Quantum
Delta NL

CRITICAL RAW MATERIALS FOR QUANTUM TECHNOLOGIES

Towards European technology sovereignty in an emerging industry

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Contents

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1 Introduction

Quantum technology is still in its early days, but the contours of an emergent industry are being shaped today. As one of Europe's leading quantum ecosystems, Quantum Delta NL believes that we have a responsibility to think ahead: how will and should a quantum industry look like and how can we anticipate its impact on the economy, society and global technology landscape?

As a national technology programme, we are working with partners world-wide. Quantum is a global effort with connections that transcend nation state boundaries across the globe. At the same time, we believe that quantum is part of a truly European deep tech agenda. To ensure that we create a solid foundation for this emerging industry, we are proactively investing in a dialogue with relevant players from science, industry and policy about the role of quantum in strengthening European sovereignty.

At this point in time, there is not yet a dominant design for quantum computing, communication and sensing systems. The technology is rapidly developing; we see hundreds of entities around the world competing to capture the unique value produced by quantum technology. Earlier, Quantum Delta NL published two supply chain assessments on quantum computing and communications, for which the scope was limited to critical components[1]. In this white paper we take up one of the recommendations from those reports and look in-depth at critical raw materials.

As the young quantum industry matures, the European Union (EU) in parallel has moved to define new policies on critical raw materials (CRMs) that are indispensable for our future economies. To this end, in March 2023 the European Commission launched the CRM Act to safeguard the security of supply of materials that are essential for current and future technologies[2]. The importance of this regulation is exemplified by the recent Chinese export control restrictions on gallium, germanium and graphite as part of their strategic competition with the United States[3]. These restrictions could limit the EU's access to materials that are critical for the production of semiconductors and batteries.

Given this context, there is an increasing need for a mapping of the critical raw materials that are currently required for quantum technology. Such an assessment is essential to be aware of potential risks and makes it possible to proactively mitigate future bottlenecks in the supply chain.

This white paper presents the first set of findings of our study and answers the question: which critical raw materials are likely candidates to be part of the future supply chain for quantum technology? We chose to limit the scope to those aspects of quantum computing, communication and sensing platforms that are currently under development in the Netherlands. Next to a comprehensive visualisation of the materials, semi-manufactured goods and application areas, we also compare today's policy developments in this regard.

2 Results

The answer to our central question can be found in Figure 1 on the next page, which is also the main result of our study. This Sankey diagram provides an overview of the most important raw materials that are required for quantum technology R&D in the Dutch ecosystem for quantum computing, communication and sensing.

The logic in constructing this figure is from right to left (for a certain hardware component, you need certain processed goods, for which you need certain materials), while a supply chain is visible from left to right. This approach produces valuable insights without being an exhaustive overview of all the materials required in the technology development. A more in-depth analysis might reveal other materials that are necessary in trace amounts. Moreover, it is hard to predict where R&D is going: the (combination of) materials which yield the best results is still an active field of research. We therefore expect this picture to change over time.

