Renewable Carbon as a Guiding Principle for Sustainable Carbon Cycles

Why it is right to choose renewable carbon as a guiding principle for sustainable development in the chemicals and materials sectors

A paper of the Renewable Carbon Initiative

February 2022

The Renewable Carbon Initiative (RCI) is an interest group of more than 30 well-known companies founded in September 2020

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The Renewable Carbon Initiative

The Renewable Carbon Initiative (www.renewable-carbon-initiative.com) is an interest group of more than 30 well-known companies from the wide field of the chemical and material value chains. It was founded in 2020 to collaboratively enable the chemical and material industries to tackle the enormous challenges in meeting the climate goals set by the European Union and the sustainability expectations held by societies around the globe. The industry needs to do more than just use renewable energy. Because decarbonisation is not an option for the chemical and material sector, as it is entirely based on the use of carbon, an alternative strategy is required: **defossilisation through renewable carbon.**

Members

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Short Version

What is the primary cause of human-made climate change? The usual answer is: CO_2 and other greenhouse gases. But is CO_2 really the core of the problem? Might it not be more relevant to consider where CO_2 originates? Recent climate data indicates that 72% of anthropogenic[1] climate change comes directly from extracted fossil carbon from the ground, while the other 28% comes from agriculture and forestry – mainly land-use change and livestock production[2]. Presenting the first part of the new Intergovernmental Panel on Climate Change (IPCC) climate science report in August 2021, the UN Secretary-General António Guterres warned that fossil fuels are destroying the planet, and that the report "*must ring the death bell for coal and fossil fuels*."[3]

In other words, CO_2 is not at the core of the climate problem. CO_2 can actually be cycled between atmosphere, biosphere and technosphere. Instead, the core issue is the additional fossil carbon that is taken out of the ground via crude oil, natural gas or coal, which is utilised in our technosphere and ultimately released in the atmosphere as additional CO_2 or other emissions. If the inflow of additional fossil carbon and the related CO_2 emissions were prevented, the CO_2 content of the atmosphere would no longer increase. Considering the current annual GHG emissions of 55 Gt CO_2eq, the remaining budget for staying within the climate targets will be spent entirely within the next 7 to 12 years (1.5°C) and 21 to 30 years (2°C).[4] To show how urgent and all-encompassing this issue truly is: when considering the UN Sustainable Development Goals (SDGs), the consequences of climate change will have a negative impact on all 17 SDGs.

The conclusion is clear: in order to rapidly mitigate climate change and achieve our global ambition for greenhouse gas emission reductions, the inflow of further fossil carbon from the ground into our system must be reduced as quickly as possible and by high volumes. In the energy and transport sector, this means a vigorous and fast expansion of renewable energies, hydrogen and electromobility, the so-called decarbonisation of these sectors. The EU has already started pushing an ambitious agenda in this space and will continue to do so, for instance with the recently released 'Fit for 55'

1 A glossary of many renewable carbon related terms can be found at https://renewable-carbon-initiative.com/renewable-carbon/glossary/

2 Based on data from https://www.pbl.nl/sites/default/files/downloads/pbl-2020-trends-in-global-co2-and-total-greenhouse-gas-emissions-2019-report_4068.pdf

3 https://eminetracanada.com/the-un-secretary-general-has-questioned-canada-saying-the-report-on-fossil-fuels-must-ring-the-bell-of-death/245826/

4 The CO_2 budget left is shown online and updated here: https://www.mcc-berlin.net/fileadmin/data/clock/carbon_clock.htm (2021-09-15): 7 years and 10 months for surpassing the limit to stay within 1.5°C target.

package. However, these policies have so far largely ignored other industries that extract and use fossil carbon. The chemical and plastics industries have a high demand for carbon and are essentially only possible with carbon-based feedstocks, as most of their products cannot do without carbon. Unlike energy, these sectors cannot be "decarbonised" and molecules will still need carbon. In December 2021, for the first time ever, the European Commission (EC) published a communication paper on sustainable carbon cycles[5]. Such a new policy approach must be further detailed to ensure the source of the carbon and carbon cycles can be optimised to minimise environmental impact, moving to more sustainable chemicals and materials.

In this paper the importance of tackling the embedded carbon in chemicals and materials is highlighted and an approach to minimise its environmental impact and maximise reduction of GHG emissions is proposed, in accordance with the objectives of the Paris Agreement.

Uncovering and tackling the "invisible carbon footprint" of chemicals and derived materials

Of the total fossil carbon sourced today, about 85% is used for energy and 10-15% for chemicals including plastics[6]. In highly industrialised countries such as Germany, an even higher share (20%) of crude oil is used as feedstock for the chemical industry[7]. For most primary petrochemical industries, roughly 70% of their carbon footprint originates from the carbon embedded in the molecules. The chemical sector will need more and more carbon in the coming decades, if only because of the growing world population and increasing prosperity. At the same time, due to the decreasing demand from the energy and transport sectors, it is rapidly becoming the largest driver of global fossil carbon demand and is on track to account for about 50% of total carbon demand in 2050.

This is further confirmed by large oil and gas companies massively focusing on the growing carbon demand from the chemical and plastics industries, as their two main markets of energy and transport are being decarbonised.

This trend means that policymakers must urgently address the use of fossil carbon in chemicals and materials. The large quantities of fossil carbon involved will continue to enter the atmosphere as CO_2 for decades, e.g., via degradation or incineration, and can no longer be ignored from a climate policy perspective. New political approaches are needed towards the resource base of chemicals and plastics, especially because chemistry cannot be "decarbonised". Its products are primarily composed of carbon. Guidance is needed to satisfy the increasing demand for carbon by the chemical industry while avoiding further utilisation of fossil carbon and replacing it with viable alternatives. This means a "defossilisation" of the chemical industry.

5 Communication from the Commission to the European Parliament and the Council. Sustainable Carbon Cycles. 15.12.2021. https://ec.europa.eu/clima/system/files/2021-12/com_2021_800_en_0.pdf

6 Based on https://www.pbl.nl/sites/default/files/downloads/pbl-2020-trends-in-global-co2-and-total-greenhouse-gas-emissions-2019-report_4068.pdf

7 www.petrolplaza.com/news/28695

Sourcing carbon responsibly and better integrating EU climate and circular economy policies will be key

To decouple chemistry from fossil carbon, other sources of carbon must be found that do not lead to additional CO_2 emissions because they keep the carbon circular. The key question is which non-fossil carbon sources can be used in the future. Rapid developments in biosciences and chemistry have unlocked novel, renewable and increasingly affordable sources of carbon, which provide us with alternative solutions for a more sustainable chemicals and materials sector. These alternative sources are: biomass, utilisation of CO/CO_2 (CCU) and recycling. They are combined under the term "renewable carbon", which by definition includes recycled/circular carbon (see excursus: Renewable Carbon). All three carbon sources together can be sustainably developed in a way that they completely substitute fossil carbon. The future chemical and derived-material industries must obtain carbon feedstocks exclusively from the atmosphere, biosphere and technosphere, keeping the carbon inherently renewable and in circular utilisation. The equivalent to decarbonisation in the energy sector via renewable energy is the transition to renewable carbon in the chemical and derived-materials industries. Both strategies avoid bringing additional fossil carbon extracted from the ground into the atmospheric cycle. The EC recognised this in its communication paper from December 2021[8]:

> *"Fossil carbon will be replaced by more sustainable streams of recycled carbon from waste, biomass and directly from the atmosphere to supply the organic chemistry processes for the synthesis of sustainable products and fuels."*

Mastering this mix of new carbon sources will create a pathway to replace additional fossil carbon in products with carbon coming from renewable sources. Not every application based on renewable carbon is automatically sustainable – but any application based on fossil resources can never be sustainable. Renewable carbon is a necessary but not yet sufficient condition for sustainability. If the chemical and plastics industries want to quickly become climate-neutral – and that is exactly what is needed – the use of renewable carbon feedstocks must become a political guiding principle that enables rapid and large-scale change for their raw materials base.

For the first time since the beginning of the industrial revolution, the decoupling of the chemical and derived materials industries from fossil resources from the ground is possible. Both technology and investment capital are available for the transformation of the entire economy from fossil to renewable carbon. But the high investments that are required for such a transformation need a clear direction that provides investors and the industry flexibility, security, and financial viability.

The carbon source of products has historically played no role at all in political decisions related to the chemicals and plastics sectors, at least until the EC published their communication paper on "Sustainable Carbon Cycles" in December 2021. Renewable carbon is the approach that will enable the chemical and derived-materials industry to become an important part of a sustainable future – it can originate from biomass, CO_2 utilisation and from recycling. As a guiding principle, renewable carbon enables the industry to think out of the box of established boundaries and stop the influx of additional fossil carbon from the ground.

8 Communication from the Commission to the European Parliament and the Council. Sustainable Carbon Cycles. 15.12.2021. https://ec.europa.eu/clima/system/files/2021-12/com_2021_800_en_0.pdf

Political recommendations to support the transformation to renewable carbon

The above-described systematic change will not only require significant efforts from industry, but must be supported by policy measures, technology developments and major investments. In order to implement the outlined rapid and high-volume transition away from fossil carbon, and to demonstrate its impact, a supportive policy framework is essential. The emphasis should be put on sourcing carbon responsibly and in a manner that does not adversely impact the wider planetary boundaries nor undermines societal foundations. An overarching carbon management strategy is required that also takes specific regional and application-related features into account, to identify the most sustainable carbon source from the renewable carbon family. This will allow for a proper organisation of the complex transition from today's fossil carbon from the ground to renewable energy and to renewable carbon across all industrial sectors.

Following extensive preparation on developing and finetuning the renewable carbon concept and as part of the work on this paper, a longer list of recommendations has been developed. This list shows what it would mean to include renewable carbon as a guiding principle in political decisions.

Eleven Policy Recommendations ranked by the members of the Renewable Carbon Initiative (RCI)

1. **Renewable carbon must become an integral part of policies and targets,** as a key element to tackle the root of the climate problem, stopping the inflow of further fossil carbon and embracing embedded carbon in chemicals and derived materials as an inherent part of EU policies.
2. **Carbon management must become an integral part of all policies and targets:** properly organising carbon as a circular resource across all industrial sectors the complex transition from today's fossil carbon from the ground to renewable energy and to renewable carbon.
3. **Support the transformation of existing chemical infrastructure from fossil to renewable carbon** to achieve the necessary volumes and truly create impact.
4. **Massive expansion of renewable energies and green hydrogen grids, in combination with CCU** as a vehicle for storing and transporting renewable energy.
5. **Supporting market access for products based on renewable carbon** with binding renewable carbon quotas in "drop in" products, for example.
6. **The removal of carbon (from the atmosphere) by CCU should be positively considered** – especially the substitution of fossil carbon via renewable carbon in the production of chemicals and derived materials.
7. **Financial support / tax advantages / tax exemptions for fossil carbon utilisation must be removed.**
8. **Renewable carbon standards, certificates and labels**, renewable carbon preferred product databases and public procurement.

9. **Proper carbon management must also enable the transformation of biofuel plants into chemical suppliers.**

10. **The non-level playing field for material and energy use in the bioeconomy sector must be overcome.**

11. Put **scope 3 emission** more in the focus of climate policy to really become carbon neutral.

A more comprehensive and scientific argumentation why renewable carbon is a relevant guiding principle towards climate change mitigation can be found in the long version of this paper.

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Long version

Introduction

In this paper, the Renewable Carbon Initiative (RCI) presents multiple arguments outlining the manner in which carbon is sourced for the chemical and derived materials sector is essential for holistic climate change mitigation and the road towards net zero emissions. Until now, EU climate policy has largely focused on *decarbonising* the most carbon-intensive sectors. However, this definition ignores the carbon embedded in chemicals and products, which is the universal building block of life and cannot be removed. It is therefore urgent to address this issue and transform EU policies to achieve more sustainable chemicals and materials, not only looking at carbon as an emission but also as a feedstock. The communication paper on "Sustainable Carbon Cycles" by the EC, published in December 2021[9], is a first step in this direction. For the first time the importance of carbon beyond the decarbonisation strategy is recognised:

> *"Organic chemistry exploits the uniqueness of carbon to produce highly complex molecules for the pharmaceuticals, chemicals, plastics and advanced materials of our daily life. [...] we need to recycle carbon from waste streams, from sustainable sources of biomass or directly from the atmosphere, to use in place of fossil carbon in the sectors of the economy that will inevitably remain carbon dependent."*

The RCI has one central goal: The utilisation of fossil carbon as raw material for chemicals and materials must be stopped and replaced with renewable carbon in order to restore the sustainability of global carbon cycles. This transformation requires the development of a value model for carbon that supports a change in understanding of carbon – from a problem towards accepting it as an essential feedstock for the industry. The paper delves deeper into the already well-known details of climate change but introduces a new perspective in order to highlight why it is so essential to start considering carbon as a feedstock. Dealing with human-made climate change requires us to look beyond renewable energy. This paper elaborates on:

a. why climate change is a significant issue that affects all other sustainability goals (and metrics)
b. how embedded fossil carbon significantly contributes to climate change
c. why there is a need to act quickly and in large scale
d. why renewable carbon is a suitable guiding principle for the transformation of the chemical industry
e. why carbon management is a necessary tool to restore the sustainability of carbon cycles

These insights and fresh perspectives should feed into the EU policy agenda, and we have made policy recommendations on how best to integrate the concept into current and upcoming political strategies and agendas like net zero targets or the 'Fit for 55' package revisions.

