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Uranium endowments in phosphate rock

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HIGHLIGHTS

- We identify components that underlie the recovery of uranium from phosphate rock.
- We estimate that 11,000tU may have been recoverable from phosphoric acid in 2010.
- Recovery is a resource conservation and environmental pollution control strategy.
- To ensure investment in recovery technology, profitability needs to be secured.

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ABSTRACT

This study seeks to identify and specify the components that make up the prospects of U recovery from phosphate rock. A systems approach is taken. The assessment includes i) reviewing past recovery experience and lessons learned; ii) identifying factors that determine recovery; and iii) establishing a contemporary evaluation of U endowments in phosphate rock reserves, as well as the available and recoverable amounts from phosphate rock and phosphoric acid production. We find that in the past, recovery did not fulfill its potential and that the breakup of the Soviet Union worsened then-favorable recovery market conditions in the 1990s. We find that an estimated 5.7 million tU may be recoverable from phosphate rock reserves. In 2010, the recoverable tU from phosphate rock and phosphoric acid production may have been 15,000 tU and 11,000 tU, respectively. This could have filled the world U supply-demand gap for nuclear energy production. The results suggest that the U.S., Morocco, Tunisia, and Russia would be particularly well-suited to recover U, taking infrastructural considerations into account. We demonstrate future research needs, as well as sustainability orientations. We conclude that in order to promote investment and production, it seems necessary to establish long-term contracts at guaranteed prices, ensuring profitability for phosphoric acid producers.

1. Introduction

Phosphate rock is a naturally occurring material with high phosphate (P) concentrations. The vast majority of phosphate rock is used in the manufacturing of P-based fertilizers. Both phosphate rock and its intermediary product, phosphoric acid, are known to include appreciable amounts of elements suitable for by-product recovery, such as rare earth elements, silver, and uranium (Altschuler, 1980b; Lounamaa et al., 1980). They are also known to include about sixteen elements that are potentially hazardous to human health, such as arsenic, cadmium, and uranium (Kratz et al., 2011; Van Kauwenbergh, 1997). These elements are being redistributed within the environment via fertilizer products and related production processes and may present radiological and toxic risks to human health and the environment (Schnug and Lottermoser, 2013).

Because energy security, food security, and environmental health are critical challenges for sustainable development in the 21st century, recovering uranium as a by-product from phosphoric acid presents a particularly interesting case, encompassing all these issues. In the past, U was commercially recovered as a by-product when U demand was high, e.g., to be included in the nuclear fuel cycle. Since the turn of this century, recovery interest has again been rising as global demand for U surpasses supply. Starkly increasing U prices, reaching USD$135/lbU on the spot market in 2007, are associated with recovery reconsideration on the part of the phosphate rock industry, as well as uranium companies, electric utilities services, and the IAEA (Areva, 2007; Cameco, 2011; IAEA, 2011; UxP, 2013; Hilton and Dawson, 2012).

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The underlying bases for U recovery are thus economic by-product considerations. Recovery, in addition, may be beneficial in terms of the following four sustainability issues:

- Energy security
  Recovered U can enlarge and diversify the global U resource pool; moreover, it may secure domestic production. Since 1990, the world U market has faced supply bottlenecks because production can no longer keep up with demand. Although the situation has increasingly been improving since 2007, the existing gap cannot be bridged by using conventional primary resources within an acceptable timeframe (OECD, 2012). Because the gap is predicted to grow in the future, it has been suggested that more than one single measure must be taken to ensure short- to long-term supply security (Dyck, 2009). U from phosphate rock has been singled out as a cost-intensive alternative to U resources (Tulsidas, 2011).
- Food security
  U recovery prior to fertilizer production is a measure that can be taken to generate a U-free product, which allows control over dissipation into the environment during processing; moreover, by-product recovery may render the unit production of phosphate rock or phosphoric acid more profitable.
- Environmental health
  Recovery is an effective measure that can be taken to prevent the dispersion of P fertilizer-derived U in the environment in very low concentrations (Schnug and Haneklaus, 2008).
- National security
  U recovered from phosphate rock may be used in nuclear weapons production. This potential use is the most hidden, but it is likely not the least explored.

A more detailed description of these recovery benefits is presented in Appendix A. These security issues are coupled with the resource conservation theme, i.e., that recovery is part of planned management that may optimize resource and process utility while at the same time reducing unintended social and environmental consequences.

