

Critical Minerals Supply Chain: Addressing an Energy Transition Bottleneck

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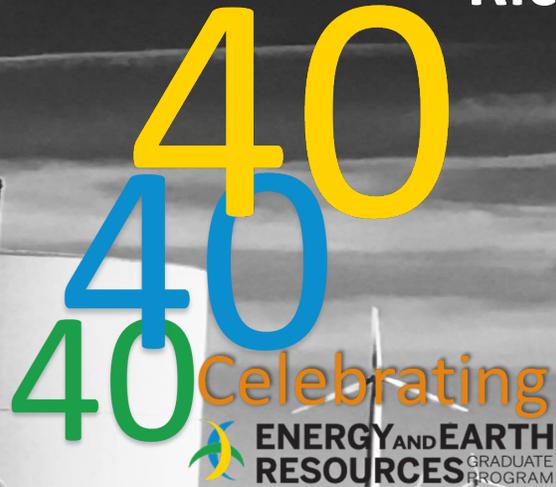
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TEXAS Geosciences

The University of Texas at Austin
Jackson School of Geosciences

Photo courtesy of David Leary, 2018

multidisciplinary studies for interdisciplinary solutions

Solving energy resource problems

Every earth resource problem is multidisciplinary

Solving three simultaneous equations:

$f(x_1)$ = sound science and technology

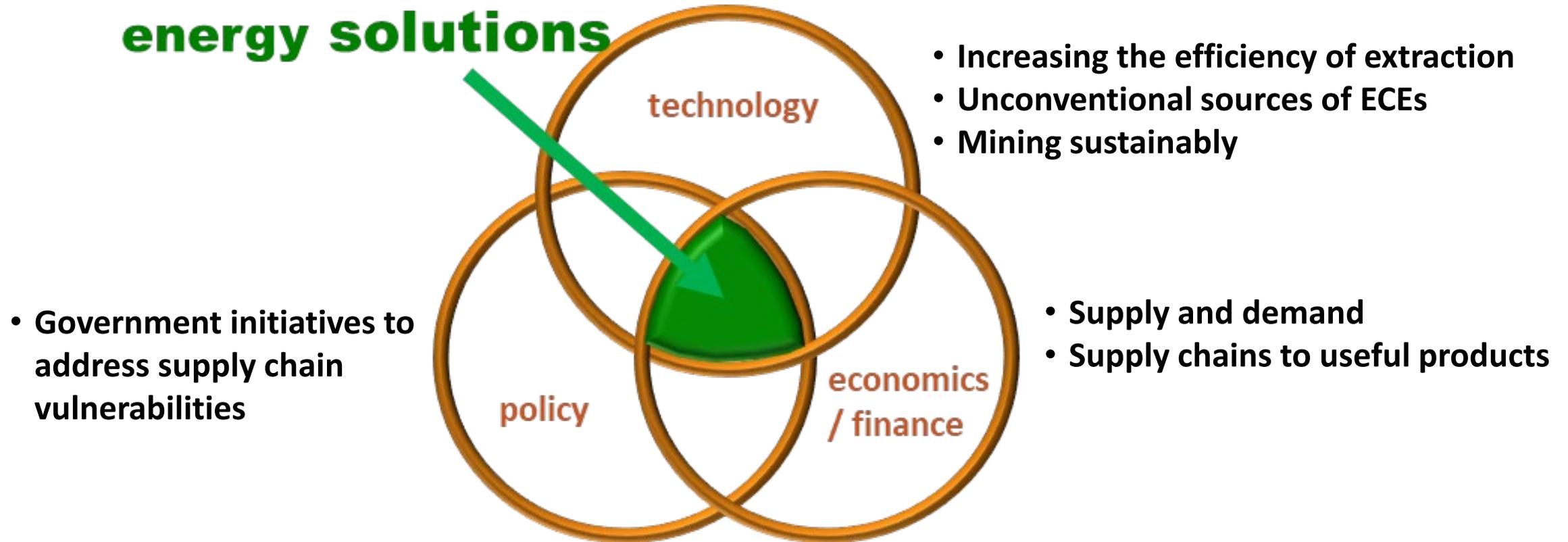
$f(x_2)$ = consistency with policy which adequately addresses the welfare of society