9 Communication from the Commission to the European Parliament and the Council. Sustainable Carbon Cycles. 15.12.2021. https://ec.europa.eu/clima/system/files/2021-12/com_2021_800_en_0.pdf

Excursus

Renewable Carbon – what the term means and why it carries momentum

At the time of its establishment in September 2020, RCI's declared goal was "to support and speed up the transition from fossil carbon to renewable carbon for all organic chemicals and materials." It was expressly stated that through this, "RCI addresses the core problem of climate change, which is extracting and using additional fossil carbon from the ground that will eventually end up in the atmosphere." All participating companies strive – in one way or another – to phase out the use of fossil carbon from the ground and to replace it by carbon sources from above the ground. The RCI initially was based on nova-Institute's elaboration of the renewable carbon concept (Carus, Raschka et al. 2018 and 2020) which defined renewable carbon as coming from the biosphere, atmosphere or technosphere – but not from the geosphere. This includes bioeconomy ((re)grown), carbon capture utilisation ((re) captured) and recycling ((re)cycled).

This concept has weaknesses as well as strengths. To combine three very technologically diverse areas under one umbrella term is daring and subject to criticism. Comparability is difficult in terms of sustainability, regulation is set down in a multitude of different documents (and at extremely differing stages of progress), knowledge in one sector does not mean expertise in another, etc. There will always be proponents of one or two of the three renewable carbon sources who oppose the other option(s). There will be justified concerns regarding the greenwashing of certain technologies by putting them in the same pot as more established ones. On the one side, there will be criticism regarding the inclusion of "recycling", and on the other side, critical voices who fear that this concept could lead to higher acceptance for biomass utilisation than for recycling. It is very well possible that such a comprehensive concept will make for some tedious and repetitive discussions.

However, bridging these conflicts is exactly what makes the RCI and its renewable carbon concept meaningful

The strategy aims to find a new, holistic narrative for carbon in the chemical and materials sectors, which cannot be decarbonised but – on the contrary – will always need more carbon. The initiative is about carbon management of all carbon flows and offers a consistent overall picture. This is meant to be a simple,convincing and positive concept, which is straightforward to communicate. Similar to how today fossil and renewable energy are differentiated today, the distinction between fossil and renewable carbon is useful to build a consistent overall picture for the future. At the same time, it allows for concrete decisions about which of the three alternatives is the best choice in a given application, technology, project, company, region etc. to be made on a case-to-case basis.

By offering a comprehensive perspective, the concept becomes much more powerful than the three sectors by themselves. The concept leads from the individual sectors to an overarching question of how chemistry and materials can be supplied with sustainable carbon in the future.

In order to create a new mindset and a new communication narrative, it is vital to use one strong and concise term instead of watering down the momentum by offering alternatives.

From an established use perspective, there is no agreed definition for the term renewable carbon. There are no official definitions set up by standards or regulation. Scientific and political documents use a variety of terms to designate different concepts regarding sustainable material choices[1]. To give one concrete example, according to the Renewable Energy Directive (RED) definitions, a fuel produced from biogenic CO_2 and green hydrogen will not be considered a biofuel, but a "Renewable Fuel of Non-Biological Origins".
In any case, there are also multiple examples from the fields of recycling and CO_2 utilisation that use the term "renewability", so the RCI did not freely invent these contexts. And moreover, awareness and acceptance of RCI's use of the phrase is growing and several companies, associations and scientists have already adopted it.

Semantic analysis shows that "renewable" is a fitting term to describe the three carbon sources biomass, CO_2 and recycling. While the term is more established for bio-based resources, there is no linguistic reason why it should not be applied to other bountiful, limitless, and sustainable resources that can be utilised again and again.

Finally, it is ***difficult to really separate between the different carbon streams*** above the ground. For example, what about biogenic fractions in recyclates or chemically recycled biopolymers? If and how should different CO/CO_2 sources be classified? CO_2 from direct air capture is certainly not recycled carbon: the technical plant uses the same CO_2 as plants or trees. On the other hand, it is usually said that CO_2 is used in a circular fashion in the bioeconomy. Which implies that biogenic carbon is also recycled carbon. Do algae, fed with fossil CO_2 from power plants, supply recycled or biogenic carbon?
They are all perceived together as the renewable carbon family and all replace fossil carbon from the ground. This becomes especially relevant for future activities of the RCI and when the shift becomes reality.

1 Some examples are the Renewable Energy Directive or the Renewable Carbon Index for cosmetics according to ISO 16128.

1. Climate change is an existential threat to life on earth

1.1 Human-made impact of climate change

"Average Northern Hemisphere temperatures during the second half of the 20th century were very likely higher than during any other 50-year period in the last 500 years and likely the highest in at least the past 1,300 years." (IPCC 2014 and 2021[10]). The world's leading climate scientists warn that the next 10 years, until 2030, are crucial to limit global warming to a maximum of 1.5°C. Compared to 1.5°C, a 2°C temperature increase will significantly raise the risks of droughts, floods, extreme heat, species extinctions, crop failures and poverty for hundreds of millions of people.

The observed drastic increase in temperature correlates with the beginning of the industrial revolution, where the exploitation of fossil fuels and fossil carbon from oil, coal and natural gas has started. Since then, the average temperatures have been rising globally by more than 1°C. Concurrently, the CO_2 concentration in the atmosphere has been rising steadily as well. Since the first methodological measuring of CO_2 concentrations in the atmosphere back in the 1960s, where it averaged 315 ppm (= 0.0315 %), it increased to an annual average of 415 ppm (= 0.0415 %) CO_2 in 2020. The vast majority of climate scientists agree that humanity is very likely the driving factor of this accelerated climate change, and that CO_2 is the major driver.

Direct consequences of an increased temperature and changing climate are already materialising all over the world. **Droughts** have become more frequent, even in moderate regions like Central Europe. **Glaciers are vanishing** at astonishing speed and even **Antarctica** is melting three times faster now than it did just a decade ago[11].

This is just the tip of the iceberg and does not sufficiently capture the existential threat of climate change for all of us. The facts are out there, though perhaps not sufficiently highlighted: the IPCC has scientifically established that climate change has **significant effects on freshwater resources** (reduced water availability, reduced water quality, increased flood risks), on **land and soil** (droughts, loss of agricultural lands, increased extreme weather events like storms, wildfire, pests and disease outbreaks), on **oceans** (acidification, warming, ocean level rising, loss of islands and densely populated coastal regions) and on **animals and plants** (loss of habitat, loss of biodiversity, invasive species shift in species distribution). All of these have an impact **on human society**.

Diminishing fish stocks, longer and more extreme droughts and the negative impact on freshwater resources are detrimental to UN SDGs like "**zero hunger**", "**clean water and sanitation**", "**no poverty**" or "**good health**". Climate change also affects people without the means to cope and adapt, and this can lead to potential conflicts with respect to "**peace and justice**", "**inequalities**", "**education**" or "**gender equality**". All of these impacts will be already significant at a global

10 IPCC, 2014: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp. Author's note: after a first analysis of the new update in the IPCC report published in 2021 (Climate Change 2021: The Physical Science Basis), both reports arrive at similar numbers and conclusions.

11 A. Shepherd et al., "Mass balance of the Antarctic ice sheet from 1992 to 2017," Nature 558 (2018). https://doi.org/10.1038/s41586-018-0179-y. For a journalistic summary, see Kendra Pierre-Louis, "Antarctica is melting three times as fast as a decade ago," New York Times, June 13

temperature increase of 2°C, which is far from the worst scenario. In recent years scientists have started to discuss the danger of reaching so-called tipping points, where elements of the global climate system could shift into a different state[12]. One example could be polar ice melt reaching a tipping point where there is no return to a balanced state of seasonal ice growth. Such changes can take place abruptly and, in some cases, irreversibly. One controversial scenario describes the risk of Earth entering so-called "**Hothouse Earth**" conditions. A "Hothouse Earth" climate will in the long term stabilise at a global average of 4-5°C higher than pre-industrial, even if human emissions of greenhouse gases would stay within the defined 2°C limit. In any case, to avoid drastic consequences of climate change, global warming should be limited as much and as fast as possible.

The global risk report 2022 of the World Economic Forum (WEF) includes the so-called Global Risks Perception Survey 2021-2022, where a network of experts from academia, business, government, civil society and thought leaders were asked about the severity of global risks and how they affect other risks within the next 10 years. Answers from roughly 1,000 participants resulted in an overview of what is perceived as the most potentially damaging risk and how these risks will aggravate other risks. The by far highest ranked risks were climate change, extreme weather, and biodiversity loss, with significant aggravation of the latter two by climate change. A detailed overview of most potentially damaging risks and risks they will aggravate can be seen in Figure 1 below. In the lower segment of the figure, the significant impact of climate change on other risks is depicted. It further highlights the critical and urgent issue that human-made climate change has become, particularly as these results are focused on the upcoming 10 years and climate change and its consequences are perceived already within that timeframe as the overwhelmingly risk by these experts.

Climate change is such an existential threat that its consequences will impact every single UN Sustainable Development Goal (SDG).

12 A more detailed comment on tipping points (Climate tipping points – too risky to bet against") was made by Lenton et al., 2020 on the nature.com website: https://www.nature.com/articles/d41586-019-03595-0, accessed 21-08-05

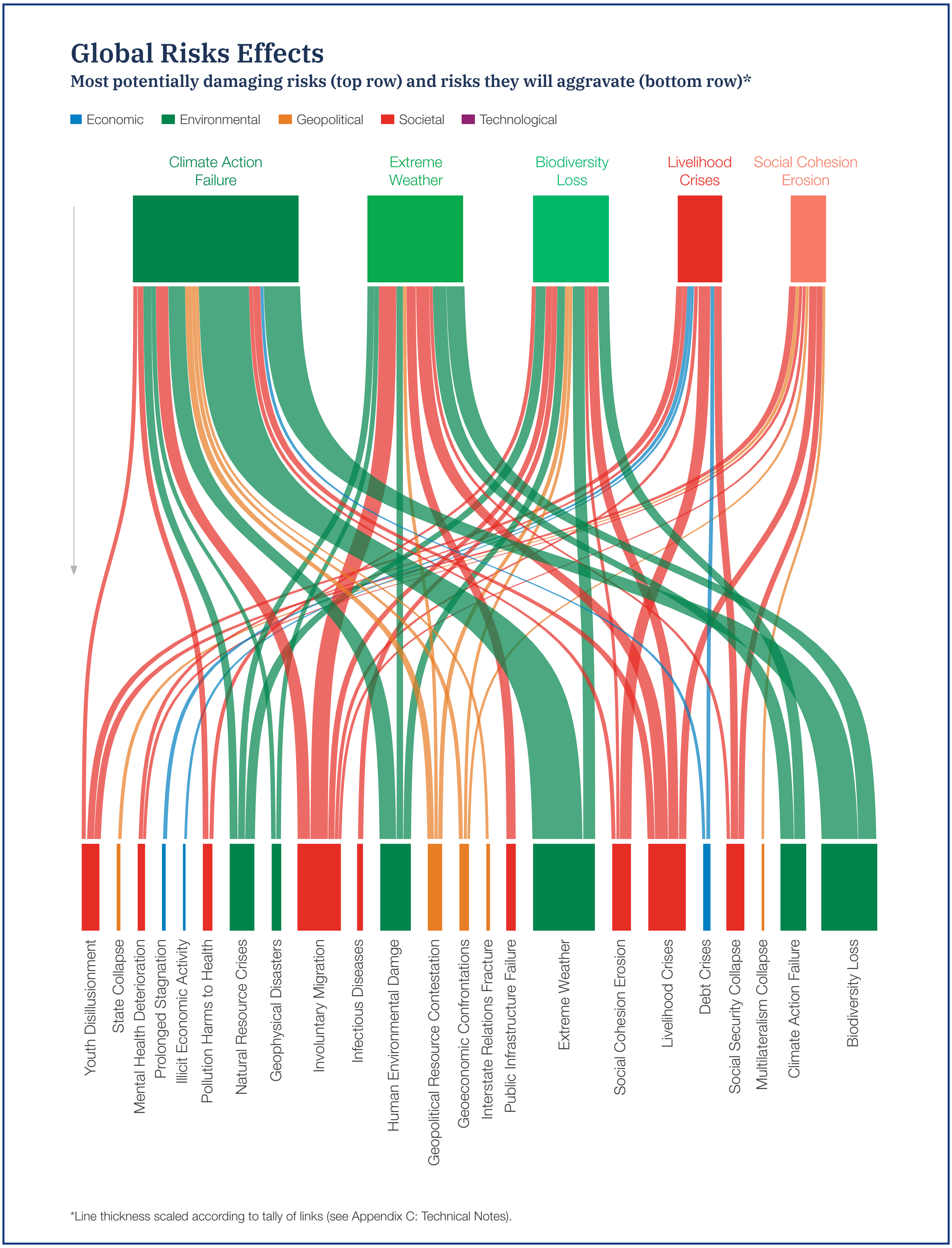

Figure 1: Global Risk Effects taken from the World Economy Forum "Global Risk Report 2022", Credit to E. Granados Franco, M. Kuritzky, Richard Lukacs, Saadia Zahidi et al., Global Risk Report 2022, © 2022 World Economy Forum. Available online at https://www3.weforum.org/docs/WEF_The_Global_Risks_Report_2022.pdf

1.2 The main reason for anthropogenic climate change is fossil carbon

There is common scientific agreement that only a small group of greenhouse gases are responsible for human-made climate change: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and fluorinated gases (F-gases). Usually, the impact of each of these gases is translated into the amount of CO_2 that equals the impact on climate change (CO_2 equivalent) in order to put all gases contributing to climate change into a single, commensurate unit. These numbers can be used for comparisons and enable us to show that fossil carbon is by far the biggest reason for climate change. Looking at recent statistics summarised by the Netherlands Environmental Assessment Agency PBL, the key GHGs emitted by human activities add up to 55.6 Gt CO_2eq for the year 2019[13].

