Brightsite Transition Outlook 2022

Detailed background

Brightsite
Transforming industry

Besides this detailed background, a shorter version is also available. You can download this version or request a printed document via www.brightsitecenter.com

1. Foreword and management summary

In 2015, the Netherlands—together with 195 other countries—signed the Paris Climate Agreement to limit global warming to preferably 1.5 Celsius. Global targets and measures to reduce greenhouse gas emissions were then formulated. In the Netherlands, this led to the National Climate Agreement in June 2019, with the now more stringent target of reducing emissions by 60% in 2030 and reducing them to zero in 2050.

The chemical industry, which is active on a large scale in Limburg at the Chemelot site in Geleen, can make a substantial contribution to the achievement of these climate goals, given its size. For this purpose and together with Sitech, TNO and Maastricht University, the Brightsite partnership was set up as an initiative of Brightlands Chemelot Campus in 2019 with the aim of developing and applying innovative technologies. Brightsite's central mission is twofold: to demonstrate that the climate targets at Chemelot can be achieved and to train a new generation of researchers and engineers to put them into practice.

Brightsite Transition Outlook gives an overview of the insights that have been gained about how and when the climate targets can be achieved at Chemelot. In summary, it is clear that the target for 2030 is expected to be achieved largely through measures identified by the companies at Chemelot. However, the zero-emissions target for 2050 will require various new solutions.
The Brightsite partnership is preparing a range of new technology options. To this end, Brightsite has now developed a model-based approach for Chemelot that can be used to test potential options. This has revealed which technologies in the field of electrification and use of green raw materials will need to be developed and applied in order to reach the emissions target for 2050 in an economic and socially responsible way. To a large extent, this will involve relying on the initiatives of and collaboration with (future) external suppliers of renewable electricity and raw materials. To maximize potential outcomes, intensive co-operation with governments is needed. It would be desirable for the national government to take a stimulating and directing role, for instance, by setting up a 'Climate Agency NL'. This kind of initiative could also coordinate cooperation at a European level, especially in the light of the cross-border nature of the climate problem.

Combining the Dutch chemical and high-tech industries with the relevant different supply companies offers opportunities to take a leading international roles and to provide meaningful employment for new generations of employees and researchers.

This Brightsite publication (April 2022) was produced under the direction of Paul Brandts (Brightsite Intelligence Officer) and Dick Koster (advisor) in collaboration with the Brightsite management and the Program Managers. The publication is built from facts and knowledge as of January 2022 and is expected to receive an annual update.

[1] See www.brightsitecenter.com

2. The national and international climate change context and targets

2.1. International context

The link between the concentration of CO_2 and other greenhouse gases in the atmosphere increased over the last 150 years and the acceleration of global warming observed since that time is becoming increasingly pronounced, as illustrated in Figure 2.1.

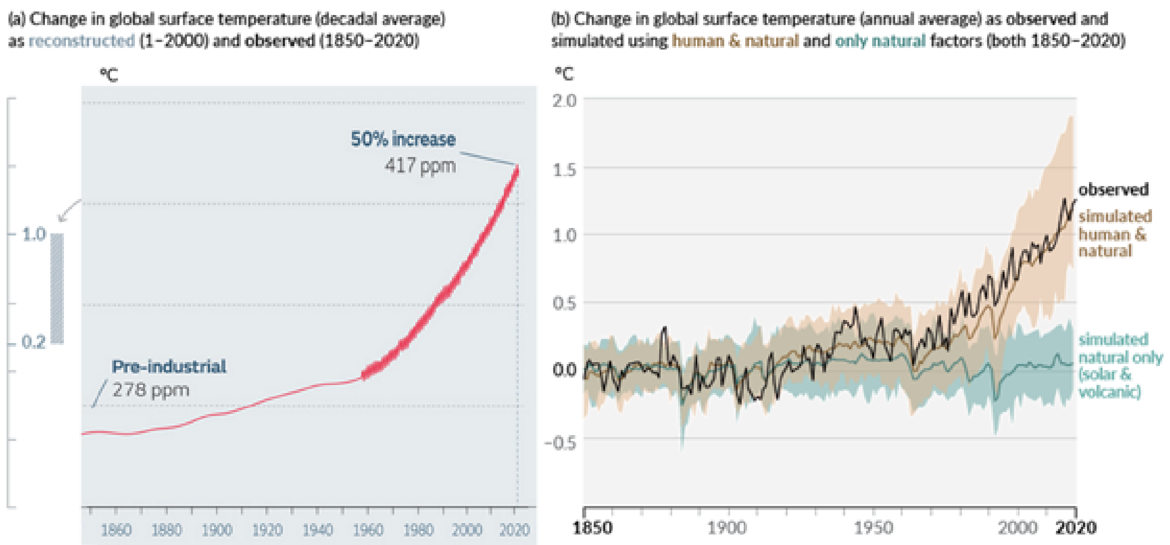


Figure 2.1: Relationship between the increase in CO₂ in the atmosphere due to human activities (left) and global warming (right).

In 2015 and together with 195 other countries, the Netherlands signed the Paris Agreement on Climate Change. The aim of this agreement is to limit global warming to a maximum of 2 degrees Celsius and preferably 1.5 degrees Celsius. It is clear from the recently published Figure 2.2 that if the linear warming observed since 1970 continues, these limits will be reached as early as 2033 and 2059.

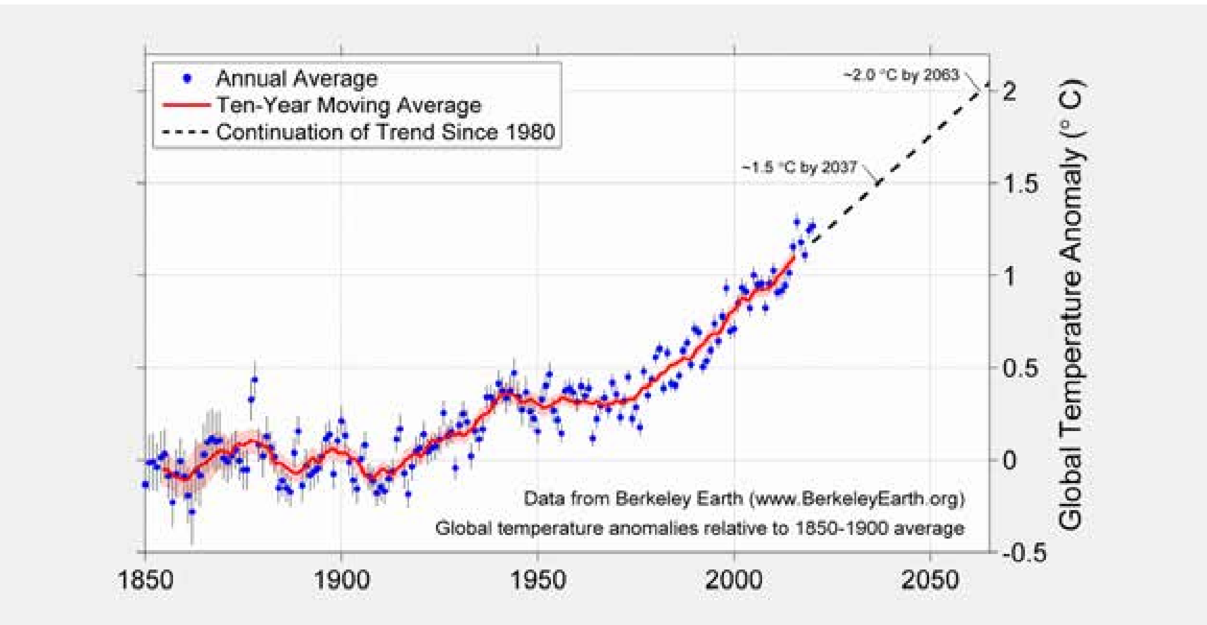


Figure 2.2: Historical and foreseeable global warming (without additional measures)

Globally, governments and businesses have increasingly set targets and implemented measures to reduce greenhouse gas emissions since 2016. In the Netherlands, this led to the National Climate Agreement in June 2019, with the target of 1990 reducing greenhouse gas emissions by at least 60% in 2030, based on the European Climate Law. This is an interim step toward full climate neutrality with 0% net emissions in 2050.

2.2. Differentiation and allocation of emissions

The formulation and implementation of policies and regulations makes a distinction between 3 types of greenhouse gas emissions—scope 1, scope 2 and scope 3—depending on their origin. Scope 1 emissions originate from companies at their own site. Scope 2 emissions are released from external generation of electricity for on-site use. For scope 3, a distinction is made between upstream and downstream emissions. Scope 3 Upstream mainly concerns emissions released outside the company due to the supply of raw materials. Scope 3 Downstream emissions are released outside the company at the end of the lifecycle of products, such as during the incineration of plastic products.

Due to these emissions being generally interrelated, their origin, connection and release are explained in more detail in Appendix 1. The data for 2019 published by Statistics Netherlands is used to interpret the extent of emissions, as economic activity in that year had not yet been distorted by the international coronavirus crisis. This includes the contribution of the activities of Netherlands industry as a whole and the specific contribution of chemical companies at Chemelot.

2.3. Origin of emissions at Chemelot

At the Chemelot site in Limburg, the Netherlands, nearly 4 megatons (Mt)[2] of naphtha produced from petroleum and more than 1 Mt natural gas are used annually for the manufacture of plastic products and fertilizers, producing (in CO_2 eq.[3]) 5.8 Mt CO_2 and nitrous oxide (N_2O) in emissions. These scope 1 emissions contribute approximately 30% to the total greenhouse gas emissions of Limburg and contributes about 3% to total emissions in the Netherlands. Figure 2.3 gives a schematic overview of the mass and energy flows and the associated scope 1, 2, 3 emissions at Chemelot.

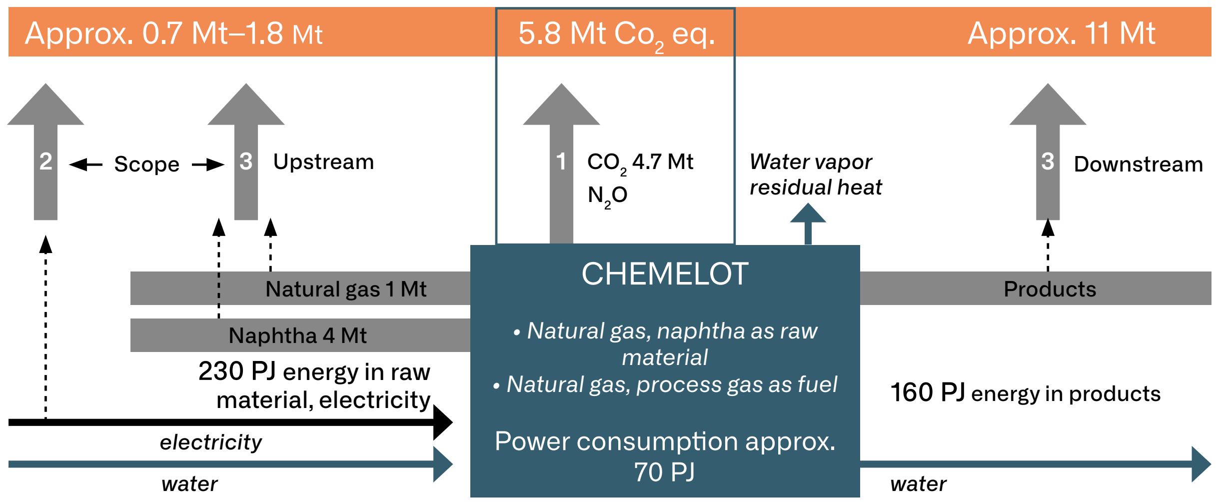


Figure 2.3: Raw materials and energy flows and Scope 1, 2, 3 emissions at Chemelot (2019 emissions and factors)

[2] 1 Mt is 1 million tons. Further referred to as Mt
[3] To add the influence of different greenhouse gases, it is converted to CO_2 equivalent. The emission of 1 kilograms of ni-trous oxide is equal to that of 298 kilograms of CO_2 (equivalent to 298 CO_2 eq.).

This shows that the primary scope 1 emissions of these activities amount to 5.8 Mt CO_2 eq. on an annual basis, but that in addition a total of approximately 14 Mt CO_2 eq. scope 2 and 3 emissions are generated outside Chemelot. Of this amount, approximately 11 Mt CO_2-equivalent, scope 3 Downstream emissions are caused by fossil carbon released after use of plastic (intermediate) products in incineration or processing.

In order to implement the National Climate Agreement, Chemelot has the target of reducing scope 1 emissions to zero in 2050. In addition, Chemelot also aims to replace fossil carbon in the manufactured products. In 2016, the '2025 Vision for Chemelot' expressed the ambition to become the most sustainable and competitive chemical site in Europe in 2025. At the time, in 2018, this vision was supplemented with the target of achieving fully climate-neutral operations by 2050 and becoming the safest site in Europe. The practical steps and projects to be taken to reduce CO_2 emissions by 2030 was outlined in a brochure prepared as part of the implementation of the National Climate Agreement .[4] To coordinate implementation, the companies involved jointly established the 'Chemelot Sustainability Team', which in 2018 mapped the origin of emissions present at Chemelot and the options for reducing them. In addition to the reduction of emissions of scope 1 greenhouse gases, the ambition was formulated to replace at least 1 Mt of naphtha oil and 0.2 Mt of natural gas (equivalent to -20% compared to 2018) with non-fossil raw materials by 2030, which means that some of the products that are ultimately produced can also be manufactured in a 'green' manner. This also reduces scope 3 emissions by more than 3 Mt (equivalent to approx. 25%). For this 'commodity transition', a declaration of intent[5] was signed by government and industry in 2018, which—unlike the climate agreement—has not yet been developed into formal national policies.

