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Electrolyzer materials: overall assessment of supply sustainability and vulnerabilities

As hydrogen produced from electrolysis demand skyrockets, electrolyzer manufacturers may soon face issues in the supply of critical raw materials, with added pressure from other markets such as EVs

Charlotte de Lorgeril
Partner Energy
+33 6 24 73 18 34
charlotte.delorgeril@sia-partners.com

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Executive summary

While renewable hydrogen development fosters a sustainable economy, electrolyzer manufacturers need to deal with material challenges to keep up with a growing demand

In the coming years, significant development of the renewable hydrogen economy will sharply increase electrolyzers demand, as up to 850 GW of installed capacity is required by 2050, whilst current capacity only reaches 0.3 GW. Comprised of some key materials that are critical to the clean energy transition, electrolyzer manufacturers and governments will have to adapt their supply strategy to a highly strained global market to secure future business development.

Hydrogen production will face material challenges…

Ores and refining concentration
The current electrolyzer market heavily depends on resources that are unevenly distributed. This may lead to supply vulnerabilities and monopoly positions.

Economic instability
Among the 6 critical materials studied, 3 are more volatile than oil prices. This is mainly due to highly concentrated reserves or minerals being a by-product of another resource.

Socio-environmental challenges
Mining can harm to local communities and ecosystems. It has significant risks regarding energy and water consumption as well as the protection of human rights and workers safety.

.. to varying levels, depending on the technology…

Alkaline technology
Alkaline which is currently the most mature technology - uses very few critical material apart from nickel.

PEM technology
PEM electrolyzers need platinum-group minerals in anode-cathode systems; these minerals have strong vulnerabilities regarding both supply chains, economic and socio-environmental aspects.

SOEC technology
SOEC technologies rely on rare-earth minerals therefore their criticality will be strongly linked to the government's effort to deploy significant recycling projects.

… needing government support to secure future supply

R&D Support
Technological breakthroughs will be needed to reduce the quantity of materials and find less vulnerable alternatives.

Develop recycling processes
For metals which can not be replaced with other alternatives, recycling is a must. It allows countries with no reserves to reduce supply risks.

Strengthen strategic partnerships
Diplomacy with key supplier countries is needed to secure and diversify future supply roads.

Develop knowledge on material supply risks
To mitigate risks it is necessary to build intelligence on the future challenges related to critical material in the hydrogen economy

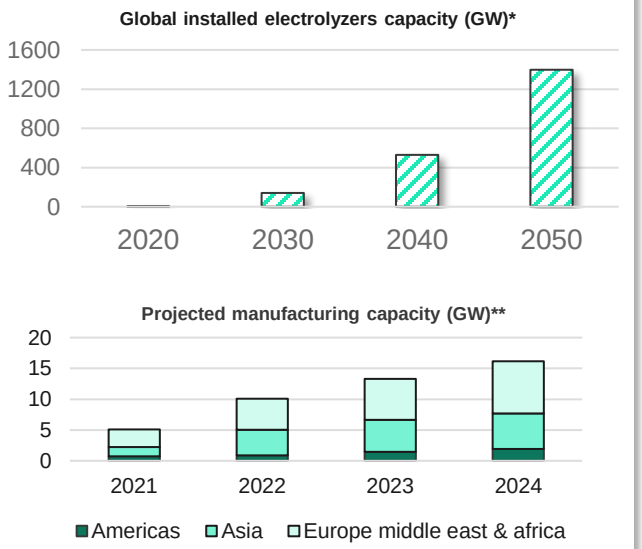
**Source : IEA – Hydrogen Analysis 2021*

Electrolyzers supplying hydrogen will thrive in the next decades

Electrolyzers have several mineral requirements

Hydrogen is being discussed as one of the **key solutions to meet global decarbonation goals** as it can be used as **clean fuel, feedstock or reagent** for industrial or transport applications. To do so, hydrogen needs to be produced through **low carbon technologies, such as water electrolysis coupled with renewable energy**. Installed **electrolyzer capacity is therefore expected to rise significantly** in the coming years, which will lead to **a sharp increase in the demand for certain materials.**

