AAPG Webinar

Pivoting 2021: Energy Industry Supply Chains

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Susan Nash, Ph.D. Moderator

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

For the *YouTube* Presentation (here)

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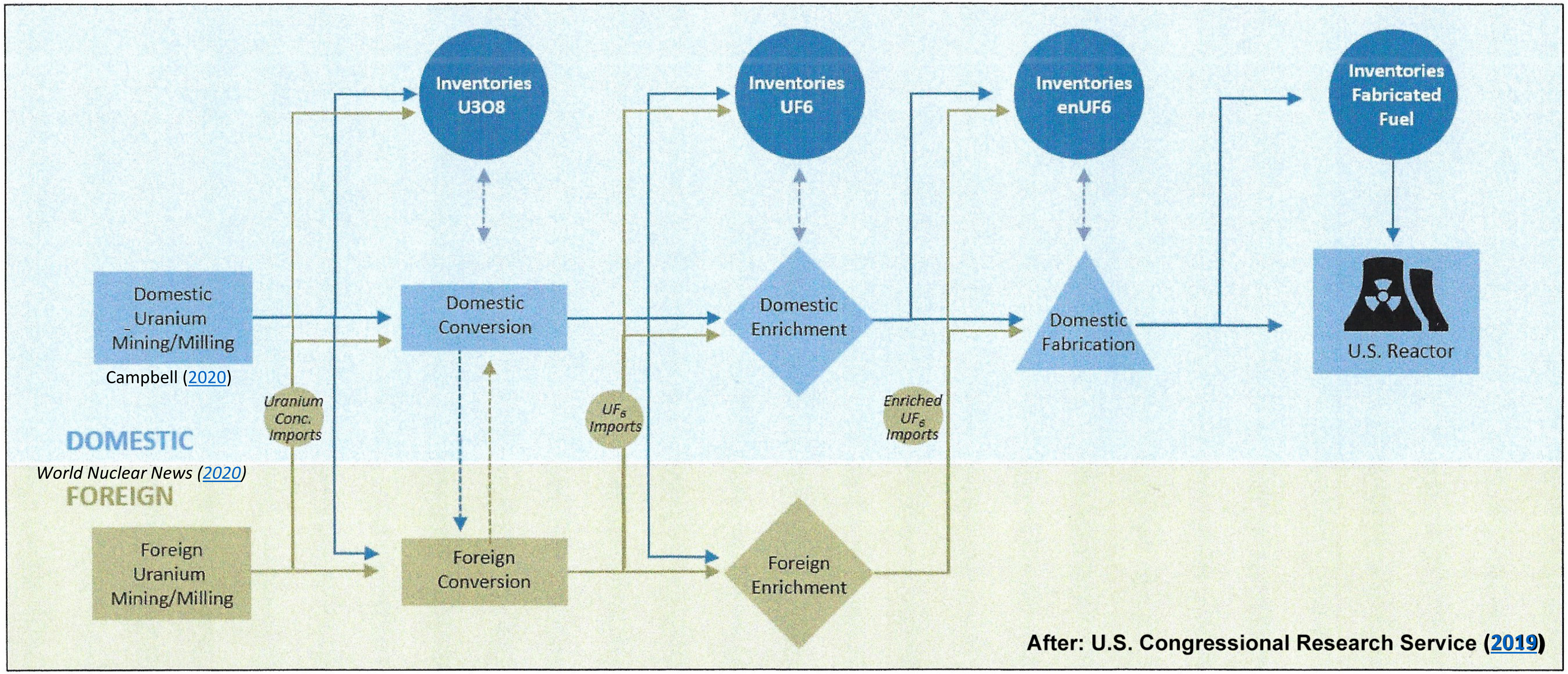
Current Front End of Nuclear Fuel (Uranium) Supply Chain



