EXECUTIVE SUMMARY

Critical Minerals for the Hydrogen Economy

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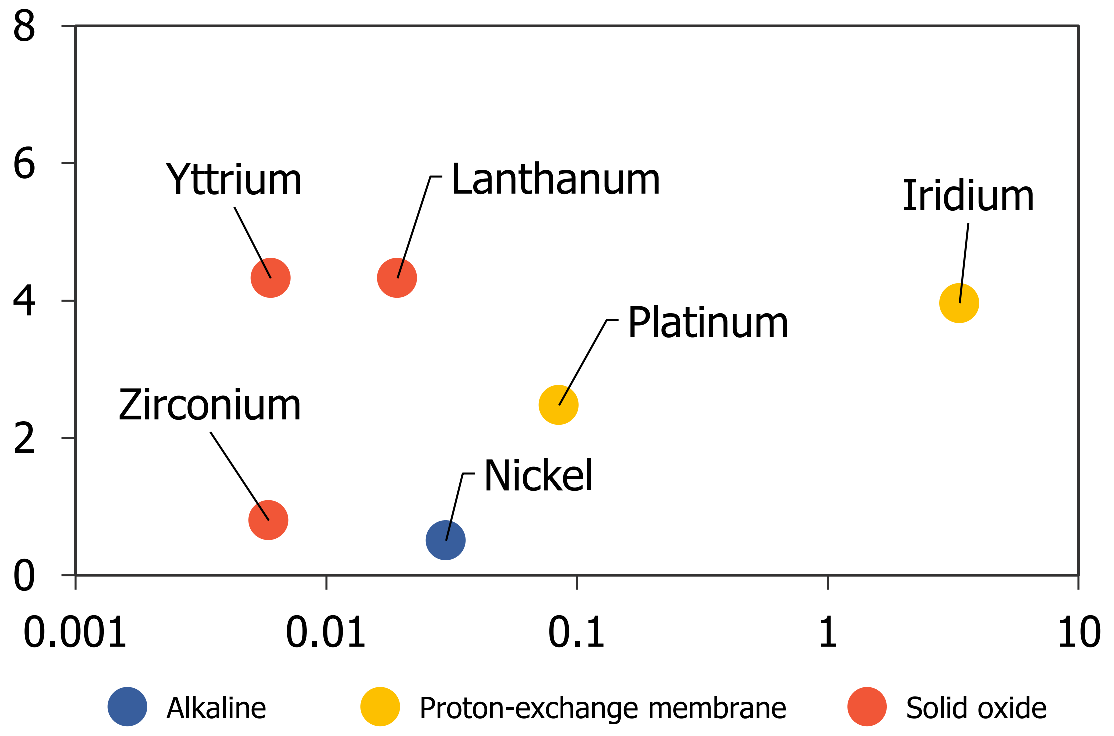
Executive Summary

As more countries pursue deep decarbonization strategies, hydrogen will play a critical role in their energy transition. Precious metals and minerals are deeply embedded in renewables and electrification technology. The hydrogen economy is no different. Key minerals such as platinum, iridium, nickel, and rare earth elements play a crucial role in the roll-out of hydrogen production through electrolysis.

Our analysis finds that iridium is the biggest bottleneck to the multi-GW installation of water electrolysis plants, whereas other crucial platinum-group metals (PGMs) and rare earths, although abundant, are strongly concentrated in few countries, threatening future roll-out of electrolysis technologies. Clients should consider investing in finding alternative materials to these critical minerals for electrocatalysts and investing early in a recycling infrastructure, which would alleviate some of these choke points in future supply.

Critical Minerals for Electrolysis

Supply risk (*y*-axis);
Criticality (*x*-axis)



There are four generations of electrolysis technology to produce low-carbon hydrogen

Alkaline

Alkaline electrolyzer cells (AECs) consist of two electrodes immersed in an alkaline electrolyte and separated by a diaphragm. AECs are the most mature electrolysis technology and deployed at large scale in industrial applications.

Proton-exchange membrane (PEM)

PEM electrolyzer cells (PEMECs) consist of two electrodes separated by a solid proton-exchange polymer membrane. PEMECs operate in an acidic environment. PEMECs are currently being scaled up for industrial applications.

