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Potential uranium supply from phosphoric acid: A U.S. analysis comparing solvent extraction and Ion exchange recovery

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ABSTRACT

Phosphate rock contains significant amounts of uranium, although in low concentrations. Recovery of uranium as a by-product from phosphoric acid, an intermediate product produced during the recovery of phosphorus from phosphate rock, is not unprecedented. Phosphoric acid plants ceased to produce uranium as a by-product in the early 1990s with the fall of uranium prices. In the last decade, this topic has regained attention due to higher uranium prices and expected increase in demand for uranium. This study revisits the topic and estimates how much uranium might be recoverable from current phosphoric acid production in the United States and what the associated costs might be considering two different recovery processes: solvent extraction and ion exchange.

Based on U.S. phosphoric acid production in 2014, 5.5 million pounds of U_3O_8 could have been recovered, which is more than domestic U.S. mine production in the same year (4.9 million pounds U_3O_8). In comparison, uranium demand from U.S. nuclear plants in the same year was 53 million pounds U_3O_8 of which nearly 10% could have been met by uranium from phosphoric acid production. Annualized costs for a hypothetical uranium recovery plant are US$44–61 per pound U_3O_8 for solvent extraction, the process used historically in the United States to recover uranium from phosphoric acid. For ion exchange, not yet proven at a commercial scale for uranium recovery, the estimated costs are US$33–54 per pound U_3O_8. These results suggest that it is technically possible for the United States to recover significant quantities of uranium from current phosphoric acid production. For this type of uranium production to be economically attractive on a large scale, either recovery costs must fall or uranium prices rise.

1. Introduction

Uranium fuels nuclear power. In 2015, nuclear power plants worldwide operated with over 375 GWe of total capacity corresponding to an annual uranium requirement of 174 million pounds U_3O_8 (World Nuclear Association, 2015). World nuclear capacity is projected to either increase slightly to 386 GWe (low estimate) or significantly to 632 GWe by 2035 (high estimate) and uranium requirements are expected to change correspondingly (International Atomic Energy Agency, 2015).

Conventional resources, defined as uranium resources with previous production as a main product, a co-product or a significant by-product, are estimated at 42 billion pounds U_3O_8.[1] In comparison, unconventional uranium resources are uranium resources at very low-grade or those from which uranium could be recovered as a non-significant by-product (Nuclear Energy Agency and International Atomic Energy Agency, 2014). Various authors estimate that from 16 billion to 57 billion pounds of U_3O_8 are contained in unconventional resources, almost all of which are in phosphate-rock resources – but not all of which are recoverable (De Voto and Stevens, 1979, Gabriel et al., 2013, International Atomic Energy Agency, 2001, Nuclear Energy Agency and International Atomic Energy Agency, 2014, Ulrich et al., 2014, and World Nuclear Association, 2015). Considering worldwide uranium consumption in 2015, this is equivalent to approximately 95–330 years of world supply at current rates of use – if it becomes commercially feasible to recover. Gabriel et al., (2013) estimate around 53% of this uranium to be recoverable (9 billion from their estimated resources of 17 billion pounds).

This study estimates how much uranium might be recoverable from current phosphoric acid production in the United States and what the associated costs might be. To estimate costs, two different recovery processes are considered: solvent extraction and ion exchange. Based on U.S. phosphoric acid production in 2014,

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[1] Identified conventional resources.

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Table 1
Past uranium recovery from phosphoric acid in the U.S. (Walters et al. 2008, Pool 2004, personal communication with Pool 2015).

Location	Process[a]	Capacity P_2O_5 (tonnes/yr)	Capacity U_3O_8 (lbs/yr)[b]	Operating period	Cumulative production U_3O_8 (lbs)[c]	Producer (phosphoric acid/uranium)
1952 – 1961						
Joliet, Illinois	Precipitation	100,000	80,000	1952–1961	n/a	Blockson
Bartow, Florida	OPPA	100,000	80,000	1955–1961	n/a	IMC
Tampa, Florida	OPPA	200,000	160,000	1955–1961	n/a	US phosphoric Products (Gardinier)
1976–1999						
Bartow, Florida	OPAP	n/a	330,000	1976–1980	228,000	W.R. Grace/Uranium Recovery Corp.
Pierce, Florida	DEHPA-TOPO	450,000	400,000	1978–1981	722,000	Farmland/Wyoming Minerals Corp.
Uncle Sam, Louisiana	DEHPA-TOPO	675,000	690,000	1978–1999	14,008,000	Freeport/Freeport Minerals Co.
Donaldsonville, Louisiana	DEHPA-TOPO	360,000	420,000	1981–1998	6,268,000	Agrico/Freeport Minerals Co.
New Wales, Florida	DEHPA-TOPO	1,000,000	800,000	1980–1992	13,176,000	IMC/IMC
Bartow, Florida	DEHPA-TOPO	720,000	600,000	1981–1985	718,000	CF Industries/IMC
Plant City, Florida	DEHPA-TOPO	680,000	600,000	1980–1992	8,806,000	CF Industries/IMC
Tampa, Florida	OPPA	500,000	420,000	1979–1982	507,000	Gardinier/ Gardinier
U.S. Total					44,433,000	

