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Veröffentlichungsversion / Published Version
Stellungnahme / comment

Zur Verfügung gestellt in Kooperation mit / provided in cooperation with:
Stiftung Wissenschaft und Politik (SWP)

Empfohlene Zitierung / Suggested Citation:
Ansari, D., Grinschgl, J., & Pepe, J. M. (2022). *Electrolysers for the hydrogen revolution: challenges, dependencies, and solutions.* (SWP Comment, 57/2022). Berlin: Stiftung Wissenschaft und Politik -SWP- Deutsches Institut für Internationale Politik und Sicherheit. https://doi.org/10.18449/2022C57

SWP

SWP Comment

NO. 57 SEPTEMBER 2022

Electrolysers for the Hydrogen Revolution

Challenges, dependencies, and solutions

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Due to Europe's gas crisis and the Russian invasion of Ukraine, ramping up the hydrogen market has become more urgent than ever for European and German policymakers. However, ambitious targets for green hydrogen present an enormous challenge for the European Union (EU) and its young hydrogen economy. Apart from the demand for electricity, there is above all a lack of production capacities for electrolysers. The envisioned production scaling of electrolysers is almost impossible to achieve, and it also conflicts with import efforts and cements new dependencies on suppliers of key raw materials and critical components. Although a decoupling from Russia's raw material supply is generally possible, there is no way for the EU to achieve its goals without China. Aside from loosened regulations and the active management of raw material supply, Europe should also reconsider its biased preference for green hydrogen.

The ongoing energy crisis and Russia's invasion of Ukraine have pushed hydrogen into an increasingly central role in the EU's climate and energy policy plans. Already in 2020, the EU set ambitious targets in its hydrogen strategy. Yet, the European Commission's (EC) latest proposal, REPowerEU, now specifies and raises those targets dramatically. First, the previously demanded 10 million tonnes of annual hydrogen production within the EU are to be complemented by another 10 million tonnes of annual imports by 2030. Second, REPowerEU corrects the previous estimate for the required domestic electrolysis capacity: Not 40 gigawatts (GW), but 120 GW of electrolysis capacity will be needed to produce 10 million tonnes of hydrogen in Europe. The revised targets are intended to achieve the EU Fit for 55 emission targets as well as energy independence from Russia.

The EC plans to rely exclusively on green hydrogen. It is obtained by separating water molecules (H_2O) into hydrogen (H_2) and oxygen (O_2) in an electrolyser powered by renewable electricity — without direct carbon dioxide (CO_2) emissions. However, there are also other, low-carbon technologies that produce hydrogen, such as steam reforming with natural gas, including CO_2 capture — so-called blue hydrogen.

It is questionable whether the ambitious EU goals can be realised while only relying on one technology. The additional renewable electricity needed to produce 10 million tonnes of hydrogen would amount to almost the entire EU-27 electricity generation from wind and solar power in 2021.

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Yet, manufacturing the electrolysers themselves will be even more challenging: The electrolysis capacity currently installed in the EU will need to increase almost 900-fold within just eight years. Moreover, Europe faces the dual challenge of ramping up electrolysis capacity while simultaneously securing its own market share in electrolyser manufacturing.

In the emerging technology-based energy world — and given the intensifying economic and geopolitical competition — a rapid expansion of electrolysis capacity and the capacity to construct electrolysers can become decisive factors in determining the location of industrial activity. Currently, Europe's position in the market is still strong, and the EU is trying to emphasise its sovereignty in industrial and energy policy. For example, the Green Deal and the European Industrial Strategy call for the creation of strategic value chains around renewable energy technologies. With the Clean Hydrogen Alliance, the EU aims at promoting private-sector pilot projects and rapidly increasing hydrogen production. The issue of resilient raw material supply chains is also rising on the EU's agenda.

However, current plans hardly seem to consider geopolitics, industrial policy, and resources policy, especially vis-à-vis electrolysers. Against the background of the threatening fragmentation of the world economy and the emergence of a globalisation characterised by mercantilism, the first thing to do is to identify possible dependencies and vulnerabilities for the European electrolyser industry to guard against (geopolitical) risks. It is imperative to consider supply chains for raw materials and the sourcing of critical components on the one hand, as well as the increasing market dominance of competitors in electrolyser manufacturing on the other.