As shown in Figure 2.3, the climate impact resulting from the use of fossil raw materials at Chemelot and the ensuing scope 3 emissions generated is much greater than that of scope 1 emissions alone. This also applies to the chemical industry in the Netherlands as a whole. Chemelot's ambition for the total (scope 1+2+3) reduction is in the order of magnitude of almost 20 Mt CO_2 eq. By way of comparison, in 2019 the total amount of emissions generated by the five Dutch coal-fired power plants amounted to 13.9 Mt CO_2 eq.[6] The Chemelot emissions reduction targets for 2030 (3 Mt less scope 1 + 3 Mt less scope 3) are thus comparable to the closure of a modern coal-fired power plant running full-time. Achieving the ambition of zero emissions by 2050 is comparable to the additional closure of two more such power plants.

[4] "We have more than just a plan," Chemelot brochure, May 2018
[5] https://www.rijksoverheid.nl/documenten/rapporten/2017/01/24/grondstoffenakkoord-intentieovereenkomst-om-te-komen-tot-transitieagenda-s-voor-de-circulaire-economie
[6] https://nl.wikipedia.org/wiki/Kolencentrales_in_Nederland. A coal-fired power plant producing 0.8 GW of electricity and with an efficiency of 40% in electricity consumes about 2 Mt of coal annually while emitting 6.5 Mt of CO_2.

2.4. The Brightsite Innovation Program

Enabling the innovations needed for the energy and commodity transition will require much more extensive research, development, scaling-up and coordination with stakeholders on and around Chemelot. For the support and implementation of the required developments, the Brightsite partnership was established at Chemelot in 2019 as an initiative of Brightlands Chemelot Campus with Sitech, TNO and Maastricht University. The Brightsite program is not exclusively focused on greenhouse gas emissions at Chemelot, but also addresses the relevant safety, developments and (climate) impacts involved for suppliers of raw materials, product consumers, societal stakeholders and governments. A tailor-made educational program is also being used to train a new generation of researchers and employees needed to achieve these aims. Structural funding has been provided by the partners, Chemelot companies and the province of Limburg, while the innovation and educational program is to be coordinated and implemented by Brightsite. The activities carried out by Brightsite, and the resulting insights, are explained below.

Figure 2.4 provides a schematic overview of the structure and integration of the various components of the Brightsite program. This shows that the technological innovations for further reduction of greenhouse gas emissions come from the sub-programs in the areas of electrification (1), substitution of raw materials (2) and process and site innovation (3). It is also evident that the development and application of the necessary innovations are based on appropriate training of researchers and employees (6). In addition, it has been indicated that technical innovations are only useful if they are developed and applied in a safe and socially acceptable way (4). The sum total of the possibilities and impossibilities arising from the aforementioned programs will determine the integrated transition scenarios developed in program (5) that are necessary to achieve the more far-reaching emissions reductions in a timely, economically and socially responsible manner.

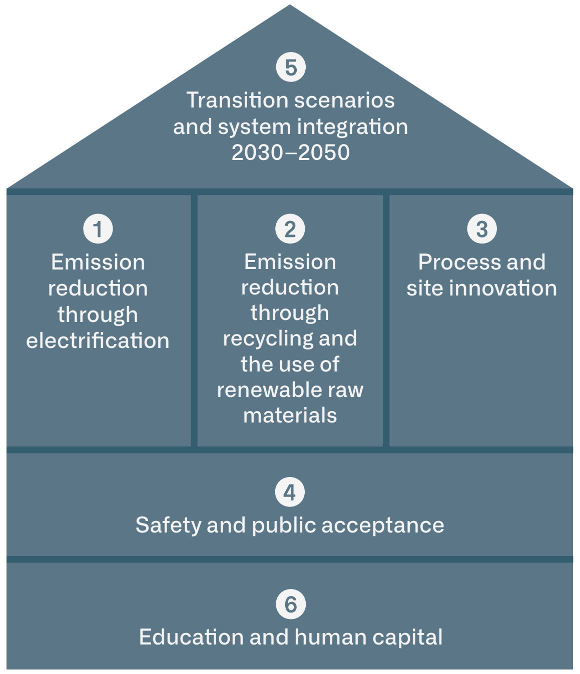


Figure 2.4: Integration of Brightsite program lines

In Chapter 4 we discuss the insights that Brightsite has now acquired and the main lines and focus of the innovation program. More detailed and updated background information is available on the Brightsite website, www.brightsitecenter.com.

[7] See www.brightsitecenter.com

3. Chemelot in transition

3.1. .Chemelot: Past, current situation and options to 2030

The figure below shows the structure of the previous, current and future evolution of scope 1 greenhouse gas emissions at Chemelot.

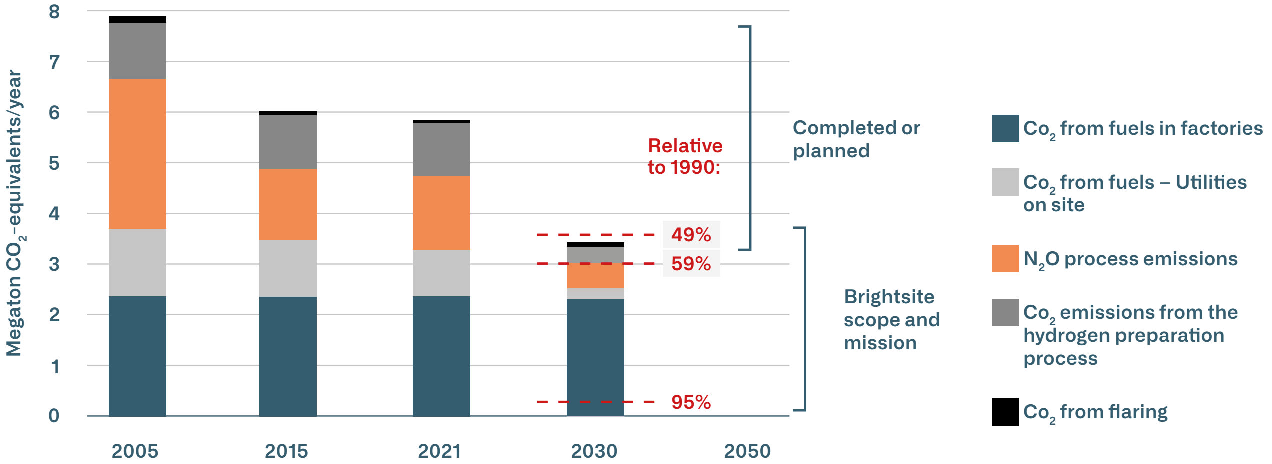


Figure 3.1: Origin and options for reducing Scope 1 greenhouse gas emissions at Chemelot..

It shows that emissions at Chemelot have been significantly reduced since 2005, particularly by measures to reduce N_2O emissions. To achieve the 2030 targets, **Fibrant** has now made an in-vestment of over EUR 40 million to further reduce the N_2O emissions associated with caprolac-tam production by over 0.67 Mt CO_2 eq. In addition, **AnQore** is preparing to make an investment that will see N_2O emissions from acrylonitrile production reduced by 0.4 Mt CO_2 eq. by 2030. Together, these measures will result in a further reduction of over 20% in Chemelot's current scope 1 emissions. The only other realistic option for reducing Chemelot's scope 1 significantly further before 2030 is in CO_2 capture, transportation and storage. The most appropriate source of emissions is the CO_2 released from the current production of hydrogen from natural gas, which is used in the production of ammonia, fertilizer and melamine by OCI. In the process currently used by OCI, the production of approximately 200 kilotons of hydrogen releases approximately 1 Mt of CO_2 in pure form each year, accounting for almost 20% of Chemelot's total scope 1 greenhouse gas emissions. Given the time frame in which alternative options are realistically possible, **OCI**, with the sup-port of Brightsite, has prepared a plan to capture 0.5 Mt CO_2 per year (about 50% of the total) as an interim solution, and to transport it in liquid form by ship via the river Meuse to Europoort for storage under the seabed of the North Sea. At a later stage, this transportation could possibly be done by pipeline. The capture, transportation and storage of CO_2 under the seabed (of the North Sea) is technically possible, but for the time being social and political support is not unan-imous. In the short term, however, OCI has no other solutions for limiting emissions that are compatible with present operations at Chemelot. In the medium term, OCI expects that an in-creasing proportion of the hydrogen needed can be purchased from producers employing pro-cesses with a lower net CO_2 emission. One of the first options may be the preparation of an in-vestment of about EUR 600 million by **RWE** at Chemelot for the construction of a gasification plant that can produce about 40 kilotons of hydrogen annually, by processing residual waste (originating from Limburg). Although pure CO_2 will also be produced, it is not based on fossil fuels and can also be collected, transported and stored. This could potentially make a significant contribution to the reduction of the scope 1 greenhouse gas emissions from Chemelot and could conceivably even result in negative emissions. In the distant future, connection to a national or international hydrogen network—preferably fed by hydrogen generated with sustainable energy—could offer additional options for meeting the hydrogen demand at Chemelot in a climate-friendly way.

The government has recently made its 2030 targets more stringent. This is expected to lead to a faster rise in the CO_2 charge, which the government imposes on industry to promote a reduction in greenhouse gas emissions. With support from Brightsite, additional energysaving measures currently under assessment could be implemented at Chemelot to meet the new 2030 targets.

3.2. Options and prerequisites for achieving the 2050 targets

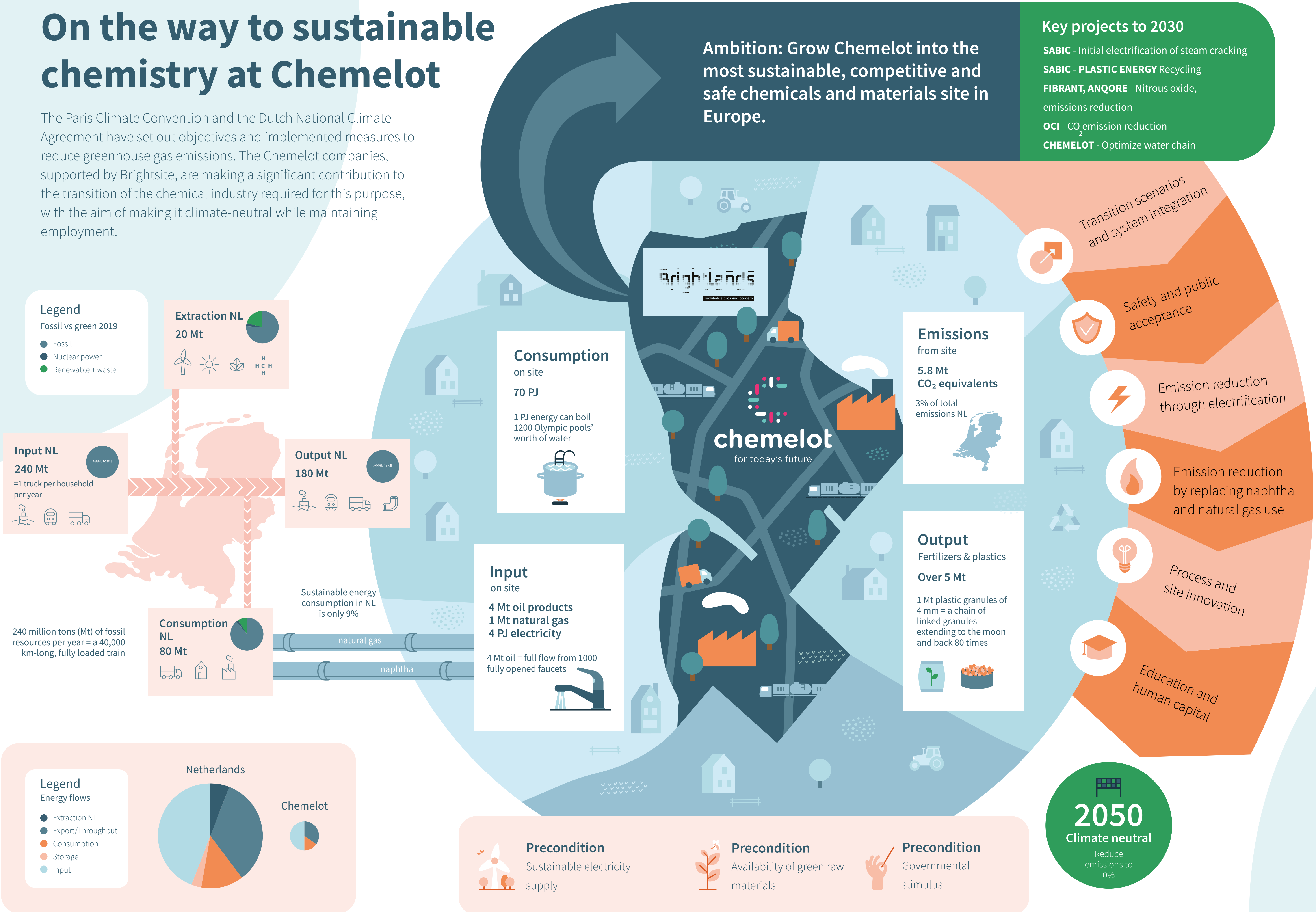
Based on the above-described and additional measures, Chemelot is expected to achieve the 2030 climate target for reductions of greenhouse gas emissions. However, it is also clear from Figure 1.2 that to achieve the 2050 targets, significant further reductions in CO_2 emissions are required. To this end, the current large-scale combustion of natural gas and process methane—released during steam cracking—will have to be phased out at Chemelot. Alternative options are technically conceivable for this purpose, but they can only be meaningfully developed and applied if sufficient and affordable renewable electricity becomes available for this purpose in good time. Chemelot only has a very limited ability to generate the required sustainable (CO_2-free) electricity on the site itself and is therefore dependent for its energy transition on (timely) investment and security of supply from external energy producers and grid operators.

