NOTE

PROGRAMME ENERGY AND RAW MATERIALS

CRITICAL METALS SUBSTITUTION: A NEW DIPLOMATIC LEVER?

By **Dr. Alexandre Nominé, Dr. Janez Zavašnik, Rajarshi Rakesh Sahai,** and **François Rousseau**

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ABOUT THE AUTHORS

Dr. Alexandre Nominé / Associate Professor University of Lorraine teaching at Mines Nancy, Researcher at Institut Jean Lamour, Senior Researcher at Jožef Stefan Institute in Ljubljana

Alexandre Nominé is Associate Professor University of Lorraine teaching at Mines Nancy and researcher at Institut Jean Lamour. He is Senior Researcher at Jožef Stefan Institute in Ljubljana. He is the principal Investigator of HERawS and Greenano European project. His current research is about the assessment and discovery of sustainable materials for substitution of raw materials.

Dr. Janez Zavašnik / Senior Researcher at Jožef Stefan Institute in Ljubljana and Max-Planck Institute for Sustainable Materials in Dusseldorf

Dr. Janez Zavašnik is Senior Researcher at Jožef Stefan Institute in Ljubljana and Max-Planck Institute for Sustainable Materials in Dusseldorf. He is the local coordinator of HERawS, Greenano and ThermoDust European project. He is member of Eurofusion network and the scientific leader of a German-Slovenian partner group on high-performance materials.

Rajarshi Rakesh Sahai / Expert, RJB Renewable Holdings, Amsterdam, The Netherlands

Rajarshi Rakesh Sahai is a seasoned executive with expertise in driving transformations, fostering innovation, and forging strategic alliances across the mobility, energy tech, and corporate strategy sectors. He is lately engaged in a consulting/expert capacity with German and Asian automotive majors, EIT Urban Mobility, and investment firms while steering his own investment vehicle - RJB Renewable Holdings - in Amsterdam, the Netherlands

François Rousseau / Director, Mines Nancy

François Rousseau is a member of 'Corps des Mines', after different experience in state agencies in the domain of industrial safety and environment. He became Director of Mines Nancy in 2016. Under his leadership, Mines Nancy has been constantly ranked within the top 10 engineering program in France and also elected "Most commited school in Green Transition" by the economic newspaper *Les Echos*. His current research is about the contribution of Artifical Intelligence for the discovery of sustainable materials.

ABOUT HERawS Project

HERawS (Highlights on European Raw Materials Sustainability) is an Erasmus+ research project examining Europe's transition from fossil fuels to critical metals dependency. The multidisciplinary initiative addresses three key areas: analyzing the potential of critical metals for digital and green transitions, documenting the role of raw materials in transformation processes, and mapping the costs and risks of shifting from oil-based to metal-intensive economies. The project delivers educational programs for researchers, policymakers, and SMEs, alongside public awareness tools including expert podcasts and an interactive assessment simulator for evaluating critical materials impact. By combining research with practical educational resources, HERawS aims to inform decision-making around Europe's raw materials challenges as the continent navigates supply chain vulnerabilities and strategic dependencies in an evolving global materials landscape.

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IRIS has developed extensive expertise over several decades in the geopolitics of energy production and trade and is strengthening its research team on raw materials for the energy transition. Through this expertise, the Energy and Raw Materials programme provides public and private institutions and organisations with unique analytical capabilities, based on a detailed monitoring of international relations and influence dynamics surrounding these issues.

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GROWING DEPENDENCE ON METALS

The energy and digital transitions are radically transforming our raw material needs. While energy can be renewable, its production, transportation, and storage require sophisticated devices - solar panels, wind turbines, batteries, hydrogen conversion systems. Similarly, artificial intelligence, despite its virtual nature, depends entirely on physical hardware composed of chips and semiconductors.

This technological revolution is accompanied by an explosion in demand for critical metals. All studies converge toward a spectacular increase: over 400 % for dysprosium and cobalt in the coming decades. This exponential growth raises crucial questions about our supply capacity and, by extension, about the very success of our transitions. Moreover, as critical metals become the new oil, we also need to ideally avoid the excesses and dependencies of the oil economy. We have a rare chance to realign our diplomacy in a contemporary world that is arguably more multi-polar and an active challenge to hegemonies and forced dependencies.

