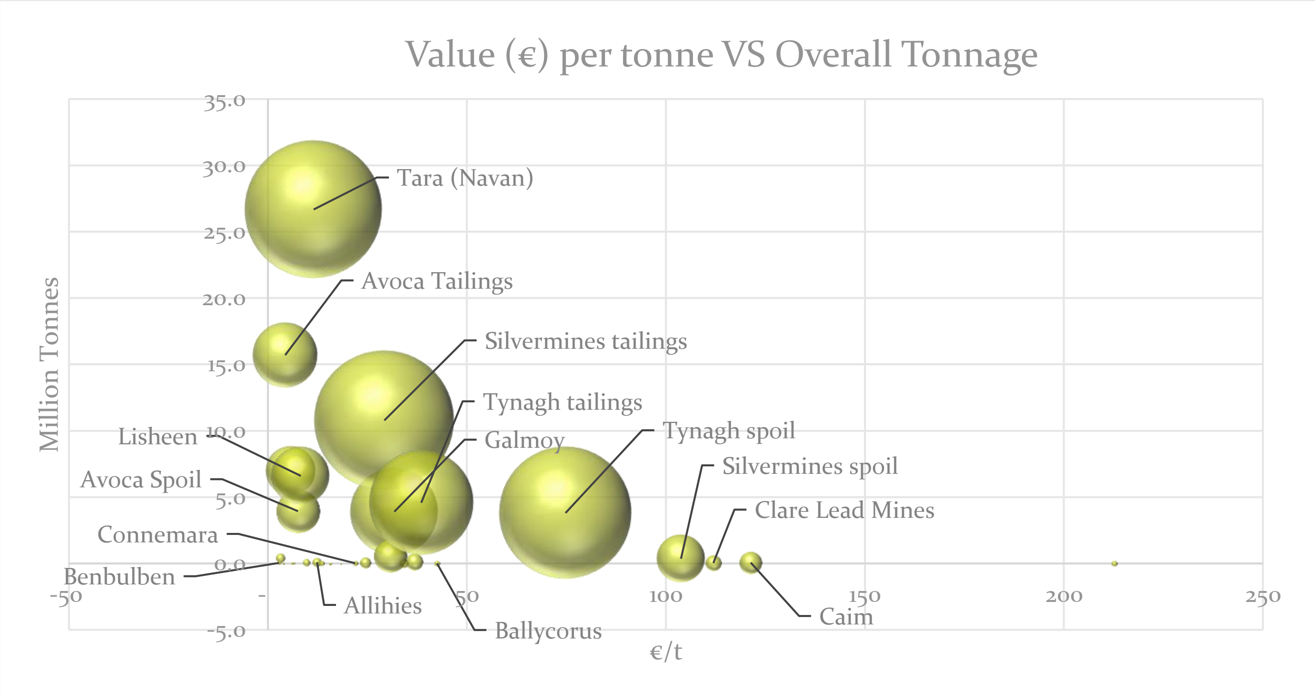

Figure 8.1 Chart showing value (€) per tonne Vs overall tonnes

Bubble size determined by overall site value.

