Circular Transition *Indicators (CTI)*

→ Guidance for the chemical industry to accelerate the deployment of circular metrics

World Business
Council
for Sustainable
Development

Contents

Thank you to the members of the Circular Chemical Working Group:

ARKEMA

BASF
We create chemistry

Chemours™

CLARIANT

covestro

DOW®

EVONIK
INDUSTRIES

HUBER

iff

Infineum

سابك
sabic

Sika®

SOLVAY

SYENSQO

Thank you to the CTI Advisory Group :

AFRICAN CIRCULAR
ECONOMY NETWORK

CIRAIG

CIRCLE
ECONOMY

CIRCLE
ECONOMY
CONSULTING

Executive *Summary*

Executive Summary

The global economy is predominately linear and so are chemical value chains. As an example, more than 90% of plastics worldwide originate from virgin fossil resources[1] and they are generally subject to low reuse and recycling rates.[2] As demand for resources increases exponentially in a finite Earth system, it is urgent to decouple resource consumption from value creation. Embracing the principles of a circular economy and accelerating the adoption of circular business models are therefore paramount.

With 95% of all manufactured products and materials relying on chemical processes, the chemical industry is a cornerstone of the global economy. Many complex, intertwined value chains that span almost every segment of the economy use chemicals.[3] The industry is in a unique position to enable and catalyze the transition of global value chains to a circular economy. Seizing this opportunity requires a cross-sector system approach that allows companies in all value chains to harness the power of chemistry for their circular transformation. To navigate this change effectively, a consistent approach to measuring circularity within the sector is essential.

Fact-based circular transition roadmaps using robust metrics are central to an effective transformation of the industry and its value chains. Standardized circular metrics drive convergence and consistency in value chains and can serve to unlock the deployment of circular strategies throughout the chemical sector. Fostering transparency on a company's circular performance – from raw material to product use and end of life – sheds light on opportunities and enables the emergence of new and profitable business models. It also helps drive decision-making on circularity and sustainability, contributing to building strong accountability systems.

The Circular Transition Indicators (CTI) is a comprehensive sector-agnostic circularity measurement framework, applicable at the product, business or company level. It is publicly available to companies from all sectors and of all sizes. This guidance leverages the **WBCSD Circular Transition Indicators v4.0 (CTI v4.0)** and focuses on CTI's headline indicator for material circularity as the methodology's foundation for circularity performance measurement. The reports aim to:

- Clarify and harmonize key circularity definitions and measurement;
- Discuss common industry challenges in increasing circularity;
- Share best practices that increase circular in- and outflows and the adoption of circular business models.

This guidance report is the outcome of the collaboration of 11 major chemical companies over 18 months. It is part of WBCSD's broader Chemicals Circularity project dedicated to achieving chemical value chain transformation to a net-zero emissions, nature-positive and more equitable industry.

> *"Nothing is lost, nothing is created, everything is transformed"*
>
> *Antoine-Laurent de Lavoisier, often referred as the father of modern chemistry*

The report, directed at all stakeholders in the chemical industry and chemically intensive value chains, supports practitioners in the development and implementation of circular strategies and its performance measurement. To do so, this report:

1. **Provides guidance on measuring circularity.** This report provides guidance on how to measure CTI's material circularity indicator. Split in two parts – circular inflow and circular outflow – this guidance helps companies from the sector interpret and implement the metrics based on industry standards and needs. For example, it formulates detailed principles for renewable materials along with additional guiding principles to determine recyclability. It also applies guiding principles on how to determine recyclability to the specific case of reagents – a large proportion of all chemicals designed to transform through a chemical reaction.
2. **Promotes the adoption of a common approach.** Emerging technologies such as chemical recycling and carbon capture and utilization (CCU) are new opportunities for the chemical industry. This report considers their opportunities – and the controversies surrounding them – and discusses how to properly account for them using CTI. Additionally, it discusses the role of chain of custody approaches for tracing renewable and recycled feedstock, communicating the need for a harmonized approach.
3. **Fosters the development of emerging practices in the industry.** Circular strategies that go beyond recycling and focus on lifetime extension strategies receive too little attention. This reports shows the opportunities lifetime extension strategies bring, such as reusing or refurbishing. Biodegradability is also a minority recovery strategy and would benefit from further focus to support its broader implementation in diffusive applications.
4. **Discusses common industry challenges.** Common challenges associated with circularity and its measurement include lack of access to primary and secondary data and the limited availability of circular materials. To ease access to data, the companies involved in this work call for the development of a data exchange mechanism for circularity that fosters access to traceable, verifiable and credible circularity data to properly inform circularity assessments and decision-making.

This report shows the chemical industry's potential and how companies in chemically intensive value chains can push their circular ambitions and measure their progress. Several leading companies are already paving the way. We invite this ecosystem's stakeholders to use the guidance and contribute to standardizing the measurement, deployment and scaling up of circular solutions in chemically intensive value chains.

Introduction

01.

01. Introduction

Chemicals are ubiquitous in the global economy: more than 95%[4] of all manufactured products require chemicals. Their use spans the complex and intertwined value chains covering almost every segment of the global economy. These chemical value chains are predominately linear. For example, more than 90% of plastics worldwide originate from virgin fossil resources[5] and they are generally subject to low reuse and recycling rates.[6] The chemical industry has therefore the chance to seize a unique opportunity to drive positive impact. Doing so requires a cross-sector system transformation enabled by a circular economy and the power of chemistry. Such a transformation must have climate, nature and equity at the center to shift the modus operandi from volume optimization to maximize stakeholder value creation.

The transition to a circular economy is a system transformation that requires a new way of producing, designing and using products and materials. Shaping a circular economy for chemicals requires the application of the 10R strategies[7] – refuse, rethink, reduce, reuse, repair, refurbish, remanufacture, repurpose, recycle, recover – to design out waste, lower the total amount of virgin materials necessary for chemical production,[8] implement safe and sustainable by design principles and enhance social value. These interventions have the potential to reduce pressure on ecosystems and benefit human health through the minimization of waste and pollution. In return, the circular economy holds tangible benefits for the industry: pursuing resource efficiency through circular approaches, strengthening supply chain resilience (such as resource-use optimization, virgin material input reduction) and enhancing value chain collaboration.

Fact-based circular metrics are central to an effective and credible transition to a circular economy. Standardized, universally recognized metrics have the potential to establish a common circularity language for the whole value chain, focusing efforts where they are the most impactful. The chemical industry is an early adopter, with many chemical companies using circular metrics already. However, there is great diversity in measurement systems and definitions, suggesting maturity is still at an early stage. In the development of this guidance, we surveyed the practices of 11 leading global chemical companies, representing about 6% of chemicals produced worldwide. This survey highlighted the need to standardize circular metrics practices to drive convergence and consistency in those value chains using chemicals and the products made with them.

In 2020, WBCSD developed the **Circular Transition Indicators (CTI)** as a sector-agnostic framework for businesses to measure circularity. The indicators bring transparency and a common approach to metrics shared by value chains and business ecosystems. This quantitative, data-driven and flexible framework supports company circularity assessments at the corporate, business unit or product level. CTI therefore reinforces decision-making, steers investments towards those that help implement circularity at scale and helps companies prepare for disclosures in line with the European Union's Corporate Sustainability Reporting Directive (CSRD) **European Sustainability Reporting Standard 5 (ESRS 5) on Resource Use and the Circular Economy**. Aligned with the Global Reporting Initiative's standard for materials (**GRI 301**) and for waste (**GRI 306**) and with the developing International Organization for Standardization (ISO) standard for a circular economy (**ISO 59020**), CTI supports businesses as they implement these standards. CTI is therefore a relevant framework to consistently standardize chemical industry practices with value chain practices.

Actors in the sector manufacture chemicals upstream in the various value chains, transforming them into component and products. This position in the value chain brings challenges that make the deployment of circular metrics difficult, for example understanding what these chemicals become along these value chains. This guidance builds on the CTI framework and aims to overcome these challenges by driving standardization in measurement methods, adding specificity where necessary, fostering the sharing of best practices and enhancing preparedness for the upcoming non-financial disclosures on circularity mentioned earlier. It also enables companies to focus the conversation on effectively driving circularity inside the company and its value chains. Transparency on a company's circular performance, including raw material types and sources, could unlock new profitable business models and opportunities, while helping drive decision-making on circularity and sustainability and building accountability systems.

Methodology

This CTI guidance for the chemical industry **focuses on material circularity, CTI headline indicator**. It is the outcome of a sector-wide collaboration that aims to promote circularity and transparency through aligned metrics, with the objectives to:

- → Empower companies to steer portfolios supported by quantitative, data-based insights;
- → Bring clarity and harmonize definitions;
- → Discuss common challenges in increasing circularity;
- → Create opportunities for synergies for greater circularity adoption by the industry and value chains;
- → Share best practices in circular solutions, their measurement and reporting;
- → Build capacity for the further development of WBCSD's Circular Transition Indicators.

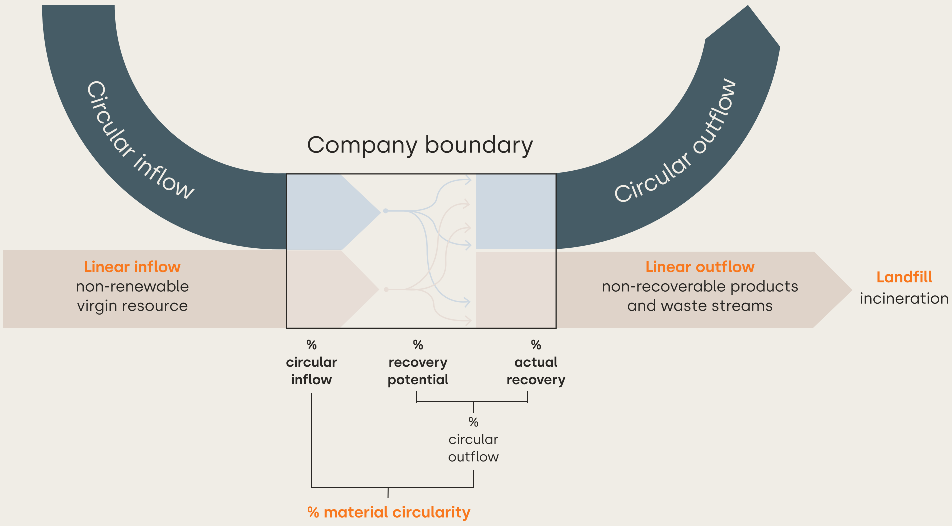
In this guidance, we summarize common challenges, potential solutions and best practices in enabling the consistent measurement of circularity by the chemical sector using CTI. It is the outcome of the WBCSD Chemical Circularity Working Group that ran from September 2022 to August 2023. To scope the work, we completed individual company interviews and complemented them with surveys on the different elements of material circularity. We then used these inputs to prioritize the focus for the sector guidance. We supplemented this work with desk research and organized workshops to align practices. We have designed this document specifically for circularity practitioners from the chemical industry and chemical-intensive sectors to use when developing, reviewing and assessing their circular performance.

The Circular Transition Indicators - Methodology

CTI is based on an analysis of the material flows that enter and leave the company's boundaries. By analyzing these flows, the company determines its capacity and ambition to minimize resource extraction and waste material.

1. **Circular inflow** covers aspects related to all materials that enter the company's boundary and shows how procurement is a key lever for the circular economy. The % circular inflow is the percentage of the total inflow that can be considered circular. In this report, this section specifies what materials companies can consider circular inflow and how to measure this.
2. **Circular outflow** measures the end-of-life of products and materials after use. Outflow consists out of two intervention points:
   - → Recovery potential measures how the company designs products to ensure recovery at functional equivalence.[9]
   - → Actual recovery measures how much of the company's products are recovered, which is dependent on the collection systems and waste infrastructure in place for recovery.

Figure 1: Illustration of material flows



The circular outflow section covers topics related to definitions, calculation methods, building intelligence on downstream use and the fate of products, and the drivers for the adoption of circular metrics.

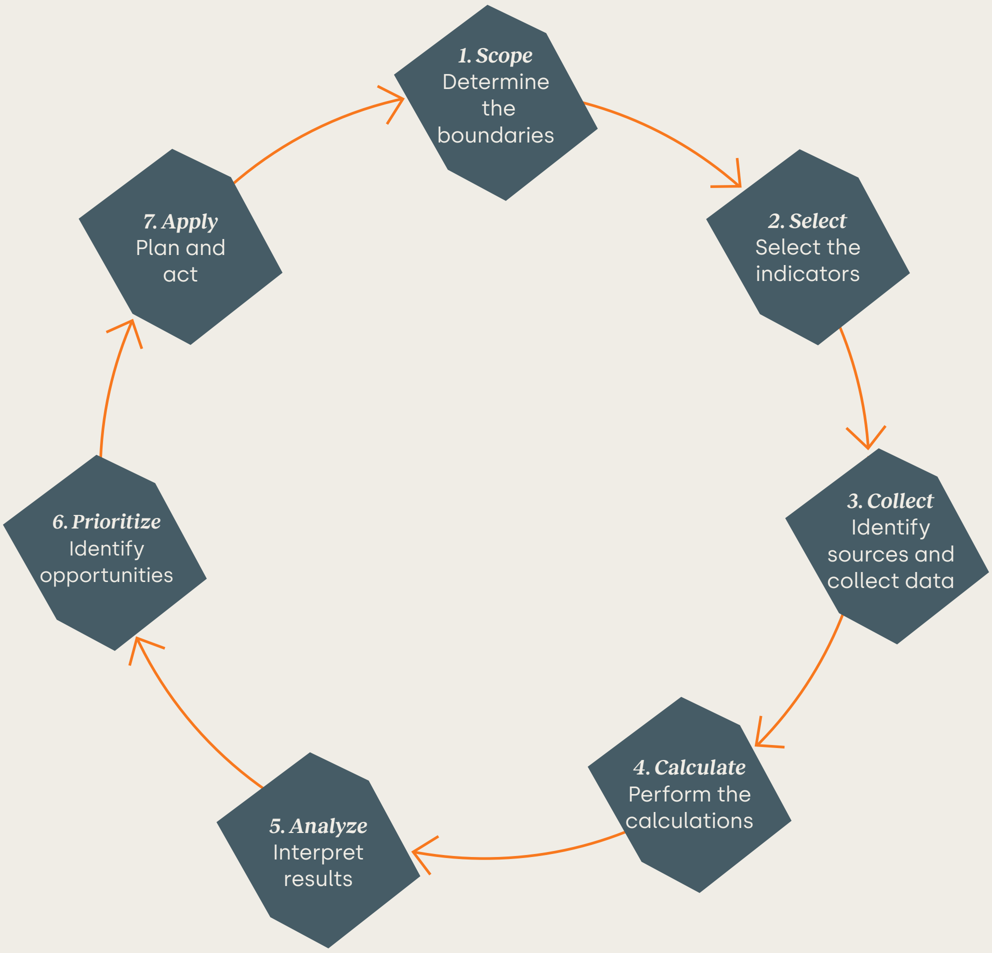
Measuring circular inflow and outflow determines a company's performance in closing the loop, expressed in the **% of material circularity**, calculated as the weighted average between circular inflow and circular outflow. Beyond its headline indicator, % material circularity, **CTI v4.0** includes additional indicators offering companies further insights to their circularity.