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

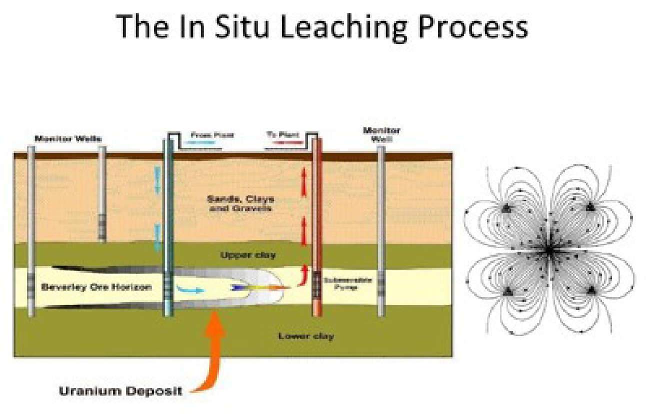
Notes: The figure shows a simplified version of the nuclear fuel supply chain for domestic nuclear power reactors.

"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

Campbell (2020)

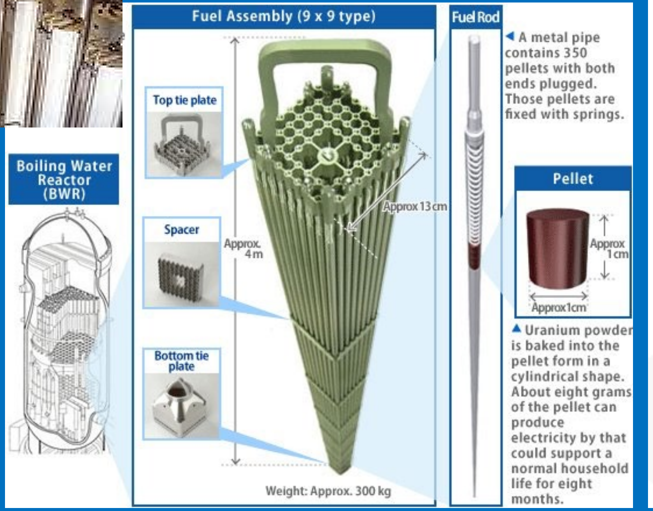
Campbell, et al., (2007)

