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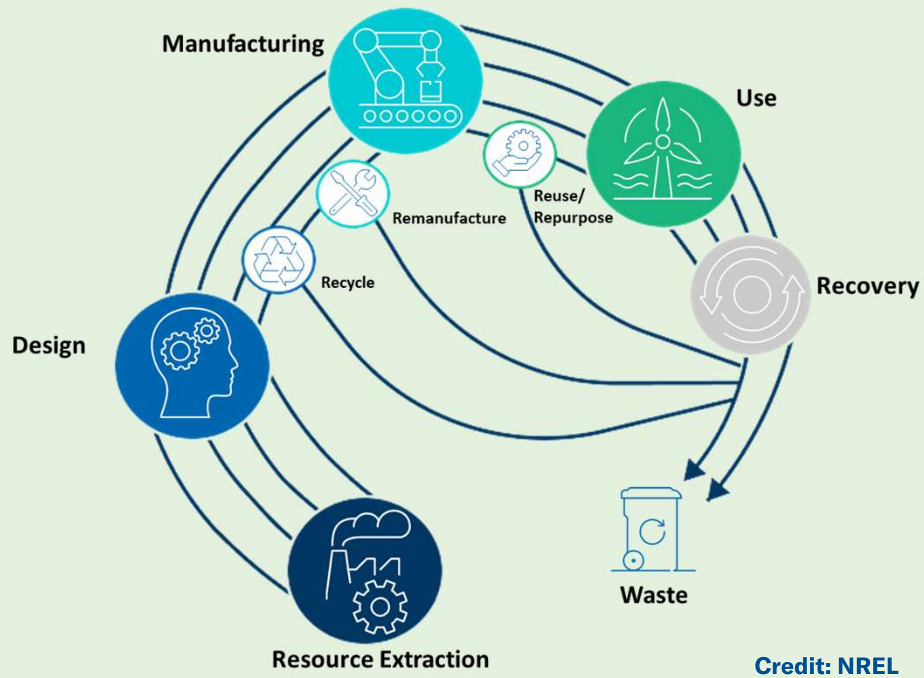
Addressing Tomorrow's Environmental Challenges Today

Evaluating Opportunities for a Circular Economy in the U.S. Renewable Power Sector

Introduction

As companies begin to invest heavily in the energy transition, how can we best address the waste problem that will be created by the adoption of clean energy technologies?

- The energy transition will lead to a rapid deployment of solar and wind technology over the next 25 years, creating significant demand for materials like iron and steel, rare earth metals, and silicon. By 2040, existing solar and wind plants will begin decommissioning, creating a potentially significant waste stream and raising a number of questions that this study seeks to address:
  - What types of materials are needed for the energy transition? Where are they currently sourced?
  - What will happen to the key materials embedded in these plants at end of life? Can they be recycled in the U.S. and re-used in solar and wind plants or for other uses?
  - How do we make renewable energy generation a more circular economy?
- This study relies on a forecast of renewable capacity and estimates of materials required per plant to calculate the quantity of materials needed to make the energy transition a reality. A forecast of solar and wind plant retirements is used to identify when end of life disposal and recycling will be required.
- The following is an excerpt of a broader report on circularity in the renewable power sector.



