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Viewpoint

Making Uranium Recovery from Phosphates Great Again?

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The United States is the world's largest consumer of uranium. In 2017, the great majority (93%) of this uranium was imported. A recent investigation by the current administration found that foreign uranium imports and the supply of related products—essential for the U.S. nuclear arsenal, blue-water navy, and power plants—pose no threat to national security. Declining domestic uranium mining is, however, regarded as a significant concern.

Uranium miners in the United States initiated the investigation, hoping for quotas on foreign uranium imports that would allow them to better compete with enterprises, often state-run and heavily subsidized, abroad. Quotas, if implemented, could, in fact, re-energize uranium mining in the U.S. They could also remotivate uranium recovery from unconventional resources, namely phosphates, which, at its height, contributed nearly 20% of the country's uranium requirements in the 1980s and is now poised to become monetarily profitable again and may be implemented much faster than new uranium mines that, ultimately, would have to be in someone's backyard.

Phosphates—and here, specifically, sedimentary phosphate rock—can contain considerable amounts of associated uranium, in regard to both concentrations and overall quantities. Phosphate rock is the fourth-most mined material on earth and used primarily (>90% globally) for mineral-fertilizer production.

Techniques to recover uranium from phosphoric acid, a liquid, intermediate product of phosphate-fertilizer production, are well-known[1,2] and were used in the United States and, to a smaller extent, elsewhere on an industrial scale until the late 1990s, when uranium prices plummeted, making recovery uneconomic for fertilizer producers.

■ URANIUM QUANTITIES IN PHOSPHATES

Increased environmental awareness, national energy security, and potentially rising uranium prices have led to a renewed global interest in the technology. Gabriel et al.[3] and Ulrich et al.[4] estimated that phosphate-fertilizer producers could provide slightly more than 15% of the world's peacetime uranium requirements. Similar studies were conducted for Argentina, where uranium as a byproduct of phosphate-fertilizer production could account for 8−9% of uranium requirements,[5] the EU (2% of uranium requirements),[6] and the United States (10% of uranium requirements).[7] In these studies, the quantity of uranium that could be recovered from phosphates would often outperform current traditional domestic uranium production. Kim et al.[7] estimated, for instance, that 5.5 million pounds U_3O_8, more than the domestic production for 2014 (4.9 million pounds U_3O_8), could have been provided by the U.S. phosphate industry.

Figure 1 compares uranium production with uranium imports per year in the United States. Further, historical uranium recovery from phosphates and potential uranium recovery from phosphates in the U.S. are indicated. With decreased uranium mining in 1990, quantities of uranium that could have been recovered from phosphates were larger than quantities actually mined. In Figure 1, uranium from all phosphate mines in the U.S., as well as uranium in phosphate rock imports, are considered. While its concentration is relatively high in Florida (160 mg/kg; compare this to the longest-operating, fifth-largest commercial uranium mine, Rössing in Namibia, with average uranium concentrations of 200−300 mg/kg and 0.003 mg/kg average concentration of uranium in seawater) and would justify recovery, it may not be that high at other locations (e.g., Idaho: 107 mg/kg and North

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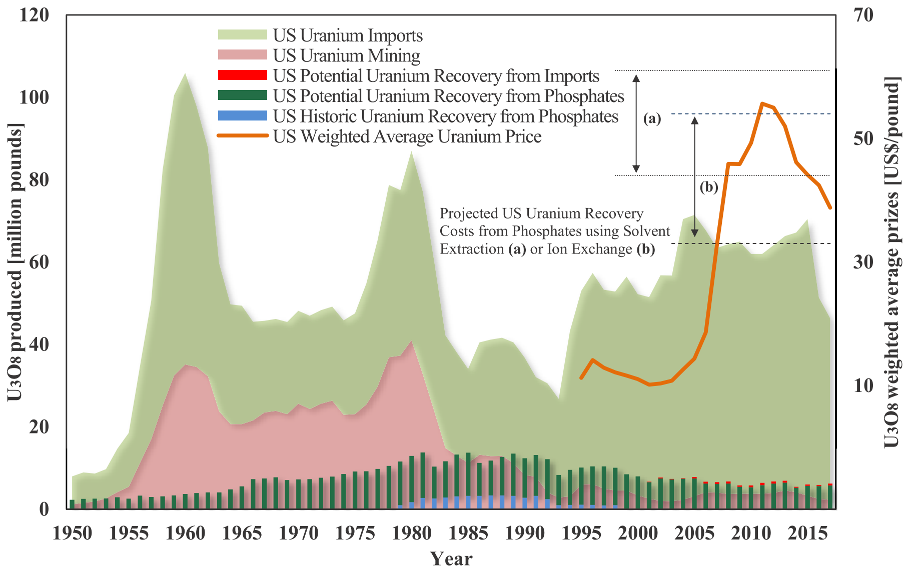

Figure 1. U.S. uranium imports, domestic uranium production, potential and historic uranium recovery from phosphates, and weighted-average uranium prices as well as projected minimum and maximum costs for uranium recovery using solvent extraction (a) and ion exchange (b) in the United States (Source: EIA[8] and Beltrami et al.[1]).

Carolina: 65 mg/kg). Thus, profitable uranium recovery would be more challenging. In this context, it is worth noting that the majority of radiotoxic uranium (70–80%) not recovered was—and will continue to be—dissipated by fertilizer on agricultural soils. The remainder will enter the phosphogypsum waste stream (a slurry of calcium sulfate and water that shows low levels of radioactivity and, thus, has limited use).