In addition to the energy transition described above, which limits scope 1 and 2 emissions, a further reduction of scope 3 emissions can be achieved by a commodity transition, which would mean finding alternatives for current fossil raw materials. For the use of natural gas as a raw ma-terial for the production of hydrogen at Chemelot, sustainable alternatives are also conceivable in the longer term if 'green' methane from non-fossil carbon sources is used instead. In addition, it is possible to further scale up or import the production of hydrogen from waste by connecting Chemelot to a national or international hydrogen network. Along the way, natural gas and pro-cess methane from steam crackers are also expected to be converted to hydrogen and building blocks for the plastic value chain (i.e. acetylene, ethylene) using new plasma technology cur-rently being developed at Brightsite. The replacement of fossil naphtha as a raw material requires the timely availability of large quantities of alternative non-fossil raw materials. This commodity transition makes a major contribution to the broader societal transition to a circular economy, which aims to use as few new fossil raw materials as possible. This can be achieved by recovering carbon-containing product wastes for use as feedstock through mechanical and/or chemical conversions and supplementing them with bio-based raw materials, where necessary. However, this will require the availability of large quantities of carbon-containing waste and/or bio-based raw materials and the development of new processes.

Brightsite
Transforming industry

On the way to sustainable chemistry at Chemelot

The Paris Climate Convention and the Dutch National Climate Agreement have set out objectives and implemented measures to reduce greenhouse gas emissions. The Chemelot companies, supported by Brightsite, are making a significant contribution to the transition of the chemical industry required for this purpose, with the aim of making it climate-neutral while maintaining employment.



4. Options, choices and prospects

4.1. Introduction

As indicated in Chapter 2, Chemelot requires both an energy transition and a commodity transition to reduce Chemelot scope 1 emissions in 2050 to zero (as well as at similar industrial sites). This also applies to the Chemelot scope 3 Downstream emissions, for which government policy has yet to be developed. In Chapter 3 that the main technological pillars for this were briefly described as being supported by the use of (renewable) electricity and circular (re)use of non-fossil starting and waste materials. In order to apply these changes in a safely and economically responsible way and to obtain the required product quality on that basis, many associated sub-processes will undergo changes. Collectively, these changes will ultimately lead to a complete transition at the Chemelot site and the way in which industrial-scale chemical processes are operated in the second half of the 21st century.

The following sections discuss in more detail the background and perspectives of the technological, social and educational leads identified by Brightsite. Where possible, sections include both a quantitative indication of the actual prospects for reducing emissions at Chemelot and the anticipated specific contribution to this by the implementation of the Brightsite program.

4.2.Electrification

4.2.1. Chemelot options

Electrical heating of plants

In view of the high availability and until recently relatively low costs, natural gas is currently being used on a large scale in the chemical industry for steam production and the heating of processing plants. At Chemelot, the combustion of natural gas generates more than 2 Mt of CO_2 annually. Given the relatively low concentration of CO_2 in the combustion gases, CO_2 capture and storage is not technically or economically feasible. However, just as in the domestic sphere, these CO_2 emissions can be avoided if electrical heating is switched to (sustainably generated) electrical energy. Based on an inventory carried out by Brightsite, electrification options have been identified for the short and (medium- to) long term which would reduce the scope 1 greenhouse gas emissions at Chemelot by about 40% compared to 2015.
A first, but still modest, step will be made in the short term with regard to the production of steam. For this purpose, an investment of EUR 6 million has been prepared by **USG**— which provides the production, distribution and supply of electricity, steam and gases at Chemelot—for the commissioning of an electric steam boiler plant that will deliver a reduction of 9 kilotons of CO_2-eq. emissions per year, from 2023.

For a much larger reduction in CO_2 of approximately 1.6 Mt, Chemelot should switch to electrical cracking of naphtha (or replacement non-fossil raw materials) to produce the precursors for polyethylene and polypropylene manufacturing. This will require the development of a whole new generation of cracking plants with investments of more than EUR 1 billion. This challenge has been taken up jointly by various international consortia in recent years. To this end, **SABIC**, a Chemelot-based company collaborates with BASF and Linde,[8] as well being an active member of a consortium in the Netherlands that since 2020 has included Dow and Shell[9]. This topic has also been on the European agenda of the "Cracker of the Future" Consortium since 2018, in which **Borealis, Total, Repsol** and **Versalis** work together[10]. Given what is still needed for the development and construction of this new generation of cracking plants at Chemelot, the resulting potential reduction in emissions cannot be expected before 2040.

[8] https://www.basf.com/global/en/media/news-releases/2021/03/p-21-165.html
[9] https://corporate.dow.com/en-us/news/press-releases/dow-shell-electric-cracking-technology.html
[10] https://insights.globalspec.com/article/17484/new-cracking-tech-to-decarbonize-olefin-production

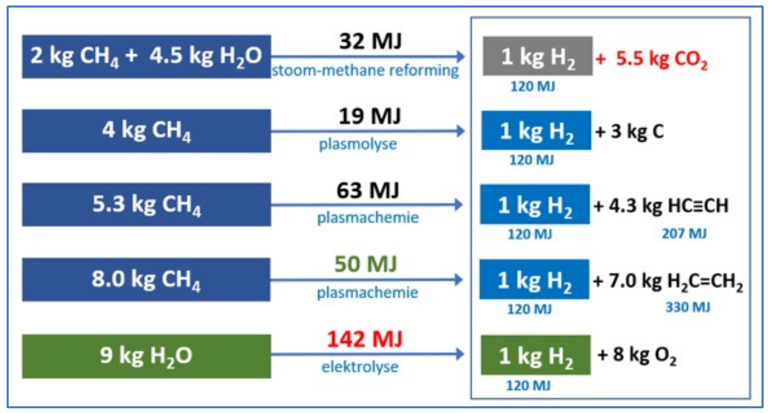
Electrical production of hydrogen

In addition to being a source of energy for heating, **OCI** uses large-scale natural gas as a feedstock in the production of hydrogen at Chemelot, as described in Chapter 3. The process currently in use releases a large amount of CO_2 as a process gas[11] which, as shown in Figure 3.1, accounts for almost 20% of Chemelot's total greenhouse gas emissions. In principle, hydrogen can be produced without CO_2 using water with commercially available electrolysis technology, if renewable electricity is used to do so. However, because hydrogen in water is strongly bonded to oxy-gen, this requires a relatively large amount of electricity. Given the still limited availability and cost price of hydrogen produced in this way, it is not yet a viable alternative for Chemelot. One potentially more efficient alternative that has been explored by Brightsite is the production of hydrogen from methane without CO_2 emissions using electrically powered plasma technology.

4.2.2 Brightsite focus

The feasibility study carried out by Brightsite showed that it is possible to release hydrogen from methane without the formation of CO_2 using plasma technology. A plasma consists of a gas in which particles of high energy are present, such as those formed naturally in flames and lightning bolts. For artificial and controlled generation of plasmas, several electrically powered methods have been developed and are available on an industrial scale. These can be used to process materials and surfaces or to activate chemical processes in a reactor. The formation of a plasma does not require oxygen. Compounds containing carbon such as methane therefore do not burn and can be converted into compounds valuable to the chemical industry such as hy-drogen and acetylene or ethylene, without the formation of CO_2. As a result, the value of the carbon present in natural gas (or methane from cracking processes) is no longer released as CO_2 through emissions into the atmosphere.
Due to the weaker bonding of hydrogen in methane, its release, compared to the electrolysis of water described above, requires about 85% less energy. If products other than carbon are formed directly, although more energy is required, more valuable by-products such as acetylene or ethylene are formed in addition to hydrogen. Figure 4.1 gives an overview of the energy required to produce hydrogen from methane and water with the currently applied SMR[12] and possible alternative electrolysis and plasmolysis processes.

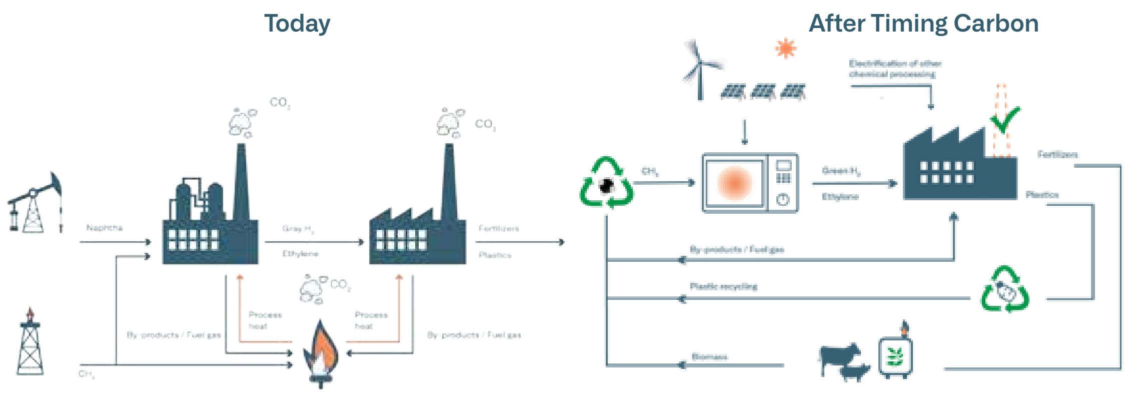
Figure 4.1: Comparison of energy required for production of hydrogen from methane and water with currently applied (SMR) and possible alternative electrolysis and plasmolysis processes.



[11] The reaction $CH_4 + {}_2H_2O \rightarrow CO_2 + {}_4H_2$ produceert CO_2 produces CO_2 as reaction product: process gas. In addition, CO_2 is created as natural gas is burned to provide the energy required for this reaction: this is flue gas. Both fall within Scope 1. Electrification of SMR only eliminates flue gas.
[12] **S**team **M**ethane **R**eforming

At Chemelot in particular, plasma technology could conceivably be used to produce both hydrogen for **OCI** and ethylene for **SABIC** from methane, with the associated synergy and economies of scale. As a source of methane, (CO_2-free) natural gas can be used for the time being, but this route also offers an alternative use of the methane generated (inevitably)—around 15% of which is formed as a process gas in the cracking processes described above. At present, this process gas, together with fossil natural gas, is burned to heat the cracking process with the associated CO_2 emissions. Future electrification of the cracking process may potentially create a large surplus of methane on Chemelot, which can be converted into valuable products for the chemical industry using a plasma process, without CO_2 emissions. Clearly, this can contribute greatly at Chemelot to the economic applicability of the electrical cracking process envisioned by SABIC. The possible transition at Chemelot is shown schematically in figure 4.2.

Figure 4.2: Schematic representation of the transition to a CO_2-free, circular chain based on plasma technology.



For deeper research, the 'safe by design' development and upscaling of the plasma process and exploration of related potential applications at and outside Chemelot, **Maastricht University** has established a new **Chair in Plasma Chemistry**, to which Professor Gerard van Rooij was appointed in May 2021[13]. To carry out the experimental research, the Brightsite partners have formed a joint plasma technology group, and a dedicated plasma lab was opened **at Brightlands Chemelot Campus** in November 2021. The research program and associated facilities focus on three complementary innovation and application windows to 2050. Both the fundamental possibilities as well as the applicability and related scaling up and application of plasma technology will be investigated on this basis.

4.2.3 Impact at Chemelot

Electrification of the various heating processes and the production of hydrogen, combined with energy savings, will enable Chemelot to achieve an almost complete reduction in the current scope 1 CO_2 emissions generated by these operations. Based on this, Chemelot's total scope 1 greenhouse gas emissions could fall to 0.4 Mt CO_2 eq. by 2050, which would mean a 95% reduction compared to 1990. Conversion of methane using plasma technology is seen by Brightsite as a potentially game-changing technology, which could reduce the current CO_2 emissions of the chemical industry, while also keeping carbon within the loop of a circular economy. Plasma technology may also make it possible to convert not only methane, but also carbon-containing naphtha and waste plastic in an economically feasible way. In addition, this technology is a potentially applicable alternative for reducing greenhouse gas emissions from industrial nitrogen chemistry. The plasma-activated formation of HCN is thought to be a building block for ABS and other nitrogenous plastics used in high-grade applications. The formation of ammonia (NH_3) and NO_x as a raw material for fertilizer is also possible, as well as the conversion of waste streams containing NH_3. Given the nature of the innovations, there are additional opportunities for the development and industrial application of plasma technology by linking Chemelot to the internationally leading Dutch, high-tech industry.

