# Recovering rare earth metals from waste

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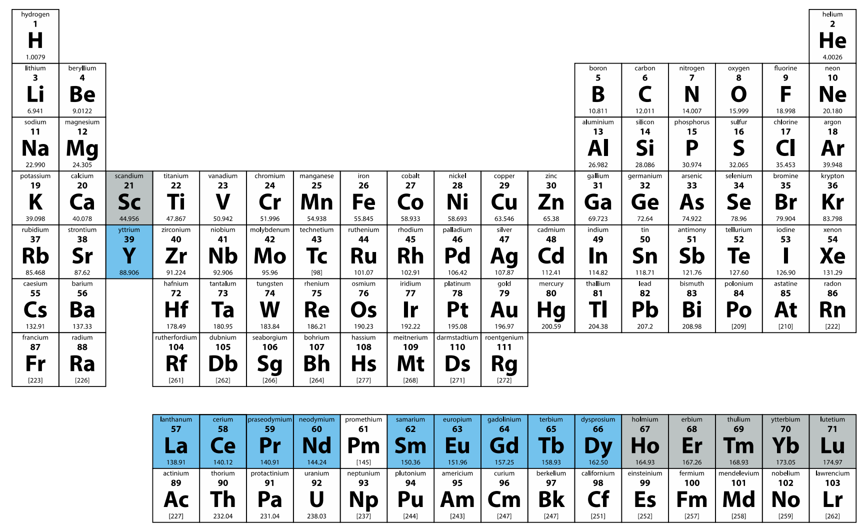
# In brief:
# production and use of rare earth elements

Rare Earth Elements (REEs)

- Few substitutes
- Over 97% produced in China
- <1% are recycled
- Energy and resource intensive to produce
- Utilized by existing and emerging technologies (including clean energy technologies)

(US DOE 2011, EU 2014, Reck and Graedel 2012, Zaimes et al 2014)

# Societal Risks for Rare Earth Metals

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- **Supply risk**: "critical" to many high tech industries, could easily become a tool/victim in trade wars.
- **Environmental risk**: little data on impacts of primary production, but technically difficult (REEs are chemically similar) leads to high chemical and energy use.

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# Possible solution: recover REEs from wastes (secondary source)

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- Increase supply, nations with lots of REE-containing wastes could become major producers
- Recycling is **usually** more environmental friendly than making from primary ores.


| Primary | Secondary |
|---|---|
| Mine / Ore | In-use stocks, E-Waste, or End-of-life Products |
| Composition<br>Ore Grade (%) | Composition<br>Concentration by weight (%) |
| Extraction Technology | Recovery Technology |


VS.

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# Possible sources of REE from wastes

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Coal Combustion Products (CCPs)

- Ash byproducts of energy production from coal
- Current end of life – impounding, concrete, structural fill, road base
- Also contain heavy metals

Industrial byproducts and wastes

- Phospho-gypsum
- Dross/slag
- Red mud

Electronic waste

- Phosphors from LED, LFL
- NiMH batteries
- Laptops, desktops
- Cellphones
- Speakers

# Two approaches to better understand potential of recovering REEs from waste

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1. Characterize how much REE is in different waste streams (tons) and how likely is it be to easy to extract (grade). Compare with REE production and demand.
2. Techno-economic analysis to estimate potential profitability and emissions from lab scale processes.

