Critical Materials in Electrolyzers and Fuel Cells

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JOINT CENTER FOR DEPLOYMENT & RESEARCH IN EARTH ABUNDANT MATERIALS

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CONSORTIUM FOR HYDROGEN AND RENEWABLY GENERATED E-FUELS

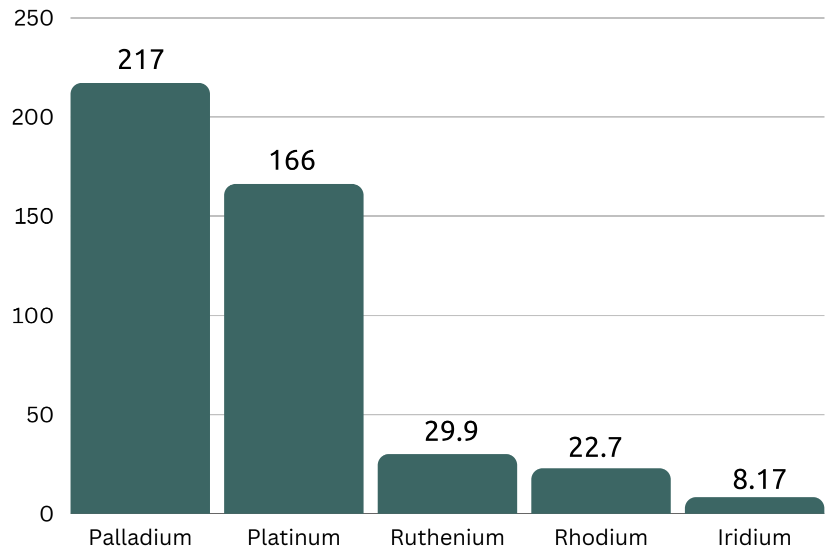
Critical Minerals in Hydrogen Production

U.S. domestic market of hydrogen is estimated at approximately 10 million metric ton per year where almost all of hydrogen is produced through steam methane reforming, a carbon emitting technology. Availability of clean hydrogen becomes crucial to decarbonize current hydrogen market and hard-to-abate sectors. Growth of the new energy sector, including large scale manufacturing of electrolyzers and fuel cells, poses a number of challenges related to supply chain robustness.

Platinum group metals (PGMs), designated as critical materials by the U.S. government, represent a class of metals that include platinum (Pt), palladium (Pd), rhodium (Rh), ruthenium (Ru), and iridium (Ir). PGMs are among the least abundant elements on earth (Figure 1) and occur in only a few countries worldwide, with the majority of production and reserves in South Africa and Russia. Two PGM mines operate in the United States, although both are owned by a South African company and produce less than 7% of world supply.

Shortage of primary platinum and iridium is expected in the 2030s due to the increasing role of clean hydrogen in energy transition. There is a great amount of uncertainty due to the novelty of polymer electrolyte membrane (PEM) electrolyzers and fuel cells technology, recovery rates of PGMs, speed and degree of adoption of low carbon hydrogen as a fuel and feedstock.

Figure 1. Global mine production of PGMs (tons), 2020



Source: US DOE, 2022

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KEY ACRONYMS

FC	Fuel cell
PEM	Polymer electrolyte membrane
PGM	Platinum group metals
PNNL	Pacific Northwest National Lab

US Department of Energy (DOE) specifies that reducing or replacing platinum and recovering other critical metals in fuel cells and polymer electrolyte membranes (PEMs) is a major R&D goal. Iridium availability is the main bottleneck for PEM producers that poses a significant risk for the United States, which is 100% reliant on import of iridium.

Although PGM catalysts have been used in many industrial processes for a long time, **their recovery from electrolyzer membranes and fuel cells is a new area that needs research and scalable technology**.

Currently, PEM water electrolyzers are estimated to have platinum (Pt) content in a cathode catalyst of 0.26 kg Pt/MW and an anode catalyst loading of 0.45 kg Ir/MW (Figure 2). Current efforts to reduce PGM content in electrolyzers and fuel cells focus on using nanoparticles, which accentuates the need to invest in researching recovery rates of Ir.