The Circular Transition Indicators - Process cycle

The CTI framework outlines seven process steps that cover one CTI assessment cycle: 1) Set the scope, 2) Select the indicators, 3) Collect data, 4) Calculate, 5) Analyze, 6) Prioritize and 7) Apply. Following a cyclic approach is core to the CTI v4.0 methodology. Building a baseline, setting targets and periodically monitoring progress enable the operationalization of circular approaches across the company. Having a clear methodology with specific steps that are repeatable enables decision-makers to understand the impact of circular approaches on performance and business models. The annex provides additional information on these steps.

This report focuses on the implementation of material circularity, a foundational indicator of CTI, and discusses challenges and opportunities identified to be most relevant to the industry. This provides the industry with a starting point for the consistent measurement of circularity, following the CTI process cycle.

Figure 2: The seven steps of the CTI framework



Measuring circular inflow *in the context of chemicals*

02.

02. Measuring circular inflow *in the context of chemicals*

This chapter guides the measurement of circular inflow in the chemical sector.

What is inflow?

Inflow measures the weight and material composition of all incoming materials into the system's boundary. These materials can be classified as:

1. Fossil-based virgin inflow
2. Non-virgin inflow (defined as materials used in a previous cycle)
3. Renewable inflow (defined as regenerative or at least sustainably grown and managed biomass resources).

Non-virgin and renewable materials are both considered circular inflow. The circular inflow percentage is defined as the weight percentage of the product/material that can be considered circular compared to the total inflow. Measuring circular inflow requires information on the material composition of incoming materials or feedstocks.

Relevant topics identified as a priority to foster circular inflow in the chemical sector

Desk research and interviews with companies involved in developing this guidance suggested the themes presented in Table 1 as a priority to increase the circularity of chemical inflows.

This chapter guides the measurement of circular inflow in the chemical sector.

Table 1: **Prioritized themes to foster the quantification of circular inflow**

Objectives	Prioritized themes
2.1. Clarify circular inflow definitions for the chemical sector	**Topic 1** – Further specify the definition of renewable materials → Propose criteria to assess what "sustainably grown" renewable materials means for the chemical sector → Identify relevant certification schemes to consider when assessing sustainably grown renewable materials **Topic 2** – Clarify how to consider chemical recycling in the CTI methodology **Topic 3** – Suggest how to consider carbon capture and utilization as an alternative to virgin materials
2.2. Traceability in a circular economy: guidance for circular inflow	**Topic 4** – Clarify how to consider mass balance approaches in the CTI methodology
2.3. Levers to increase circular inflow	**Topic 5** – Discuss the availability of circular material and data on circularity

2.1 Clarify circular inflow definitions

Topic 1: Sustainably grown renewable inflow

The circular economy provides a framework for actively regenerating local ecosystems and landscapes while building a nature-positive system. It is a solution framework that empowers organizations to address global challenges by fundamentally redesigning systems based on three principles:

1. eliminate waste and pollution;
2. circulate products and materials;
3. regenerate nature.

For the chemical sector, replacing fossil feedstocks with biomass is an important pillar in achieving the global climate targets set in the Paris Agreement.[10] However, not all bio-based materials are considered circular. To avoid burden shifting,[11] the CTI methodology requires additional considerations:

- Prioritize the use of biomass waste, residues and by-products as feedstock; examples include straw, tall oil or bagasse.[12]
- When using primary and secondary biomass, this needs to be **regeneratively produced[13] or at the least sustainably grown/managed**.

Accessing biomass resources has social and environmental implications, including agricultural intensification, direct and indirect land-use change, and impacts on farmers and local communities.[14] This is why CTI requires biomass resources to be at a minimum sustainably grown or when possible produced using regenerative principles, and harvested at a rate that natural growth and replenishment occur after extraction for companies to account for them as circular. This criterion is also present in standards such as the ISO standard for a circular economy (**ISO 59020**) or the **European Sustainability Reporting Standard 5 (ESRS 5) on Resource Use and the Circular Economy** and is part of the **European bioeconomy strategy.**[15] It is best practice to systematically prove that biomass is sustainably grown using certification schemes. The Science Based Targets Network (SBTN) has defined a **list of high-impact commodities**[16] that are raw and value-added materials used in economic activities. These materials are known to have material links to the key drivers of biodiversity loss, resource depletion and ecosystem degradation. Assessment of these materials is extra critical.

To support the responsible scaling up of renewable raw materials in the chemical sector, companies that contributed to this work expressed the need for additional guidance to operationalize the concept in a harmonized way. This acknowledges that classification as “sustainably grown” depends on the socioeconomic impacts on the land and its alternative use. An exhaustive generic definition is therefore not yet possible.

Use of a certification scheme to ensure biomass is sustainably grown

We surveyed the practices of the companies involved in developing this guidance and found that they often use certification schemes to verify that they sustainably source the materials they use. The scope of sustainability aspects covered under certification schemes differs depending on the type of biomass, the geography and other considerations. The most frequently used certification schemes to assess the sustainability of the biomass include: Forest Stewardship Council (**FSC**), Roundtable on Sustainable Biomaterials (**RSB**), International Sustainability & Carbon Certification (**ISCC**), **Better Biomass**, Sustainable Biomass Program (**SBP**), Carbon Offsetting and Reduction Scheme for International Aviation (**CORSIA**), Round Table on Responsible Soy (**RTRS**), Roundtable on Sustainable Palm Oil (**RSPO**) and **Bonsucro**.

Our review showed that these certification schemes typically cover:

- Governance, environmental and socioeconomic aspects such as compliance with national and international laws;
- Land conservation and anti-deforestation;
- Greenhouse gas (GHG) emissions;
- The maintaining of productivity and soil protection;
- Water and air and labor conditions;
- Land rights, community development and food security concerns.

A "sustainably grown" criteria is also present in the **Renewable Energy Directive RED II**. In this directive, the European Commission defines binding sustainability criteria for biofuels used in Europe that serve as a good starting point for materials produced from biomass in a circular economy. RED II prioritizes GHG emissions savings, biodiversity, carbon stock preservation, land use and land-use change. Yet, it has received criticism for its lack of consideration for socioeconomic criteria and sustainability risks in forest management.[17]

Broadening the scope, Welfle & Röder[18] have created the most comprehensive mapping to date of existing certification schemes based on a set of sustainability indicators from the EU RED II criteria, Global Bioenergy Partnership's sustainability indicator framework,[20] the Roundtable on Sustainable Biomaterials assessment criteria and the United Nations Sustainable Development Goals (SDGs).[22] This uncovers what sustainability aspects the different existing schemes actually cover (see Table 2) and can serve as a guide in selecting certification schemes.

Table 2: Sustainability themes covered by common certification

Categories	Coverage of Sustainability Themes	RED	Voluntary Certification Schemes								
			Full Bioenergy Assessment Schemes & Frameworks				Sector Focused Schemes				
			RSB	ISCC	Better Biomass	ISO 13065	SBP	CORSIA	RTRS	RSPO	Bonsucro
Social aspects	**Health**			✓	✓	✓	✓		✓	✓	✓
	Livelihoods		✓	✓		✓	✓	○	✓	✓	✓
	Society		✓			✓	✓	○	✓	✓	✓
Economic aspects	**Economy**			✓		✓	✓		✓	✓	✓
	Infrastructure						✓			✓	
	Feedstocks		✓			✓	✓				
	Technologies		✓			✓	✓				
	Energy Sector		✓								
	Bioeconomy		✓								
	Land Strategy	✓			✓	✓	✓		✓	✓	✓
Environmental aspects	**Land & Ecosystems**	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Air Quality		✓	✓		✓	✓	○			
	Water Systems		✓	✓	✓	✓	✓	○	✓	✓	
	Climate Governance		✓			✓	✓		✓	✓	✓
	Carbon & Emissions	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Replacing Fossil Fuels				✓		✓	✓			

✓ Coverage of sustainable theme within certification scheme.

○ Planned future coverage of sustainability theme within certification scheme.

Source: Welfle & Röder (2022).[23]

Table 3: Sustainability indicator assessment

CTI Definition

Material needs to be produced using regenerative principles, harvested at a rate that allows natural growth and replenishment after extraction.

Sustainability indicator assessment framework for biomass

Categories	Themes	Indicators
People	Health	Health & Wellbeing
		Food Systems
		Land Management
	Livelihoods	Decent Work
		Jobs & Skills
		Change in income
	Society	Equality
		Peace, Justice & Strong Institutions
		Partnerships
		Energy Access
Development	Economy	Economic Performance
		Economic Stimulation
	Infrastructure	Infrastructure Requirements
	Feedstocks	Production Processes
		Mobilization
		Distribution
	Technology	Innovation
		Efficiencies
		Techno-Economics
	Energy Sector	Bioenergy
		Energy System Performances
	Bioeconomy	Added Value Products
		Bioenergy Complementing Wider Sectors
	Land Utilisation	Land Characteristics
Natural Systems	Land	Soil
		Ecosystems
	Air	PM Pollutants
		Oxide Pollutants
		Heavy Metal
	Water	Water Use & Efficiency
		Water Quality
		Water Systems
Climate Change	Governance	Climate Action
		Standards
	Carbon & Emissions	Whole Life Cycle Emissions
		Land & Carbon Stocks
		Counterfactual Considerations
	Energy System	Replaced Fuels

Source: Adapted from Welfle & Röder (2022).[24]

Recommendation to overcome the limitations of existing certification schemes

As shown in Table 2, no certification scheme can capture all desired sustainability principles. Welfle & Röder[25] point out that social aspects are a weakness among certification schemes and companies involved in developing this guidance have confirmed this.

In addition, certification schemes are not yet available for each and every biomass sources, such as new biomass sources for chemicals (like algae, lignocellulose or Camelina) or large globally traded commodity biomass feedstocks (like corn). The companies involved in developing this guidance indicated that companies may tackle some sustainability aspects outside of the certification schemes, for instance through supply chain due diligence. Companies can also use tools such as social life-cycle analysis to support strategic decision-making on the social and economic impacts of a biomass source.

Recommendations when certification is absent

In cases where a certification scheme is absent, this guidance recommends one of the following approaches:

- Execute a dedicated due diligence process to ensure the biomass meets sustainably grown principles: Companies must carry out their own due diligence checks and monitoring to ensure they consider relevant sustainability principles. They can use Table 3 as a guide to start building these processes, combined with a risk-based approach to help prioritization.
- Join forces with partners to launch multicompany initiatives to certify specific biomass (see an example in Table 4).
- Combine both approaches.

Table 4: Example of a multicompany initiative to certify biomass

Sustainable Castor Caring for Environmental & Social Standards

Arkema and BASF are collaborating with Jayant Agro-Organics and Solidaridad on the Sustainable Castor Caring for Environmental & Social Standards (SuCCESS) project.[26] This program aims to enhance the supply of sustainable castor bean products through a sustainable castor certification scheme that incorporates environmental and social standards.

They developed these standards in accordance with globally accepted principles and local stakeholder involvement with clear social, economic and environmental objectives. The scheme includes the adoption of good agricultural practices to increase yields and farmer incomes, the efficient use of water resources and the maintenance of soil fertility. It drives good waste management practices and enables better health and safety routines and respects human rights. The Pragati project, run by Arkema, BASF, Jayant Agro-Organics and implementation partner Solidaridad supports farmers in complying with the certification scheme.

BASF's Düsseldorf-Holthausen site is the first to gain SuCCESS certification in the personal care industry. The program has produced over 50,000 metric tons of certified castor beans and has more than 6,250 certified farmers and 19,000 certified hectares. This initiative advances sustainability by offering a circular ingredient for personal care products that is both a nature-based ingredient and aims to enhance environmental and social performance by improving farmer practices and the well-being of farmers and workers.

Conclusions and recommendations

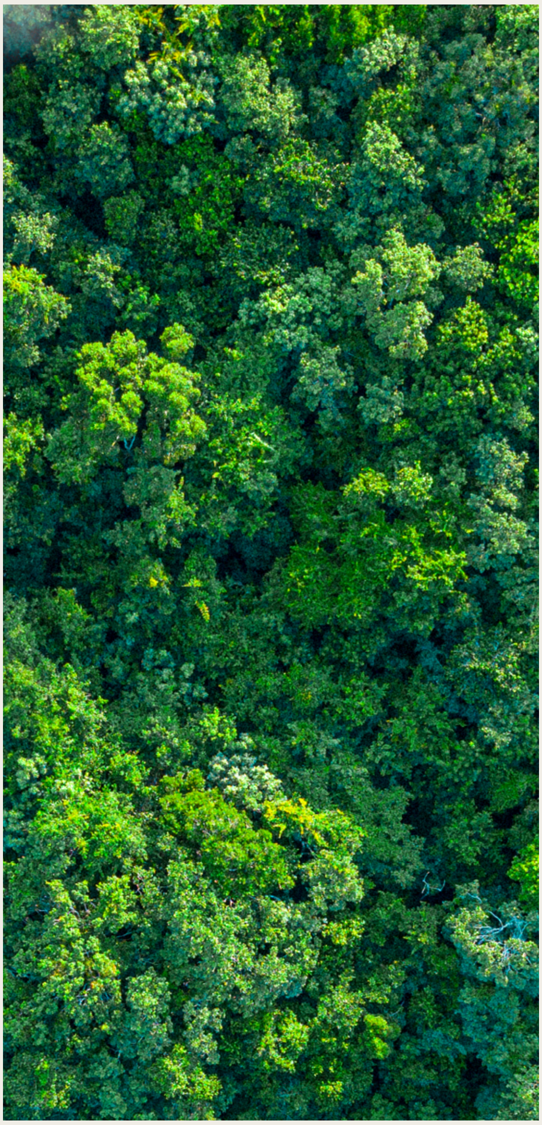
A sustainably grown criterion for renewable materials in CTI is critical to ensuring that biomass resources are a sustainable accelerator for a circular economy.

The definition of sustainably grown is dependent on the land and its resulting local social and environmental impact. However, comprehensive sustainability indicators can help guide companies in assessing impacts (Table 3). Practically, chemical companies can implement this criterion using certification schemes, which partly cover relevant sustainability aspects identified (Table 2).

To cover all relevant aspects and in the case of absence of certification schemes, this guidance advises chemical companies to execute their own due diligence checks (guided by relevant indicators from Table 3) or join forces through multicompany initiatives to address identified gaps.

Companies carrying out independent supply chain due diligence are responsible for ensuring they meet all sustainably grown and managed criteria as outlined above to report performance on circular inflow when including biomass resources.

The assessment of whether the biomass resources used meet the sustainably grown criteria depends on the company's own review.



Topic 2 – Chemical recycling

Chemical recycling refers to emerging recycling technologies that convert waste plastic materials into a recycled feedstock for use in producing new chemicals and plastics. Chemical recycling includes enzymatic processes. These technologies often enable the restoration of virgin or near-virgin feedstock quality, aiming to maximize the retention of functional characteristics. They complement mechanical recycling and contribute to expanding the amount of recyclable waste plastics. Some technologies also enable reductions in preliminary sorting and cleaning.[27]

CTI considers materials from chemically recycled feedstock as circular[28] and complementary to mechanically recycled feedstock as chemical recycling can take place when mechanical recycling is no longer possible.