This study seeks to identify and specify the components that make up the prospects of U recovery. We investigate uranium endowments in phosphate rock, their available and recoverable amounts, and the potential impact of U recovery on the nuclear fuel supply and attempt to assess recovery likelihood in general. A systems approach is taken. We use descriptive and empirical analyses to create a comprehensive analysis that examines the larger picture and the interrelationships within it. These remain less well-examined because most studies take a fragmented look at the various potentials. Our assessment includes i) reviewing past recovery experience and lessons learned; ii) identifying the factors that determine recovery; and iii) establishing a contemporary evaluation of the geo-potential in phosphate rock reserves, as well as those in phosphate rock and phosphoric acid production.

The article is organized as follows: First, the methods and materials are presented. After considering the findings regarding the historic recovery experience and the limiting factors that influence recovery, estimates of available and recoverable uranium are discussed in relation to their nuclear fuel supply potential. We comment on the relevance of recovery and conclude with future research needs, as well as sustainability orientations.

2. Methods and materials

2.1. Historic contextualization

Uranium recovery from phosphate rock is not without precedence. Twice in the past, U has been recovered in different countries. Scientific publications, as well as reports from national energy commissions and industry, were reviewed to provide historical background on the recovery potential, trends, and messages. The most accessible data identified and reported are from the U.S., a pioneer in the field.

2.2. Factors influencing the recovery potential

A SWOT analysis was performed to identify both phosphate rock industry-internal factors (strength and weaknesses) and industry-external factors (opportunities and threats) that influence recovery potential. Factors were gathered during expert talks with twelve industry stakeholders involved in applied research and development, phosphate rock production, U recovery technology, and consulting. SWOT analysis, first applied in the 1960s (Learned et al., 1969), is considered an established planning tool for strategic resource management (Kajanus et al., 2012) due to its inclusive approach. The analytical framework was thus applied to i) identify the relevant factors affecting the recovery potential and ii) structure them. This assessment is limited to profiling the complex landscape of challenges and opportunities that affect the decision to recover in the broadest sense.

2.3. Estimating recoverable U in phosphate rock and phosphoric acid

An evaluation of the geologic resource potential of 21 phosphate-rock-producing countries was performed. The aim was to gain a contemporary magnitude perspective on how much U would be theoretically available in and recoverable from phosphate rock. Further, we aimed to identify countries that are particularly well-placed to recover uranium and use the recovered U to either fill domestic requirements or provide for the global market (so-called hot spots). The following procedure was applied:

In the first step, the available tons of U were calculated for phosphate rock reserve estimates made by the International Fertilizer Development Center (IFDC) and the U.S.G.S. (Jasinski, 2013; Van Kauwenbergh, 2010) based on the mean U contents in phosphate rock reported by De Voto and Stevens (1979). We applied a 90% recovery rate from the acid to calculate the recoverable U, according to the work of Becker (1988).

In the second step, we estimated the available and recoverable uranium from phosphate rock produced in 2010 according to production data of the U.S.G.S. (2013) and uranium contents in rock estimated by Van Kauwenbergh (1997). Again, a 90% recovery rate from the acid was applied.

In the third step, we estimated the recoverable U from phosphoric acid production at 100% capacity in 2010, using acid capacity, P_2O_5, and U content data from the IFDC (2012) and Van Kauwenbergh (1997). There are two reasons to calculate based on phosphoric acid: First, uranium can only be recovered from phosphoric acid via the Wet-Process Phosphoric Acid (WPPA) production (see Appendix A for an explanation of the WPPA production and the U recovery process). Second, estimates derived from acid are more valid because they account for possible domestic production. This is related to the fact that phosphate rock is a globally traded commodity. Countries that produce phosphate concentrate (i.e., phosphate rock after mining and beneficiation; see Fig. A.1) may either produce phosphoric acid with less than the mined total or not produce acid at all. Countries that produce acid may import phosphate rock for its production. A single phosphoric acid plant may use various types of rock from various countries, deposits and beds in various quantities throughout the course of a production year.

In the fourth step, we compared the theoretically recoverable U amounts in 2010 with global and domestic uranium requirements. Data on uranium demand and supply were acquired from the “Red Book”, arguably the most comprehensive and authoritative publication on uranium by the OECD-NEA and the IAEA (OECD, 2006; OECD, 2012).

Country selection was based on the following criteria: The selected countries i) hold a large part of the world's known phosphate rock reserves, currently estimated at 71 billion t (Jasinski, 2012), ii) are major phosphate rock producers; iii) may play an increasing role in future phosphate rock production, and iv) are relevant due to other U–P supply–demand structures.