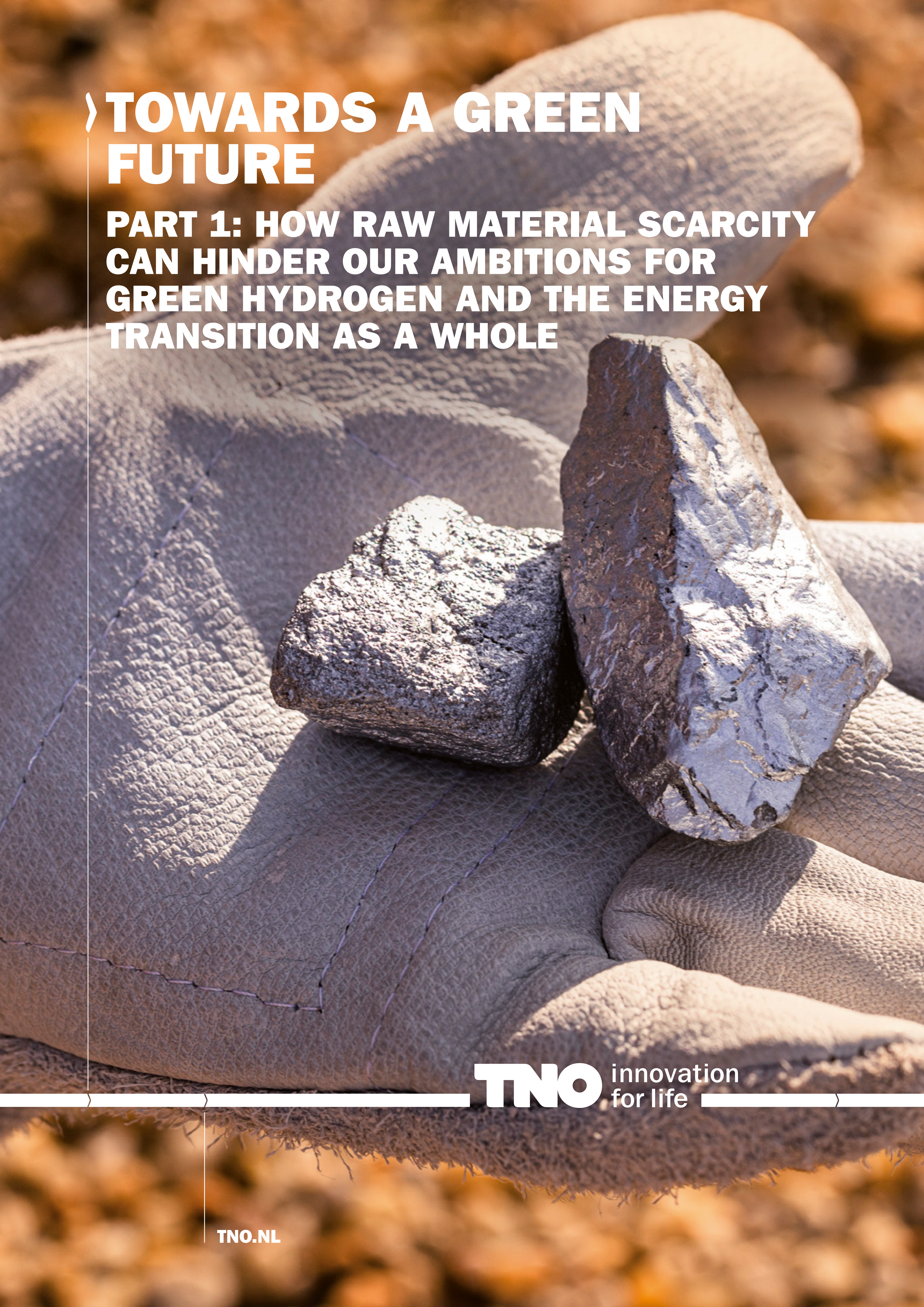
TOWARDS A GREEN FUTURE

PART 1: HOW RAW MATERIAL SCARCITY CAN HINDER OUR AMBITIONS FOR GREEN HYDROGEN AND THE ENERGY TRANSITION AS A WHOLE



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TOWARDS A GREEN FUTURE:

PART 1: HOW RAW MATERIAL SCARCITY CAN HINDER OUR AMBITIONS FOR GREEN HYDROGEN AND THE ENERGY TRANSITION AS A WHOLE

When you decide to build a house, you know you will need materials in order to do so. You also know that those materials will probably be readily available. When constructing a completely new sustainable energy system, you self-evidently need rapidly increasing levels of supplies as well. However, the potential supply risks for some 'exotic' (critical) materials required for this sustainable energy system has hardly been taken into account when drafting future energy plans. In this paper we will focus on green hydrogen production in particular: there is an expected shortage of the metal iridium an essential material in hydrogen production, if we aim to realize the European hydrogen plans for 2050. With iridium being in high demand also for other applications, the entire energy transition is in danger of slowing down – or coming to a complete halt. It's time we take action. All good plans, however, begin with an overview of potential bottlenecks.

