Aaron D Wilson

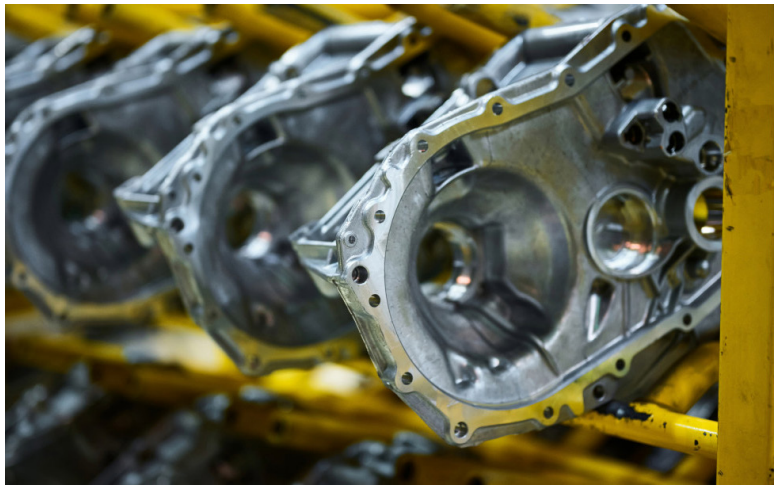
Chemical Separations Group Lead, INL

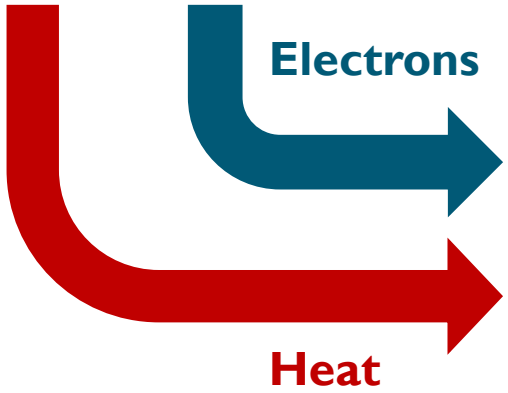
3/19/20225

Sea Water Desalination and Minerals

Nuclear Power and the Blue Economy

Nuclear Power-driven desalination integrated with mineral recovery





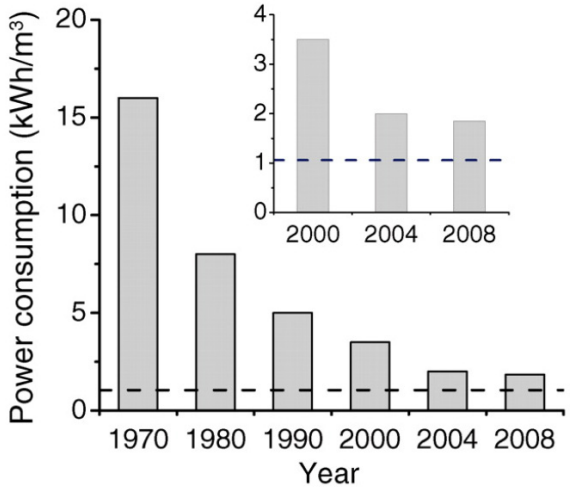
Desalination and Nuclear pairing draw backs:

- Last resort water source (i.e. undesired infrastructure cost)
- Low energy demand (i.e. energy mismatch)
- Electrically driven

Mineral Recovery and Nuclear pairing advantages:

- Feeds revue generating international market
- Well matched energy demand
- Electrically and thermal demand

Technical Challenge and Opportunity



Elimelech, M., & Phillip, W. A. (2011). The future of seawater desalination: energy, technology, and the environment. science, 333(6043), 712-717.

- **Challenge:** No realistic reduction in Desalination energy cost.
  - **SOTA World:** Israel and Saudi Arabia have reduced the cost of SWRO to 0.30-0.40 USD/m^3.
  - **Current Practice US:** The Carlsbad Plant in San Diego costs are 2.76 USD/m^3.
- **Opportunity:** Redefining the technical challenge (i.e. Film-to-Digital).

Brine Mining Redefines the Economics of Desalination: Integrating mineral recovery would transform **desalination** from an infrastructure cost to revenue generating **mineral resource and processing industry.**

- Adding mineral recovery would result in ×10-30 the revenue/cost in the case of magnesium from seawater. Specifically Saudi Arabia wants to transform desalination from a ~1 billion USD/year infrastructure cost into revenue of ~10-35 billion USD/year.