$f(x_3)$ = financial viability to attract the interest of investors

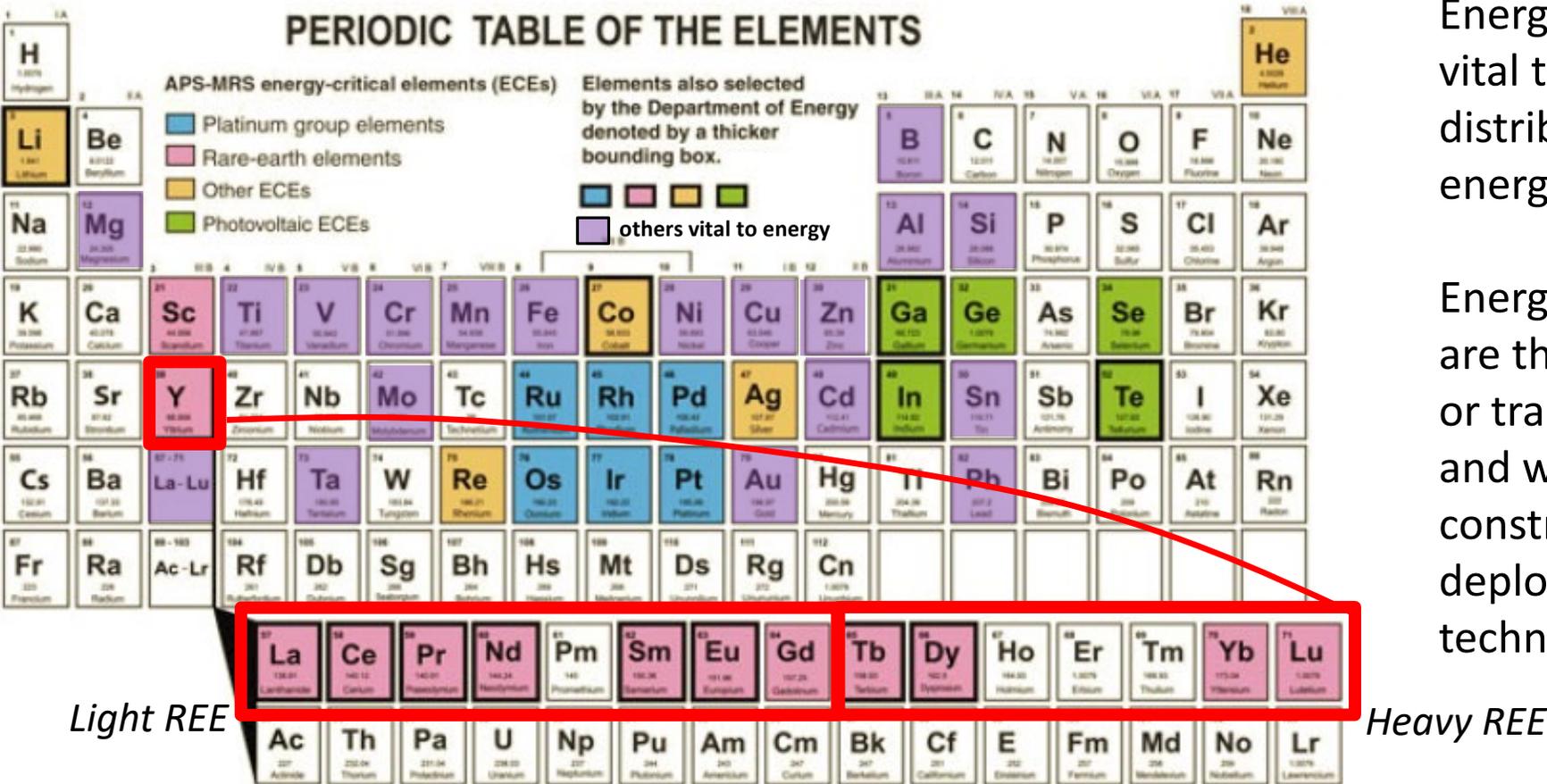


The broad panorama