THE ENERGY TRANSITION WILL REQUIRE LARGE AMOUNTS OF CRITICAL MATERIALS

As stated in the Paris Climate Agreement, the EU is facing the challenge of curbing CO_2 emissions.[1] In order to achieve that goal, a large upscale of all sustainable energy assets will be required by 2050. These assets include, for example, wind turbines, PVs, batteries and electrolyzers for the production of green hydrogen. Their construction will require vast amounts of metals and minerals, some of which (e.g. platinum, iridium, cobalt) are considered "critical".

Materials are considered "critical" if they are essential for the EU economy and at the same time have a relatively high risk of supply disruption.[2] According to the European Commission (EC) there are a couple of reasons for a vulnerable supply. First of all, if the material can only be sourced from a few countries (especially when these countries have unstable or non-cooperative regimes). Or if certain producers hold a monopoly: this makes the supply chain unreliable in case of local conflict or if trade restrictions are imposed. Thirdly, if no relevant substitutes are available for the material or if the material is currently not being recycled.

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[1] *https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement*

[2] *Definition of "critical" as used by the European Commission. https://op.europa.eu/en/publication-detail/-/publication/2d43b7e2-66ac-11e7-b2f2-01aa75ed71a1*

The availability of "critical raw materials" (CRMs) has recently[3] been a topic of debate as the COVID-19-pandemic has laid bare the vulnerability of supply chains. In particular the role of China, a dominant source of critical materials for the EU,[4] is the subject of criticism. The past shows that the Chinese government uses its strategic position by strengthening its grip on critical material reserves.[5,6] Other critical materials producing countries also exert their influence on supply chains through trade barriers.[7]

For quite some time it is acknowledged that critical materials are needed for the energy transition. And that this supply is not guaranteed. The first risk analysis of the EC dates back to 2010[8] and recently, several more studies discussed the materials demand for energy transition technologies such as batteries, solar cells and wind turbines.[9,10,11,12,13] These studies demonstrate that there are significant challenges ahead regarding the timely delivery of materials for the generation and storage of renewable energy. However, the material demand for green hydrogen production, expected to play a significant role in the energy transition, is a highly relevant, yet overlooked issue.

THE CURRENT MATERIALS SUPPLY DOES NOT MEET THE EU GREEN HYDROGEN DEMAND

Hydrogen is a crucial element in the decarbonization of various EU sectors because of its many applications: it can serve as a fuel for e.g. cars, feedstock for industry to make other products and a heating source for industrial processes as well as buildings.

In a sustainable energy system hydrogen has two important functions. First of all that of a "buffer": hydrogen can be made when there is a surplus of electricity from fluctuating energy sources such as wind or solar power. To use an example: when there is a lot of wind power available but no demand at that moment, hydrogen can be made. This hydrogen can be used later and thus functions as a "buffer". Secondly, hydrogen can be stored in tanks and transported through pipes or by ship or truck. The availability of hydrogen offers multiple options to transport energy: it can be transported to places where there isn't an expensive high voltage network or where the network capacity isn't sufficient.

These multiple functions guarantee a significant place for hydrogen in the future. Because of this, multiple scenarios for the future of hydrogen in the EU are made. Though the projected demands of hydrogen for the EU in 2050 vary widely, one of the more prominent projections suggests that around 8100 PJ (petajoules) of hydrogen will be required.[14] For comparison, this is more than 2.5 times the current annual energy consumption of the Netherlands or 60% of that of Germany.[15,16]

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[3] *https://ec.europa.eu/commission/presscorner/detail/en/ip_20_1542*

[4] *https://ec.europa.eu/growth/sectors/raw-materials/specific-interest/critical_en*

[5] *https://www.policyforum.net/chinas-raw-materials-strategy/*

[6] *Rabe, W., Kostka, G., & Smith Stegen, K. (2017). China's supply of CRMs: Risks for Europe's solar and wind industries? Energy Policy, 101, 692–699*

[7] *OECD iLibrary | Export controls and competitiveness in African mining and minerals processing industries (oecd-ilibrary.org)*

[8] *Critical raw materials for the EU - Report of the Ad-hoc Working Group on defining critical raw materials, June 2010*

