The U.S. Uranium and REE Supply Chains: A Brief Discussion

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Source: CRS generated a conceptual diagram depicting uranium material flows at the front-end of the nuclear fuel cycle.

Notes: The figure shows a simplified version of the nuclear fuel supply chain for domestic nuclear power reactors.

“Domestic” and “Foreign” are used here consistent with DOE’s interpretations of the terms. Domestic refers to physical facilities operating within the United States, regardless of a foreign corporation ownership. In some instances, domestic uranium producers, suppliers, enrichers, and utilities operating in the United States have foreign ownership or are subsidiaries of foreign corporations. The term foreign is used to describe any non-U.S. based facility or material origin. Foreign inventories may exist in other countries, but are not shown here.
Domestic Sources of Uranium


The In Situ Leaching Process


Domestic Sources of Conversion & Enrichment

Gaseous Centrifuges

Domestic Sources of Fuel Fabrication

The Nuclear Fuel (Uranium) Supply Chain - From Mining to Storage

Open Pit / Underground

Isotopic separation U$^{235}$ from U$^{238}$ by gaseous diffusion
From 0.07% U$^{235}$ to 3.0% U$^{235}$

mining
conversion
enrichment

In-Situ Recovery & Processing

From Yellowcake to UF$_6$ $\text{U}_3\text{O}_8$ Contains >99% U$^{238}$

fuel fabrication
(Fuel Pellets)

nuclear reactor

front end of cycle

back end of cycle

“final” disposition
(Storage / Re-Use)

“spent fuel reprocessing”

interim storage
(Fuel Rod Cooling)

(Only Loss of 5% of Contained Energy)

U.S. EIA (2021)

Note: Used Fuel should be stored (not disposed) and should be used in “breeder” reactors, which are under development now. For discussion of storage of used uranium fuel, See Conca (2017).

Campbell (2020)


Isotopic separation U$^{235}$ from U$^{238}$ by gaseous diffusion
From 0.07% U$^{235}$ to 3.0% U$^{235}$

U.S. EIA (2021)
### Power Plant Economics: Nuclear Fuel Costs Make all the Difference

<table>
<thead>
<tr>
<th></th>
<th>Nuclear Power Plant*</th>
<th>Natural Gas Plant**</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production Rate: 1,000 MWe</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Capital Costs:</td>
<td>$6 Billion</td>
<td>$2 Billion</td>
</tr>
<tr>
<td>Fuel Costs/Year:</td>
<td>$64 Million</td>
<td>$450 Million</td>
</tr>
<tr>
<td>Construction Time:</td>
<td>7 years</td>
<td>3 years</td>
</tr>
<tr>
<td>Interest Rate:</td>
<td>3%</td>
<td>3%</td>
</tr>
<tr>
<td>Repayment/Year:</td>
<td>$285 Million</td>
<td>$57 Million</td>
</tr>
<tr>
<td>Electricity Sales / Year</td>
<td>$525 Million</td>
<td>$525 Million</td>
</tr>
</tbody>
</table>

#### Three SMR Units*
- Sum of Production: 1,000 MWe
- Capital Costs: $1.5 Billion
- Fuel Costs/Year: $64 Million
- Construction Time: 3 years
- Interest Rate: 3%
- Repayment/Year: $160 Million
- Electricity Sales / Year: $525 Million

#### What’s the Difference in the Economics?
- Natural Gas Plants are built faster and have lower capital costs, but natural gas fuel costs are about 7X higher than uranium fuel costs.
- Natural Gas Plants pay off in 10 years, but large-scale Nuclear Power Plants pay off in 25 Years.
- Natural Gas Plant lifetime is about 15 years, but Nuclear Power Plant lifetime is >50 years, similar to most Hydroelectric Power Plants.
- Nuclear Power Plants generate much greater profit over a longer period of time than Natural Gas Power Plants.
- With introduction of SMRs, economics become superior to Natural Gas Plants, led by lower fuel costs.

*Climate Friendly
** Climate Unfriendly

[ Economic model after Ruzic (2019) ]
Assessment of U.S. Rare Earth Element Supply Chain

• The Annual Global Rare Earth Market was ~$8 billion in 2018, whereas the U.S. only consumes around 7% of global demand of REE by weight.

• U.S. imported ~$160 million worth of rare-earth compounds and metals (excluding Yttrium and Scandium) in 2018, while importing $2.6 trillion worth of finished products in 2018

• The majority of REE’s imported into the U.S. is in finished products, and not as a raw material (per USGS), ~$120 million (excluding Y & Sc); Estimated REE Value >$1.5 billion in products (excluding Sc).

• The U.S. Government is now supporting domestic production of REEs for national security and technical independence.

• China has become a net importer of REEs associated with permanent magnets; and will be likely net importer of other REEs by 2030, hence China’s interest in Greenland Minerals and Australian REE mines.

• Growing world demand for high-tech and green technologies will increase the demand for rare earth elements for foreseeable future.

• Changing market drivers could stabilize, and even increase rare-earth market prices for high demand compounds.... specialized applications.

• Additional uses for more abundant REEs still needed and opportunities for exploration may develop.

• REE recovery from coal-based feedstock and coal-ash waste has been proven technically feasible.

• Economic feasibility is greatly dependent on market conditions of each REE.

• Research is occurring to reduce or replace REEs in many finished goods.

• U.S. rare-earth industry is being coupled with domestic supply chain including U.S. deposits.

• Even with a successful domestic REE industry, China will continue to control the REE market for many years ... because they are producing and marketing finished products containing REEs to the world.


After Network News Wire (2020)
After Campbell, et al., (2020)

**Bottom line ....**

- Historical trade routes are changing,
- Change depends on demand, country, source G-T, and location of refiners,
- Supply chains in flux, &
- Specific REE Demand increasing (magnets, etc).
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Questions?

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For additional information on the subjects just briefly discussed in this presentation, search any key words in the I2M Web Portal. For a mini-webinar video on the use and content of the Web Portal, see (here).

For Dynamic Updates:

Uranium
Nuclear Power
Rare Earths

For the PDF of this presentation containing hyperlinks, see: https://i2massociates.com/downloads/U-REESupplyChains2021.pdf