Carbon Dioxide (CO_2): 74.2 % or 41.3 Gt CO_2eq
The major driver of CO_2 emissions is the combustion of coal, oil, and natural gas. But there are other, often neglected, sources of CO_2 emissions. On the one hand, these are material uses of carbon, e.g. for the production of chemical feedstock, cement, lime or coke production. On the other hand, these are direct human-induced impacts on forestry and other land uses such as through deforestation, land clearing for agriculture, and degradation of soils. 89% of CO_2 emissions are due to fossil fuels, 11% from land-use changes. This is in line with the latest IPCC numbers, which calculate that from global CO_2 emissions between 2010–2019, 86% are based on fossil fuels and 14% based on land use change.

Methane (CH_4): 17.8 % or 9.9 Gt CO_2eq
Methane emissions largely occur due to agricultural activities (livestock), waste management, crude oil extraction, and biomass burning. At least 33% of all methane emissions are due to fossil fuels (or even higher[14]). This is again in line with the latest IPCC numbers, which calculate that from the global CH_4 emissions between 2008–2017, around 32% were based on fossil fuels, roughly 60% based on agriculture and waste and the remaining 8% due to biomass burning and biofuels.

Nitrous oxide (N_2O): 5 % or 2.8 Gt CO_2eq
Agricultural activities, in particular fertiliser use, are the primary source of N_2O emissions. Fossil fuel combustion also generates N_2O, but only to a small extent.

Fluorinated gases (F-gases): 3 % or 1.7 Gt CO_2eq
The main contributors to F-gas emissions are industrial processes, refrigeration, and the use of a variety of consumer products, which include hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF_6).

When adding up the carbon-containing methane, carbon dioxide and HFC/PFC, it becomes evident that approximately 92% of the GHGs contain carbon. 89% of CO_2 emissions (i.e. 36.76 Gt CO_2) are from fossil fuels, and at least one third of human-induced methane emissions (i.e. 3.3 Gt CO_2eq) are also derived from fossil fuels. In total, roughly 40.1 of 55.6 Gt CO_2eq or 72% of all GHG emissions were based on fossil carbon.

13 https://www.pbl.nl/sites/default/files/downloads/pbl-2020-trends-in-global-co2-and-total-greenhouse-gas-emissions-2019-report_4068.pdf

14 Recent estimates point to an even higher fossil share of methane emissions: „About half of our methane emissions come from the fossil fuel industry – oil, coal and gas – while the other half is from agriculture (land use changes and livestock) and waste sites (organic waste). Livestock, particularly, cows are a major source of methane“. Adam Vaughan: The methane mystery, in: New Scientist, 22 May 2021

In the year 2019, 80% of the carbon-containing GHGs or 72% of the entire GHGs originated from additional fossil carbon from the ground. The use of additional fossil carbon from the ground, is the main cause of the greenhouse effect and anthropogenic climate change.

The remaining non-fossil carbon comes from land-use changes due to forestry, agriculture and livestock production. But this carbon can be balanced by a sustainable circular bioeconomy, where the uptake and the release of carbon are the same, and by reforestation which could even lead to higher uptake, rather than release of carbon.

1.3 How much carbon can still be released into the atmosphere?

A carbon budget is a simplified way to demonstrate the amount of additional emissions allowed to enter the atmosphere and keep global warming within a desired level. It can be calculated by relating cumulative CO_2 emissions to global mean temperature increase. The IPCC has undertaken tremendous effort to calculate remaining cumulative budget ranges that provide us with realistic chances to stay below certain thresholds. In its most recent publication from 2021[15], the following **remaining cumulative budgets** starting from end of 2020 have been calculated:

- **400** (66% chance) / **500** (50% chance) / **650** (33% chance) Gt CO_2eq if we want to stay below 1.5° C threshold
- **1,150** (66% chance) / **1,350** (50% chance) / **1,700** (33% chance) Gt CO_2eq if we want to stay below 2°C threshold

If emissions continue at current levels, we will reach a 50% chance of surpassing the 1.5°C threshold in 9 years and a 50% chance of surpassing the 2°C rise in global warming in 25 years. This sum can also be recalculated by how much additional fossil carbon we can still afford to extract from underground. 1 Gt CO_2 emissions relate to 0.273 Gt C (1/3.664). Therefore, we should not extract more than **110–170 Gt of fossil carbon** for a chance to keep global warming below 1.5°C and **310–460 Gt of fossil carbon** for 2°C. Proven reserves of fossil fuels are by far larger than the remaining budget. Based on calculations by BP for the end of 2019, it is calculated that the following proven reserves of fossil carbon remain: 910 Gt carbon bound in coal, 200 Gt carbon bound in crude oil and 110 Gt carbon bound in natural gas[16].

When considering the current annual extraction of 10-11 Gt fossil carbon from the ground, the remaining budget will be spent entirely within the next 10 to 15 years (1.5°C) or 30 to 45 years (2°C).[1] The transition to replace fossil carbon by renewable energy and renewable carbon is inevitable and must happen quickly and by large volumes!

1 *The CO_2 budget left is shown online and updated here: https://www.mcc-berlin.net/fileadmin/data/clock/carbon_clock.htm*

15 IPCC report AR6, Climate Change 2021: The Physical Science Basis: https://www.ipcc.ch/report/sixth-assessment-report-working-group-i/

16 Fossil reserves according to BP: 1,069 Gt of coal (~85% carbon content), 1.733 thousand million barrels (i.e. 235.7 Gt) of crude oil (85% carbon content), 199 trillion cubic metre (i.e. 143 Gt) of natural gas (75% carbon content). https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2020-full-report.pdf

A recent publication by the Institute for Sustainable Resources, University College London, came to a similar conclusion[17]:

> *"Unextractable oil, fossil methane gas and coal reserves are estimated as the percentage of the 2018 reserve base that is not extracted to achieve a 50% probability of keeping the global temperature increase to 1.5 °C. We estimate this to be 58% for oil, 59% for fossil methane gas and 89% for coal in 2050. This means that very high shares of reserves considered economic today would not be extracted under a global 1.5 °C target."*

These data show that the market, left alone with cheap fossil feedstocks, will not be able to solve the climate crisis on its own. Strong instruments are needed that push our economy away from fossil carbon where it is already densely sequestered.

All of this has to happen quickly, because the window for action to achieve the Paris Agreement targets is diminishing. The complete substitution of fossil carbon with renewable energies and renewable carbon is one of the greatest challenges humankind is facing. This task requires a comprehensive, globally coordinated strategy – namely carbon management supported by a coherent policy framework (details below).

In its recent report "Net Zero by 2050 – A Roadmap for the Global Energy Sector"[18], the rather conservative International Energy Agency (IEA) urgently calls for rapid action as well:

> *"We are approaching a decisive moment for international efforts to tackle the climate crisis – a great challenge of our times. The number of countries that have pledged to reach net-zero emissions by mid-century or soon after continues to grow, but so do global greenhouse gas emissions. This gap between rhetoric and action needs to close if we are to have a fighting chance of reaching net zero by 2050 and limiting the rise in global temperatures to 1.5 °C. Doing so requires nothing short of a total transformation of the energy systems that underpin our economies. We are in a critical year at the start of a critical decade for these efforts."*

While the IEA naturally focuses its attention on the energy sector, the consequences for the chemical and materials industries are also examined in this paper. The basic message is the same, but the implementation is fundamentally different.

No additional fossil carbon must be allowed to enter the atmosphere, but at the same time carbon is an essential part of our daily lives. The carbon that is needed for the countless products of modern life must no longer be taken from the ground, because sooner or later it ends up in the atmosphere.

17 Welsby, D., Price, J., Pye, S. et al. Unextractable fossil fuels in a 1.5 °C world. Nature 597, 230–234 (2021). https://doi.org/10.1038/s41586-021-03821-8

18 International Energy Agency 2021: Net Zero by 2050 – A Roadmap for the Global Energy Sector. France, May 2021.

1.4 Climate change mitigation: A sixfold challenge

When considering the report "Net Zero by 2050" by the IEA and the assessment reports of the IPCC, five key challenges to mitigate climate change can be summarised. These five challenges focus on energy sources, also for transport, on the circular economy with improved circularity and efficiency and on reducing the carbon footprint of land use. In this paper, we seek to add a sixth challenge that considers the raw material base for sectors that are dependent on carbon. These challenges are visualised in a graphic called the "Climate Change Mitigation Star" (Figure 2).

In the foreseeable future the energy sector can meet the demand for electricity and heat through renewable energy sources without extracting or emitting fossil carbon. There are comprehensive strategies for decarbonisation – a term that makes a lot of sense in the context of energy – and strong investment in solar, wind and hydro energy as well as hydrogen as an energy carrier and for storage.

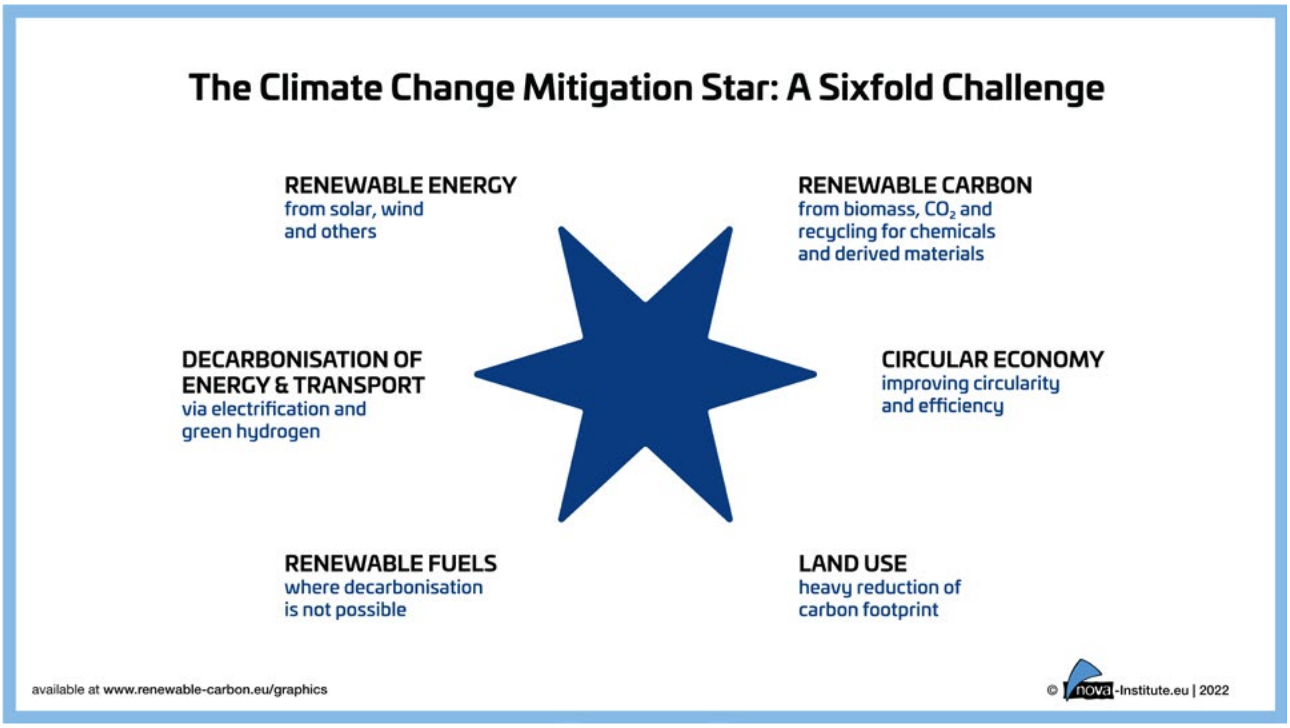

Figure 2: The Climate Change Mitigation Star

For challenges in the energy sector, viable concepts have been adopted. Michael Le Page from the New Scientist wrote:

> *"Managing the transition to better energy sources is now not about can or can't, but will or won't. [...] Not that long ago, many people doubted whether wind and solar power could ever supply a sizeable amount of energy at a reasonable cost. No longer. 'It's clear that renewables have massively outperformed most people's expectations and continue to do so on a regular basis,' says Simon Evans at Carbon Brief, a UK website specialising in climate analysis. 'We are getting closer to the point where renewables are going to genuinely cut into fossil fuels."*[19]

19 Freely quoted and expanded from: Michael Le Page „A new energy world“ in New Scientist, 7 August 2021, based on the last report of the International Energy Agency. Available online at: https://www.newscientist.com/article/mg25133463-600-how-we-can-transform-our-energy-system-to-achieve-net-zero-emissions/#ixzz74l6gVbQf

There are no corresponding concepts to decarbonisation of the energy sector for the chemical and materials sector yet. Decarbonisation itself also is not the way forward for the chemical and materials industries, which are fundamentally based on the use of carbon. For a comprehensive climate change mitigation concept, the challenge of the embedded carbon in chemicals and derived materials needs to be properly addressed as well.