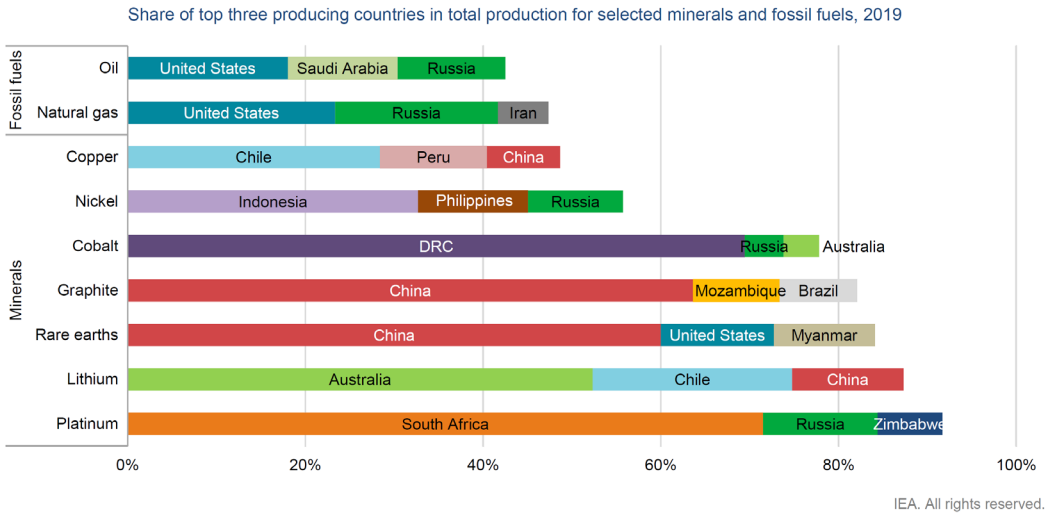
Critical Materials for Next-Generation Technology, Weapons Systems, and Energy Infrastructure

Rio Tinto - Kennecott Utah Copper (12% of the US supply)

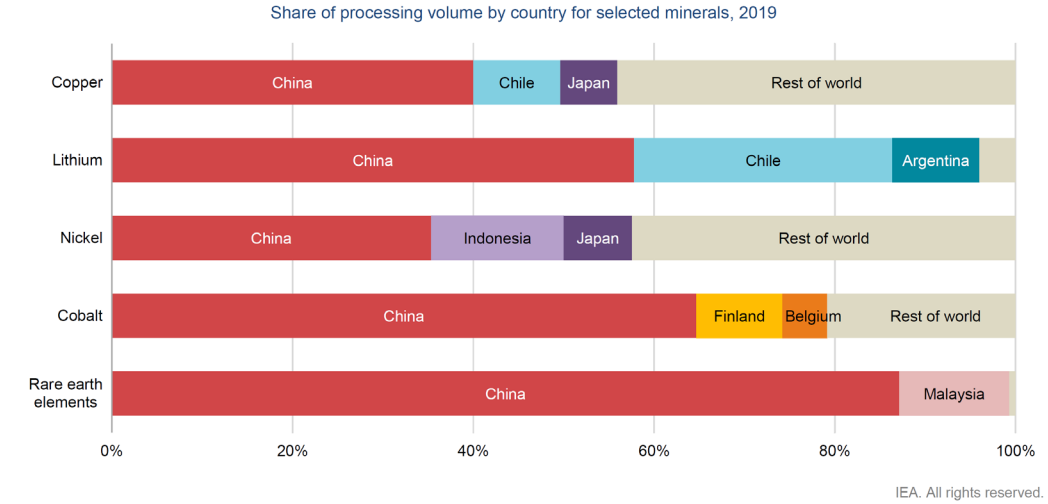
The Role of Critical Minerals in Clean Energy Transitions