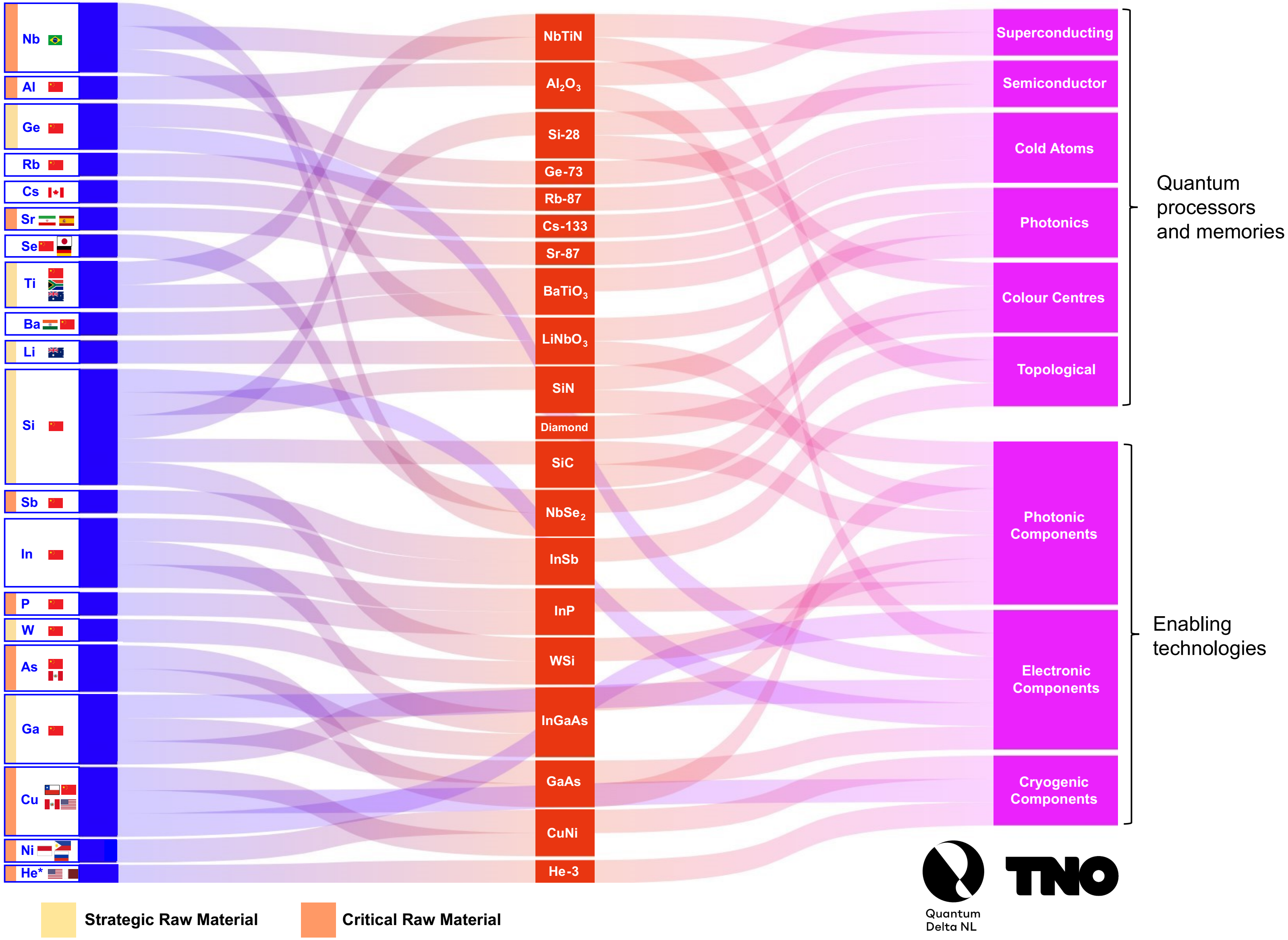

Figure 1 Overview of the materials that are required for quantum technology R&D in the Dutch ecosystem. From left to right: raw elements, semi-manufactured goods and isotopes, and components for quantum processors and enabling technologies. The flags indicate the top countries that together currently hold >50% of global mining & refining capacity[4,5,6]. The yellow and orange indicators denote which materials are earmarked as strategic and critical raw materials respectively by the European Commission[7]. *He-3 is mostly produced from H-3 (tritium).

NbTiN: Niobiumtitaniumnitride, Al_2O_3: Aluminiumoxide, Si-28: Silicon-28, Ge-73: Germanium-73, Rb-87: Rubidium-87, Cs-133: Cesium-133, Sr-87: Strontium-87, $BaTiO_2$: Barium titanate, $LiNbO_3$: Lithium niobate, SiN: Silicon Nitride, SiC: Silicon Carbonate, $NbSe_2$: Niobium Diselenide, InSb: Indium Antimonide, InP: Indium Phosphide, WSi: Tungsten Disilicide, InGaAs: Indium Gallium Arsenide, GaAs: Gallium Arsenide, CuNi: Cupronickel, He-3: Helium-3.

For this overview diagram we drew inspiration from the comprehensive study by the Joint Research Centre (JRC) on materials for strategic technologies and sectors in the EU[8]. This study does not include quantum technology in the most recent update of 2023. When looking at quantum, we decided to deviate a little from the JRC work by excluding a demand forecast. In the current phase of quantum technology, it is unclear which hardware platform will ultimately prove successful; it is also impossible to predict whether, and if so to what extent, quantum technology systems will be mass-manufactured. For the same reason we also excluded the “assemblies” step in the supply chain as was done for the JRC study.

