# Commercial Recovery of Metals from Coal Ash

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ABSTRACT

Aim: To provide a landscape of the recovery of metals from coal ash by-products from power stations, taking a commercial and environmental perspective. Method: Literature review and interviews with 28 experts. Findings: A review of 11 global ash samples revealed that metal values ranged from nearly $4,500 to $46,500/tonne of ash at the current market prices, with significant values seen particularly for scandium, dysprosium, yttrium and aluminium. Although there are already Coal Combustion Products there is growing political and social interest driving developments, with concerns over the large volumes of ash, the impacts of metal ore mining, and ensuring critical raw material supplies. Large scale operations already exist for the extraction of aluminium and germanium. In addition, further companies are identified that are developing technologies for recovery of magnesium, rare earth elements (REEs), scandium, gallium, vanadium, titanium and others. Furthermore, processes are being commercialized in North America to extract metals and simultaneously recover the bulk materials for use in construction, the chemicals industry and other applications. This means that the different revenue streams may not be mutually exclusive and makes it potentially relevant to both Class C and Class F coal ashes. Conclusions: A number of companies appear to have promising technologies, and several scenarios are identified which would help facilitate economically viable recovery of metals from coal ash. The environmental impacts require further consideration as there is little data comparing metal extraction from virgin materials to the recovery from these waste streams. Further research areas are highlighted.

## AIM AND METHODOLOGY

In the midst of the USA EPA's decision making on the management of coal ashes in 2014, a review was conducted to explore the opportunities and challenges for commercial metal recovery from these materials.[1] The aim of the review was to provide industry and stakeholders with a global landscape and profiles of key commercial activities and experts in the area of recovery of metals from coal ash by-products from power stations, in order to help facilitate decision making related to opportunities for an environmentally sustainable as well as commercially viable business.

Over 100 scientific papers and conference proceedings, 150 patents and 60 press releases were reviewed, in addition to company websites and annual reports where available. To obtain current insights 28 interviews were conducted with experts across the value chain, as follows:

- 6 coal power stations and fly ash management companies
- 12 metal recovery technology companies
- 7 academics and researchers
- 3 stakeholders (associations, consultants)

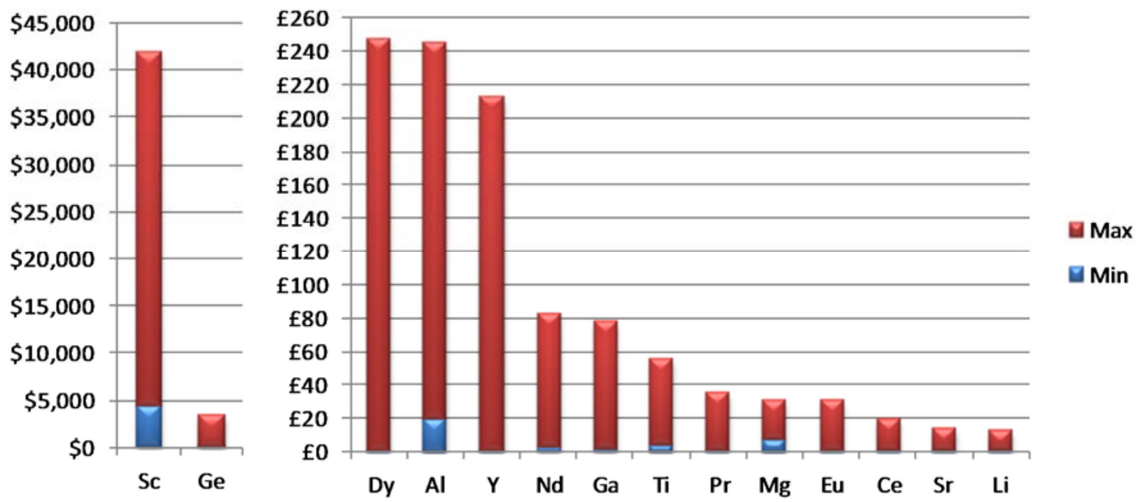
This paper discusses some of the key findings from the review.

## BACKGROUND

Records of commercial mineral extraction from coals have been found dating from the 1800s, when a number of plants operated in the US e.g. for recovery of vanadium and silver from coal mines.[2] More recently the interest in extraction from coal ash specifically has increased, particularly as concerns have grown over the overall management of fly ash in some regions, as well as environmental and resource issues of mining primary raw materials, and the risk of supply of certain critical materials found in coal ash.[3-7] However, despite the political, societal and environmental drivers, there remains uncertainty about the regulatory and economic aspects, and there also seems to be a lack of data on the full environmental footprint of the various metal recovery processes.