In the following segment the focus will be entirely on this issue and introduce the renewable carbon concept in detail.

The key question is how to defossilise the chemical industry, which non-fossil carbon sources can be used in the future. The chemical and material industry must get its carbon exclusively from the atmosphere, biosphere and technosphere, keeping the renewable carbon in a cycle.

2. Renewable carbon as a guiding principle

2.1 The renewable carbon concept for the chemical and derived material sector

> *„It is not CO_2 that is at the core of the climate problem, but the additional fossil carbon that we take out of the ground and which gets released in the atmosphere as CO_2 or other emissions. If the inflow is prevented, the CO_2 content of the atmosphere will no longer increase.“ (Carus 2020)*

Key to understanding the renewable carbon concept is the following premise: the more fossil carbon taken out of the ground, the bigger the CO_2 problem above the ground will become. If carbon sources are only used from above the ground, the increase of CO_2 in the atmosphere will end. A true solution here should tackle the problem at its roots and stop adding more fossil carbon into the cycle above ground. There is also an alternative to using fossil carbon: renewable carbon from biomass, CO_2 utilisation or recycling. Together with renewable energy, the concept can become the foundation of a sustainable future (Figure 3).

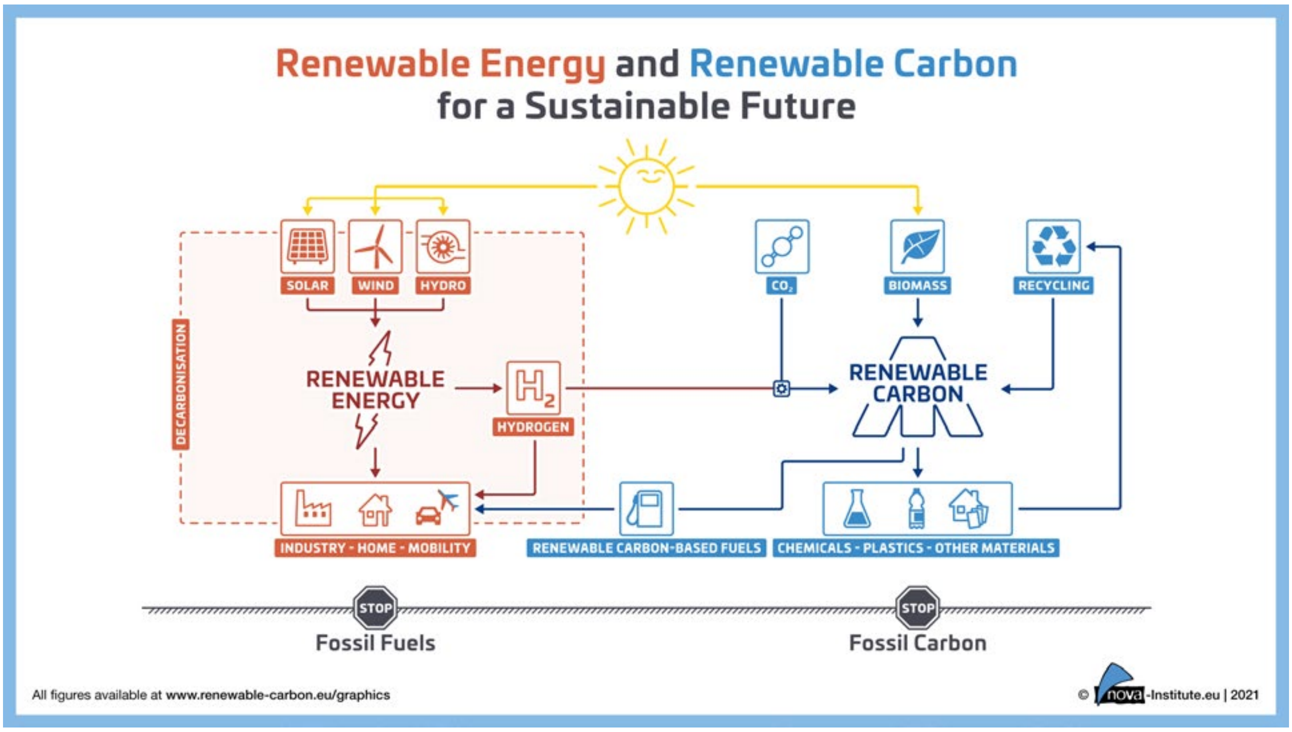

Figure 3: Renewable Energy and Renewable Carbon for a Sustainable Future

The renewable carbon concept was first introduced by nova-Institute in the year 2018 and comprehensively presented in paper no.12 “Renewable Carbon – Key to a Sustainable and Future-Oriented Chemical and Plastic Industry: definition, strategy, measures and potential”[20]. It gives a full and in-depth picture of renewable carbon and related strategies. The paper provides **clear definitions** (see Excursus: Renewable Carbon) of the available renewable carbon sources, **pros and**

20 www.renewable-carbon.eu/publications/product/nova-paper-12-renewable-carbon-key-to-a-sustainable-and-future-oriented-chemical-and-plastic-industry-%E2%88%92-full-version/

cons of each of the different sources, a **discussion of the huge market potential**, **scenarios** for a chemical and polymer industry fully based on renewable carbon, and **political measures** to support a quick transition to renewable carbon. It outlines the cornerstones of the transition from fossil carbon to renewable carbon for all organic chemicals and materials. The paper was in response to the increasing need for reform in the chemical industry and offers a comprehensive approach for policy and industry alike.

The equivalent to decarbonisation via renewable energy in the energy sector is the transition to renewable carbon in the chemical and derived materials industries. Both strategies avoid bringing additional fossil carbon from the ground into the cycle and can be summarised under the new term "defossilisation".

The RCI is not alone in this assessment. Scientists of the university of Oxford wrote in May 2021: "Three approaches to sourcing carbon for polymer production in a net-zero carbon environment stand above the rest: (i) use of biomass (plants and wastes) as an alternative raw material, with atmospheric CO_2 uptake occurring during crop growth (i.e. indirect capture); (ii) use of CO_2 captured directly from the atmosphere or chemical processes as a carbon source; and (iii) circular use of waste or discarded polymer product as a source of carbon via recycling"[21].

This concept is even more important to hedge against shrinking demand from the energy and transport sectors, big oil and gas companies are focusing massively on the growing carbon demand of the chemical and plastics industries, with the intention of meeting this demand through fossil fuels in the long term as well. This aspect and the associated large quantities of fossil carbon that will continue to enter the atmosphere as CO_2 for decades can no longer be ignored from a climate policy perspective.

The main takeaway from the above segment is rather straightforward. By managing to avoid further utilisation of fossil carbon, the vast majority of GHG emissions can be prevented. This would be a decisive step towards climate change mitigation and come with many further positive effects related to the SDGs. This is also exactly what the renewable carbon concept addresses; replacing fossil carbon in chemicals and materials with renewable alternatives.

Using more renewable carbon instead of fossil carbon from the ground for chemistry and its myriad of downstream products in modern life is definitely a move in the right direction, because it enables true net-zero emissions by keeping carbon in a cycle. Therefore, renewable carbon can put the chemical and materials sector on track towards climate protection and sustainability.

21 Collett K. et al. 2021: Industrial need for carbon in product; Final 25% Series Paper. Oxford Smit School of Enterprise and the Environment. Available online at: https://www.smithschool.ox.ac.uk/publications/reports/Industrial_Need_for_Carbon.pdf

2.2 The difficulty of transforming from slow and small to fast and big while keeping the right direction towards sustainability?

There is little time remaining to reduce our GHG emissions and to put our economy on a sustainable pathway. Achieving sustainability is a challenge in terms of practical implementation. In modern sustainability assessments, a multitude of dimensions, criteria and indicators should be considered to receive a holistic picture. Complex analyses are often conducted, expert opinions commissioned, and solutions discussed, sometimes spanning over years. The results of these processes are not always straightforward, because the investigated product may only be better in some respects, e.g. providing benefits towards one goal but drawbacks towards another goal. This leads to intricate outcomes, which complicate, weaken, delay, or prevent decision-making. Improved animal welfare through increased space for grazing for example can lead to higher resource demands and thus higher CO_2 emissions per unit, renewable energy can require more land than conventional power plants, and the use of fertilisers and pesticides can at the same time be positive (higher yields, less arable land required) and negative (nutrient pollution, biodiversity loss). There are practically no solutions that are better in all aspects to be evaluated – in a complex system, answers will never be black and white. The relative importance of the different criteria has to be discussed too and it is difficult to find a consensus as well – especially on a global scale. There is some growing agreement that climate and biosphere integrity (biodiversity) are two key impact categories of the most importance at global scale, performing a regulating role for many other impacts (which may be more or less important at local scales) – but not everybody agrees.

Therefore, the often-ambiguous results of sustainability assessments can make it difficult to derive clear recommendations on innovative solutions. This is a barrier for the industry to switch to alternative solutions, because any critical point in a sustainability assessment can be a red flag. Herein lies a major issue: the established economic system is largely based on fossil carbon, the driving force behind climate change. At the same time, the dangers of all alternative systems have been comprehensively analysed and described in such detail that any shift away from the established system becomes a tedious, risky, expensive, and slow to implement[22]. But the threat of climate change and its interconnection to biodiversity are increasingly understood and require fast action via scalable and disruptive innovation and large-scale business transformation.

2.3 A shift from sole efficiency-focus towards a higher effectiveness

Companies continuously try to improve today's products. The goal is usually higher efficiency, to gain the same benefit with less environmental impact and more output with less input – as the chemical industry has successfully experienced over the past decades. Efficiency is focused on improving the existing and it is an important tool that companies are rightfully pursuing in their endeavours. But it ignores the fact that overall emissions and environmental impact are not necessarily reduced if only efficiency is maximised. In times of global population growth and an increase in the level of prosperity, efficiency increases are not sufficient to reduce total global greenhouse gas emissions. Additionally, rebound effects can have significant impacts, for example if a technology or product

22 This can also lead to an issue called "paralysis by analysis", which means the "Inability to respond effectively to a situation due to an over-analytical approach or to an excess of available information." (Oxford University Press: https://www.lexico.com/en/definition/analysis_paralysis (last access 21-08-11).

becomes more efficient and cheaper and is therefore used more often. Efficiency is in a sense "direction-blind". A world is possible in which everything becomes continuously more and more efficient, but total emissions and other environmental impacts continue to rise nonetheless.
This is currently reflected in reality. CO_2 emissions from around the world are not falling, despite all the new technology, and climate targets cannot be met with current growth rates. Yet the goal is clear and frequently formulated nowadays: climate neutrality or net zero.

In contrast to the highly prevalent efficiency-focus, the renewable carbon concept aims at increasing effectiveness. What is the difference between being 'efficient' and being 'effective'? 'Effective' means "adequate to accomplish a purpose; producing the intended or expected result"[23], whereas "efficient" means "performing or functioning in the best possible manner with the least waste of time and effort"[24], or in our context: "… with the least waste of resources". Being effective is about doing the right things, while being efficient is about doing things right.

To substitute fossil carbon, a variety of new technologies will be needed, some of which are still under development. Even if some do not perform better than petrochemicals yet, they move in the right direction – and are often the better solution in the medium term. That is the difference between efficiency and effectiveness. After a hundred years of learning and optimisation, today's petrochemical industry is very highly integrated and extremely efficient. Outperforming their products with new technologies and process chains is often not possible from scratch. But petrochemicals are not effective, not adequate for the purpose of climate change mitigation, as they bring large amounts of new fossil carbon into circulation. Although the additional carbon might be less per product, cheaper prices mean it sells correspondingly more products (rebound effect). As such the chemical industry did things right (more efficient), but not the right things (not effective) in recent decades. Only the decoupling of chemistry from fossil raw materials is effective here and the rapid switch to renewable carbon seems to be the answer.