Chemical recycling technologies are rapidly developing and so are their efficiency, cost-effectiveness and scalability.[29] If operated under verified, ethical, safe and environmentally sound conditions, chemical recycling technologies can enable greater access to recycled lower carbon emissions products. Stakeholders, including non-governmental organizations and academia, have voiced concerns about the environmental impact of chemical recycling technologies, in particular the energy intensity. Data exists demonstrating how chemical recycling contributes to regenerating materials while emitting less greenhouse gases than incineration.[30] This guidance acknowledges that companies should not use chemical recycling as a substitute for high-value recovery strategies such as reuse, refurbishing nd remanufacturing.

As such, CTI recognizes these technologies, with the aim to stimulate their development and the improvement of their environmental performance. This aligns with the Ellen MacArthur Foundation's New plastic economy principles.[31]

Table 5 presents chemical recycling initiatives from the companies involved in developing this guidance.

Table 5: Chemical recycling initiatives from members

Pyrolysis from mixed plastic waste and tires

ChemCycling, BASF's chemical recycling business, manufactures high-performance products from chemically recycled plastic waste and end-of-life tires at an industrial scale. BASF cooperates with technology partners that use a thermochemical process called pyrolysis to transform plastic waste into secondary raw material (pyrolysis oil), substituting virgin fossil feedstock. It uses a third-party certified mass balance approach to trace and attribute recycled benefits to products made in this multi-output process.[3]

Pyrolysis used from plastics

Early in 2024, SABIC is in the final stages of constructing the first commercial advanced recycling unit to produce pyrolysis oil at the Chemelot industrial park in Geleen, the Netherlands. Pyrolysis oil is a key feedstock in manufacturing, as part of their TRUCIRCLE portfolio, SABIC's certified circular polymers from the upcycling of mixed and used plastic. SABIC uses the pyrolysis oil as an alternative to traditional fossil materials. The new commercial unit converts low-quality, mixed plastic waste otherwise destined for incineration or landfill into oil. The company is running the project under a joint venture called SPEAR (SABIC Plastic Energy Advanced Recycling) and is executing it with a Top Sector Energy Subsidy from the Ministry of Economic Affairs in the Netherlands. The new unit in Geleen will enable SABIC to significantly upscale the production of certified circular polymers to provide customers with greater access to circular materials while acting as a drop-in solution.

Topic 3 – Carbon capture and utilization as an alternative to virgin materials

Carbon capture and utilization (CCU) holds significant potential to catalyze the shift to a circular economy. CCU is a diverse set of technologies that allow for the capture and use of CO_2 as a feedstock to make essential products such as chemicals, building materials or synthetic fuels.

For example, companies can use CO_2 and pair it with hydrogen to produce methanol, one of the building blocks of materials such as plastics, fabrics and fibers.[33]

CCU presents a dual solution when capturing CO_2 emissions from industrial processes and power generation and repurposing it to create products and materials. According to the International Energy Agency (IEA), CCU could reduce the reliance on finite fossil resource and avoid CO_2 emissions.[34] This transformational approach aligns with the principles of a circular economy that conserves, reuses and recycles resources in a closed-loop system. As nuanced by the IEA, the ability for CCU technologies to reduce, remove or avoid emissions depends on factors such as the time that a product retains carbon, the carbon intensity of processing and the CO_2 source it replaces – this requires careful consideration.

Sustainable CCU technologies are currently under development. The pipeline of projects announced by the chemical industry holds the potential to capture 10 Mt of CO_2 per year from 2030 onwards (0.005% of total emissions from the chemical industry in 2023).[35]

Table 6 highlights two chemical companies that are exploring the potential of these technologies.

As CCU technologies are still emerging, it is too early to know which technologies will be the most relevant in driving circularity. CTI acknowledges the potential for all developing CCU technologies to increase the percentage of circularity of a company and its products.

Captured carbon is a renewable flow (such as from direct air capture) or waste inflow from either power generation or another industrial process. In both cases it replaces a virgin inflow of materials. For this reason, CTI considers captured carbon as circular inflow. CTI does not consider it under circular outflow as it considers only materials and not emissions to the biosphere.

Table 6: Examples of chemical companies exploring the potential of these technologies

Producing high-value specialty chemicals from CO_2

Evonik and Siemens Energy have partnered and invested in Rheticus II,[36] a research project to produce high-value specialty chemicals from CO_2 and water using electricity from renewable sources and bacteria. The innovation initiative aims to reduce the use of fossil raw materials in developing a more environmentally friendly production process that employs biotechnology and therefore contributes to advancing circularity.

The Rheticus project uses a two-step process. First, it converts water into hydrogen using electrolysis and renewable energy. Then, it uses hydrogen and CO_2 as a feedstock for the biotechnological production of specialty chemicals.

Scaling up CCU projects requires significant investment in research and development, as well as in infrastructure. It therefore requires collaboration between different stakeholders, in the value chain and beyond, including governments, industry and academia. In the early development phases, Rheticus benefited from Federal Ministry of Education and Research funding. As the availability of sufficient and affordable renewable energy is particularly crucial for the process, it provided the motivation behind the development of the partnership and later the joint development between Evonik and Siemens Energy.

Decarbonizing petrochemical building blocks with CCU

In 2015, SABIC's affiliate United Petrochemical Company (Saudi Arabia) started what was at the time the largest CO_2 purification plant of its kind.[37]

Using a proprietary technology, each year, the plant recovers and purifies 500,000 metric tons of CO_2 from the production of ethylene glycol that would otherwise be emitted into the atmosphere. The process converts it into feedstock for the production of chemicals such as urea, a nutrient for agriculture, and methanol, a building block for other chemicals, as well as liquefied CO_2 for the food and beverage industry.

In 2023, SABIC, Scientific Design, a SABIC affiliate licensing ethylene glycol technology, and Linde Engineering, a subsidiary of Linde, announced the intention to explore a partnership to leverage SABIC's proprietary CO_2 recovery and purification technology and deploy it for ethylene oxide and ethylene glycol production plants worldwide.

The company's sustainability targets were the motivation behind this CCU project; a strong network of affiliate companies helped bring it to life. The initiative contributes to substituting virgin feedstock and avoiding industrial process emissions.

2.2 Traceability in a circular economy: guidance for circular inflow

Topic 4: Chain of custody models to support transparent claims: the role of mass balance approaches

According to the **ISO 22095** definition, chain of custody models create transparency in the value chain on "the origin of inputs material, product components, product outputs and the conditions under which they are produced."

Table 7 defines five Chain of Custody (CoC) models.

Table 7: Chain of custody (CoC) models

Model	ISO 22095 definition
Identity preservation	The materials or products originate from a single source and their specified characteristics are maintained throughout the supply chain.
Physical segregation	Specified characteristics of a material or product are maintained from the initial input to the final output. **Note:** Commonly, material from more than one source contributes to a chain of custody under the segregated model.
Control blending	Materials or products with a set of specified characteristics are mixed according to certain criteria with materials or products without that set of characteristics, resulting in a known proportion of the specified characteristics in the final output. This can also be referred to as the "single percentage method".
Mass balance	Materials or products with a set of specified characteristics are mixed according to defined criteria with materials or products without that set of characteristics. **Note:** The proportion of the input with specified characteristics might only match the initial proportions on average and will typically vary across different outputs.
Book and claim	The administrative record flow is not necessarily connected to the physical flow of material or product throughout the supply chain. **Note:** This CoC model is also referred to as a "certificate trading model" or "credit trading". This is often used where the certified/specified material cannot, or only with difficulty, be kept separate from the non-certified/specified material, such as green credits in an electricity supply.

Why five chain of custody models exist

Circular feedstocks are still available in limited quantity. Whether they are renewable or recycled, it is often necessary to blend them with virgin sources to produce chemicals. Measuring recycled content in materials can be difficult as physical measurement techniques are lacking. This is applicable for both mechanical and chemical recycling technologies. In addition, the complex intertwined value chains involving the use of chemicals make traceability particularly challenging. Chain of custody models aim to overcome this.

Chemical assets intend to support the economically viable and effective production of the chemicals and products made from them. They are large, capital intensive and require a quantity of feedstock that is much greater than available circular inputs. Rebuilding new assets at the scale of available circular inflows is unlikely to be economically viable, supported by the financial community and compatible with the urgency of the transition. In this context, physical segregation is often not possible. The transition to a circular economy therefore requires an accounting model that caters for mixed inputs.

Table 7 presents the chain of custody models available and covers different practices to allocate sustainable and circular content to output products, including in cases where physical segregation is not possible.

Two chain of custody models are available **when physical segregation is not possible:** mass balance and book and claim. Contrary to identity preservation, segregation and controlled blending, mass balance and book and claim use attribution approaches.

Book and claim

Book and claim is a certificate trading system without any physical connection with the product. Companies use this model widely in renewable energy and credit trading. In some specific cases, book and claim combined with adherence to strict and transparent principles could support the transition to a circular economy. It is, however, subject to controversies in tracing products and materials. In addition, CTI aligns with the **Greenhouse Gas Protocol** to ensure consistency between accounting rules for circularity and GHG emissions. The Greenhouse Gas Protocol does not include market-based accounting approaches such as book and claim and is evaluating the appropriateness of market-based accounting methods.[38] As such, CTI cannot integrate book and claim as a recognized chain of custody model for quantification of circularity performance.

Mass balance

Mass balance is a chain of custody model that incorporates sustainable feedstock with other feedstocks. It enables the tracking of the net amount of sustainable materials as they move through a complex, multiple output production process, for example, when integrating raw materials of chemically recycled or biomass origin in large chemicals assets.

Most industrial case studies use a credit mass balance according to **ISO 22095**. It decouples the circular raw material benefits (such as recycled or renewable content), accounts for the respective process losses and resulting conversion factors and then rejoins the resulting benefits and the output products within the system boundary. Established certification schemes such as **FSC**, **ISCC Plus**, **REDcert** and **RSPO** enable this. Multi-output systems require the allocation of the circular benefits. Two methods are available:

- **Proportional allocation:** This means splitting the allocation of benefits from using recycled or renewable content according to yield or distribution. As an example: an input of 20% recycled feedstock results in an attribution of 20% recycled content to the output materials.
- **Non-proportional allocation:** This is also called free allocation, as the benefits from recycled or renewable content, for example, can be freely allocated to the different process outputs within the system boundary.

Advantages of the mass balance approach

- It allows for the **tracking and transparency** of sustainable feedstock that cannot be physically differentiated from linear alternatives.
- The approach facilitates the use of existing infrastructure, as sustainable feedstock can be mixed with linear feedstock. This considerably **reduces the cost of and barriers** to accelerating the transition to circular inflow.
- Materials are **always verified and assured** using certification, increasing transparency.
- It must be chemically/technically possible to include the input molecular/atoms in the attributed output.

Mass balance challenges

Mass balance is subject to debate due to its complex nature, which makes it difficult to socialize, and to the flexible allocation rules that allow for the decoupling of sustainable inputs and the output products.[39] Value chains still require further alignment on allocation rules to ensure they address all actors' needs so that this can lead to transparency and a common understanding on the subsequent claims made through mass balance accounting.

This calls for the development of a standardized protocol so that companies can make claims based on mass balance approaches in a credible way and a fair comparison can be made among sectors. **ISCC Plus** and other certification schemes have proposed boundary conditions and allocation rules, including conditions for credit transfer between sites. **ISO 13662** is under development and aims to standardize the field of chain of custody to ensure that associated claims are credible. The GHG Protocol has started a two-year process to evaluate the use and implications of market-based accounting approaches (including mass balance) for emissions accounting. Within this process, it will develop additional guidance for these approaches to ensure the integrity of global GHG accounting systems.

Recommendations

The CTI framework is a common language on circularity shared across value chains that ensures the same understanding and measurement of success for circularity.

Circular feedstocks are available in limited but increasing quantities. Yet, the production of chemicals happens mainly in large-scale and multi-output assets that require input streams well in excess of available circular feedstocks. This means that physical segregation of products by feedstock is, in the main, unfeasible. At the same time, value chains in the global economy are highly intertwined and expected to remain so. Therefore, we call for an accounting model that caters for mixed inputs in a transparent and traceable way and supports the transition to a circular economy.

Mass balance is one of these accounting models and, as such, can be a key enabler of the transition to circular economy. Its complex nature and allocation rules are still subject to alignment among value chains actors. There is also a need to develop a standardized protocol so that companies can make claims based on mass balance approaches in a credible way that prevent the duplication of claims and ensure fair comparison among sectors.

This guidance recommends that CTI aligns with the criteria and standards that will result from the ongoing efforts by ISO and the GHG Protocol in this respect. Until a wider consensus is reached on allocation rules in the Greenhouse Gas Protocol, CTI users should accept and acknowledge circular materials identified through mass balance only when verified through credible certification schemes and when transparency on the allocation rules used is provided. By adopting this approach in CTI, we aim to encourage the development and scaling up of circular feedstocks and the manufacturing of products derived from them.

2.3 Levers to increase circular inflow

Topic 5: Availability of circular material and data on circularity

In the scope of this work, we identified the availability of circular material and access to data related to material inflow as barriers to increasing circular inflow.

Availability, access and procurement of circular raw materials

Companies involved in developing this guidance indicated that the global stock of circular raw materials is a highly strategic yet very complex question to assess.

Developing a realistic estimate is key for companies to strategize an upscaling plan for circular solutions and de-risk their circular investment decisions (such as innovation, asset, supply chain). This is particularly difficult in the current fast-changing environment. Circular raw materials are indeed by nature smaller in size, geographically scattered and coming from diversified value chains and smaller actors. The understanding of impacts associated with these raw materials is also changing rapidly. Policy barriers exist that prevent the movement of some of these materials (for plastic waste, for example). Furthermore, the identification and coordination of circular raw materials is very complex. Circular raw material procurement success stories often imply the creation of sizable demand to ensure a stable supply of circular materials, which is not always possible for smaller individual actors, or the development of strong partnerships, which limits replication at scale.

The availability, access and procurement of circular raw materials remain for now a significant barrier for companies and represent a potential risk to upscaling circular solutions in companies.

Access to upstream data

Measuring circular inflow requires completing a full material inventory and collecting the associated data from suppliers delivering these materials. These data inputs include information on the percentage of secondary content, the toxicity and the conditions under which it was grown and processed (renewable materials) or collected and transformed (recycled feedstock). They may result from aggregating data from a series of successive suppliers.

According to the experiences shared by companies contributing to this guidance, these pieces of data are not always available. When they do exist, they may not be as reliable as needed or confidentiality considerations may restrict the exchange of data. The cost of data collection and the value of data remain vastly underestimated. This poses a serious challenge in calculating circular inflow.

We are working on several solutions that help to promote greater transparency across the value chain. Our **Partnership for Carbon Transparency (PACT) iniciative**, which is specifically tailored for carbon accounting, offers a methodology and infrastructure that enables the exchange of scope 3 carbon emissions data at the product level between supply chain actors. PACT substantially lowers the effort of having to collect individual pieces of data from suppliers and standardizes carbon data. It includes harmonization of the definitions and methods of measuring scope 3 carbon emission data and technical specifications to enable the exchange of consistent and comparable data.

We are exploring the application of this approach within circularity. Building on the success of our **Digital Product Passport project** and PACT's Pathfinder, the **Circularity Data Exchange (CDX)**, a workstream within our Circular Product and Material Pathway program, seeks to enable the circular economy through the exchange of product and material data.

An effective circular economy designed for high-quality continuous material loops requires the circulation of resources and information. Product circularity data is both essential to understanding the content and composition of a product (inflow) and the fate of the product (outflow). This information can support companies in designing and producing products that optimize resource use and adapting business models to ensure materials stay in the economy (close the loop) and do so at their highest value (optimize the loop).