The value of the metal content of coal ash depends upon the concentrations of elements, which, as seen in the data provided in the full review, can vary greatly depending on the source of the coal.[1] This makes it very difficult to provide an accurate generalised valuation. However, analysis of the potential economic value of a selected set of ash samples, as shown in Fig. 1 below, suggests that scandium and germanium enriched coals may present the highest extractable value (excluding the very rare examples of precious metal enriched coals). Even the lower level of scandium content seen appears to suggest nearly $5,000 per tonne of fly ash is achievable, with the more enriched ashes reaching over $40,000 per tonne of fly ash, although further analysis of additional content data is required to verify this. In addition, from the data seen, there seems to be coals with enriched levels of dysprosium, yttrium and/or aluminium that may each return $210 to $245 per tonne of fly ash at the current market prices.

**Figure 1: Estimated valuations for selected metals based on the minimum and maximum concentrations from various fly ash sample data sources (US$/tonne fly ash)***




*Notes for Figure 1

1. Selected metals were those estimated to be worth over $10 per tonne fly ash for maximum concentrations
2. Sources of metal concentrations: Rare earth metal content estimated from laboratory analysis for ash from coal deposits in US, Russia, China and Middle East, (Seredin & Dai, 2012), and a range of concentrations measured from coal fly ash collected from power facilities in Europe, US, Mexico and Spain (Median et al, 2010; Arroyo et al, 2009; Mardon & Hower, 2004; Zhang et al, 1997) as summarised by Mayfield & Lewis, 2013. Also, unpublished data from analysis of power station fly ash from coals from Russia, Columbia, S. Africa, US, UK and unknown sources by the British Geological Survey.
3. Prices obtained from the London Metal Exchange, www.mineralprices.com, www.asianmetal.com, and www.metal-pages.com from data between May – September 2014
4. For full details see Appendix C of Commercial Recovery of Metals from Coal Ash – Global Review, Lucid Insight Ltd, www.lucid-insight.com/briefings

A number of specific coal beds have been identified over the years with enriched levels of metals such as gold, platinum, nickel chromium, and rare earth elements (REEs), and some have been specifically targeted for metal recovery, but these tend to be relatively rare.[8,9,10]

In addition to varying metal content across coal sources, different fractions within coal or coal ash may contain higher levels of particular materials. For example, the distribution of REE seems to be partitioned by size, with smaller size particles having higher concentrations of REE. In a paper investigating fly ash from Jungar, China, it was found that in addition to the partitioning of the light and heavy REE, the total REE (LREE + HREE) progressively increased from 246 ppm in the > 120-mesh fraction to 583 ppm in the < 500-mesh fraction.[11] Partitioning of REEs has also been reported by RockTron during research conducted at Birmingham University. They found higher concentrations of more valuable metals in the denser phases.[12] This may present an opportunity for pre-treatment to reduce the volumes of materials to be processed and increase the concentrations, although this area appears to require further exploration.

## COMMERCIAL RECOVERY ACTIVITIES

The main current commercially scaled up activity seen for the recovery of metals from coal ash is for germanium, with plants in China and Russia, where specifically enriched seams are mined and processed to recover the germanium from the ashes. There are also some examples of commercialised alumina extraction in China, some of which are summarised in Table 1 below, again from highly enriched coal ash, although these operations are not believed to be currently profitable.[13]

**Table 1: Examples of Industrial Alumina Plants in China**

| Company | Location | Commercialisation Phases |
|---|---|---|
| Datang International Power Generation | Tuoketuo | Went into operation in 2012<br>1st and 2nd phase complete, 3rd phase planned<br>• Aiming for production of 500,000 tonnes of alumina and 560,000 tonnes of active calcium silicate |

| Company | Location | Commercialisation Phases |
|---|---|---|
| Shenhua Group | Erdos | The first phase demonstration project completed in 2011, with second and third phases of the project are expected to be completed at the end of 2020<br>• Aiming for 4 million tonnes of alumina annually |
| Kaiyuan Ecological Aluminum Co | Erdos | 1st phase underway, with 2nd phase planned<br>• Aiming to produce 0.6 million tonnes of alumina and 0.18 million tonnes of Si-rich products |
| Erdos Electrical Metallugical Co | Erdos | • 1 million tonnes of alumina at metallurgical grade, along with by-products such as silica white (0.51 million tonnes), sodium silicate (0.77 million tonnes) and zeolites (6.52 million tonnes). |

**Source:** Z.T. Yao et al., Fuel 120 (2014) 74–85[13]

Other commercial ventures that have been identified are in the process of development and scale up of a range of different processing technologies, and target metals. Some interesting developments are underway to recover the bulk minerals in the ash as well as extracting the metals, aiming for greater utilisation, and maximum valorisation, of the waste material, as seen in Table 2 below.