Figure 2. Key elements in PEM and FC production chain

Raw materials	Processed materials	Subcomponents		End product	EOL recovery
	Perflourosulphonic acid	Electrolyte membrane	Membrane electrode assembly (MEA)	PEM fuel cell and electrolyzer cell stack	**PEMFC** Pt from membrane electrode assembly; **PEMEC** Pt & Ir from membrane electrode assembly; Graphite, Titanium from bipolar plates
	Sulfonated polyether ether ketone				
	Polystyrene sulphonic acid (PEMFC)				
PGM (Pt)	Pt or Pt alloys	Cathode catalyst			
PGM (Ir)	Ir or Ir alloys (PEMEC)	Anode catalyst			
Graphite	Carbon metal oxide, carbides, etc. (PEMFC)	Catalyst support			
Graphite	Graphite composites	Gas diffusion layer			
Titanium (Ti)	Ti mesh/felt/foam				
Chromium, Nickel	Stainless steel mesh				
Chromium, Nickel; Titanium	Stainless steel (Ti-coated for PEMEC)	Bipolar plates			
Graphite	Carbon fiber	End plates			
Chromium, Nickel	Stainless steel				
Aluminum	Aluminum	Seal			
	Thermoplastic				
	Elastomer – Silicone, Viton				

Source: US DOE, 2022

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Most major PEM fuel cell catalyst manufacturers are located outside the US, including Johnson Matthey, Umicore, Heraeus, Tanaka Precious Metals, and others.

The companies producing iridium catalysts for PEM electrolyzer applications include DeNora, an Italian company with operations in Texas; Tanaka Precious Metals; and others.

Despite the uncertainty of scale and speed of low carbon hydrogen deployment, significant competition for raw materials across the value chain is emerging. The load of demand for critical materials may vary, and some models forecast 80% reduction in iridium load for PEM electrolyzers.

Academic literature has projected extremely low future iridium requirements – between 0.005 kg per MW by the late 2020s and 2030s and 0.001 by 2100. The US DOE's H2NEW consortium has established a range of targets for the industry including a target of 0.039 g per MW.

If those targets are achieved, the demand for PGMs will be significantly lower than current projected levels (Figure 3) helping prevent bottlenecks and lower the overall cost of clean hydrogen.