Climate change is one of the great challenges of our time. Clear visions, strategies and measures are needed on how life and the economy on our planet can be managed without the emission of fossil human-made GHGs as quickly as possible. The Climate Mitigation Star (Figure 1) might be a valuable visualisation on the key topics to be addressed. All in all, we are far too slow on our path to efficiently and effectively counter the effect of anthropogenic climate change. This is in large parts due to the complexity of sustainability, the connected heavy uncertainty in industries and the political unwillingness to prioritise appropriately. A drastic change of our industrial systems is needed, and this requires massive investments in new technologies, clear framework conditions and a guiding principle to provide industries with certainty to move in the right direction. In principle, an analogy to the renewable energy sector can be drawn. Many questions remain about energy storage, requirements for grids of the future or necessary capacities, but the direction towards renewable energy is clear. A similar concept addressing fossil carbon as a raw material could guide a system change towards sustainability for the chemical and material sectors.

We need a system change, a guiding principle that enables our economy to shift away from a sole efficiency-focus towards a higher effectiveness that allows to think out of the box of established boundaries: stopping the influx of additional fossil carbon from the ground.

23 https://www.dictionary.com/browse/effective

24 https://www.dictionary.com/browse/efficient

2.4 Why renewable carbon works well as a guiding principle for the future of the chemical and materials sector

Science, politics and society as a whole consider climate change as probably the most important challenge for the next few decades. But it is clearly not the only one. In recent years, in particular the loss of biodiversity has prominently moved into public focus, and many other challenges are reflected in global sustainability indicators like the SDGs. But as was pointed out in detail above, climate change has a strong influence on practically all of these indicators. Losses of and major changes in habitats due to climate change are among the most important causes of biodiversity loss and they are heavily increasing in significance. Climate change is already responsible for most of our sustainability issues, and it is a ticking time bomb with high uncertainty on how violently it will explode.

Excursus

"Why rescuing the climate and saving biodiversity go hand in hand"

> *"Global warming is a "threat multiplier" for habitats and species already under pressure – by understanding how the problems are linked, we can solve two crises at once. But our chances are better if we think more smartly about the links between biodiversity loss and climate change, and tackle both of these issues together. Done right, a rescue plan for nature can be part of a plan for saving humanity from the worst of climate change – and vice versa.*
>
> *The world has warmed around 1°C since pre-industrial times. That is already having a dramatic effect on wildlife. In the Arctic, for example, the loss of more and more sea ice each summer is affecting many animals, from walruses to polar bears.*
>
> *One recent study[1] looked at the effect of future climate change on 80,000 species in 35 of the most wildlife-rich areas, including the Amazon rainforest and the Galapagos Islands. With warming of 5°C by around the 2080s, half of these species would no longer be able to survive in these areas.*
>
> *In many parts of the world, even if suitable habitat remains, many species may not be able to reach it, because their paths are blocked by cities, roads, farms and fences. The same study found that if animals were able to move freely, 2°C of warming would result in the loss of 20 per cent rather than 25 per cent of species."[2]*

1 Warren R et al. 2018: The implications of the United Nations Paris Agreement on climate change for globally significant biodiversity areas (https://link.springer.com/article/10.1007%2Fs10584-018-2158-6)

2 Le Page, M 2021: Why rescuing the climate and saving biodiversity go hand in hand. New Scientist 7 April 2021 (https://www.newscientist.com/article/mg25033291-800-why-rescuing-the-climate-and-saving-biodiversity-go-hand-in-hand/#ixzz6zh4eyKXd)

Breaking climate change down to a guiding principle, it has been shown that 72% of climate change is caused by additional fossil carbon from the ground. The remaining 28% occurs due to land use changes and livestock production. But these emissions can be remedied – albeit a big and complex challenge – e.g. with proper land use management and reduced meat consumption. The tightly stacked fossil carbon on the other hand was sitting below ground for millions of years, and once it is excavated and transformed, there is (at least for the foreseeable future) no technology available to return it to its dense constitution underground. It is here where the problem should be tackled and where a guiding principle would be most effective.

The further influx of additional fossil CO_2 emissions must be reduced as quickly as possible and stopped completely. It is therefore of fundamental importance to leave fossil carbon in the ground and not add more of it into the techno- and atmosphere. In the energy sector, this strategy is described as decarbonisation via renewable energy. Similar to how renewable energy is understood as the sustainable future of the energy system, renewable carbon can be understood as the sustainable future of the chemical and materials sector – from carbon sources below the ground to carbon sources from above the ground. The equivalent in the chemical and materials sector is the substitution of fossil carbon by renewable carbon. Both mean defossilisation. A simplified framework with renewable carbon as a guiding principle would head towards an overarching goal (mitigating anthropogenic climate change) but provide a wide enough avenue for industries to innovate, to investigate and to develop and implement different technological pathways. As such, renewable carbon should become a guiding principle for the transformation of chemistry and its derived materials sectors.

With the focus on renewable carbon, analogous with the famous Greek myth, one does not simply cut off a head from the sustainability hydra, from which two new ones then grow, no, one targets the myth's immortal head in the middle: the fossil carbon that is continually being added to the atmosphere and technosphere.

The focus on renewable carbon shifts thinking towards the goal that needs to be achieved and provides a guiding principle along which companies can align their developments. With the phasing out of fossil carbon comes a drastic reduction of additional greenhouse gas emissions. A complete shift to renewable carbon is an absolute goal that will be a central pillar to enable climate neutrality, regardless of wealth or population growth.

2.5 Carbon Management – required for renewable carbon as a guiding principle

If renewable carbon were to be established as a guiding principle towards a sustainable economy, a critical element would be the implementation of a proper carbon management.

Carbon management is properly organising the complex transition from today's fossil carbon from the ground to renewable energy and to renewable carbon across all industrial sectors. Such a management would not only require effort from the industries, but should be flanked by policy measures, technology developments and major investments.

For the energy sector, the path to manage renewable energy is largely consensual: renewable energy sources, especially solar and wind energy, together with hydrogen as storage and energy carrier, can cover more than 95% of the total energy demand by 2050[25,26] and thus decarbonise the energy sector as far as possible. But principally, there is no lock-in of specific renewable energy sources, so that the transition towards the final goal is open to any technology that provides renewable energy, and the best solutions can be implemented for different regions and situations. The simple, but clear goal of shifting towards renewable energy sources is a primary indicator, a guiding principle that enables the transition of the whole sector. In the energy sector, carbon management means avoiding the use of carbon where possible (e.g. electrification, H_2, fuel cells), and identifying best solutions in cases where carbon will be required in the long-term.

Some countries already have renewable shares of 50% in the energy sector today. The International Energy Agency describes in their report "Net Zero by 2050 – A Roadmap for the Global Energy Sector" from 2021, what such a decarbonisation would mean:

> *"Ever-cheaper renewable energy technologies give electricity the edge in the race to zero. Our pathway calls for scaling up solar and wind rapidly this decade, reaching annual additions of 630 gigawatts (GW) of solar photovoltaics (PV) and 390 GW of wind by 2030, four-times the record levels set in 2020. For solar PV, this is equivalent to installing the world's current largest solar park roughly every day. Hydropower and nuclear, the two largest sources of low-carbon electricity today, provide an essential foundation for transitions. As the electricity sector becomes cleaner, electrification emerges as a crucial economy-wide tool for reducing emissions. Electric vehicles (EVs) go from around 5% of global car sales to more than 60% by 2030."*

What is required is an overarching carbon management strategy that also takes specific regional and application-related features into account, to identify the most sustainable carbon source from the renewable carbon family.

25 LUT University and Energy Watch Group 2019: Global Energy System based on 100% Renewable Energy.

26 Carbon Tracker Initiative 2021: The sky's the limit –Solar and wind energy potential is 100 times as much as global energy demand.

For the whole chemical and material sector such as plastics or detergents as well as wood in construction, the situation is different, as these products are based on carbon which cannot be substituted or decarbonised. The carbon is embedded in these products[27]. Here, the task of carbon management is to examine the current and future demand for carbon. What is the long-term carbon demand of chemicals and derived materials? And how can this demand be met as sustainably as possible, including all alternative carbon sources – without any additional fossil carbon from the ground?

A proper carbon management should simultaneously apply the same sustainability requirements to all renewable carbon streams – biomass, CO_2 and recycling. Such a strategy does not yet exist, but first documents in regard to its development were released end of 2021[28]. It is indispensable to shift towards renewable chemicals, materials, and products. It enables the development of a realistic strategy to completely substitute fossil carbon and thus tackle the climate problem at its root.

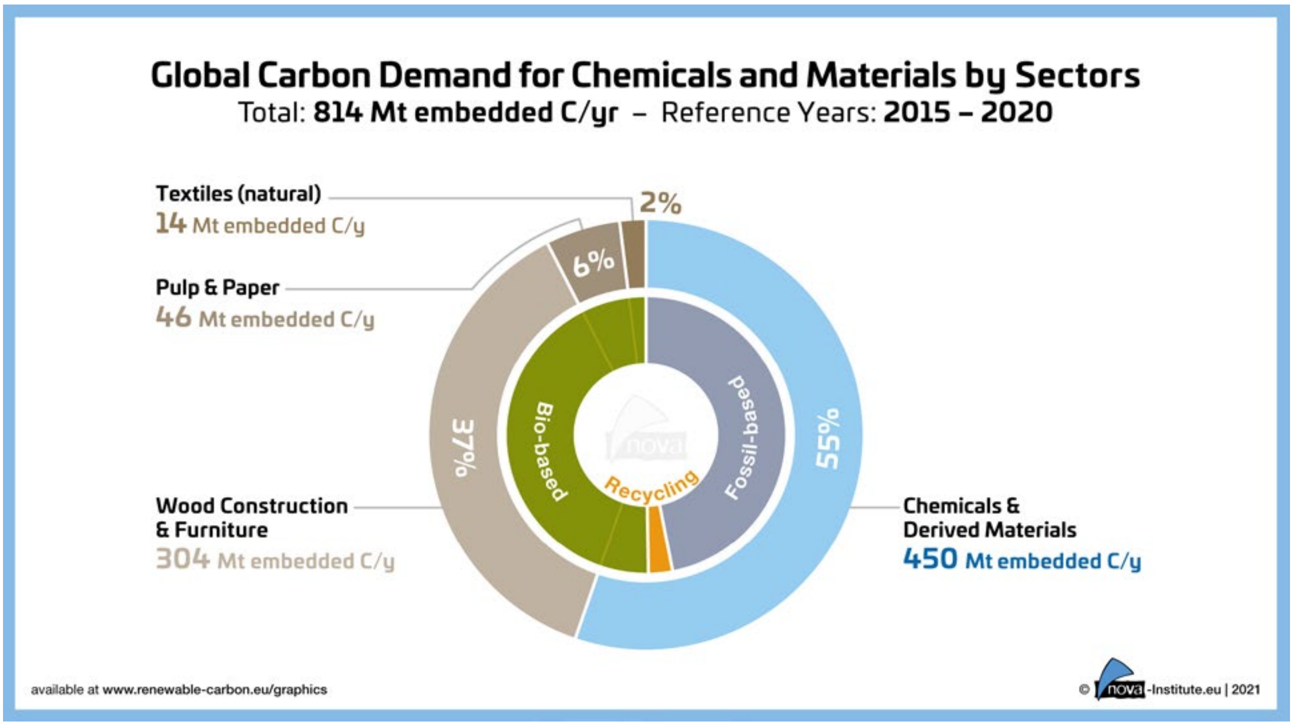

Figure 4: Global carbon demand for chemicals and derived materials by sectors

27 The term “embedded” here refers to only the carbon that is actually bound in the structure of the molecule, not any otherwise process-related carbon or emissions. There is no standardised term for “embedded” carbon, the IEA speaks of “embodied” carbon (International Energy Agency 2021: Net Zero by 2050 – A Roadmap for the Global Energy Sector. France, May 2021), in the EU ETS the term “carbon content” and “chemically bound” are mainly used, and Kircher mainly refers to “product-bound” carbon (Kircher, M. 2021: The framework conditions must be aligned to the requirements of the bioeconomy. EFB Bioeconomy Journal 1 (2021), https://doi.org/10.1016/j.bioeco.2021.100003).

