ESRC Earth Sciences Research Center
Sultan Qaboos University Oman
1st International Conference in Earth Sciences and Energy Transition
Muscat-Sultanate of Oman 6-10 February 2023

Springer | Publishing Partner

Raw materials requirements to meet the demand for green hydrogen electrolyzers

Bernardo Teixeira[1], Miguel Brito,[1], António Mateus[1]

[1] Universidade de Lisboa, Faculdade de Ciências, Instituto Dom Luiz (IDL), 1749-016 Lisboa Portugal
bdteixeira@fc.ul.pt

Abstract. The global energy transition is evolving rapidly with several multi-million-dollar projects in numerous technologies around the globe. Hydrogen is not an exception. Thanks to its properties, hydrogen represents an unavoidable energy vector that could play a crucial role in energy transition programs. Portugal aims to be on the “green hydrogen” front row, settled on the country’s high irradiation and strong winds to couple renewable energy production with electrolyzers. Implementing these technologies requires raw materials, and we will focus on the electrolyzers’ requirements to assess this technology’s impact on the availability of cobalt, iridium, nickel, platinum, and titanium. The Portuguese hydrogen plan envisages 2 GW of electrolyzers installed capacity by 2030. Far more impressive is the need to install around 720 GW of electrolyzers globally to get on track with the Net Zero Scenario by 2030. Currently, the primary type of electrolyzers deployed are alkaline. Still, it is expected that the proton exchange membrane alternative will start gaining momentum, and by 2024 the deployment should achieve parity, which we assume will maintain until 2030. To accomplish the 2030 plan, for the electrolyzers alone, Portugal will take between 7 to 8 tons of cobalt, 0.7 to 1.4 tons of iridium, 800 to 1000 tons of nickel, 0.07 to 1.7 tons of platinum, and 400 to 500 tons of titanium. Worldwide we calculate 2520 to 2880 tons of cobalt, 252 to 504 tons of iridium, 288000 to 360000 tons of nickel, 25 to 612 tons of platinum, and 144000 and 180000 tons of titanium, strictly for the electrolyzers. Considering these figures, constrictions in the future supply of iridium are expected since its current annual production does not exceed ca. 8 tons. Technical improvements regarding iridium material intensity or its substitution in the catalyst are crucial for a proper hydrogen economy based on the versatile PEM electrolyzers to develop and avoid supply bottlenecks.

Keywords: Hydrogen, Electrolyzers, Raw Materials, Iridium

1 Introduction

The hydrogen momentum is strong, pushed mainly by the recognition of its critical role in realizing the commitments governments have announced in recent years to uphold net zero GHG emissions [1]. Portugal is no exception and intends to be on the front row for “green hydrogen” production, settled on the country’s high irradiation and strong winds to couple renewable energy production with electrolyzers. The Portuguese hydrogen roadmap envisages 2 GW of installed “green” electrolyzers by 2030 [2]. Far more impressive is the global need for around 720 GW of installed electrolyzers to get on track with the Net Zero Scenario by 2030 [4]. Notably, if all current projects in the pipeline are realized, 240 GW of electrolyzers will be installed by 2030 [1].

Hydrogen may be produced from water electrolysis using renewable sources of electricity ("green hydrogen"), from steam reforming of fossil fuels ("grey hydrogen"), from steam reforming of fossil fuels and subsequent capture of the produced carbon dioxide ("blue hydrogen"), and even other alternatives [3]. Implementing any of these technologies requires raw materials. In this work, we focus on the requirements for electrolyzer production to assess the impact on the availability of cobalt (Co), iridium (Ir), nickel (Ni), platinum (Pt), and titanium (Ti).

2 Data, scenarios, and assumptions

The analysis is based on the Portuguese Hydrogen Roadmap [2], which aims to deploy 2 GW of electrolyzers by 2030, the currently known project on the pipeline for 2030, standing at 240 GW [1], and the Net Zero Scenario of IEA [4] with 720 GW of installed capacity by 2030. One of the most challenging tasks is the definition of the market share for each electrolyzer technology. Alkaline and proton exchange membrane (PEM) electrolyzers are the leading technologies in the market. Alkaline electrolyzers are a well-established technology, but it is expected that PEM will compete for a substantial market share [5], and by 2024 they will achieve market parity which we assume will maintain until 2030. Estimates on the material intensity considered for each technology were based on data compiled from the literature (Table 1).

Table 1 - Material intensity (kg/MW) for alkaline and PEM electrolyzers.

	Alkaline electrolyzer		PEM electrolyzer		Sources
	minimum	maximum	minimum	maximum	
Cobalt	7	8			[6]
Iridium			0.7	1.4	[5], [7], [8]
Nickel	800	1000			[9]
Platinum			0.07	1.7	[7], [10]
Titanium			400	500	[5], [7]

3 Results

The requirements pondered in each scenario were calculated according to the assumptions indicated in the previous section. The results are summarized in Table 2, with the maximum and minimum material needs for each scenario, up to 2030.

Another critical part of the intended analysis is the impact the implementation of hydrogen technologies may have on the supply of raw materials. For this, we considered as reference the data from USGS regarding the production of the selected metals in 2020, the available reserves, and estimated resources (Table 3) [11]. As Pt and Ir are platinum group metals (PGM), the resources and reserves are combined in PGM, thus including palladium (Pd), osmium (Os), ruthenium (Ru), and rhodium (Rh).