Table 8.2 Approximation of *in-situ* value of historic mine waste in Ireland

Mine Name	Tonnes	Ag €	Ba€	Cu€	Phosphate €	Pb€	Sb€	Se€	Zn€	Total
Silvermines tailings	10,778,269	-	-	6,122,738	-	194,830,633	-	-	114,180,326	315,133,697
Tara (Navan)	26,673,608	129,100,263	-	-	-	-	-	-	241,816,478	306,366,609
Tynagh spoil	3,805,086	-	-	19,671,409	-	77,136,097	-	-	187,713,013	284,520,519
Tynagh tailings	4,576,000	-	-	20,980,232	-	108,943,436	-	-	46,338,643	176,262,311
Galmoy	3,900,000	-	-	-	-	35,438,748	-	-	88,391,142	123,829,889
Avoca Tailings	15,698,565	-	-	14,925,429	-	49,927,723	-	-	3,095,447	67,948,599
Lisheen	6,600,000	-	-	-	-	9,595,722	-	-	44,875,503	54,471,225
Gortdrum tailings	6,964,000	-	-	39,457,315	-	-	-	-	-	39,457,315
Silvermines spoil	355,153	-	-	224,378	-	12,688,592	-	-	23,947,863	36,860,834
Avoca Spoil	3,936,835	-	-	8,416,889	-	20,362,254	-	-	936,873	29,716,016
Glendasan	557,645	-	-	442,625	-	11,184,967	-	-	5,537,629	17,165,221
Caim	64,800	-	-	966,037	-	6,598,176	-	-	296,815	7,861,027
Glendalough	116,467	-	-	192,796	-	1,766,761	-	-	2,321,316	4,280,873
Clare Lead Mines	34,962	284	-	706,149	-	1,269,297	-	-	1,937,139	3,912,869
Glenmalure	71,453	-	-	27,670	-	1,401,647	-	-	318,912	1,748,229
Abbeytown	426,606	-	-	109,120	-	468,282	-	-	756,097	1,333,499
Doolin	35,502	-	-	-	1,193,883	-	-	17,953	-	1,211,836
Allihies	94,246	-	-	1,163,496	-	-	-	-	-	1,163,496
Bunmahon	78,411	-	-	735,273	-	15,818	-	-	8,175	759,266
Gortdrum spoil	2,282	90,548	-	376,560	-	-	18,081	-	-	485,190
Ballycorus	11,391	126,808	-	14,789	-	321,588	-	-	20,603	483,787
Ballycummisk	30,024	-	-	309,362	-	4,038	58,018	32,897	-	404,315
Connemara	16,543	136,115	-	23,792	-	168,993	-	-	34,269	363,169
Benbulben	42,906	-	81,912	23,813	-	8,343	-	-	7,390	121,459
Tassan	5,956	-	-	-	-	51,655	-	-	41,754	93,409
Lady's Well	10,263	-	61,758	-	-	-	-	-	-	61,758
Brow Head	7,952	-	529	50,502	-	-	-	-	-	51,030
Hollyford	1,663	-	-	36,811	-	151	-	-	-	36,962
Letter	772	-	830	25,420	-	335	-	-	-	26,586
Hope	5,684	-	991	-	-	15,587	-	-	5,198	21,776
Crookhaven	500	-	-	8,862	-	69	-	-	228	9,159
Mizen	197	-	26	1,182	-	59	221	-	-	1,488

Table 8.3 Summary showing €/t, total tonnes and total site value

Mine	€/t	Mt	M€		Mine	€/t	Mt	M€
Gortdrum spoil	213	0.002	0.485		Crookhaven	18	0.000	0.009
Caim	121	0.065	7.861		Tassan	16	0.006	0.093
Clare Lead Mines	112	0.035	3.913		Ballycummisk	13	0.030	0.404
Silvermines spoil	104	0.355	36.861		Allihies	12	0.094	1.163
Tynagh spoil	75	3.805	284.521		Tara(Navan)	11	26.674	306.367
Ballycorus	42	0.011	0.484		Bunmahon	10	0.078	0.759
Tynagh tailings	39	4.576	176.262		Lisheen	8	6.600	54.471
Glendalough	37	0.116	4.281		Mizen	8	0.000	0.001
Letter	34	0.001	0.027		AvocaSpoil	8	3.937	29.716
Doolin	34	0.036	1.212		BrowHead	6	0.008	0.051
Galmoy	32	3.900	123.830		Lady'sWell	6	0.010	0.062
Glendasan	31	0.558	17.165		Gortdrumtailings	6	6.964	39.457
Silvermines tailings	29	10.778	315.134		AvocaTailings	4	15.699	67.949
Glenmalure	24	0.071	1.748		Hope	4	0.006	0.022
Hollyford	22	0.002	0.037		Abbeytown	3	0.427	1.333
Connemara	22	0.017	0.363		Benbulben	3	0.043	0.121

The monetary values given in Table 8.2 and Table 8.3 are not in any way intended to be indicative of the existence of an economic resource at any of the mine sites mentioned.

9.0 League Table

The findings of this study have been collated in one table, with various parameters, to identify the mine waste sites most likely to lead to a successful mine waste reprocessing project.

9.1 Method of Scoring

Each site was scored according a number of criteria:

- presence of base metals readily processed by existing operators in Ireland. Effectively this means zinc, lead or silver, as Tara Mines is the only mine operating in Ireland. Otherwise, material would either have to be in concentrate form that is acceptable to smelters, or shipped abroad to be processed at another mine. Each base metal was worth 10 points;
- presence of 'credit' commodities, i.e. gold or silver. Each credit element was worth five points;
- presence of or potential for CRMs. The presence of CRMs was worth 10 points and the potential was worth five points;
- overall value of the site, according to Table 8.2. All 32 sites were ranked and the highest was given a score of 32, all the way down to one;
- value per tonne of material, according to Table 8.3. This was ranked in the same way as for overall value.

