drift
for transition

The raw material transition for the Port of Rotterdam

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Preface

We have become increasingly aware of the (negative) social and ecological impact of the materials that are required in our modern societies to eat, (re)build houses, provide energy and live. Our dependency on fossil fuels, linear organisation of the use of materials and geopolitical dependencies are all part of the unsustainability of our current materials economy.

The Port of Rotterdam (Nico van Dooren, Monique de Moel and Ruud Melieste) asked DRIFT to, together with stakeholders, develop an integrated perspective on the Port of Rotterdam's challenges posed by the raw material transition: to provide an analysis and transition strategies on how to move through the complexity of the uncertain development of the current port system, the different resource streams and a variety of actors and transition trajectories.
Several experts and actors from in and around the Port of Rotterdam have taken part in developing the analysis and strategy this document describes. Their participation has co-shaped this analysis by providing their strategic views and creative ideas and by validating our analysis and conclusion in interviews and/or in one or multiple (online) sessions.

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March 2024

Design & layout by Teun Strikkers

Summary

The raw material transition is about the availability and usage of various materials that are under pressure, both from the perspective of major societal challenges related to exceeding planetary and social boundaries and from the need to ensure a reliable supply. The Port of Rotterdam is increasingly experiencing tension in the extraction, production and consumption of (raw) materials. The energy transition and decarbonisation goals push the demand for a variety of materials.. Moreover, the limited supply of materials, limited recycling capacity, limited availability of land and labour, and geopolitical dependency and sensitivity have put pressure on the access to raw materials.

The challenge for the Port of Rotterdam is to robustly position itself in the raw material transition in order to secure its relevance and position in the economy and society of north-west Europe and the Netherlands. For the port, three material flows are most heavily impacted by the pressures: critical raw materials (CRMs), organic chemicals (OCs) and construction materials (CMs). Each of these streams faces different transition challenges:

CRMs are materials that are critically needed for production technologies of high economic importance but are limited in supply (in terms of geopolitical concentration and total availability) and unevenly distributed globally. As a result of the energy transition, the demand for CRMs is expected to skyrocket from 2-60 times its current demand by 2050, showing that there is a real urgency and significant uncertainty related to how to deal with CRM demand and supply. The transition of CRMs is in an early stage, but has already become an issue of great concern, so the challenge for the Port of Rotterdam is how to effectively respond to this situation and fulfil the needed supply of CRMs in order to achieve circular and climate goals, while at the same time building a resilient and diversified CRM supply chain.

While the production of OCs is not as geographically restricted as that of CRMs, OCs need to move towards a circular and more biobased system. This transition towards a green chemistry is gaining momentum, but this upscaling has also brought new challenges. The main transition challenge in the port cluster is to accelerate the transition, find space and the 'best' chemical alternatives as well as address the material (biobased) lock-ins that might rely too much on the current OC industry.

The transition in CMs is mainly driven by the transition of the construction industry to use CO_2-neutral or negative materials. The challenge with greening the materials used in construction is that the currently used steel and cement are very hard to decarbonise and are very energy-intensive, thus putting pressure on the demand for CRMs and green hydrogen. An increased use of biobased materials (including wood) appears to be not only possible but also unavoidable. However, current supply chains are very locked into using conventional steel and cement. The transition is heading towards a tipping point; therefore, the main challenge for the Port of Rotterdam is to move beyond this and to develop a circular supply chain for alternatives such as wood.

Crucial for the challenges of these material streams in relation to each other and the energy transition is to find strategies in which tackling the challenge in one transition also helps tackling that of other transitions, instead of current strategies in which often one transition is furthered, but another transition is made even more challenging.
DRIFT, using the input from the stakeholder sessions, proposes a strategic framework with four different pillars, each with one main overarching strategy.

Pillar 0: Substitute and dematerialise: The overarching base strategy is to reduce our demand for globally scarce and geopolitically concentrated resources where possible. This can be achieved by switching to more abundant materials (preferably with a lower CO_2 and a smaller energy footprint) or reducing material and fuel use in applications.

Pillar 1: EU-level resource diplomacy: It is essential to reposition the EU in world trade flows by establishing European resource diplomacy in an increasingly multi-polar world. Resource diplomacy goes far beyond formal state relationships, and thus, it also indicates an important role for the Port of Rotterdam.

Pillar 2: New backbones and commodities into the northwest European hinterland: The current infrastructural backbones (such as pipelines) and traded commodities in which the Port of Rotterdam has a central position are those of a linear economy; new backbones with the port as a hub are needed for a circular economy if the port wants to maintain its central position in the future, which is far from a given.

Pillar 3: Reform the regional Rotterdam cluster: The regional cluster extends beyond the formal Port of Rotterdam boundaries, and reforming it could be done by establishing a new spatial order and infrastructure to literally make space for the new economy in the region in which the Port of Rotterdam operates.

Which pillars get more or less emphasis depends on the type of raw material. Strategies for CRMs are mostly tuned to the global level and focus on supply chain diplomacy. For both CMs and OCs, the proposed strategies highly involve the regional hinterland, building up new bidirectional supply chains and secondary commodities. For OCs, the local cluster is also highly important, especially given their physical footprint and the challenge of a new spatial order in the Rotterdam cluster. Per pillar, there are a variety of other strategies to secure availability of resources, some specific for one of the resource flows and some more general.

Executing the strategies and translating them into action is not a given; some have not yet been set in motion, and some have been hampered or slowed down. Thus, the port cluster is at a crossroads between strategies, of which the main one is to further build upon its current strengths with the risk of being locked in (physically, economically and/or mentally) versus transforming those strengths and creating alternative futures. This also relates to diversifying the business model of the Port of Rotterdam Authority itself, where the current one may not fit new activities that need to be developed or that are not appealing enough in the current situation. There is a risk adversity to take measures that the cluster might regret, while at the same time, to stay ahead, a first mover advantage is needed but is inherently uncertain. Moreover, another crossroad has emerged locally: limited available land and space seem to be current restrictions, while several strategies do not take up (much) space and the decline of some (fossil) activities might suddenly free up space. Lastly, waiting for higher governance levels such as the EU to put all the right conditions in place could take a long time; therefore, a proactive multi-governance approach could speed this up.

We conclude this summary by highlighting the actions to take at the crossroads and the most important actions resulting from the strategies for the three material streams. We highlight the actors of power – the Port of Rotterdam Authority's main partners – to successfully perform each action in Table 1. These include existing/new business actors in the cluster, regional public actors and those in the national government.

Table 1. The main actors to act at the crossroads and the ten main actions for the three resource streams

Action	Stream	Business	National government	Regional government
Actions at the crossroads				
1a. Create opportunities for alternative futures with specific second priority fields	All	X	X	X
1b. Reserve space for radical opportunities	All	X		X
1c. Set up integral teams for the resource transition	All	X	X	X
2. Develop additional business models for the Port of Rotterdam Authority	All		X	X
3. Allow 'may regret' approach to investments for a first mover advantage	All	X	X	
4a. Adopt strategies with a limited impact on local land use	All	X		
4b. Develop a strategy/plan that can be implemented if major current industrial activity stops	All	X	X	X
5. Create a multi-scale governance approach	All	X	X	X

Action	Stream	Business	National government	Regional government
10 main actions for the three resource streams				
1. Create a supply chain for biobased construction materials	CMs	X		
2. Set up long-term partnerships for sustainable forestry	CMs		X	
3. Build up circular infrastructure for wood and biobased materials	CMs	X	(X)	X
4. Develop a dematerialisation strategy	OCs/All	X	X	X
5. Fully commit to chemical and mechanical recycling	OCs	X		X
6. Connect with regional hinterland	OCs			X
7. Proactively develop CRM policies and integrate them with the organisation	CRMs	X		
8. Proactively collaborate on CRM diplomacy together with the government and take the lead in establishing international partnerships	CRMs	X	X	
9. Create a focused CRM strategy	CRMs		(X)	
10. Invest heavily in recycling	CRMs	X		X

Chapter 1

Introduction

The Port of Rotterdam is facing the challenge of transforming from a fossil petrochemical cluster that focuses on refining to a new energy and chemistry port. As Europe's largest port, this challenge is a tremendous one, as the port area was responsible for 22.5 megatonnes of CO_2 emissions in 2022. The Port has committed to reducing its emissions by as much as 55% by 2030 and to being carbon-neutral by 2050. Innovations such as carbon capture and storage and low-carbon hydrogen as well as saving energy will be key to achieving this.

The main focus of the energy transition is to reduce greenhouse gases. However, other challenges related to exceeding our planetary and social boundaries, such as biodiversity loss and the threat to the health of our living environment, require more and different action. These societal problems are connected to energy transition and affect a wider system: they relate not only to the extraction, production and consumption of energy, but also to the extraction, production and consumption of (raw) materials.

Six developments have put pressure on the availability or usage of these raw material flows and show both the urgency and the interconnectedness of this transition:

1. Increased demand. This is mainly due to the current energy transition. The energy transition requires the electrification of many processes and the installation of enormous numbers of solar panels, wind turbines and batteries as well as new infrastructure. This mainly increases the demand for a range of materials, some currently labelled as 'rare' others most likely becoming rare due to the huge increase in demand in the years to come.
2. Limited supply of materials. This is often caused by the location of the materials. These limits mainly relate to the extraction, transport and refining of materials. Some material deposits are highly concentrated in a specific area, while refining is concentrated in another. As mining activities have shifted largely outside of the European Union (EU), dependencies of the EU have increased, and the level of extraction as well as the refinement has become more dependent on local factors, such as social-political stability.
3. Limited recycling capacity. The ambition of the EU is to develop a circular economy that in part aims to reuse as many materials and retain as much value as possible. This will limit the demand for raw materials and contribute to a pollution-free world. However, implementation of such circular ambitions has not yet resulted in a steep increase in recycling capacity, neither locally or in north-west Europe close to the source of consumption.
4. Decarbonisation goals. Industries that are dependent on fossil fuels are developing alternative forms of production as well as using different forms of raw materials to be able meet decarbonisation targets. These new processes often require more space and more energy, as optimalisation has not often occurred. This increases not only the demand for (biobased) resources but also for renewable energy and, thus, for critical raw materials
5. Geopolitical dependency and sensitivity. These limit access to the material supply chain. Over the past three years, the COVID-19 pandemic and the war in Ukraine have shown the vulnerability of international trade links and dependency on one main trading partner. Also, many geopolitical conflicts have been and likely will be centred around the control of key materials.
6. Limited availability of land and labour. This plays a role at the local level in north-west Europe. Land and labour (or space) are needed for the recycling of materials. Moreover, new biobased processes require a different use of land (to harvest crops and process them) and new labour force skills.

Most of these developments are highly connected to the level of the EU and the world, showing that the transition is not exclusive to the Port of Rotterdam. The Dutch national government recently published its vision for the (raw) material transition (Grondstoffen voor de grote transities), and previously, Germany (Rohstoffenstrategie der Bundesregierung) and the EU (Critical Raw Materials Act) published strategies related to this transition. By 2030, the EU aims to domestically source 10% of the critical raw materials it consumes annually, such as lithium, cobalt and rare earth elements (REEs).

Moreover, the EU aims to recycle at least 25% and process 40% of its annual consumption. However, these goals are not only rather limited but also voluntary and have not yet been translated into action.

The challenge and opportunity for the Port of Rotterdam is to position itself at these different scales – from the local level to the north-west European and global levels – in relation to the (raw) material transition. The aim of this research is to provide input for a raw material transition strategy for the Port Authority, as well as to analyse these challenges and provide strategies that capture the resulting opportunities. The research will also offer an action perspective for the Port of Rotterdam to guide it in the successful implementation of this new raw materials strategy. Hence, our main question is: How can the Port of Rotterdam robustly position itself in the (raw) material transition?

In the following sections, we explore strategies for the Port to navigate the (raw) material transition. Section 2 discusses the transition challenge for each of the three material flows most heavily impacted by six developments. Section 3 presents several transition strategies that can be implemented to deal with the transition challenges. Section 4 provides an analysis of the five crossroads the Port now finds itself at and strategies, actors and actions that will ensure that it moves successfully forward into the future.

Chapter 2

Three Raw Material Flows

The three resource streams – CRMs, Organic Chemicals and Construction Materials – are heavily impacted by the six developments described in the introduction. Together, the three streams represent two-thirds of imports into the Netherlands by mass and one-third by value[i] and the majority of raw materials that flow through the Port of Rotterdam[1]. These three resource streams are the following:

- Critical Raw Materials (CRMs): these materials are by definition of significant economic importance and involve geopolitical risks. The supply of these CRMs goes along with social, economic and geopolitical risks; that is why they are considered critical. They are also heavily used in green technologies. Typically, these are relatively high-value low-volume metals, such as rare earths, platinum group metals, cobalt or lithium. But more voluminous trade flows, such as natural rubber, phosphate rock and aluminium ore, are also increasingly recognised as CRMs.

- Organic Chemicals (OCs): The chemical industry produces a wide variety of products, including polymers (such as plastics, paints, coatings, glues etc.), fuels (such as diesel, gasoline and kerosine) and many other products derived from crude oil and fossil gas (such as pharmaceuticals, asphalt, solvents and lubricants).