Which electrolysers for Europe?

The various electrolysis technologies differ mainly in the components used and the maturity of the technologies themselves. Currently, only two technologies are sufficiently mature, and they will likely account for the lion's share of the electrolyser capacities to be installed over the coming decades: alkaline electrolysers (AEL units) and polymer electrolyte membrane (PEM) electrolysers.

AEL is the oldest, most mature, and — with 61 per cent of the world's installed capacity — most widespread type of electrolyser. Its advantages lie in the relatively simple electrolyser design and, hence, a comparatively simple manufacturing process. AEL units are flexible enough to react with sufficient speed to intermittent solar and wind power generation. However, at more than 50 minutes, its cold-start time is quite long — the technology is therefore more suitable for base-load operation than for peaks.

PEM electrolysers are younger than their AEL counterpart. Their global market share is currently just below 31 per cent, but it is growing rapidly. Above all, PEM technology offers a very fast cold-start time of only 10 to 20 minutes and an even faster reaction time to fluctuating electricity production. PEM units are therefore particularly suitable for peak hours in power grids with a high share of renewables. However, in technical terms, they are less mature and, as they require rare metals for their manufacture, they are usually more expensive than AEL models.

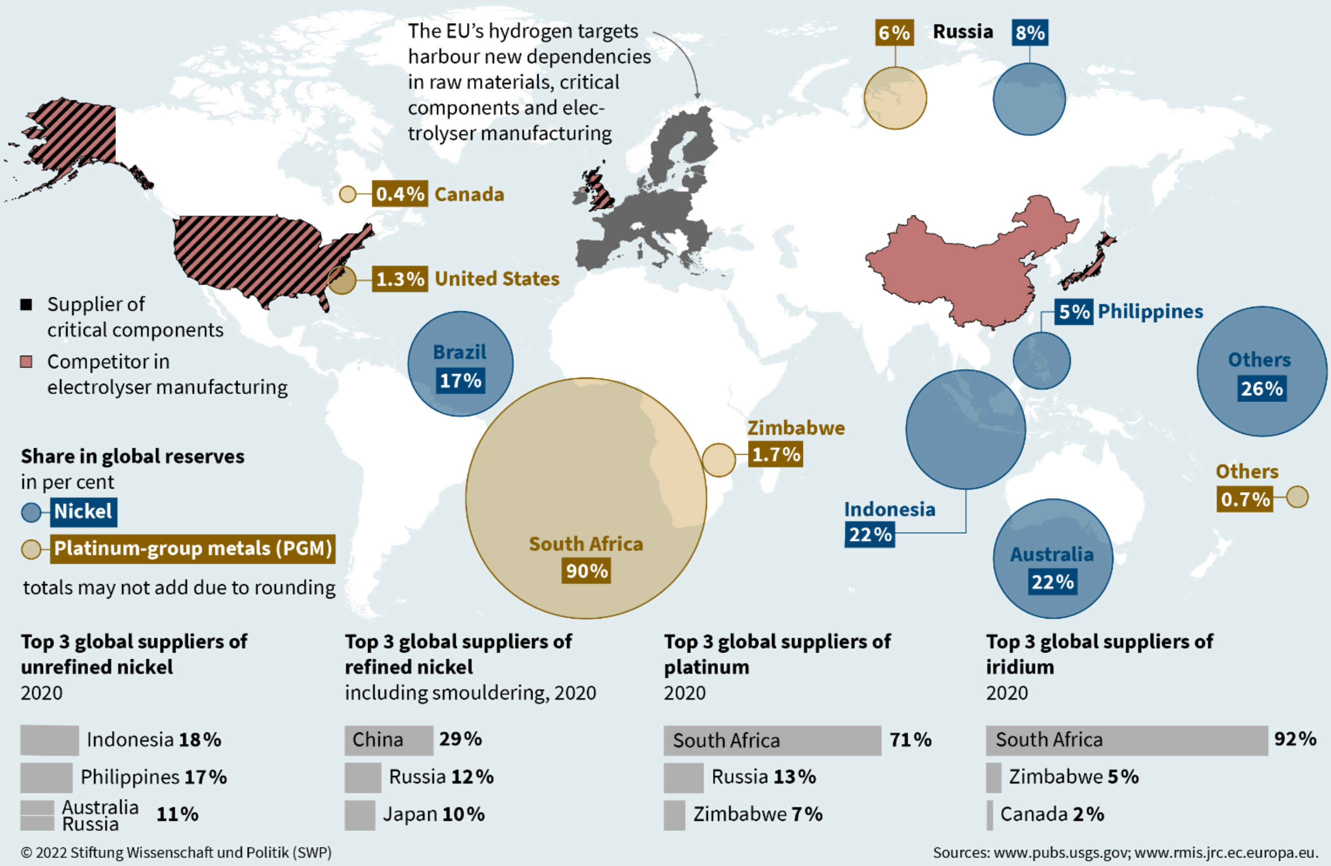
Although Europe has committed itself to green hydrogen, its policy seems indifferent regarding the electrolysis technology. This is wise, since electrolysis capacity from every possible source will come in handy to meet production targets.