[9] *Kleijn, E.G.M. (2012), Materials and energy: a story of linkages, Ph.D. Thesis*

[10] *Global energy transition and metal demand - an introduction -Elmer Rietveld, Hettie Boonman, Toon van Harmelen, Ton Bastein, 2018*

[11] *Metal demand for renewable electricity generation in the Netherlands, Pieter van Exter, Sybren Bosch, Branco Schipper, Benjamin Sprecher, René Kleijn, 2018*

[12] *Minerals for Climate Action: The Mineral Intensity of the Clean Energy Transition, The World Bank, 2020*

[13] *Critical Raw Materials for Strategic Technologies and Sectors in the EU – European Commission Joint Research Center (JRC), 2020*

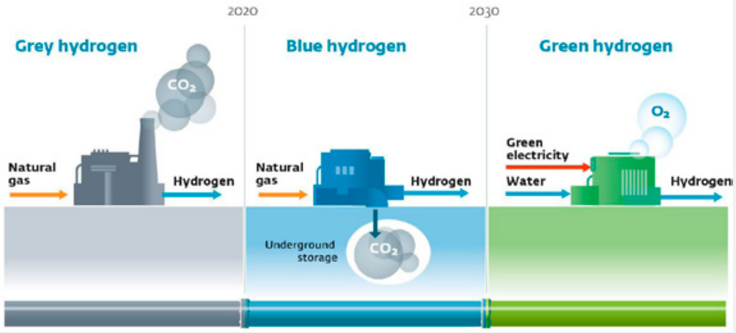
[14] *The scenario which is taken here, is the 'ambitious' scenario of the FCH which can be found here: https://www.fch.europa.eu/news/hydrogen-roadmap-europe-sustainable-pathway-european-energy-transition. This 'ambitious' scenario is taken to test the boundaries of how much critical materials would be needed to supply green hydrogen for the EU. Even though FCH projects that some part of 8100 PJ will be produced as blue or gray hydrogen, we are assessing the 100% green scenario to understand the scale of potential material shortages related to green hydrogen production on the long-term.*

[15] *https://www.clo.nl/indicatoren/nl0052-energieverbruik-per-sector*

[16] *https://energytransition.org/2018/01/german-energy-consumption-grew-in-2017-emissions-stable/*

Hydrogen can be produced in various ways, but splitting water into hydrogen and oxygen via an electrical current (electrolysis) is considered the most viable sustainable option (see “Why green, not blue” box below). For this process one needs an electrolyzer. All current electrolyzer types, require critical materials as catalysts for splitting the water molecule. At this moment, green hydrogen is only produced at a much smaller pilot-scale.[17] To put this into perspective: in order to produce the mentioned 8100 PJ of green hydrogen, a 7x upscaling of the current EU hydrogen production capacity will be needed in the next 30 years.[18] This means that the amount of CRM which will be needed for the production of green hydrogen will also increase significantly.

BOX 1: GREEN OR BLUE HYDROGEN?



Source: Gasunie | Longread Hydrogen - What is hydrogen?

There are different “types” of hydrogen: “grey”, “blue” and “green” hydrogen. The difference lies in the way the hydrogen is produced and if this production is sourced from fossil-based feedstock.

At the moment, hydrogen is mostly produced from natural gas, which leads to CO_2 emissions. This hydrogen is called “grey” hydrogen. If CO2 emissions are captured and stored underground using “Carbon Capture and Storage” (CCS) technologies, the resulting hydrogen is called “blue”. “Blue” hydrogen does produce less CO_2, but only if the CCS technology is in place. Currently, CCS is not being applied on a large scale mainly because the high cost and the technology still needing advancement.

Even though blue hydrogen can be used as an interim solution while green hydrogen infrastructures are being constructed, on the long-term it should be phased out because:

- large-scale blue hydrogen infrastructures might lead to a fossil fuels “lock-in”: in case we invest largely in CCS infrastructures it could potentially stop the transition to more sustainable and non-fossil-based green hydrogen alternative. This is one of the reasons CCS has led to public opposition in many countries.
- the large degree to which CCS is required for blue hydrogen production: current global CCS capacity will need to increase 15x to meet the EU hydrogen demand (assuming we only store CO_2 from hydrogen production and nothing else).[19]

That is why in the long-term only hydrogen produced from water and renewable electricity (“green” hydrogen) can help significantly and sustainably reduce CO_2 emissions and why green hydrogen is being chosen as the scope for this publication.