Credit: NREL

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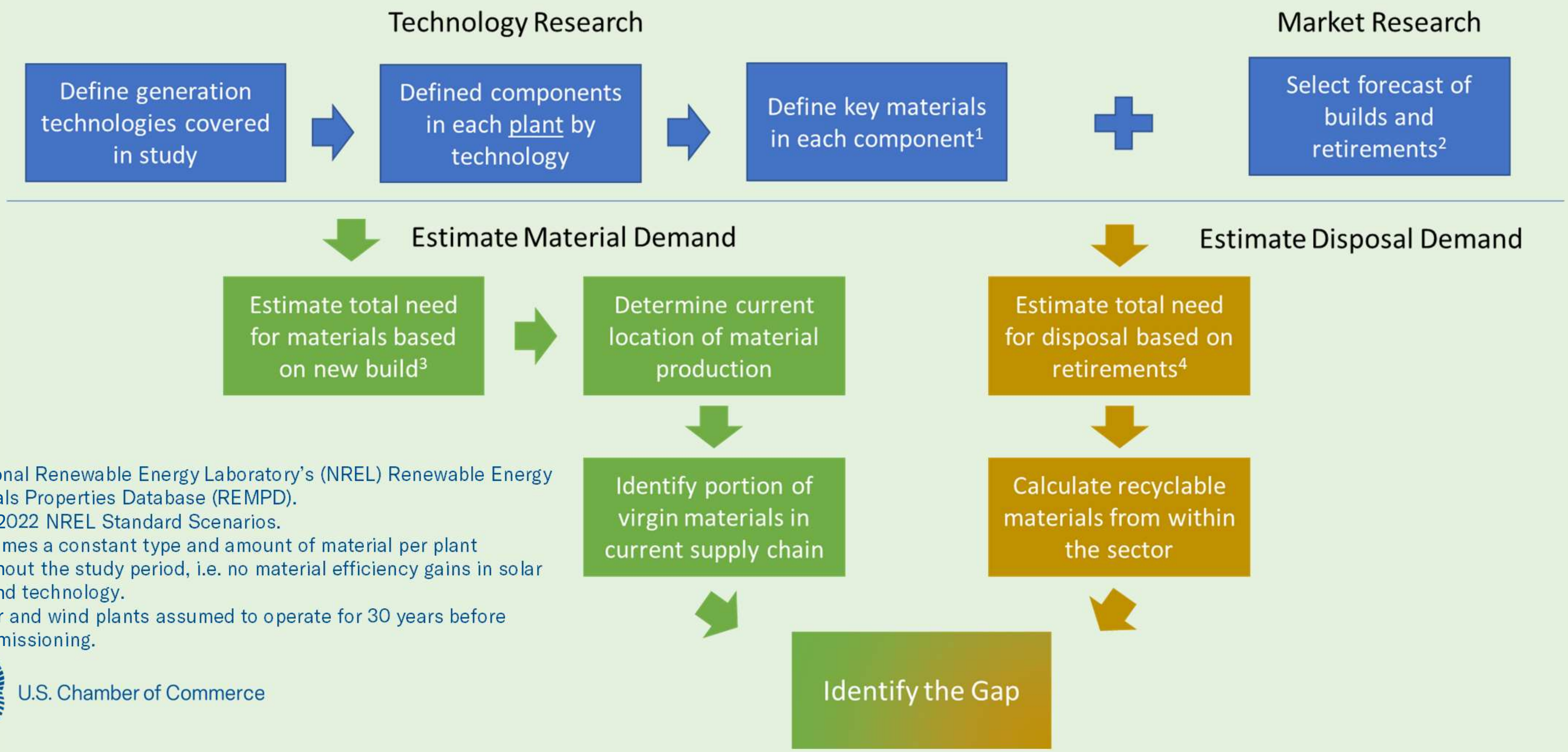
Overview of the Renewable Generation Sector Circularity Analysis

FTI's analysis combines estimates of material embedded in solar and wind plants with projections of unit builds and retirements to estimate the circularity gap.



1. National Renewable Energy Laboratory's (NREL) Renewable Energy Materials Properties Database (REMPD).
2. The 2022 NREL Standard Scenarios.
3. Assumes a constant type and amount of material per plant throughout the study period, i.e. no material efficiency gains in solar and wind technology.
4. Solar and wind plants assumed to operate for 30 years before decommissioning.