Raw material supply chains and critical components

The massive expansion of Europe's electrolyser fleet requires taking a critical look at the supply chains of both electrolysis technologies. A distinction must be made between upstream raw material supply chains and critical components (i.e. industrially produced plant parts).

Figure

Green hydrogen for the EU: Competitors in electrolysis manufacturing and raw materials suppliers



Sources: U.S. Geological Survey, *Mineral Commodity Summaries 2022* (Reston, VA, 2022); Gian Andrea Blengini et al., *Study on the EU's List of Critical Raw Materials (2020). Final Report* (Luxembourg: Publications Office of the European Union, 2020).

Nickel and platinum: Indonesia and South Africa are (hardly) an alternative to Russia and China

AEL units require no rare metals. Only nickel and (nickel-plated) stainless steel are needed. Although nickel deposits are neither rare nor spatially concentrated, the supply of nickel is problematic. To date, between 35 per cent and almost 50 per cent — measured in either trade value or weight — of all nickel imports to Germany and the entire EU originate from Russia. The country ranks fourth in the world for nickel reserves and is therefore a relevant player for both unrefined and refined nickel (see Figure). Other countries, such as India (22 per cent), the Philippines (5 per cent), and Australia (22 per cent), account together for almost half of the world's global nickel reserves; they also hold a similar share in global nickel mining output (see Figure). Thus, they may represent an alternative to Russian supply. However, in 2020, Indonesia prohibited the export of raw nickel to keep nickel refining and its value added within its borders. The EU has already raised a complaint with the World Trade Organization against Indonesia's policy. The Philippines are pursuing a similar strategy. Australia's refining capacity, on the other hand, covers only 7 per cent of the global market.

China is a key player in nickel smelting (an important precursor to refining) and refining, despite Indonesian and Philippine ambitions. Although China does not possess major nickel reserves, its smelting and refining operations are estimated to exceed three-quarters and one-third of global supply, respectively. Thus, the EU has to decide between purchasing smelted or refined nickel from Indonesia — for which it will compete with China — or raw nickel from Australia and the Philippines that has mostly been smelted in China thus far. The prospective costs and risks that arise with the ambitions to break away from Russia are significant.

Yet, the situation concerning PEM electrolysers is even more challenging. Cathodes and anodes in PEM units are usually made from platinum and iridium, respectively. They belong to the so-called platinum-group metals (PGMs) and are among the most scarce, carbon-intense, and expensive metals. There are no known alternatives for the use of iridium in PEM units. Europe's import dependency on platinum and iridium reaches 98 per cent and 100 per cent, respectively.

Global PGM deposits are strongly concentrated in South Africa, which is the world's largest supplier of platinum and iridium (see Figure). The current mining rates of both metals will only allow for an annual increase of PEM electrolysis capacity from 3 to 7.5 GW. However, the demand is expected to increase massively by 2030 — which will require a substantial growth in mining activity.