[13] https://www.maastrichtuniversity.nl/nl/nieuws/benoeming-profdr-gerard-van-rooij-tot-hoogleraar-plasma-chemistry

Replacing the current use of natural gas and methane from the cracking process and the production of hydrogen at Chemelot with electrification will require very large amounts of electricity, which are not available or foreseeable at present. Production, transmission and use of the 0.7–1.7 gigawatts[14] of electricity required annually will require large-scale investments in power generation, transmission connections and related infrastructure both at and outside of Chemelot. A national approach is needed to meet these and similar electricity needs in other (pioneering) industrial regions in a timely and sustainable way. If sufficient electricity is ultimately available in time, the scope 1 greenhouse gas emissions at Chemelot can be significantly reduced. The CO_2 emissions associated with the generation and transportation of electricity are calculated as scope 2 emissions for Chemelot. This portion of the scope 1 emissions is for the Netherlands as a whole. To avoid a waterbed effect—whereby Chemelot's scope 1 emissions decrease but increased outside the site—the generation of the required electricity should cause the lowest possible emissions and thus be generated sustainably and as free of CO_2 equivalents as possible.

4.3. Replacement of fossil resources

4.3.1. Chemelot options

Ambition for scope 3 emissions

As explained in Chapter 1, the National Climate Agreement's mission at Chemelot is strictly limited to reducing the scope 1 emissions generated by the on-site companies' own product manufacturing. The much larger scope 3 emissions associated with the extraction and transportation of fossil raw materials, as well as the use and eventual disposal and incineration of products manufactured with them, are not included. However, given the associated climate impact and increasing consumer awareness, the companies at Chemelot and in the Brightsite program are also explicitly addressing opportunities to reduce scope 3 emissions. The basis for this is provid-ed by use or reuse of plastic or household waste and bio-based raw materials. In view of their origin, the use or reuse of these raw materials does not lead to a net increase in CO_2 and does not count as scope 1 emissions. Despite these clear 'green' climate effects, the use of plastic waste the chemical applications is still under discussion because of the associated (road) trans-portation and the possible nuisance of odor and vermin caused by storing large quantities of (contaminated) waste.
To be usable as a fully fledged substitute, these alternative basic materials must often be converted at high temperature into liquid and gaseous products, which are usable in current processes as an alternative raw material or feedstock[15]. The activities carried out in the context of this commodity transition and the possible impact on the scope 3 emissions at Chemelot are explained below.

Reuse of plastic waste

Various complementary technologies are being developed for the reuse of plastic waste. The common denominator here is that the (re-)usable components are first separated by means of a mechanical process and, where necessary, chemically converted to obtain the required purity and quality. For the reduction of the current use of naphtha produced from fossil oil, **SABIC** and **Plastic Energy** have laid the groundwork for the construction of a pilot plant at Chemelot based on an in-vestment of about EUR 200 million[16]. This will allow 20 kilotons of plastic waste to be reused on an annual basis as raw material for the manufacture of polyethylene, polypropylene, PVC, elastomers and acrylonitrile. To put this important first step into perspective, it should be stated that scaling up by a factor of 200 will be necessary to replace the current use of fossil naphtha. One foreseeable limitation here is that many other applications and candidates are conceivable for this type of large-scale use of plastic waste[17], which means that the future market

[14] Chemelot Cluster Energy Strategy (CES Chemelot), March 31, 2021
[15] What are referred to as commodity chemicals, produced and used by the chemical industry worldwide in large quantities and of a standard quality.
[16] https://www.sabic.com/en/news/26247-sabic-and-plastic-energy-set-to-start-construction-of-pioneering-advanced-recycling-unit

will be limited in this respect

Use of bio-based raw materials
In addition to the recycling of plastic waste, the use of CO_2-neutral, bio-based raw materials is one of the most eligible alternatives. Bio-based raw materials are harvested from woody or plant materials formed naturally or produced through environmentally conscious agricultural practices. Currently, these products are burned as biomass in power plants or converted to ethanol as an additive for automotive fuel. This short-cycle use of bio-based raw materials as an alternative fuel has been encouraged by the government, given its scope for short-term reduction of fossil fuel emissions. While using bio-based raw materials as fuel is "green", it also has relatively high CO_2 emissions as well as the societal and climatic impacts of its production and transportation—factors that have resulted in it recently coming under increasing public and political pressure, and in the phasing out of subsidies. However, the use of bio-based raw materials as alternative feedstock to replace fossil petroleum and natural gas in the chemical industry offers much more sustainable opportunities, as it can be combined with recycling of the products to be manufactured based on them. This, in principle, allows 'biogenic' carbon to be sequestered for a very long time in the products manufactured with it. In view of this positive perspective, a great deal of effort has already been made by the chemical industry and its suppliers. Various sources and technologies are available or in development for the use of bio-based raw materials[18].

CO_2 as raw material
An ultimate but probably very long-term solution for replacing current fossil raw materials is to create alternative raw materials from CO_2 and sustainably produced hydrogen. Commercial technology is available to do this, but it requires a great deal of renewable energy and can therefore only[19] be used for demonstration projects for the time being. As more and cheaper renewable energy becomes available, the scope for application will widen. In the distant future, it may also be possible to convert CO_2 extracted from the atmosphere, which in principle could bring about full circularity in the use of non-fossil raw materials.

4.3.2. Brightsite focus

Pretreatment of plastic waste
Given the state of the art and outlook for applications, the Brightsite program is primarily focused on the development of pretreatment methods to make mixed and/or contaminated plastic waste streams or biomass (more) suitable as an alternative raw material. At Chemelot, this will require a larger proportion of the waste streams to be made suitable, particularly for SABIC's polyethylene production processes. The conversion takes place with so-called pyrolysis processes which converts plastic waste at high temperature into a 'green' oil that can be used as a replacement for fossil naphtha. Only a small part of the currently available plastic waste is directly suitable for conversion into pyrolysis oil for a naphtha cracker. A larger stream of (sorted) plastic waste, while containing much usable plastic, is mixed with too much other plastic materials and contamination to be suitable for the above application. Brightsite is working on the development of pretreatment methods to recover and separate useful and valuable components from plastic waste. Given the fundamental questions involved, an academic collaboration was started in 2020 with the group of Prof. Weckhuysen at **Utrecht University**. To further enhance this research area, a new **Chair in Circular Engineering** at **Maastricht University** has been established, to which Prof. Kim Ragaert was appointed in September 2021[20]. In addition to this, the extent to which plasma technology could be used for plastic recycling in the distant future will also be investigated. An initial literature study on this subject has been completed and will be translated into a closer assessment of an initial concept for such a process in 2022.

Use of bio-based raw materials
With regard to the use of bio-based raw materials, Brightsite completed an initial study in 2020 to map out the various potential applications at Chemelot. On this basis, further research will be carried out into the extent to which the use of bio-based raw materials for the production of hydrogen for **OCI** and bio-based naphtha for **SABIC** can contribute to the greening of other product chains at Chemelot. As part of this, **Fibrant** is exploring the possibility of "greening" the approximately 500 kilotons of phenol used annually as a raw material for nylon production through the use of biomass-derived alternative feedstock. Any follow-up studies will involve explicit collaboration with organizations specifically focused on the application of bio-based raw materials.

Conversion methods
Gasification hand pyrolysis techniques are being adapted and developed by various external parties for the conversion of waste materials and bio-based raw materials into gaseous and liquid precursors that can be used at Chemelot. Brightsite keeps in touch with these developers in order to stay informed of the practical applicability at Chemelot. Where necessary and possible, Brightsite will contribute to tests on an industrially relevant scale and the technical modifications required to achieve this. Here too, Brightsite evaluates and quantifies the impacts in terms of the effect on scope 1, 2 and 3 emissions at Chemelot and in the Netherlands, as well as associated climate impact.

4.3.3. Impact at Chemelot

Currently, for the production of plastics, Chemelot processes approximately 450 tons per hour of naphtha produced from fossil oil, which is supplied by pipeline from refineries in Europoort and Antwerp. Brightsite has ascertained that the associated scope 3 greenhouse gas emissions can, in principle, be fully reduced in 2050 through the (re)use of waste and bio-based raw materials. However, the amount of waste and bio-based raw materials available for this purpose in the Chemelot region are by no means sufficient or suitable for achieving this at Chemelot, either logistically or economically. In addition, there are several sites in the Netherlands and neighboring countries that are expected to make increasing use of these alternative raw material sources to make a similar transition. At Chemelot, however, insight can be gained into safety, health and societal aspects, and experience can be gained through the development and production on the pilot-project and demonstration scale. The ultimate, large-scale conversion of waste and bio-based raw materials will have to be carried out largely off-site, as is currently the case for the refinement of (fossil) crude oil. Reuse of CO_2 may also be considered in the future. To organize and implement this—as with the sustainable electrification infrastructures—new partnerships, initiatives and direction on an national and international scale are required. Chemelot can play a prominent role here on a European scale, given its combination of an industrial site and innovative campus. The **Chemelot Circular Hub**[21] initiative was established in 2021 in order to jointly adopt this role together with partners in the Chemelot region, as is outlined in Appendix 2.

17 For example, see https://www.vemw.nl/Nieuwsoverzicht/2021-05-20-Buisleidingen-ARRRA-Chemelot.aspx for Chemelot's position in the Northwest European ARRRA cluster for chemicals and materials
18 https://www.shell.nl/media/venster/shell-bouwt-grote-installatie-voor-biobrandstoffen.html
19 https://www.wattisduurzaam.nl/32692/energie-besparen/transport/drie-badkuipen-verkiezingskerosine-graag
20 https://brightsitecenter.com/kim-ragaert-joins-fse-as-the-new-chair-of-circular-plastics
21 Zie https://www.chemelotcircularhub.com

4.4. Process and site innovation

4.4.1. Chemelot options

The integrated site of the future

At Chemelot, 17 independent companies with approximately 60 factories are currently in operation. The extensive integrations dating from the DSM period extend to both the processing plants they use and the related management of energy, raw material, product and residual flows, and are still in place. This sets Chemelot apart from most other chemical sites and, by comparison, it can make better use of the integration and efficiency of the separate activities. The energy and raw materials transitions described in the previous paragraphs, as well as the changes required for this on and off site, require an integrated and coherent approach. Chemelot is therefore ideally suited as an incubator and testing ground for innovation initiatives. In addition to the programs relating to the electrification and non-fossil raw materials described above, the Brightsite program has a third integral process- and site-oriented innovation pillar. This process- and site-innovation program focuses on the identification and development of "site qualifiers" that will enable Chemelot to distinguish itself in the future as the safest, most sustainable and efficient site in Europe and thus become attractive to investors in the large-scale roll-out of sustainable technologies on the site. Brightsite is working closely with **Business Development at Chemelot** and with **Brightlands Chemelot Campus**. Topics that have been addressed to date are outlined in more detail below.

Reduction of process emissions

In order to determine the possible emission reduction of CO_2 and other greenhouse gases, the Brightsite program has mapped out options for modifying the current processing plant at Chemelot and drawn up recommendations to facilitate the choice between possible alternatives. The application of more far-reaching options for the capture and storage of CO_2 depends mainly on the availability of infrastructure for transportation from Chemelot via external pipelines. Due to the provincial and national impact, availability of this is largely dependent on external decision-making and consortium formation. In terms of using CO_2 as a raw material, it has been established that this would require such a large amount of additional electricity that it is unrealistic, over and above the currently projected demand for electrification. Similarly, it has been found that the further development of technology to prevent the formation of N_2O is not worthwhile, given investments already made and planned. Finally, it has been established that at a later stage—when less steam is needed at the site due to electrification—a significant reduction in CO_2 emissions at Chemelot will still be possible through the conversion or reuse of residual gases.

Use of residual heat

As shown in Figure 2.3, at Chemelot, 70 petajoules (PJ)[22] of residual heat is currently emitted annually at Chemelot through the emission of mainly low-temperature flue gases, heated air and water vapor. In principle, it is technically possible to use some of this residual heat both at Chemelot and in its vicinity. However, in view of the measures that would have to be taken to implement this at the Chemelot site, the resulting net reduction in scope 1 emissions would barely be profitable or would not be profitable at all. Off-site use of this residual heat for households and businesses could lead to a significant reduction in current emissions if it were used for district heating.

Watermanagement

Large quantities of process and cooling water are required for the performance of current processes in the chemical industry. At Chemelot this involves, per year, 44 million m^3 of river Meuse water pumped from the Juliana canal and purified on site. After use, any impurities on site at Chemelot are removed in the **IAZI**-managed water treatment plant. Purified cooling and process water (28 million m3)—the quality of which complies with the environmental permit—is then discharged into the surface water of the river Meuse. Additionally, due to evaporation in the cooling towers, approximately 30% of the water taken in is released into the atmosphere as high-purity water vapor. As part of the energy and raw materials transition, several new processes will be introduced and a number of existing ones will be phased out by 2050, in order to meet the greenhouse gas emission targets. Continued compliance with environmental standards will require constant attention to controlling the resulting impacts on the volume and quality of wastewater.