Increasing global demand for decarbonation drives electrolyzer market…



…requiring several minerals to successfully scale up

Mineral found in components of ALK, PEM & SOEC electrolyzer stacks

Component	ALK - Alkaline	PEM – Proton Exchange Membrane	SOEC – Solid Oxide Electrolyzer Cell
End plates	Steel	Steel	Steel
Current collectors	Gold plated copper	Gold plated copper	Gold plated copper
Inter- connectors	Plastic	**Titanium**/Graphite	Chromium alloy
Gaskets	Rubber	Rubber	Rubber
Anode	Precious metal (Zr.)	**Iridium**	Strontium/Sc./Mg.
Cathode	**Raney-Nickel**	**Platinum**	**Nickel/Yttrium**/Sc./Mg.
Electrolyte	Asbestos/Polymers	**Titanium**	**Yttrium**/Gadolinium
Electrolyte membrane	Potassium hydroxide	Nafion Polymer	**Yttrium/Zirconium**

*Source : IEA 2020c – SDS scenario ; **IRENA

Legend: **Mineral** → To be further investigated hereafter, as identified with high criticality potential in literature

Electrolyzers' stack critical materials

Market growth of the 6 assessed materials is primarily driven by an alternative demand to the manufacture of electrolyzers

Yttrium

- **Autonomous driving technologies** — *Increases computational and memory storage performance*

Zirconium

- **Nuclear industry** — *Outer covering of uranium*
- **Ceramic industry** — *Increases opacity and resistance to abrasion and chemical reaction*

Nickel

- **Batteries** — *Major compound of Li-ion batteries*
- **Stainless steel** — *Increases formability, weldability and ductility and corrosion resistance*

Titanium

- **Paint industry** — *Best pigment to increase whiteness and opacity*
- **Miltary and aerospace industries** — *Strengthen critical structural parts*

Platinum

- **Catalytic converters** — *Oxidizes carbon monoxide and hydrocarbons*
- **Fuel cells** — *Major material for cathode*

Iridium

- **Engine industry** — *Extends lifespan of high-grade spark plugs*
- **Digital technologies** — *High performance material for LED technologies*

Criticality is investigated through its entire scope

Supply Risk

The supply of materials is very sensitive to reserves' level, concentration, extraction and processing from a geographical and geopolitical perspective. Moreover, there may be a technological hurdle in the extraction process if an increase in supply Is required for specific materials.

Economic vulnerabilities

Materials may have economic issues related to their price volatility. It may be caused by poor supply, increasing demand or because the material is a by-product of another mineral. High volatility prevent investor from having clear sights therefore increasing financial risks.

Social and Environmental Risks

Some materials can be harmful to both people and the environment. They may use an substantial amount of fossil fuels, water and generate waste during extraction. Above all, human rights and equality among people may be at risk.

Sources : LCA of materials represented in FCH technologies – FCH-JU (2018) ; Kiemel et al. (2021) ; Petzold et al. (2020) ; IEA (2021)

Synthesis of criticality assessment - Material & technology

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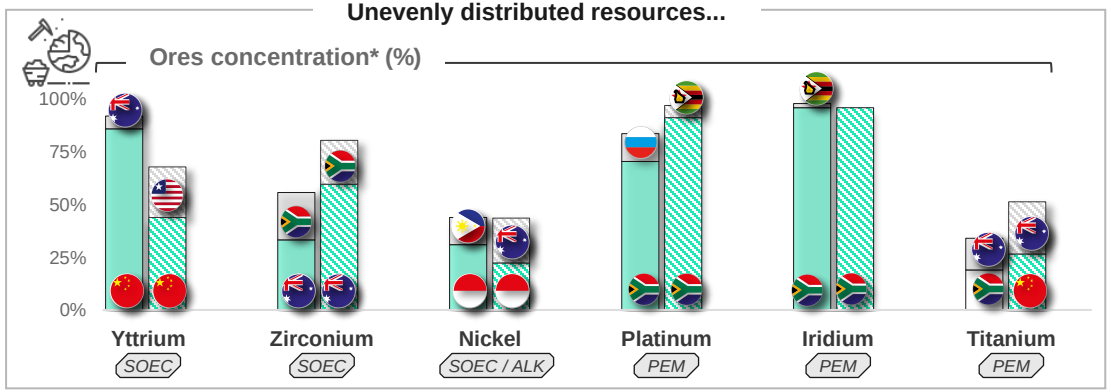
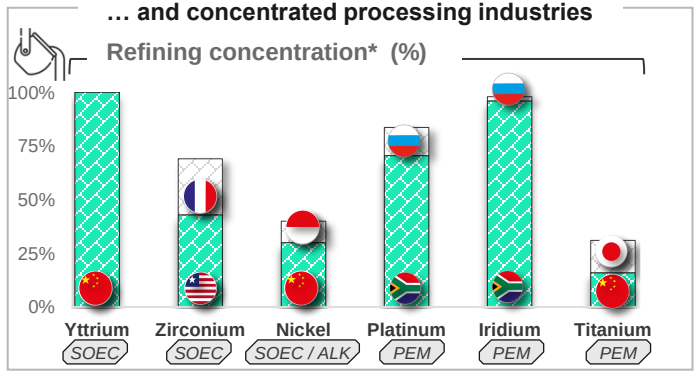
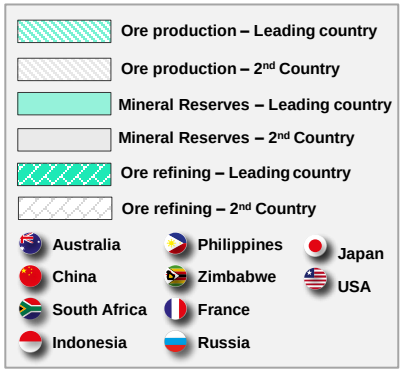
Supply risks