World Energy Outlook Special Report

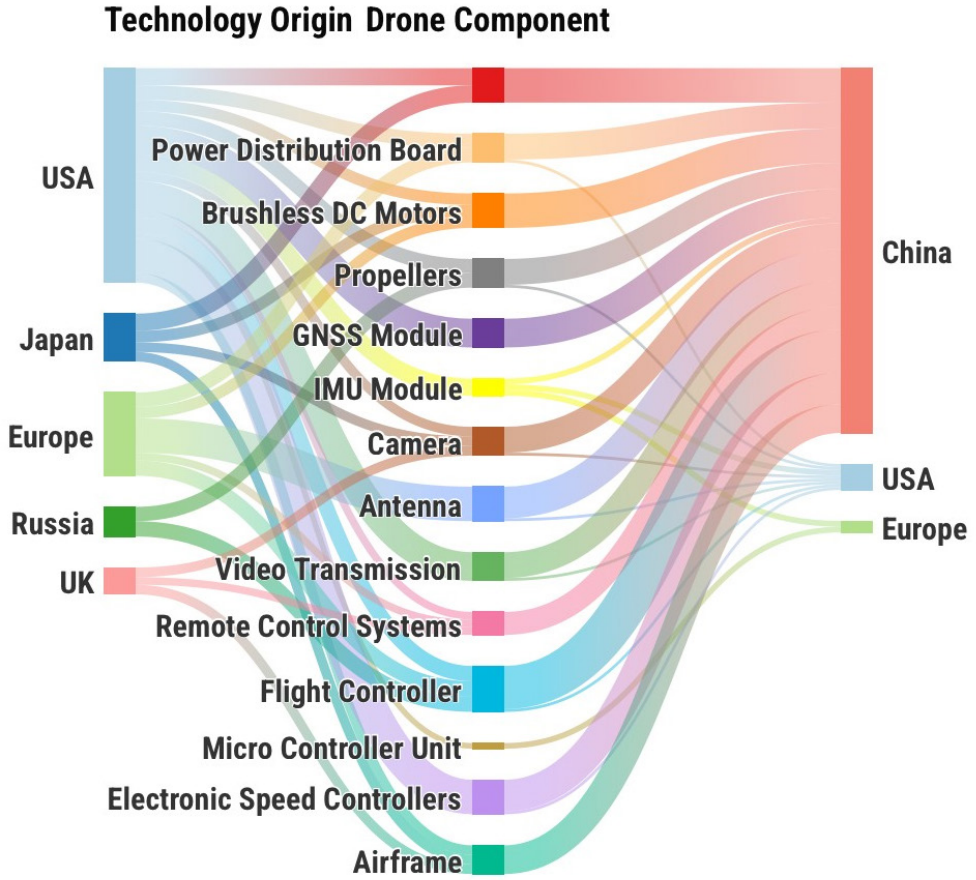
Minerals are sourced globally and processed in China



The level of concentration is similarly high for processing operations, with China's significant presence across the board