[a] OPPA: Octyl-pyrophosphoric acid; OPAP: Octyl-phenylphosphoric acid; DEHPA-TOPO: Mixture of di-2-ethylhexy phosphoric acid and tri-octylphosphine oxide. For details about the processes, refer to Appendix A. Recovery Processes.
[b] Capacities presented can be considered as initial design capacities reported by each company. At stable operating situations, actual output may increase due to process optimization and/or higher ore grade. This explains why cumulative productions are greater than expected cumulative production (annual capacity of U_3O_8 multiplied by years of operation) at some operations.
[c] Source: Personal communication with Pool (2015).

5.5 million pounds of U_3O_8 could have been recovered, which is more than domestic U.S. production and corresponds to nearly 10% of the U.S. demand for uranium in same year. Costs of recovering uranium for a hypothetical plant are US$44–61 per pound U_3O_8 for solvent extraction and US$33–54 per pound U_3O_8 for ion exchange.

The remainder of the paper is organized as follows. The background section provides a brief history of uranium recovery from phosphoric acid and uranium in phosphate rock. The data-and-method section explains the sources of data and method of cost estimation. The results section presents the quantity and cost estimates for the two processes. The implications and concluding sections suggest implications and summarize findings of the study.

2. Background

2.1. History

Recovering uranium from phosphoric acid produced during the recovery of phosphorus from phosphate rock is not unprecedented in the United States (Table 1). Uranium was recovered in the United States during two periods in the second half of the 1900s. In the 1950s and early 1960s, three plants in Florida recovered uranium from phosphoric acid. Although exact production figures are not available, the overall level of production during this period was limited. The first period came to an end in early 1960s as the price of uranium fell and recovering uranium from phosphoric acid became uneconomic. The second period began in the middle of 1970s, following a significant increase in uranium prices, and lasted until the 1990s. Eight plants were active in the United States, and 44 million pounds U_3O_8 were produced. Later in this period, uranium prices fell and phosphoric acid plants ceased to produce uranium as a by-product in the 1990s. The most recent production on a commercial scale occurred in 1999, and no production on a large scale has been reported since then.

In the last decade, producing uranium from phosphate rock has regained attention due to higher uranium prices and expected increase in demand for uranium. Recent studies of uranium in phosphate rock focus on (a) physical availability of uranium in phosphate rock (Adam and Eltayeb, 2009, Ragheb and Khasawneh, 2010, Schnug and Haneklaus, 2014, Ulrich et al., 2014), (b) recovery processes (Beltrami et al., 2014, Elsayed et al., 2013), or (c) case-specific cost estimation by industry (Frame, 2011, PhosEnergy, 2013, 2015). NUKEM, Inc. and CF Industries proposed recovering uranium from phosphoric acid at one of CF Industries' operations in Florida and a feasibility study was completed in 2009 (Frame, 2011, 2015, personal communication). Most recently, a transportable demonstration plant based was tested in the United States (PhosEnergy, 2013, 2015).

2.2. Uranium in phosphate rock

Phosphate rock contains phosphate minerals that can be mined profitably, providing the phosphorus used in fertilizers. Estimated U.S. production of phosphate rock was 27.1 million tonnes in 2014. Florida and North Carolina produced 80% of total output, with the remaining 20% produced in Idaho and Utah. Reserves are estimated as 1100 million tonnes (Jasinski, 2015a).

Most of the world's phosphate rock production is from sedimentary deposits. Sedimentary phosphate rock worldwide contains 18–40% P_2O_5 by weight and 70-220ppm of uranium, roughly proportional to P_2O_5 content (World Nuclear Association, 2015).

2.3. Phosphoric acid production

Phosphate rock is mainly used in the production of wet process phosphoric acid and superphosphoric acid in the United States (Jasinski, 2015a).[2] These intermediate products are used primarily in manufacturing fertilizer. The production of phosphoric acid from phosphate rock is illustrated in Fig. 1.

Phosphate ore mined in the United States contains sand, clay, and large pebbles. These impurities are removed by beneficiation, which usually starts with wet screening. After being mined and beneficiated, phosphate rock goes through a wet digestion process.

[2] Other uses of phosphate rock are animal feed supplements, direct application to soil as fertilizer, and elemental phosphorus production (Jasinski, 2015b).