- Construction Materials (CMs): These often have a major CO2 footprint that is hard to decarbonise, such as steel or cement, next to wood and other materials that can actually be carbon neutral or even a carbon sink (under the right conditions). CRMs such as bauxite (ore) and OC products such as plastics are also used as construction materials.

[i] We leave the import of finished products out of our scope in this document, but we do address the CRMs contained in these imports. We do not discuss food import/export/processing, as we feel that this transition is of a very different nature than (other) raw materials (commodities) and that these warrant their own study. Calculation based on the import/export data for Netherlands from the UN COMTRADE database

Strategic action is needed in order to continue current decarbonisation as well as ensure the sustainability and availability of raw materials for use in products. The conclusion of this section will show that the three material flows are each uniquely affected and that the current developments are insufficient to meet future demand, leading to challenges for the EU and its cluster. But first, we will discuss each of the streams.

2.1 Critical Raw Materials

Current system

CRMs are materials that are essential for production technologies of high economic importance, but they are in limited supply (in terms of geopolitical concentration and total availability) and unevenly distributed globally. The main drivers of this imbalance are the increases in demand due to the energy transition as well as geopolitical developments and sensitivities. Table 2 lists the CRMs as currently defined by the EU. There is uncertainty related to the future demand of these metals, as the estimates are primarily dependent on the currently used assumptions and models that aim to predict future demands. However, it is clear that this list will likely expand.

Table 2. CRMs as currently defined by the EU

EU 2023 critical raw materials **(strategic raw materials in bold)**		
Aluminium/Bauxite	Gallium	Platinum group metals
Antimony	Germanium	Phosphate Rock
Arsenic	Hafnium	**Phosphorus**
Baryte	**Helium**	Scandium
Beryllium	**Heavy rare earth elements*** **	Silicon metal
Bismuth	**Lithium***	Strontium
Boron/Borate**	**Light rare earth elements********	Tantalum
Cobalt	Magnesium	Titanium metal
Copper	**Manganese***	Tungsten
Coking Coal	Natural Graphite*	Vanadium
Feldspar	Niobium	
Fluorspar	**Nickel***	

Notes. *Strategic if battery grade. **Strategic if metallurgic grade. ***Heavy rare earths are the following (in bold if strategic): **Samarium,** Europium, **Gadolinium, Terbium, Dysprosium,** Holmium, Erbium, Thulium, Ytterbium, Lutetium. **** Light rare earths are the following: Yttrium, Lanthanum**, Cerium, Praseodymium, Neodymium**[ii]

[ii] Promethium, although chemically a rare earth element, at the boundary between heavy and light, is even for a rare earth element, very rare in occurrence and barely has non-research applications and is thus apparently not considered strategic and/or critical by the EU.

The scale of each CRM is different, as can be seen from the graph in Fig. 1. The graph shows the difference in the weight of each CRM currently used by the EU. At the upper end, there is coking coal and aluminium (refined), each was used at more than ten metric megatonnes in Europe per year. At the lower end of the scale, there are the rare earth elements (REEs), gallium and hafnium, starting at 0.23 metric tonnes up to around 100 metric tonnes per year.

A significant contributor to the rising demand for CRMs, and a source of uncertainty, is the energy transition. Among experts, there is a major of debate on the exact demand deficiencies. The differences in opinion can be attributed to how the energy system is going to be designed and with what resources, what technologies will primarily be used and what will be consumers' behaviour. For example, if batteries are used for grid stabilisation, the type of battery technology used will heavily impact the quantity of lithium[2].

Clearly indicative of the urgency of following the climate goals is that the current CRM stock is sufficient to meet only 25% of the demand, depending on the specific material (also see Table 3 below). However, the specific increase in each material demand is highly dependent on the material itself. For example, in the case of zinc, from a 10% to 15% increase in supply is needed. For lithium, this ranges from 35 to 60 times more compared with current demand[3].

Table 3. Additional CRMs needed to meet the goals for energy transition[4]

Metal	Extra material needed to meet EU 2030 goals (factor)	Extra material needed to meet EU 2050 goals (times)
Lithium	18x	35-60x
Copper	3x	35-60x
Cobalt	5x	3-14x
Nickel	2x	1-4x
Rare Earth Elements (REEs)	5x	7-26x

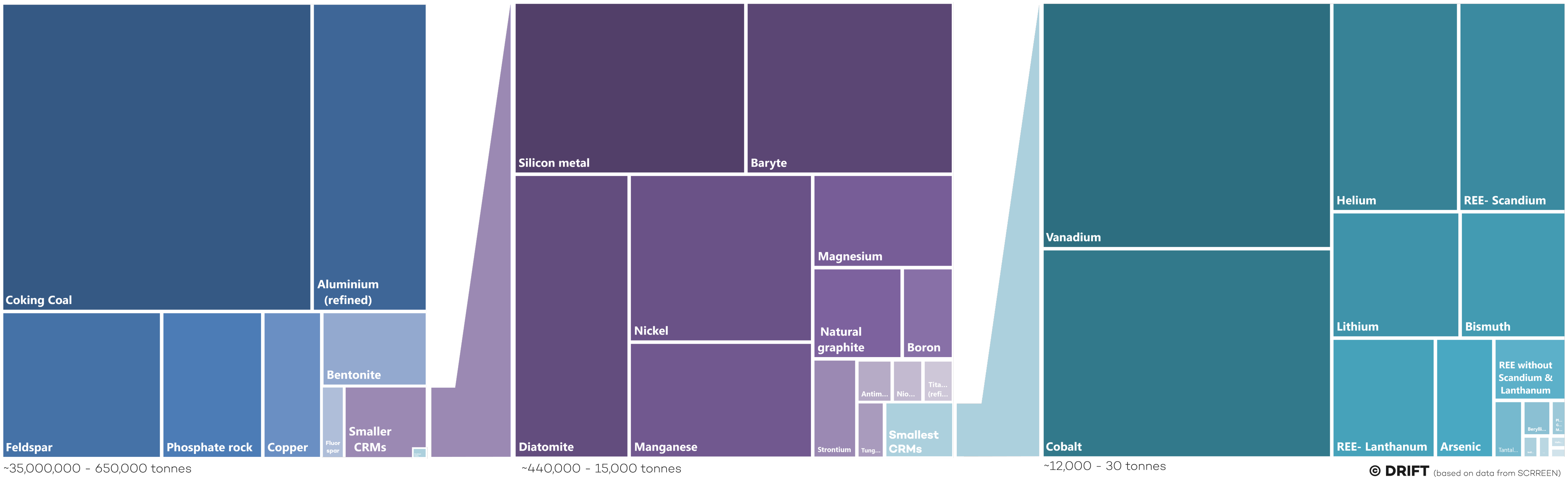

Figure 1. Average annually consumed CRMs by the EU member states. The difference in size indicates the proportional difference in weight (tonnes). From left to right are the most to least used materials by weight. These figures are based on data from 2016-2020, largely sourced from the SCRREEN Network. Numbers do not include materials exported.

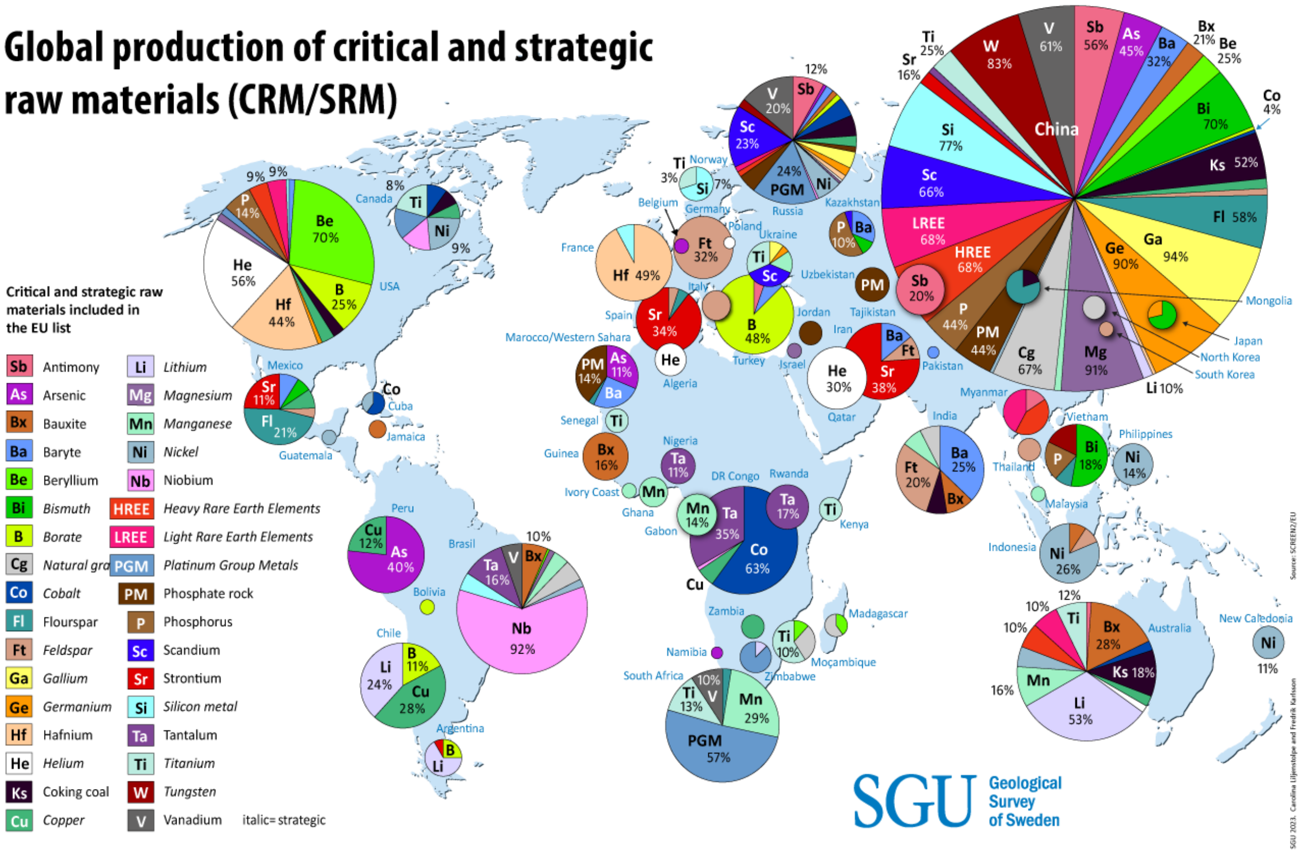

Figure 2. Global production of critical raw materials[5] (https://www.sgu.se/en/mineral-resources/criti-cal-raw-materials/).

Each CRM is mined in a limited number of countries, ranging from countries within the EU or close to the EU geopolitically (Spain's monopoly on strontium or the US dominance in beryllium) to very unstable countries (e.g. the Democratic Republic of the Congo's dominance in cobalt). However, China is in a class by itself in being in the forefront of securing its own supplies and dominating the export market. China extracts sizeable quantities of REEs; it currently has over 30% of the world reserves[6] and 70% of the world's mining production[7].

These kinds of production percentages are indicative of a growing power imbalance between the EU and China in this respect, although the exact level of power depends on more factors. For example, China's attempts to weaponize REEs against Japan had only a limited effect because it turned out to be hard to prevent the small quantities needed to reach Japan via other routes.

However, with respect to higher volumes of CRMs, it is a different story, and even partial blockades or disruptions could severely impact the EU. Moreover, the aim of China is to gain control over CRMs, not only as raw materials but also in refined products, and over the infrastructure through which the materials and products pass, even if it does domestically mine these resources. China has, for example, no significant reserves of copper and lithium but is the second largest producer of copper[8] and with a 60% market share, the largest producer of lithium. But also for REEs, China supplements processing of domestic mining with imports, achieving a share of 90% of the world's refinement capacity[9].

Current developments

As previously mentioned, the current high demand for CRMs is expected to grow exponentially. The EU and its member states are so far lacking behind other geopolitical powerhouses in developing CRM strategies as well as implementing them. The current system is changing as the EU released the Critical Raw Materials Act in March 2023. This act aims for a minimal share of domestic extraction, processing and recycling within the EU and for a reduction in the dependency on non-EU countries with a dominant position in supply. Innovation networks are also being set up, but the question arises as to whether this is enough.

Due to COVID-19 and the war in Ukraine, the dependencies of the EU and the Netherlands on foreign markets have become clearer and have increasingly been put on the political agenda. With regard to CRMs, the EU has made resources available through its RawMaterials project as well as developing the Critical Raw Material Act. RawMaterials has most of its resources dedicated to mining, with a geographic focus on the Nordic countries. This is understandable, as mining requires vast financial resources as well as development, but this means that little investment is made in R&D for recycling or urban mining. The Netherlands has played only a minimal role in this innovation community, which is indicative of the Dutch strategy on this so far.
The EU has thus been awakened and begun to deal with the increasing scarcity. The EU has realised, as stated by Von der Leyen (at the 2022 WEF): '*So, we must avoid falling into the same trap as with oil and gas. We should not replace old dependencies with new ones'*. But notwithstanding these positive developments, momentum and scale are still small given the EU's current weak position, thus making the EU vulnerable. To a large extent, the EU has already fallen into a trap again, especially as practical solutions, like opening mines, take 15–20 years to develop. It is necessary for the EU to decrease this scarcity.