Figure 3. Cumulative demand for Ir and Pt up to 2050 from hydrogen production

Source: Hydrogen Council, 2022

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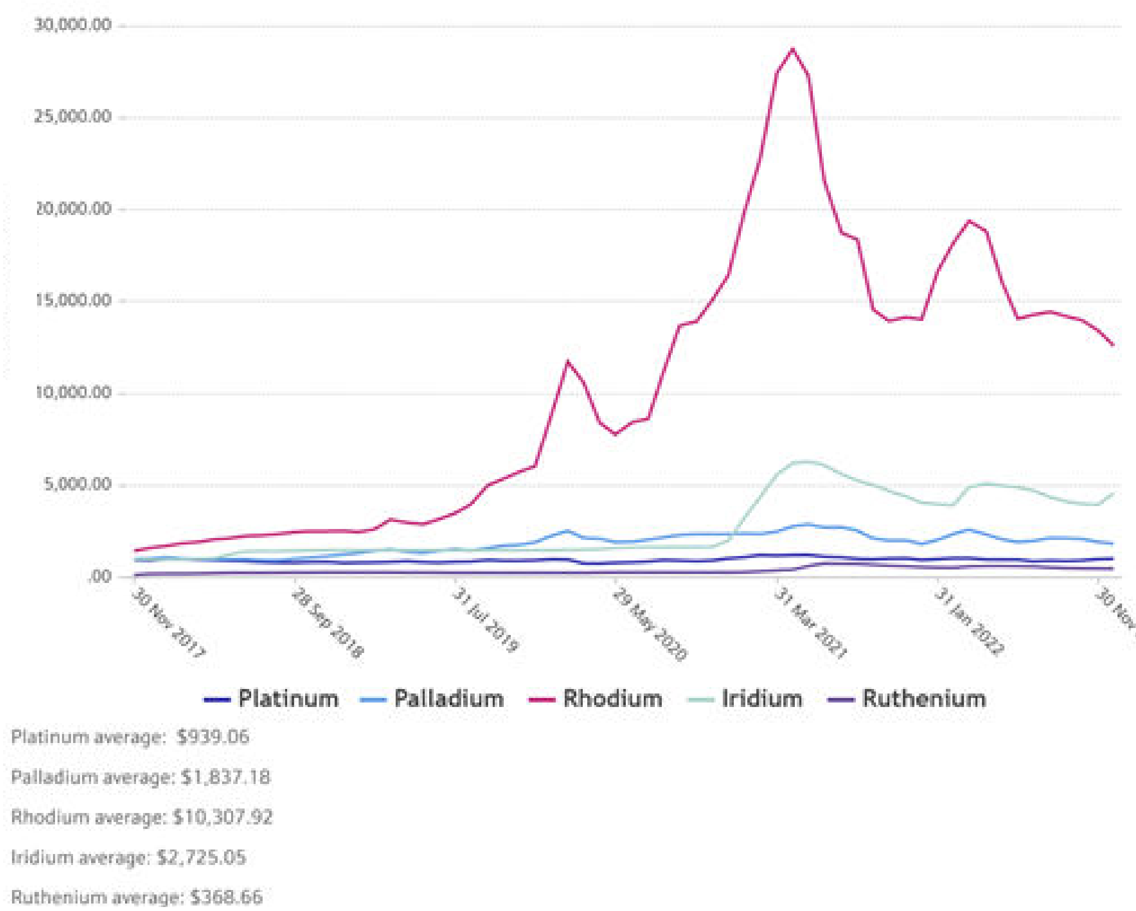
US Position and Susceptibility to Risk

Platinum group metals are in high demand due to their widespread use in novel sectors, namely electronics, clean technologies, and traditional industries such as automotive or jewelry. These factors as well as the negative effects of the global pandemic and geopolitical tensions have contributed to PGM prices on the rise and remaining highly volatile.

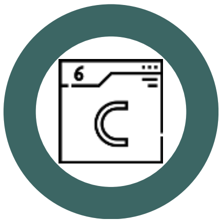
Figure 4. PGM prices, $/troy oz



Source: https://platinum.matthey.com/

High-Risk Electrolyzer and Fuel Cell Materials
(for all types of electrolyzers)

GRAPHITE/ACTIVATED CARBON

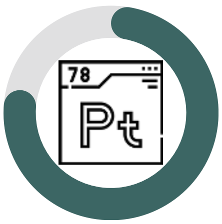


The US is **100%** dependent on foreign sources, mainly China, to meet domestic demand of natural graphite which is used in metal supports for cathodes and electrolyte plates. In 2020, China was the world's leading graphite producer, producing an estimated 62% of total world output.

IRIDIUM

Iridium mining is concentrated in South Africa and Zimbabwe. Iridium is a by-product of the primary PGM mining (platinum and palladium), so its production rates are irresponsive to pricing. The US is **100%** reliant on imports to meet the demand. Hence, improving end-of-life recycling rates to at least 90%, and low catalyst loading targets of 0.05 g/kW are crucial to meet future iridium demand.

PLATINUM

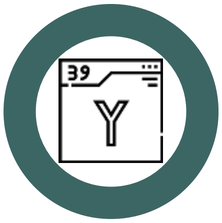


Platinum mining is mainly concentrated in South Africa (72% of global production), followed by Russia and Zimbabwe. The United States is **79%** reliant on imports to meet its platinum demand. The main U.S. import sources of platinum are South Africa, Germany, Italy, and Switzerland.