Process digitization

Digital technology already plays a crucial role in the chemical industry in controlling processes and monitoring the safety and quality of plants used for this purpose. In view of the exponential developments in the field of digital technology, more far-reaching digitization options are continually emerging at an increasingly rapid pace. In particular, the development of artificial intelligence to access and interpret digital information without human intervention offers new and currently unused opportunities. In addition, there are new developments in the mathematical description and modeling of complex systems, like those of an integrated chemical site such as Chemelot. These developments can potentially be used to minimize emissions and optimize operations per process, per company and as a whole site in what will be a more dynamic supply of (renewable) energy and raw materials in future.

4.4.2. Brightsite focus

After the orientation phase, based on the available information, insights and urgency, the focus of the activities of this part of the Brightsite program will be primarily to improve current and future water management at Chemelot. Given a recent tightening of environmental requirements, a specific program has been set up by Brightsite in cooperation with **IAZI** and **regional water authorities** to meet future standards in a timely manner, and to achieve possible savings in water use in the process. The level of ambition for this program is to completely eliminate the need to discharge water. Due to the lack of appropriate government policy to stimulate the use of industrial residual heat outside the Chemelot site, this option is not yet of interest to the companies at Chemelot. However, Brightsite will endeavor to improve this situation in consultation with the relevant stakeholders and suppliers. An example of this is the option of storing, transporting and releasing heat using a heat battery based on salt (de)hydration technology, as currently developed for smaller-scale applications by the TNO-TU/e spin-off **Cellsius**[23].

In the area of digitization, Brightsite is conducting a further exploratory study to identify the most relevant opportunities for Chemelot in the context of the energy and raw materials transition. Figure 4.3 shows the various steps currently planned for the development and application of the process and site innovation technologies at Chemelot, as described above.

[22] Om een indruk van deze hoeveelheid energie te geven: het gemiddelde jaarlijkse aardgasverbruik van bijna 20 000 woningen komt neer op 1 PJ energie uit aardgas. Echter lang niet alle 70 PJ van Chemelot afgevoerde residuele warmte heeft een zodanige kwaliteit (tem-peratuur) dat die in aanmerking komt voor stadsverwarming.
[23] https://cellcius.com

4.4.3 Impact at Chemelot

With regard to CO_2 and N_2O emissions, the measures already foreseen by the site users are expected to lead to a reduction of 1.5 Mt CO_2 eq. For the reuse of the current 70 petajoules of residual heat on Chemelot, approximately 10% is eligible on the basis of information and in-sights currently available. To this end, the technical-economic aspects of possible alternatives to the current, standard use of cooling towers and their impact on the heat and energy balance of Chemelot will have to be identified. The use of residual heat in the built environment will not lead to a reduction of scope 1 emissions at Chemelot, but it can save around 0.17 Mt CO_2 of scope 1 emissions in the Netherlands outside the built environment.
Investment in digitization can help reduce greenhouse gas emissions through improved efficiency of current and future processes. The additional significance of this contribution for Chemelot as a whole is not yet known at present. It depends on the degree of automation and process control in each plant. Brightsite will carry out a further inventory in cooperation with the companies involved. More generally, the further development of Chemelot is unthinkable without research into and

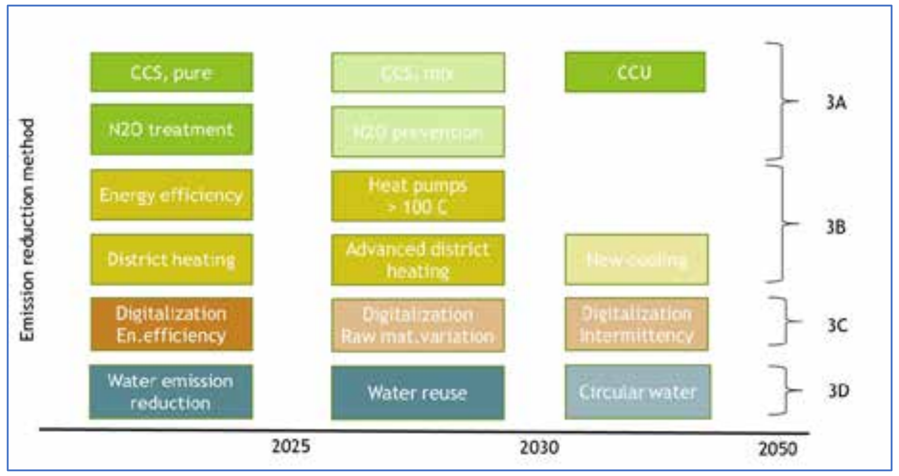


Figure 4.3: Roadmap for developing and applying technologies focused on the innovation of processes and sites.

further implementation of new digital techniques. Developments in artificial intelligence in particular are expected to play an increasingly important role in this, in particular, with respect to making processes safer and more flexible during the transition to the use of new energy systems and raw materials. Brightsite will actively follow and communicate these developments and the possibilities for implementation at Chemelot through the expertise and research work carried out by the partners.
With regard to emissions to- and use of water, technology at Chemelot is rapidly evolving, as are legislation and public opinion. In order to be prepared for this, Brightsite and its (Chemelot) partners will proactively identify, implement and, where necessary, develop existing technologies and those currently under development for measuring and removing contaminants. Based on these insights, a roadmap will be drawn up to chart the effort required in the coming years and thus the attainable emission levels.

4.5. Transition scenarios

4.5.1. Chemelot options

The previous paragraphs describe the technological options that are available and are consid-ered possible in the future so that Chemelot can meet the targets of the National Climate Agreement and the associated standards for greenhouse gas emissions in 2030 and 2050. In view of the great diversity of options and the integrated nature of the business activities, an over-arching and integrated approach is required in order to map out the possible impacts and make the right choices in time for the preparation and implementation of the corresponding transition scenarios.

4.5.2. Brightsite focus

This section of the Brightsite program is primarily aimed at bringing together, acquiring and translating available technical-economic knowledge and other relevant information and expec-tations in order to meet the emissions targets of the National Climate Agreement in a timely manner. Based on this, largely substantiated scenarios and transition paths are designed, tested and compared for the implementation of the necessary innovations at Chemelot. In order to gain a better command of the diversity of possible interactions and dependencies of subaspects, these elements are brought together in integrated software models that can be translated into impacts at the Chemelot system level. Brightsite first developed the **Chemelot Integrated Model System** (**CIMS**) model. This model is based on the current factory plants and supplemented by possible alternative technologies for making the Chemelot site environmentally sustainable. Figure 4.5 is a schematic representation of the structure of the CIMS and its modules.

4.5.3. Impact op Chemelot

Based on Chemelot's target of finally reducing Scope 1 emissions at Chemelot to zero in 2050, CIMS will be able to establish appropriate transition paths for the introduction of available (fu-ture) technologies. Figure 4.5 shows an example of a possible transition path. In this scenario, the scope 1 emission targets for 2030 and 2050 are realized almost entirely through a combination of suc-cessive and additional interventions as indicated in the figure. In this example, in addition to the measures already implemented to reduce the emissions of N_2O, a structurally large-scale capture, transportation and storage of CO_2 (CCS[24]) is required. From 2027 onwards, an additional contribution will be made by decommissioning the natural gas-fired power plant at Chemelot. From 2033, the replacement of fossil raw materials by gasification and pyrolysis of (plastic) waste or bio-based raw materials is anticipated, and from 2044 the switch to heating plants with ex-ternally supplied electricity (renewable or otherwise).

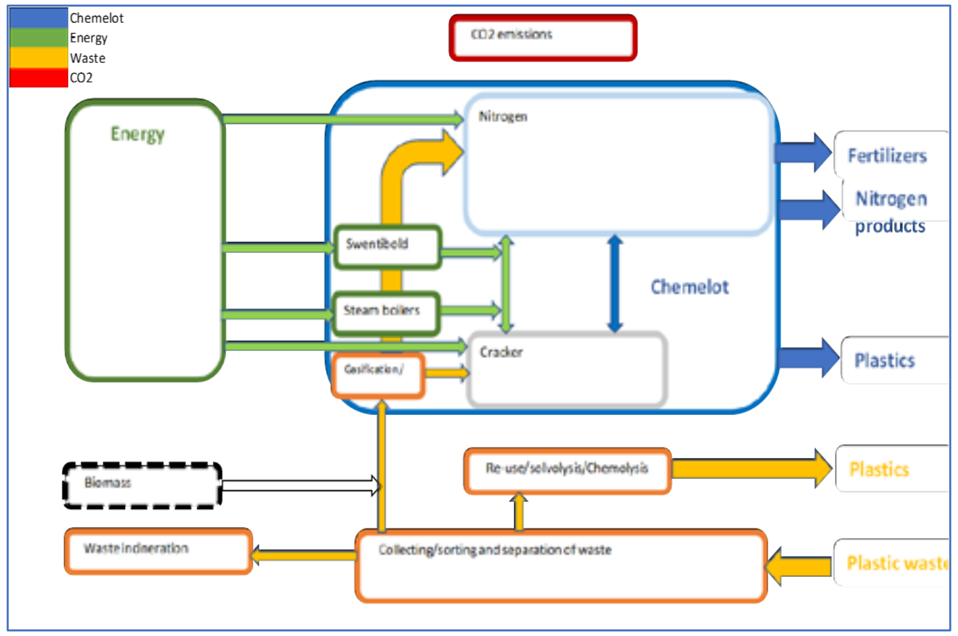
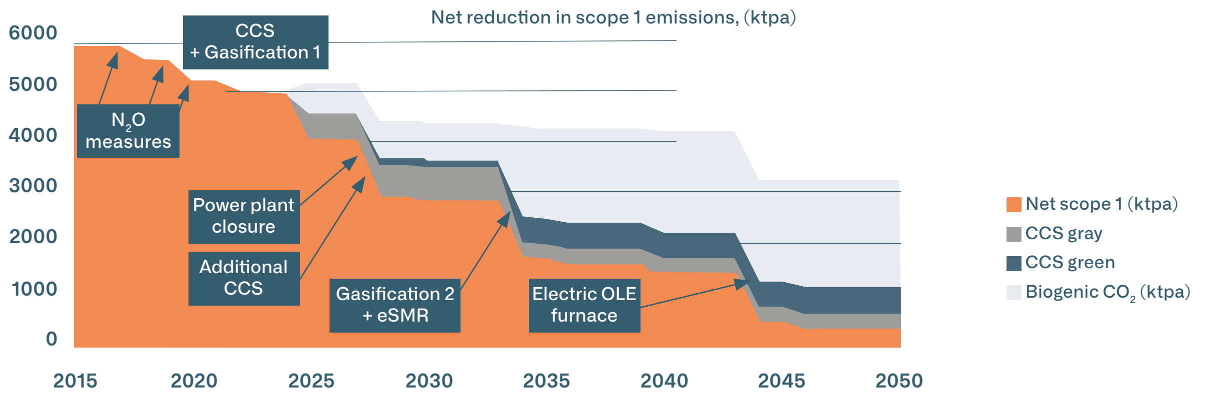


Figure 4.4: Modular structure and integration of Chemelot Integrated Model System (CIMS)

[24] Carbon Capture and Storage



This example describes only one combination of possible interventions and the resulting optimal transition path for reducing scope 1 emissions calculated by the model. Inputting other boundary conditions, options and targets into the model results in modified transition paths. Based on these kinds of scenarios, better informed and timely choices can be made for the implementation of the various interventions at Chemelot.

The next modeling step is to work on extensions of the CIMS to describe scope 1, 2, 3 emissions as well as system impacts on a na-tional scale. Following on from this, an even more comprehensive **SCIAR**[25] model is being de-veloped. This model can be used to map the current and future national and international energy and raw material flows required and available for the manufacture of current and prospective future products. The model enables us to make it clear which influence the intervention inputs included in the CIMS can prevent or promote the applicability at Chemelot. These influences are not only technological but also societal in nature. As indicated above, the societal dimen-sion will be addressed through the collaboration with university partners including **Maastricht University, Radboud University Nijmegen and Eindhoven University of Technology.**

4.6. Safe and acceptable innovation

4.6.1. Chemelot options

In order to ensure a good working and living environment for employees and local residents, Chemelot not only wants to be the most sustainable and efficient chemical site in Europe, but also the safest and healthiest. The use of alternative energy, raw materials and technologies as a result of the energy and raw materials transition therefore also requires constant attention to preventing undesirable impacts (e.g., water, soil, noise, light, particulate matter) that this may cause in the Chemelot working and living environment. This part of the Brightsite program pro-actively identifies the (possible) various safety and acceptance aspects of eligible innovations at and around Chemelot.

4.6.2. Brightsite focus

In this part of the Brightsite program, explicit attention is given to the individual and public acceptance aspects of new options associated with potential application at Chemelot. Based on this, the program is structured in complementary lines that respectively focus on understanding and influencing human and cultural aspects, the design of control processes and of methods and guidelines for intrinsically safe facilities and practices. One example recently completed by Brightsite is the **'Early Warning Safety Monitoring'** system developed in collaboration with **AnQore**. Through the automated screening of recently communicated company information, the software developed for this purpose detects early signals that precede any eventual occurrence of malfunctions and incidents.