All hydrogen currently being produced on a large scale is grey. Blue hydrogen is produced on a smaller scale while “green” hydrogen production can be measured on only a MW (megawatt) scale. (As a reference: the amount of MW produced by a typical average gas powerplant is ~100-500MW).[20]

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[17] ‘Green hydrogen’ is being produced on MW-scale. https://www.tno.nl/en/focus-areas/energy-transition/roadmaps/towards-co2-neutral-fuels-and-feedstock/hydrogen-for-a-sustainable-energy-supply/ten-things-you-need-to-know-about-hydrogen

[18] https://www.fch.europa.eu/news/hydrogen-roadmap-europe-sustainable-pathway-european-energy-transition

[19] Current CCS capacity 40Mtpa - Global CCS institute (2019). Global status of CCS targeting climate change Gray hydrogen emissions (Steam Methane Reforming technology) – 75 g/MJ, https://greet.es.anl.gov/publication-smr_h2_2019#:~:text=The%20median%20CO2%20emission%20normalized,Rutkowski%20et%20al%20(2012)

[20] https://www.kivi.nl/uploads/media/5d48107106834/Factsheet%20Gascentrale.pdf

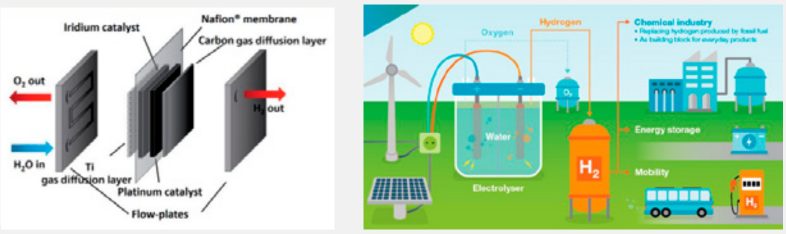
To calculate the amount of CRM needed for the 2050 EU production of green hydrogen, one should first look at which CRM are used in the different types of electrolyzers. Two types of commonly used electrolyzers are analyzed: PEM-type and AEL-type electrolyzers (see box 2). PEM electrolyzers make use of iridium and platinum, while AEL electrolyzers contain nickel, cobalt and platinum. It is very likely that PEM and AEL electrolyzers will be used simultaneously in the future energy system due to their individual advantages and disadvantages (see also box 2).[21]

For the sake of this study, we will assume that half of the total green hydrogen (4050 PJ) will be produced via PEM electrolyzers and the other half through AEL electrolyzers. Next to this, the growth in the green hydrogen production up to 8100 PJ in 2050 was spread evenly over the coming 30 years (2020-2050). During this period, electrolyzers will reach the end of their lifetime and thus need replacement, increasing the demand for CRMs. This was also taken into account.

Data on the capacity of these electrolyzers, their lifetime and the amount of critical materials used in the electrolyzers was based on literature, expert knowledge and verification with market parties.[22]

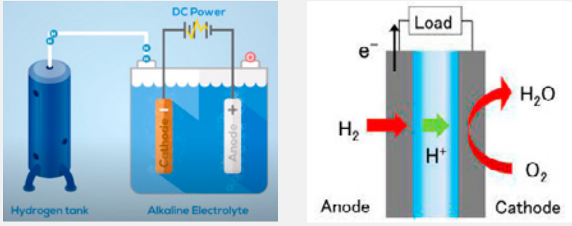
BOX 2: WHAT ARE ELECTROLYZERS?

Electrolyzers convert water and (renewable) electricity to hydrogen by splitting the water molecules into hydrogen and oxygen. This process is called electrolysis. The core an electrolyzer is the so-called “stack”, the part where electrolysis takes place (see picture below). These “stacks” consist over several layers of which one is a membrane (a “filter”). This membrane often contains the critical materials which functions as a catalyst for the reaction. The electrolyzer stacks will produce green hydrogen when they are connected to a sustainable power source (e.g. PV panels or wind turbines. (see picture below). After the hydrogen is produced it can be stored (compressed in tanks) and transported. It can be used as an energy storage solution (e.g. to store an excess of green electricity), as a feedstock chemical or as a fuel for fuel cells. To increase hydrogen production, larger and more stacks should be installed into the electrolyzer.



Picture reference: Cronin et al. and ‘after Akzo Nobel and Gasunie’

There are several types of electrolyzers: polymer electrolyte membrane electrolyzers (PEM), alkaline water electrolysis (AEL or simply “alkaline”) and solid oxide electrolyzer cells (SOEC).