■ ECONOMICS OF RECOVERY

Despite relatively low uranium prices, civilian nuclear-power-reactor owners/operators in the United States purchased a total of 40 million pounds U_3O_8 equiv (U_3O_8e) of deliveries from U.S. and foreign suppliers during 2018 at a weighted-average price of US$ 38.81 per pound U_3O_8e.[8] Almost 42% of this uranium originated in Canada and Australia; some 40% came from Kazakhstan, Russia, and Uzbekistan, and nearly 10% originated in the United States. U.S.-origin uranium was delivered at a weighted-average price of US$ 45.26 per pound U_3O_8e.[8] In this context, costs for uranium recovery from phosphoric acid using industrially proven solvent-extraction technology are projected to range from US$ 44–61 per pound U_3O_8 in the U.S. today and are, thus, on the cusp of being economically profitable.[7,9] Uranium recovery using processes built on ion exchange, as yet unproven on a commercial scale for uranium recovery but currently being tested on a pilot-plant scale by PhosEnergy (an Australian company) in the U.S., may further reduce costs to US$ 33–54 per pound U_3O_8. Even greater cost savings could be realized if radiotoxic uranium is leached directly, before the digestion process, from beneficiated phosphate rock, making not only the final fertilizer but also the phosphogypsum byproduct virtually uranium-free.[10] Although gypsum is a widely used building material, phosphogypsum is usually stored indefinitely because of its low radioactivity, which results from naturally occurring uranium (and, to a smaller degree, thorium) in the processed phosphate rocks. Some 100–300 million tons phosphogypsum are produced annually worldwide, so that making this material available for unobjectionable utilization could save the fertilizer industry hundreds of millions of U.S. dollars in otherwise accruing annual storage costs.[10] Moreover, in regard to the aforementioned direct costs for uranium recovery from phosphates that can be estimated today, it is worth noting that we may be confronted with accruing indirect costs for groundwater purification from fertilizer-derived uranium if current practices remain unchanged.

■ QUO VADIS URANIUM RECOVERY?

Uranium recovery from phosphates is already a good idea with regard to resource conservation and the envisaged Sustainable Development Goals (SDGs) of the United Nations. The framework provided by national U.S. policymakers will determine whether or not uranium will again be recovered during fertilizer production. In this context, quotas on foreign uranium imports in the U.S. may, in fact, knowingly or unknowingly provide a framework that incentivizes uranium extraction during U.S. fertilizer production and, thereby, make uranium recovery from phosphates great again.

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Notes

The authors declare no competing financial interest.

■ REFERENCES

(1) Beltrami, D.; Cote, G.; Mokhtari, H.; Courtaud, B.; Moyer, B. A.; Chagnes, A. Recovery of Uranium from Wet Process Phosphoric Acid by Solvent Extraction. *Chem. Rev.* **2014**, *114*, 12002−12023.

(2) Singh, D. K.; Mondal, S.; Chakravartty, J. K. Recovery of Uranium From Phosphoric Acid: A Review. *Solvent Extr. Ion Exch.* **2016**, *34*, 201−225.

(3) Gabriel, S.; Baschwitz, A.; Mathonnière, G.; Fizaine, F.; Eleouet, T. Building future nuclear power fleets: The available uranium resources constraint. *Resour. Policy* **2013**, *38*, 458−469.

(4) Ulrich, E.; Schnug, H.-M.; Prasser, E. Frossard, Uranium endowments in phosphate rock. *Sci. Total Environ.* **2014**, *478*, 226−234.

(5) López, L.; Castro, L. N.; Scasso, R. A.; Grancea, L.; Tulsidas, H.; Haneklaus, N.; Nacional, C.; Atómica, D. E.; Libertador, A.; Aires, C. B. Uranium supply potential from phosphate rocks for Argentina' s nuclear power fleet. *Resour. Policy* **2019**, *62*, 397−404.

(6) Tulsidas, H.; Gabriel, S.; Kiegiel, K.; Haneklaus, N. Uranium resources in EU phosphate rock imports. *Resour. Policy* **2019**, *61*, 151−156.

(7) Kim, H.; Eggert, R. G.; Carlsen, B. W.; Dixon, B. W. Potential uranium supply from phosphoric acid: A U.S. analysis comparing solvent extraction and ion exchange recovery. *Resour. Policy* **2016**, *49*, 222−231.

(8) EIA. *Uranium Marketing Annual Report*, 2019; https://www.eia.gov/uranium/marketing/.

(9) Hore-Lacy, I. *Production of Byproduct Uranium and Uranium from Unconventional Resources*; Elsevier Ltd, 2016; http://dx.doi.org/10.1016/B978-0-08-100307-7.00009-0.

(10) Al Khaledi, N.; Taha, M.; Hussein, A.; Hussein, E.; El Yahyaoui, A.; Haneklaus, N. Direct leaching of rare earth elements and uranium from phosphate rocks. *IOP Conf. Ser.: Mater. Sci. Eng.* **2019**, *479*, 012065.

■ NOTE ADDED AFTER ASAP PUBLICATION

Due to a production error, this paper was published ASAP on January 15, 2020, with an incorrect version of Figure 1. The corrected version was reposted on January 16, 2020.

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