This part of the Brightsite program also identifies the possible technical risks associated with the future use of alternative technologies and (bio-based or waste) raw materials. As an example, in the context of the future deployment of plasma technology, the various safety aspects associated with this were identified in 2021. Other examples include the involvement in the **Delta Corridor**[26] project for the construction of CO_2 pipelines, the realization of a multimodal corridor to the port of Stein[27] and the external storage of waste plastics.

In terms of public acceptance, initial questions and reactions from the area around Chemelot have already been registered with regard to the possible storage of waste plastics and the relat-ed increase in transportation movements and other possible nuisances (e.g. odor, vermin). These kinds of questions and reactions are expected to increase. Brightsite is preparing for this by having an up-to-date overview and knowledge about the new technologies and develop-ments associated with it. To this end, a set of answers to "frequently asked questions" has been set up for each subject. For a Chemelot future that is acceptable to the surrounding area, public participation is a prerequisite. Brightsite supports Chemelot and has now established a '**Stake-holder Engagement Thinktank**' with the participation of experts from the universities of Eindhoven, Nijmegen and Leiden, among others. This ensures that the most recent knowledge and experience in stakeholder participation is incorporated and available.

4.6.3. Impact at Chemelot

In 2022, Chemelot is a cluster of various (chemical) companies. Due to the transition of Chemelot, the diversity of companies and activities will only increase. As a result, differences will be apparent in the local safety culture, but the shared responsibility for current safety and the ambition of continuously improving safety performance will remain a constant. With the introduction of new and other production processes, technologies and raw materials to enable Chemelot's transition, new and other and aspects of safety and public acceptance will emerge, in addition to the familiar ones. The insights obtained at Brightsite regarding hazards, risks and societal aspects associated with the development and introduction of new raw materials and technologies will help companies at Chemelot to make the transition as smooth as possible for employees and the surrounding area. The use of Early Warning Safety systems will ensure that companies at Chemelot can detect and resolve possible disruptions more often and at an earlier stage, thus reducing the actual occurrence of incidents and the associated nuisance.

The expertise built up in this part of the Brightsite program will increasingly serve as a sounding board and provide added value for additional legislation and regulations to be drawn up by the government in the area of the safety of technologies, control processes and raw materials. Based on this, Brightsite will support Chemelot to demonstrate in practice how a cluster of different companies, activities and cultures can jointly shape the safety policy on a multi-user site.

[25] Source, Commodity, Intermediate, Application en Resource; zie https://brightsitecenter.com/sciar/

[26] https://www.limburg.nl/publish/pages/5919/samenvatting_haalbaarheidsstudie_delta_corridor_1.pdf

[27] https://www.limburg.nl/publish/pages/298/mirt_onderzoek_goederenvervoercorridors_oost_en_zuidoost.pdf

4.7. Educatie & Human Capital

4.7.1. Chemelot options

In setting up Brightsite, there was a recognition that new initiatives would be needed to attract and train researchers and collaborators to develop and apply the new technologies needed for the climate transition of the chemical industry. In the context of Brightsite, partner **Maastricht University** has taken the initiative to develop new, tailor-made courses at the bachelor's and master's level for this purpose as well as two associated chair positions.

Bachelor of Science Circular Engineering

Developed by **Maastricht University** (**UM**) and launched in September 2021, the interdisciplinary bachelor's degree in **Circular Engineering** aims to educate engineers with a strong technical foundation, combined with knowledge of the natural sciences and mathematics. In addition, students will learn that it is only possible to reduce or even eliminate the ecological footprint of products, processes and services if the entire lifecycle is considered and integrally optimized. Moreover, students learn that the public is watching this process closely (i.e., also with regard to safety and health) and has an influence on this process and the acceptance of possible (partial) solutions.

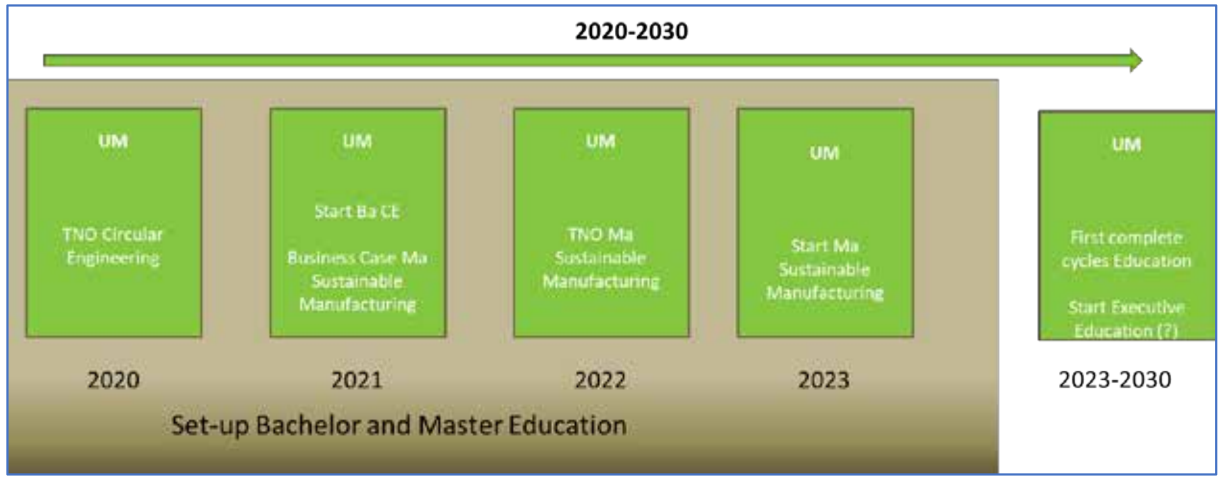


Figure 4.6: Steps in the establishment of Brightsite Education and Human Capital program.

There is strong national, regional and international demand to contribute to the transition to a sustainable and competitive chemical industry. Building on UM's existing strong research areas in chemical industrial processes and bio-based raw materials, the bachelor's degree in Circular Engineering is intended to play a key role in this transition. The developed course will achieve this by training new engineers who will go on to play a central role in the development and implementation of circular processes. Both in the development of models, activities and technologies to make society and industry circular, and in the design and development of sustainable products and processes, with the associated raw materials, energy and end-of-life issues and solutions. In addition to the realization of the above-mentioned bachelor's degree, preparations have been made for a follow-on course 'Sustainable Manufacturing' to be offered at the master's level in 2024. Figure 4.6 visualizes the building blocks and steps in the multi-year Education and Human Capital program described above.

Connection to higher/senior vocational education levels

Linking with higher and senior vocational education institutions for both education and research is also part of the Brightsite educational program. As a result, Zuyd University of Applied Sciences now has the firm intention of establishing a lectureship that ties in with the above mentioned programs at bachelor's and master's level. In tandem with this, contacts with Vista College have resulted in the teachers of this senior secondary vocational course becoming involved, where possible, in research projects and other initiatives at the higher vocational education and academic levels. The aim is for the lecturers to gain direct experience of these developments and to be able to apply it to the changes that this research will bring about for future functions and courses at the senior secondary vocational education level.

4.7.2. Brightsite focus

Chairs of Plasma Chemistry and Circular Plastics

To further strengthen the appeal and academic positioning of the aforementioned programs, the establishment of a **Plasma Chemistry Chair,** which is new in the Netherlands, provides program content and personnel. During the transition period, it became clear that plasma activation is a potentially very suitable method for Chemelot to realize the electrification of processes.
For that reason, exploration, development and application now forms the technological heart of program line 1 as explained in section 4.2. For the substantive academic content of this part of the Brightsite program, Professor Gerard van Rooij, who previously worked at the top national NWO institute **DIFFER**, has been appointed at Maastricht University as of 1 May 2020. Additional university staff have also been hired. Based on the results of the exploratory study conducted during the transition period by the collaborating Brightsite and Chemelot partners **OCI** and **SABIC**, a jointly equipped plasma laboratory for this purpose was opened at Chemelot in November 2021.

Similarly, tangible steps have been taken to strengthen and profile the UM position in the field of Circular Plastics. The focus here is on converting plastic waste streams for various eligible recycling techniques in order to achieve significant savings in the use of fossil naphtha, as described in Section 4.3. To make this ambition a reality, Professor Kim Ragaert was appointed in September 2021 and has entered into a partnership in this area with Professor Weckhuysen's group at **Utrecht University**.

4.7.3. Impact at Chemelot

The Circular Engineering program and the development of a trained, technical workforce in Limburg is a vital part of the Brightsite project. The importance of regional economic growth leading to well-paying, highly skilled jobs in the region will depend on the industrial base proac-tively driving forward the energy transition in the context of the net-zero and circular economy ambitions of the Netherlands and Limburg. The **BSc Circular Engineering** program and its associ-ated research and education expertise and infrastructure, both in Maastricht and on the Chemelot campus, will support industrial stakeholders on several fronts in implementing the transition agenda.

The BSc Circular Engineering program is designed to produce technology graduates in line with a number of specialisms relevant to the Chemelot site. In addition to the technical specialist are-as, circular engineers will have a holistic view of the challenges of energy transition and an awareness of the regional and global societal context in which technologies and industries exist. The political nature of the path to net-zero is clear, and without an explicit appreciation of the nature of the energy transition that path will be even more challenging. As the Circular Engineering BSc program progresses, students in the program will develop links with residents of the Chemelot campus and Brightsite partners in the course of their studies. This is especially true with regard to work done during the numerous project and research periods in the program. Program management plans to develop networks to support the students, drawing on existing networks of young professionals at Chemelot. This initiative will ensure that students develop a professional awareness and vision of the challenges of the industrial energy transition during their studies. We also envision a feedback loop whereby the organizations employing the young professionals working closely with students as mentors become increasingly connected and aware of a range of viewpoints and ideas that emerge from these informal relationships. When students graduate from the program, Chemelot will be directly impacted by the increased holistic view of engineering graduates of the energy transition and their skills in engaging with indus-try. Graduates of Circular Engineering will begin to affect Chemelot through direct entry into the labor market, or through engagement with industry through master's-level research projects in UM's associated research groups, such as the plasma chemistry and circular plastics research teams mentioned earlier. Indirect benefits of the educational programs are obtained through the income generated for the research groups through their contribution to teaching and pro-ject work for the programs. **The AMIBM, Circular Plastics research group** and **Plasma Chemistry teams** will all be contributors to teaching- and research-based learning in the undergraduate program.
The involvement of the research teams will help to maintain and improve the relevance and quality of the BSc over time. Master's-level educational programs will be developed in alignment with the outcomes of the BSc program. This will further enhance the contribution to the provision of technical skills in the region.

5. 5. Final review: What is possible and necessary, looking toward 2030 and 2050

5.1. What Chemelot can do

The exploratory studies already carried out by Brightsite have made it clear that, based on the available technologies, Chemelot's scope 1 greenhouse gas emissions can be reduced by 60% in 2030 compared to 1990, in line with the targets of the National Climate Agreement. In addition to the measures already taken to reduce N2O emissions, this will primarily require the structural capture, transportation and storage of CO_2 (CCS) under the seabed (of the North Sea). A first step toward completing this would require the replacing of the current usage of natural gas and fossil naphtha, which can be provided by the conversion of plastic or household waste or bio-based raw materials. In order to become fully climate-neutral by the target year of 2050, further (re)use of plastics or household waste and bio-based raw materials will be required, as well as a complete transition to heating processing plants that use (renewable) electricity instead of the combustion of natural gas and process methane currently used. To achieve this, technical solutions are available or possible in the long term. However, their further development and availability depends largely on external suppliers and environmental factors.

Just as Chemelot is currently almost entirely dependent on suppliers of fossil raw materials (naphtha and natural gas) and (gray) electricity, this will continue to be the case in the future with regard to the provision of green raw materials and sustainable energy. The timely availability and commercial applicability of these resources at Chemelot is therefore largely dependent on initiatives and cooperation undertaken with suppliers and customers, as well as the government's management, regulation and support in this regard. The following paragraphs discuss the environmental factors crucial to Chemelot's raw materials and energy transition in more detail.

5.2. Need for more suppliers of green raw materials

Both now and in the near future, the availability of green, raw materials which could be used at Chemelot as alternatives to fossil natural gas and naphtha is limited. As described in Section 4.2, this large-scale, industrial transition will require the conversion of the relevant diversity of base materials[28] into semi-finished products (also known as commodities) of a consistent quality. This requires no less than the development of an entirely new 'green raw materials industry' that can ultimately compete on price and quality with the current fossil-based oil and gas version.

It will become apparent in the future to what extent this new industry will be formed by the transition of the currently established companies and to what extent the renewal will be undertaken by new players. It is likely that the burning of fossil materials will be stopped on a shorter timescale, but that the use of natural gas and (suitable) crude oil as raw materials will continue for a longer period of time. This is partly due to the shortfall in the required, large amounts of suitable, non-fossil carbon needed to accommodate the economic growth expected before 2050. There is an expectation that the radical innovation required will have to come from current or new companies and consortia that have access to the necessary investment budgets for this purpose. New value chains with new participants are expected to emerge as part of this transition. Companies at Chemelot that purchase sustainable raw materials in these chains can play an initiating role for the new suppliers as 'launching customers'. A practical example of this is the role currently played by **SABIC** in its collaboration with **Plastic Energy** to build a pilot plant for the reuse of plastics.