Transition challenge

We are at the start of a dramatically growing global imbalance between supply and demand of CRMs, with the EU, and within the EU, the Netherlands is in a particularly vulnerable position, becoming increasingly dependent on mining, processing and/or production concentrated in geopolitical areas with internal volatilities and/or a hostile relationship with Western countries. The EU's energy transition may be hampered and/or become largely dependent on the import of finished goods. Combined with the EU's energy position, this may lead to significant further de-industrialisation. The question then remains as to how we can fulfil the needed supply of CRMs to achieve circularity and climate goals while, at the same time, building a resilient and diversified CRM supply chain.

2.2 Organic chemicals

Current system

The Port of Rotterdam is a key location for integrated refining and petrochemical complexes, and these complexes, including storage areas and terminals, cover about half of the port's total area. A key feature of such complexes is that they receive input from crude oil and natural gas and produce fossil fuels as well as (chemical building blocks for) higher-value materials and products, such as (precursors for) polymers. The current organic chemistry system, which can be seen simplified, as shown in Figure 3, is mostly linear. Traditionally, this route from crude oil to chemical product processes is served by three different types of companies/industries: 1) refineries, which transform oil into various distillates: most (in volume) being fuels, some being the feedstock of the chemical industry, 2) petrochemical industry (producing bulk chemicals) and 3) fine chemicals (focussing on various higher value chemicals, such as coatings or pigments). The current organic (petro)chemistry system, which is illustrated in Figure 3 (without showing fine chemical production), is mostly linear.

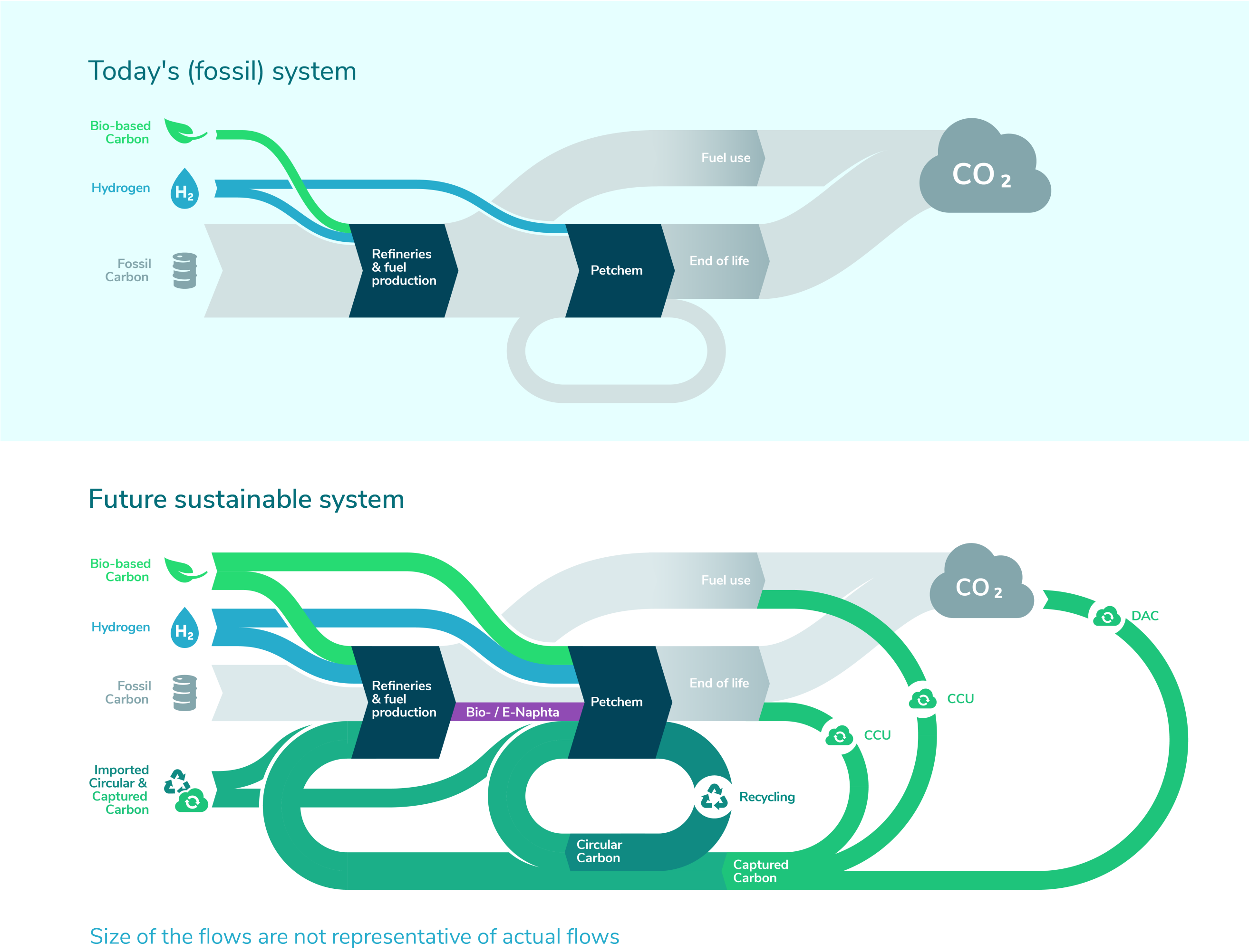

Figure 3. Depiction of current and future basic organic chemical industry, developed by Power2X and Deltalinqs[10]. It illustrates the challenge of moving from a linear to a circular (and biobased) system. Note that 'future' could also be the intermediate state (with a final state without any crude oil). Also, note that the future system may also generate negative emissions by permanently storing carbon (in the medium term by using air captured CO_2 in products or in the long term by sequestering CO_2 or coke in permanent storage).

Current developments

The growth in refining is now over, where the concept of 'peak oil' was once only a fringe theory; organisations such as BP, Shell and McKinsey predicted that 2019 would be the peak oil year. Thus even among key actors within this system, the eventual end of a linear and fossil is broadly accepted. Refining volumes will go down dramatically in the next decade (2030-2040), as more and more vehicles become electric. The only possible exception to this is the refining for fuels that are hard to decarbonise fuels such as kerosene (Billing, Ferro & Fitzgibbon 2021)[11], which may continue after 2050.

Figure 3 schematically depicts the different routes to move beyond a linear fossil system: (1) the use of biobased carbon sources; (2) chemical recycling; (3) carbon capture and use (or storage) from stationary sources (e.g. waste incineration); (4) capturing CO_2 directly from the air; (5) the use green hydrogen sources. The sixth route of mechanical recycling is not depicted. On all these routes, there is momentum, although some operate at the kilotonne scale, while others, such bio-refining, have already upscaled to the megatonne scale.

Fierce debate about the interplay between these routes remains, bringing uncertainty that affects the entire industrial chain and its main processes, starting with feedstock and refining and continuing to demand, forms of recycling and possible end products. Even if some processes have reached the megatonne scale, we are still very far from a future system that can even meet the demand for current non-fuel usage.

Currently, high volume biorefining already exists in Rotterdam (such as Neste, which refines bio-oil). While the use of biobased sources is scaling up, this upscaling also means that current sources of biobased material may no longer be sufficient (such as waste streams) to meet future demands. Innovations may be needed, such as switching to different polymers. Traditional supplies are made out of CH (hydrocarbon), while supplies from biomass are based on CHO (carbon-hydrogen-oxygen). Reducing CHO-based chemicals to CH chemicals requires extra energy, which in turn will mean higher material requirements of CRMs (to produce the necessary renewable energy). Simply put, making oxygen part of the final product, instead of trying to get rid of it, reduces energy need in production. Using biomass strategically can better utilise these unique characteristics. In more traditional forms, biomass can be converted to fuels, for example, by using anaerobic digestion to biomethane. However, biomass can also be converted into useful chemicals directly, such as producing glycerol from lignin12. Further, secondary chemicals can be created using microbial cell factories by processes such as metabolic engineering. However, these technologies are not as well developed and scaled up as current high volume bio-technologies.

Mechanical recycling is also already at the megatonne scale in Europe, with some facilities processing regional plastic waste in Rotterdam, and has been done at scale for decades, but only for a fraction of all plastics, and often leading to lower quality plastics than the original product. It may appear tempting to forego mechanical recycling for chemical recycling altogether, as chemical recycling appears to be an easier route to make plastics that are literally 'good as new'. But economic and energy costs for chemical recycling can be very high, so a feasible future system would need to move from mechanical recycling of some of its plastics to high-quality recycling of most of its plastics.

Chemical recycling is quickly gaining momentum. Chemical recycling breaks down the plastics into their core components and builds the molecules from the monomer or even single carbon molecules up again. The current vision is to use chemical recycling only for the processes that are unable to be re-used or recycled by other means of recycling, as it costs more energy. The advantage of chemical recycling is not only in terms of its versatility in recycling but also that the output of the recycling process has the same quality as virgin-based plastics. Activities centred around chemical recycling also started in Rotterdam with, for example, Xycle and Pryme, companies that convert plastics into pyrolysis oil.

One challenge is that chemical recycling benefits from large-scale processes, making Rotterdam a prime location for these processes, but our waste systems are not necessarily organised at the required scale. Chemical recycling clusters need to collect waste streams from very large geographic areas to create enough volume.

However, relying only on recycled forms of carbon will not meet (future) demand, as some virgin material will always need to be fed into cycles, to compensate for inevitable losses in quantity and quality in the cycle. There are two solutions that both might be needed to fill this gap: (1) biomass, and (2) carbon capture and utilisation (CCU) including direct air capture. However, although promising technologies, these are still in their infancy stage and will require large amounts of energy; thus, they are currently nowhere near economically competitive.

All these technologies gaining momentum together also brings competition for **more space** and alternative energy streams. In the future, petrochemical clusters (and companies within) could be **competing for the same resources** (waste streams, renewable energy and carbon from CCU and biowaste). Given the expected drop in total throughput because of chemical recycling, dematerialisation and electrification, competition will be fierce between European clusters. Also, on a global scale, European clusters will need to compete against clusters with more ready access to cheap energy (now natural gas and in the future, possibly more favourable climate conditions and land availability/prices). Another factor is that 'green field' developments in areas that lack synergy potential with existing clusters but have better land (and work force) availability and prices may lead to competition.

The expert participants in the sessions for this project concluded that biobased chemistry is on the verge of a breakthrough in upscaling, which will have major consequences for the Port of Rotterdam. In July 2023, the Dutch government awarded subsidies through the 'Groeifonds' (Growthfund) on the BioBased Circular (BBC) programme, which is aimed at bio-polymer development in the Netherlands. Through this programme, the goal is to fund flagship plants as well as demo plants that are working on producing lactic acid as well as glycol, among other chemicals. Additionally, elsewhere in the Netherlands, an FDCA flagship is being constructed that supplies the resources needed to produce plant-based PET. This shows that biorefineries are indeed on a path towards a breakthrough.

Transition challenge

The transition towards a green chemistry is gaining momentum, but this upscaling has also brought new challenges. The EU faces the challenge of scaling up existing green chemical industries and new innovations in order to fully transform its petrochemical complexes into circular green chemical complexes. The main transition challenge is finding space and the 'best' chemical alternatives. New developments benefit from co-location close to the existing (petro) chemical industry, but finding additional space near such clusters is challenging. Also, access to sufficient, affordable green energy and/or finding ways for less energy-intensive production remains challenging.

The second challenge is that currently processes are scaling up that provide organic commodities equal to, or very close to, commodities made from oil (and natural gas), which are often a relatively easy 'drop-in' substitution further down the chemical and fabrication chain. However, these commodity chemicals were developed in an era of cheap energy and abundant hydrocarbons, and these are not necessarily also the best or most efficient commodities in a biobased circular economy in the long term. Entirely new chemical commodities with new properties may emerge with both great potential and great barriers because they cannot be 'dropped in' into further chemical processing and manufacturing processes.

2.3 Construction Materials

In this document, CMs are defined as commodity materials used for their constructive properties in buildings and infrastructure. These are mainly steel and concrete (although steel is also used in machines, appliances, vehicles, ships etc.). As Figure 4 shows, from an ecological point of view, concrete and steel are major contributors to the ecological footprint and embedded CO_2 (the latter also closely aligns with embedded energy and, thus, stresses energy dependency). The EU is also very dependent on imports of steel (or iron ore as its precursor). Therefore, we will focus on these materials (and possible replacements). Other major contributors have been discussed in 2.1, especially climate control and other electr(on)ical systems that embed a great deal of CRMs. Other major products of the (petro)chemical industry, such as bitumen (for roofing) and plastics (insulation[iii] and windows), are part of CMs but were discussed in subsection 2.2 on Organic chemicals.