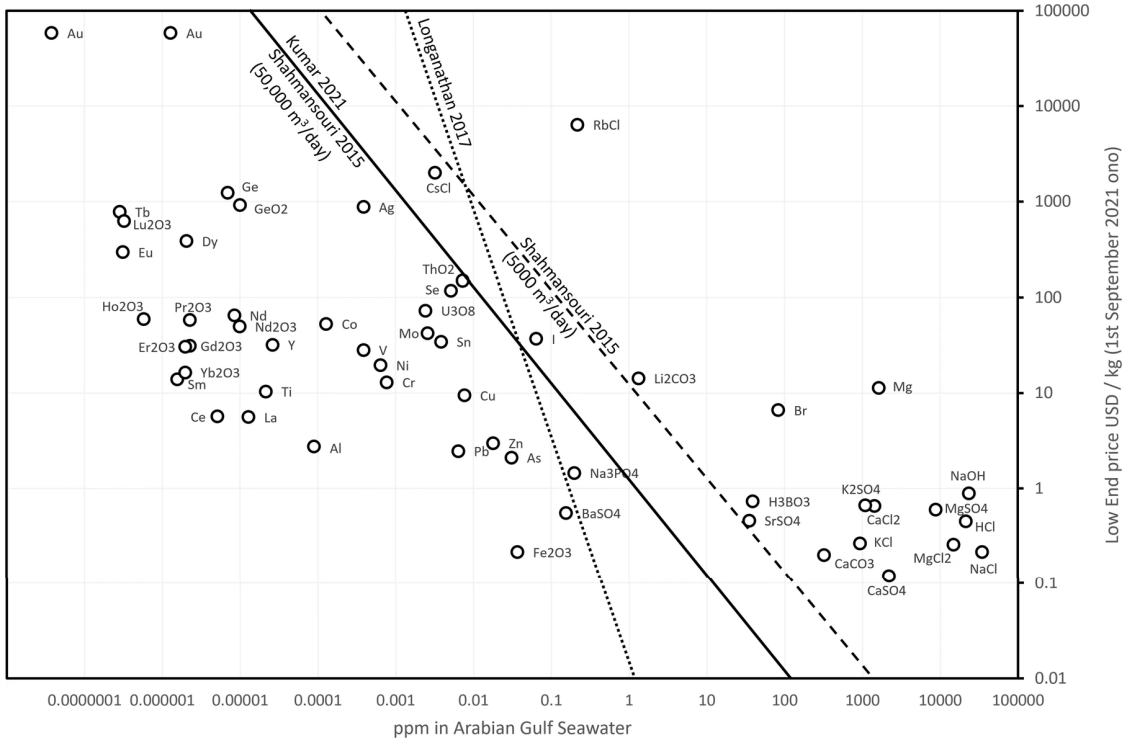


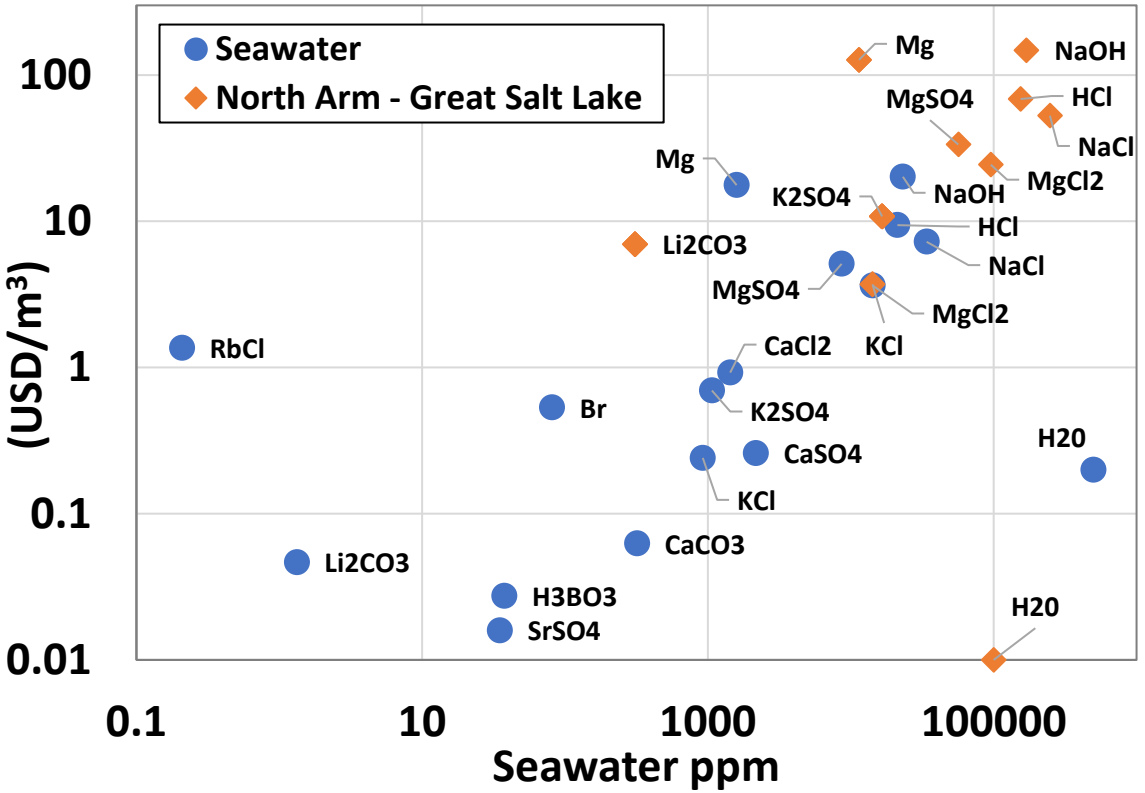
Tae-Yoon Kim, *The Role of Critical Minerals in Clean Energy Transitions*, International Energy Agency, 2022.