What we see in the graph

In the left column we can see that five out of the twenty materials we identified are not earmarked by the EU CRM Act as either critical or strategic raw material. Critical raw materials are those that have both high economic importance for the EU and a high supply risk, while strategic raw materials are those that are important for technologies that support the twin green and digital transition, as well as defence and aerospace objectives[5]. As mentioned earlier, quantum technology is not (yet) explicitly included as strategic technology sector in the context of CRM policy, but due to its increasing importance for the EU, it could be included in the future.

In terms of mining and refining capacity, China holds key positions in fourteen out of the twenty materials, and for nine of these it controls more than half of the global supply. As is the case for many other sectors, China therefore has a lot of leverage for materials that are required for quantum R&D. Overall, we are highly dependent on non-EU countries for the supply of all of the raw materials.

There is an important difference to other sectors, however. The volumes of raw materials that are currently required for quantum technology are namely insignificant compared to global yearly mining volumes. For example, a dilution refrigerator requires in the order of tens of kilograms of copper for its production, while approximately 20 billion kg of raw copper is mined every year[9,10].

This can partly be attributed to the fact that quantum technology inherently operates at extremely small scales, but more importantly: the sector is still in a research phase and there is no mass manufacturing yet.

Instead of focussing on raw materials, it is worth looking at the next step of the refinement process. In fact, our assessment reveals that already today there are clear bottlenecks in the materials supply chain. These are not related to mining itself and occur in the processing step where semi-manufactured goods and isotopes are made. We depicted this in the middle column of the graph.

For quantum technology (in the current stage of R&D), it is therefore less relevant to consider the raw materials on their own – we should rather zoom in on the processed materials downstream in the supply chain. Looking ahead, this is where potential chokepoints might occur in the near future. Those working on supply chain policies would benefit from an in-depth understanding of the underlying supply chains for the materials listed in the middle column of Figure 1.

Potential chokepoints

An example of such a bottleneck is helium-3, which is required for the operation of dilution refrigerators. This isotope of helium is mostly made from the nuclear decay of tritium, which is a natural by-product in the production of nuclear weapons. Given that the US and Russia hold the largest arsenal of the these systems, they are also the biggest producers of helium-3 globally. In particular, the production is controlled by the US Department of Energy Isotope Programme in the United States and Rosatom in Russia, who have contracts with commercial gas suppliers for market distribution. This implies that the supply can artificially be controlled by (a small number of) national governments. Since helium-3 is also used for medical imaging and border protection[11], this can lead to unexpected market dynamics and spikes in prices and delivery times. In 2015 the US Department of Energy for example declared that there would be no public auction of helium-3 that year, while the price was already high at $2,750 per litre[12]. Next to helium-3, we identified at least three other potential chokepoints in the materials supply chain that require further attention (not specified here).

Our interviews further revealed that we need to look carefully at the fabrication facilities that are required for producing these complex quantum materials. This includes equipment necessary for e.g. etching, deposition, lithography and other fabrication steps. All of the corresponding necessary equipment is very expensive and require a highly stable and clean environment for their operation. Once set up, these facilities are perfectly suitable for creating state of the art devices in small volumes, but are less suitable for large-scale manufacturing. At the time of writing, reproducibility is hampered by the wide variety of processes and materials that are used on the same machinery, which can cause contamination and requires exact recalibration. In addition, it is still unclear how a device design impacts the ultimate performance when it is actually manufactured. The European Qu-Test and Qu-Pilot programmes are a first step towards resolving this bottleneck by setting up a network of testing and pilot lines facilities in the EU[13].

Links to international policy

The geopolitical background of this topic is undeniable present. In July this year, China announced restrictions on the export of gallium and germanium, and later in October supplemented these with export controls on graphene, citing national security concerns. These materials are important for the semiconductor and battery supply chains respectively; but gallium and germanium are also relevant for quantum technology (see Figure 1). In order to create resilient, realistic supply chains for the young quantum industry, we need to invest in adequate mapping and monitoring.
The European Commission is committed to do so for the semiconductor industry as part of pillar 3 of the Chips Act[14]. At the same time, we also need policies that build on such insights and proactively develop mitigation options for quantum technology. The EU should invest in the required capacity in order to reduce critical dependencies – and to increase reciprocity with non-EU countries.