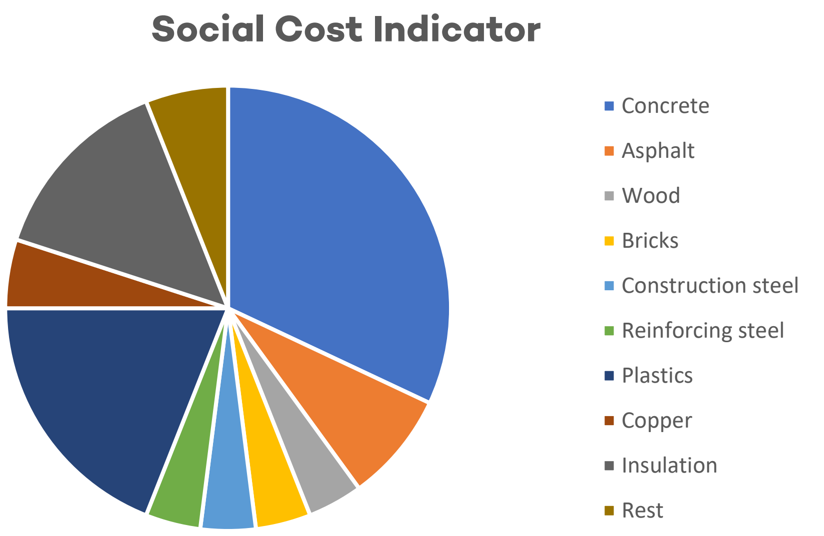

Figure 4. Current CO2 and MKI footprint of a residential building. MKI is a LifeCycleAnalysis-based shadowprice for a wide range of environmental impacts, *(NIBE Potentie van Biobased Materialen in de Bouw – Een onderzoek naar mogelijkheden en impact)*

In this document, CMs are defined as commodity materials used for their constructive properties in buildings and infrastructure. These are mainly steel and concrete (although steel is also used in machines, appliances, vehicles, ships etc.). As Figure 4 shows, from an ecological point of view, concrete and steel are major contributors to the ecological footprint and embedded CO_2 (the latter also closely aligns with embedded energy and, thus, stresses energy dependency). The EU is also very dependent on imports of steel (or iron ore as its precursor). Therefore, we will focus on these materials (and possible replacements). Other major contributors have been discussed in 2.1, especially climate control and other electr(on)ical systems that embed a great deal of CRMs. Other major products of the (petro)chemical industry, such as bitumen (for roofing) and plastics (insulation[iii] and windows), are part of CMs but were discussed in subsection 2.2 on Organic chemicals.

Current system (of steel and cement)

Steel production requires a lot of energy, and the chemical process itself also produces significant amounts of CO_2. This can be attributed to the removal of oxygen from iron ore, as it binds to carbon (forming CO_2), which is at the heart of iron production. Also, only a fraction of iron ore originates from the EU (mostly from Sweden), creating further dependencies on other countries. Major iron ore producers are in Australia and BRICS countries (Brasil, Russia, China, South Africa). China has about half of the world's steel production capacity[13]; however, given the huge domestic demand for steel, China does not dominate global exports in steel, but is dependent on ore imports for meeting domestic demand (although it plans to reduce this[14]). There is some economic market concentration in iron ore mining, with the top five iron ore producers covering about half the market) with Australian, Brazilian and, to a lesser extent, Indian companies.

[iii] Many other materials as insulation are used, but of current used materials, plastics have a much higher environmental footprint as most biological or byproducts (mineral wool), Bouwfysica 2-2018, "DE CIRCULARITEITSPRESTATIE VAN ISOLATIEMATERIALEN", https://nvbv.org/l/library/download/urn:uuid:01978c2a-35de-4e92-85c4-6d21d0a69c0e/de+circulariteitsprestatie+van+isolatiematerialen.pdf

Concrete is the world's most used material (by mass) for construction[15]. Portland cement, the active ingredient for concrete, shares with steel the characteristics of the chemical production process itself: also requiring significant heat and having intrinsic CO_2 emissions. Simply put, cement is produced by removing CO_2 from $CaCO_3$ (calcium carbonate), and like steel, this is an energy-intensive process. Together with steel, this makes cement an industrial CO_2 emission source that is hard to tackle, and current efficiency gains are far below what is needed to meet climate targets[16]. The EU-27 is largely self-sufficient, with most cement domestically produced and used, with little import and export (about 5% each compared with domestic production)[17], not taking into account that energy to produce cement is mostly imported.

Current developments

Two main approaches to more sustainable steel and cement processing are under development (in addition to tweaking current processes to increase efficiency): 1) making steel and cement more sustainable and 2) switching to alternative materials (mainly wood). While other biobased fibres also fulfil an important role in the transition towards more sustainable business practices, these are not part of the scope of this document. Steel can be made by green hydrogen, both as a source of heat and to remove oxygen. This solves the CO_2 emissions issue, but not the import dependency, and only the energy dependency issue if sufficient renewable energy is available. Such green forms of steel production are being developed, for example, with pilot plants in Sweden[18]. However, most of the industry is still using conventional fossil-based methods, given the currently prohibitive costs of using hydrogen and the limited green (or blue) hydrogen availability.

Cement can be made by using a sustainable heat source, and the CO_2 emissions of the chemical process itself can be reduced by using raw material with less carbon content (such as ashes from other industrial processes, ceramic waste etc.). These materials are largely waste products, so avoiding toxic contamination is crucial. However, even a modest CO_2 reduction of 4% to 8% over the 2030-2050 period is called by the industry itself 'extremely challenging'[19], mainly due to limits in availability of these alternatives given the immense scale of cement production.

The second approach is substitution wood as a replacement for steel and concrete. Wood is a low-CO_2, low-energy contender as a replacement of concrete in the building industry. A sustainable wood materials economy in equilibrium is long-term carbon-neutral (except for CO_2 emissions for transport, processing, gluing, recycling etc). In such a circular system, wood cycles from seedling to full grown tree, to timber, to a cascade of applications as wood construction material, with as many cycles as possible, to finally being composted or burned for energy (releasing the CO_2 absorbed back into the atmosphere).

Medium-term building up of such a wood economy would provide a significant CO_2 sink. Building up new forests and increasing stocks of wood in use in buildings can both be significant CO_2 sinks for decades to come or even a century, and the CO_2 will remain sunk as long as the forests and wood cycle exists. In fact, in 2020, existing EU forests absorbed around 10% of yearly EU CO_2 emissions (300 MT of CO_2 in 2020[20]).

Not surprisingly, wood is seeing a revival of interest as a building material in the Netherlands (and North-West Europe), with many pilots, including high-rise buildings, that have been realised in the last years, and many parties advocating greater use. There is momentum now for biobased building, which is a rapidly growing niche and is soaring now in the Netherlands, with many small-scale biobased projects throughout the country. It is now officially supported by the Dutch government, which recently announced it will provide subsidies towards biobased building at a value of 200 million euros[21].

At the same time, there are still challenges to achieving a more large-scale switch to wood use in the construction industry, and many note here that there is no mature wood supply chain in the Netherlands to facilitate such a switch (as described in a recent report by DRIFT)[22].

Also, geopolitically, wood is a very feasible replacement for cement and steel and in terms of the energy these materials require. The

EU is a net exporter of sawn wood (with an expected increase in production), even if it is an importer of wood chips and the like (until recently, especially from Belarus and Russia) [23,24]. The EU is more than self-sufficient in wood overall[iv], and in principle, Europe has enough forest, or the possibility to plant it, to provide the supply to meet the significant increase in wood demand (vd Lugt et al., 2021[25]).

However, challenges can be identified. First, as long as the EU is in a relatively open market with the world market, self-sufficiency does not preclude being impacted and having an impact on global shortages. Although nowhere near experiencing the (future) pressure exerted on other material markets, the global supply of (sustainable) forestry is expected to be challenged to keep pace with the world wood demand growing by approximately 35% by 2050. This growth is mostly owing to autonomous growth in current applications (not substitution)[26]. Unless the EU becomes a closed bloc, this may lead to price hikes (as recently happened after the COVID and Ukraine supply crises).

Moreover, there are credible predictions that the EU, by using more wood for construction materials in a purely open market, will in the medium term, tip the balance from being a slight net exporter to a slight net importer[v]. This would, thus, require active strategies by the EU to stimulate domestic production or protect its market if it wants to maintain its current net export position.

Another, perhaps even more important, route to (maintaining) self-sufficiency or (increasing) export position is to increase wood recycling and to move to a 'many lives' of cascading use of wood products. Wood can be very circular as a product by cascading its use in various products. Wood as a material can be recycled, and wooden elements in construction can be re-used, but currently wood often gets downgraded quickly and ends up in a waste incinerator. Applying cascading to wood and other materials is therefore essential to make it a more sustainable and resource secure system. This again requires a mature, circular supply chain to be developed.

One advantage, even if wood has to be imported, is that wood has a long tradition of sustainability certification of wood imports. This system is not perfect, e.g. recent limited imports from China have been challenging to assess in terms of sustainability, but much more developed than other biobased commodities. The EU is taking steps to implement stricter legislation to ensure certification of wood through Forest Law Enforcement, Governance and Trade (FLEGT) and national partnerships.

Besides wood/timber, there are numerous other biobased materials that can replace concrete and steel in construction. Some of these are already being utilised in building applications. For example, in the Netherlands, hemp is being grown and used in building construction as a replacement for concrete. To do this, chalk is added to the hemp parts. While not yet being fully adapted to mass installation, developments are underway to make construction with hemp more standardised and industrialised[27]. Another biobased material, such as straw, can replace petrochemically based insulation[28]. In addition to wood, these and other biobased materials provide great ways to store carbon and are regenerative, thus making it possible to create a more renewable construction industry.

[iv] Wood products are quite varied in quality and type, even more than just distinguishing between sawn wood and other products, so being net neutral in forestry product imports/exports does not preclude dependencies related to some types and qualities.

[v] The EU is expected to become slightly more dependent on imports in the future. Building more with wood as a substitution for steel/cement in the EU could tip the balance further towards becoming a net importer. If and how much does depend on the specific building construction method used. Wood frame houses, as in the US, require less wood while solid wood houses, which are more climate resilient (temperature management) require more wood. The Food and Agriculture Organization of the United Nations (FAO) has estimated that if EU would build like they do in the US, the EU would increase consumption by 46 million m3 of industrial roundwood, with less than half of that extra demand being met by increased local production, leading to self-sufficiency in industrial roundwood dropping about 3% (from very roughly 90%). In the case of solid wood wall construction in the EU, this drop would be significantly higher as much more wood per house would be required.

Transition challenge

Regarding sustainable forms of cement and steel, there are developments towards sustainable cement and steel, but the energy and CO_2 intensity of these processes represent formidable challenges. Especially given the current and future weak (green) energy position of the EU, and notably that of North-West Europe, a strategy cannot primarily be based on greening cement and steel. Becoming dependent only on green, but still energy-intensive, processes also exacerbates the EU's dependency on CRMs for domestic hydrogen and other energy production and/or its dependency on hydrogen and other energy carrier imports. Thus, this incremental innovation is not enough.

There is an opportunity to more fundamentally tackle these issues associated with steel and cement by switching to wood for a significant part of construction works (e.g. houses) or other biobased materials. However, the challenge is that the construction industry and supply chains are very locked into using conventional steel and cement constructions. The challenge is to develop a supply chain that is fully circular, for example, one that gives wood products the longest life possible through cascading.

2.4 Three material streams in transition

Having outlined the current state, developments and challenges for (North-West) Europe in the previous sections for each of the three most important groups of material flows for the Port of Rotterdam, the question that remains is how these flows relate to each other and to the energy transition and what the state of transition is for the Port.

Positive dynamics between raw material transitions and the energy transition are crucial

As we described in section 2.1, given its current weak CRM position and global scarcity, the EU cannot make the energy transition. This is because 1) for too long, we have tried to solve the material circular challenge by (implicitly) assuming green energy would be abundant, and 2) we have tried to solve the energy transition challenge separately from the raw material transition by assuming raw materials would not be a limiting factor. Without a CRM transition the energy transition cannot be completed.

This has led to a situation where although the EU has come a long way to sort out how to develop a green energy system in terms of technology, infrastructure, and economics, this could all come to a crashing halt because the EU neglected raw material aspects. Also, vice versa, the raw material transition puts pressure on the energy transition: the extreme levels of recycling necessary to implement an effective CRM strategy or the increased global movements of secondary materials can also further increase the challenge for the energy transition.

What is then needed are developments and strategies for each transition that alleviate, not exacerbate, the challenge for other transitions. These would include, for example, switching to low energy materials in material transitions, choosing less energy-intensive recycling options, making local loops to reduce transport energy where possible and using dematerialisation and degrowth strategies.

State of transition for the Port of Rotterdam: each material stream in a different phase

While the Port of Rotterdam is already working on different initiatives, many of which can be found on their interactive map[29], an integrative perspective on the challenge is still missing. For the Port of Rotterdam, each resource stream's state of transition is unique and in a different phase of the transition, as is depicted by an 'S-curve'[30] in Figure 5.