The system is crude, but, similar to the economic calculations, should give a reasonable indication of which sites merit further investigation. The researcher did consider scoring based on cut-off values for the various commodities, but as the potential processing methods and their operational parameters are not known, it was felt that this would be adding a level of precision that could be misleading.

9.2 Results and Discussion

The top five is made up of: Tynagh spoil; Clare lead mines; Tynagh tailings; Silvermines spoil; and Galmoy. Clare lead mines is the smallest of those, in terms of tonnage, but has a high score for metals, credits and CRMs, as well as for the relative value of the materials. Caim comes in at sixth, further emphasising the argument that it is worth closer consideration. The bottom five consists of: Lady's Well; Benbulben; Mizen; Crookhaven and Brow Head. Benbulben is the only one of the bottom five not part of the West Cork Cu-Ba district.

Table 9.1 League Table for Historic Mine Sites showing scores for each category.

Mine District	Rank	Base metal	Credit	CRMs	Overall Value	Relative Value	Total
Tynagh spoil	1	20	5	10	30	28	**93**
Clare Lead Mines	2	20	5	10	19	30	**84**
Tynagh tailings	3	20	0	5	29	26	**80**
Silvermines spoil	4	20	5	0	24	29	**78**
Galmoy	5	20	5	0	28	22	**75**
Caim	6	10	0	10	21	31	**72**
Silvermines tailings	7	20	0	0	32	20	**72**
Avoca Spoil	8	10	5	15	23	8	**61**
Lisheen	9	20	5	0	26	10	**61**
Glendalough	10	10	5	0	20	25	**60**
Tara (Navan)	11	10	5	0	31	12	**58**
Glendasan	12	10	5	0	22	21	**58**
Gortdrum spoil	13	0	5	5	13	32	**55**
Glenmalure	14	10	5	0	18	19	**52**

Mine District	Rank	Base metal	Credit	CRMs	Overall Value	Relative Value	Total
Ballycorus	15	5	5	0	12	27	**49**
Avoca Tailings	16	10	5	0	27	4	**46**
Ballycummisk	17	10	0	10	11	14	**45**
Abbeytown	18	20	5	0	17	2	**44**
Doolin	19	0	0	5	16	23	**44**
Letter	20	10	0	5	4	24	**43**
Connemara	21	10	5	0	10	17	**42**
Gortdrum tailings	22	10	0	0	25	5	**40**
Tassan	23	0	10	5	8	15	**38**
Hope	24	20	0	5	3	3	**31**
Bunmahon	25	0	5	0	14	11	**30**
Allihies	26	0	0	0	15	13	**28**
Hollyford	27	0	5	0	5	18	**28**
Brow Head	28	10	0	5	6	7	**28**
Crookhaven	29	10	0	0	2	16	**28**
Mizen	30	10	0	5	1	9	**25**
Benbulben	31	0	0	10	9	1	**20**
Lady's Well	32	0	0	5	7	6	**18**

10.0 **Conclusions**

There is sufficient evidence to suggest that an environmentally and economically beneficial valorisation project or projects can take place in Ireland.

Data were collated from a number of sources, with the Historic Mines Report (Stanley, et al., 2009), being of particular value, as was the Aurum Report (McGrath, 2016) and the Minerals4EU project. The data were collated onto a master spreadsheet, with coordinates in Irish National Grid (TM65). The spreadsheet is reproduced in Appendix 1 and the original will be filed with the EPA.

The sites were characterised according to the commodity types, with major commodities, minor commodities and critical raw materials (CRMs), as defined by the EU.

Potential processing methods were considered, from methods that are already established and in commercial use, to methods that are still at research-stage. Gravity/density methods were identified as being among the most likely to be applicable to the historic mine sites.

From a legal and regulatory standpoint, any valorisation project will be treated like a conventional mining project, with all of the standard requirements in terms of planning permission, IPPC licences and mine licences.