Solid oxide

Solid oxide electrolyzer cells (SOECs) consist of two electrodes separated by a solid ion-conducting membrane. SOECs operate at temperatures above 800 °C. They are currently at the pilot scale with the first industrial deployment expected within five years.

Anion-exchange membrane (AEM)

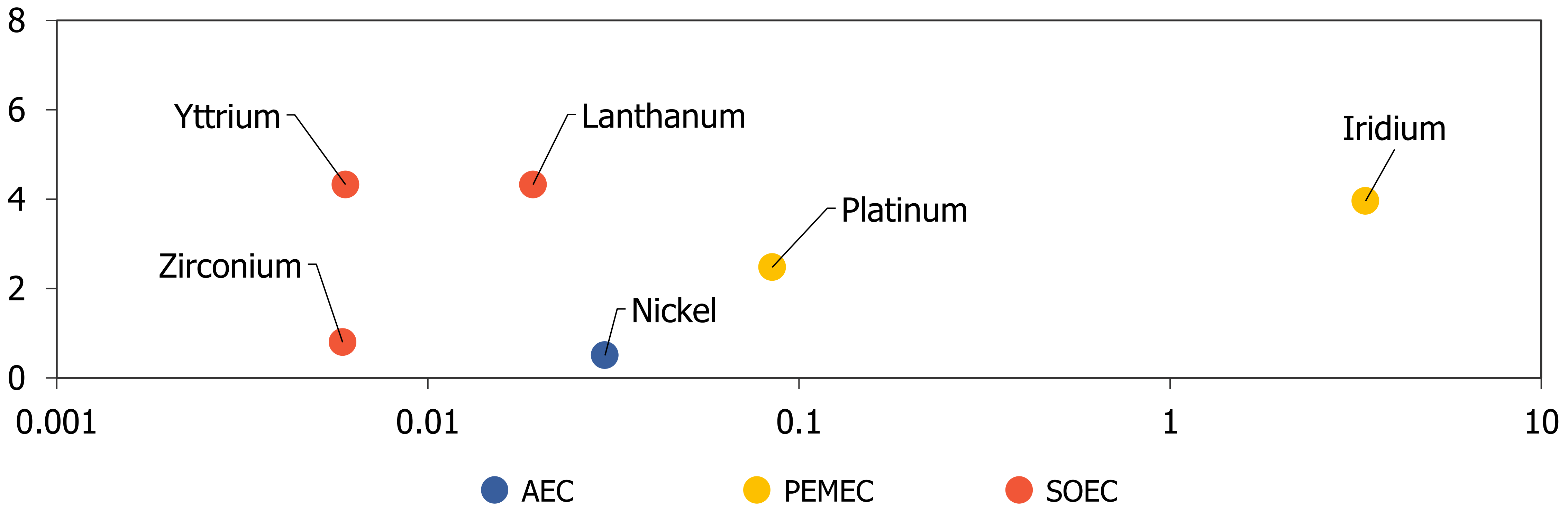
AEM electrolyzer cells (AEMECs) consist of two electrodes immersed in an AEC and separated by a solid anion-exchange polymer membrane. AEMECs are currently at the laboratory scale with the first industrial deployment expected within 6–8 years.

The material requirement for electrolysis technology will vary by cell architecture

	AEC	PEMEC	SOEC	AEMEC
Electrolyte	Aqueous potassium hydroxide	Solid electrolyte	Solid oxide electrolyte	Aqueous potassium hydroxide
Separator/ membrane	Zirconium oxide	Fluorinated polymer membranes (Nafion)	Yttria-stabilized zirconium (YSZ)	Aromatic and aliphatic hydrocarbons polymers
Anode catalyst (oxygen side)	Nickel alloy-plated steel/nickel-cobalt	Ruthenium or Iridium oxides/platinum-carbon	Nickel/YSZ	Nonplatinum group metals/nickel-based alloy
Cathode catalyst (hydrogen side)	Nickle-based alloys	Platinum or platinum-palladium	Lanthanum-strontium-manganite/YSZ	Nickel-iron-molybdenum grown on nickel foam
Bipolar plates	Nickel-coated stainless steel	Platinum/gold-coated titanium	Stainless steel/iron-nickel alloy	Nickel-coated stainless steel
Frames and sealing	Sulfonate/ fluorinated polymers	Sulfonate/fluorinated polymers	Ceramics/glass	Silicon/fluorinated polymers

The criticality analysis highlights the significance of minerals to electrolyzers as well as their supply risk

Critical minerals for electrolysis
Supply risk (*y*-axis);
Criticality (*x*-axis)



Note: The analysis does not include AEMECs as the technology is still at the laboratory scale with sparse data on mineral consumption and unclear commercialization timeline.