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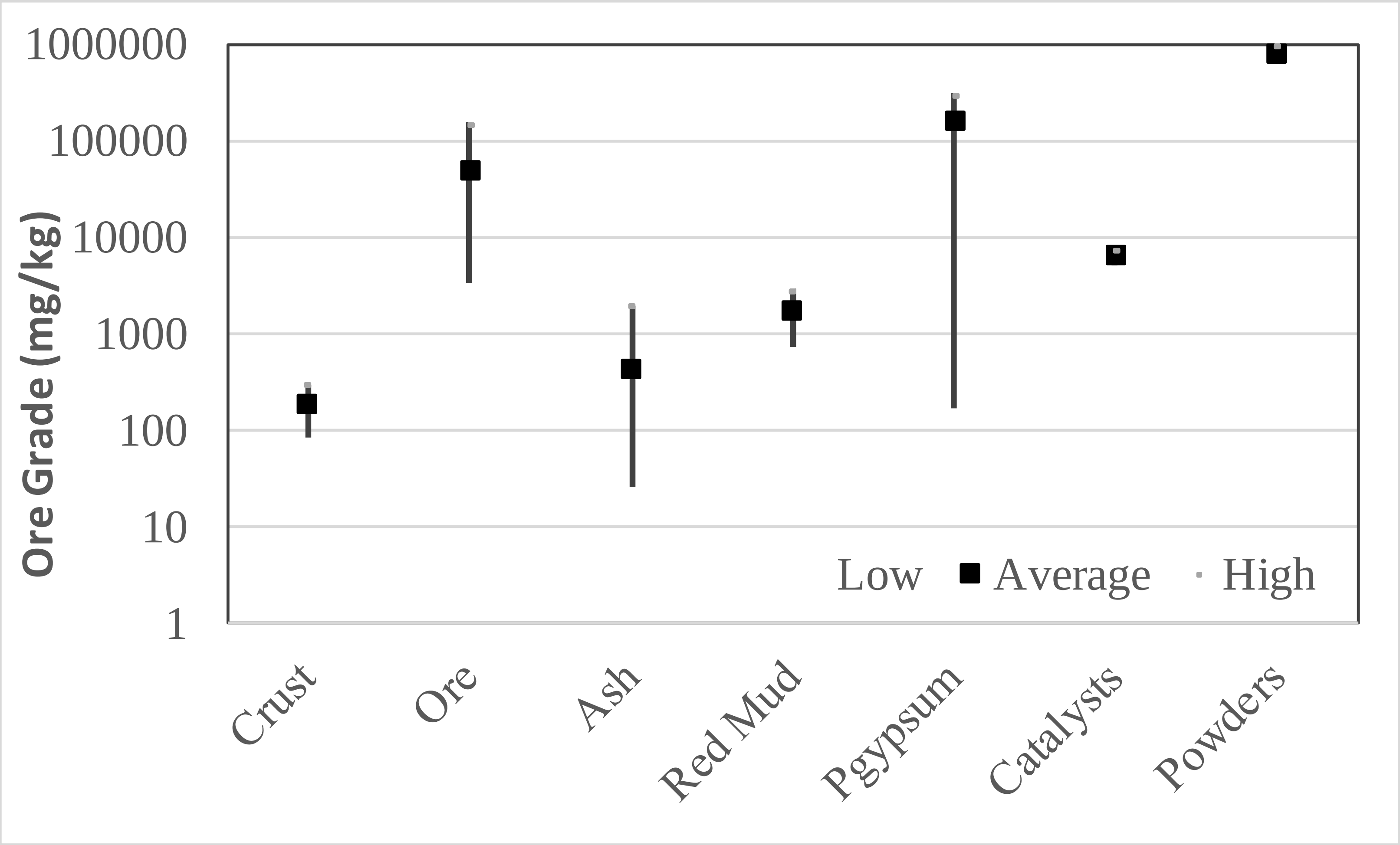
# “**Ore**” grade or quality of resource:
What is the concentration of REEs in wastes versus earth sources?