sustainable energy solutions



Definitions



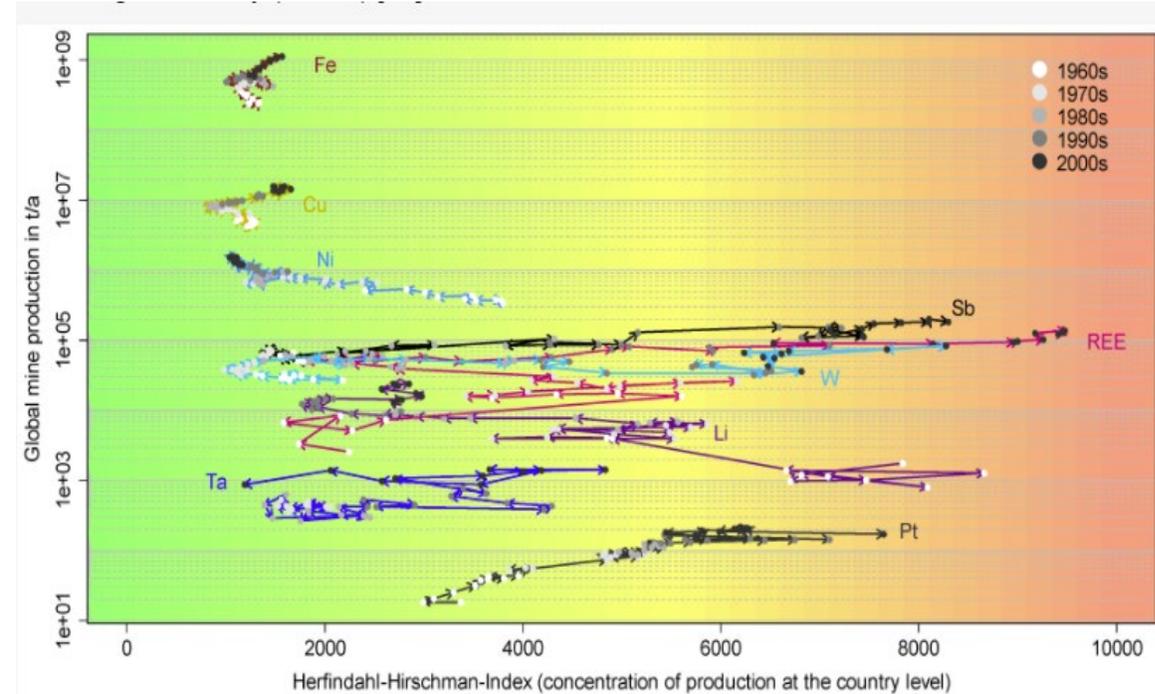
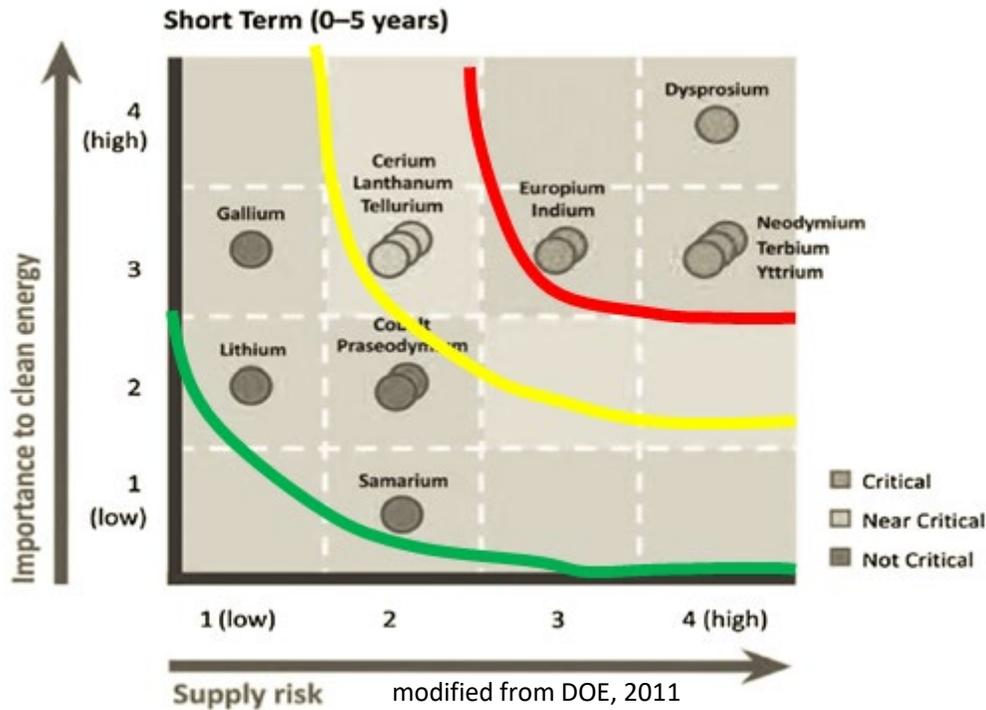
modified from Hurd et al., 2012