Research

Iridium will be a major bottleneck for deployment of PEMECs, while AECs and SOECs face few challenges

Nickel

Nickel is widely used across water electrolysis technologies for hydrogen production. Today, a 1-GW electrolyzer uses anywhere between 800 to 1,000 tonnes of nickel. From the chart on the previous slide, nickel has a lower criticality score (<1) than other minerals. It also has a low supply risk since as many as 25 different countries around the world carry nickel reserves. However, its wide usage across other energy applications such as in fast-growing battery energy storage has seen nickel prices soar to a decade high. The IEA estimates that further increase in nickel prices could have significant affects on future battery and electrolyzer supply chains.

Iridium and platinum

Our criticality analysis clearly shows that iridium usage (criticality score >1) is the biggest bottleneck to meeting projected 2050 PEMEC installations. Iridium is far scarcer than platinum. However, due to its excellent catalytic activity in highly acidic conditions, finding promising alternatives is a challenge. Our analysis also shows that while platinum is a crucial mineral for PEMECs to flourish in the future, the world is likely not going to run out of platinum. However, supply risk is relatively high for both minerals as PGM production is concentrated in South Africa.

Zirconium, yttrium, and lanthanum

While zirconium is a non-critical mineral, yttrium and lanthanum show up in the high supply risk region of the chart. China produces nearly 4 times the volume of rare earths than the second largest producer, the U.S. Nearly 95% of these mineral reserves are in China, increasing their supply risk as SOEC technology scales up to decarbonize industrial applications. A lack of strong alternatives to these minerals add to the criticality of yttrium and lanthanum.

OUTLOOK

Find opportunities in material discovery for electrolyzers

Supply shortages of critical minerals will drive the need for alternatives and optimization of existing electrocatalyst loading. Chemicals and materials companies have an opportunity to accelerate material discovery by leveraging their internal knowledge even if they do not develop the electrolyzers themselves.

Clients should focus on reducing the use of PGMs, especially finding alternatives to iridium usage in PEMECs, as the technology matures from MW-scale units to GW installations. This will not only reduce the total cost of installed capex but will most importantly alleviate supply risks.

While electrolyzers available today are ready for commercial applications, there is still potential to innovate. New innovations in zero-gap electrolysis or membrane-less electrolyzers could unlock at least 10% to 15% efficiency improvements that can result in lower capex installations. Clients should monitor developments in emerging electrolyzer technologies that will disrupt the space and potentially displace existing electrolyzers.

OUTLOOK

Prepare for the new market of recycling electrolyzers

Most electrolyzer stacks will last a maximum of 7 to 10 years before refurbishment or replacement. As electrolyzer companies focus on GW-scale manufacturing facilities, we expect to see them partner with engineering, procurement, and construction (EPC) firms to not only optimize operations and maintenance and refurbish stacks but, more importantly, enable recycling of stacks in partnership with metals recyclers.

There will be an electrolyzer recycling industry. Companies should look to supply chain partnerships like opportunities we see in the battery recycling market today, where recyclers are partnering across the battery production value chain. In the electrolyzer market, this could mean partnerships between mining players, stack producers, EPCs, and recyclers.