How the US and its allies can rebuild economic security
By Edlyn V. Levinearchive and Fiona Murrayarchive 2024

Seawater Minerals by Value and Concentration



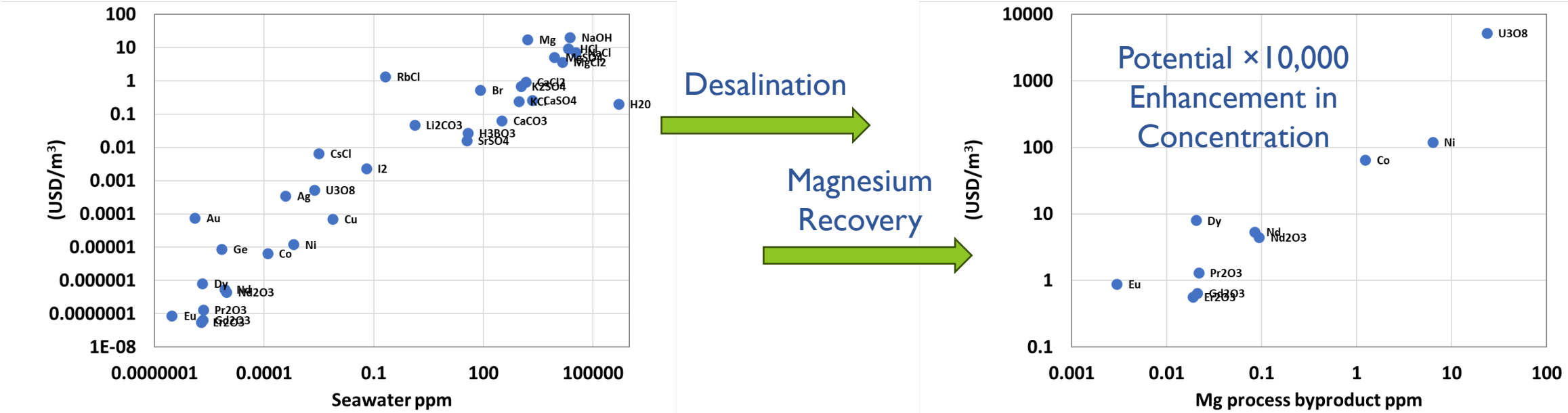


Additional considerations include:

- Material processing costs (includes local energy costs)
- Market elasticity (how much can the local or global market absorb?)
- Cost/ease of transport/storage

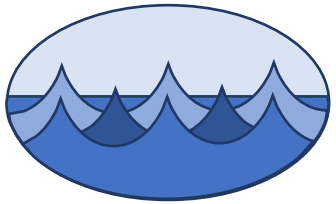
B.A. Sharkh, A.A. Al-Amoudi, M. Farooque, C.M. Fellows, S. Ihm, S. Lee, S. Li, N. Voutchkov, Seawater desalination concentrate—a new frontier for sustainable mining of valuable minerals, NPJ Clean Water. 5 (2022) 1–16. https://doi.org/10.1038/s41545-022-00153-6.

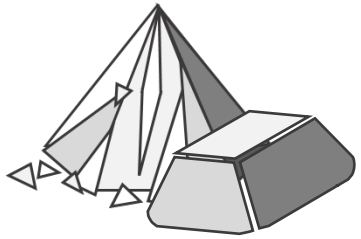
Active Separations Path to Critical Minerals



- Active separations which sequentially increases the concentration of target materials enhancing the effectiveness of selective (DLE, direct lithium extraction recovery) and passive adsorbents.
- This approach aligns with conventional industrial mineral recovery practices and “Grade is King” considerations.
  - Moves smaller volumes to target more dilute components.
  - Avoids system fouling and degradation.
  - Requires lower selectivity per step.