https://www.researchgate.net/publication/259420442_Energy-critical_elements_for_sustainable_development

Energy Elements (EE) are those vital to the production, distribution, storage and use of energy resources (e.g. Cu)

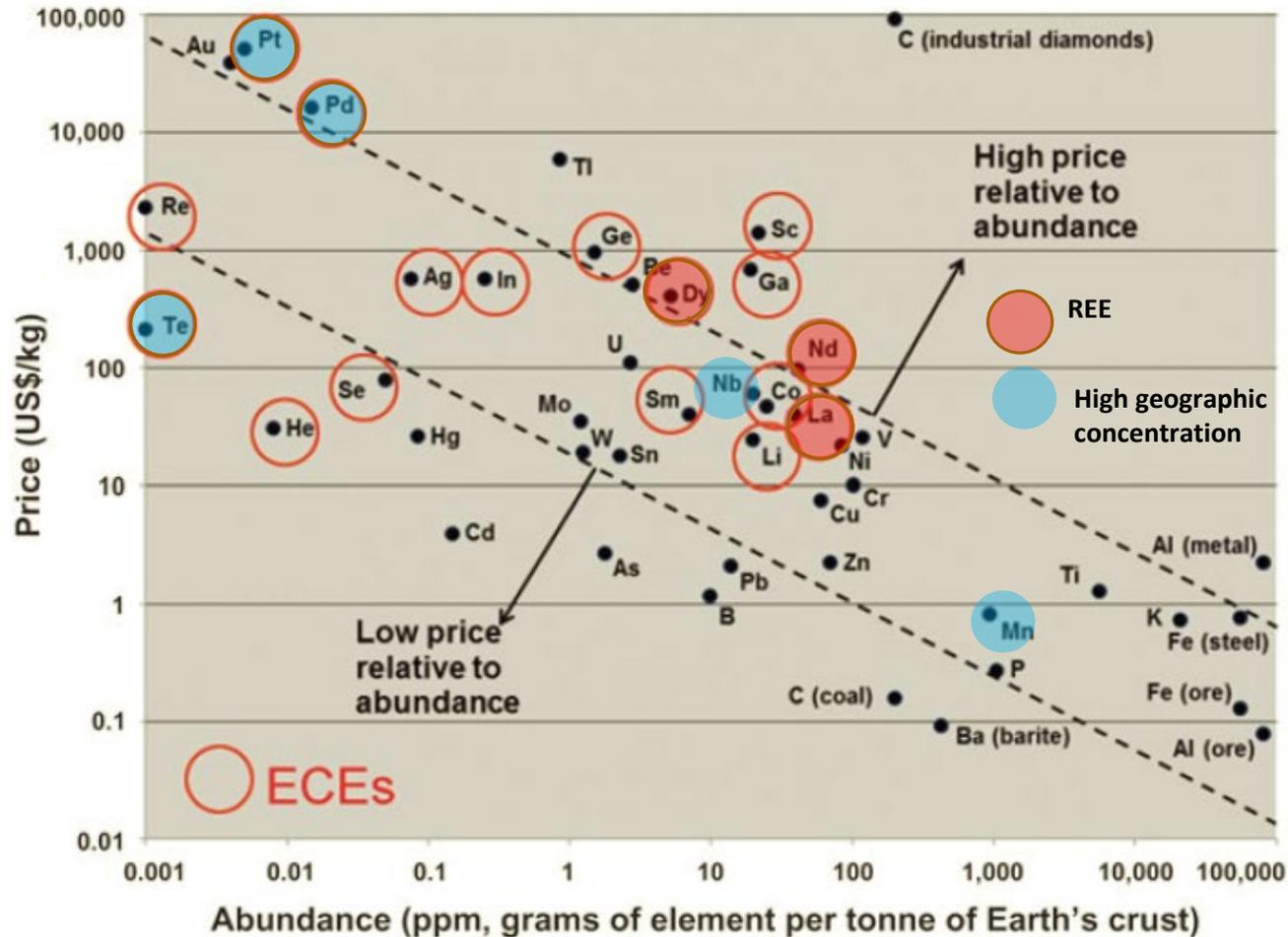
Energy Critical Elements (ECE) are those not mined, refined or traded in large quantities and whose supply could constrain adoption and deployment of new energy technologies (supply risks)