Reserves, extraction and processing are highly concentrated







- In the current market environment, **manufacturers of electrolyzers heavily depend on a limited number of countries** for the sourcing of key materials. Thus, **geopolitical tensions** could threaten their ability to meet their production targets.
- Reserves are **unevenly distributed**, and most of the well-equipped countries are already extracting ores from their own supply.
- **China and South Africa lead both** reserves and refining sites of key hydrogen materials.
- **Protection of intellectual property** and **foreign direct investments screening** in refining technologies should also be considered.

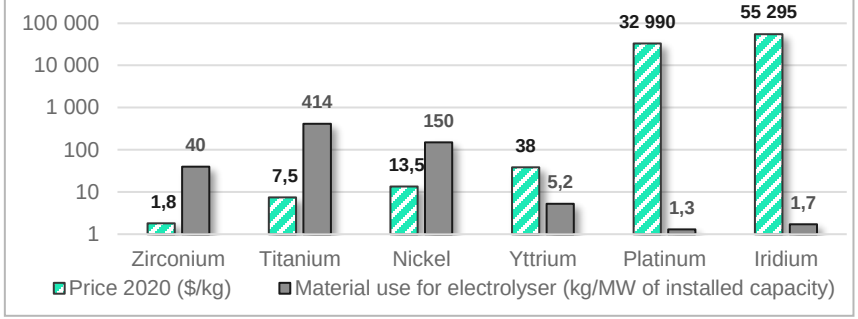
*Sources : BRGM, USGS, European Commission, Kiemel et al. (2018)

Economic vulnerabilities

Prices, trends & demand

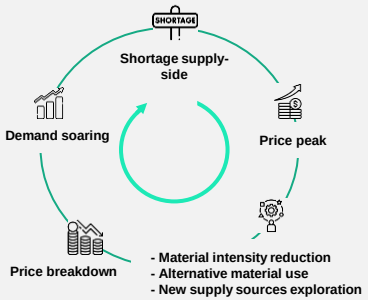
	Future demand intensity of the materials (~2035)	Supply-side scarcity	Average price volatility 2010- 2021*
Zirconium	●○○○ *Stable ceramic market*	●○○○ *Important reserves and substitutes available*	●●●○ **0,40 - High**
Titanium	●○○○ *Electronic, desalination plants and prosthetic technologies*	●●○○ *Important reserves and substitutes available*	●○○○ **0,11 - Low**
Nickel	●●●● *Massive increase in Lithium-ion batteries' demand*	●●●○ *Concentrated and low reserves in unstable countries*	●○○○ **0,26 - Medium**
Yttrium	●●○○ *O_2 sensors in autonomous cars*	●●●● *Concentrated and low reserves in unstable countries*	●●●● **0,73 – Extremely high**
Platinum	●●●○ *Fuel cells markets to skyrocket*	●●●● *Already low reserves balance and hard to extract*	●●○○ **0,25 - Medium**
Iridium	●●●○ *Huge increase in demand for digital screens*	●●●● *By-product of platinum mining*	●●●● **0,74 – Extremely high**
Legend: ●○○○ / ●●●● (Low ▲ ▲ High)		*Illustration to gauge the scale used – scoring for* **Oil**	●●○○ **0,29 - Medium**