G. Gaustad, E. Williams, and A. Leader (2019). under review

# Quantity and Quality in Context

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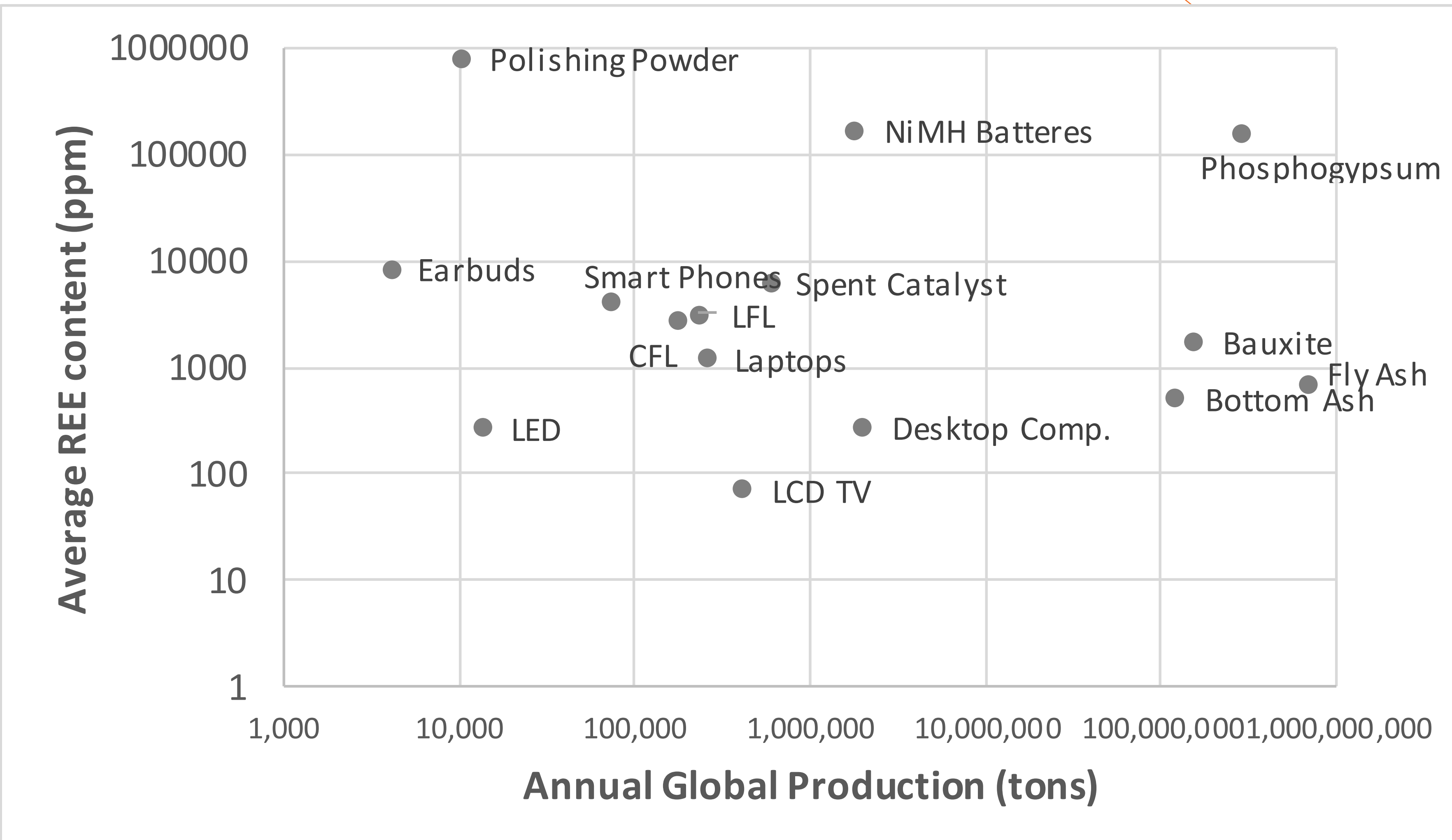


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# Could REE from coal combustion products meet current and future REE demands?