WBCSD, together with partners, seeks to develop methodological guidelines that standardize the approach to circularity data.

Measuring circular outflow *in the context of chemicals*

03.

03. Measuring circular outflow *in the context of chemicals*

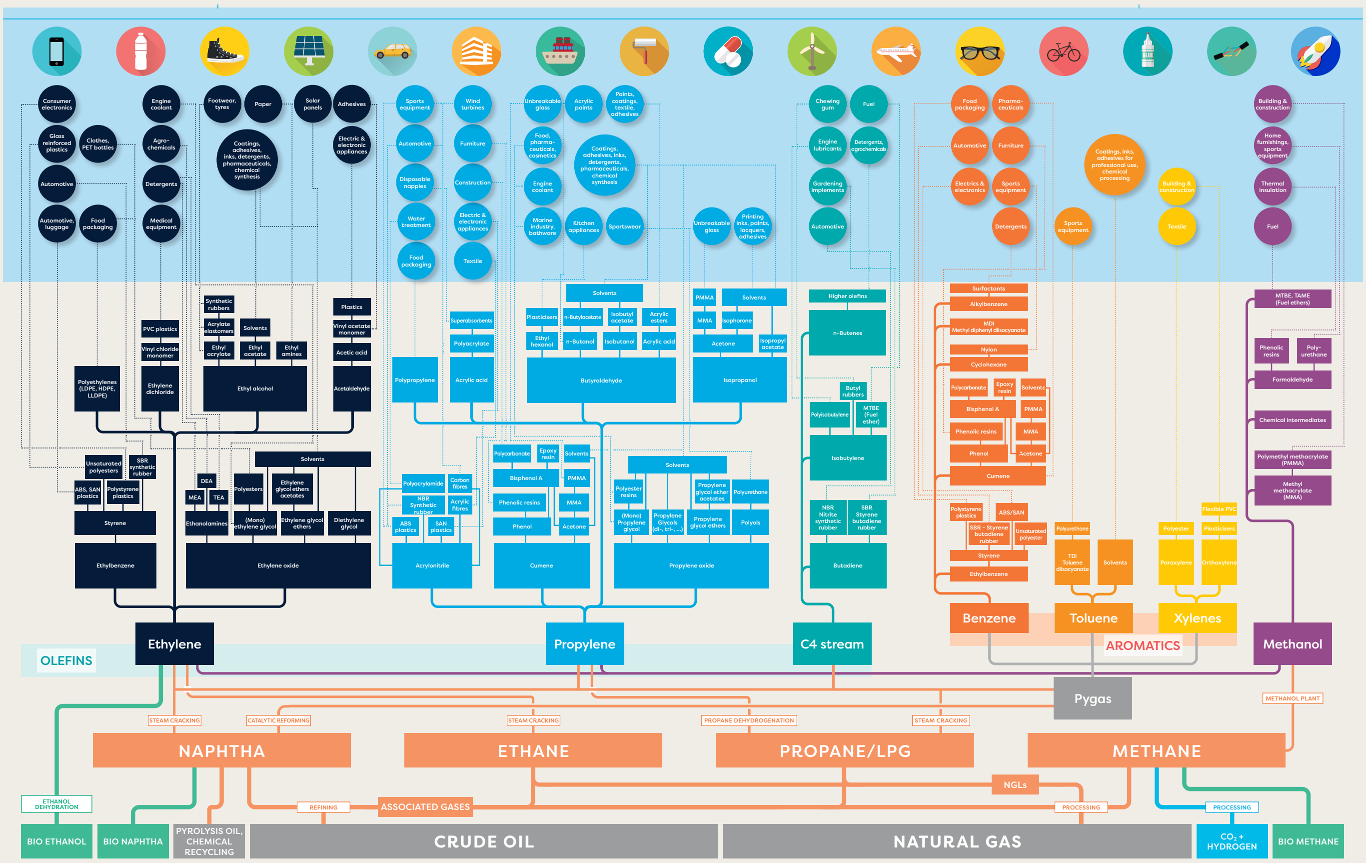
3.1 Chemistry, chemicals and outflow

The calculation of a chemical company's circular outflow is not a straightforward exercise. The essence of chemistry is that reagents transform into other products through reversible or irreversible reactions. Some chemical processes, in nature or in the industrial world, allow for the minimizing of reagents and energy for a specific reaction, for example enzymes and catalysts. This makes the circularity notions of reducing, reusing and refurbishing challenging when applied to the context of chemicals. In addition, a chemical product most times does not result in one end-product. Synthetic materials derived from chemicals may result from a succession of reactions, involving different sequences combining chemicals and other materials. These sequences, or production steps, performed sometimes by different actors, make the understanding of the fate of a chemical in a value chain particularly complex, as Figure 3 suggests. This value chain complexity and the fact that most chemicals transform during reaction make measuring circular outflow difficult.

On the other hand, the chemical industry is upstream in the value chain, which is a strong asset in enabling the upscaling of circular design and increasing the valorization and recirculation of materials. This puts chemical companies in the driver's seat when facilitating circularity in their value chains. Regulatory disclosure requirements are another driver in measuring circular outflow as companies must increasingly report on the fate of their material outflows, which is stimulated by voluntary pledges (such as Plastic Pacts) and regional regulations (like the CSRD ESRS E5 standard).

This chapter aims to provide guiding principles to enhance the transition to a circular economy by aiding in the measurement of circular outflow in the chemical industry. Acknowledging the need to foster new approaches in the development of a circular economy, we have designed them to stimulate innovation, investments in and collaboration on the development of alternative circular business models, regenerative technologies and recycling infrastructure.

Figure 3: Origins and fate of chemicals in the global economy's intertwined value chains[40]



Source: Petrochemicals Europe (n.d.).[40]

What is outflow?

CTI defines outflow as the flow of products and materials from the moment they leave the company to when they reach the end of their life. These materials can be:

1. Linear outflow: non-recoverable products and waste streams (incinerated or landfilled). The materials are not designed to be recovered and/ or were not demonstrably recovered.
2. Circular outflow: demonstrably recovered materials that circulate in value chains.

The CTI calculation for this is:

**circular outflow =
(recovery potential x actual recovery)**

- → **Recovery potential** measures the ability for company's products to be technically or biologically recovered (e.g., by designing for disassembly, repairability, recyclability, biodegradability, etc.).
- → **Actual recovery** measures how much of a company's outflow is actually recovered and reintroduced into the economy. This can occur through direct recovery strategies, such as take-back schemes, or indirect recovery, such as second-hand markets or recycling.

Relevant topics identified as a priority to foster circular outflow in the chemical sector

Desk research and interviews with companies involved in developing this guidance suggested the themes presented in Table 8 as a priority to increase the circularity of chemical outflow.

Table 8: Prioritized themes on circular outflow

Objectives	Prioritized themes
A. How to define & measure circular outflow	→ Explore what the recovery potential definition means in the context of chemicals with respect to: → **Topic 1** – Recyclability and the contribution of different technologies → **Topic 2** – How to consider biodegradability → **Topic 3** – Extending lifetime: reuse & refurbish → **Topic 4** – Guiding principles to assess recovery potential for a reagent → **Topic 5** – How to approach actual recovery

3.2 How to define and measure circular outflow for the chemical sector?

Recovery potential

What recovery modes does the chemical sector use?

We mapped the recovery methods deployed and the challenges in implementing them during stock-taking interviews with companies involved in developing this guidance.

The recovery methods mentioned include mechanical recycling, chemical recycling and biodegradation. Companies also mentioned energy recovery as an end-of-life scenario. In general, the CTI definition does not consider energy recovery in the technical cycle as a recovery type. CTI v4.0 details the conditions under which companies may consider energy recovery from biomass circular.

Recycling remains the most deployed strategy in the short term in the technical cycle and in all sectors.[41] This is also true for chemicals: as confirmed by companies contributing to this guidance, chemical and mechanical recycling are the most prominent strategies.

The WBCSD report on a "Paris Agreement" for recycling Earth's resources estimates that the global economy would need to increase to an 80-90% recycling rate for common materials, such as concrete, metal, biowaste, wood, paper, plastics, e-waste and electric vehicle batteries, to operate within planetary boundaries. This stresses that we need a significant increase in recycling rates. However, recycling strategies alone are not enough. Companies need to complement recovery strategies with other higher value recovery strategies, such as reduce, reuse and refurbish. Our mapping showed, however, that companies involved in developing this guidance are using some higher value recovery methods, such as refurbishing, at a much lesser degree.

Measuring recovery potential

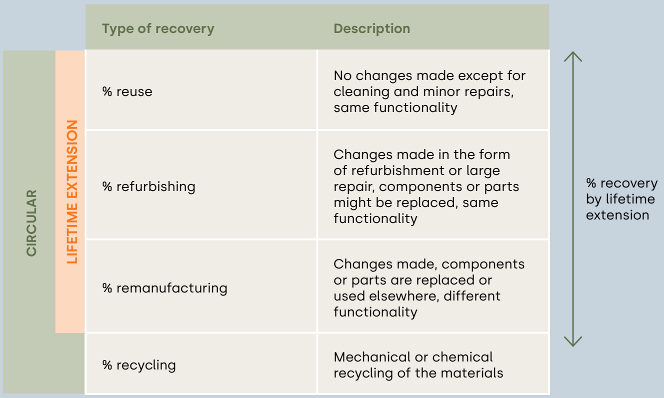
CTI makes recovery measurable by analyzing whether the product is *"**technically feasible** and **economically viable** to be recovered at the same level of functional equivalence through reuse, repair, refurbishment, repurposing, remanufacturing, recycling and biodegrading."*[42]

These criteria ensure that companies are likely to deploy the recovery methods considered in reality. The CTI methodology identifies several types of recovery for materials, as shown in Table 9.

We explore hereafter what recyclability, biodegradability and reduce/reuse/refurbish mean to and in the chemical industry, as well as how CTI can capture this.

Table 9: Recovery types in CTI

Technical sphere



		Type of recovery	Description	
CIRCULAR	LIFETIME EXTENSION	% reuse	No changes made except for cleaning and minor repairs, same functionality	% recovery by lifetime extension
		% refurbishing	Changes made in the form of refurbishment or large repair, components or parts might be replaced, same functionality	
		% remanufacturing	Changes made, components or parts are replaced or used elsewhere, different functionality	
		% recycling	Mechanical or chemical recycling of the materials	

Source: WBCSD Circular Transition Indicators v4.0, p. 59)

Biosphere

Biodegradation is a recovery method in which the product biologically decomposes under set circumstances (e.g., temperature, time and presence of bacteria), returning its nutrients. This can happen, for instance, through composting and anaerobic digestion. A product can only be considered biodegradable if its levels of toxins or hazardous substances fall within recognized thresholds (e.g., as per the Cradle to Cradle Product Standard Restricted Substances List (RSL)).

Source: WBCSD Circular Transition Indicators v4.0, p. 77)

Topic 1 – Recovery potential: recyclability

CTI definition

To ensure companies are likely to deploy recycling methods in reality, the CTI definition includes two key criteria:

- → **Technical feasibility:** the recovery technology has to be proven and exist;
- → **Economic viability:** the recovery option is supported by infrastructure.

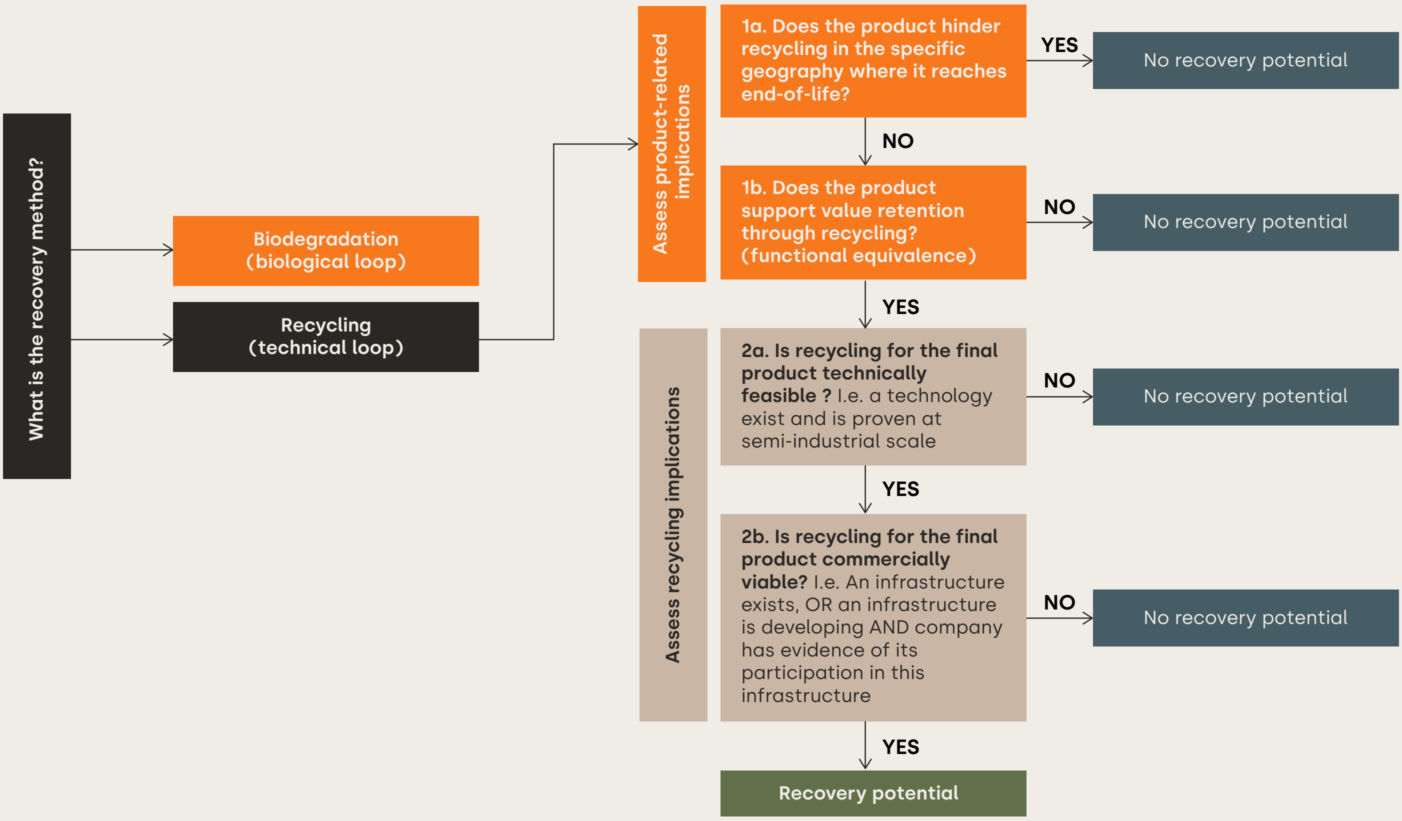
Key considerations in determining recyclability criteria

Companies involved in developing this guidance confirmed they consider both technical and economic viability when determining recyclability. However, this guidance recommends a common sector definition for recyclability and guiding principles on how to assess recyclability, in particular how to assess technical and economic viability.

This guidance proposes a formulation of criteria for recyclability to accelerate the circular economy and reward best practices. This includes a two-step approach, presented in **Figure 4**.

Figure 4 presents a decision tree that summarizes the criteria developed for the chemical sector.