THE FOUR DIMENSIONS OF SUPPLY RISK

To understand the challenges ahead, we need to analyse four interconnected dimensions:

Geological Dimension

Metals are not evenly distributed in the Earth's crust. The contrast is striking: there is a ratio of approximately 1 to 10-100 billion between silicon (as oxide) and iridium. This natural scarcity is compounded by uneven geographical distribution, concentrating certain resources in specific regions of the globe.

Industrial Dimension

The materials value chain follows a complex path: ore extraction, concentrate formation, then refining to obtain the final metal. These steps are not necessarily performed in the same country. The lithium example is revealing: although China's ore reserves are modest, China largely dominates the manufacturing of concentrates needed for batteries.

Geopolitical Dimension

Metals are progressively becoming instruments of international policy. Some countries, like Indonesia with nickel, ban the export of raw ores to move up the value chain. Others use these resources as retaliation tools, as China did during the Senkaku Islands crisis with Japan, or more recently in response to tariffs imposed by Donald Trump administration in the United States of America (US).

ACCEPTABILITY AND FEASIBILITY DIMENSION

Mining remains an industry with significant environmental and social impact, despite considerable improvement efforts. Europe, despite having significant reserves, struggles to develop new mining projects due to population opposition and indeed other challenges that have compounded with a historic shift to knowledge and finance economy. Paradoxically, while the mining industry is not considered a green investment, the "green" sectors of the European taxonomy depend heavily on it.

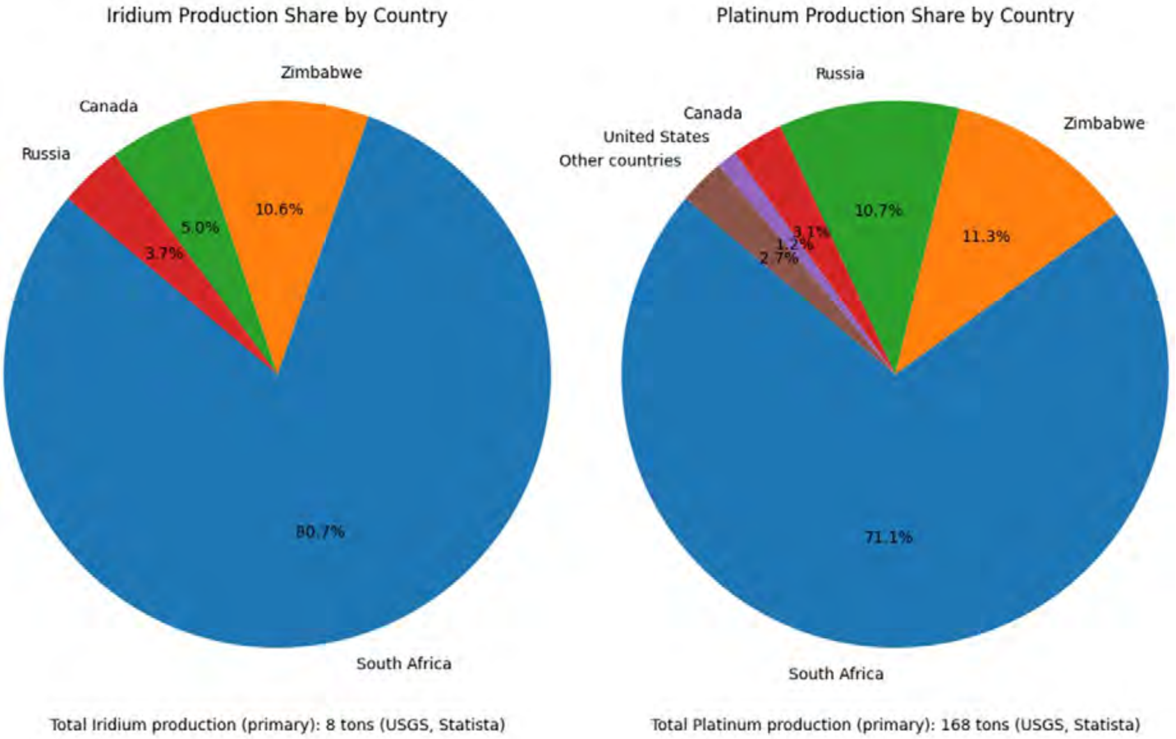
The Revealing Example of Hydrogen

The hydrogen economy perfectly illustrates these tensions. Planned investments in this sector reach hundreds of billions of euros. Yet, the dominant technology in terms of performance (Proton Exchange Membrane) depends heavily on platinum group metals (mostly Platinum and Iridium), concentrated over 80 % in South Africa and Russia.