The iridium shortage is less a result of geological scarcity than one of the social and economic conditions required for increased mining activity. In 2013, for example, violent protests against working conditions in South African platinum mines led to a temporary export ban and high price spikes. Russia is the world's and Europe's second-most important supplier of platinum, as it accounts for 13 per cent of all supply. Decoupling from Russia will therefore further cement Europe's import dependence on South Africa. Zimbabwe (which currently supplies 7 per cent of all platinum in the world and 5 per cent of iridium) faces conditions that are similarly fragile as those in South Africa, and is therefore exposed to the same risks. A genuine diversification of PGM supply is virtually impossible, since South Africa has also by far the largest reserves (90 per cent). More stable mining countries, such as the United States (US) and Canada, will experience an increase in PGM demand themselves — especially since US companies are also eying manufacturing PEM electrolysers. The US is relying on the Defense Production Act to push domestic PGM production to supply its own demand, which is why the US, which accounts for only 2 per cent of global platinum supply, might cease to supply the world market.

As a bottom line, diversifying the nickel supply away from Russia yields considerable yet surmountable costs, whereas Europe's dependence on nickel smelting in China and PGMs from South Africa has no workaround.

Dependencies on critical components for PEM electrolysers

The production of AEL units does not require any components whose security of supply poses specific risks. All components are ordinary industrial materials and can be obtained from within Europe.

The supply chain for PEM electrolysers is similar to that for AEL units, albeit less developed and with fewer suppliers. The high market concentration creates dependencies, mainly on firms from the US, Japan, and the United Kingdom (UK) (see Figure). Although they hardly pose a geopolitical risk, the market concentration makes the EU vulnerable to price developments and logistics issues.

Three PEM components are considered to be especially critical: polymer electrolyte membranes, support catalysts, and the membrane electrode assembly (MEA).

Polymer electrolyte membranes replace the liquid electrolyte used in AEL models and are critical to the performance of PEM electrolysers and the purity of the hydrogen. There is a Europe-based producer that supplies the membrane's raw material, so that risk is manageable. However, the membranes themselves have to be imported from the UK, the US, or Japan. This allows these three countries to maintain existing advantages in technology and production scaling.

Support catalysts in PEM electrolysers enhance the electrochemical reactions of the cell. The three leading companies for these components are based in the EU, the UK, and Japan, respectively. Also in this case, the incumbents' technological lead is a major entry barrier for newcomers.

The MEA — a harmonised assembled stack of proton exchange membranes, catalysts, and electrodes — is essential for the electrolysers' performance. One of the leading producers is based in the UK, but other manufacturers worldwide, especially in China, are scaling up their manufacturing capacity.

Upscaling the manufacture of electrolysers

Europe has a strong position, but there are barriers to upscaling

The (lack of) production capacities for electrolysers is another obstacle to the realisation of the EU's goals. According to the EC, reaching the REPowerEU targets for domestic production alone will require 120 GW of electrolysis capacity. However, the EU-wide electrolysis capacity in 2021 was just 0.135 GW, and the global production capacity in 2020 was capped to some 2 GW per year. The EU already announced 118 GW of electrolysis capacity for 2030 (of which 73 GW will be in Spain), but the final investment decisions are still pending in most cases. Only 64 out of 750 pilot projects within the Clean Hydrogen Alliance deal with electrolyser manufacturing.

Europe already hosts electrolyser manufacturers with expertise in all variants, as well as strong research facilities. These actors include both large industrial players, such as thyssenkrupp and Siemens, as well as smaller companies, which often focus on emerging technologies that are not yet mature. Currently, 60 per cent of global electrolyser manufacturing capacity and 40 per cent of electrolysis capacity are located in the EU. Moreover, Europe has the lead in terms of technology: It holds approximately 40 per cent of all relevant patents. Its lead is particularly strong when it comes to PEMs.

Electrolyser manufacturers, however, often complain that their customers have yet to make final investment decisions, which is why manufacturing capacities cannot be scaled up. Their customers, in turn, criticise the strict legal requirements proposed in drafts for the EC's delegated act. It is decisive for the definition of green hydrogen and the conditions required for its production.

The original draft specified "additionality": From the end of 2026 onward, only electricity from newly built and non-subsidised solar and wind parks was to be used for electrolysis. Secondly, it required spatial and temporal correlation: From 2027 onwards, an electrolyser was only to be allowed to use electricity generated in the same hour, in the same bidding zone, and by plants directly connected to the electrolyser. However, these strict rules ignore the fact that electrolysers must be operated for at least 4,000 hours each year to be cost-competitive. Hence, a recent vote by the European Parliament rejected these two provisions. For a quick market ramp-up, further discussions about the definition of "clean hydrogen" are necessary.