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Key Materials by Renewable Technology and Circularity

Material	Crystalline Silicon Solar	Thin Film Solar	Land-Based Wind	Offshore Wind	Circularity Status	Circularity Notes
Alloying Metals[2]	X	X	X	X	🟢	Alloys are frequently recycled along with the alloyed steel.
Aluminum	X	X	X	X	🟢	Recycling technology is mature and recycled frequently.
Balsa			X	X	🔴	Research is ongoing into how to recycle balsa wood from blades.
Cadmium and Tellurium		X			🟡	Highly recyclable in theory, but not yet tested in large quantities.
Carbon Fiber and Fiberglass			X	X	🔴	Research is ongoing into how to recycle these materials.
Concrete	X	X	X		🟡	Concrete is recyclable but is often left in the ground instead.
Copper	X	X	X	X	🟢	Recycling technology is mature and recycled frequently.
Float Glass		X			🟡	Recyclable, but there are economic and technical barriers.
Iron and Steel	X	X	X	X	🟢	Recycling technology is mature and recycled frequently.
Lead				X	🟢	Lead is easy to recycle and recycled frequently.
Plastic	X	X	X	X	🟡	Most plastics are recyclable, but they are usually landfilled.
Rare Earth Metals[3]			X	X	🟡	Limited success in recycling, and capacity is still small.
Silicon	X				🔴	Research is ongoing into how to recycle polysilicon.
Silver	X				🔴	Silver is recyclable, but very difficult to recycle from solar cells.
Solar Glass	X	X			🟡	Recyclable, but there are economic and technical barriers.

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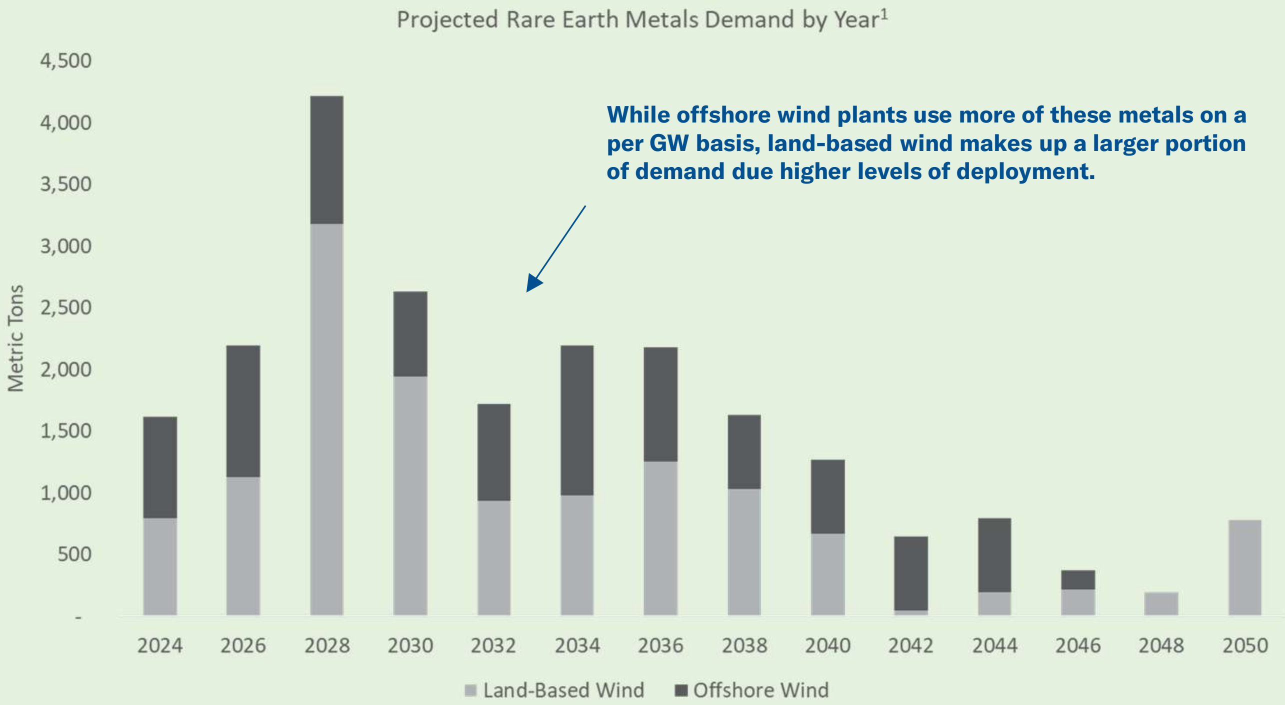
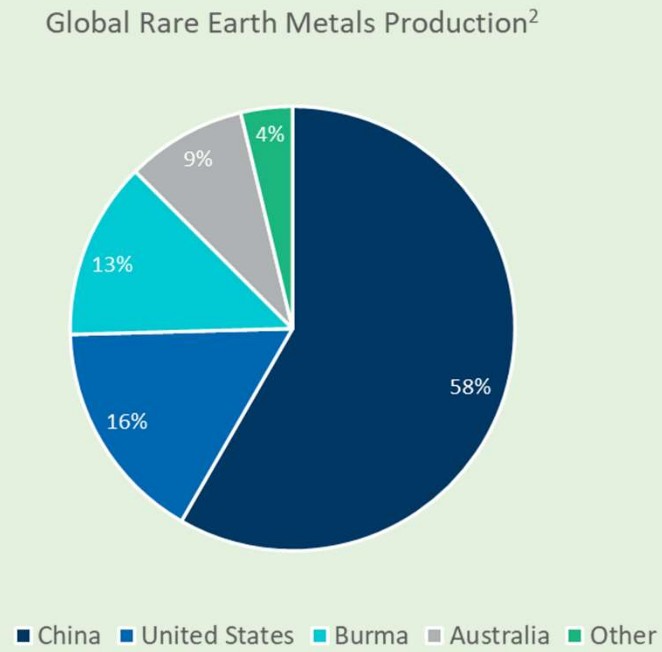
1. Materials usage derived from REMPD. Circularity status based on FTI evaluation of publicly available data.
2. Includes chromium, manganese, nickel, and zinc. Primarily used in steel alloys, they are rarely recycled directly.
3. Includes neodymium and praseodymium. Other rare earth metals are used in smaller amounts.