Desalination and Mineral Production at Plant Scale

Input	Product	Power Requirement	
	70 million m^3 water/year	30 MW Likely Electric	**Infrastructure Cost** 35-70 million USD/year
140 million m^3 seawater/year	140 million kg Mg/year	640-1,600 MW Thermal and Electric	**Mineral Revenue** 280-980 million USD/year



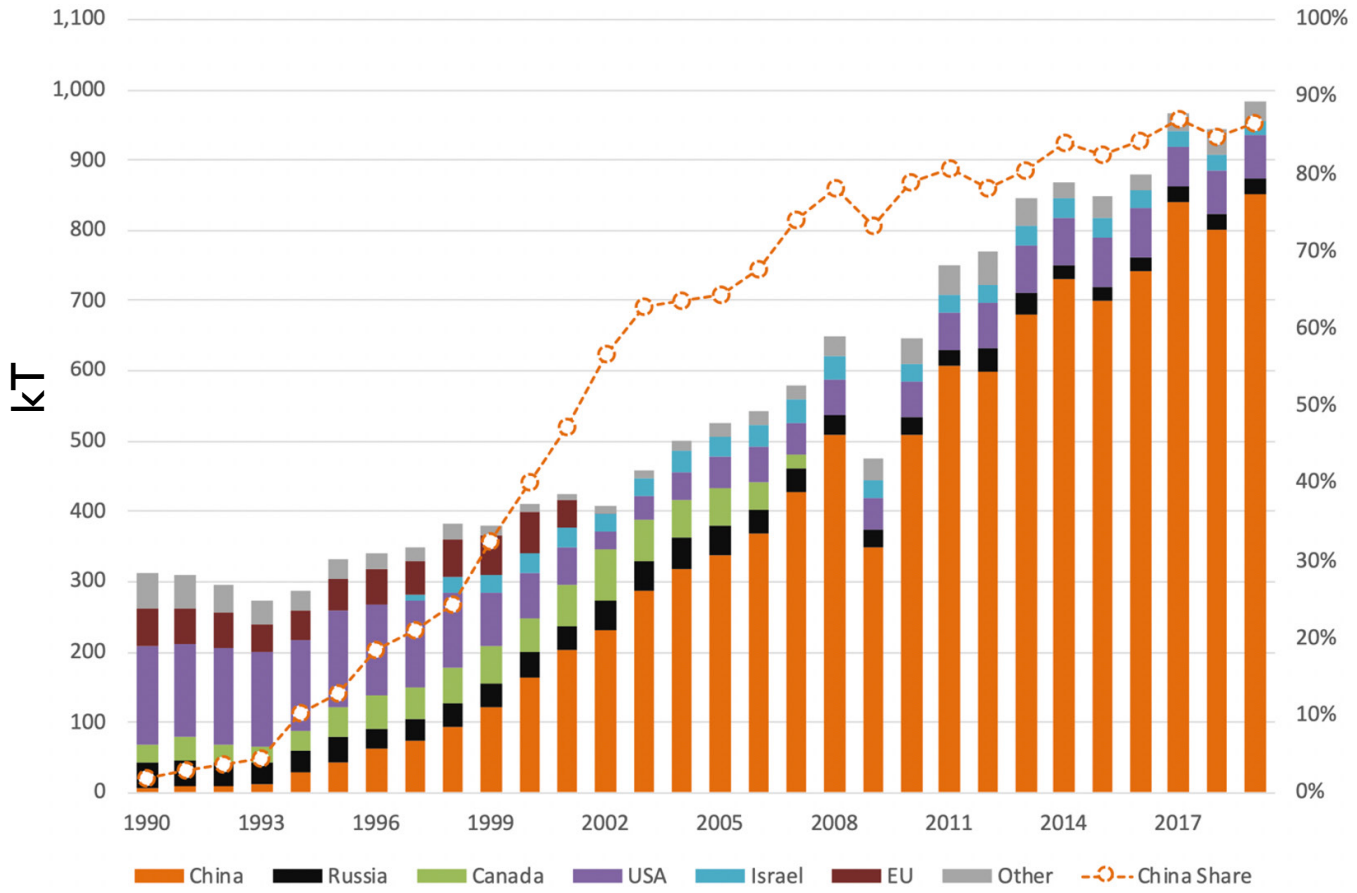
- Integrating mineral recovery would transform **desalination** from an infrastructure cost to revenue generating **mineral resource and processing industry**.
  - ×10-30 the revenue/cost in the case of magnesium from seawater.
- Magnesium or other minerals in brines would serve as the gateways to the recovery of more dilute critical materials.

Magnesium Alloys the Future of Structural Materials

- **Lightest structural material** (33% lighter than aluminum).
- Alloys amongst the **high specific strength** (strength/mass).
- **Easy to recycle** (50% the energy than aluminum);
  much easier to recycle than titanium or carbon fiber.
- **Easy to work** (major labor reduction versus carbon fiber).
- **Plentiful** with plurality of sources (~1 Kg per m^3 of seawater).
- **Stable Value** 2-7 USD/Kg (2012-2023) and drop-in replacement for Al.