28 RCI 2021: Press release “Political tailwind for alternative carbon sources”, available at https://renewable-carbon-initiative.com/media/press/?id=304

A recent study by nova-Institute, commissioned by Unilever, for the first time determined the global demand for embedded carbon in chemicals and derived materials and developed a scenario for 2050 that does not require any additional fossil carbon[29]. Please note that this is an "explorative scenario", which means that data and statements for 2050 and also derived figures (e.g. Figure 4) are based on plausible assumptions[30]. The demand for carbon embedded in organic chemicals and their derived materials is 450 million tonnes (Mt) per year. 85 % of this demand is generated by fossil-fuel-based resources, 10 % by biomass and only 5 % by recycling, meaning 15 % (67.5 Mt) are renewable. The demand for embedded carbon is set to rise. Increasing population, higher incomes and a growing middle class will drive the need for products and thus also for carbon – and this includes already increased material efficiency and changes in personal behaviour. By 2050, the authors estimate that the demand for carbon embedded in organic chemicals and derived materials will increase to 1,000 Mt per year. The renewable carbon supply will have to be increased by a factor of 15 until 2050 (from 67.5 Mt currently to 1,000 Mt) to cover the needs of the chemical and materials sector – without using additional fossil carbon from the ground. This complex task will require cross-sector collaboration from industry, governments and consumers through a harmonised carbon management.

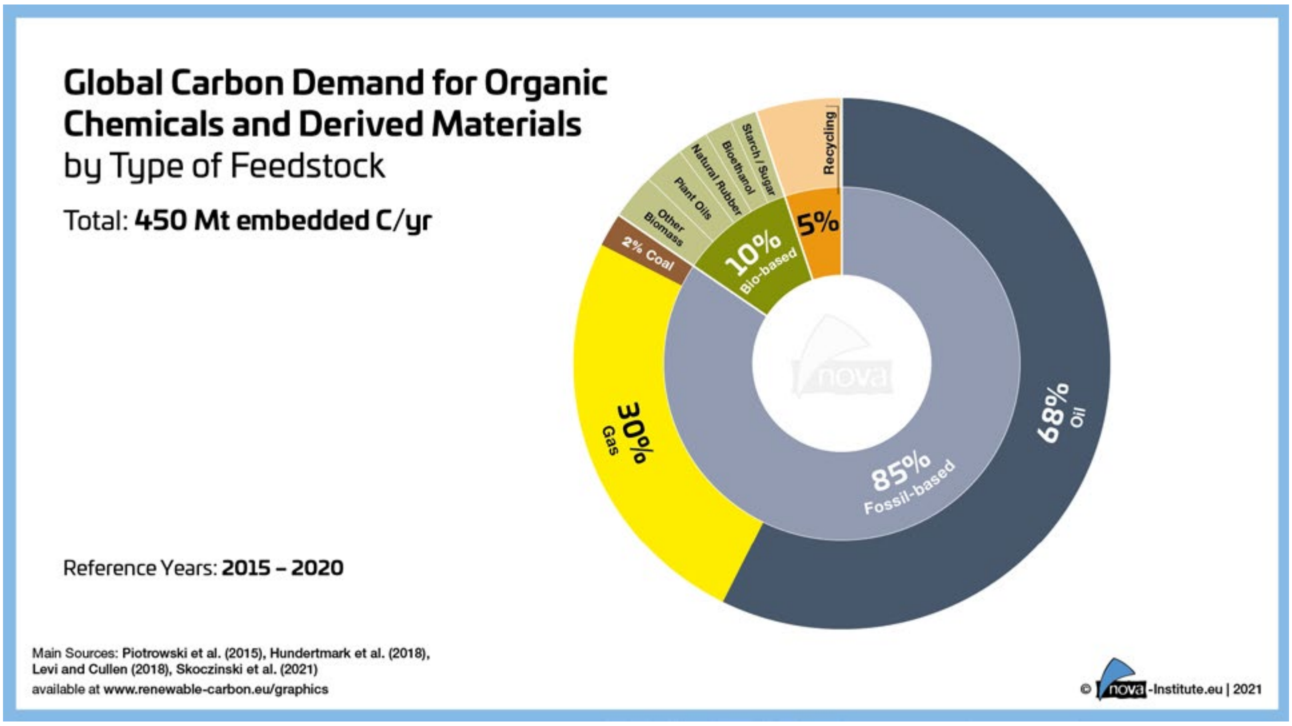

Figure 5: Global carbon demand for organic chemicals and derived materials

Sharing, re-using and recycling play the main role in keeping carbon in a closed loop, in line with the Circular Economy. Mechanical and chemical recycling industries will be largely responsible

29 Kähler, F., Carus, M., Porc, O., vom Berg, C. 2021: Turning off the Tap for Fossil Carbon – Future Prospects for a Global Chemical and Derived Material Sector Based on Renewable Carbon (www.renewable-carbon.eu/publications/product/turning-off-the-tap-for-fossil-carbon-future-prospects-for-a-global-chemical-and-derived-material-sector-based-on-renewable-carbon/)

30 For further information, please refer to https://renewable-carbon.eu/publications/product/turning-off-the-tap-for-fossil-carbon-future-prospects-for-a-global-chemical-and-derived-material-sector-based-on-renewable-carbon/

for innovating their processes to better re-use and recycle carbon. Since keeping the entire carbon in cycle is technologically not possible, additional renewable carbon sources such as biomass and CO_2 capture and utilisation become necessary. For both options, sufficient land is available[31,32] for either cultivation or the production of the required renewable energy. With the three renewable carbon sources combined, it will be possible to keep using all the products without the need for any additional fossil carbon sourced from the ground (Figure 5).

For the first time since the beginning of the industrial revolution, which was only possible because of cheap access to fossil carbon sources, we are able to completely decouple the chemical and derived materials industries from virgin petrochemicals. Technology, as well as investment capital, is available for the transformation from fossil to renewable carbon of the entire economy.

31 The demand for biofuels for road transport will decline drastically over the next decades in parallel with the success of the electric vehicle and the hydrogen fuel cell. It would be the task of politics to support the transformation of bioethanol and biodiesel producers currently feeding into the road transport sector into producers of raw materials for the chemical industry. In this way, the considerable investments and technological developments would not be lost and no additional arable land would be needed to supply the chemical industry with renewable carbon.

32 Piotrowski, S., Carus, M., Essel, R. 2015: Global bioeconomy in the conflict between biomass supply and demand. nova paper #7 on bio-based economy, Hürth 2015-10. Download at https://renewable-carbon.eu/publications/product/nova-paper-7-on-bio-based-economy-global-bioeconomy-in-the-conflict-between-biomass-supply-and-demand-%E2%88%92-full-version/

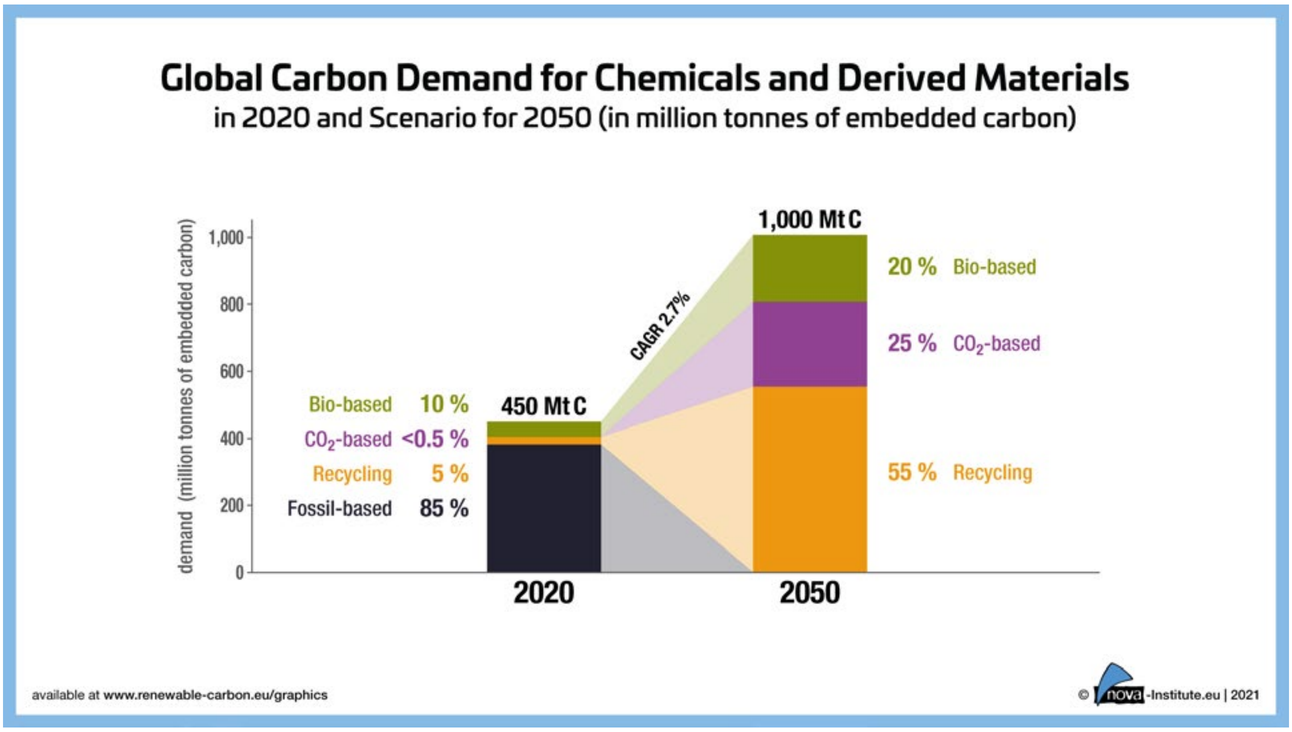

Figure 6: Global carbon demand for chemicals and derived materials

The exclusive use of renewable carbon as feedstock is a key condition for the chemical industry to achieve climate neutrality. The use of renewable carbon in the chemical and derived material industries is what decarbonisation is in the energy sector.

With decreasing carbon demand from the energy sector and increasing demand from the chemical and materials sector, the structure of carbon demand changes fundamentally between energy and chemicals & materials: While today the embedded carbon demand of chemicals & materials virtually disappears compared to the energy sector, both sectors will be almost equal in 2050 (Figure 6).

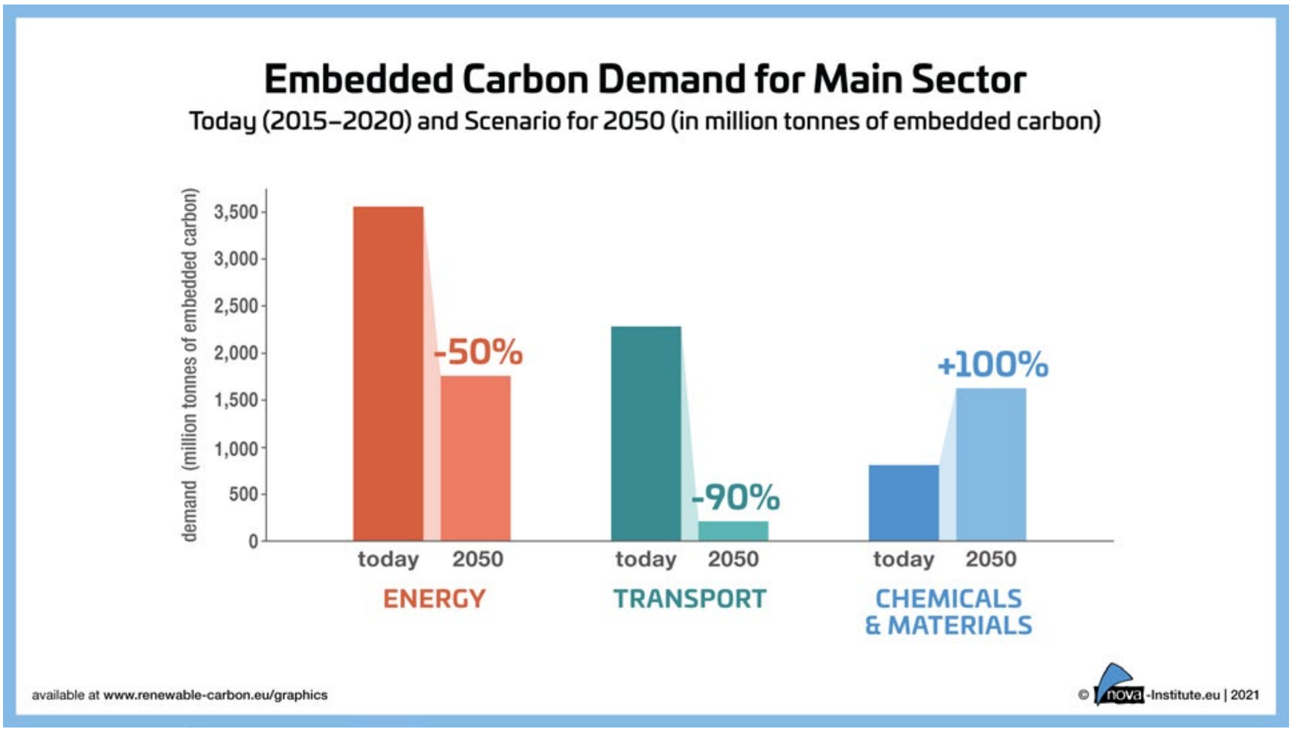

Figure 7: Embedded carbon demand for the main sectors

The two graphs show the raw material flows in the circular economy, in which carbon plays an important role as a raw material. Figure 7 shows the entire value chain from cradle to grave, the waste hierarchy and the potential cycles for all raw materials. It visualises how renewable carbon fits perfectly into the concept of a circular economy (Figure 8), as all renewable carbon sources are kept in a cycle enabling the realisation of sustainable carbon cycles.