Material Demand: Rare Earth Metals

U.S. wind plants will require around 22.5 thousand metric tons of rare earth metals by 2050.



While offshore wind plants use more of these metals on a per GW basis, land-based wind makes up a larger portion of demand due higher levels of deployment.



Rare earths production is currently concentrated in China. Increasing domestic recycling from all sources, including wind turbines, would reduce reliance on foreign supply chains and decrease GHG emissions from processing and production and transportation of materials.

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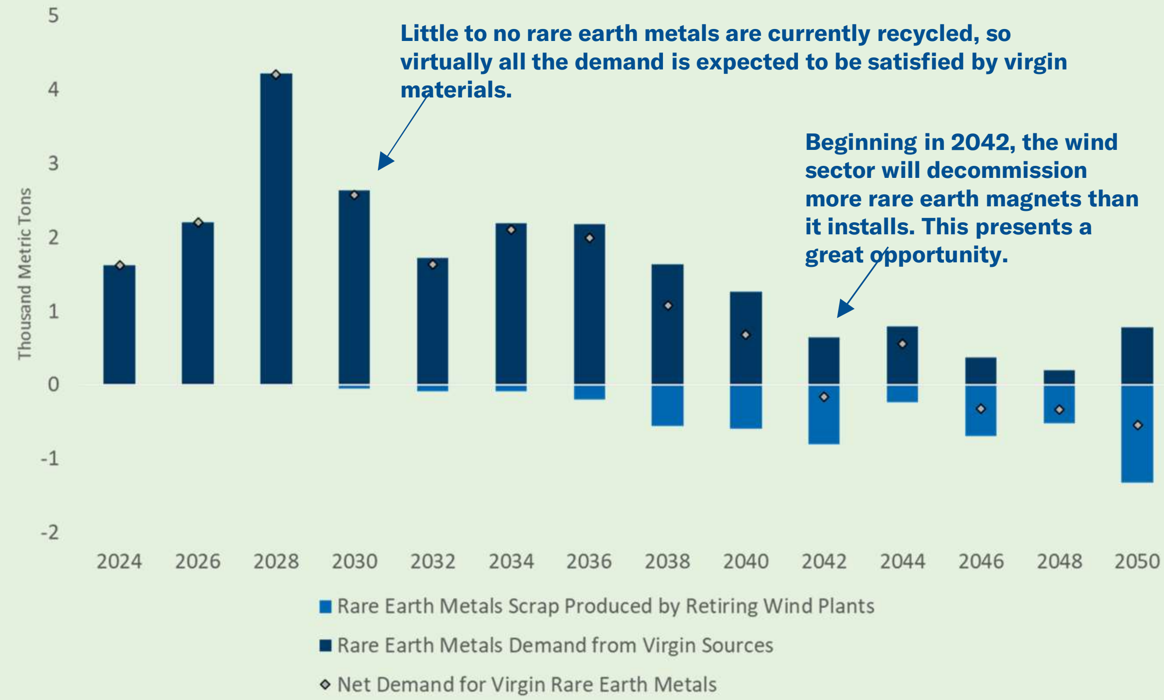
1. FTI calculation using DOE REMPD data and NREL Standard Scenarios. Volumes include neodymium and praseodymium.
2. USGS Minerals Commodities Summaries 2022. Data is for all rare earth metals.