[28] Plastics/household waste, bio-based raw materials and CO_2 from the atmosphere; see 4.3

5.3. Need for more sustainable electricity suppliers

In order to be able to dispense with the burning of natural gas or fossil process gases (methane) to heat processing plants by 2050 and to use sustainable electricity instead, various large-scale adjustments are still needed in generation, supply and application. As described in 4.1, the development of electric cracking plants is considered technically feasible and has recently been taken up worldwide by various consortia of end-users. Before large-scale investment decisions can be taken to apply this new technology at Chemelot, structural certainty is needed regarding the availability of the (sustainable) electrical energy required for the purpose. In comparison, the amount of electricity that should be available to Chemelot is equivalent to what is currently produced by one or two modern gas-fired power plant(s). This represents as much as 30–90% of all renewable electricity generated from wind and solar power in the Netherlands in 2019[29].

Given the comparable electricity needs of other chemical and industrial sites and new entrants such as data centers, it is already evident that the current (renewable) electricity supply is large-ly insufficient for this purpose. The same applies to the infrastructure of network operators to make electricity locally available for Chemelot and similar large-scale consumers. While the chemical industry and Chemelot has direct involvement and influence in the transition to the use of green raw materials, this does not unconditionally apply to the fulfillment of the (sustain-able) energy demand. The development of energy sources and necessary technical facilities are of national interest for all industrial and societal sectors. In this regard, Chemelot is largely de-pendent on third parties for both sufficient generation of CO_2-free energy and the transport of electricity to the site, which may mean a delay in achieving the energy transition deemed tech-nically possible and the achievement of associated emission targets for 2050.

5.4. What can the government do?

In order to achieve the national emissions targets at Chemelot and comparable industrial sites, there will be a sharply increasing need for sustainable raw materials and electricity, as indicated above. The most important obstacles to the development of the new value chains for green raw materials required for this purpose are outlined in the '**Green Chemistry New Economy**' Action Agenda[30]. This agenda points to the need to improve the conditions for chain formation between the chemical industry and new supply sectors such as waste processing and agriculture, improved financing opportunities for new initiatives and designing stimulus policies. In the area of renewable electricity, there is a better starting point, as existing companies and new consortia have taken up the development and operation of offshore wind farms with government sup-port. After initial subsidies, this means that they can now compete with fossil fuel-based elec-tricity generation at a competitive market price. However, in order to meet the rapidly growing needs, an exponential expansion of the infrastructure for the generation, transmission and system management of electricity is still required to make it available on the scale of industrial sites such as Chemelot. Electricity producers and network operators are aware of this issue, but are already experiencing difficulties responding in a timely manner to changes in the supply of and demand for renewable energy.

[29] CBS, Renewable Energy in the Netherlands 2019
[30] https://groenechemie.nl/

In order to achieve the ambitions of the National Climate Agreement in a timely and sustainable way, the impasses and possible failures of the market outlined above must be overcome. This calls for a long-term 'Delta Plan-type' approach on a national scale and the accompanying stimulating management by the government. A national 'Climate Agency NL' could ensure the necessary developments and coordinate cooperation with the European Environment Agency. If this removes enough existing uncertainties and risks on a national or international scale, new initiatives can be expected to develop on a commercial basis.

A new, internationally leading activity for the global market may emerge in the Netherlands. In view of the nature of climate technology, there are particularly good opportunities here for the continuity of the chemical sector through establishing links with the internationally leading position of the Dutch high-tech industry, as well as with the leading waste processing and bio-based raw materials sectors. Advances similar to those developed over the past 30 years by ASML, as well as supplier development based on the long-term roadmap of the semiconductor industry are also considered possible in the field of climate technology, along with the associated, positive impacts on future national employment and the economy.

5.5. What can and will Brightsite do?

Given the external dependencies indicated above, it is currently impossible to indicate with certainty what will be realistically possible at Chemelot when after 2030. What can be done, however, is to periodically perform and share technical and scenario analyses with increasing reliability, based on the model-based approach described in 4.3. The various scenarios can be tested for their sensitivity to changes in prices, regulations and availability of renewable raw materials, energy and CO_2 emissions. In this way, 'no-regret' options with high potential and limited risks can be identified, which will therefore be the best candidates for development and integration at the Chemelot site of the future. Based on such analyses, it is already clear, for example, that the use of plasma technology for methane conversion and gasification technology as well as other methods for chemical recycling of plastic waste shows stable positive results in these types of 'stress tests'. Using this approach, Brightsite will continuously test the potential economic and societal impact of new technologies and if deemed suitable, translate them into transition scenarios for Chemelot. Where there are positive results and high potential, Brightsite will also mobilize the necessary resources together with partners and stakeholders to scale up such technologies from the laboratory and pilot project phase to demonstration plants. As a subsequent step, Brightsite will be able to translate and extend the approach and outcomes followed for Chemelot to similar industrial sites and connect with other internationally developed resource- and energy-based models[31].

Last but not least, the start of the dedicated training courses at various educational levels and the expansion of related chairs and infrastructure for experimental research and development at Chemelot will ensure that international talent is trained and settled in Limburg to put the opportunities and challenges outlined above into practice.

[31] Examples include Energy Transition Model (ETM), Carbon Transition Model (CTM) and Life Cycle Assessment (LCA) modeling.

Interested in participating?

If you would like to know more about how Brightsite supports the transition of the chemical industry or if you would like to contribute to it, please contact us at info@brightsitecenter.com

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APPENDIX

APPENDIX 1. Outline of scope 1, 2 and 3 emissions and origins

For important but diverse reasons of a scientific, political or commercial nature, the classification of greenhouse gas emissions into scope 1, scope 2 and scope 3 is widely used. Examples include the formulation and implementation of policies and derived regulations and assessment methods such as a Life Cycle Analysis (LCA) or Assessment. In order to understand how important aspects of this classification relate to the climate and especially **related to unique opportunities in the chemical industry, such as those at Chemelot, to mitigate climate warming from its own position**, the classification is explained in more detail below. An important aspect is the relative nature of scope 1, 2 and 3: the numerical values of emissions to be assigned to them depend on the point of view of the defining entity in question and are therefore not absolutely applicable.

1.1. Scope 1, 2 and 3 emissions

Scope 1 emissions are generated by sources within the entity in question. Examples of such an entity are a busi-ness park, a societal sector, a country, the EU or even a household. If we consider the Nether-lands as an entity, then Dutch scope 1 emissions are caused by the greenhouse gas discharged on Dutch territory. This translates directly to each entity within Dutch territory: they each have their own scope 1 emissions, which are part of the Dutch scope 1 emissions. For example, an industrial site such as Chemelot has its own scope 1 emissions produced by the CO_2 and N_2O emissions discharged on the site. The incineration of waste and the slow digestion of material in landfills or the environment also contribute to the scope 1 emissions originating from Dutch territory. In principle, taken together, the sum of the emissions from all entities on Dutch terri-tory constitutes Dutch scope 1 emissions[32]. And similarly, the sum of the scope 1 emissions of all nations on earth constitutes the total greenhouse gas emissions of humankind.

In 2019, Dutch scope 1 emissions measured in CO_2equivalents totaled[33] 181 Mt[34]. The contribution of Dutch industries was 53.4 Mt[35], of which 17.5 Mt CO_2 eq.[36] originated from the chemical industry. The emissions of the companies at Chemelot amounted 5.8 Mt: a 10% share of the total industrial scope 1 emissions in the Netherlands. Reducing scope 1 emissions is a key pillar of current Dutch policy. This policy also concerns Chemelot, which like the Netherlands is part of a **gigantic international energy and raw materials system** that supplies energy and raw materials (see below), but whose production is part of the Dutch chemical industry.

Scope 2 emissions are related to the electricity consumed within an entity, which was generated outside this entity. For example, the Dutch scope 2 emissions are generated by the production outside the Netherlands of imported electricity and consumed within the Netherlands. However, the emissions of electricity produced in the Netherlands are covered by scope 1 of the Netherlands. In the same way, Chemelot's scope 2 emissions are outside Chemelot as a result of the production of electricity imported and consumed at Chemelot. Chemelot's scope 2 emissions are covered by the Dutch scope 1 emissions where the electricity involved was produced in the Netherlands. This is almost entirely the case.

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[32] There are also a number of agreement issues surrounding the emissions caused by international aviation and maritime shipping.
[33] In addition to CO_2, nitrous oxide (N^2O, nitrous oxide), methane (CH^4) and fluorinated gases (F gases) contribute to the warming of the atmosphere. In order to calculate the influence of these different greenhouse gases, the emissions figures are converted to CO_2 equivalent, abbreviated to CO^2 eq. The emissions of 1 kilogram of nitrous oxide is equal to 298 kilograms of CO_2 eq. And the emission of 1 kilogram of methane is equivalent to 25 kilograms of CO_2 eq.
[34] Greenhouse gas emissions are typically expressed in Mt CO_2 eq. 1 megaton is 1 million tons.[35] 89% CO_2, 11% overige broeikasgassen
[35] 89% CO_2, 11% other greenhouse gases
[36] CBS, https://www.cbs.nl/nl-nl/dossier/dossier-broeikasgassen/hoofdcategorieen/welke-sectoren-stoten-broeikasgassen-uit-

Scope 3 emissions are emissions that originate outside the boundaries of the entity as a result of the entity's activi-ties and originate from sources not owned and not managed by the entity and over which the entity does not have direct control[37]. This "formal description" is applicable to a wide range of sustainability considerations of a different nature, also outside the chemical industry. The scope 3 emissions are therefore very complex in nature. Nevertheless, in order to properly under-stand the position of the petrochemical industry in scope 3, and in particular a very significant consideration around the development and use of renewable raw materials, the definition used in LCAs is very useful. This states that scope 3 emissions are considered to encompass all prod-uct-related emissions throughout their life cycle and to therefore include the manufacture, use and disposal of products[38]. Scope 3 emissions can also be linked to entities and for this purpose are divided into Upstream and Downstream emissions, as viewed from the entity in question. The previously mentioned relative nature of the scope 1,2,3 classifications is evidenced by the fact that in value chains, scope 3 of one entity is often scope 1 of another.

Scope 3 Upstream emissions mainly originate outside the entity due to the extraction from fossil sources and production of imported raw materials and products, which are processed or consumed within the entity. Examples include methane emissions in the extraction of natural gas, energy consumption and associated CO_2 emissions to extract, refine and further process oil from (sometimes difficult to access) sources (into naphtha, phenol), and to transport all raw materials to Chemelot. If the demand for oil, gas or coal products decreases, so that less oil, gas or coal is extracted from the ground, the scope 3 Upstream emissions will decrease.

It also follows from the above that Chemelot's scope 3 Upstream emissions are partly covered by the Dutch scope 1 emissions. The decisive factor is the extent to which the upstream activities for Chemelot took place within or outside the Netherlands. This depends heavily on the international market and may vary over time. Not all upstream activities for naphtha preparation (i.e. oil extraction, transportation, refining, processing and transportation to Chemelot) are usually carried out entirely within the Netherlands. Another consequence of this is that a further breakdown of these emissions 'in or outside the Netherlands' is not accurately known: the data required for this is not known. Economically, the origin of raw materials does not play a significant role at present, but that may change in the future when the origin of sustainable raw materials (certification) is factored in. However, there are good (and scientific) studies on upstream emissions, which nevertheless provide a good indication of Chemelot's scope 3 Upstream emissions.

Scope 3 Downstream emissions are related to downstream use, outside the entity, of products or intermediate products made within the entity. These include emissions resulting from further processing of the product or intermediate product into consumer products, the use of the product by the consumer and the end-of-life fate of the product as waste. This is complex, as consumer products are often com-posed of multiple components and materials of diverse and often untraceable origins. This is where we enter a gray area: the root cause of scope 3 Downstream emissions is not always clear. The question then arises as to whether, for example, an upstream producer can be held responsible for the use of a product by a consumer, who also has a degree of responsibility in this regard[39 40].

A notorious and for petrochemicals very important exception is what are known as the end-of-life emissions for plastics. These are CO_2 emissions that occur when end-of-life plastic-containing products (waste) are burned or slowly decompose in the environment (as litter or in landfills).

[37] See e.g. https://www.carbontrust.com/resources/briefing-what-are-scope-3-emissions of https://www.rvo.nl/actueel/evenementen/inspiratietours-co$_2$-reductie-industrie-scope-1-2-en-3-uitstootverlaging-de-keten
[38] Therefore excluding its own Scope [1] and [2] contributions, if Scope [3] is viewed from its own entity

The magnitude of these 'scope 3 Downstream end-of-life emissions' is target and can be objec-tively and quantitatively related to the amount of carbon in the product waste. This brings the producer of plastics that are incorporated into the product into the picture: the petrochemical industry. If they bring fossil raw materials into the product value chains, then over time it there-fore leads to additional fossil CO_2 emissions[41] proportional to the amount of fossil carbon in the product waste. Within the broader scope of scope 3 Downstream emissions, this factor is de-scribed as: "fossil raw materials used in products in relation to associated fossil, end-of-life emis-sions spread over time," which is usually referred to as 'scope 3 Downstream emissions of plastics'. The same interpretation is used in this document.