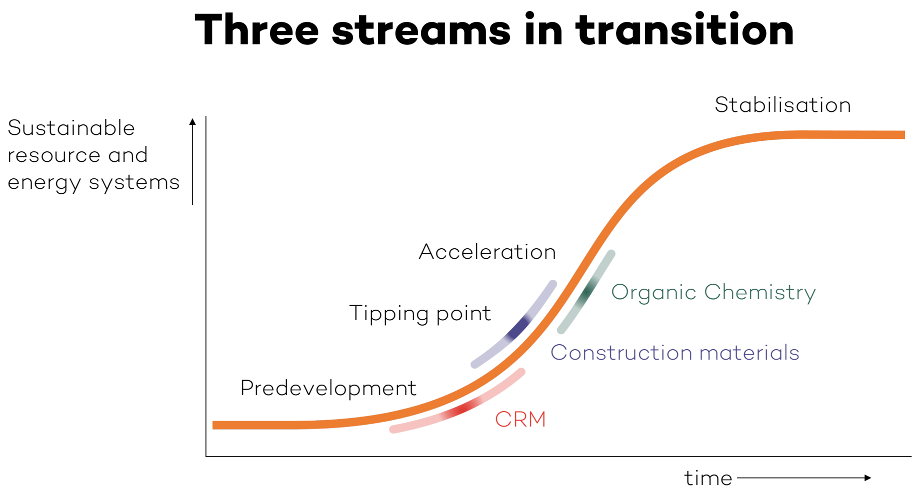

Figure 5. Three resource streams in transition perspective, mapped on and S-curve.

Organic Chemicals need further acceleration: scale up!

OCs are in the most advanced phase of the transition towards a renewable resource and energy system. The paradigm has already shifted; the question is only 'when' and 'how'. Specifically, more renewable refining systems are being implemented, and research is being conducted for alternative feedstock. Biorefineries are already being utilised in the Port of Rotterdam. Additionally, infrastructure already exists in terms of OCs, possibly making the transition in some processes easier. As described in the previous section, the challenge is one of scaling up to volumes to a point where they meet the (reduced) total demand in terms of not only production capacity but also infrastructure. The Port of Rotterdam as a large existing petrochemical complex can play a vital role in this, which is also essential for future viability of chemical industry in Rotterdam, and existing industry, infrastructure and services provide excellent conditions for such a scale-up. But to achieve a smooth transition from a linear fossil to a circular chemical industry, largely within the existing physical, environmental and risk space of the current Port of Rotterdam, this borders on a mission impossible.

Construction Materials are heading towards a tipping point: 'chain up'! CMs are not as far along as OCs in terms of transition. While wood is used in various construction projects and in other regions in the world, and even the EU is making much more use of biobased materials, it is not yet mainstream in our region. At the level of the individual building, wood and other biobased are more and more often considered, but this is still a niche with a huge potential. Moreover, a mature wood supply chain also needs to be built up. The future supply chain of wood and other biobased products also needs to be innovated to 'mass customisation' production to reduce costs, give more design freedom and reduce the use of labour. Currently, the Port of Rotterdam is involved in the logistics of CMs, such as steel and iron but also wood. As described in section 2, there are clear indicators that the CM composition will change. The potential role of the Port of Rotterdam in terms of CMs could therefore change, but before the transition reaches maturity, alternative supply chains need to be established.

CRMs are in an early stage, but highly urgent: wake up!

Currently, the role of the Port of Rotterdam in terms of CRMs is limited, and the volumes traded of (purified, processed) CRMs are often smaller than are typical for a large port. However, the strategic value of CRMs can be big factor for the Port of Rotterdam. Opportunities for the CRM processing industry may emerge, and CRMs are embedded in the finished products in whose import/export the Port of Rotterdam has a strong position. The future of CRM trade may thus affect the Port of Rotterdam in this way, or lead to making the Port of Rotterdam a favourable location for ‘reverse logistics’ of these finished products at their end-of-life and for recovering these CRMs.

Chapter 3

Strategy for the Port of Rotterdam Authority

To face the challenges outlined in the previous sections, we present a strategic framework to scale up, chain up and wake up. We will present this as a 'multi-scale' strategy for the Port of Rotterdam in four pillars, each pillar describing a different scale, from the European level to north-west Europe and the regional cluster. These are the pillars for securing availability of resources. Furthermore, as was highlighted already in chapter 2, a switch to more available (and less polluting) raw materials can also be made, and this is the 'base pillar zero'. For each pillar, we identified a main strategy for the Port Authority of Rotterdam:

Pilar 0: Substitute and dematerialise: The base strategy is to reduce our demand for globally scarce and geopolitically concentrated resources where possible, by switching to more abundant materials (preferably also with a lower CO_2 and smaller energy footprint) or reducing material (and fuel) use in application, also through innovation.

Pilar 1: Resource diplomacy: Reposition the EU in world trade flows by establishing European resource diplomacy in an increasingly multi-polar world. Resource diplomacy goes far beyond formal state relationships, thus also indicating an important role for the Port of Rotterdam

Pilar 2: Create new backbones and commodities into the north-west European hinterland: The current infrastructural backbones (such as pipelines) and traded commodities in which the Port of Rotterdam has a central position are those of a linear economy; new backbones with the Port of Rotterdam as a hub are needed for a circular economy if the Port of Rotterdam wants to maintain its central position in the future.

Pilar 3: Reform the regional cluster (which extends beyond the formal Port of Rotterdam boundaries): This can be done by establishing a new spatial order and infrastructure to literally make space for the new economy in the region in which the Port of Rotterdam operates.

Figure 6 depicts these main strategies in each of the four pillars in a strategic framework, which we will discuss in the following subsections. In this framework, we also summarise the importance of the strategic pillar for each resource flow, as some pillars are more important for a specific resource flow than for others. For CRM strategies, the emphasis is on the global level and focus on supply chain diplomacy. In contrast, for CMs and OCs, the proposed strategies focus on involving the regional hinterland and building up new bidirectional supply chains and secondary commodities. For OCs, the local cluster is also highly important, especially given their physical footprint and the challenge of a new spatial order in the Rotterdam cluster.

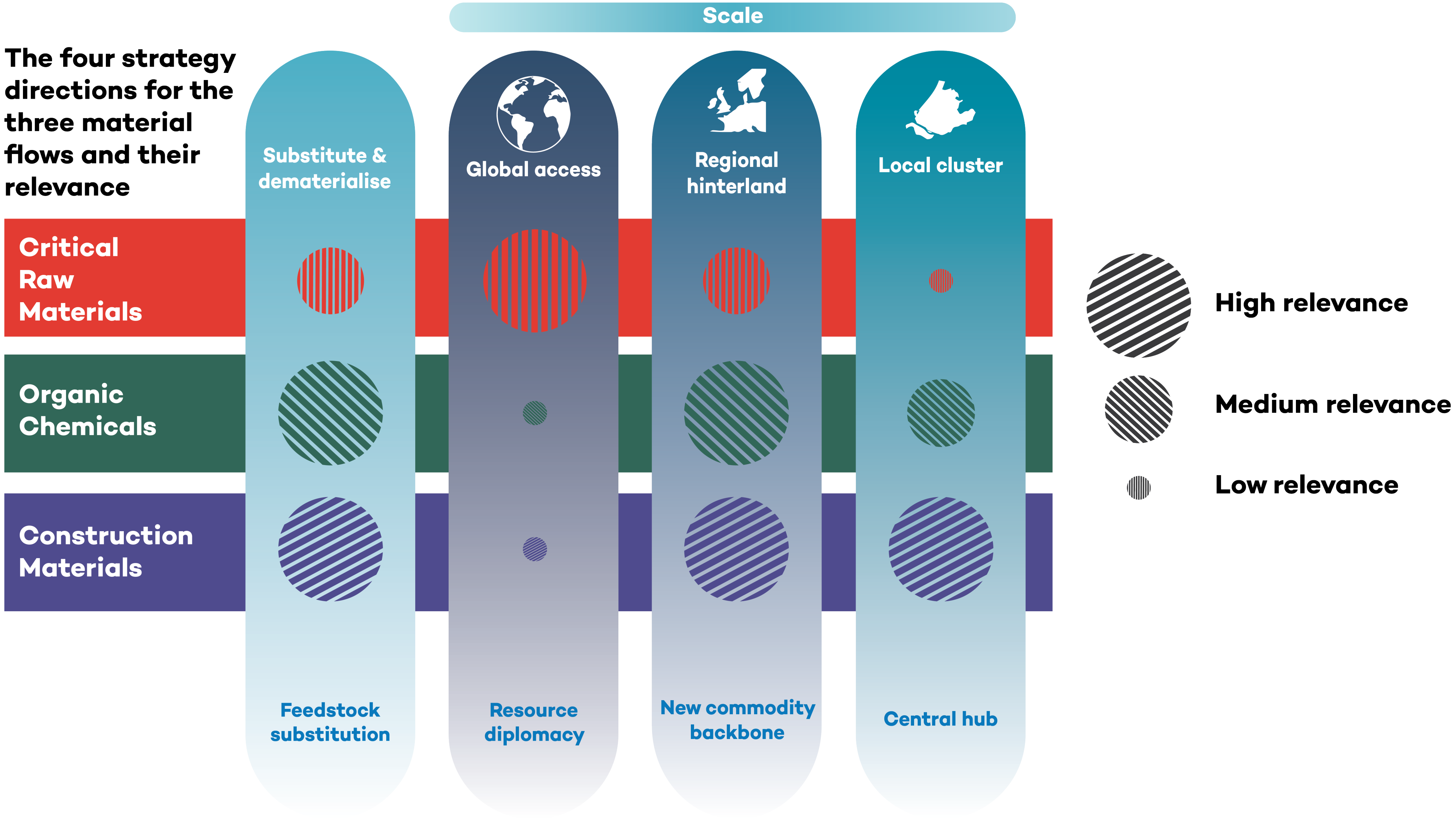

Figure 6. Strategic framework of pillars showing their main strategies their relative importance for each of the resource flows. The size of the circle indicates how much strategic focus for each of the flows is on each of the pillars.

3.1 Pillar 0: Substitute and dematerialise

Substitution is a general firm strategic base to start from, and as it is not necessarily connected to one of the geographical scales. We consider it to be 'base pillar zero'. Switching to more available raw materials can avoid the need to secure access to scarce raw materials in an increasingly competitive, polarised and volatile world. Often, substitution means switching from a (very) scarce to a significantly less scarce raw material, possibly also one that is locally more available. However, we would like to note that substitution is not a panacea. Substitution is not always possible, as raw materials may be relatively abundant but still far from being unlimitedly available. So, even for substituted materials, the other three pillars may still be relevant.

For OCs, substitution of raw materials is key, even though the elemental base remains hydrocarbons. Crude oil and natural gas as feedstock for hydrogen and carbon will be replaced by biological sources for carbon and hydrogen, supplemented by additional green (or blue) hydrogen (possibly also as an energy source together with electrification). Oxygen atoms present in biological sources may remain in the final products. Few decarbonisation pathways foresee a (very) long-term future for crude oil (and natural gas) as feedstock, even if opinions differ as to how quickly the transition can be made and if there should be an intermediate phase of (life cycle) carbon-neutral fossil-based materials (e.g. by Carbon Capture and Storage).

Biological sources will still be scarce, necessitating 'cascading' or 'multi-use' of sources: e.g. from a plant-based raw material, first the most valuable substances can be extracted to use, for example, in cosmetics or pharmacy directly, after which substances for use in bulk chemicals can be extracted[31]. What remains after processing, such as coke, can be burned for energy, although long-term sequestering of such material can also be an economic way of carbon capture and storage. The use of biomass to directly burn stationary energy will be phased out.

Substitution strategies for CMs are also mainly about decarbonisation. To illustrate, there are excellent options to replace steel, cement and, to some extent, plastics with wood and other biobased materials in many applications. A compelling case has emerged through the combination of long-proven technologies (or adaptations with a very high technological readiness level), possibilities to innovate in the industrialisation of 'mass customisation', and offering a solution for very hard to reduce emissions from steel and cement production. However, this is far from mainstream at the moment, and, specifically for the Netherlands, it is challenging to develop a mature wood chain. In addition, steel and cement will remain important, as not everything can be made from biobased materials.

CRMs are by definition critical in the current system. Substitution occurs by market forces, such as switching away from copper to aluminium (power cables) or stainless steel (pipes). Innovation and scaling-up of such innovations (or revived old technologies) have been developed to substitute for CRMs such as new battery chemistries. CRMs also partially overlap with construction materials (e.g. wood can in some applications replace aluminium).

Four more overarching strategic implications are the following:

1. Development of a mindset that appreciates the volume and added value of raw material flow that may appear unimportant in the present system (e.g. wood).
2. Anticipation/awareness of (risks for) decreasing volumes of available raw materials (especially as a combined effect with more recycling/reusing, see Pillar 3).
3. Positioning the Port of Rotterdam as a start-up/scale-up location for substitution materials such as new battery chemistries (see also Pillar 3).
4. Development of (practical) knowledge of the (technical) options of multi-functionality of installations and infrastructure to allow for substitution.