The imbalance between supply and forecast demand is alarming. Some countries will see their green hydrogen investments compromised by supply disruptions. Western countries risk not being at the top of Russian and South African priorities, making our platinum supply diplomatically expensive.

The current situation is revealing: Russian platinum group metals escape sanctions. But what would happen if Russia sanctioned us by banning the export of these metals or simply introduced export restrictions and compliances like that of China? With only South Africa left, we would have to develop a circumvention system similar to the one Russia set up for oil - buying through third countries, at considerable additional costs.

Share of Iridium- and Platinum-Producing Countries in Total Primary Production



Sources : USGS, Statista

SUBSTITUTION: A PATH TO DIPLOMATIC EMANCIPATION

Faced with these constraints, several solutions emerge in the public debate: degrowth, reasonable consumption, circular economy. These approaches, while essential, will probably not be sufficient to solve the entire problem in an otherwise exponentially growing demand reality.

A third path, still largely ignored, deserves our full attention: substitution. This approach requires a fundamental paradigm shift. For centuries, materials research has optimised the cost-performance ratio. Today, a third dimension is imposed: sustainability, including environmental impact and supply security.

Between a reasonably performing solution with secure supply and an ultra-performing solution with uncertain supply, industrialists will systematically choose the first option. Hence the urgency to accelerate research in Europe aimed at substituting the most critical metals, thus giving us diplomatic breathing room.

CHALLENGES IN SUBSTITUTION RESEARCH

Hope lies in alloy science. While the number of pure elements is limited to 92, the possibilities for combination are infinite. Since the Bronze Age, humanity has exploited the synergistic effects of metallic mixtures. Promising platinum substitutes are already emerging, alloying this metal with other elements. The ultimate goal would be to develop a substitute containing no critical metals.

This research, however, faces the immensity of the field of possible. With 92 elements, the number of possible alloys - binary, ternary, quinary - reaches astronomical proportions. Cantor estimated this number at 10^{89}, more than the number of atoms in the universe! While most of these combinations will prove uninteresting, the probability of discovering revolutionary solutions remains significant.

CONDITIONS FOR SUCCESS

For substitution to become a true diplomatic tool, two conditions are necessary:

Clear Public Demand and Adequate Resources

The example of the messenger ribonucleic acid (mRNA) vaccine against Covid-19 demonstrates that with clearly formulated demand and associated resources, the impossible becomes possible. A few thousand researchers enabled billions of humans to emerge from the pandemic. We therefore need research programs specifically dedicated to substituting metals that obliterate our diplomatic leverage. Moreover, it will also require a certain degree of diplomatic clarity and stability of policy direction, as we also saw during the Covid-19 crisis and the competition for vaccines between sovereign states (e.g. Deutchlland vs USA) and the wider complexity of supranational priorities in the European Union (EU).

Rapid Sustainability Assessment Methods

It is crucial to develop tools that allow scientists to quickly identify sustainable solutions. The European HERawS project has developed a rapid alloy sustainability analysis tool, taking into account individual metal risks and increased risk when multiplying the number of elements. In metallurgy, the absence of a single metal can compromise all the properties of the alloy.

Such solutions will invariably feedback on the earlier condition as more and more clarity will emerge on the extents of possibilities and underlying costs to scaling such innovations to reality. While developing substitutes will depend on the choices made by relevant actors, developing tools remains key to having that optionality for Europe and humanity at large.

CONCLUSION

Everything remains to be discovered in metallurgy. More than ever, this discipline will have a determining role in succeeding the energy transition while avoiding it becoming a source of geopolitical tensions, as oil has been between producing and consuming states. Critical metal substitution represents a unique opportunity to regain control over our energy and diplomatic destiny in a technocratic dimension, possibly helping the world avoid tensions and refocus us on the bigger goal of climate change management.

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IRIS
INSTITUT DE RELATIONS INTERNATIONALES ET STRATÉGIQUES

2 bis, rue Mercœur - 75011 PARIS / France
+ 33 (0) 1 53 27 60 60
contact@iris-france.org

iris-france.org

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