Table 2 - Material needs for the three different scenarios studied—values in tonnes.

	Portugal		World Net Zero Scenario		World Pipeline Projects	
	minimum	maximum	minimum	maximum	minimum	maximum
Cobalt	7	8	2,520	2,880	840	960
Iridium	0.7	1.4	252	504	84	168
Nickel	800	1,000	288,000	360,000	96,000	120,000
Platinum	0.07	1.7	25	612	8	204
Titanium	400	500	144,000	180,000	48,000	60,000

Table 3 - Available reserves, resources, and yearly production (in tonnes) for key metals.

	Reserves	Resources	Annual Production
Cobalt	7,500,000	25,000,000	170,000
Iridium			8
Nickel	100,000,000	300,000,000	2,700,000
Platinum			180
Titanium	750,000,000	2,000,000,000	9,000,000
PGM	70,000	100,000	450

4 Discussion and conclusions

The requirements for the Portuguese hydrogen roadmap are almost negligible compared to the global raw material needs for the same purpose. If enacted in the next five years, no problems should arise in its implementation. Regarding the calculated demand for Co, Ni, Pt, and Ti, none seem to raise red flags for implementing hydrogen technology worldwide. The exception is Ir, whose needs range from 84 to 168 tonnes in the Pipeline Projects scenario, and from 252 to 504 tonnes in the Net Zero scenario.

Iridium is a by-product of Pt and Pd mining, being always dependent on the production of the latter two metals. Moreover, the current production hegemony could generate further stability problems in the global supply chain. In fact, South Africa ensures 83% of the worldwide Ir production, complemented by outputs from Canada (4%), Russia (3%), and Zimbabwe (10%), according to the latest available USGS data in 2020 [12]. These four countries supplied 8.1 tonnes of Ir in 2020.

We are assessing the material needs for electrolyzers up to 2030. Therefore, none of the newly built electrolyzers is expected to be decommissioned by 2030. Consequently, recycling Ir from electrolyzers is not a real possibility for the short term, and the outputs potentially yielded by EOL products are not enough to fulfill the expected demand. Thus, we consider all the needs for Ir in the following years to come mostly from primary production, despite the current >25-50% range of Ir recycling rate from EOL products. In such conditions, the demand for Ir in the least material intensity scenario (minimum world projects pipeline) will triple by 2030. For the highest demanding scenario (Net Zero Scenario maximum values), the yearly production must steeply increase to meet demand sixteen times above the level recorded in 2020. These figures highlight one fundamental issue: it will be challenging to attain the commitments using a large share of PEM electrolyzers and only employing "green hydrogen" technologies. More research is needed focusing on the Ir material intensity, as it needs to fall considerably, or finding a proper replacement for Ir. Another consequence is the need to consider alternative hydrogen technologies other than "green hydrogen," especially the low-carbon ones like "blue hydrogen," "turquoise hydrogen," or "pink hydrogen" [3]. The resulting mix of technologies will be fundamental to develop a fully sustained hydrogen economy.

References

1. IEA: Global Hydrogen Review 2022, 284p (2022).
2. DGEG: Roteiro e Plano de Ação para o Hidrogénio em Portugal, 80p (2019).
3. Ajanovic, A., Sayer, M. & Haas, R.: The economics and the environmental benignity of different colors of hydrogen. Int J Hydrogen Energy 47, 24136–24154 (2022).
4. IEA: Net Zero by 2050 - A Roadmap for the Global Energy Sector, 224p (2021)
5. Kiemel, S., Smolinka, T., Lehner, F., Full, J., Sauer, A., Miehe, R.: Critical materials for water electrolyzers at the example of the energy transition in Germany. Int J Energy Res 45, 9914–9935 (2021).
6. Fuel Cells and Hydrogen Joint Undertaking: Addendum to the Multi-Annual Work Plan 2014 - 2020. 55p (2018)
7. Bareiß, K., de la Rua, C., Möckl, M., Hamacher, T.: Life cycle assessment of hydrogen from proton exchange membrane water electrolysis in future energy systems. Appl Energy 237, 862–872 (2019).
8. Carmo, M., Keeley, G.P., Holtz, D., Grube, T., Robinius, M., Müller, M., Stolten, D.: PEM water electrolysis: innovative approaches towards catalyst separation, recovery and recycling. Int J Hydrogen Energy 44, 3450–3455 (2019).
9. IEA: The Role of Critical Minerals in Clean Energy Transitions, World Energy Outlook Special Report. International Energy Agency, 287p (2021)
10. Bachmann, T.M., Carnicelli, F., Preiss, P.: Life cycle assessment of domestic fuel cell micro combined heat and power generation: Exploring influential factors. Int J Hydrogen Energy 44, 3891–3905 (2019).
11. USGS: Mineral Commodity Summaries 2022. 206p (2022).
12. USGS Platinum-Group Metals Statistics and Information Minerals. https://www.usgs.gov/centers/national-minerals-information-center/platinum-group-metals-statistics-and-information, last accessed 2023/01/03