Picture reference: ‘Analysis of Trends and Emerging Technologies in Water Electrolysis Research Based on a Computational Method: A Comparison with Fuel Cell Research’

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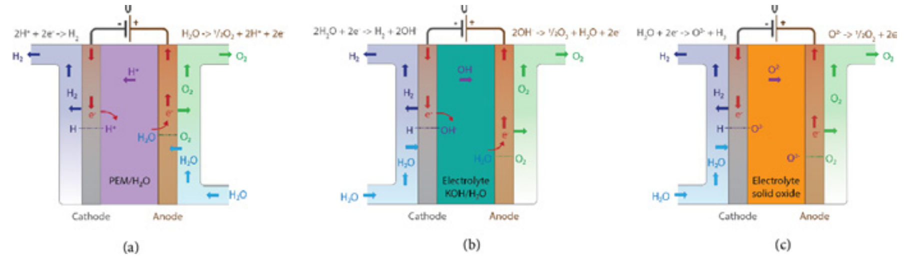
[21] *https://iopscience.iop.org/article/10.1088/1755-1315/371/4/042022/pdf#:~:text=The%20structure%20of%20the%20PEM,%2Dpole%20spacing%5B4%5D.*

[22] *A detailed list of the critical raw material compositions of the electrolyzers can be found in the subsequently published paper by the same authors ‘The unavailability of materials will hinder the production of green hydrogen. Part 2: what can be done?’ or by contacting the authors for more information.*



Picture reference: 'An Analytical Model for the Electrolyser Performance Derived from Materials Parameters'

PEM and AEL electrolyzers are currently commercially available. SOEC electrolyzers have a lower "technology readiness level" (TRL) and are still under development. Therefore PEM and AEL are the focus of this study. PEM and AEL electrolyzers both make hydrogen, but due to different operating principles they have their advantages and disadvantages, making them suitable for different types of applications.

AEL electrolyzers make use of a cathode and an anode in an alkaline electrolytic fluid. The principle is reminiscent of that of a battery. AEL electrolyzers contain platinum, cobalt and nickel. The most notable advantages of AEL electrolyzers are that the technology is well-established, they are relatively low-cost, the number of electrolyzer stacks can be easily increased, and they contain fewer critical materials compared to PEM. Disadvantages of AEL are the lower current densities, lower efficiency, and the fact that the electrolytic fluid is corrosive. The typical lifetime of an AEL electrolyzer is ten years.

PEM electrolyzers use a membrane (a solid polymer electrolyte) between the cathode and anode instead of a liquid. They typically contain iridium, platinum and tantalum. The most notable advantages of PEM are the high-current densities and efficiency, the rapid system response which makes it suitable for dynamic operation, and the fact that the system is more compact than AEL. Disadvantages of PEM electrolyzers are the high cost of components (partially due to the scarcity of critical materials), their lower durability, and the fact that it contains acid which causes a corrosion hazard. The typical lifetime of a PEM electrolyzer is seven years.

Only the critical materials being part of the electrolyzer stack itself were taken into account: other parts, such as compressors and the electricity supply, are outside the scope of this publication.[23]

Table 1 shows the amount of CRM needed for the production of 8100 PJ of green hydrogen as a percentage of the current global annual production. Let's look at the amount of iridium needed annually to reach their expected production capacity of 8100 PJ green hydrogen by 2050. In order to reach this level of hydrogen production in the EU, the annual iridium demand for electrolyzers alone would be 122% of the current global annual iridium production.[24]

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23 *https://www.researchgate.net/figure/Advantages-and-disadvantages-of-alkaline-and-PEM-electrolysis_tbl1_263470190*
https://iopscience.iop.org/article/10.1088/1755-1315/371/4/042022/pdf#:~:text=The%20structure%20of%20the%20PEM,%2Dpole%20spacing%5B4%5D.

24 *When 8100 PJ of green hydrogen will be produced by 50% PEM and 50% AEL electrolyzers, both producing 4050 MW. See footnote 19.*

Next to iridium, green hydrogen requires a significant percentage of the annual global platinum production (25%). The demand for nickel – both Class-1 (high-purity) and Raney nickel (specific alloy) – and cobalt seem to put less pressure on the total availability of these materials.

Table 1 *Annual critical material demands for 8100 PJ of green hydrogen production (50% PEM, 50% AEL) and the other applications of the critical materials*

Stack	CRM	Amount required for green hydrogen in 2050, as % of current global annual production	Also used in
PEM	Iridium	122%	Electronics (43%), electrochemistry (27%), chemical industry (7%)
PEM&AEL	Platinum	25%	Car catalysts (80%), jewelry (10%), chemical industry (5%)
AEL	Raney-Ni	0.4%	Ni: stainless steel, magnets, batteries, coinage, alloys, chemical industry
AEL	Nickel (class 1)	2%	Same as described for Ni above
AEL	Cobalt	0.1%	Batteries (42%), alloys (23%), materials (10%)

THE COMPETITION FOR CRITICAL MATERIALS: WILL THE ENERGY TRANSITION GET ENOUGH?