Figure 4: Guiding principles to determine recyclability for the chemical industry



Step 1: Product-related principles

Companies should apply first **product related principles**:

- → At a minimum, the product does not hinder the recycling of products made from the chemicals considered in the specific geography when the product reaches the end of its life; otherwise, it is considered linear;
- → CTI requires the recovery of the end-product at the same level of functional equivalence.

If the product meets the conditions above, then companies need to consider the **recycling principles.**

Step 2: Recycling principles

The recycling potential is assessed by looking at the technical and economic viability. This required further consideration of the following to harmonize practices in the chemical sector:

- → The diversity of products in the chemical industry, acknowledging that large volume plastics, sometimes called a "commodity" (PE, PP, PET, etc.), may benefit from established waste management infrastructure while the specialty chemicals or plastics made from them may not.
- → New recycling technologies under development or scale-up could contribute to increasing the amount of recyclable waste. These may not all be fully deployed at scale and in all geographies. Circular metrics should, however, encourage investments in innovation, technologies and the development of recycling ecosystem within certain boundaries.

Implications are reflecte in a more detailed definition as follows:

1. Recycling is **technically viable** when a technology to recycle a product is **demonstrated** at least at **semi-industrial scale**[43] and plans exist to scale this at commercial scale. This can be accounted for in circular metrics in the capacity and geography considered and backed up by facts. It is otherwise considered linear.

   Once the recovery option is technically viable then "economic viability" needs to be demonstrated. Recycling processes are in most cases more expensive than virgin production. This sole criteria does not constitute a criteria to decide whether the model is economically viable.

2. Instead, recycling is considered economically viable when:

   A1) Infrastructure and its business system exist

   OR

   A2) Infrastructure and its business system is being developed

   AND

   B) The company:

   - → Has evidence of its substantial financial participation in the pilot

     OR

   - → Has evidence of substantial investment in establishing a shared infrastructure (e.g., investing resources, creating partnerships or ventures.

Under these conditions, this can be accounted for in circular metrics in the capacity and geography considered and backed up by facts.

Best practices in the industry

The group also agreed it is best practice when a company, in a **market leadership position** for a specific chemical product, **takes responsibility for setting up recycling infrastructure for this type of product**. Activities supporting this may include embedding waste management business activities in the scope of mergers and acquisitions for the product family or including design for recycling strategies as a mandatory R&D criterion (such as mono-material strategies).

Table 10 presents selected examples of current practices to enhance recyclability.

Conclusion

Enabling the recyclability of products is an important lever for the chemical industry to enable circularity. Companies increasingly need to report on this. We developed the guiding principles presented in Figure 4 for technical and economic viability to harmonize how the sector puts CTI's "Recovery potential" definition into practice. We created them to encourage a fact-based approach and the development of recycling technologies and infrastructure within temporal and geographic boundaries.

Table 10: Recyclability initiatives from the Circular Chemical Working Group

Recycling de-icing fluid

For safety reasons, Aircraft wings have to be free of ice and snow. To prevent this, the sector uses special fluids to de-ice planes and protect them from re-icing before take-off. De- and anti-icing fluids are based on either ethylene or propylene glycol. While glycols are easily biodegradable, the degradation process uses up large amounts of oxygen, thus potentially harming aquatic organisms. To overcome this, Clariant has developed **Safewing** and offers customers a recycling management solution.[44] In 2023, **Clariant** and **Finavia** introduced recycled propylene glycol for aircraft de-icing at **Helsinki airport**.[45] This represents 500 metric tons of recycled propylene glycol, manufactured to match the quality of virgin fossil de-icing fluid. This circular approach reduces CO_2 emissions in two ways: it prevents the degradation of glycol in sewage treatment and significantly reduces demand for virgin fossil raw material.

Recycling of single-use medical instruments

Syensqo's Ixef polyarylamide (PARA)[46] is a high-end specialty polymer. Such specialty materials do not benefit from recycling infrastructure like those that exist for commodity polymers such as polyolefins or PET. Syensqo has therefore joined forces with two partners to set up a take-back scheme:

- → Ostium Group designs and manufactures single-use medical instruments for orthopedic surgery;
- → Cosmolys, a biomedical waste treatment company, collects, decontaminates and recycles medical devices to return recycled Ixef PARA to Synesqo;
- → Synesqo can then manufacture recycled high-performance material for use in demanding automotive or sport and leisure equipment.

While the initiative is for the EU market, the three partners are considering extending this to the US market.

Medical device regulations restrict the use of recycled materials, making closed loop recycling impossible, a fact that is driving open loop recycling. According to Syensqo, recycled Ixef PARA has a carbon footprint 70% to 80% smaller than that of its virgin equivalent, reducing the environmental footprint of other high-demand products.

Bio-based polyamide 11 shoe

Arkema has been collaborating with Swiss sportswear brand On to create the first fully recyclable bio-based shoe. This Cyclon shoe is made from Rilsan polyamide 11, a bio-based plastic made of a renewable resource, sustainable castor beans (as part of its Pragati Sustainable Castor Initiative[47]). It makes all the shoe's components with the same material, which makes recycling easy, as the shoe can go in one piece to recycling. The company sells it in a circular business model that includes a subscription with a take-back scheme. It collects worn out shoes and sends them to Agiplast, the Arkema subsidiary specializing in high-performance plastic recycling, enabling the recycling of the material through the Virtucycle program.[48]

Topic 2 – Recovery potential: biodegradability

CTI definition

CTI defines biodegradation as **a recovery method in which the product biologically decomposes under set circumstances (e.g., temperature, time and presence of bacteria)**, returning its nutrients. These nutrients, such as nitrogen, phosphorous, potassium and micronutrients are made available to plants and can be used to help regenerate the land.[49] In CTI, a product can be considered biodegradable if its levels of toxins or hazardous substances fall within recognized thresholds, as per the **Cradle to Cradle Product Standard**.

Note: Biodegradable products can be made of renewable resources or from fossil-based raw material.

The potential of biodegradation

As mentioned in the introduction, biodegradability is a minority recovery strategy in the chemical sector. The member interviews also confirmed that the companies do not systematically assess biodegradability for chemical products.

This guidance recognizes the existing controversies, in particular with biodegradable plastics. For other types of chemicals, they also acknowledge the potential of biodegradability in combatting pollution and the relevance of biodegradability as a recovery strategy for chemicals in the composition of products ending up in the environment because of their designed use (such as detergents).

The challenges of biodegradation

Companies contributing to this guidance highlighted several roadblocks that hinder the deployment of biodegradation as a recovery strategy:

- Little clarity on the role of biodegradation recovery strategies compared to other recovery options such as recycling;
- Lack of harmonization: a variety of biodegradation standards exist, differing from application to application and from region to region;
- Little clarity on what really happens to biodegradable products, including uncertainty on the time they take to biodegrade, which raises risks of environmental damage between disposal and degradation;
- Lack of policy incentives or mandates to stimulate market adoption of relevant biodegradable solutions.

The role of biodegradation & the fate of biodegradable products are not clear

Companies involved in developing this guidance indicated that there is little clarity on when biodegradation is the best recovery option to optimize the environmental performance of a product. Biodegradation as a recovery method is often controversial when associated with biodegradable plastics, including issues surrounding incomplete degradation and adverse environmental impacts despite full biodegradation. Issues surrounding biodegradation include:

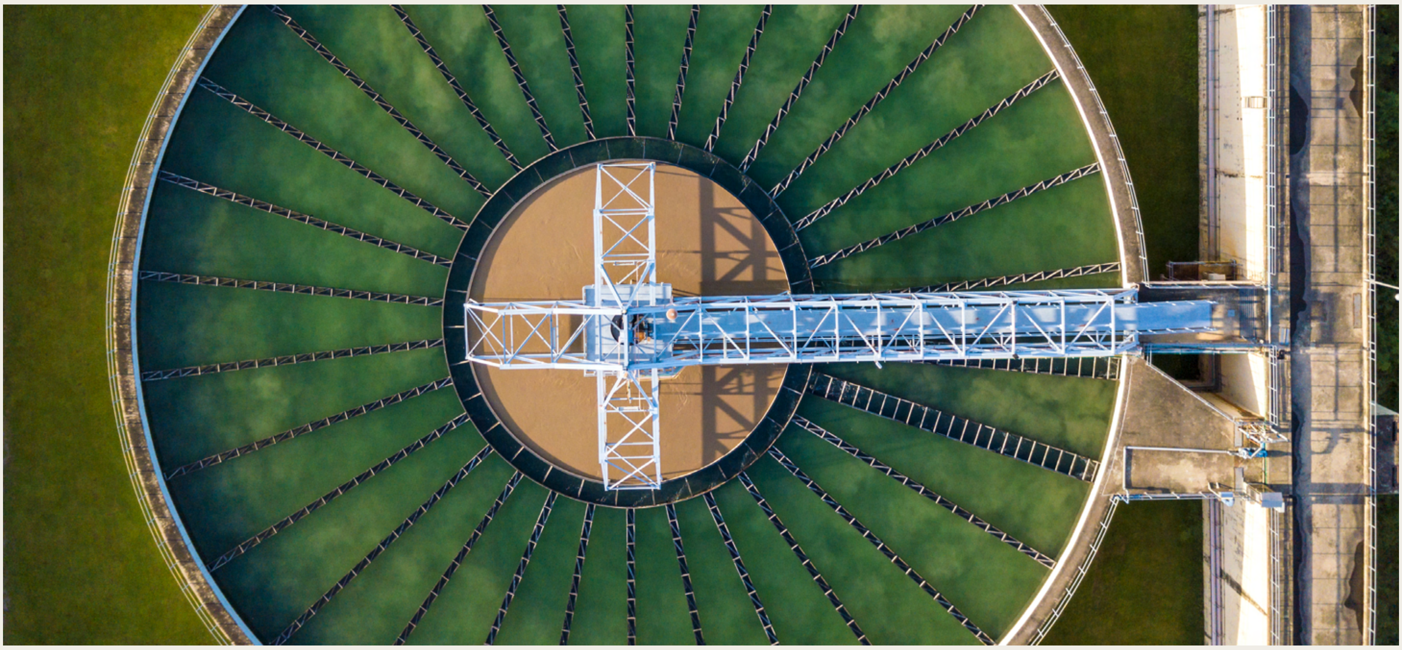
- Different biodegradable materials have different degradation rates and mechanisms, potentially leading to incomplete breakdown or harmful byproducts released in the environment if not performed in a controlled environment.[50]
- Biodegradable products can be potentially more environmentally harmful than their virgin counterparts if they end up in a landfill.[51]
- The effectiveness of biodegradation is highly dependent on the chemical structure, additives and other ingredients of a product. For plastics, biodegradation is dependent on the type of microorganism used and specific water and oxygen conditions, which are difficult to guarantee in home composting or industrial composting facilities.[52]
- Complete biodegradability does not mean no adverse environmental impacts. The plastic leakage report[53] shows that polymers with high rate of biodegradation may still negatively impact the environment by the time they have fully biodegraded (such as when animals ingest them).

Lack of harmonized standards on biodegradation

Companies contributing to this guidance mentioned the multitude of application- and geography-specific biodegradability tests and standards as a barrier to design for biodegradation.

The Organisation for Economic Co-operation and Development (OECD) guidelines (including OECD 302B inherent and OECD 301F ready and various labels) was mentioned as a commonly used reference, which the CTI methodology also recommends. These guidelines are a set of testing methods used to identify and characterize the biodegradability potential of chemicals and are the most relevant internationally agreed testing method used to assess biodegradability.[54]

There are, however, limitations to these biodegradability testing methods that prevent companies from deploying this recovery strategy further. These limitations include arbitrary boundary conditions and reference values. The criteria for biodegradable products are often also prescribed at the application level and happen to vary from country to country. There are also numerous certifications and labels to identify biodegradable materials, for instance the term "bioplastics". These guidelines and standards may lead to confusion in practice[55] as they are not always compatible with local waste management practices. It is thus necessary to review and harmonize these guidelines globally to bring the chemical industry clarity on how to design products with broadly applicable biodegradability characteristics. This would also allow for adequate comparison between biodegradable products. There is therefore a need for further work on practical, reliable, harmonized biodegradability[56] test methods and standards.



Lack of policy incentives or mandate

There is no legally binding legislation in place encouraging the application of biodegradability as a recovery strategy. Some work relative to biodegradable plastic is ongoing in Europe, with the European Commission aiming to improve a shared understanding of where this recovery option can bring benefits.[57] There are currently no market incentives to trigger the adoption of biodegradable products.

Conclusion

It is not easy to identify where biodegradation is a recovery strategy to recommend.
Each case requires careful consideration.[58]
While there are little to no policy or market incentives, this guidance acknowledges the potential of biodegradability in combatting pollution and the relevance for chemicals in the composition of products ending up in the environment because of their designed use (such as detergents, medication or nutrients).[59] Enabling further uptake of biodegradability as a recovery strategy for products designed to end up in the environment would require further work on standard harmonization, the understanding of biodegradability mechanisms and progress on testing.

Table 11: Member biodegradable solvent example

Eco-friendly solvent

Rhodiasolv IRIS, a product from Syensqo, is an oxygenated solvent designed for applications such as industrial cleaning, resin clean-up, foundry resins, paint stripping, paints and coating formulations. This solvent is biodegradable, non toxic, non-flammable and contains a low number of volatile organic compounds (VOC). It is therefore suitable for application in end-products that are dissipative, for which they can represent a circular alternative.[60]

Topic 3 – Extending lifetime: reuse & refurbish

In the Planet Positive Chemicals: Pathways for the chemical industry to enable a sustainable global economy[61] issued in September 2022, Systemiq and the Center for Global Commons stress the need to decouple business models from volume-based to value-based models in a way that reduces physical demand for finite resources and contributes to the transition to net-zero emissions by 2050. This requires the implementation of circular strategies such as the **service-based business model**, also known as chemical as a service, cited as an example in the same report. Broadening the scope, this reinforces the **strategic importance** of implementing product lifetime extension strategies[62] at each step of the value chain. Applying these concepts for chemicals is, however, not trivial, as mentioned above.

Developing this guidance, we focused on mapping companies' existing reuse and refurbish practices and understand how CTI can measure and stimulate these strategies in the diverse context of base, intermediate and fine/ specialty chemicals.

CTI defines lifetime extension strategies as:

- **Reduce** – an overall decrease in the amount of material input necessary for the product;
- **Reuse** – a recovery strategy where the material undergoes no changes and keeps the same functionality;
- **Refurbish** – a strategy where the material maintains the same functionality with only minor changes made, e.g., replacement of minor parts or repair.

Reuse and refurbish differ from recycling as:

- The product's/material's functionality remains;
- There is no invasive process of breaking the material/product down.

Illustration examples to distinguish recycling from refurbishing

Example 1: When a packaging container made of polypropylene (PP) is processed to be transformed into a car bumper, the original functionality is not maintained; the original product is broken down to be reshaped into another product. This is recycling.

Example 2: When a used catalyst is rejuvenated to regenerate its performance, it maintains its integrity and functionality. This is refurbishing.

Considering the entire value chain where a specific chemical is used, reuse and refurbish strategies can equally be applied **before** the final product for which chemicals are used reach the consumer (**pre-consumer**, meaning staying within industrial applications) or **after** that (**post-consumer**), contributing to closing shorter or longer loops.