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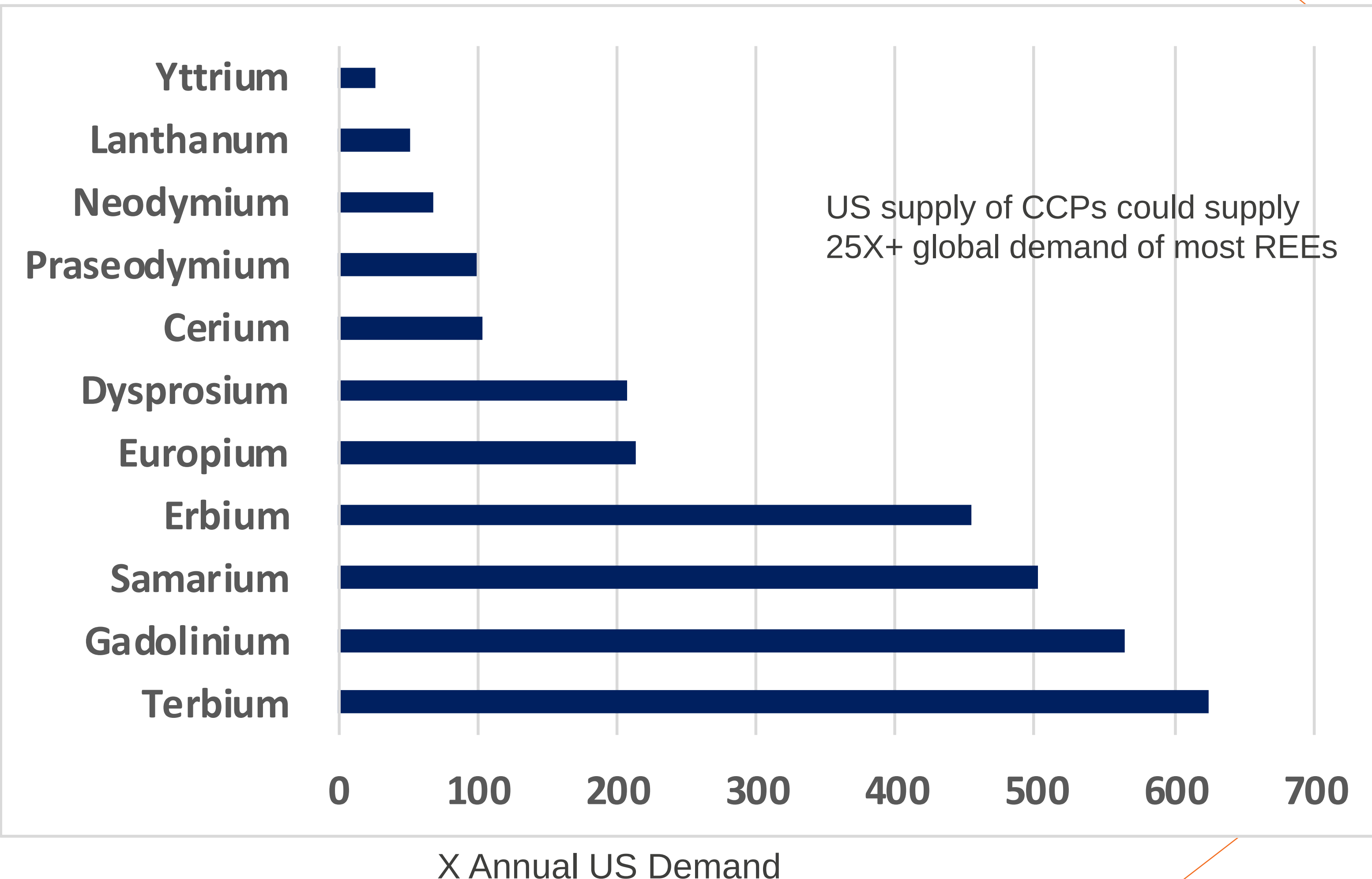


Yes in principle, but at what **cost?**

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# Lots of lab-scale extraction studies

| Technology | REE source | Reference |
| --- | --- | --- |
| acid leaching | fluorescent lamps | tian 2016 |
| dense medium centrifugation | fluorescent lamps | hirajima 2005 |
| flotation separation | fluorescent lamps | hirajima 2005, otsuki 2008 |
| L-L extraction | fluorescent lamps | mei 2009, Meor 2013 |
| hydrometallurgy | fluorescent lamps | rabah 2008, de michelis 2011 |
| photocatalytic extraction | fluorescent lamps | wu 2013 |
| ionic liquid extraction | fluorescent lamps | yang 2012, 2013 |
| supercritical extraction | fluorescent lamps | shimizu 2005 |
| alkaline roasting | fluorescent lamps | wu 2014 |

Result:
Range of yields
Quantified inputs

| Technology | REE source | Reference |
| --- | --- | --- |
| hydrometallurgy | NiMH batteries | Rodrigues 2010 |
| hydrogen decrepitation | magnets | Walton 2015 |
| pyrometallurgy | magnets | Okabe et al 2003 |
| ionic liquid/solvent extraction | magnets | Vander Hoogerstraete et al 2013 |