STRONTIUM

US imports 100% of the strontium it requires, although significant domestic strontium deposits exist across the country. The main import sources of strontium for the United States in 2020 were Mexico and Germany, which makes the supply somewhat secure.

YTTRIUM



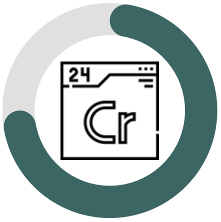
Yttrium is commonly used in SOEC. Currently, the US does not have a significant domestic demand for yttrium. Primary end uses include catalysts, ceramics, lasers, metallurgy, and phosphors. The country is currently 100% reliant on imports for yttrium, and 94% of the supply comes from China.

Moderate-Risk Electrolyzer and Fuel Cell Materials

ALUMINUM

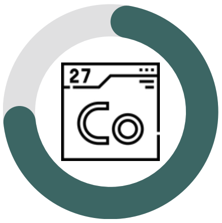
Aluminum is primarily produced from alumina extracted from bauxite. Resources are concentrated in Africa, Oceania, South America and the Caribbean, and Asia. The US imports ~**50%** of domestic demand from Canada (50%); the United Arab Emirates (10%), Russia (9%), China (5%), and other nations (26%).

CHROMIUM



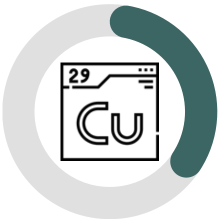
Chromium is supplied mainly by South Africa. As of 2020, the United States was **75%** reliant on imports to meet its chromium demand. The main global suppliers of chromium to the United States in 2020 were South Africa, Kazakhstan, Mexico, and Russia.

COBALT



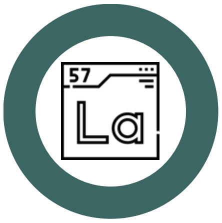
The United States was **76%** reliant on imports to meet its cobalt demand as of 2020. Cobalt is used mainly to produce superalloys for aircraft gas turbine engines. Globally, cobalt mining is concentrated in Congo, and China is the largest supplier of refined cobalt. The main US suppliers of cobalt intermediates (e.g., cobalt powders) in 2020 were Norway, Canada, Japan, and Finland.

COPPER



Import reliance of the United States for refined copper is fairly low: around **37%** in 2020. The US mines, smelts, refines, and recycles copper, and it has significant copper reserves. The main US suppliers of refined copper are Chile, Canada, and Mexico.

LANTHANUM

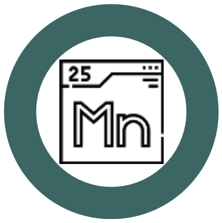


There is no domestic production of lanthanum in the United States; it relies for **100%** of its domestic lanthanum demand on imports from China. This reliance will lessen once the primary domestic rare earth mine, Mountain Pass in California, starts separating light rare earths at its mining facility in 2022.

Moderate-Risk Electrolyzer and Fuel Cell Materials *(continued)*

MANGANESE

In 2020, the United States was 100% reliant on imports, including imports from Gabon (69%), South Africa (17%), Mexico (8%), and Australia (4%). There is no significant domestic supply of manganese.

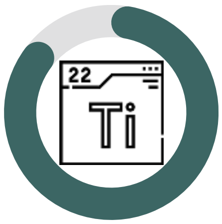


NICKEL

The domestic nickel demand is for stainless and alloy steels (≈85%), nonferrous alloys and superalloys, electroplating, and other uses. It is currently 50% met by imports, mainly from Canada, Finland, Norway, and Russia.

TITANIUM

Production of titanium mineral concentrates is mainly concentrated in China, South Africa, and Australia. In 2020, The United States imported 88% of its titanium mineral concentrates demand and more than 50% of titanium sponge demand. The main US suppliers of titanium mineral concentrates were South Africa, Australia, Madagascar, and Mozambique and those of titanium sponge were Japan, Kazakhstan, and Ukraine.