High prices and relative material intensity



- **Most mineral demand and supply balance** is the result of the so-called "**feedback control cycle**". Shortages on the supply-side lead to demand-side adaptations and conversely, shortages and peaks generally **disappear in a relatively short period of time**.
- However, when production is **highly concentrated** (ex: yttrium) and/or mineral **is a by-product of another metal** (ex: iridium), minerals prices can become **extremely volatiles**, thus **reducing investment safety.**

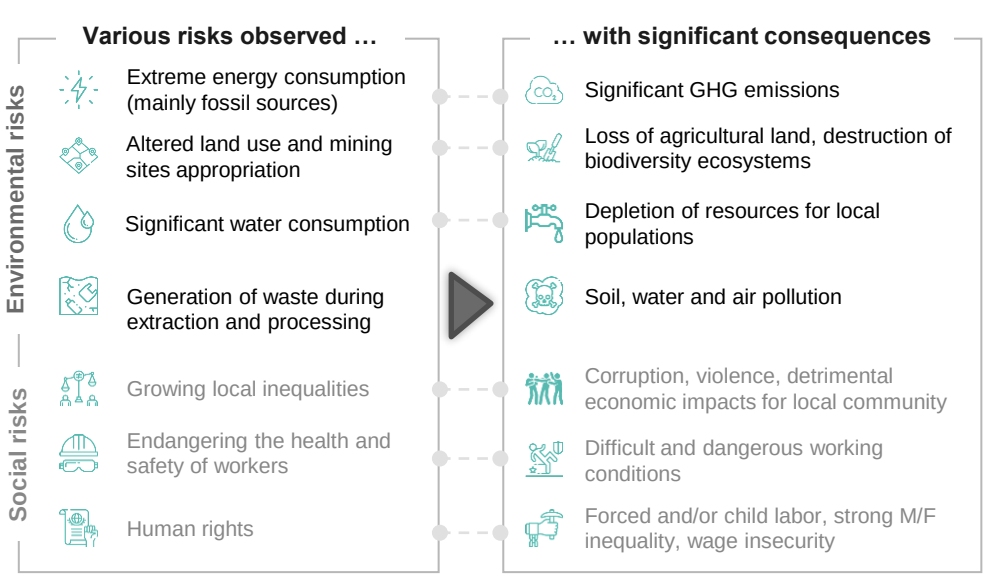
Feedback control cycle

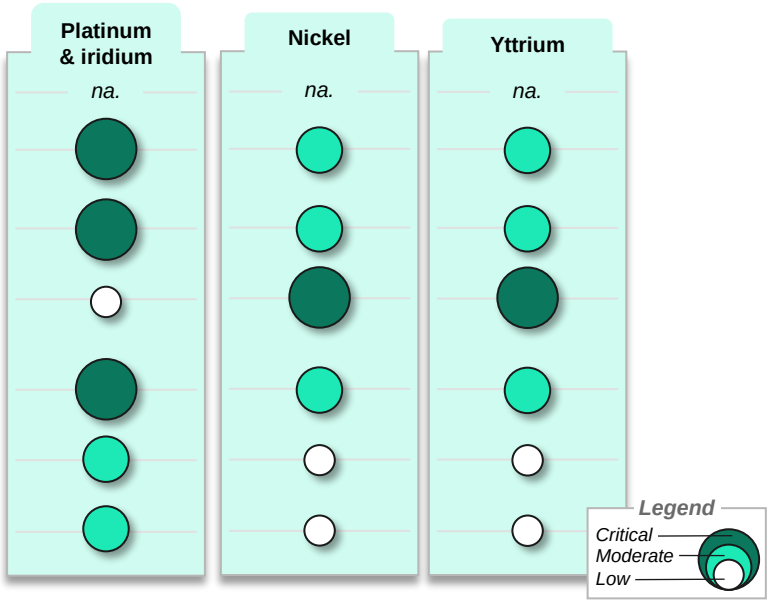


*Average price standard deviation (2010 – 2021) calculated as $\frac{\sqrt{\sum_{i=1}^{n}(x_i-\bar{x})^2}}{n}$. Sia Partners analysis – Mineral's price data from USGS.