Criticality matrices



- High tech metals with low production or produced as by products, where production is geographically concentrated, have the highest supply risk
- Heavy and light REE are consistently identified as high risk
- Criticality is in the eye of the beholder

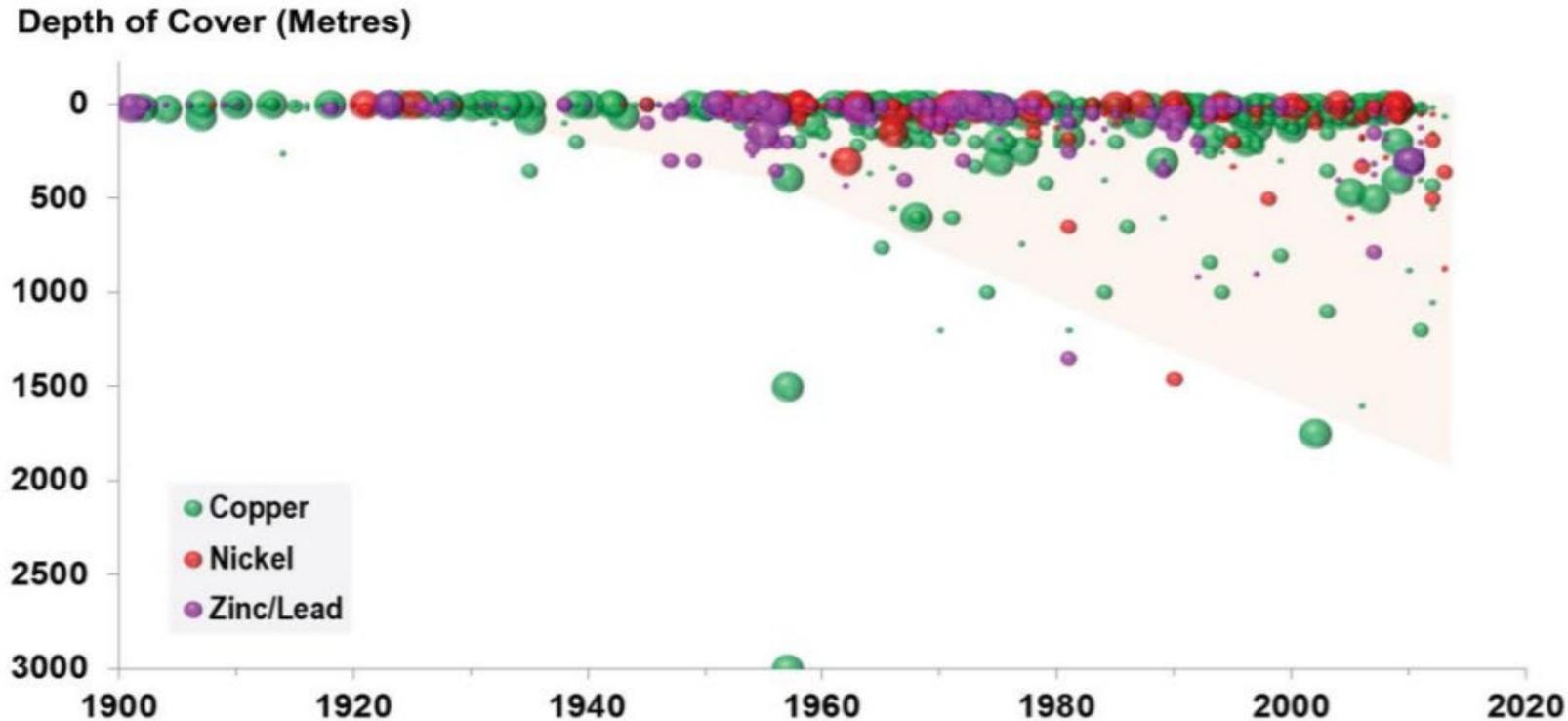
EE / Abundance vs. price



modified from Hurd et al, 2012

- ECE have moderate to low abundance
- REE are not rare
- Numerous ECE have high geographic concentration
- Expected correlation between abundance and price