There are alternative sources of carbon that can be used in the petrochemical industry as a raw material, and which can prevent the above-mentioned fossil emissions in the future. Two of these are bio-based raw materials and CO_2 (Chapter 4). In principle, the petrochemical industry can switch to this. This also applies to the third alternative carbon source: carbon in product waste. By recycling plastic, the related Scope 3 end-of-life emissions are prevented. This not only contributes to reducing climate warming, but also to all raw materials, because recycling reduces demand for all new virgin material, whether it be bio-based raw materials, CO^2 or new fossil carbon (e.g. from petroleum).

As with scope 3 Upstream, Chemelot scope 3 Downstream emissions can occur inside and outside the Netherlands. This is mainly determined by the quantity of product exported across na-tional borders (and any import of waste). The Dutch scope 1 portion of Chemelot scope 3 Down-stream emissions comes from Chemelot products in waste for Dutch waste incinerators (CO_2) or landfills (slow emission of CO_2 and CH_4).

1.2. Impact of fossil resources on the climate

The effect on the climate of fossil materials currently extracted and used in an almost linear economy (e.g. oil, ground and shale gas, coal and lignite and others) is determined by their almost complete conversion into CO_2 within a relatively short period of time. This occurs when used as a fuel and is delayed when used as a raw material: it takes a bit longer before it is discarded, burned or decomposes in the environment. Switching to biomass or CO_2 as a raw material prevents this, but costs (extra) energy, which must therefore be CO_2-free. A circular econo-my that recycles plastics keeps carbon—including fossil-based carbon—in circulation longer and better and slows down and therefore dilutes CO_2 emissions over time, as proportionally less virgin fossil material needs to be put into circulation. For the chemical industry, the conclusion is therefore that the amount of virgin fossil carbon that the chemical industry is able to 1:1 re-place in its chemical products with carbon from waste, biomass or CO_2, is a quantitative measure for future prevention of Co_2 emissions, relative to the use of virgin fossil material in those products. In the relatively short term of a few years this has the same effect on the climate as the reduction of scope 1 emissions (Geyer).

[39] In the legal arena, there are moves taking place, as illustrated by some recent judgments (Urgenda, Shell).
[40] The use of fertilizer also leads to Scope [3] Downstream emissions: Co_2, nitrous oxide and methane from cropped land. However, fertilizer products containing no carbon, such as Chemelot's ammonium sulphate, also causes such emissions. One of the reasons for this is soil acidifi-cation due to oxidation of ammonia from fertilizer by air. The acid release (soil acidification) is controlled by minerals such as lime, which produces CO_2 emissions from the mineral. Micro-organisms also interact with fertilizers, resulting in nitrous oxide. These Scope [3] Down-stream emissions are caused by soil conditions and stimulated by the pursuit of optimal crop yield: a consumption factor. Consumption patterns also play an important role in other Scope [3] Downstream emissions.
[41] Fossil emissions of products manufactured now are spread over time. This is determined by the amount of time carbon is stored in the various product applications (or "hold-up time"). For packaging, the hold-up time is short (months), construction applications (a small minor-ity) are measured in decades. A good explanation can be found at R. Geyer et al., "Production, use, and end-of-life fate of all plastics ever made," Science Advances, Vol. 3, Issue 7, 2017. 42 PBL, 2015. Data over de scope 3 Upstream emissie van de Nederlandse binnenlandse consumptie zijn schaars

1.3. International integration of emissions

Given its favorable geographical location and transportation possibilities, the Netherlands has a relatively large economic sector and associated process and chemical industry in the area of importing, processing and exporting fossil raw materials and (semi-)manufactured products based on them. Figure A1.1[42] shows Dutch imports, throughputs, domestic consumption and exports of coal, natural gas and petroleum in 2019, as well as the energy[43] contained in these products.

In total, imports amounted to 240 Mt oil (product), coal and natural gas, as well as the extraction of 20 Mt natural gas from national sources. The total amount of energy in all these fossil fuels was more than 11,000 PJ. However, total consumption of this in the Netherlands amounted to 'only' 3000 PJ, which means that almost three times the amount of imported energy eventually leaves the country again This concerns partly the energy content of directly imported products (particularly petroleum), and partly the energy content of petroleum products pro-cessed and exported in the Netherlands, such as fuels, chemicals and plastics, including some from Chemelot. The specific position of the Chemelot chemical industry within the total of the national import and export flows is shown at the bottom of the flow chart.

In addition to the raw material and energy flows, this figure also shows the related scope 1, 2 and 3 emissions from a Dutch and Chemelot perspective. As mentioned earlier, the Dutch scope 1 emissions in 2019 were approximately 181 Mt CO_2 equivalent. By comparison, the net Dutch scope 2 emissions are almost negligible because the underlying electricity generation largely takes place in the Netherlands and the emissions from this are part of the scope 1 emissions. The scope 3 Upstream emissions caused by extraction and transportation of raw materials are in the order of 100 Mt CO_2 eq. The scope 3 Downstream emissions—which are directly linked to the total amount of carbon present in natural gas, oil and coal—amounts to approxi-mately 520 Mt CO_2 eq. The national scope 1, 2 and 3 emissions related to imports, processing and transit of fossil raw materials total to approximately 800 Mt CO_2 eq. This does not include the scope 3 Upstream emissions from goods and food components produced elsewhere, which have an order of magnitude of about 200 Mt CO_2 eq.[44] and which brought the total Dutch scope 1, 2 and 3 emissions in 2019 to about 1000 Mt CO_2 eq. In 30 years' time, as a result of interna-tional efforts, this will therefore have to be reduced to climate neutrality.

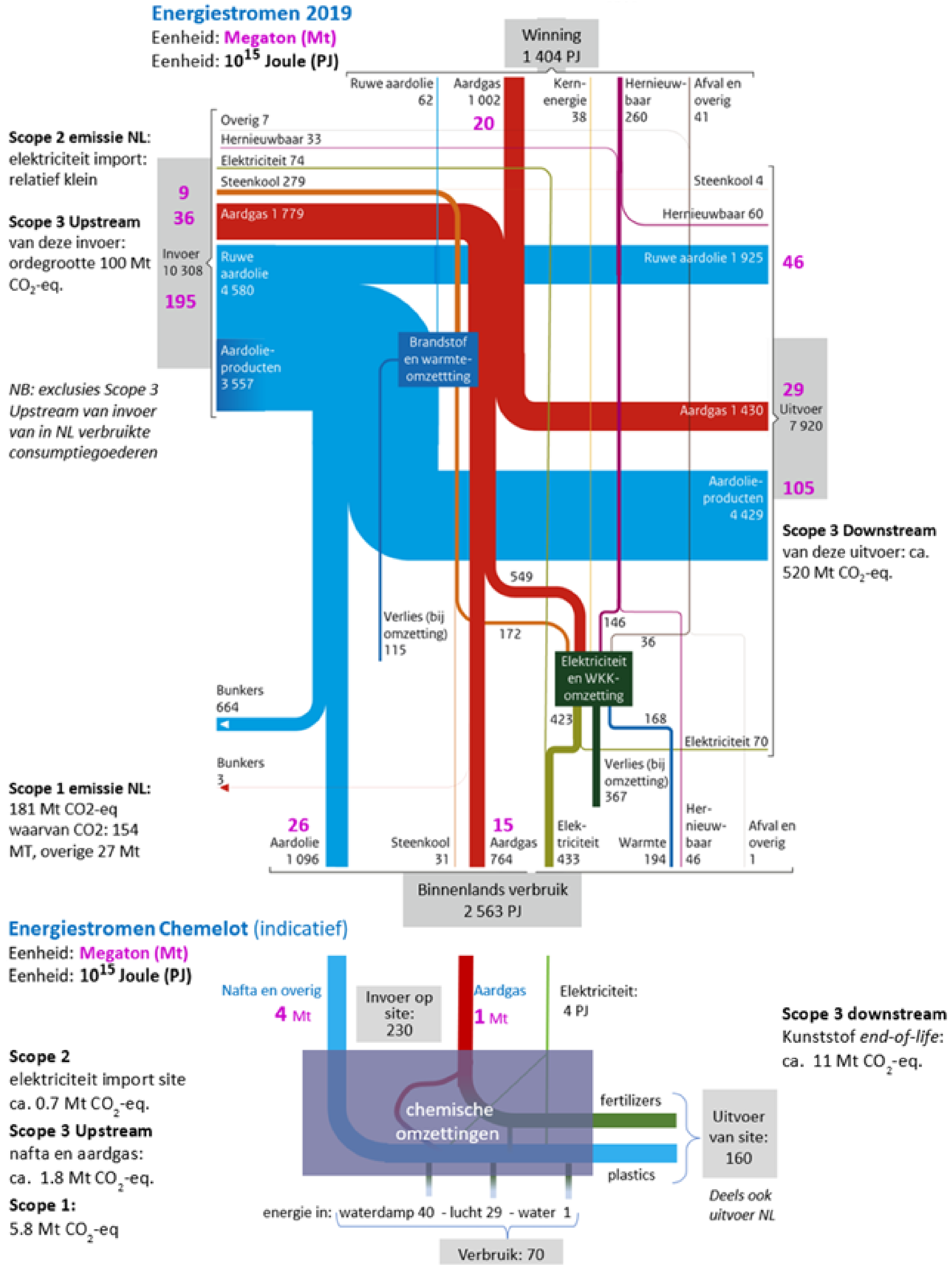

Figure A1.1:Dutch energy flows and Scope 1, 2, 3 emissions in 2019. Pink numbers: Megatons, e.g. on imports [at top left]: coal (9), natural gas (36), crude oil and petroleum products (195 Mt). Black digits: Petajoules PJ, e.g. on imports 10308 PJ

[42] Source: CBS
[43] Shown in Petajoules (PJ). One Petajoule is enough energy to bring the water from 1400 Olympic pools to the boil.
[44] PBL, 2015. Data on the Scope 3 Upstream emissions for Dutchdomestic consumption is limited.

1.4. Climate and policy

As has already been mentioned, reducing the scope 1 emissions from industry is a key pillar of current Dutch policy. It should be clear, however, that the climate does not distinguish between scope 1, 2 or 3. This means that for the "carbon in plastics" described above, the petrochemical industry and any entities cooperating with it can take an important step in combating greenhouse gases, namely by replacing the fossil carbon in its products with non-fossil carbon. However, there is no Dutch government policy for the scope 3 Downstream emissions at pre-sent. As a result, an essential potential climate contribution of the petrochemical industry is currently not adequately encouraged.

The Dutch chemical industry is a global player exporting the majority of its products across national borders. By taking the lead in replacing fossil carbon sources for the manufacture of plastics and chemical products with non-fossil carbon from (plastic) waste and bio-based raw materials, the Dutch petrochemical industry and specifically that at Chemelot can influence the greening of products and reduction of related emissions worldwide. In the absence of sufficient policy incentives, however, international market forces are the only other mechanism that will be decisive in initiating the transition to non-fossil raw materials and sustainable products based on them. However, due to the higher costs of non-fossil raw materials and products based on them, the market demand is only gradually increasing, which complicates the required billion-dollar investments, including those for potential key players at Chemelot. In view of the international nature of the chemicals and plastics market, policy needs to be developed at the Dutch and European levels. In order to be proactive and trigger public policy in this area, the replacement of fossil raw materials with sustainable alternatives is a main focus for Brightsite.

APPENDIX 2

Chemelot Circular Hub

What is a Hub for Circularity?

The concept for Hubs for Circularity (H4C) has been introduced in the Processes4Planet's (former SPIRE) vision, supported by the European Commission. Chemelot Circular Hub is inspired by this concept. H4Cs are selfsustaining economic industrial ecosystems for full-scale Industrial-Urban Symbiosis and Circular Economy. They are closing energy, resource and data loops and bringing together all relevant stakeholders, technologies, infrastructures, tools and instruments necessary for their incubation, implementation, evolution and management. In a H4C the process industry teams up with the regional community, research/academia, the public sector and society, applying disruptive innovation and design to recycle to arrive at new sustainable business models, industries and residents' involvement.

In recent years, it has become increasingly clear that technology development alone is not sufficient for the successful transition of the site toward the 2050 targets. This is already apparent from the site-boundary-transcending aspects of program elements (see 3 and 4b), where logistical and non-technological aspects play a role, such as the potential to develop sources for renewable raw materials, the supply capacity of CO_2-free electricity and the use of residual heat off-site. There are also related issues such as: the amount of traction in the market for sustainable products; the currently limited availability of sustainable raw materials and electricity for Chemelot; the new environmental legislation (participation); and educating and attracting engineers for circularity. Recently, the EU has been focusing much more strongly on integrated regional public support when allocating public funds, which means that when the EU allocates its funds to large projects such as those required at Chemelot, it will assess how they are embedded in the (envisaged, sustainable) society and how well they are supported by the public. Chemelot Circular Hub[45] has been set up with the aim of creating consortia that bring together this required degree of integration on the basis of the partners' autonomous contributions and to jointly achieve it by means of integrated development consortia.

As one of the CCH partners, Brightsite aligns its programs with other CCH partners in terms of content and strategic tactical approach while retaining its own responsibilities. Through its systems approach, modeling expertise, integrated transition expertise, upscaling expertise and expertise in sustainable chemical technologies, Brightsite is developing unique competencies, and has the potential to grow into a regionally and nationally important knowledge center in the coming years.

[45] https://www.brightlands.com/brightlands-chemelot-campus/circular-hub

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