China on its way to a market takeover

In addition to the regulatory obstacles, the European electrolyser industry is also facing strong competition — first and foremost from China (see Figure). At present, China holds about 35 per cent of the world's manufacturing capacity for electrolysers. Although European manufacturing capacity exceeds China's capacity, the latter has already become the world's largest producer of electrolysers. China's advantage is grounded in significantly lower costs: It can produce electrolysers with similar efficiency and quality levels as the European ones, but at one-fifth of the cost. China has focussed on AEL units so far, of which it accounts for half of global production.

The trend is accelerating: In 2022, China's manufacturing capacity is expected to increase fivefold to 2.5 GW per year. This development is being actively pushed by state and industry. China's 14th Five-Year Plan (2021—2025) names the hydrogen industry as one of six industrial priorities. Leading manufacturers of solar PV systems as well as state-owned companies have entered the market. They are pursuing the same strategy that has already yielded dominance in other sectors, such as the solar industry: massively upscaling production, thereby reducing unit production costs, and promoting rapid technological progress. Until now, China has only supplied its domestic market. However, the industry is increasingly turning to international customers, at higher prices — for example in the Arab Gulf States.

A global race for market share ... and electrolysers

Whether the European electrolyser industry will face the same fate as Europe's former domestic solar industry remains an open question. However, both industries are structurally different: Solar PV modules are small in size, easily transportable, and their production is largely standardised. In contrast, electrolysers are more bulky and typically customised. Moreover, the European solar industry was mainly dominated by smaller and younger companies, whereas most European electrolyser manufacturers are large multinationals. In any case, China's rise as the world-leading producer of AEL units shows that Europe's technological lead and market position is deteriorating. Even with PEM technology, China is gradually gaining a foothold. The US is also increasingly interested in the market, and the country has become a serious competitor for PEM electrolysers.

Therefore, electrolysers themselves could turn out to be a global bottleneck for the hydrogen market ramp-up. Even the expected fivefold increase in European production capacity by 2023 is unlikely to achieve the EU's ambitions. Realising the plans would require unparalleled progress in capacity expansion — something only feasible with wartime-like, centralised control over resources. Hence, to reach its aims, Europe might have to rely on the growing Chinese electrolyser industry — new dependencies included.

Notably, REPowerEU not only aims at producing green hydrogen within the EU, but it also necessitates an equal amount of imports — which will require electrolysers, too. Since global electrolyser manufacturing capacities are limited, the parallel ramp-up of imports and domestic production might create difficult trade-offs. Moreover, plans for hydrogen production and use also exist beyond Europe's borders. With the China Hydrogen Alliance, the country is aiming at a scale similar to the EC's: 100 GW by 2030. Therefore — and depending on the speed of the (global) expansion of electrolyser manufacturing capacities — the high installation targets could cement new dependencies and/or massively drive up the prices for electrolysers.

Policy recommendations: Realism, pragmatism, strategy

Electrolysers are at the heart of the emerging green hydrogen world. However, the challenges associated with scaling up their manufacture are often neglected. In their current form, the aims of the REPowerEU proposal are hardly feasible. Achieving them requires close-to-impossible growth rates in mining, metallurgy, electrolyser manufacturing, and electricity generation. The accelerated market ramp-up seeks to advance independence from Russian energy imports — yet, electrolysers themselves create new dependencies. A global bottleneck could fuel competition for electrolysers and, thus, make green hydrogen even more expensive.

Despite these unfavourable conditions, the EU, its member states, and their companies could seek to ameliorate these problems. Six measures makes this possible.

First, the EU, its member states, and their companies should address the risks due to dependencies in the raw material supply chain for electrolysers. A mix of technological innovation and government support may prove the best solution. Since a diversification of PGM suppliers seems difficult to achieve, or even impossible, it is imperative to quickly build recycling infrastructure on the one hand, and to reduce the iridium load in PEM electrolysers on the other.