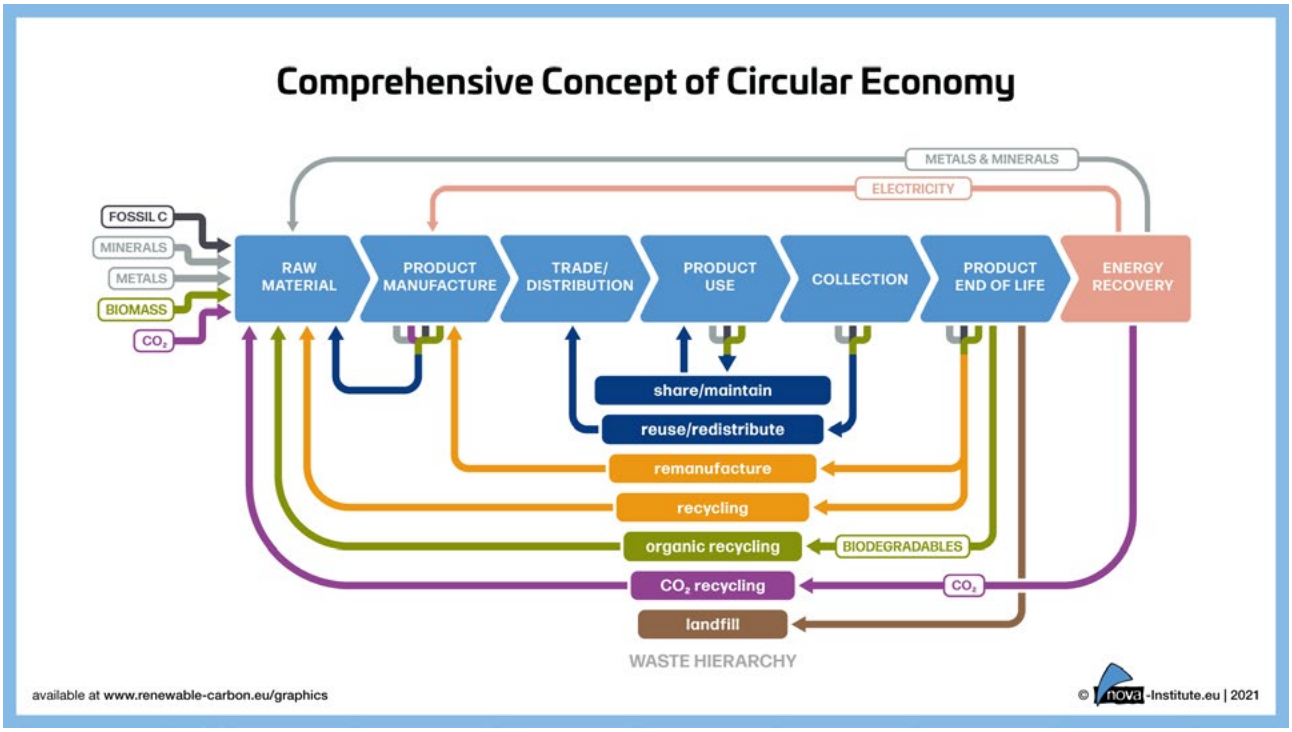

Figure 8: A comprehensive concept of the circular economy

And the following Figure 9 shows how the recycling of carbon in the future plastics industry may look like in a renewable carbon-based system. Two points should be considered in particular: Firstly, a full cycle cannot be realistically accomplished with recycling alone. Biomass and CO_2 are needed as additional renewable feedstocks to compensate for losses along the life cycle. And secondly, the continuous inflows of biomass and CO_2, instead of additional fossil carbon from the ground, mean that recycling consists less and less of the original fossil carbon. With each year, the share of what once was fossil carbon becomes smaller until finally the recycling stream comes exclusively from non-fossil sources.

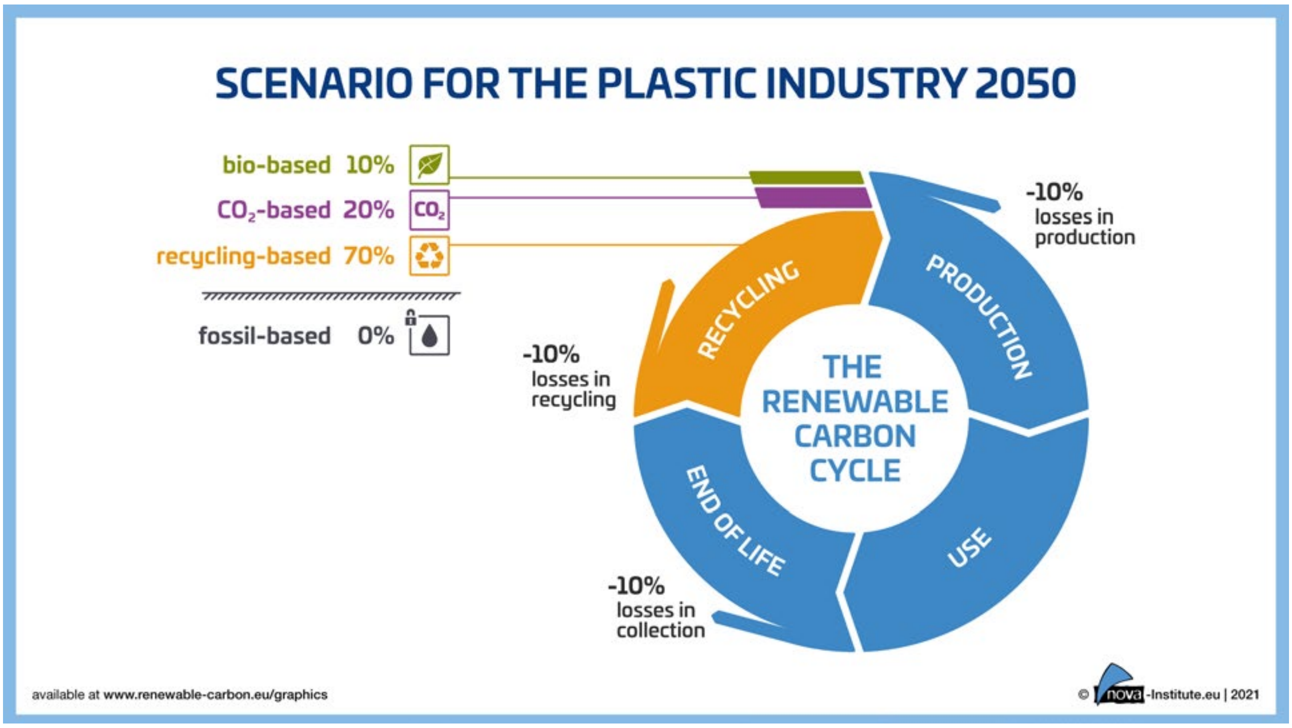

Figure 9: The renewable carbon cycle as scenario for the plastic industry 2020

Excursus
Carbon capture and sequestration in carbon management

More and more often, carbon capture and storage (CCS) is suggested as an option to store fossil carbon back underground. But can CCS be a viable solution to store fossil carbon from the ground back underground after use? Today, most international experts agree that CCS of CO_2 from fossil point sources or even direct air capture is only the last climate change mitigation option, as it is expensive, risky (prone to leakage) and the necessary volume is usually underestimated.

Unproven CCS should not be used to justify continued fossil fuel expansion. It makes much more sense to substitute fossil fuels from the ground with renewable energies than to introduce an end-of-pipe technology, which constitutes a lock-in effect for fossil power plants. The investments in CCS would be much better channelled into solar and wind energy and green hydrogen. In this way, the investments would not only have reduced CO_2 emissions, but at the same time contribute to a new energy system. The following recent quotes support this view:

> *"That is a point Watson can't emphasise enough, either: the faster we cut emissions today, the less we will need to rely on sucking huge amounts of CO_2 out of the air."*[1]

> *"The models show that combining recycling, biomass utilisation and carbon capture and utilisation, net-zero emission plastics could be achieved with considerably lower energy demands and operational costs than those associated with current fossil fuel-based production technologies combined with carbon capture and storage."*[2]

> *"Nothing short of stopping the expansion of petrochemical and plastic production and keeping fossil fuels in the ground will create the surest and most effective reductions in the climate impacts from the plastic lifecycle."*[3]

The chemical and derived material industry needs renewable carbon streams additional to recycling, and for a sustainable path, this cannot entirely be covered by biomass. CO_2 utilisation (CCU) is a more useful application of captured carbon than CCS and will become indispensable to provide renewable carbon for the chemical industry of the future.

1 Vaughan, A. (2021): Inside the race to scale up CO_2 capture technology and hit net zero. New Scientist 18 August 2021

2 Meys, R. et al. (2021): Achieving net-zero greenhouse gas emission plastics by a circular carbon economy, Science 1 Oct 2021, Vol 374, Issue 6563, pp. 71-76, DOI: 10.1126/science.abg9853

3 Plastic & Climate, The Hidden Costs of a Plastic Planet. CIEL and others, May 2019. https://www.ciel.org/project-update/plastic-climate-the-hidden-costs-of-a-plastic-planet/

2.6 Renewable carbon and sustainability

The focus on renewable carbon is the most efficient, effective, and sustainable way to reduce CO_2 emissions in the chemical and material sector already in the medium term. As a guiding principle, renewable carbon could trigger rapid and systematic phase-out of fossil carbon through real technical implementation and investment in renewable carbon technologies – not end-of-pipe technologies or offsets.

Not every application based on renewable carbon is automatically sustainable – but any application based on fossil resources can never be sustainable. Mathematically speaking, renewable carbon is a necessary but not yet sufficient condition for sustainability.

There are two major elements to consider when addressing sustainability within the renewable carbon concept.

The first element is: Is carbon needed in the application or can the application be decarbonised? Most material applications, such as chemicals, plastics and a variety of, are based on organic chemistry and require carbon on a permanent basis – in contrast to the energy sector, which can be largely decarbonised sooner or later with electricity and hydrogen. A peculiar case is the transport sector, as it is in a phase of transition but has some notable exceptions. The aviation sector will likely stay dependent on carbon-containing fuels (such as kerosene) in the long term.

The second element: What is the most sustainable carbon for the given situation? Which renewable carbon source is best suited for a particular case should be based on feedstock availability, technology and market conditions, as well as specific environmental and social issues. This depends on regional factors, concrete applications and production pathways, and the answers will differ from case to case. There is no one-size-fits-all or universal solution but whatever carbon source is used, it must be renewable carbon. To transform the chemical and derived materials industry into a system that is fit for a sustainable future, renewable carbon should become a guiding principle on a global scale. On a local level, a comprehensive understanding of framework conditions will be necessary to identify the best source of renewable carbon for a particular application.

In Sweden and Finland, the most sustainable carbon will probably come from forestry. At good sugar beet locations, these plants and their carbon might be the favourites. In biomass-poor locations and countries with good green hydrogen supply, captured CO_2 use will be ideal, in areas with an implemented waste collection and recycling system, mechanical recycling might be the most feasible option for renewable carbon, and in regions with a strong chemical industry, chemical recycling will be a prominent option.

LCA analyses (or any appropriate level of assessment) will most of the time point to significant implementation challenges to scalable, environmentally sustainable solutions. Biomass as an example illustrates the dilemma: a large number of sustainability criteria – which are quite understandable in detail – restrict the usable biomass to an extent where a substitution of the fossil system in a relevant way is simply not possible. At the same time, these restrictions miss the fact that the fossil system and global warming themselves are considerable threats to biomass production and biodiversity via climate change. While the heavy number of criteria exist with the intention to protect the ecosystems, at the same time they indirectly promote and protect the heavily damaging system in place and complicate the development of better alternatives over time.

We should not be deterred by these challenges. The consideration of renewable carbon as a guiding principle makes it possible to move quickly and on a large scale in the right direction towards climate mitigation. Whilst keeping the direction of travel (i.e. stopping the use of fossil feedstock), sustainability assessments should be used to identify the major environmental areas of impact to tackle as well as shape roadmaps that target best uses for a certain category of carbon feedstock. In the case of biomass LCAs highlight environmental trade-offs related to the material use of biomass versus biofuels, uncovered potential emergent properties of the system under future scenarios and provided stimulus to redirect available biomass for more targeted fossil fuel replacement (e.g. waste biomass for static heat and power plants) as well as to look for different technology solutions for transportation, which was a good outcome.

In combination, renewable carbon as a guiding principle and reliable sustainability assessments will enable the industry to move in the right direction faster and identify the best options to scale up in volume.