...and we have just scratched the surface



N = 1034

Note: Size of bubble refers to "Moderate", "Major" and "Giant"-sized deposits.

Excludes Nickel Laterite deposits

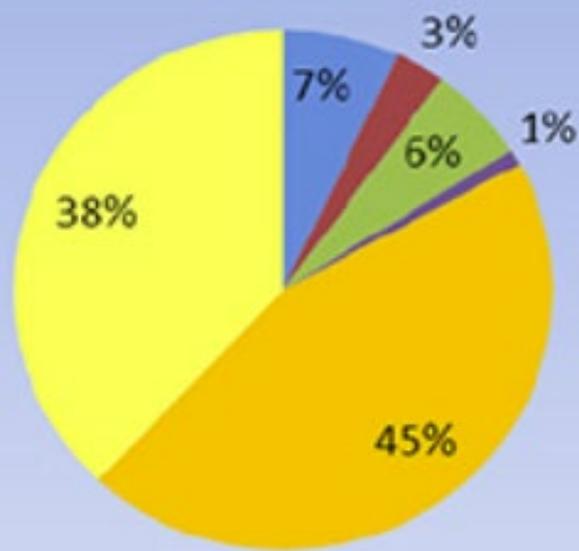
<https://www.geolsoc.org.uk/~media/shared/documents/RFG/RFG%20Full%20Report%202015.pdf?la=en>

Nickless et al., 2015

- Most historically producing ore deposits have surface expressions
- Demand has pushed exploration, development deeper underground; higher cost (incl. energy)