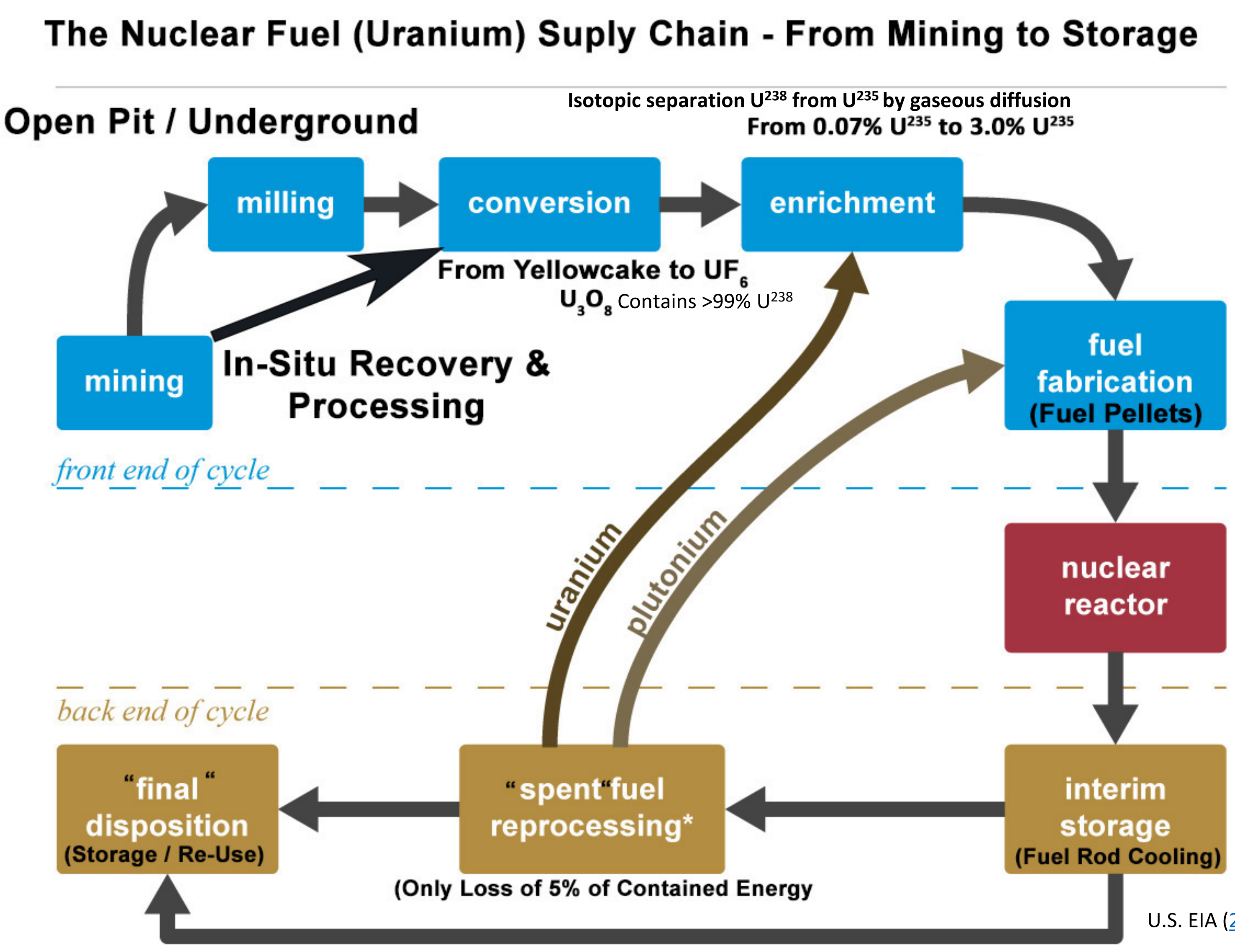


Gaseous Centrifuges

Domestic Sources of Conversion & Enrichment

Domestic Sources of Fuel Fabrication





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).

Power Plant Economics: Nuclear Fuel Costs Make all the Difference …… **Introduction of SMRs ?**

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

But …

Three SMR Units* Sum of Production: 1,000 MWe
$1.5 Billion
$64 Million
3 years
3%
$160 Million
$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.

[Economic model after Ruzic (2019)]

*Climate Friendly
** Climate Unfriendly

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.

Summers (2019) and after Campbell, et al., (2020)

REVIVING THE U.S. REE MARKET

The U.S. Department of Energy estimates that in 2018 the global REE market was valued at approximately $8 billion. The U.S. imports all of the REEs it consumes, about 80% of which comes from China. In 2018, the DOE said that the nation imported about $160 million worth of rare earth compounds and metals, excluding yttrium and scandium. However, the real economic cost of REEs is deceptive insomuch that the nation imports nearly all of its REE in the form of finished goods rather than raw material.

UNDISPUTED LEADER IN URANIUM, VANADIUM — AND NOW REES

Since the late 1990s, the nation has effectively ceased processing any REEs, while China established a commanding global position controlling 90% of global production. Last year, the Pentagon began changing that dynamic by committing to provide funds to REE mines and processors through the Defense Production Act. Then, in a milestone moment for the industry and country, in October 2020, Energy Fuels Inc. produced a mixed REE concentrate from monazite sand at its wholly owned White Mesa Mill in Utah.