ZIRCONIUM

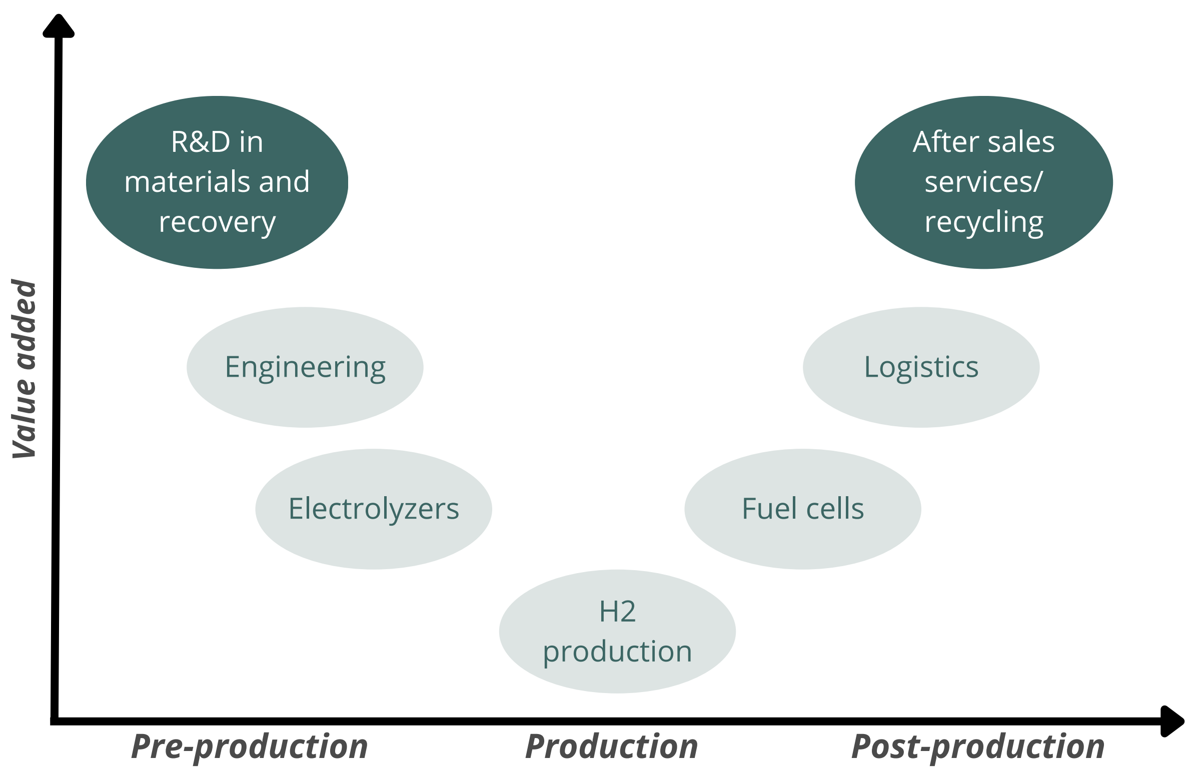
US was a net exporter of zirconium before 2020 and now is regarded to be cost-competitive among domestic and global suppliers.

Conclusions

Competition for PGMs and other critical minerals among various industries will continue to grow putting additional stress on clean energy value chain. These include transportation applications, for example aerospace and automotive industries, raw materials processing such as petroleum refining, stainless steel and heat-resisting steel, goods manufacturing, including packaging, electrical machinery, electronics, consumer durables, etc.

Use of PGMs in electrolyzers and fuel cells presents challenges to the green H2 sector but also opportunities to upgrade Washington's position in the production chain by becoming a center for R&D, including development of PGM-free electrolyzers and fuel cells, and recovery of critical elements. The "smile" diagram (Figure 5) is used to show distribution of value, derived from knowledge and technologies, across different segments of production chain. From economic development and job creation standpoint, moving into higher value segments ensures long-term sector growth.

Figure 5. Opportunities to move up the green H2 value chain



Source: CHARGE

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