It has become clear that in comparison to the total CRM production, green hydrogen will require significant shares of the available amounts of iridium and platinum. Moreover, these materials are currently also used in other products. These other applications will not disappear from the stage. As a matter of fact it could be reasoned that the demand for the other applications will also rise in the future due to a rising global population and improved standards of living. This means that the total demand for CRMs will increase greatly. When all these applications are also taken into account and the demand of 8100 PJ of green hydrogen by 2050 is added, that results in an annual demand for iridium as depicted in Figure 2.

Figure 2 depicts future iridium usage for applications including electronics and chemical production (yellow) in metric tons per year. On top of that the amount needed for green hydrogen if we are indeed to increase EU production to 8100 PJ is shown (blue). The dark blue parts of the graph indicate the amount of iridium required to increase capacity towards 8100 PJ while the light blue parts depict the amount of iridium needed to replace electrolyzers which are at the end of their lifetime. Finally, the green line shows current annual iridium production. This line also highlights that future demand for iridium exceeds current supply by many times.

The increased demand for critical materials might lead to noticeable supply disruptions sooner rather than later: within the coming decade, it is expected that critical materials will become increasingly difficult to purchase. By “difficult”, we mean that their price might increase or show volatile behavior. There might also be periods when the material is not available at all.

> **“CRITICAL MATERIALS BEING NOT AVAILABLE WILL HAMPER THE ALREADY AMBITIOUS PLANS TO TRANSFORM OUR ENERGY SYSTEM TO A SUSTAINABLE ONE.”**

One might say that a hydrogen demand of 8100 PJ is too high and that the scenario of producing 8100 PJ by 2050 taken here is too ambitious. However, if this is the case, this example helps us to look at the potential severity of the problem as it stands now. Indeed, research might, for example, decrease the amount of critical materials necessary in electrolyzers.

> **“IN THIS HYDROGEN SCENARIO THE EU ALONE NEEDS MORE THAN THE CURRENT GLOBAL ANNUAL PRODUCTION OF A SPECIFIC MATERIAL MAY SERVE AS A REALITY-CHECK THAT THE AVAILABILITY OF MATERIALS SHOULD NOT BE TAKEN FOR GRANTED AND THAT PLANS FOR THE ENERGY TRANSITION WHICH DO NOT TAKE MATERIALS INTO ACCOUNT CAN GRIND TO A HALT IN THE EXECUTION.”**

Amount of iridium required annually for various applications, ton/year

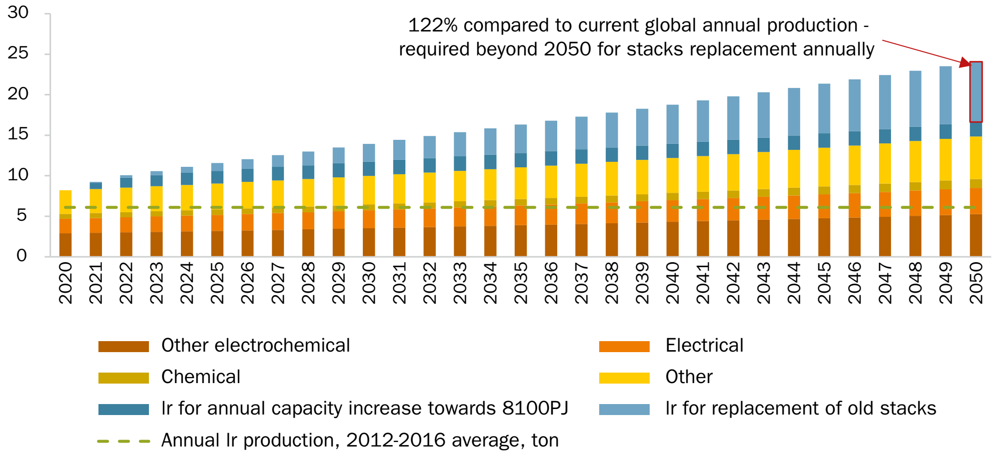

Figure 2 *Amount of iridium required annually to upscale green hydrogen production and for other uses*[25]

The paragraphs above highlight the potential severity of the problem in the case of green hydrogen production for the EU. But the problem is far more extensive and intertwined than just this specific case. This is illustrated by three examples.

