

# Accepted Manuscript

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PII: S1002-0721(18)30013-9

DOI: [10.1016/j.jre.2018.01.002](https://doi.org/10.1016/j.jre.2018.01.002)

Reference: JRE 132

To appear in: *Journal of Rare Earths*

Received Date: 8 January 2018

Accepted Date: 10 January 2018

Please cite this article as: Huang Z, Fan M, Coal and coal byproducts: A large and developable unconventional resource for critical materials – rare earth elements, *Journal of Rare Earths* (2018), doi: 10.1016/j.jre.2018.01.002.

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## Coal and coal byproducts: A large and developable unconventional resource for critical materials – rare earth elements

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### Abstract

Rare earth elements (REEs) are critical materials and provide significant values to national security, energy production, environmental protection and economic growth. The supply of REEs in U.S. solely relies on import as domestic production of REEs were ceased because of the environmental concerns during mining and lack of competitiveness. Nonetheless, unconventional REEs-containing resources, including produced water, acid mine drainage, and coal and coal byproducts (C&CBs) contain significant amounts of REEs. However, the concentrations of REEs in these resources are several orders of magnitude lower than that of REEs ores. Thus, extraction of REEs from these materials is challenging. Here we report REEs extraction with environmentally friendly method that successfully concentrated REEs from 312 ppm in fly ash to 99.4% in the final product. Especially, the five critically important REEs (Dy, Eu, Nd, Tb, and Y) account for up to ~63% of the total weight of all REEs in the final 99.4%-purity product. Coal fly ash is one of the major solid coal utilization byproducts, representing great potential resources for REEs extraction. Extraction of REEs from these unconventional resources could be the way to secure domestic supply of these critical materials.

Key words: Rare earth elements (REEs), REE oxides (REEOs), coal and coal byproducts, critical materials

Rare earth elements (REEs) are a group of 17 chemical elements in the periodic table, including scandium, yttrium and 15 lanthanides. REEs are critical materials and have significant values in national security, energy production, environmental protection and economic growth<sup>[1]</sup>. Due to the special electro-magnetic, metallurgical and optical properties, REEs play irreplaceable roles in global clean energy technology development. REEs are widely used in high-technology products such as permanent magnets, lasers, health care devices, catalysts, rechargeable batteries and many others<sup>[2-5]</sup>.

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