**Table 2: Example Technology Developers**

| Company | Metals | Other Mineral Recovery |
|---|---|---|
| **Elixsys** | Aluminium, Trace metal concentrate | Construction materials<br>Slow release materials<br>Microsilica |
| **Emission Resource Group** | Various incl Mg, Ti, Al, REEs | - |
| **Expansion Energy** | Various incl Ga, Ge, Ni, U, V, Fe, REEs, Zr | Bulk industrial materials |
| **Keystone Metals Recovery** | Aluminium, Titanium<br>Also iron and trace metals | Silica materials |
| **Latrobe Magnesium** | Magnesium | Construction materials/silica |
| **Naval Research Laboratory (US DoD)** | REEs | - |

| Company | Metals | Other Mineral Recovery |
|---|---|---|
| **Neumann Systems Group** | REEs ,Various | - |
| **Orbite Aluminae** | Aluminium, Scandium, Gallium (later others) | - |
| **PSI Corp** | REEs, Scandium, Yttrium | - |
| **RockTron** | REEs | Construction materials<br>Specialist spherical particles<br>Cenospheres<br>High purity carbon |
| **Umicore** | Germanium | - |

**Source:** Commercial Recovery of Metals from Coal Ash – Global Review, Lucid Insight Ltd, www.lucid-insight.com/briefings [1]

CONCLUSIONS

There are a number of commercial enterprises at various stages of development to recover metals from coal ashes. Extraction of aluminium has been shown to be technically feasible in scaled up operations, but it is unlikely to be currently economically viable in its own right. However, some companies developing alumina extraction processes in North America are combining this with the recovery of other saleable products, thus aiming to maximise the value obtained from multiple products. Even so, they are likely to have a minimum requirement for alumina content, which may not be available in all coal ash. In addition, further details of the properties of the resultant bulk material would be required to understand the quality and therefore its usability. This is similar to the venture of Latrobe Magnesium, which is planning plants for the extraction of magnesium and cementitious and silica materials from selected enriched brown coals in Australia (Latrobe) and other countries.

In addition, several of the companies identified aim to produce a concentrated mix of trace metal salts, and these will either have to be transported to a separation/refinery facility, or the companies will need to integrate methodologies for this into their plants. These steps do not appear to be fully determined in most cases and may represent significant economic cost that may not be viable within current markets and supply chains, but requires further investigation.

It seems from the research conducted for this review that in order for metal recovery from coal ash to be economically viable one or more of the following will be required:

1. Increased regulations with cost implications for ash storage and/or disposal.
2. Pre-treatment of the coal and/or ash to isolate metal containing fractions or help isolate the metals in a more concentrated form and thus reduce the volumes to be processed.
3. Sourcing of enriched coal or ashes with at least one specific valuable mineral.
4. The ability to recover the metals as well as utilise the remaining ‘bulk’ materials for construction or other applications.
5. The ability to extract efficiently a range of valuable trace metal salts into a concentrate for further processing.
6. Regionally centralised metal refineries that can separate and purify individual metals from concentrated salt mixtures sourced from multiple ash processing facilities, in order to benefit from economy of scale.
7. The ability to co-locate, or regionally-locate, the ash processing facilities with the ash reserves and, if required, the metal concentrate refinery, in order to minimise transport costs.

In addition to the economic viability, the environmental impacts of the metal recovery processes need to be addressed. Production of further hazardous waste streams and consumption of large amounts of fossil based energy during processing does not fulfil the resource efficiency and circular economy principles and this would need to be reviewed in detail with the technology providers to ensure that any operations do not result in a greater environmental footprint than mining of primary resources.

A number of players were profiled in detail during the review, with an outline of their technologies, stage of development and future plans. However, further verification and investigation under confidentiality agreement with the players would be required by interested parties to fully explore and evaluate the processing steps, specific feedstock requirements, models for predicted costs and revenues, environmental footprint and supply chain requirements.

Although this is a challenging area, there are a number of companies that appear to have promising technologies worthy of further investigation. In terms of a truly circular solution the ultimate goal should be to cleverly segregate the different materials within the ash and utilise all these to their highest value, from infill and commodity uses, through to functional materials for higher value applications in construction and the chemicals industry, as well as metal recovery.

## FURTHER INVESTIGATION

The following areas have been highlighted as important and warrant further investigation, but were outside of the scope of this review:

1. Economic feasibility of using standard technologies for the separation of specific metals from concentrated trace metal salt mixtures.
2. Pre-treatments for coal and/or coal ash to isolate metal containing fractions before processing.
3. Environmental life cycle analysis of metal production from primary resources compared to the proposed metal recovery processes for coal ash feedstock.
4. Supply chain models.
5. Full analysis of coal ash metal content data to verify ranges, and identify target coal sources.
6. Quality and functional properties of bulk materials obtained in parallel with the metal recovery processes.

Full report or sections, with full profiles of players, can be obtained from www.lucid-insight.com/briefings

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