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[25] *Current iridium uses: PGM Market Report (2020), Johnson Matthey. Growth of 2% per year from 2019 level for all uses assumed. Iridium required for capacity increase and stack replacement: TNO analysis. Current iridium supply: Average 2012-2016, EU Critical Material Factsheets, 2020*

The problem is not limited to iridium and platinum or to the application of CRMs in electrolyzers. Next to electrolyzers, other sustainable energy applications require CRM, for example wind turbines (e.g. boron, dysprosium, neodymium), batteries (e.g. cobalt, lithium, niobium), photovoltaics (e.g. indium, high-grade silicon) and fuel cells (e.g. cobalt, palladium, platinum, titanium, strontium). A shortage of lithium and cobalt for battery production has already been published by multiple battery manufacturers.[26] This indicates that the issue of the energy transition being under pressure of material shortage does not only apply to the production of green hydrogen,but can be extended to other sustainable energy value chains such as electric driving and solar power.

Competition will arise because of critical materials being necessary for multiple applications. As shown in Table 1, critical materials are used in multiple applications. If there is a shortage of a particular material this will impact all applications. For example: if there is a iridium shortage and as a result the prices will rise, both the electrolyzer industry and the electronics industry will have to deal with this. Next to the fact that both industries will be under pressure, competition will arise: which sector is able to purchase the materials for the higher price or which sector has secured its supply chain the best? This leads to a question if essential industries such as the energy sector will be able to secure the materials they need.
In addition, some energy assets which are all equally crucial to the energy transition need the same critical raw materials (e.g. windmills, batteries and electrolyzers needing nickel) which could increase the competition effect even more within the energy sector.

The material demand has the shape of a hockey stick, not of a flat line. In this publication we predict, for the ease of example, that the build-up towards the 8100 PJ of hydrogen production capacity will be evenly distributed towards 2050 (as can be seen in Figure 2). However, this will in real life not be the case: the technology to build large-scale electrolyzers is still under development. It is more likely that renewable energy technologies will be experiencing exponential growth rates.[27] In other words: we might underestimate the issue now (“We experience no scarcity at this moment.”) while in a couple of years we will be faced with a fait accompli of a sharp rise in demand because of the scale-up of the energy transition assets shifting into a higher gear.

The EU is not the only region needing critical materials. The whole world is in the process of building sustainable energy assets. For the example of large-scale production of green hydrogen: Japan and Canada started sizeable projects based on green hydrogen. China reports that it wishes to increase the amount of hydrogen-fueled vehicle to increase from 5000 to 1 million the coming 10 years.[28]

The worldwide demand for (green) hydrogen will thus potentially be many times that of the EU.[29] As for the EU scenarios, the global hydrogen demand scenarios vary widely. The highest demand is reported by the Hydrogen Council in 2017, stating a global annual demand for hydrogen in 2050 to be 78000 PJ. Shell reports the lowest prediction of the global hydrogen demand at 9000 PJ.[30]

These examples are for hydrogen only and are used to illustrate the scale of the potential problem when looked at it globally.

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[26] *https://www.mining.com/tesla-hit-by-battery-shortage-amid-rallying-lithium-cobalt-nickel-prices/*

[27] *Tackling material constraints on the exponential growth of the energy transition*

[28] *https://www.researchgate.net/publication/343291486_Is_China's_Hydrogen_Economy_Coming_A_Game-Changing_Opportunity*

[29] *https://www.powermag.com/countries-roll-out-green-hydrogen-strategies-electrolyzer-targets/*

[30] *https://www.researchgate.net/publication/343291486_Is_China's_Hydrogen_Economy_Coming_A_Game-Changing_Opportunity*

> **“WHEN CRITICAL MATERIAL SCARCITY WILL INDEED IMPACT THE PRODUCTION OF ELECTROLYZERS, WINDMILLS AND BATTERIES, THIS COULD MEAN THAT THE ENERGY TRANSITION CANNOT TAKE PLACE ACCORDING TO PLAN BECAUSE OF A PROBLEM NOBODY SAW COMING: WE HAD NO MATERIALS TO BUILD THE ASSETS.”**

This can in its turn lead to the EU not reaching their climate goals in time.
We cannot afford to have our energy transition be delayed by material supply disruption, so it is time for action.

TIME FOR ACTION: HOW THE EU MUST ENSURE THE MATERIALS ARE THERE TO BUILD OUR ENERGY SYSTEM

If sustainable energy assets cannot be built because of critical materials not being available, this has a negative effect on the progress of our energy transition. Subsequently we might not be able to reach our Climate Goals.