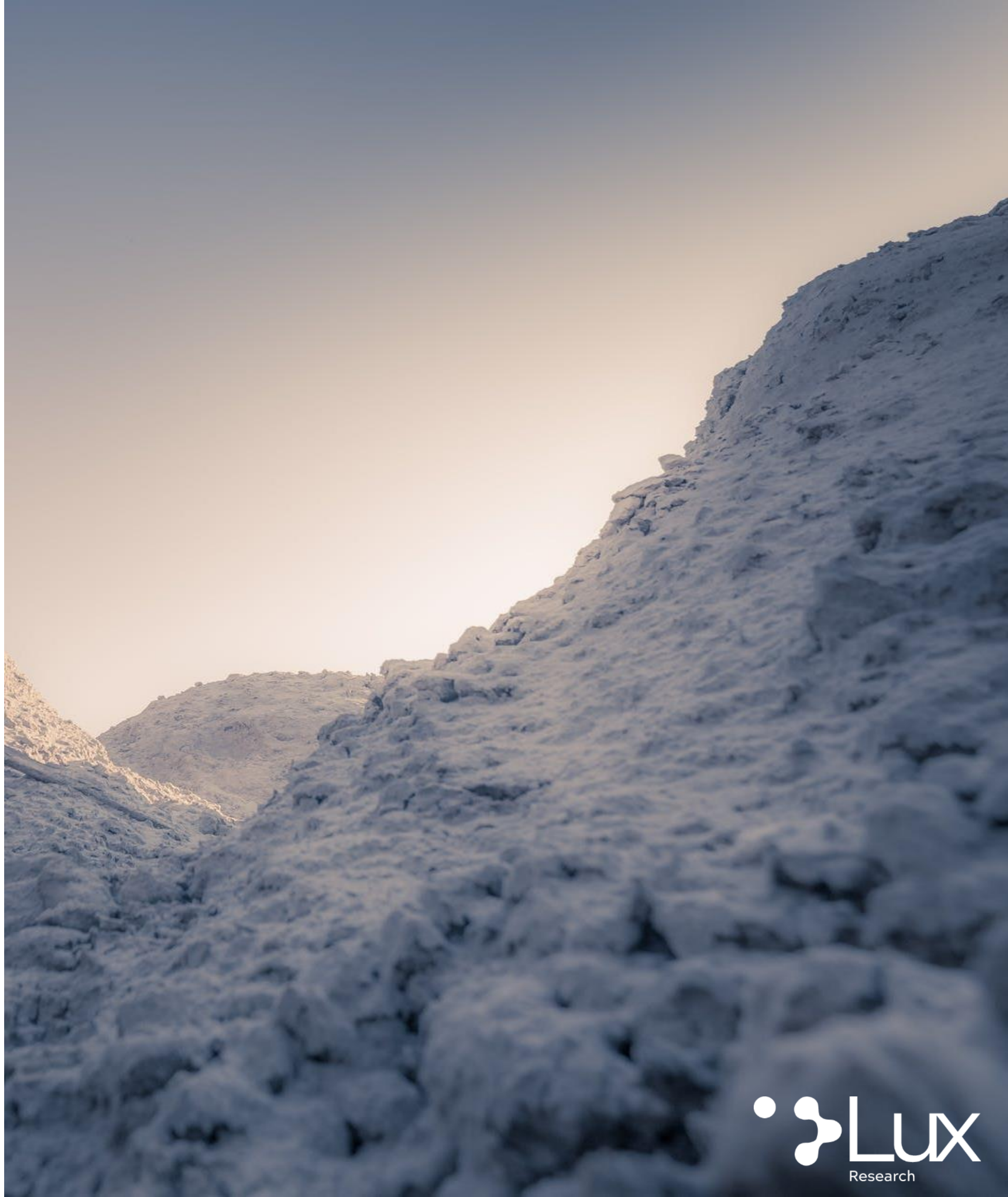
We are already seeing initiatives to fund sustainable hydrogen manufacturing and electrolyzer recycling in the U.S. and Europe. By 2035, clients should expect to see complete electrolyzers being recycled as technologies like automated sorting and dismantling along with metals extraction and purification technologies become mainstream.

OUTLOOK

Electrification means that there is more electrolysis to come

The focus of this report is on water electrolyzers for the hydrogen economy, but electrification of the global energy system is spurring renewed efforts into a broader shift from thermochemistry to electrochemistry. While water electrolyzers are now firmly established for decarbonizing hydrogen production, academics, technology developers, and corporations are exploring other industrial processes that can benefit from electrochemistry. This has resulted in the new developments in CO_2 electrolyzers for hydrocarbon chemicals, direct ammonia synthesis through electrolyzers, molten oxide electrolysis for refining iron ore, and even electrolyzers for producing concrete from electricity.

As with water electrolyzers, the development and eventual deployment of these novel electrochemical platforms will disrupt the demand of minerals. It is therefore important to monitor the innovation landscape of electrochemistry and preempt any material supply challenges that may arise.



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