The economic assessment of the sites produced some interesting results. There are a number of ways to rank the sites, but a few sites, such as Tynagh spoils, ranked highly in both overall value and relative value. Some smaller sites, such as Caim, also ranked quite highly. The results of the economic assessment indicate that there is potential for both large and small valorisation projects, and there may be similarly diverse approaches to the processing methods and operational set-ups for such projects.

The league table resulted in four of the top five ranked projects being from large, relatively recent mines (Tynagh, Silvermines and Galmoy), with only the Clare lead mines being a smaller, historic site. Caim also scored highly (sixth). The lower end of the table consisted entirely of very small, historic mines with low tonnages and limited commodities. Four of the five lowest ranked sites were part of the West Cork Cu-Ba district.

11.0 **Recommendations**

Further research is certainly warranted as this study has, with others, demonstrated that the potential certainly exists for economically viable valorisation projects on the existing Irish mine waste sites.

Future work should concentrate on better understanding the nature of the sites, with sampling taking place from an economic standpoint and at depth within the waste heaps. Further research also needs to be carried out on the potential processing techniques to find those which are likely to be most successful, both environmentally and economically. Please see Section 6.0 for more detail on recommendations.

12.0 Glossary

ArcGIS	A commercially available GIS software package
Base Metals	Non-precious metals, used for industrial purposes. The most common base metals are copper, lead, nickel and zinc
Comminution	The crushing or grinding of material to a desired grain size
Gangue	The non-economic material within which valuable minerals are found
GIS	Geographic Information System – a means of displaying and modelling spatial data
Spoil	Mine waste which has not gone through the process used for concentrating the ore
Tailings	Mine waste which has been crushed, ground and processed in a flotation plant
Valorisation	The reprocessing of mine waste (tailings or spoil) to produce raw materials in an economically viable way