Given the potential impact of critical material scarcity, action on a European scale action is required. The solutions to the critical materials problem can be divided into two categories:

- Technological advancement
- Policy & regulation

The role of technology

Technology will play an important role in the reduction of critical materials usage in applications such as electrolyzers. Without technological development, the EU strategy for obtaining enough critical materials is limited to “buying as much as possible” – a short-term and short-sighted solution. Through technology it will be possible to prevent the use of a material like iridium (e.g. by reducing the amount of iridium or substituting it with an alternative) or to extend the lifetime of electrolyzers. One might also investigate recycling iridium. These three options (prevention, extension and recycling) and their impact are described in more detail in part 2 of this publication to be published by the same authors. We can already reveal that the substitution of iridium by different materials seems a promising strategy.

Although technological advancement is a certain part of the answer, most of the technologies that could decrease our reliability on virgin CRMs are still in an early stage of development. At this pace it will take years before these technologies are ready to be implemented: by that time the energy transition might already be feeling a shortage in materials. A joint pan-European research initiative is essential: a significant increase in scale and priority is needed to develop these technologies fast. Coordinated research agendas, involvement from policy makers and industries is needed.

A network of RTOs, including TNO, jointly researches electrolysis and the decrease of critical raw materials in electrolyzers. More info can be found under the reference.[31]

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[31] *https://www.tno.nl/en/about-tno/news/2020/11/european-rtos-accelerating-development-of-electrolysis/ this website includes the position paper ‘HySpeedInnovation’ on the topic of innovation in the field of electrolysis*

The role of policy & regulation

Technological advancement is, however, not the “golden goose” and will not solve the problem on its own. Making sure critical materials are available is a task of national and European scale: it involves geopolitics, strategy and regulation. Individual member states can control their own supplies to some extent, but they cannot solve the entire EU’s materials within the required timeframe. European-scale action and coordination by industry as well as governmental bodies is therefore essential.

The US and China treat the availability of raw materials as a strategic point for their economic development and national security. For years they have actively developed policies regarding the acquisition of critical materials and safeguarding their supply chains.[32] Europe is now also taking first steps towards a similar strategy in 2020[33]: the ‘Critical Materials Alliance’[34] was launched in September 2020. One of the tasks of this Alliance is to be the link between industry and policy makers. This is a first step towards action.

Secondly, regulation of the critical materials markets might be the only option. In case mitigating the critical materials issue is not sufficient, we are facing the choice for which applications certain materials may be used. So far, the market has proven to be effective in balancing supply and demand. However, if there will indeed be a shortage, can the market ensure that materials are mainly applied to fighting climate change? Or will this pressing global issue have to compete products such as phones or jewelry?

Policy makers need to consider the effects of market competition. Regulations might ensure that critical materials are available to and used in the most essential industries. Only that way will critical materials be applied in the most societally beneficial way.

> **“LET’S SECURE THE SUPPLY OF CRITICAL RAW MATERIALS TO ESSENTIAL EU INDUSTRIES TO MAINTAIN A STRONG POSITION AND GUARANTEE USE IN APPLICATIONS WHICH ARE TO THE SOCIETAL AND ENVIRONMENTAL BENEFIT OF ALL.”**

NEXT STEPS

Clarity on critical material usage in sustainable energy assets and the critical material markets are essential. The authors propose to combine the literature on critical material demands of energy assets already available and filling the gaps: on some assets little data is available. It is essential to link this data to plans and scenarios that the EU and national governments are making in order to see the bigger picture of critical material demand.

Moreover, it should become habit to think of the materials needed when devising such plans and scenarios: the energy system and the material system evidently interlinked and it is essential to be aware of this. ‘The availability of materials’ should be on the agenda of any (national) government if this is through a separate Ministry of Materials or a national research institute building up the right knowledge to support policy makers.

In part 2 of this publication the authors dive deeper into technological options for decreasing the amount of critical materials needed for electrolyzers and other potential solutions.

Let’s join efforts between RTOs, industry and governments to make a significant change and apply mitigating technologies and suitable and solid policy concerning critical materials. Only in this way will we have enough materials to build our house.

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[32] *https://foreignpolicy.com/2020/05/25/china-trump-trade-supply-chain-rare-earth-minerals-mining-pandemic-tensions/ (US) and https://www.aspistrategist.org.au/dependence-on-china-for-rare-earths-wont-change-without-investment-in-whole-supply-chain/ (China)*

[33] *https://ec.europa.eu/commission/presscorner/detail/en/ip_20_1542*

[34] *https://ec.europa.eu/commission/presscorner/detail/en/ip_20_1542 and https://www.crmalliance.eu/*

TNO

TNO is the Dutch research center for applied science. Amongst its researchers are experts in the field of the energy transition, critical raw materials, circular economy and sustainability. Look at www.tno.nl for all focus areas of the research done at TNO.

TNO has an open innovation laboratory that focuses on electrolysis technologies scale-up - Faraday lab. See more details here.

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