Gap Analysis: Rare Earth Metals

Rare earth recycling is technologically difficult and still in its infancy so there is not currently sufficient capacity to recycle these materials at scale.

- In 2050, the US is projected to decommission over 1,300 combined metric tons of neodymium and praseodymium, two of the most common rare earth metals used in land-based and offshore wind technology.[1]
- For comparison, U.S. mines produced just 43,000 tons of rare earth metals in 2021[2], but there are many competing uses for these materials in medical devices, computer components, and electric vehicle motors.
- There is some small-scale recycling capacity available today.
  - One company in San Marcos, Texas designs and builds programs to collect rare earth magnets from MRIs, electric motors, hard drives, and electric vehicles.
  - The DOE has also provided funding to two companies in Colorado and Iowa to develop non-toxic rare earth element recycling techniques.

Virgin Rare Earth Metals Demand vs Rare Earth Metals Scrap from Wind Retirements[3]



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Conclusions and Implications of the Renewable Sector Analysis

While circularity is currently achievable for some materials, recycling methods for others are in their infancy. Further research and funding is required to fully address the future environmental challenge of solar and wind waste.

Circularity Can Provide Diverse Benefits

Achieving circularity in renewables would generate meaningful environmental and economic benefits.

- Improving circularity in this sector will reduce U.S. dependence on foreign supply chains and decrease GHG emissions associated with the production and transport of virgin materials.
- The development of domestic recycling capability will support investment in U.S. industries and may result in significant economic benefits.[1]

Progress Toward Circularity Varies

For some materials, a degree of circularity has already been achieved but for others, much work remains to be done.

- The U.S. is a leader in using scrap iron and steel to create new products, incorporating recycled materials at a rate nearly double the global average.
- The U.S. produces almost none of the silicon cells needed for crystalline silicon solar panels and lacks an economic incentive and technology for recycling them.
- Rare earth metals show a promising path forward – some recycling capability is already developing and funding is being directed towards it.

A Holistic View is Needed

Due to the rapid growth projected in renewable deployment, recycled materials will need to come from other sources.

- Nearly all the growth in the renewable sector is expected over the coming 10-20 years. in this period, there will be insufficient recyclable material available from retirements of wind and solar.
- For many metals, recycled materials could be sourced from other sectors. Iron and steel, for example, could be recycled from retiring fossil fuel plants.
- In the short term, however, sources of recyclable silicon and rare earth metals are limited relative to the projected demand from new wind and solar plants.

1. FTI will formally evaluate the potential economic benefits of circularity in a future phase of the study.