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APPENDIX 01

Compiled Spreadsheet

Mine	County	Easting	Northing	Major Commodities				Minor Commodities				CRMS		Penalty Elements			Volume m^3	Tonnes	Ag g/t	Ba %	Cu %	Phosphate %	Pb %	Sb%	Se%	Zn%	Ag €m	Ba€m	Cu €m	Phosphate €m	Pb €m	Sb €m	Se €m	Zn €m	Total €m
Abbeytown	Sligo	165991	329711	Pb	Zn	Ag		Cu	Ni					Hg	As		205099	426606			0.005		0.060			0.078	-	-	0.11	-	0.47	-	-	0.76	1.33
Allihies	Cork	59000	45000	Cu				Cu									34906	94246			0.256						-	-	1.16	-	-	-	-	-	1.16
Avoca Spoil	Wicklow	319800	182000	Pb	Cu	Ag		Zn	Ni	Au?		Sb	REE?	As	Cd		1458087	3936835			0.044		0.285			0.011	-	-	8.42	-	20.36	-	-	0.94	29.72
Avoca Tailings	Wicklow			Pb	Cu	Ag											7547387	15698565			0.020		0.175			0.009	-	-	14.93	-	49.93	-	-	3.10	67.95
Ballycorus	Dublin	322283	221384	Pb	Ag			Zn									4219	11391	23		0.027		1.553			0.080	0.13	-	0.01	-	0.32	-	-	0.02	0.48
Benbulben	Sligo	173217	345263	Barite				Cu				Ba					15891	42906		1.269	0.012		0.011			0.008	-	0.08	0.02	-	0.01	-	-	0.01	0.12
Bunmahon	Waterford	243962	98996	Cu	Ag			Au									29041	78411			0.194		0.011			0.005	-	-	0.74	-	0.02	-	-	0.01	0.76
Caim	Wexford	288549	140967	Pb	Cu			Zn	Mn			Sb					24000	64800			0.309		5.603			0.202	-	-	0.97	-	6.60	-	-	0.30	7.86
Clare Lead Mines	Clare	141735	176868	Pb	Ag	Zn		Zn	Cu			Sb		As			12949	34962	0.0168		0.419		1.998			2.445	0.00	-	0.71	-	1.27	-	-	1.94	3.91
Clare Phosphate	Clare	108345	196999	Phosphate				Ni	Se			REE?		U			13149	35502				47.5			0.0024		-	-	-	1.19	-	-	0.02	-	1.21
Connacht Coalfield	Leitrim, Roscommon, Sligo	193000	314000	Coal				Ni	Zn												n/a						-	-	-	-	-	-	-	-	-
Connemara	Galway	99410	251843	Pb	Ag			Zn	Ni					As			6127	16543	17		0.030		0.562			0.091	0.14	-	0.02	-	0.17	-	-	0.03	0.36
Donegal Pb	Donegal	247847	437881	Pb	Ag			Zn		Au?		Sb		As			1361	3675			n/a						-	-	-	-	-	-	-	-	-
Galmoy	Kilkenny	226967	172363	Zn	Pb	Ag		Cu										3900000					0.5			1	-	-	-	-	35.44	-	-	88.39	123.83
Gortdrum spoil	Tipperary	187111	141012	Cu	Ag			Au				Sb		As	Hg		845	2282	82		3.4199			0.1013			0.09	-	0.38	-	-	0.02	-	-	0.49
Gortdrum tailings				Cu													3348077	6964000	0		0.1174			0			-	-	39.46	-	-	-	-	-	39.46
Leinster Coalfield	Carlow, Kilkenny, Laois	257000	179000	Coal				Cu	Ni	Pb	Zn			As													-	-	-	-	-	-	-	-	-
Lisheen	Tipperary	222479	166404	Zn	Pb	Ag		Ni										6600000					0.08			0.3	-	-	-	-	9.60	-	-	44.88	54.47
Monaghan	Monaghan	275550	330110	Au				Pb	Zn	Ag		Sb		As			2206	5956					0.4772			0.3093	-	-	-	-	0.05	-	-	0.04	0.09
Monaghan				Pb	Zn							Ba					2105	5684		0.11595			0.1509			0.04035	-	0.00	-	-	0.02	-	-	0.01	0.02
Silvermines spoil	Tipperary	182343	171560	Pb	Zn			Ag		Cu		Ba					131538	355153			0.013		1.966			2.975	-	-	0.22	-	12.69	-	-	23.95	36.86
Silvermines tailings				Cu	Pb	Zn											5181860	10778269			0.012		0.995			0.467	-	-	6.12	-	194.83	-	-	114.18	315.13
Tara (Navan)	Meath	285100	271676	Zn		Ag											12823850	26673608	5							0.4	64.55	-	-	-	-	-	-	241.82	306.37
Tipperary	Tipperary	193361	154077	Cu				Ag									616	1663			0.459		0.005				-	-	0.04	-	0.00	-	-	-	0.04
Tynagh spoil	Galway	174935	213024	Pb	Zn	Ag	Ba	Cu	Ni			Sb	Ba	As	Hg	Cd	1409291	3805086			0.107		1.115			2.177	-	-	19.67	-	77.14	-	-	187.71	284.52
Tynagh tailings				Cu	Pb	Zn		Ba									2200000	4576000		0.027433666	0.095		1.310			0.447	-	0.19	20.98	-	108.94	-	-	46.34	176.45
West Cork Cu-Ba	Cork	97657	32197	Cu				Pb	Zn			Ba	Sb	As			11120	30024			0.214		0.007	0.025	0.005		-	-	0.31	-	0.00	0.06	0.03	-	0.40
West Cork Cu-Ba				Cu								Ba					286	772		0.7147	0.682		0.024				-	0.00	0.03	-	0.00	-	-	-	0.03
West Cork Cu-Ba				Cu								Ba					2945	7952		0.0442	0.132						-	0.00	0.05	-	-	-	-	-	0.05
West Cork Cu-Ba				Cu	Pb		Zn										185	500			0.368		0.008			0.020	-	-	0.01	-	0.00	-	-	0.00	0.01
West Cork Cu-Ba												Ba					3801	10263		4							-	0.06	-	-	-	-	-	-	0.06
West Cork Cu-Ba				Cu								Ba					73	197		0.0861	0.124		0.017	0.014			-	0.00	0.00	-	0.00	0.00	-	-	0.00
Glendalough	Wicklow	308265	192695	Pb	Ag			Zn	Cu	Au?				Cd			206535	557645			0.016		1.104			0.438	-	-	0.44	-	11.18	-	-	5.54	17.17
Wicklow	Wicklow	308265	192695	Pb	Ag			Zn	Cu	Au?				Cd			43136	116467			0.034		0.835			0.879	-	-	0.19	-	1.77	-	-	2.32	4.28
Wicklow	Wicklow	309195	198887	Pb	Ag			Zn	Cu	Au?				Cd			26464	71453			0.008		1.079			0.197	-	-	0.03	-	1.40	-	-	0.32	1.75

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