Dematerialisation and/or **degrowth** are two other related main strategies that avoid the use of (critical) materials, by, for example, using less material to produce the same product by smarter design (for example, plastic soda bottles are nowadays made from thinner plastic films), by making smaller products such as cars and houses (which also greatly reduce energy needs), by not using products at all (e.g. asking whether we really need that many devices with a screen that all more or less have the same function), or by more shared use of products (for example, moving from owned vehicles to shared vehicles and shared rides). Like many other strategies, such as for more recycling, these examples all have in common that they require smart design of products, processes and behavioural influencing. In terms of strategic activity, the Port of Rotterdam could promote such activities by connecting and housing initiatives that operate under these principles or by opting for lobbying.

3.2 Pillar 1: Resource diplomacy

Resource diplomacy does not only mean diplomatic state contacts, although these can play an important role, but also entails a whole spectrum of strategic activities in supply chains with both hard and soft powers (see the menu below). In terms of resource diplomacy and what can be done to answer the transition challenges for the Port of Rotterdam, the main focus of the resource diplomatic strategy is on the national and EU levels. The specific role that the Port of Rotterdam can fulfil is discussed in subsection 3.4 and chapter 4.

In this subsection, we will first discuss in depth what the developments are within this pillar by addressing the role of the EU, providing a menu of possible strategies, examining the three emerging strategies for the Port of Rotterdam and applying the pillar of resource diplomacy to the three resource streams.

Resource diplomacy and the role of the EU

European resource diplomacy is not limited to the EU as a supranational state or institution; it is also bound to the myriad of European countries, companies, other organisations and networks. In some respects, such as formal trade policies, the EU institutional level is key. But even after witnessing a largely united European foreign policy response to the Russian invasion, power politics and state agendas within the EU will continue to play an important role in shaping countries' behaviour on the international stage. Also, in other geopolitical blocs, how companies, other organisations and networks within these organisations pursue their own agendas should not be underestimated. Resource diplomacy should thus not only be interpreted much broader than the actions of the EU high representative, the European Commission or the EU diplomatic service, but also encompass diplomatic action at the level of states, regions and companies within the EU. Some of these entities have already been much longer and much more aggressively engaged in resource diplomacy than the EU itself. The scope of such diplomacy should also include the entire supply chain: a raw material may be widely available in many countries, but if the processing into pure material is concentrated in a single, hostile country, that still leaves the EU vulnerable.

One interesting possible turning point at the EU institutional level is the extent to which it is willing to engage in all the possible measures of resource diplomacy. Some measures, such as using a standard setting as a tactic, are engrained in EU policy and strategy, while others, such as strategic support, are becoming more acceptable. Introducing non-tariff barriers, such as domestic sourcing quotas, export bans or import tariffs and limiting foreign direct investment (FDI), may be more controversial, let alone the (threat of) military power to secure access.

In addition, the EU should appeal to other areas where it has considerably more diplomatic power than to the domain of resources alone. These powers can be utilised as a leveller on the resource agenda, where the EU could even try to turn its weaknesses into strengths. For example, (north-west) Europe faces the risk of becoming uncompetitive in energy-intensive processing of raw materials due to, amongst others, high energy prices post-Russian/Groningen gas, environmental regulations, scarce and high wage technical workforce. This may make it easier to offer more equal collaborations to resource-rich countries, in which these countries are allowed to add value to resources in their home country, possibly using cheap renewable energy in their country for this, as long as European countries and companies have a reliable supply of processed materials for the industry that remains in (or returns to) the EU. The EU's position would also improve by using the strategies of the other pillars to reduce the current extreme levels of dependency.

Rottterdam: local resource diplomacy in the global perspective

While resource diplomacy is often conducted on a national or supranational level, the Port of Rotterdam and the cluster can pursue the three resource diplomacy strategies as underlined in the menu above through indirect lobbying, equal bilateral partnerships and stockpiling of resources.

In the myriad of ongoing and possible diplomacy activities, the Rotterdam Port Authority and Port of Rotterdam cluster can contribute to (indirectly) lobbying, while others may take a more active leadership role. Of all possible diplomacy options, working on more equal bilateral partnerships for specific flows or activities appears to be promising for the scale of the Port of Rotterdam and where the port cluster operates. This could also build upon current efforts of 'hydrogen' diplomacy, which is about allowing other countries to build up their production industry and to extend this to other resources as well.

Also, given the large flow of resources through the Port of Rotterdam, the region could play a role in buffering and stockpiling strategic raw materials centrally. This strategy connects to the Port of Rotterdam as a trading point and price index, currently for oil, but in the future, potentially also for other material flows. Of course, this may be limited by the available space, especially for voluminous flows (see Pillar 3). The renewed attention to physical security, for example of pipe and cable infrastructure of the North Sea, also has implications for the Port of Rotterdam as a central hub and processing points for many resource flows and the strategy of stockpiling.

Resource diplomacy applied to the three material streams

For CRMs, the geopolitical and, thus, diplomatic aspects are cautiously on the EU policy agendas but not yet in the Netherlands. The Port of Rotterdam and the cluster could participate in this by setting up bilateral supply chains as described above and as currently developed for green/low-carbon hydrogen. Also, strategic stockpiling of CRMs in the region is an option, and given that CRMs are relatively small in volume compared with other flows, they also allow processing in limited space (see Pillar 2).

Many CMs, both biobased and mined, are not as geopolitically sensitive as CRMs, at least not right now. Some construction materials, such as aluminium, are already on the CRM list or close to that status. For these CRMs, diplomacy is an option. In some scenarios, biobased materials, such as wood or even steel,

Menu of general strategies for resource diplomacy (potential strategies for the Port of Rotterdam Authority are underlined)

1. Vertical integration of national/EU companies with foreign activities. For example, EU chemical companies can also own a mine in Latin America or start belt and road type programmes. Or they can work defensively to protect gainst vertical integration by placing legal limits on (controlling) shareholding for foreign investors.
2. Promote joint development/ownership of supply chains, whereas in contrast to strategy 1, the source country is offered the opportunity to develop its own added-value industry, delivering refined raw materials.
3. (Stimulate) strategic stockpiling and local buffer capacity (such as strategic oil reserves).
4. Set import/export restrictions and tariffs, minimum domestic sourcing quotas (pharmacy), export limits/quotas/exhibitions (of both primary and secondary resources), exempt export of processed (imported) materials from VAT and other taxes. Provide direct financial subsidies for domestic production and reforestation (e.g. US and now EU green subsidies).
5. (Stimulate to) diversify into multiple supply chains from multiple countries/blocs/regions.
6. Fight unfair competitive advantages of other blocs and try to level the playing field through standard setting (or take competitive advantage).
7. (Stimulate) resource hedging: e.g. by long-term contracts, futures, financial instruments (for example, a company badly affected by high prices could swap risk with a company making a lot of money on high prices).
8. (Stimulate) industrial alliances.
9. Employ the military: Establish hard defensive protections (e.g. you build up a deterrence that prevents other countries from disrupting your supply chains from third countries; e.g. Australia's navy build-up to secure shipping lanes. Or if you are a malevolent actor, use your offensive capabilities to just take resources from others).
10. Various soft power options, dialogues, symbolic projects etc. often combined with the above (hearts and minds).

Note. This list is partially based on a list from The Hague Centre for Strategic Studies, Securing critical materials for critical sectors[32].

may also face significant gaps between supply and demand. Therefore, setting up long-term partnerships in the present may be attractive to give the EU a frontrunner role. For example, in the case of wood, it can take several decades between increasing production capacity (e.g. forests) and having more yield (only to a limited extent, as reducing forest stocks can also be a short-term option). Investing in partnerships for sustainable forestry could be set up, although this is perhaps a less obvious choice for the Port of Rotterdam.

For the supply of OCs, biobased feedstock (wood could be included in this list), a similar situation as biobased materials exists: the urgency is less extreme compared with that of CRMs. It might increase in the future, for example, when (food) crops are used as input. It can be expected that the total volumes needed are much lower than current crude oil input because of more mechanical recycling, chemical recycling, CCU and electrification of many internal combustion engine (ICE) applications. Critical for resource diplomacy in the short term is the sourcing of low carbon hydrogen, such as green hydrogen. To increase volumes, existing green hydrogen diplomacy by countries and the Port of Rotterdam could be stepped up. Green hydrogen is needed not only as feedstock in OCs, but also as an energy source, and there are very few scenarios in which global energy flows would become less geopolitical or scarce in the future.

3.3 Pillar 2: Positioning the Port of Rotterdam in the world and north-west Europe: secondary commodity backbone

Not only will Europe's, and thus the Port of Rotterdam's, relationship to the rest of the world change but also the Port of Rotterdam's relation with its hinterland. This change will affect the position of the Port of Rotterdam and the currently looming transitions of the three resource flows. Repositioning is therefore an important strategic pillar for success in these transformative times.

To fully grasp the possibility of a repositioned Port of Rotterdam, we first discuss the current role of the Port of Rotterdam in relation to north-west Europe. Second, we discuss what repositioning from the current 'trunk' network to a spoke and hub network could look like and what general conditions need to be met. Lastly, we zoom into the three resource flows and indicate a multitude of hinterland-oriented strategies.

Current role of the Port of Rotterdam in relation to north-west Europe

Global scarcity and the EU's relatively weak resource position will force the EU to become a domestic producer of raw materials once again and take re-use and recycling to the next level. In addition, some 'demateralisation' will be almost inevitable. Just as the 1970s oil crises made us drive smaller, more fuel-efficient cars, the material and energy scarcity this century may lead to dematerialisation. Electrification is also a driver of dematerialisation in shifting from fuels to batteries (although renewable electricity production and storage requires CRMs and chemical energy carriers may be needed to balance supply and demand).

Fundamentally, the type of network and hub/trunk position of the Port of Rotterdam in that network will change. Currently, the logistic network of the Port of Rotterdam can be described as treelike: raw materials have many different origins that come together in large volumes in Rotterdam, from where they are distributed again into the hinterland. This network also has a dominant direction of importing from overseas and distributing into the hinterland (and nearby European destinations). This not only leads to large volumes being transhipped but also creates opportunities to add value to these streams, moving from a tree-like structure to a circular structure.

The Port of Rotterdam: future role of Rotterdam in relation to north-west Europe

In the EU, with more recycling, re-using and mining, this network changes to a multi-scale typology, as depicted in Figure 5. Many flows, often bidirectional, start and end within the regional networks. For example, a French lithium mine supplies raw material, processed by a European refinery and then exported to a Belgium battery factory and subsequently to a German car manufacturing plant, which at end-of-life also extracts the batteries from the car to be returned to the battery factory for either reconditioning or further disassembly, and thus to be processed in a recycling facility at the refinery again to purified lithium for re-use.

At the same time, the EU will be far from self-sufficient and will still rely on importing large amounts of materials, while also importing products and perhaps secondary materials. Clusters such as Rotterdam can become the link between these regional and global networks, just as they are in the present. However, if globally traded volumes and virgin production volumes shrink, competition for such positions between large ports may increase. Also, processing of secondary materials may shift to locations more central in the regional network to minimise distances in the regional network, or more local loops can be established if the technology allows for small-scale plants without losing too much efficiency. This may make the Port of Rotterdam (and/or other large European ports) the cornerstone of the system: it handles remaining import streams and secondary materials that require large-scale and integrated clusters (e.g. chemical recycling), and/or where synergies between import of virgin (or secondary) raw material from overseas and secondary materials can be created. The latter can be especially the case during the transition, where secondary materials can be blended into mainstream virgin products, as is already happening on a large scale in the Rotterdam cluster (e.g. biodiesel) and in new plants that are being built.

This does mean, however, that the Port of Rotterdam needs to invest heavily in this development. This requires space, infrastructure and other incentives within the port and surrounding area (see next section), but the Port of Rotterdam can also actively try to influence developments in the hinterland to get a more favourable position. For example, in the current system, the Port of Rotterdam has strengthened its natural geographic advantage of being at the mouth of the Rhine by being part of an extensive pipeline network (with flows to the east); such networks could also be established flowing back to the Port of Rotterdam. This may become even more vital if climate change affects the year-round guaranteed navigability of the Rhine. To compete against local loops, with the efficiency and scale of an integrated cluster, it will be vital for the Port of Rotterdam that secondary commodities are standardised to allow trade within the entire region. The Port of Rotterdam can also encourage the establishment of new supply chains. For example, some argue that the Netherlands lacks a mature wood supply chain for the construction industry, which may also hamper the realisation of the potential for importing wood through the Port of Rotterdam. Additionally, to be able to execute the resources transition, the Port of Rotterdam needs a skilled workforce. To train this workforce, collaboration should be sought with educational institutes in the region so that educational programmes can be designed that fit the needs of the transitioned resource streams, which should be part of the Human Capital Agenda that was recently launched.

Menu of hinterland strategies (potential strategies for the Port of Rotterdam Authority are underlined)

As outlined in the sections above, how the Port of Rotterdam can redefine its hub structure is partly dependent on individual choices but also involves various stakeholders from the three resource streams throughout north-west Europe. This means that some of the strategies outlined in the textbox below can be operationalised by the Port of Rotterdam itself and others in cooperation or by others.