Focusing on what's best within the renewable carbon family

It is the RCI's view that in a resolute renewable carbon strategy, sustainability assessments that focus on identifying the best alternative from the different solutions within the renewable carbon family are required. Today, comparative assessments include the benchmark of petrochemicals, where recent studies point to the fact that the footprint of fossil raw materials is significantly higher than previously assumed. The benchmarks are still critical in order to 1) identify the environmental impacts compared to the status quo of today's economy and 2) give a directional measure of the size of the prize when opting for a new route of chemicals production.

In the future, fossil carbon will however no longer be relevant and even if some renewable solutions perform worse today than petrochemical counterparts, they could be further improved and remain of high relevance in the future. Therefore, it is also important to start comparing renewable carbon routes between themselves to support decision-making. In a future where fossil resources will no longer be the norm, LCAs could compare only between solutions of the large spectrum of bio-based, CO_2-based or recycling and identify which is the best for a specific region, process and application.

Scope 3 emissions – Renewable Carbon, an effective way to reduce them

The renewable carbon concept helps to address scope 3 emissions, which are difficult for companies on their own. While scope 1 & 2 emissions in carbon accounting refer to energy- and process-related CO_2 emissions (internal & external), scope 3 emissions refer to all other emissions caused by the company's activities but not under the direct control of the company, for example through suppliers, service providers, employees or end consumers. Suppliers are particularly important, and this includes, in particular, the supply of raw materials, intermediates and products – a large proportion of which are carbon-based.

To highlight the relevancy of scope 3, average values for manufacturing companies in the chemical and plastics industries are usually around 10 to 30% of total emissions for scope 1 & 2, while scope 3 accounts for 70 to 90% of total emissions. From these, raw materials often account for up to 50%[33].

Manfred Kircher[34] wrote in this context: "... *it is important to emphasise that the EU-ETS only covers SCOPE 1 and 2 emissions. These energy-related emissions account for about 40% of the chemical industry's emissions; 60% can be assigned to product-linked SCOPE 3 emissions (EU, 2013) (Boulamanti and Moya, 2017). Accordingly, only less than half of the emissions originally attributable to the production of chemicals are priced. Essentially, these are the energy-related, not the product-related emissions; thus, the EU-ETS does not promote the switch to bio-based chemicals."*

Here lies the bridge to renewable energy and renewable carbon: If scope 3 emissions increasingly in focus and are included in statements on climate neutrality, the most effective way is to systematically and quickly convert the embedded fossil carbon of the raw materials purchased to renewable carbon – and use renewable energy for the process energy. Renewable carbon will help to tackle scope 3 emissions, and a strong scope 3 policy will support renewable carbon and drive investment in its solutions.

Externality costs of fossil carbon could be factored in

The price of climate change has been prominently quantified in recent years, but in complete contrast to the "polluter pays" principles, neither big oil and gas companies nor consumers are paying the price for the costs of global warming as a result of their consumption. Following the renewable carbon logic, a fossil carbon tax should be considered in addition or as an alternative to a CO_2 tax or limit via ETS. A tax on fossil carbon might prove more effective for a carbon border adjustment mechanism than a tax on CO_2 emissions[35]. It provides several advantages compared to a CO_2 emission tax and solves a number of central issues considered a hurdle for the implementation of a CO_2 tax, such as complexity, carbon leakage, eligibility to WTO rules or taxation coverage of all sectors in the economy. The fossil carbon tax can be implemented regionally without endangering competitiveness, as subsequent taxation or reimbursement is possible on import and export. With its focus on the raw material aspect, it is a much simpler and elegant approach than an end-of-pipe solution that looks at CO_2 emissions. A fossil carbon tax would not only encompass the energy sector, but also cover the chemical and material sectors properly.

CCU could be integrated in the EU ETS

CCU as a climate change mitigation option has been mentioned in the context of the EU ETS for the first time with the "Fit-for-55" revision, but for now it only counts for permanently bound solutions without a clear definition on what CCU technologies this might include. While some

33 Sphera Insights, Sustainability Survey 2021

34 Kircher, M. 2021: The framework conditions must be aligned to the requirements of the bioeconomy. EFB Bioeconomy Journal 1 (2021), https://doi.org/10.1016/j.bioeco.2021.100003

35 vom Berg et al. 2021: nova-Paper#15: A tax on fossil carbon is more effective than a tax on CO_2 emissions. 2021-06. Available online at: https://renewable-carbon.eu/publications/product/a-tax-on-fossil-carbon-is-more-effective-than-a-tax-on-co2-emissions/

CCU technologies bind carbon permanently, and are thus in a strong position to argue for an effect towards climate change mitigation, it is the substitution character of CCU in particular, namely recycling carbon instead of having to extract additional fossil carbon from the ground, that is an important argument for including CCU in the ETS.

Meanwhile, it became clear that permanently sequestered CO_2 in a material via mineralisation can be excluded from the obligation to surrender emissions allowances. How and to what extent the substitution character of CCU will be acknowledged remains an open question for the moment. It is still uncertain how the upcoming 6th assessment report of the IPCC will define to what extent different CCU technologies may be counted as a useful tools towards climate change mitigation.

The acceptance of chemical recycling and the mass balance & free allocation approach is indispensable

Renewable carbon as a guiding principle would pave the way for fast implementation due to a clear framework. As has been pointed out, to manage climate change the transformation of the whole industry must be accelerated with a simple guiding principle, which leads definitely in the right direction: Fading out fossil carbon in energy and materials. In that regard, the acceptance of chemical recycling and the mass balance & free allocation approach will be indispensable. Both are essential to enable the industry to transform properly and enable step-by-step improvements to achieve high volumes fast. This is particularly true for large existing chemical infrastructures, where the production of fossil-based naphtha could be stepwise transformed into renewable-based naphtha, for example.

2.7 Conclusion – Renewable Carbon as a Guiding Principle

In essence, we consider renewable carbon a strong guiding principle for a sustainable future of the chemical industry. The chemical industry needs to be decoupled from fossil carbon from the ground as a raw material and the renewable carbon concept delivers concise ideas on how to achieve this. It complements viable carbon management, which in turn would become a vital tool in the future. Renewable carbon allows specific regional and application-related features to be taken into account, to identify the most sustainable carbon source from the available options for different situations and circumstances. This requires clear definitions on terminology, measurements, accounting as well as standards and labels and a supportive policy framework.

Renewable carbon as a guiding principle helps to transform the chemical industry, because it provides enough space for actors in the value chain to operate and delivers many investment options regarding feedstock and technologies. Furthermore, industry and brands would finally have security to go through with a systemic transformation to renewable carbon.

The time for renewable carbon is now: *"We don't have to convince the brands to go for renewable carbon. The public is already convincing the brands. Things have changed dramatically in the last 2-3 years. The brands care about renewable carbon, policy should recognise to build a new policy framework."* (Simpson 2021[36])

36 Personal communication 21-08-09

3. Policy recommendations to support the transformation to renewable carbon

As has been pointed out throughout this paper: in order to make a fast and high-volume transition happen, the support of a favourable policy framework is essential. Following extensive preparative work on developing and finetuning the renewable carbon concept, the RCI has derived a list of political recommendations. These recommendations show what it would mean to include renewable carbon as a guiding principle in policy. They are meant to support the transformation from fossil carbon from the ground to renewable carbon in the chemical and materials industries and encouraging consideration by policymakers internationally. Following internal discussion and voting on a larger set of potential measures, the following eleven recommendations are supported by the majority of RCI members:

Eleven Policy Recommendations ranked by the members of RCI

1. **Renewable carbon must become an integral part of policies and targets.** Renewable carbon is key to tackle the root of the climate problem, stopping the inflow of further fossil carbon from the ground. This goes together with an understanding of the value of carbon and that the sustainability of carbon cycles must be restored.
2. **Carbon management needs to become an integral part of all policies and targets.** Carbon management is the proper organisation of carbon as a circular resource across all industrial sectors. It enables the complex transition from today's fossil carbon from the ground to renewable energy and to renewable carbon. Such a management would not only require effort from the industries, but should be flanked by policy measures, technology developments and major investments. How is the carbon demand for the chemical and materials industries developing? What renewable carbon sources are available in a given region, a country or even a whole continent? How can the demand be covered as sustainably as possible with renewable carbon?
3. **Support the transformation of existing chemical infrastructure from fossil to renewable carbon.** The large structures of refineries and integrated chemical parks must become part of the transformation. Only they have the necessary volume and here the fossil carbon demand must be replaced by renewable carbon from CO_2 and hydrogen, recycling and biomass on a large scale. This way, only renewable carbon from the atmosphere, biosphere and technosphere is utilised. A transformation of large chemical structures and refineries should be comprehensively supported and shaped politically. Otherwise, Europe could lose the backbone of its industry and become completely dependent on other regions.
4. **Massive expansion of renewable energies (solar and wind) and green hydrogen grids, in combination with CCU** as a vehicle for storing energy is needed to provide sustainable renewable carbon to the chemical and plastic industry.
5. **Supporting market access for products based on renewable carbon.** Binding renewable carbon quotas for "drop in" products in the chemical and material industries, for example. As a first step, mandatory reporting for the industry on their share of renewable carbon used as carbon feedstock could be supportive.
6. **The removal of carbon (from the atmosphere) by CCU should be positively considered,** especially the substitution of fossil carbon via renewable carbon in the production of chemicals

and derived materials, e.g. via certification. Such a certification should then also include the option of substituting fossil carbon from the ground via renewable carbon.

7. **Financial support / tax advantages / tax exemptions for fossil carbon must be removed.** Discontinuation of any funding programmes in the fossil domain. Every year, the G7 countries spend at least USD 100 billion on the production and consumption of oil, gas, and coal[37]. A recent article by the Guardian cites the International Monetary Fund, which calculated global fossil fuel industry subsidies of USD 5,900 billion for the year 2020 alone[38]. If that investment were redirected to push forward renewable carbon-based solutions and the further decarbonisation of the energy sector it could have a huge positive impact.

8. **Renewable carbon standards, certificates and labels** should be developed and implemented, renewable carbon preferred product databases created and in public procurement, renewable carbon should become the guiding principle to fade out fossil carbon in all products.

9. **A proper carbon management must also enable the transformation of biofuel plants into chemical suppliers**. As the demand for carbon-containing fuels falls, biogenic feedstocks and biofuel plants can supply the chemical industry in its transformation to renewable carbon. The biofuel infrastructure has been built up with a great deal of support and should not go to waste with the end of demand for liquid fuels. Instead, it must become the raw material basis for a new chemistry based on renewable carbon.

10. **The non-level playing field for material and energy use in the bioeconomy sector, which has been established for years, must be overcome.** The Renewable Energy Directive (RED) systematically deprives the chemical industry of biogenic raw materials and for years there have been calls for a Renewable Energy and Material Directive (REMD)[39]. The RED would become a part of carbon management to cover and link the shrinking carbon flows in the energy system, and the growing carbon demand for chemicals and materials.

11. Put **scope 3 emissions** more in the focus of climate policy to really become carbon neutral. Scope 3 emissions often form the largest share of total emissions of a company. The renewable carbon concept, paired with renewable energy, would be effective tools to minimise scope 3 emissions.

37 Simon, F. 2018. 100 Milliarden Dollar für Öl, Gas und Kohle – jedes Jahr. 2018-06-04. Last access 2018-06-04. https://www. euractiv.de/section/energie-und-umwelt/news/100-milliarden- dollar-fuer-oel-gas-und-kohle-jedes-jahr/

38 Damian Carrington 2021. Fossil fuel industry gets subsidies of $11m a minute, IMF finds, the Guardian, https://www.theguardian.com/environment/2021/oct/06/fossil-fuel-industry-subsidies-of-11m-dollars-a-minute-imf-finds

39 Carus, M., Dammer, L., Hermann, A., Essel, R. 2014: Proposals for a Reform of the Renewable Energy Directive to a Renewable Energy and Materials Directive (REMD). nova paper #4 on bio-based economy, Hürth 2014-05. Download at www.renewable-carbon.eu/publications

Why join RCI?

RCI is an organization for all companies working in and on sustainable chemicals and materials – renewable chemicals, plastics, composites, fibres and other products can be produced either from biomass, directly via CO_2 utilisation, or recycling. RCI members profit from a unique network of pioneers in the sustainable chemical industry.

RCI offers its members

- A common voice for the renewable carbon economy.
- Increased visibility of their individual renewable carbon solutions.
- Collective advocacy work to create a supportive regulatory and economic framework.
- Preparation of background information, position papers and reports on topics of relevance for the members of the RCI, e.g. on GHG reduction potential of CCU, food vs non-food crops or CCU vs CCS
- Working groups to tackle larger topics, e.g. on policy, certification and labelling of renewable carbon, sustainability or recycling
- A community platform for networking and exchange
- Support in finding solutions for your specific problems on the way to your renewable carbon goals.

Join Now

Become a part of the Renewable Carbon Initiative (RCI) and shape the future of the chemical and material industry
www.renewable-carbon-initiative.com/membership/application