Current practices

In the first interviews, the companies involved in developing this guidance had difficulty defining what reuse and refurbish meant for chemicals. This shows these strategies remain a vastly untapped opportunity to advance circularity. This also indicates that companies often do not monitor or quantify these practices. We therefore started from existing research and explored practices further with companies involved in this work.

Chemical-as-a-service (CaaS) business models offer options for reuse and refurbish strategies. In their Planet Positive Chemicals report, the Center for the Global Commons and Systemiq describe examples from the chemical industry, how they depend on the chemicals and production processes considered and where the various subsectors of the chemical industry can leverage them.[63] Table 12 provides a schematic overview. These business models value the functionality and performance delivered and can therefore result in efficiency gains. They include configurations like leasing and take-back schemes that extend the responsibility of the chemical manufacturer.

Table 12: Overview of chemical-as-a-service business model

Product-oriented models Addition of (circular) services to existing chemical products		*Process-oriented models* Services that yield process and product delivery improvements	*Results-oriented models* Management of total product (systems) to deliver outcomes instead of volumes	
Molecule and material leasing Supplier remains the owner of the chemical, but payment is based on volumes, typically coupled with recovery schemes.	Take-back schemes The supplier recovers chemicals and for reuse, typically in partnerships and/or enabled by digital technology.	Process equipment as-a-Service The equipment process and delivery of chemicals is offered as a service.	Chemical leasing The functions performed by the chemical serve as the unit of payment and chemical suppliers and users work together to optimize chemical use in fulfilling the function.	Ecosystem solutions Equipment technology, service expertise and chemicals are bundled in one system solution and payment is based on performance of this system.
REUSE/ REFURBISH	**REUSE/ REFURBISH**	**REDUCE**	**REDUCE**	**REDUCE**

Source: Adapted from: “Systemiq (2022). Planet Positive Chemicals: Pathways for the chemical industry to enable a sustainable global economy.”[64]

Opportunities for reuse and refurbish in industrial applications

The interviews and workshops with companies involved shed light on typical reuse and refurbish examples. Table 13 presents these examples and some for reduce.

Companies involved often mentioned molecule and material leasing as refurbishing strategies as the product/material comes back to the company after use and the company then brings it back to its initial functionality.

Table 13: Reuse/refurbish and reduce examples from working group members

Reuse/ refurbish

Molecule and material leasing:

- Solvent regeneration
- Purification of used chemicals

Separation medium refurbishing (product leasing):

- Molecular sieve refurbishing
- Ion exchange resins refurbishing

Catalyst refurbishing services in applications such as oil refining operations or cars

Reduce

Performance selling:

- On-site sulfiding service for biodiesel refineries
- Water treatment
- Disinfection performance selling

Synthetic production commonly uses solvents and catalysts to enable specific chemical reactions

Synthetic production commonly uses solvents and catalysts to enable specific chemical reactions.

- Solvents are usually used to dissolve reactants while catalysts accelerate or favor reactions

  Note: Solvent refurbishing is often improperly called "recycling" while its functionality remains and the operation performed consists of minor changes. This falls within refurbishing according to circularity definitions.
- Catalysts are particularly expensive and contain precious metals. They are recovered most of the time after a chemical reaction. Because of their respective functionality and massive use, they have been subject to productivity measures aimed at reducing cost by extending their life span. This makes it an attractive circular strategy.

Companies also mentioned purification or separation mediums, such as membrane or ion exchange resins, as opportunities for leasing models. We noted that leasing and contractual aspects are key to enabling the refurbish criteria as they set the conditions for the collection of materials before they are too deteriorated.

Companies also mentioned industrial symbiosis as a way to valorize the use of their by-products by other parties, reducing resource consumption. This is also considered a reuse/refurbish strategy.[65]

The examples above and in **Table 14** highlight that reuse, refurbish and reduce strategies are within the scope of control of the chemical industry. The ongoing efforts in the chemical industry to develop services-based solutions are an asset companies can leverage to create more opportunities to advance circular economy life-span extension strategies. This guidance acknowledges the business and innovation potential that reuse and refurbish represent.

Table 14: Member examples of reuse and refurbish in industrial applications

Catalyst rejuvenation

The Excel process, a service from Evonik, is a catalyst regeneration and rejuvenation service that restores the performance of used catalysts to full activity, increasing the lifespan of the catalyst and the precious metals used in the catalyst. This two-step process first regenerates the used catalyst under an oxidative atmosphere to remove both coke and sulfur. Then a chemical treatment is carried out to remove activity inhibitors, redisperse metals and restore active sites for maximum activity.

This catalyst refurbishing prevents waste and reduces greenhouse gas emissions by about 60% over a fresh catalyst, as life-cycle analysis data show.[66] This offers petrochemical refiners an alternative to virgin catalysts for a wide range of applications, from hydrotreatment from naphtha to heavy gas oil.

Performance selling: on-site sulfiding service for biodiesel refineries

Arkema has extended its offer to sell its dimethyl disulfide (DMDS) product to a customized service offering. DMDS Evolution E2 is an efficient and high-purity sulfiding agent used in conventional and biofuel refinery processes as an additive to improve process efficiency through the activation of the hydrotreatment catalyst.[67]

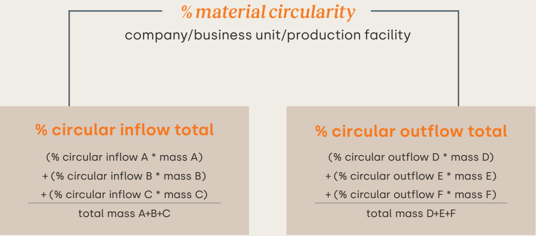
Based on over 6,000 sulfiding jobs done, Arkema has developed Carelflex, a performance-based business model to provide product and onsite service to customers. Supported by a digital monitoring system, Carelflex ensures accurate and controlled sulfiding operations, maximizes the catalyst activity and thus decreases resource consumption by injecting only the exact quantity of product required.

How CTI measures reuse & refurbish

Companies can use several indicators to express the circularity benefits of reduce, reuse and refurbish strategies. These are part of the close the loop and value the loop modules in CTI.

Close the loop

% material circularity expresses a company's effectiveness in closing material loops.



% material circularity

company/business unit/production facility

% circular inflow total

$$\frac{(\%\text{ circular inflow A} * \text{mass A}) + (\%\text{ circular inflow B} * \text{mass B}) + (\%\text{ circular inflow C} * \text{mass C})}{\text{total mass A+B+C}}$$

% circular outflow total

$$\frac{(\%\text{ circular outflow D} * \text{mass D}) + (\%\text{ circular outflow E} * \text{mass E}) + (\%\text{ circular outflow F} * \text{mass F})}{\text{total mass D+E+F}}$$

Value the loop

CTI revenue measures revenue adjusted for the % material circularity of the product portfolio.

CTI revenue (product)

$$\frac{\%\text{ circular inflow} + \%\text{ circular outflow}}{2} \times \text{revenue}$$

CTI revenue (company)

$$\sum \begin{matrix}\text{CTI revenue A}\\ +\text{CTI revenue B}\\ +\text{CTI revenue C} + \ldots\end{matrix}$$

Circular material productivity expresses a company's effectiveness in decoupling financial performance and linear resource consumption.

circular material productivity

$$\frac{\text{revenue}}{\text{total mass of linear inflow}}$$

Reuse and refurbish always result in an **increase in circular outflow** (material circularity). In the case where materials are used again and returned to the company, the materials **both** increase **circular outflow** and present **circular inflow** (closed loop recovery) for the company. We discuss the two cases below.

Case 1: Increase in circular outflow

The first indicator that expresses benefits is the **material circularity** indicator. This indicator is mandatory for every CTI assessment. Refurbishing and reuse will increase the % circular outflow. For a chemical company that has catalysts refurbished, this means that its product is recovered after use, which is considered circular outflow.

The second relevant indicator is **CTI revenue** and shows the increased monetary value created from circular activities.

Case 2: Increase in circular inflow AND outflow

The material circularity indicator will increase circular outflow and circular inflow if products are designed for refurbishing or reuse, and are then reused by the same company as inflow.

In closed loop recovery, the products circle back and enter the company's system boundary for reuse as inflow. This counts as circular inflow as these products were already used and avoids using virgin material inflow. The company would see an increase in both **circular outflow** (designing products for refurbishing) and **circular inflow** (using materials that flow back again as inputs). This means that closed loop recovery schemes (such as take-back schemes and chemical leasing) that have multiple reuse/refurbish cycles benefit from an increased circularity performance in CTI.

This also has benefits in decoupling revenue from virgin material resource consumption. The company quantifies these benefits through the **CTI revenue indicator** and the **circular material productivity indicator**.

How CTI quantifies reduction strategies

The %material circularity equation does not capture reduction strategies. Instead the **circular material productivity** value the loop indicator measures them.

Circular productivity expresses a *company's effectiveness in decoupling financial performance from linear resource consumption*. Companies can also see the impact of reduce strategies on their total virgin material consumption.

Differentiating enabling solutions from company material circularity in reuse and refurbish strategies

When it comes to measuring the circular performance of a company product or service in the context of reuse and refurbish, it is necessary to differentiate between two scenarios:

- **Scenario 1:** Making own company more circular;
- **Scenario 2:** Contributing to making third-party actors in the value chain more circular (for instance, customers, suppliers or end-users)

Both contribute to advancing circularity. They are, however, not captured the same way in circular metrics. In **scenario 1**, benefits are measured in the company CTI performance. This is in the scope of this sector guidance.

Scenario 2 will improve the material circularity of the third party using the product. This is sometimes referred as an enabling solution. This is out of the scope of this sector guidance.

We are currently working to define the methodology and metrics to quantify the contribution of enabling solutions will published the second half of 2024.

Who owns the chemical product exchanged is a key consideration to determine whether scenario 1 or 2 applies.

- When the product remains under the ownership of the company producing and refurbishing it, scenario 1 applies. The company selling could, for example, lease the product, collect it after use and then refurbish it for reuse.
- When the product ownership is passed to the next actor in the chain, the refurbishing strategies could consist of offering a service. The company could offer the service to refurbish other companies' products, which would mean scenario 2 applies.

Example: A company produces a specific catalyst for use in oil refining. The company offers a take back service so that it collects used catalyst to rejuvenate it. The company could either sell and buy back or lease the catalyst and collect it. **Scenario 1** applies in this example.

Example: A company offers a catalyst rejuvenation service that treats third-party catalysts without owning the catalyst. **Scenario 2** applies here.

Conclusion

Reuse and refurbish are relevant and nascent strategies for the chemical industry. They are already in use.

CTI quantifies reuse and refurbish strategies in the material circularity, circular revenue and circular material productivity indicators. They contribute to credibly demonstrating how the company contributes to advancing the circular economy. Companies must, however, start to embed these examples into their metrics and intensify efforts to develop their reuse/refurbish solution offerings.

As decoupling value creation from resource consumption is a corner stone of the chemical industry transformation to operate within planetary boundaries, reuse and refurbish strategies offer a largely untapped business and innovation potential in addition to advancing company circularity. For this, chemical companies can leverage their strong chemical engineering know-how (such as separation and purification) and sustainable chemistry.

Topic 4 – Guiding principles to assess recovery potential for a reagent

Definitions

A reagent is a substance added to a system to cause a chemical reaction and consumed in the course of a chemical reaction. Additives such as peroxides or inhibiters are reagents. Solvents or catalysts are not reagents.

In essence, chemicals reagents are meant to be consumed and transformed during the course of a reaction into other products. Several chemical reactions or transformations can happen before chemicals end in a manufactured product. Chemical reagents are difficult to recover individually because they are designed to be consumed and transformed during the reaction. As a large proportion of chemicals may fall in the reagent category, it was relevant for us to assess **what the levers are to foster the outflow circularity for reagents**.

Guiding principles

For that purpose, this guidance offers a guideline to assess the conditions under which companies could consider the reagent outflow as circular.

To start with, conventions define the end-of-life boundaries as follows: If the resulting chemicals from the reagent reaction are subject to future chemical reactions and then integrated into another product, the end of life is defined as the end of life of the final product.

Considering the logic and definitions proposed by CTI, and building on the outcome of the recovery potential work (see Chapter 3 / topic 1: recovery potential, Figure 4), we propose the following guiding principles to define the conditions for a reagent to be considered circular:

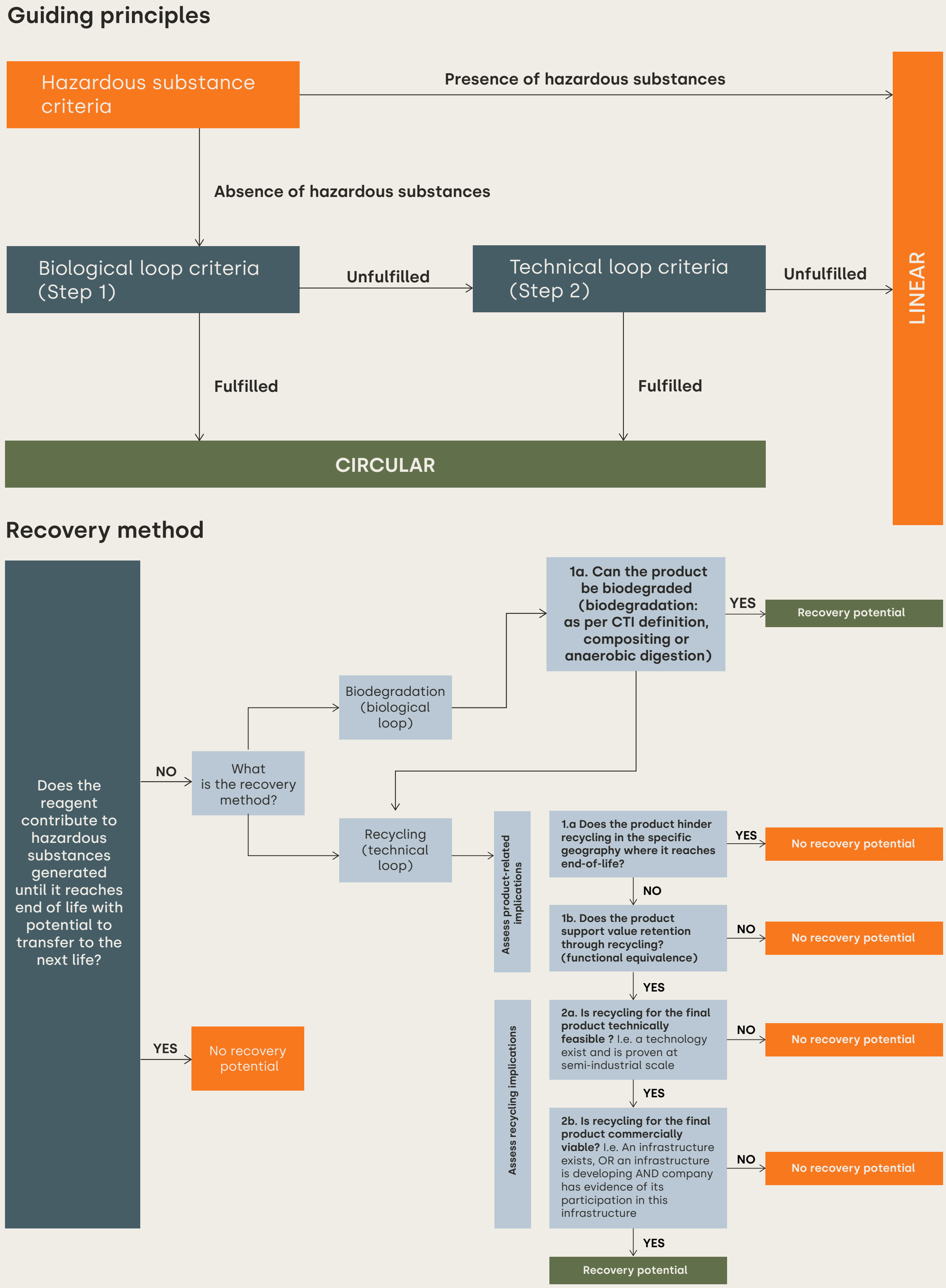
1. Does the reagent contribute to hazardous substances generated until it reaches end of its life with potential to transfer to the next life (hazardous substance criteria)?
2. What is the recovery method (recyclability & biodegradability)?
3. Apply relevant recovery method criteria.