This is not yet the case. For example, both the EU and the US Chips Act only include mapping and monitoring semiconductor supply chains. These are partly based on quantitative trade data, which is not available for quantum technology. Both regulatory frameworks further include specific actions and budgets for quantum technology, but in the US this is limited to the development of applications, standards, infrastructure and workforce, while for the EU this only includes the development of design libraries, pilot lines and testing facilities. In both cases, mapping the supply chains for quantum technology, including the raw materials, remains out of scope.

However, the US has since become more active in this regard. On November 3rd, a draft bill for the National Quantum Initiative (NQI) Reauthorization Act was published[15]. This includes an increased focus on supply chain monitoring and risk assessments, as well as the creation of a “Quantum Instrumentation and Foundry Program” to support materials and device needs for the US domestic quantum supply chain.

Moreover, an independent advisory committee earlier recommended that for the renewal of the NQI, specific attention needs to be put towards “critical isotopes and rare element needs for quantum information science research and development to ensure future supplies”[16]. Even though the exact details of the Act are still to be determined at the time of writing, experts note that there is broad political support for such a measure and expect that that the NQI will be extended.

On the other side of the Atlantic, the EU also seems to be moving in the same direction. In October 2023, the European Commission selected quantum technology as one of four critical technology areas for the EU, based on the earlier published Economic Security Strategy[17]. The corresponding announcement included that collective risk assessments with EU member states will need to take place before the end of the year. Our earlier supply chain mappings and the findings described in this white paper are a valuable contribution to this effort, but further research and collaboration across EU member states is needed in order to translate these mappings into concrete support actions for the growing quantum ecosystem.

3 Conclusions

We mapped the critical raw materials that are emerging as part of the future supply chain for quantum technology from a Dutch ecosystem perspective. This is not meant as an exhaustive overview of all the materials required, but should be seen as a useful building block towards a structural mapping and monitoring of the materials supply chain.

Our earlier supply chain assessments on critical components have already proven to support EU policies in this areas[18].

Even though the volumes in terms of raw elements are insignificant in this phase of R&D, we identified potential chokepoints further downstream in the supply chain in terms of specific semi-manufactured goods and isotopes. One such an example is helium-3. Other examples are not included in this published version of our study.

Looking at the policy landscape, it is important to note that mapping and monitoring the supply chain for quantum technology is not (yet) covered by existing EU or US policy. This might change soon

Looking ahead, further action is required to safeguard the sustainable growth of the European quantum ecosystem. A natural next step would be to extend this type of mapping to other quantum or enabling technology domains and widen the assessment into a pan-EU effort. Finally, a deepening analysis can be done for all semi-manufactured goods and isotopes to uncover the underlying supply chain and identify new bottlenecks and potential chokepoints.

Interested to know more about our results? Please do not hesitate to get in touch with us! We are keen to receive feedback and are open to explore opportunities for further collaboration on the future of quantum supply chains.

[1] White Paper: Mapping the Supply Chains for Quantum Communication | Quantum Delta NL
[2] CRM Act (europa.eu)
[3] China's New Graphite Restrictions (csis.org)
[4] Statista
[5] Study on the critical raw materials for the EU 2023 (europa.eu)
[6] CRMS 2023 - SCRREEN2
[7] Mindat.org - Mines, Minerals and More
[8] JRC Publications Repository - Supply chain analysis and material demand forecast in strategic technologies and sectors in the EU – A foresight study (europa.eu)
[9] Raw materials for emerging technologies 2021 - Fraunhofer ISI
[10] SCRREEN2_factsheets_COPPER.pdf
[11] sgp.fas.org/crs/misc/R41419.pdf
[12] Defining-the-Heliun-3-Industry.pdf (iadc.org)
[13] Homepage - QU-PILOT : QU-PILOT
[14] The EU chips act (europa.eu)
[15] Science Committee Leaders Introduce Bill to Advance and Secure Quantum Leadership - Press Releases - House Committee on Science Space & Tech - Republicans
[16] NQIAC-Report-Renewing-the-National-Quantum-Initiative.pdf
[17] Recommendation on critical technology areas (europa.eu)
[18] We expect to publish a third white paper on the supply chains for quantum sensing in the first half of 2024.

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