...and we haven't touched the seafloor

Terrestrial and Ocean Floor Deposits



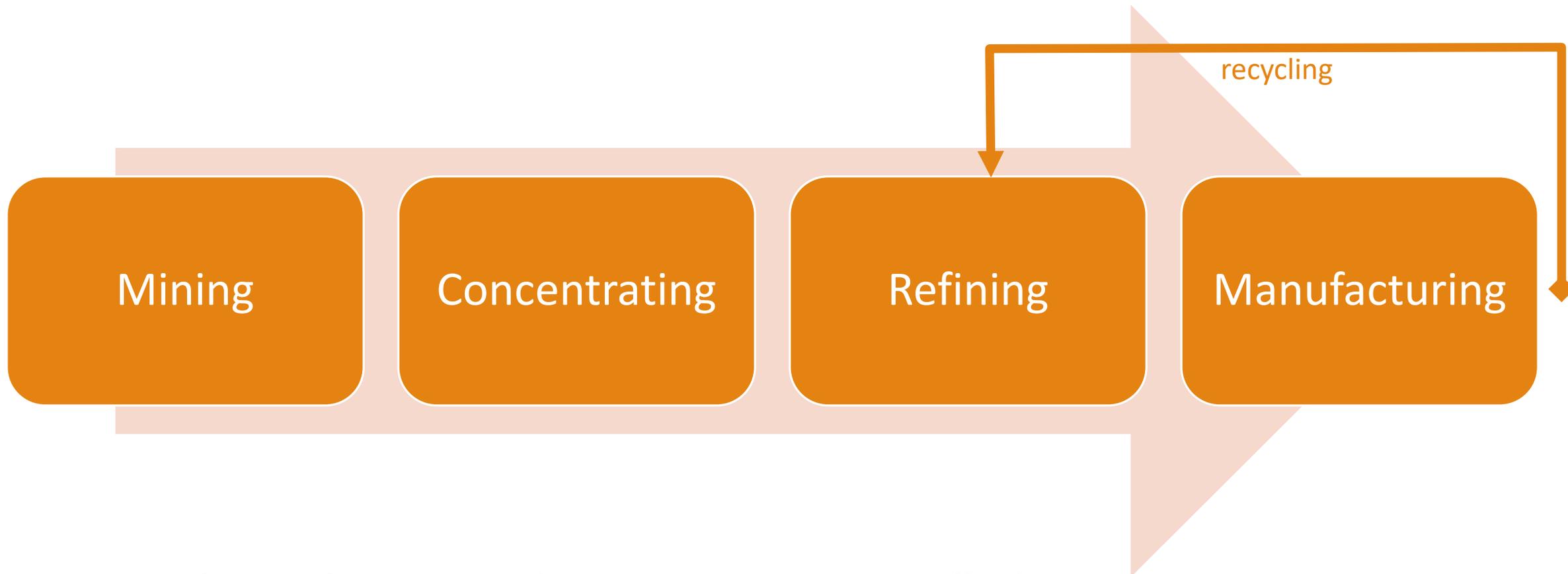
Shedd, 2015

- Sediment-hosted stratiform Cu-Co
- Magmatic Ni-Cu(-Co-PGE) sulfide
- Ni-Co laterite
- Other terrestrial
- Seafloor Fe-Mn(-Ni-Cu-Co-Mo) nodules
- Seafloor Fe-Mn(-Co-Mo-REE) crusts



<https://chinadialogueocean.net/6682-future-deep-seabed-mining/>

The supply chain



- Finding and mining an the resource is not typically the issue
- You need to play in the entire supply chain to assure full resilience
- Recycling must grow in importance

China REE Inc.

- Largest global producer is the Bayan Obo mine near Baotou, Inner Mongolia region
 - High grade (3-5.4% REE), LREE enriched
 - By-product of iron ore and niobium production
 - >80% of China's REE reserves
- Secondary production from ion exchangeable clays in Jiangxi
 - Low grade but very cheap extraction; HREE enriched
- Success formula will be difficult /impossible to replicate
 - national strategy
 - cheap labor
 - vertical integration
 - technology-specific intellectual capital
 - subsidies
 - lax environmental regs
- Global prospectivity for REE is not an issue but building processing facilities outside China will be capital intensive and challenged by social resistance (e.g. Malaysia).
 - 85% of all REE oxides (including those from Mountain Pass in the U. S.) are processed in China
 - No major mining companies have committed to REE development; are unlikely to do so given the size of the market