In addition, clear communication about the exact level of demand for those metals will allow raw material suppliers to plan ahead and provide investment security for new mining projects. Most EU countries do not have their own international mining companies. The example of the Japanese state agency JOGMEC, however, shows that foreign mining projects can still be promoted through loans, investments, and guarantees. The EU should develop a similar instrument to promote foreign private-mining activities and additionally consider creating a European mining champion.

Second, sustainability aspects in resource supply chains need to be considered. As the mining protests in South Africa have shown, neglecting sustainability can affect security of supply. Strengthening public–private partnerships and the capacities of public institutions in mining countries ensures that environmental and social criteria are taken more into account, thus possibly preventing unrest and supply disruptions.

Third, targeted bilateral commodity partnerships (especially with Indonesia, the Philippines, Australia, and South Africa) should be negotiated or expanded for certain commodities such as nickel or PGMs. Also, local refining processes should be promoted with loans and investments. Regarding the potential roles of Indonesia and the Philippines as alternative suppliers to China and Russia, integrating a raw materials component into the EU-ASEAN Free Trade Agreement currently being negotiated provides an attractive opportunity.

Fourth, policy must actively support European electrolyser manufacturers in rapidly upscaling production capacities. Government support for production scaling, appropriate loans, and guaranteed demand should provide sufficient incentives for project developers. The EC has recently proposed the creation of an EU hydrogen bank to act as a buyer for 10 million tonnes of hydrogen. However, it remains unclear whether this bank will also guarantee demand for imports. Defining hydrogen based on its CO_2 footprint instead of the production process is another crucial step that helps producers. Furthermore, keeping an eye on the competition is key: Hydrogen Europe, the European hydrogen industry association, is already warning of a "mass exodus" of the European green hydrogen industry to the US if the EC refuses to make regulations as simple and generous as those in the US. Its "Clean Hydrogen Production and Investment Tax Credit Act" allows comprehensive tax credits for "clean" hydrogen production, which it assesses simply based on the CO_2 reduction compared to conventional hydrogen. Coupled with simpler rules for production, a massive shift of capital flows to the US is likely if Europe refuses to follow suit and ease its regulations. The recent vote by the European Parliament is an important, but still insufficient, step towards preventing an exodus of producers.

Fifth, when dealing with China, the desire for sovereignty and decoupling must be balanced with maintaining the necessary supply chains. China can hardly be ignored – possibly in relation to building electrolyser capacities within the EU, but at least for ramping up electrolyser capacities in countries from which the EU seeks to import hydrogen. Europe should also not take its lead in electrolyser technology for granted. Although it is still ahead in terms of patents and production capacities, China has already overtaken Europe in terms of market share. China's market dominance is clearly increasing — which creates a trade-off for the EU and Germany, since the rapid upscaling of global electrolysis capacity is hardly possible without China.

Sixth, blue hydrogen should be a part of Europe's hydrogen plans. Instead of limiting the technological scope ex ante, the CO_2 footprint of hydrogen production can simply be valuated using the EU's CO_2 price. This simple procedure will steer hydrogen production and imports towards zero-carbon green hydrogen. In Europe, regulatory difficulties and the gas crisis make blue hydrogen uncompetitive — here, green hydrogen has prematurely become the cheapest form of hydrogen; but in regions with lower gas prices (such as the Gulf States), blue hydrogen is still cheaper. Further research will need to examine which instruments (such as long-term contracts, specialised infrastructure) are best suited to ensure that exporters replace LNG with blue hydrogen in the medium term.

The lack of electrolysers is sufficient to conclude that the EU will not achieve its goals with green hydrogen alone. Importing blue hydrogen can ameliorate the conflicting goals that result from the simultaneous expansion of domestic and foreign electrolysis capacities. Building the framework around the CO_2 footprint of hydrogen largely avoids the disadvantages that European hydrogen producers face compared to foreign ones. This step would also simplify the creation of a harmonised global certification and regulation framework.

Given the current realities of global energy markets and geopolitical circumstances, the EU must make the upscaling of electrolysis capacities a priority. In this context, ramping up the hydrogen market must trump individual preferences for certain technologies. It is of utmost importance that the EU plans realistically, behaves pragmatically, and acts strategically.

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ISSN (Print) 1861-1761
ISSN (Online) 2747-5107
DOI: 10.18449/2022C57

(English version of
SWP-Aktuell 58/2022)