Figure 5 presents decision trees built from these guiding principles. Note that when a reagent does not meet the biodegradability criteria (biological loop criteria), the company should assess recyclability (technical loop criteria) next before reaching a final answer on the circularity of the reagent.

Note: If it is not possible to answer one of the questions due to lack of evidence, then the default assumption should be a **linear outflow**.

Once the potential recovery for the reagent is determined, it is necessary to assess the actual recovery, in a similar manner as for other products and materials.

Figure 5: Guiding principles to apply circular metrics to reagents



Measuring actual recovery

Actual recovery measures what happens with materials after they have reached the end of their life. This fosters the company's understanding of the fate of its products and drives accountability in developing solutions that successfully close material loops.

CTI measures this with the **Actual recovery metric**, which is part of the % circular outflow indicator. It measures how much the company's outflow is actually recovered and reintroduced into the economy. This can occur through direct recovery strategies, such as take-back schemes, or indirect recovery, such as second-hand markets or recycling.

The upstream position of the chemical industry makes it particularly challenging to access information on what happens to products until end of life and what the actual end-of-life scenario are, as previously mentioned. This guidance calls for action on data to gain more visibility on product fate and therefore generate insights into actual recovery rates.

Topic 5 – The role of data in fostering actual recovery

Companies involved in developing this guidance mentioned that data on product use and fate is hard to access. When companies do manage to collect it, the data is of poor quality. Companies mentioned understanding the product fate in the intertwined value chains and the fragmentation of data as key factors. When customer information is available, the sales/marketing organization tends to collect it and the data is often only qualitative and descriptive.

The data needed to measure circular outflow

Chemical actors need to gather data on the recovery potential, product use and actual recovery, as shown in **Table 15**.

Table 15: **Data needed to measure circular outflow**

Type of data needed	Who owns the data?	Difficulty accessing data
Recovery potential – mass of products that can be recovered	Company R&D, tech service and marketing estimate to start, then move to collecting downstream data from the partners who are willing to provide	Medium (in chemical company control)
Data on product use	Downstream partners, consumers	High
Data on actual recovery	Databases and downstream partners, local waste collectors and municipalities	

Companies involved in developing this guidance mentioned that while recovery potential data is often in their control, that data on product use and fate is hard to access and, when collected, of poor quality.

Recovery potential data can indeed be gathered from different functions in the company, in particular the different teams participating in innovation processes.

On the other hand, companies mentioned that collecting actual recovery data on **product use and product end of life** is extremely difficult, as this:

- → Relies on external actors;
- → Requires understanding the product's fate in the intertwined value chains – which is proven more difficult for raw material actors upstream in the value chain, such as the chemical industry;
- → Is consequently very fragmented and often relies on estimates, lacking the required accuracy and reliability.

Yet, solid data on actual recovery is crucial to driving sustainability-informed fact-based conversations between value chain partners and enabling chemical industry actors to develop sustainable solutions. The latter requires enabling the assessment of different scenarios for product development as early as possible in the innovation phase.

Primary vs secondary datasets for actual recovery data

Accessing **actual recovery** data requires collecting **primary data** where possible and deploying **secondary dataset** strategies for the rest.
The broad diversity of applications for chemicals brings complexity in collecting primary data and requires upfront prioritization.

Primary data

Companies indicated access to **primary data** was likely feasible in the case of short value chains where there are a limited number of actors. This still requires strong partnerships and confidentiality agreements to be in place. Companies generally face several challenges when accessing primary data, including intellectual property protection and the cost of structuring and collecting the data. Supporting infrastructure, technology and regulations for data sharing could address these concerns but they are currently lacking and therefore a roadblock for all value chain actors.

The main challenges to sharing data include the divergence in definitions of circularity, confidentiality concerns, low data quality and resource-intensive processes.

Building strong protocols for circularity data exchange is necessary to:

- → Inform circular partnerships and strategies and enable the setting of targets that foster accountability, traceability and transparency.
- → In terms of value creation, a circularity data exchange mechanism can help companies to:
  - – Reduce costs (by, for example, increasing efficiency, preventing waste, allowing for the valorization of waste);
  - – Foster competitive advantage (enabling communication on circularity);
  - – Reduce risks and builds resilience (spotting weaknesses in supply chains, enabling companies to stay ahead of regulation and verification that prevents greenwashing);
  - – Reduce risks and builds resilience (spotting weaknesses in supply chains, enabling companies to stay ahead of regulation and verification that prevents greenwashing);

It is therefore essential to ease, harmonize and standardize data exchange to scale solutions that accelerate the shift to a circular economy. **Multilateral data flows** are also key, so that value chain partners get the data they need up- and downstream from where they operate.

In 2023, WBCSD started working in partnership with the One Planet Network (hosted by UNEP) to kickstart an initiative to shape a **Global Circularity Protocol (GCP)** to address policy and accountability gaps that can unlock circularity. This includes fostering cooperation to establish shared definitions and a harmonized methodology. It also entails **a data exchange mechanism** and **science-based targets** for circularity.

This initiative builds on WBCSD's experience on climate action through the Greenhouse Gas Protocol and the Partnership for Carbon Transparency (PACT), which have demonstrated that the exchange of primary data across value chains is most successful when supported by a commonly agreed set of rules (standards) and indicators, and a secure and confidential peer-to-peer data exchange network. In the decarbonization space, PACT is an example of a successful initiative that aims to increase transparency by facilitating primary data exchange.

Partnership for Carbon Transparency (PACT)

PACT is a WBCSD project that aims to increase carbon transparency throughout the supply chain by facilitating the exchange of verified primary carbon data in a secure and confidential peer-to peer data exchange network. BASF, Dow and Solvay[69] piloted this approach, stating it is "a foundation to create a collaborative ecosystem allowing carbon emissions data to be shared along value chains." In the automotive sector, this approach has shown how original equipment manufacturers can have accurate material and carbon data inventories.

Availability of secondary data

To estimate the end of life of products, the chemical industry uses secondary datasets with the average recycling rates of materials (such as public European data). The companies involved in developing this guidance indicated that these databases have shown limitations: they lack geographical representativeness as they were developed by and for the Global North and they are largely outdated.

However, the chemical industry is confronting increasing requests from customers to assess circularity and environmental impacts. This implies automating and digitalizing circularity and environmental data. Accessing quality data to enable measurement of such impacts remains a significant challenge. While collecting data from suppliers is labor-intensive, accessing data on a product's end-of-life in highly globalized intertwined value chains is an even more complex task, in particular as little to no initiatives support data movement from downstream to upstream. Acknowledging that a data exchange mechanism for circularity may take a few years to deliver results, this guidance calls for the development of generic datasets containing recovery statistics on materials for the purpose of supporting the assessment of end-of-life scenarios and informed decision-making during product innovation phases.

What chemical companies can do to increase actual recovery

While accessing data is a challenge for the measurement of actual recovery, companies are taking the initiative to progress their circularity outflow. This includes:

- **Recycling/take-back** schemes
    - In the cases of specialty products or in regions lacking public infrastructure, recycling schemes may not be readily available. In these cases, making investments to develop and scale collection and recycling infrastructure is an impactful response to advance circularity. This may include take-back schemes.
    - A company that is a market leader on a specific specialty chemical may take responsibility for leading the setting up of recycling infrastructure. This is a useful practice as it helps increase recovery rates for specialty chemicals that, unlike commodities such as polyolefins or PET, do not benefit from a standard waste management infrastructure.
- **Vertical integration**: Integration of end-of-life activities and recycling in the scope of merger and acquisition activities

Conclusion

Actual recovery is foundational in measuring the circular performance of a product or chemical. The upstream position of chemical companies and the complex intertwined chemical value chains make it difficult to get transparency on the fate of products at the end of their lives. The Chemical Circularity Working Group has highlighted the need for greater efforts to better grasp the fate of products at the end of their lives and drive accountability in order to develop solutions that close material loops. These include the implementation of take-back schemes, contributing to recycling infrastructure or strategic business acquisition (vertical integration) and data exchanges.

Table 16: Member actual recovery example

The Virtucycle Program[48]

Arkema has taken a leadership role in setting up a recycling stream for materials containing polyamide 11 and polyamide 12 resins, PEBA elastomers and PVDF fluoropolymers. To do so, the company acquired Agiplast, a high-performance polymer recycler/regenerator, in 2021. This enables the company to close the loop on these polymers by working in collaboration with polymer customers and downstream users to collect them for recycling and process them into high-quality recycled polymers. This supports Arkema in developing its recycled product lines. This process recovers both pre-consumer materials (such as scrap) and post-consumer materials (such as sneakers). This program also provides insights to better understand product use and how they reach the end of their lives. Additionally, Arkema gains access to quality secondary feedback to develop and drive circularity.

Conclusion
Accelerating circularity in the chemical industry

04.

04. Conclusion

Chemicals are ubiquitous, serving the complex, intertwined, predominantly linear value chains that span almost every segment of the global economy. The chemical industry plays a unique role in catalyzing the transition to a circular economy. But achieving it will require overcoming critical challenges.

This report is the outcome of the collaboration of 11 major chemical companies over 18 months to explore the role of harmonized circular metrics in advancing company progress on circularity. The collaboration focused on material circularity, the headline indicator of the **Circular Transition Indicators (CTI)**.

It was triggered by the necessity to harmonize practices and establish a common language for circular metrics. It aims at defining how to measure the performance of company/business/product contributions to the circular economy to foster informed business decisions and consistent communication along the value chain.

The working group structured the conversation based on CTI, a sector-agnostic framework used by more than 150 leading corporations across different value chains and sectors since its launch in 2020 to support the implementation of standards for circular metrics in business.

The conversation focused on material circularity as this is where circular performance assessment starts. It has unveiled key challenges chemical companies are facing in the implementation of the circular economy principles, brought best practices to light along with some opportunities and, most importantly, unlocked collective intelligence to inspire further action on developing solutions to these challenges.

This report complements CTI v4.0 in bringing the required sector specific insights to support practitioners in developing, implementing and updating their circular metrics systems.

It sets the foundations by spelling out definitions to support a set of key circular metric indicators in the specific context of the chemical industry. This ranges from the circular inflow renewable materials definition, to bringing clarity on circular outflow by developing more detailed guiding principles for recyclability (called recovery potential in CTI) for all materials, to applying these to the specific case of reagents, a family of chemicals designed to transform through a chemical reaction.

It suggests a common approach to assess the contribution to circularity for emerging technologies such as chemical recycling or CCU for materials, considering their opportunities and controversies, as well as the role of chain of custody and minimum criteria for tracing and quantifying renewable and recycling feedstocks.

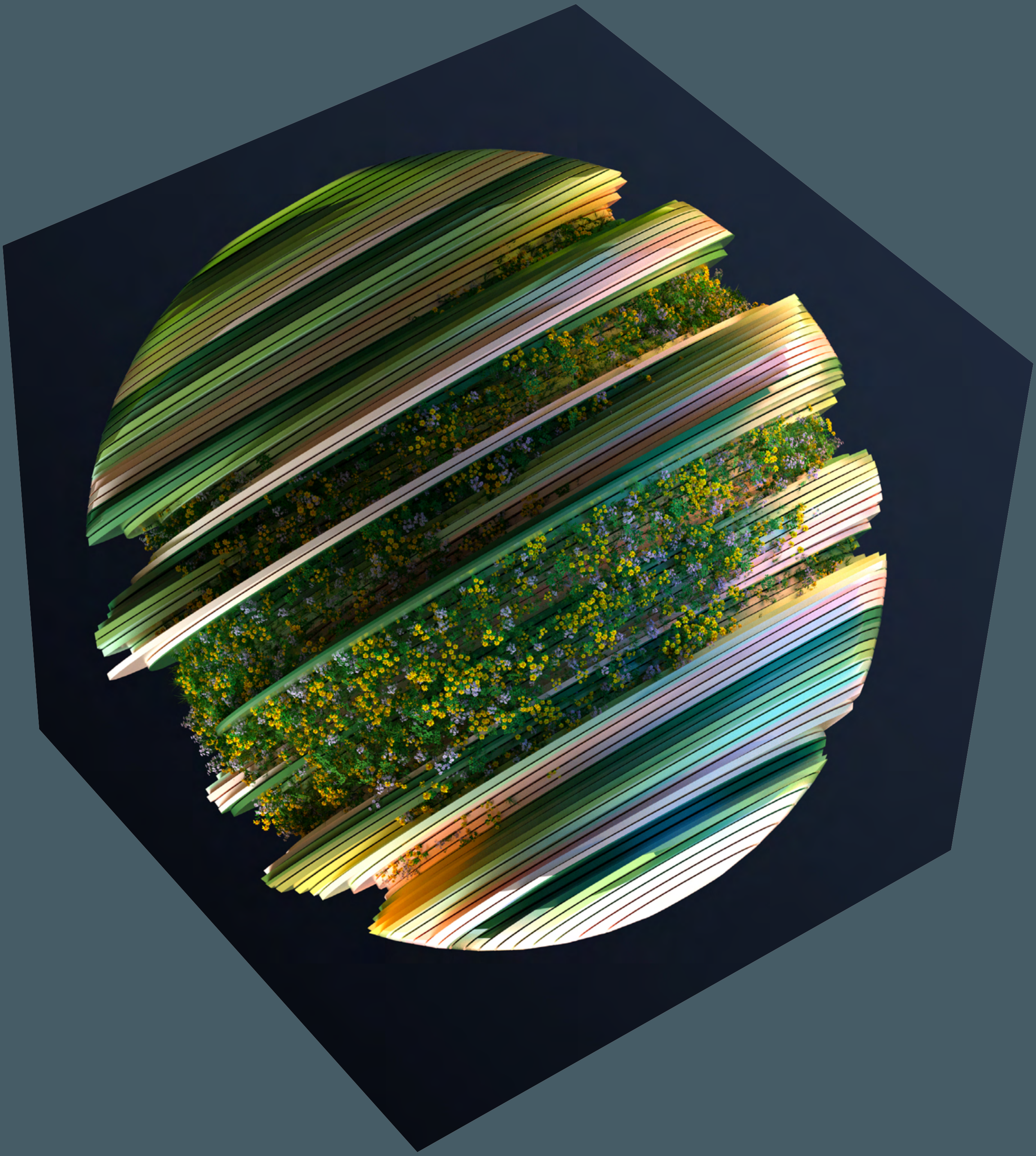
The initial survey on circular metrics practices revealed circular outflow to be largely untapped. This guidance focuses on exploring the challenges and opportunities associated with measuring the circular outflow of companies, businesses and products. Beyond recycling, it focused on exploring biodegradability, lifetime extension strategies,[70] the innovation potential they represent for companies and how to measure contribution to circularity. Access to data related to what happens to chemicals until their end of life remains a significant challenge. As such, this guidance calls for action on the development of a data exchange mechanism for circularity that fosters access to primary data required to make informed decisions.