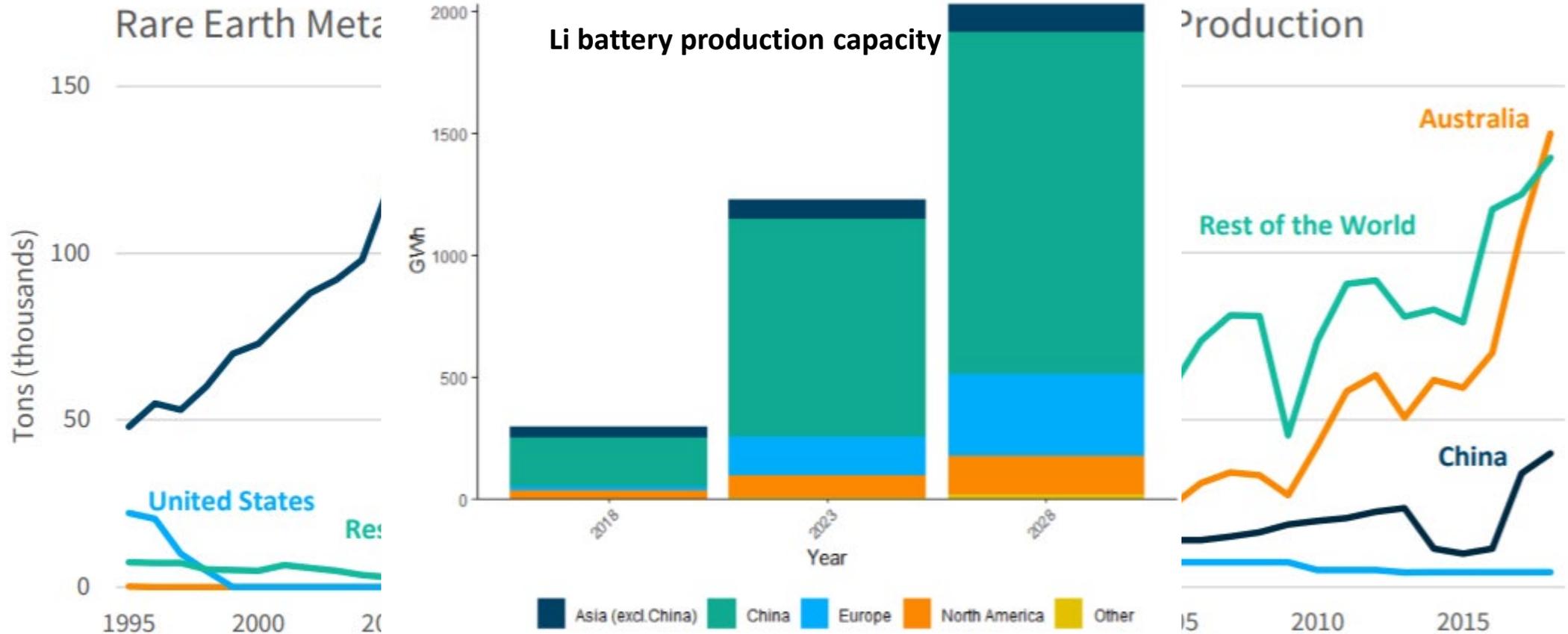


<https://www.latimes.com/world-nation/story/2019-07-28/china-rare-earth-tech-pollution-supply-chain-trade>



<https://www.bbc.com/future/article/20150401-the-worst-place-on-earth>

Li and REE production



Source: BP, *BP Statistical Review of World Energy, 2019* (London: 2019), <https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2019-full-report.pdf>.

Making mining sustainable

Panasquiera mine, Portugal



Valiero and Blight, 2019
F. Wall

- **350 Gt produced worldwide each year**
- **20X all municipal solid waste**
- **Our biggest waste form, by far**
- **...but is this waste a resource?**