Growing Market

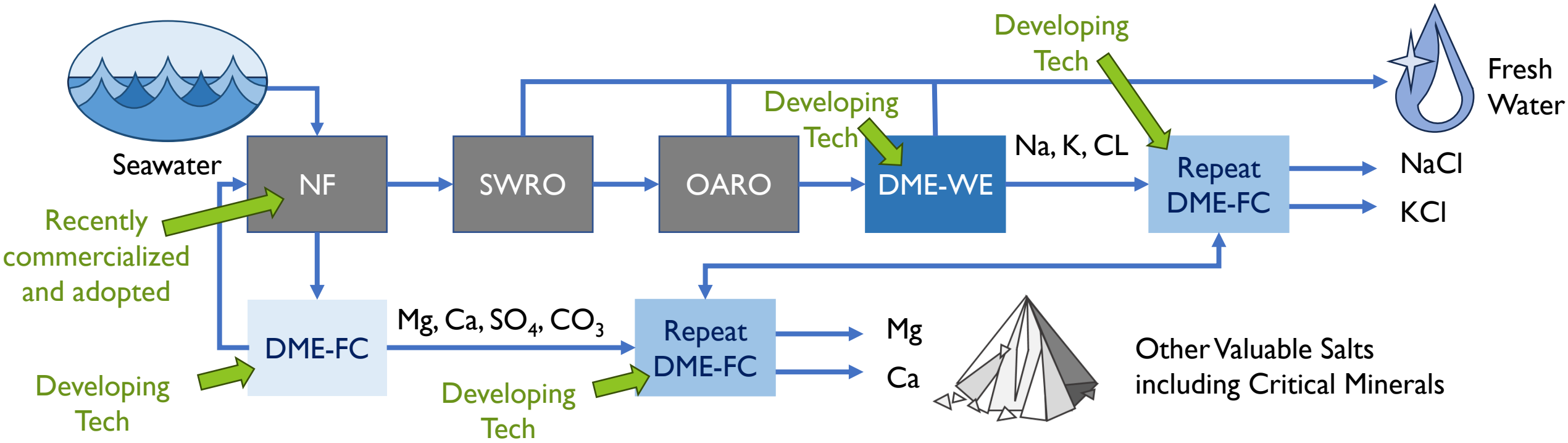
Magnesium Metal Market



Mg Applications

- 75% of Aluminum Alloys include Mg
- Ti Metal Reduction
- Diecast Mg Alloys
  - Aviation/Automotive
  - Camera/Phones
  - Premium Tools
  - Medical
- Steel Desulfurization

Path to Seawater Mineral Recovery



- SWRO has a cost of >0.4 USD/m^3 of product water.
- 1 m^3 of desalinated water requiring ~2 m^3 of seawater.
- 2 m^3 of seawater contains ~2 Kg of Mg.
- 2 Kg of Mg is valued at 4-14 USD.

Nanofiltration, NF
Seawater Reverse Osmosis, SWRO
Osmotically Assisted Reverse Osmosis, OARO
Dimethyl Ether Water Extraction, DME-WE
Dimethyl Ether Fractional Crystallization, DME-FC

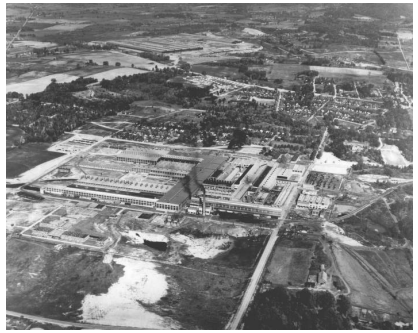
Positive Feedback between Power and Minerals Example: Tennessee Valley Authority (TVA)

Power Generation

Cherokee Dam

Positive Feedback Between Power Generation and Large-scale Consumption

Mineral Processing



Alcoa's Tennessee Operation
World's Largest Aluminum Plant during WWII

Valuable Products

Mineral Based Product

Browns Ferry Nuclear Plant

Oak Ridge National Laboratory

Nuclear Applications, EBR-I

Sustaining National Nuclear Assets

lwrs.inl.gov