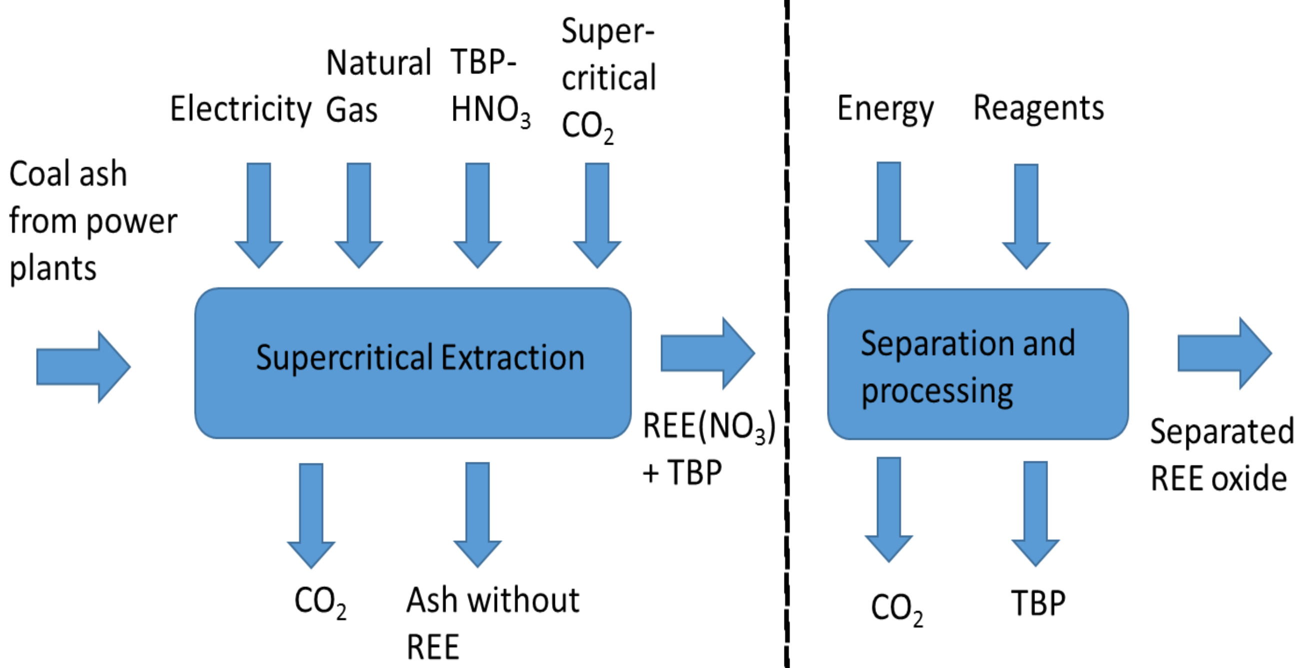
| Technology | REE source | Reference |
| --- | --- | --- |
| acid leaching | coal ash | Peiro and Mendez 2013 |
| ion exchange | coal ash | Chi et al 2013, Rozelle et al 2016 |
| bio-leaching | coal ash | Kermer et al 2016 |
| supercritical extraction | coal ash | Duan 2012, Samsonov 2007, Shimizu 2005, Sawada 2004 |

How much would scaled–up versions **cost?**

# Lab results can inform economic feasibility: example assessing recovery from coal ash

Calculated using bottom-up approach. scale up of laboratory scale process combined with industrial scale data for other applications.

Calculated using top-down approach, using range from analogous process in conventional REE industry.