Domestic production

1a. Reopening and founding new mines

1b. Planting new forests and other biobased crops

1c. Carbon capture and utilisation (CCU), including direct air capture (DAC)*

1d. Expand refining (of metals etc.)

1e. Increase EU-based manufacturing

Taking reuse and recycling to the next level

2a. Re-use, repair, refurbish (product, components)

2b. Mechanical recycling (processes where no conversion is needed, e.g. melting, filtering)* – for both organic chemistry and CRMs – in cooperation with other industrial recycling clusters such as Antwerp

2c. Chemical recycling*

2d. Minimum recycled content in products

Dematerialisation and degrowth strategies

3a. Electrification*

3b .Smaller/lighter (vehicles, living units, houses, etc.) and vehicle as a service

3c. Refuse/ban (packaging, disposables etc.)

Transport, infrastructure and commodities

4a. New bulk commodities (e.g. pyrolysis oil) (standards, published prices, exchanges etc.)

4b. Bidirectional distribution network (e.g. pyrolysis oil pipeline back to Rotterdam cluster)

4c. Short/medium range water transport (inland waterway transport, coastal, short sea shipping)

Combining clusters

5. Connect clusters and cooperate complementarily, possibly in cooperation with governments

6. Collaborate with educational institutions to ensure qualified personnel can be trained and educated

Notes: *Process happening in the hinterland/environment of the Port of Rotterdam or that could be done in the port cluster itself

Reforming the regional cluster applied to three flows

The OCs stream is in the most advanced transition stage. Secondary and/or biobased sources are already used in the Rotterdam port cluster, and more (pilot) plants are under development. Upscaling, however, will not simply mean building bigger plants alone in the Port of Rotterdam or elsewhere. A more robust secondary commodity network is needed. In such a network, large integrated clusters will probably be the 'keystone' to fully close the loop. Refurbishing products and components, mechanical recycling and pre-processing for chemical recycling all will be done within the region to make smaller local loops. Large-scale (mechanical) sorting is necessary to process all of these. The Port of Rotterdam cluster can process those flows that cannot be recycled mechanically and further develop chemical process pre-processed plastic (and other organic) waste streams. One option here may be to take a first mover advantage in establishing pipeline infrastructure for secondary flows.

For CRMs, the developments described above are much more in their infancy , and CRM volumes are in general much smaller. CRMs can be found in a myriad of products that typically require disassembly. Disassembly points could be planned to emerge centrally in the regional network (optimising transport distances), overseas (co-locating production and disassembly and using cheap labour), or (also) at the link between the regional and global, such as large ports (tapping into the point where the current distribution network is most central).

This may also depend on how coarse or fine-grained reverse logistics will be. In a circular economy, disassembly (combined with refurbishment) of products will be done by the original producer, who is at least now typically based outside the EU. One question remains as to whether these producers will establish local circular hubs to reassemble/refurbish products, or be tempted to haul products back overseas and organise reassembly/refurbishment close to production locations, also making use of cheaper labour. Currently, disassembly is labour-intensive, but use of robotics and design for disassembly/recycling may reduce this. Even if loops are not closed for individual products, other secondary flows could be generated or upgraded in recycling quality, e.g. mixed electronic waste (if the EU still allows this and importers do not further erect 'green fences'), purely on cheaper processing costs overseas. This would imply that a large reverse logistic flow will go through The Port of Rotterdam (e.g. for every container shipped in with products, a container with end-of-life products may be shipped out). This may provide an opportunity for The Port of Rotterdam to add value in this reverse flow (just as is the strategy in the imported flow), slowly shifting the disassembly point from overseas to the port. If the EU would come to a policy of not letting (some) CRMs leave Europe, the Port of Rotterdam may become the point where CRMs are removed from exported secondary materials and end-of-life products.

For biobased CMs, creating a chain (e.g. a wood-based building chain) may be needed, as these chains appear underdeveloped at the moment. In particular, sophisticated chains of mass customisation of wooden components could be a new opportunity. It is less likely that the Port of Rotterdam will play a large role in, for example, recycling concrete, as such low-value heavy secondary streams rarely travel far. It may play a larger role in the increased short sea shipping of metal scrap to smelters within the EU.

3.4 Pillar 3: The Port of Rotterdam as central hub

We have discussed how the relationship of the Port of Rotterdam cluster with the world and its European hinterland will change and how it can actively influence these larger developments and act beyond the boundaries of the port and its immediate surroundings. We also highlighted several strategies that can improve the position in terms of the three resource transitions. However, these strategies are often focused on national and supranational levels or on cooperation with stakeholders outside the region. But where does this leave the port (area) strategically?

At the core of this pillar is space in both the physical and the more abstract sense and how it is operationalised. Therefore, we start by showing some opportunities for the Port of Rotterdam to further the transitions of each resource flow. We then continue by highlighting that the relatively small area of the Port of Rotterdam means that choices have to be made as to which opportunities can be integrated and which ones cannot. We close with the specific strategies that can be utilised to further each transition's flow.

<u>Opportunities of the three flows in the Port of Rotterdam</u>

One would perhaps assume the Port of Rotterdam will be smaller as much will be dematerialised, domestically mined/grown, recycled and/or re-used within the EU. This is, however, not (necessarily) the case; opportunity for (at least physical) growth exists for the following reasons:

- Fossil imports are incredibly 'dense', both from a materials and an energy perspective; almost everything in a barrel of crude oil is used for energy or ends up as material. Many new energy carriers, secondary streams, and biobased alternatives are less energy dense and contain unusable parts or elements (e.g. water in biobased materials). So, physically, more space would be needed.
- Reverse logistics will also require facilities; right now, the dominant direction of handling containers is into the hinterland. If facilities also have to process many more non-empty containers from the hinterland, that also requires infrastructure.
- The EU is currently barely processing (such as refining) non-fossil raw materials. So, even if less primary materials are being used by the EU, this could still mean an increase in processing capacity within the EU.
- Related to the above is that green (or blue) hydrogen will be imported, but also produced locally, whereas before crude oil and natural gas were imported from other continents or delivered by pipe from Groningen or Russia. This also requires hydrogen plants in the Port of Rotterdam.
- There is a large existing fossil industry in the Port of Rotterdam, which creates great opportunities for synergy, especially in early phases of the resource transition (e.g. blending into fossil fuels and materials), but this also takes up physical space and uses infrastructure.

Physical space is not just about acres of ground but also about permitting, responsible environmental and safety regulations, and infrastructure capacity: e.g. limits to total emissions to air, noise and other nuisance limitations, safety zones around plants, powerlines and other utilities capacity, road congestion limits etc. Space is also about access to human resources in terms of skills and numbers.

Moreover, specifically for (primary) OCs, a future EU (and world) may not have smaller chemical–industrial clusters, but fewer, as scale and integration still matter. This would imply more of an all-or-nothing future for the Port of Rotterdam's currently petrochemical cluster. Choosing specific supply chains and developing competitive edges in these may therefore be necessary.

Spatial order and choices need to be made and priorities set
From this perspective, choices need to be made. At this point, the port area itself (under direct control by the Port Authority) barely has plots left to lease out. Criteria that should guide these choices should be set, such as the following:

- Added (economic) value (employment, investment, profit for Dutch society)
- Long-term sustainability and strategic importance to the region and the EU (contribution to resource independence)
- Feasibility and opportunity (competitiveness to alternative locations)
- Cooperation and expansion towards Moerdijk and Westland to build up circular structures

This is also not merely making choices but also establishing a new spatial order: taking into account existing infrastructure, (deep) water access, environmental/safety zones, and what goes where and next to what. This spatial order needs to be extended beyond the port area itself. This may not be easy, as these areas face competing spatial claims in a political environment where the current debate is very inward looking and concerned with clashing vested interests (e.g. agriculture versus building more houses).

It may also require a new infrastructure beyond the boundary of the port area. Right now, within the port area, many very heavy industry plots exist, which also require heavy industry infrastructure and services. Outside the port area, there are mostly very light industry and general business parks, requiring very little specific infrastructure. Some of the port infrastructure may need to be extended into surrounding areas. This will mean a shift from hard boundaries to gradient infrastructure and services. In this gradient, the region can also fulfil an additional role, such as producing biobased crops or treating them.

Such a new spatial order is not just a matter of finding physical space but also complements a different infrastructure with supporting roles over time. Scaling up new or promising initiatives beyond the border of the Port of Rotterdam itself requires coordination and vision of what industry and critical resources the Port of Rotterdam and the region would like to actively develop. It requires a driving and supporting role to accelerate initiatives to fit into the port and region, within or beyond the physical border of one institution.

Strategies for the Port of Rotterdam cluster
This gradient of infrastructure as well as the Port of Rotterdam itself can be filled with various of the above-and below-mentioned opportunities and strategies, as shown in the 'menu' on the next page.

(Non-exhaustive) menu of (often competing) development options within the Port of Rotterdam and surrounding area (potential strategies for the Port of Rotterdam Authority are underlined)

OCs and energy

- Various forms of chemical recycling
- Biobased organic chemistry in the form of vegetable oils or more 'complex' bio feedstocks (such lignin or cellulose)
- CCU synthetic fuel production and chemicals
- Blue hydrogen (SMR+CCS) and green hydrogen (electrolysis) production
- Sea as production site of resources

CRMs

- Metals and other raw materials refining and other processing/purification
- Metal exchange
- Combine CRM recycling with producing the necessary chemicals for these processes

Biobased CMs

- Increase wood and biobased import facilities and import these in different forms (e.g. import timber in log, plank, treated and untreated) so that rest streams can be fully utilised.
- Mass biobased wood 3D customisation plants
- Concrete recycling

Reverse logistics, refurbishment, disassembly, production

- Production, recycling and refurbishment of offshore wind and solar panels
- Reverse logistics for overseas 'return to cradle' of products and streams
- Invest in CRM removal from reverse logistics streams
- The facilitation of local mechanical recycling, refurbishment, repair or production hub

Chapter 4

At a crossroads:

Moving into action

In the previous chapter, we outlined possible raw material transition strategies for CRMs, OCs and CMs, and we discussed how these strategies could be applied to the Port of Rotterdam and the surrounding region. Many of these strategies need to be elaborated upon, and as we also highlighted in the previous chapters, some (parts of) strategies have already been set in motion. We are thus at a crossroads: several strategies have not yet been set in motion, are not gaining momentum yet, or might be hampered, for example, by the chosen pathway of the past. In this final chapter, we look at what these causes might be by discussing five crossroads where strategies for the port cluster meet, as well as the actions and different actors that will be essential in order to actively engage in the raw material transition.

4.1 Crossroads

Crossroads 1: A lock-in on current strengths versus creating opportunities for alternative futures

The main challenge for the Port of Rotterdam that hampers fully executing the strategies is finding a balance between the strengths of the existing industrial cluster and the need to have a diversified futureproof strategy focused on new strengths. On the one hand, it makes perfect sense to work with current strengths to build a new sustainable port and port industry in Rotterdam. In this strategy, the Port of Rotterdam focuses investments and interests on a port future that is transformative in many aspects but also stays close to the nature of the current port, with a focus more on the energy transition than other raw material transitions and on high volume, commodity (bio)refining and organic chemistry. This is where the Port of Rotterdam has the most synergy with existing activities, infrastructure in the port (and far into the hinterland) and reputation, and this is also where momentum in (pilot) plants and investment decisions is growing. Moreover, the Port of Rotterdam has the highest level of environmental zoning, which allows for these exact purposes, and is difficult to establish elsewhere in the country.

On the other hand, this can also lead to too narrow of a focus and a non-diversified strategy. From a transition perspective, the previous strategy is more an optimisation strategy within current boundaries than a transformation strategy. Against this one dominant strategy are dozens of other interesting opportunities that are situated within the CRMs transitions and sustainable construction materials that run the risk of not being utilised or pushed out by one dominant strategy and future image. These are not only opportunities for port development and (new) companies in the port but also opportunities to respond to urgent societal concerns. We know from the past that transitions can be much more disruptive than expected. The point where a rational argument for a strategy staying close to the current type of port ends and a dangerous lock-in because of staying in a (mental) comfort zone begins is blurry.

The only answer to this challenge is to actively seek a more diversified strategy, creating opportunities for alternative futures. This is more a transformation strategy than an optimisation strategy. Failing to do so would mean a future port area that will be unable to position itself as a major player in the raw material transition in the coming decades. Moreover, it could mean that the hinterland of the Port of Rotterdam will be affected through limited access to material streams, causing harm to both the environment and society. We thus recommend the Port of Rotterdam Authority, and other organisations and networks concerned with the future of the port and region, to do the following:

1. Adopt a principle of reserving space (square meters, environmental, resources, etc.) for opportunities that are radically different from the current port.
2. Even in a diversified strategy, not everything is possible. So, it is necessary to explicitly decide upon a small set of 'second priority' fields (next to the energy transition/commodity organic chemical transition), to guide for which developments an extraordinary effort will be made to achieve, even given constraints in which the port operates, and to find space to develop and attract activities to Rotterdam. As discussed in 4.3, this requires assessment of economic potential, long-term sustainability strategic importance, feasibility and opportunity. This also implies allowing

for alternatives that may not have the potential to be at the megatonne scale but can be of high added value and importance in other aspects.
3. Establish teams for these fields within the Port of Rotterdam Authority (or shared with other organisations/networks). If multiple teams/offices/project organisations are not feasible, establish at least a CRM team or project organisation that horizontally links with other teams within the Port Authority. An additional goal of these teams could be to continuously address the urgency of the resource transition as well as to find the right partners/collaborators so that the narrative and actions around the resource transition continue to be at the forefront of (political) discussions.