Multiple socio-environmental risks

Most energy transition metals carry significant socio-environmental risks





Mining **may be harmful** on various aspects to local communities, ecosystems and more widely to the planet. For decades, international organizations such as the UN have been working towards **more sustainable mining** by informing mining companies of the potential impacts of their activities and how to transform these into positive opportunities for people and the planet. **Renewable hydrogen forms part of the solution** as it could replace most fossil fuel use-cases in a mid to long term to decarbonized minerals' supply chain. It should be noted, that **the need in minerals for hydrogen products may exacerbate the risks presented above.**

Sources : The social and environmental complexities of extracting energy transition metals – Lèbre et al. (2020) ; Mapping Mining SDGs – World Economic Forum 2016

Conclusion

Governments need to define clear targets to secure future supply

The three key electrolyzer technologies raise supply concerns

1. Alkaline Technology

> Most materials in Alkaline technologies are **metals with no supply threats**. Thus, the technology presents low criticality regarding its materials. However, the **price of nickel and its supply should be monitored closely**, although a reduction in nickel demand is expected.

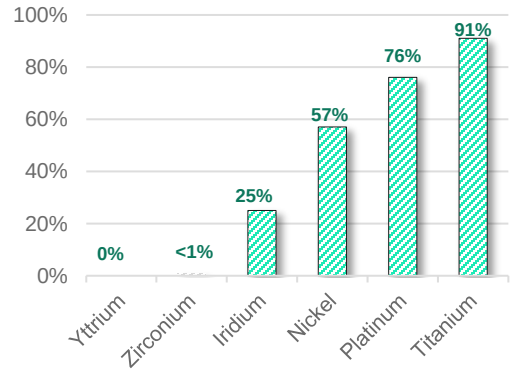
2. PEM Technology

> Most critical materials for PEM technologies are **platinum-group minerals** (Iridium, Platinum, Rhodium, Ruthenium) which have **supply, economic and socio-environmental vulnerabilities**. Thus, **R&D** will be needed to identify alternatives or reduce material intensity.

3. SOEC Technology

> Vulnerable materials in SOEC electrolyzers are mostly related to **Yttrium and Nickel**. **Deploying rare earth element recycling strategies** will be mandatory to reduce primary supply reliance and **support SOEC applications widespread.**

Worldwide end-of-life recycling rate*



Source: Recycling rate of metals, International Resource Panel, 2021

Existing solutions need governmental support to be deployed

Reducing material intensity & increase material substitution

Encouraging **material substitution and material intensity reduction** can play major role in alleviating strains on supply while also reducing costs. For instance, nickel content is expected to drop below 10g/MW for SOEC applications in the next decade** (nickel content is currently about 150g/MW)

Recycling (see on the right)

Recycling relieves the pressure on primary supply. Some recent government actions aim to increase recycling rate of critical materials to reduce importation reliance. Recycling is limited by technology, but **its main driver is economic** therefore the most recycled minerals are often the most expensive.

Develop knowledge

Business intelligence in the raw materials sector has long been overlooked. However, it is essential to **have a clear view of the criticality of certain materials and technologies** in order to develop economic resilience plans. **Further analysis and foresight are expected** in Europe and other countries in the next few years.

Strengthen economic relationships with supplier countries

Defining **clear targets related to economic diplomacy is needed** in the current state of play. Countries must **investigate new partnerships** to secure and diversify future supply and make sure to **strengthen relations with current suppliers.**

**Source : IEA, The role of critical minerals in clean energy transition, 2021*

Contacts

Charlotte DE LORGERIL
Partner Energy & Environment
charlotte.delorgeril@sia-partners.com

Yann LESESTRE
Manager Energy & Environment
Yann.lesestre@sia-partners.com

Authors

Gautier LAVEISSIERE
Manager Energy & Environment
gautier.laveissiere@sia-partners.com

Mathieu DEMOULIN
Consultant Energy & Environment
mathieu.demoulin@sia-partners.com

Remi CALVET
Consultant Energy & Environment
remi.calvet@sia-partners.com

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