FIRST MOVER, LIGHTNING PACE

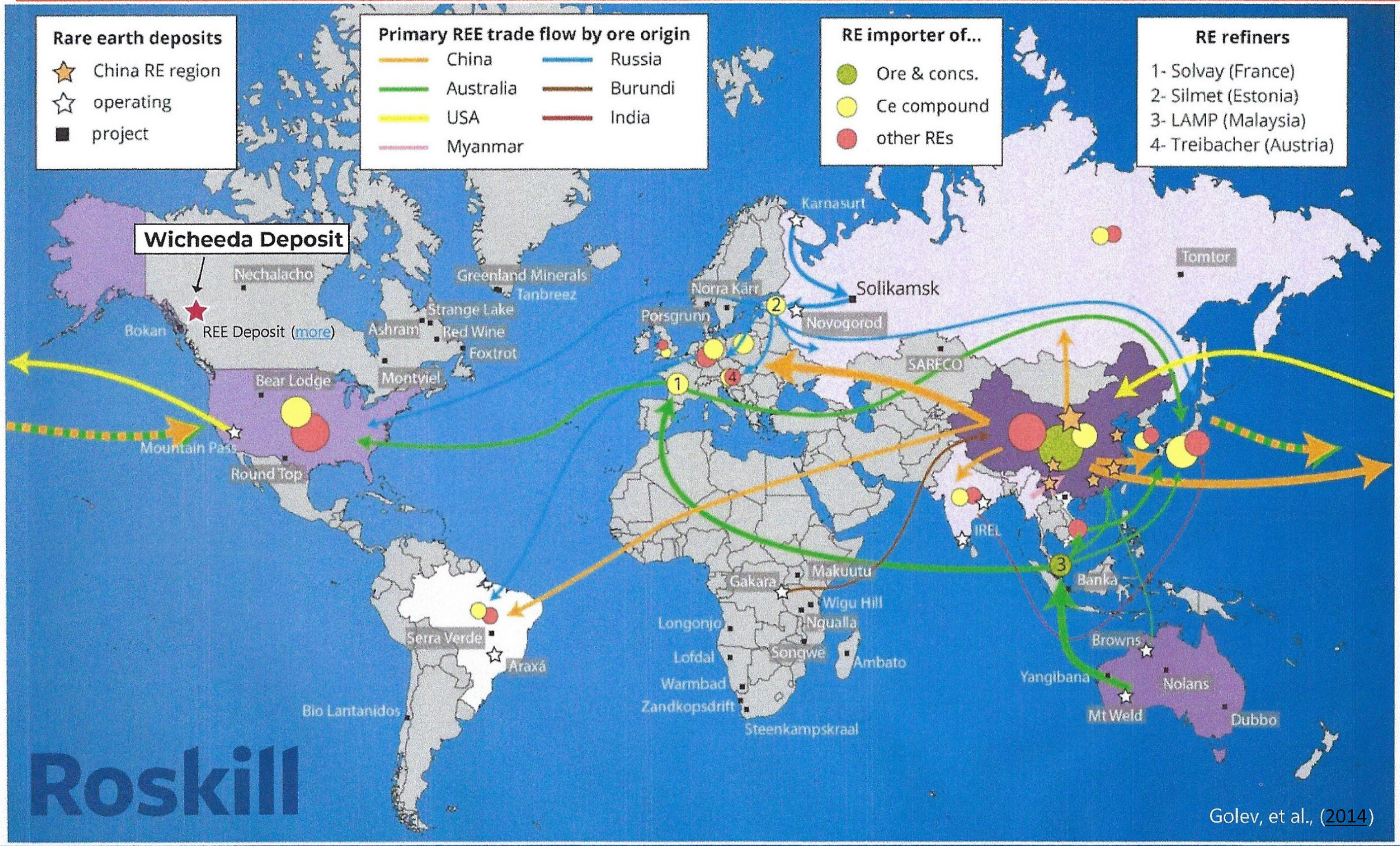
Once it announced its intention in April 2020 to build its footprint in REEs, Energy Fuels moved quickly to complete a pilot-scale monazite production run just seven months later. The company was able to accomplish this milestone quickly because it utilized existing resources, infrastructure and technologies, providing the company with a competitive advantage. The company believes it can enter commercial REE production more quickly and inexpensively than others because of its existing licensed and constructed assets and experience.

A SEA CHANGE HAPPENING

The Chemours Company isn't a name that most associate with REEs, but Chemours is one of the biggest U.S. miners of natural monazite ore through its subsidiary Southern Ionics Minerals.
Shares of **Tesla Inc.** continue to soar as investors keep bidding up electric vehicle makers as the wave of the future.
Apple Inc. may be eking its way out of China, although evidence remains to be seen to what extent.
Siemens Gamesa Renewable Energy SA is a recognized leader in the wind turbine industry with its rare earth neodymium iron boron direct drive generators for both inland and offshore windfarms.

After Network News Wire (2020)

REE Historical Trade Routes: Major Sources, REE Refiners



Golev, et al., (2014)

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).

After Campbell, et al., (2020)

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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