By not utilising the above strategies, there is the risk of keeping all eggs in one basket, because there is a strong argument that one basket is the best basket. This overarching crossroad and the strategies to navigate it also underlie a number of more specific crossroads we will discuss hereafter.

Crossroads 2: A business model close to the that of the current Port versus adopting a new business model

The current strength of the Port of Rotterdam is its current business model, in which the linear fossil industry is a major source of income, allowing for investments, maintenance of infrastructure and generation of public income for the Dutch state and city of Rotterdam. The closer the nature of the future Port of Rotterdam will be to the existing port, the more financially sustainable this current business model will be, although the future circular commodity chemical industry may not necessarily be as profitable as the current linear fossil chemical industry. But if alternative activities for other raw material streams are considered, or smaller but higher-value streams, the elephant in the room becomes how the Port of Rotterdam Authority itself will change its business model. We would recommend actively developing new business models to avoid the lack of prospect for a future business model implicitly hampering exploring such alternatives. Examples of these business models include co-financing of intellectual property and innovation, investing in projects with only long-term profitability or investing in businesses in/around the Port of Rotterdam that are working with CRMs, OCs and CMs.

Crossroads 3: Aversity to uncertainty in investments versus the first mover advantage

Aiming for first mover advantages and seeking support/resources from other actors (such as the national Dutch government) requires collective entrepreneurship. In the past, Rotterdam and the Netherlands also invested in the build-up of an oil-based commodity chemical industry under uncertainty. We should move from a 'no regret' measures approach, to a 'may regret' approach in investments, to prevent a certain 'will regret' outcome if we underinvest, as we know that the total global/European market for (petro)organic commodities will likely shrink as a result of electrification of fuel and that all critical raw materials will be a strategic priority for everybody.

Crossroads 4: Limited space versus opportunities

Even if a strategy as outlined above is taken, space (physical, environmental and space for supporting infrastructure) will be a limitation. In previous transitions in the Port of Rotterdam, new activities took place on 'green fields' by converting agricultural land and reclaiming land, while old activities were slowly phased out and space was taken over by the city. However, in the current situation, there is a (perceived) competition between old industry and new industry, but also with, but also nature, housing and space, including environmental space (such as the permitted emissions), and this competitition has become politically sensitive. Understandably, space is perceived as a limiting factor, but as we discussed in the previous chapter, not all strategies take up (much) space, such as in the following cases:

- CRMs are traded in all kinds of volumes, from materials whose world production would theoretically fit into a single shipping container (such as rhodium), to materials of which hundreds of megatonnes are traded (such as phosphate rock). The question is thus not whether the Port of Rotterdam has space for CRM activities, but which materials are traded in enough volume to need port facilities, but in small enough volumes (and enough economic value) to be interesting for the Port of Rotterdam. Figure 1 shows the difference in weight of CRMs consumed by the EU and could serve as a starting point for answering what materials are promising to play a significant role in the future port economy. These are high value streams, but they have enough volume that they require port logistics. Some CRMs are currently already handled in the Port of Rotterdam.

- Non-physical activities such as a trading exchange do not take up physical space in the port industrial area (only associated activities such as secure and verified storage).
- There may be opportunities to adapt/strengthen the infrastructure in industrial parks outside the port area proper for those activities that are now too 'light' for the core port infrastructure but lack facilities outside the port area.

We have also noted that space limits can paradoxically be an advantage in resource diplomacy: if we do not have the space for the (first steps of) processing raw materials, we can offer in bilateral collaborations with resource-rich countries to build up their own industry for this. This would allow for beneficial gains on both sides, as countries/geopolitical blocs that have space may not have all the available resources.

For those activities that require more space, at least an adaptive strategy should be followed. From historical transitions in the Port of Rotterdam (and other port/industrial complexes) we also learned that sometimes space frees up rapidly by a decline in current industrial activity, even if an active policy is in place to prevent or slow this down. So having a plan/strategy ready should this occur is crucial, and as outlined before, already being engaged on a smaller scale with alternative developments would help such a strategy.

Crossroads 5: Waiting for higher (state) levels versus a multi-scale governance approach

A recurring theme in dialogues on positioning the Port of Rotterdam in the raw material transition is its dependency on setting the right conditions on higher (state) levels, while at the same time being sceptical about these levels moving quickly enough. If the Port of Rotterdam wants to take a frontrunner role and gain first mover advantage, it should take an approach of 'multi-scale' governance in which all levels move together, or at least not waiting for these right conditions to be all in place. In respect to resource diplomacy, we also discussed that this is not the prerogative of states and supranational organisations.

Thus, whether it is setting up new bilateral supply chain collaborations for CRM throughput and processing, setting up backbone infrastructure for directing large recyclate volumes from all over north-west Europe into the Port of Rotterdam, or kickstarting a full-fledged innovative wood supply chain for the construction industry, the Port of Rotterdam Authority needs to move far outside its comfort zone to create first mover advantages, building upon its experience with regard to green hydrogen, in which the Port of Rotterdam Authority has also taken on new roles. This requires transformative and connecting leadership from the Port of Rotterdam Authority, in the sense of being proactive in different ways (lobbying, connecting, stakeholder management and regarding material flows), as we have seen in the earlier historical transitions of the Port of Rotterdam.

4.2 Ten main actions for the three resource streams

In addition to the strategies to navigate the five crossroads, we conclude by highlighting the ten most important actions resulting from these strategies for the three material streams, as discussed in this and the previous chapters. These actions are centred on the Port of Rotterdam, but the Port of Rotterdam Authority is not the sole actor to execute these actions. Hence, we also indicate the main actors of power for each action.

Action perspective for CMs:
Wood and other biobased materials can become quite important for the Port of Rotterdam because many traditional construction materials could be replaced by wood. This leads us to the following recommendations for action:

1. Create a chain for biobased construction materials, e.g. a wood-based building chain, because such a chain is lacking at the moment. In particular, a sophisticated chain of mass-customisation of wooden components could be a new opportunity for the Port of Rotterdam.
2. Set up long-term partnerships for sustainable forestry to reduce the significant gap between supply and demand for wood. This may take time to build this up, and it may even take longer, perhaps decades, before the forest production capacity can be increased and more yield can be created.
3. Build up a circular infrastructure for wood and biobased materials in order to fully utilise rest streams and process increased wood and biomass import streams. These circular facilities stretch out over a larger area than the Port of Rotterdam itself and need to be implemented in the region around the it. As part of this, it will be essential to establish a biobased and modular wood factory for construction materials. There is a place for several in the Netherlands, but the Port of Rotterdam lends itself to this.

Action perspective for OCs
Europe faces the challenge of increasing the still small-scale green chemical industry and transforming this into a circular industrial complex. Finding enough space for the waste streams and energy, such as green hydrogen, under great uncertainty is a complex puzzle. This has led us to offer the following recommendations:

4. Develop a strategy for dematerialisation because that is the key in organic chemistry for the replacement of oil by biomass. Support the development of new organic chemistry, such as new polymers and more ‘complex’ bio feedstocks. Processing into circular end products requires cooperation between different parties in different places and that needs to get off the ground. Building a secondary bulk goods network for organic chemistry fits into this. This would give the (bio)chemistry a circular boost and increase the willingness to invest in this and create a buyer’s market.
5. Fully commit to recycling, both mechanical and chemical recycling. This might imply the risk that it will only break through and scale up after 2035-2040, but that is part of so-called regret options. Create space and support bi-directional networks in the hinterland, related to chemical recycling, such as using a pyrolysis oil pipeline. Make strategic choices in the use of space, because sustainable organic chemistry takes up more space, just as recycling takes up more space. This requires spatial coordination with other partners far beyond the port area.
6. Take the step towards circularity, which will require a change in mindset. The Port of Rotterdam needs the region, and the region needs the port, which potentially doubles the surface area of the port area. The regional hinterland becomes very important, building up new bidirectional supply chains and secondary commodities. Think of extension in the direction of the Moerdijk port and Greenport (Westland). The added value of this step in terms of creating a new spatial order and a new, circular economy is a major step for the Port of Rotterdam, and can have an immense impact.

Action perspective for CRMs:
Last, but most urgent, through an active strategy for CRMs, the Port of Rotterdam can make a great contribution to the EU's struggle to get out of the 'resource trap' it is currently in as well as developing great opportunities for the port itself:

7. Proactively develop policies for critical materials and do not wait for others. Do seek cooperation where possible; see the analogy with green hydrogen, although this is a lot more difficult and even more geopolitically sensitive. Translate that proactive policy concretely within the organisation. The most effective way to do this is to organise it as a team leading a programme and let it run through the different departments, like a knitting needle. The advantage of this is that a programme cuts across different departments as the hydrogen theme is now being tackled and organised. The disadvantages may be the lack of governance and a lack of focus.
8. As the Port of Rotterdam Authority, proactively collaborate with the national government to drive diplomacy for critical materials and take the lead in international partnerships. Concretely, this raw materials diplomacy can consist of: (a) indirect lobbying, which requires certain skills, especially when it comes to countries in Africa; (b) building equal bilateral partnerships. This takes time, but is very promising on the basis of reciprocity: providing expertise on digitisation, security and sustainability in exchange for access to critical materials; and (c) building up strategic stocks, which is very attractive for Rotterdam because relatively small volumes are involved that require little space, but with great financial and strategic value.
9. Develop a transition strategy for critical materials, for the short, medium and long term. This strategy should not be based on volumes but on added value and diversification in order to spread the risks. At the same time, a focus on specific critical materials is important because each case requires its own approach and strategy. This is underlined by the difference in weight the EU uses of each CRM (see chapter 2, Figure 1). This indicates that each material has different needs in terms of handling capacity.
10. Invest heavily in recycling and reuse to add as much value as possible. Attract companies that specialise in this (reuse of solar panels, wind turbines, batteries, mobile phones) to kick-start the circular economy in the Port of Rotterdam, with the risk that this will not scale up until after 2035, but that is a so-called 'regret option' in the broad portfolio that is needed in a transition strategy.

4.3 The main actors for each action

Not only does the Port of Rotterdam Authority need to make strategic choices, but also other main actors need to actively do so for an optimal outcome for the port cluster. In Table 4, we highlight to whom the actions are most applicable next to the Port of Rotterdam Authority itself. For example, where the Port of Rotterdam Authority can make it more attractive to invest in future business operations, the government should complement this by setting obligatory baseline conditions and requirements for circularity. The Port should actively seek collaboration with the relevant actors for each action, but these actions are also direct recommendations for each of these actors. We differentiate between business organisations (existing and new), the national government in the Netherlands and the regional government (Province of South Holland and/or the municipalities of Rotterdam and neighbouring ones). This is a rough indication, so further steps are needed to explicate and specify the actions and actors in the surrounding network of the port and to map and prioritise those over time.

Table 4. The main actors to act at the crossroads and the ten main actions for the three resource streams. Notes. CMs (Construction Materials), OCs (Organic Chemicals) and CRMs (Critical Raw Materials).

Action	Stream	Business	National government	Regional government
Actions at the crossroads				
1a. Create opportunities for alternative futures with specific second priority fields	All	X	X	X
1b. Reserve space for radical opportunities	All	X		X
1c. Set up integral teams for the resource transition	All	X	X	X
2. Develop additional business models for the Port of Rotterdam Authority	All		X	X
3. Allow 'may regret' approach to investments for a first mover advantage	All	X	X	
4a. Adopt strategies with a limited impact on local land use	All	X		
4b. Develop a strategy/plan that can be implemented if major current industrial activity stops	All	X	X	X
5. Create a multi-scale governance approach	All	X	X	X

Action	Stream	Business	National government	Regional government
10 main actions for the three resource streams				
1. Create a supply chain for biobased construction materials	CMs	X		
2. Set up long-term partnerships for sustainable forestry	CMs		X	
3. Build up circular infrastructure for wood and biobased materials	CMs	X	(X)	X
4. Develop a dematerialisation strategy	OCs/All	X	X	X
5. Fully commit to chemical and mechanical recycling	OCs	X		X
6. Connect with regional hinterland	OCs			X
7. Proactively develop CRM policies and integrate them with the organisation	CRMs	X		
8. Proactively collaborate on CRM diplomacy together with the government and take the lead in establishing international partnerships	CRMs	X	X	
9. Create a focused CRM strategy	CRMs		(X)	
10. Invest heavily in recycling	CRMs	X		X

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