# Economic feasibility?

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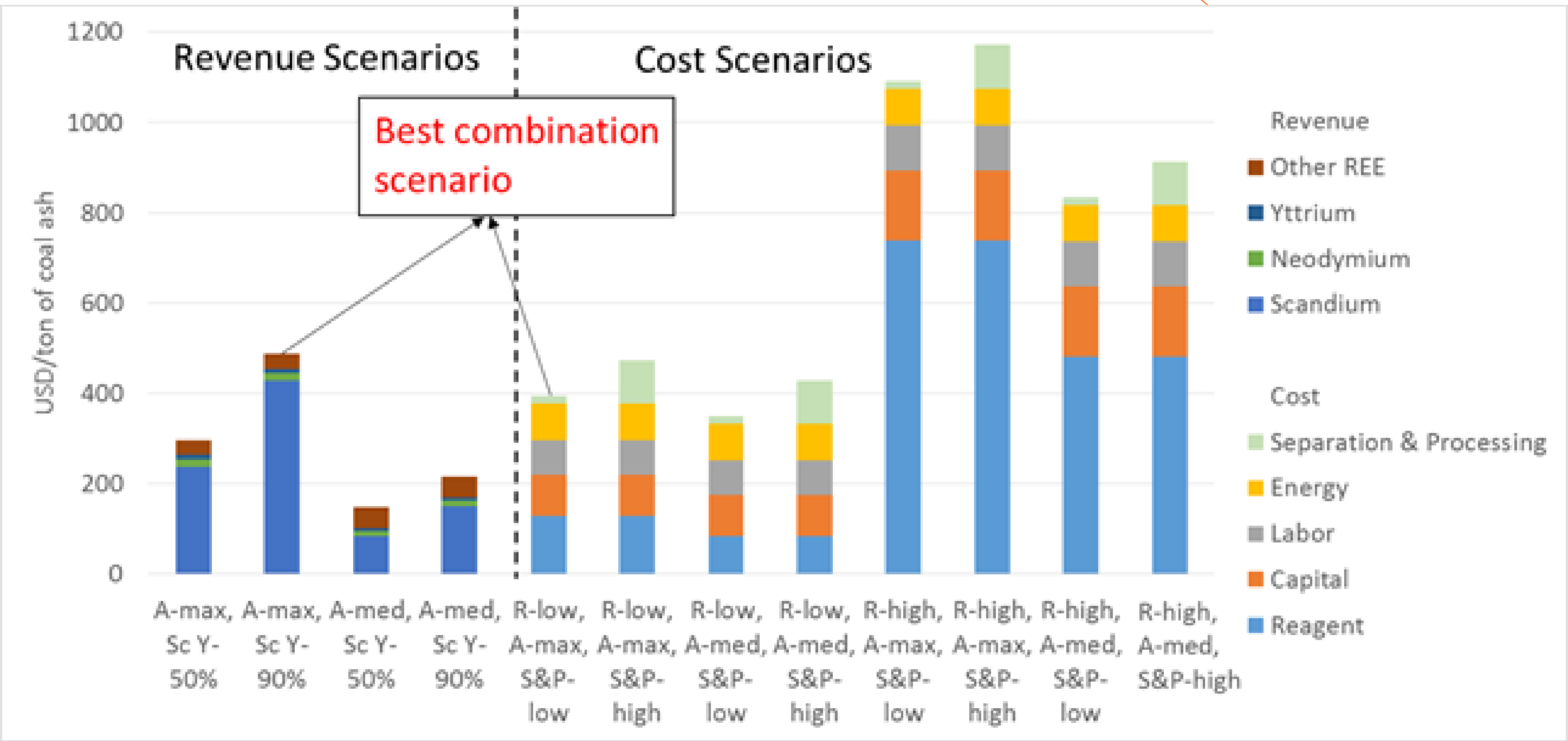


A = REE content of ash, Sc Y = Scandium yield, R = Reagent use, Reagents = $CO_2$, TBP, $HNO_3$, S&P = Separation and processing

S. Das, G. Gaustad, A. Sekar, E. Williams Techno-economic analysis of super-critical extraction of rare earth elements from coal ash. Journal of Cleaner Production. (2019)

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# Conclusions

- Path to economically feasible recovery of REEs from wastes are not yet clear.
- Our work suggests:
  - Focus attention on technologies for waste streams with **potential for large supply**
  - Content of high value REEs (like scandium) is promising, **but risk of price crash if supply increases**
  - Early on need to think about recycling reagents and/or using inexpensive ones

Thank you for your attention!

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