This report primarily focuses on how to improve the circular performance of chemical companies themselves. In addition, the chemical industry can play a significant role in enabling other value chain actors to improve their own circularity, contributing to a broader system transformation. We do not discuss the quantification of these enabling solutions here, as this is a sector-agnostic subject and is therefore the object of another piece of work to be published by WBCSD in late 2024.

This was the foundational workstream of the broader Chemicals Circularity project dedicated to harnessing the power of the circular economy to deliver on the interconnected imperatives of decarbonization, halting nature and biodiversity loss and tackling social inequality, as required by the inevitable transformation of the chemical value chain.

WBCSD is now focusing on key actions needed to drive value chain collaboration to address gaps identified across sectors. WBCSD has spearheaded the Global Circularity Protocol in collaboration with the One Planet Network (OPN) to unlock barriers to circularity.

Annex



Annex:
CTI process cycle

The CTI framework outlines seven process steps that cover one assessment cycle. Running the assessment for the first time will be informative and insightful. However, repeating the cycle regularly allows the company to monitor progress in its circular transition. **Circular Transition Indicators (CTI) v4.0** provides more information on the steps.

Step 1 – Scope: Determine boundaries

To develop meaningful insights, companies must determine the boundaries of the assessment before starting. The chemical industry includes a highly complex and diverse range of applications. We have built the CTI methodology to permit a broad range of scopes, allowing organizations to measure circularity for the entire company, a subset of the company (e.g., business unit), a site (e.g., production facility), a group of products (e.g., portfolio) or a product application, depending on needs.[71]

Step 2 – Select: Select the indicators

% material circularity is a compulsory indicator and may be complemented by other indicators relevant to the scope of the assessment. In this guidance, the focus is thus on CTI's headline indicator: % material circularity. Other indicators, such as % renewable energy, water circularity, financial circularity and sustainability impact, can be valuable for the chemical sector to add.

Step 3 – Collect: Identify sources and collect data

Data collection relies on primary data provided directly by the organization but also leverages secondary data (macro-level information).

- **Primary data** – Most indicators in the CTI framework require primary data. Using primary data will ensure the most representative and accurate results possible.
- **Secondary data** – Secondary data provides additional data points, such as data on recovery rates in different markets. For the purpose of accuracy, the use of secondary data should be limited to when primary data are not available.

Step 4 – Calculate: Perform the calculations

In this step, the formulas of the indicators are shown and calculations are performed to determine circularity performance

Step 5 – Analyze: Interpret the results

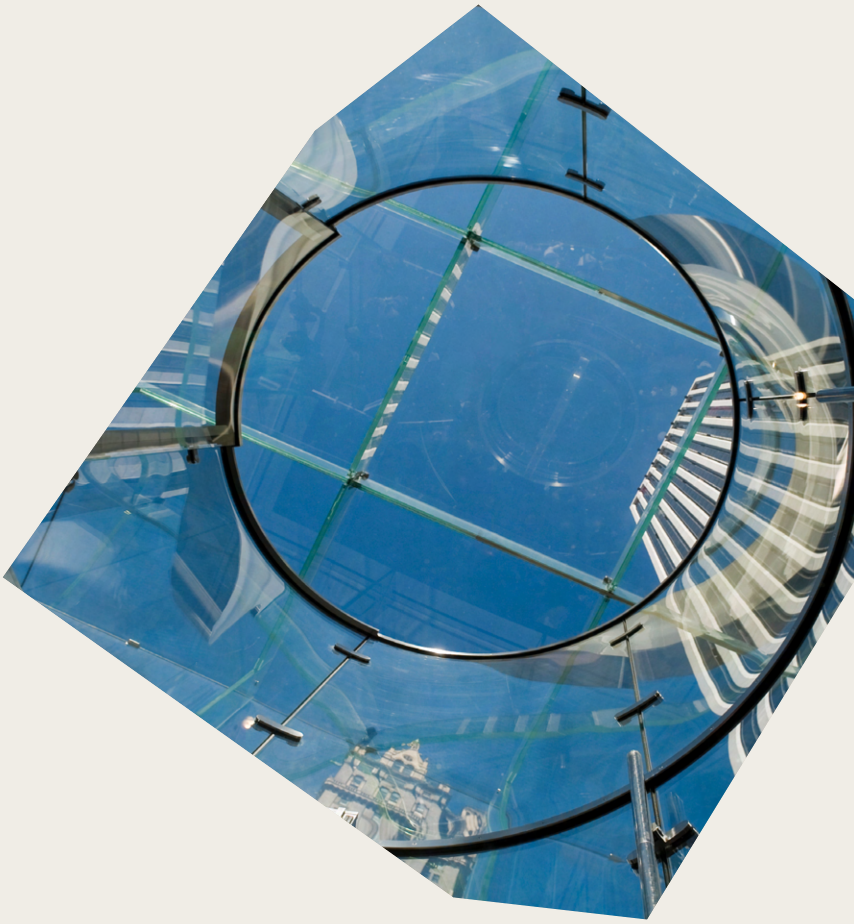
The results must receive accurate interpretation for decision-making. The results can be measured on two levels: 1) current performance and 2) performance over time. The objectives of the assessment (determined in Step 1) guide this decision.

Step 6 – Prioritize: Identify opportunities

In this step, the insights gathered on circular performance indicate which flows have the greatest potential for improvement. The company can identify linear risks and circular opportunities.

Step 7 – Apply: Plan & act

After analyzing the results, prioritizing the risks and opportunities, assessing the circular solutions and defining the business case, the next step is to formulate targets for improvement and execute related actions.



Endnotes

1 Plastics Europe. Plastics - the Facts 2022. Retrieved from: **https://plasticseurope.org/knowledge-hub/plastics-the-facts-2022/**.

2 Based on Circle Economy's Circularity Gap Report 2023, which states that only 7.2% of the world's current economy is circular. Source: Circle Economy (2023). Circularity Gap Report 2023. Retrieved from: **https://www.circularity-gap.world/2023**.

3 The International Council of Chemical Associations (ICCA) and Oxford Economics (2019). The Global Chemical Industry: Catalyzing Growth and Addressing Our World's Sustainability Challenges. Retrieved from: **https://icca-chem.org/wp-content/uploads/2020/10/Catalyzing-Growth-and-Addressing-Our-Worlds-Sustainability-Challenges-Report.pdf**.

4 The International Council of Chemical Associations (ICCA) and Oxford Economics (2019). The Global Chemical Industry: Catalyzing Growth and Addressing Our World's Sustainability Challenges. Retrieved from: **https://icca-chem.org/wp-content/uploads/2020/10/Catalyzing-Growth-and-Addressing-Our-Worlds-Sustainability-Challenges-Report.pdf**.

5 Plastics Europe. Plastics - the Facts 2022. Retrieved from: https://plasticseurope.org/knowledge-hub/plastics-the-facts-2022/.

6 Based on Circle Economy's Circularity Gap Report 2023, which states that only 7.2% of the world's current economy is circular. Source: Circle Economy (2023). Circularity Gap Report 2023. Retrieved from: **https://www.circularity-gap.world/2023**.

7 Morseletto, P. (2020). Targets for a circular economy. Resources, Conservation and Recycling. Vol. 153, Feb. 2020, 104553, ISSN 0921-3449, https://doi.org/10.1016/j.resconrec.2019.104553. Retrieved from: **https://www.sciencedirect.com/science/article/pii/S0921344919304598**.

8 According to Systemiq and the Center for Global Commons in their 2022 Planet Positive Chemicals report, implementing circular economy could decrease the consumption of raw materials required for chemical production by 23-31%. Source: Systemiq and the Center for Global Commons (2022). Planet Positive Chemicals. Retrieved from: **https://www.systemiq.earth/wp-content/uploads/2022/10/Main-report-v1.22.pdf**.

9 The company can do this through the development of various circular interventions, such as designing for disassembly, repairability, recyclability and biodegradability.

10 United Nations Framework Convention on Climate Change (UNFCCC) (2015). Paris Agreement. Retrieved from: **https://unfccc.int/process-and-meetings/the-paris-agreement**.

11 CTI complements environmental assessments, such as life-cycle assessments, and recommends using them to assess the environmental impact when switching from fossil to bio-based materials.

12 Rogelj, J. et al. (2018). Mitigation pathways compatible with 1.5 C in the context of sustainable development. In Global warming of 1.5 C (pp. 93-174). Intergovernmental Panel on Climate Change.
Appendix IX of the Renewable Energy Directive II provides a more extensive list of biomass waste and residue sources. Source: Official Journal of the European Union L 328/82 of 21.12.2018. DIRECTIVE (EU) 2018/2001 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 11 December 2018 on the promotion of the use of energy from renewable sources. Retrieved from: **https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018L2001**.

13 World Economic Forum (2022). What is regenerative agriculture? Retrieved from: **https://www.weforum.org/agenda/2022/10/what-is-regenerative-agriculture/**

14 Meyer, R. (2017). Bioeconomy Strategies: Contexts, Visions, Guiding Implementation Principles and Resulting Debates. Sustainability 9(6):1031. Retrieved from: **https://www.mdpi.com/2071-1050/9/6/1031**.

15 European Commission. Bioeconomy strategy. Retrieved from: **https://research-and-innovation.ec.europa.eu/research-area/environment/bioeconomy/bioeconomy-strategy_en**.

16 Science Based Targets Network (SBTN) (2023). High Impact Commodity List v1. Retrieved from: **https://sciencebasedtargetsnetwork.org/wp-content/uploads/2023/05/SBTN-High-Impact-Commodity-List-v1.xlsx**.

17 Mai-Moulin, T., Hoefnagels, R., Grundmann, P., & Junginger, M. (2021). Effective sustainability criteria for bioenergy: Towards the implementation of the European Renewable Directive II. Renewable and Sustainable Energy Reviews, 138, 110645. Retrieved from: **https://www.sciencedirect.com/science/article/pii/S1364032120309291**.

18 Welfle, A., & Röder, M. (2022). Mapping the sustainability of bioenergy to maximise benefits, mitigate risks and drive progress toward the Sustainable Development Goals. Renewable energy, 191, 493-509. Retrieved from: **https://www.sciencedirect.com/science/article/pii/S0960148122004463**.

Endnotes

19 European Commission. Renewable Energy – Recast to 2030 (RED II). Retrieved from: https://joint-research-centre.ec.europa.eu/welcome-jec-website/reference-regulatory-framework/renewable-energy-recast-2030-red-ii_en.

20 Global Bioenergy Partnership (GBEP). Task Force on Sustainability. Retrieved from: http://www.globalbioenergy.org/programmeofwork/task-force-on-sustainability/en/.

21 Roundtable on Sustainable Biomaterials (RSB). Sustainability framework. Retrieved from: https://rsb.org/the-rsb-standard/about-the-rsb-standard/.

22 United Nations. Sustainable Development Goals (SDGs). Retrieved from: https://www.un.org/sustainabledevelopment/.

23 Welfle, A., & Röder, M. (2022). Mapping the sustainability of bioenergy to maximise benefits, mitigate risks and drive progress toward the Sustainable Development Goals. Renewable energy, 191, 493-509. Retrieved from: https://www.sciencedirect.com/science/article/pii/S0960148122004463.
The full list of indicators is available on the University of Manchester website at https://www.supergen-bioenergy.net/wp-content/uploads/2022/05/BSIM_Guidance_Manual_FINAL_.pdf.

24 Welfle, A., & Röder, M. (2022). Mapping the sustainability of bioenergy to maximise benefits, mitigate risks and drive progress toward the Sustainable Development Goals. Renewable energy, 191, 493-509. Retrieved from: https://www.sciencedirect.com/science/article/pii/S0960148122004463.
The full list of indicators is available on the University of Manchester website at https://www.supergen-bioenergy.net/wp-content/uploads/2022/05/BSIM_Guidance_Manual_FINAL_.pdf.

25 Welfle, A., & Röder, M. (2022). Mapping the sustainability of bioenergy to maximise benefits, mitigate risks and drive progress toward the Sustainable Development Goals. Renewable energy, 191, 493-509. Retrieved from: https://www.sciencedirect.com/science/article/pii/S0960148122004463.

26 Arkema (2012). Arkema and its partners publish year 5 results for 'pragati', the world's first sustainable castor bean crop program [Press release]. Retrieved from: 2022013_Arkema-Pragati-results-of-fifth-year def.pdf.BASF (2022). BASF first chemical company to be certified on sustainable castor products [Press release]. Retrieved from: https://www.basf.com/global/en/media/news-releases/2022/03/p-22-188.html.

27 Consumer Goods Forum (n.d.). Chemical Recycling – Helping to accelerate collective action on recycling innovation. Retrieved from: https://www.theconsumergoodsforum.com/environmental-sustainability/plastic-waste/key-projects/chemical-recycling/.

28 CTI only considers the waste recycled back into materials as circular. It excludes by definition waste-to-fuel and waste-to-energy strategies.

29 Holland Circular Hotspot (2023). Chemical Recycling in a circular perspective. Retrieved from: https://hollandcircularhotspot.nl/wp-content/uploads/2023/11/online-version_Chemical-Recycling-in-Circular-Perspective-Aug23.pdf.

30 Garcia-Gutierrez, P. et al. (2023). Environmental and economic assessment of plastic waste recycling: A comparison of mechanical, physical, chemical recycling and energy recovery of plastic waste. Publications Office of the European Union. Luxembourg, 2023, doi:10.2760/0472, JRC132067.

31 Ellen MacArthur Foundation (2017). The New Plastics Economy: Rethinking the Future of Plastics & Catalysing Action. Retrieved from: https://emf.thirdlight.com/file/24/RrpCWLER-yBWPZRrwSoRrB9KM2/The%20New%20Plastics%20Economy%3A%20Rethinking%20the%20future%20of%20plastics%20%26%20catalysing%20action.pdf.

32 BASF (n.d.). ChemCycling: Creating a circular plastics economy with chemical recycling. Retrieved from: https://www.basf.com/global/en/who-we-are/sustainability/we-drive-sustainable-solutions/circular-economy/mass-balance-approach/chemcycling.html.

33 Systemiq and the Center for Global Commons (2022). Planet Positive Chemicals. Retrieved from: https://www.systemiq.earth/wp-content/uploads/2022/10/Main-report-v1.22.pdf.

34 International Energy Agency (IEA) (n.d.). CO2 Capture and Utilisation. Retrieved from: https://www.iea.org/energy-system/carbon-capture-utilisation-and-storage/co2-capture-and-utilisation.

35 Gabrielli, P., Rosa, L., Gazzani, M., Meys, R., Bardow, A., Mazzotti, M., & Sansavini, G. (2023). Net-zero emissions chemical industry in a world of limited resources. One Earth.

36 Evonik (n.d.). Rheticus: Artificial photosynthesis - a contribution to the energy transition. Retrieved from: https://www.creavis.com/en/success-stories/current-projects/rheticus.

Endnotes

37 SABIC (n.d.). Creating the World's Largest Carbon Capture and Utilization Plant. Retrieved from: https://www.sabic.com/en/newsandmedia/stories/our-world/creating-the-worlds-largest-carbon-capture-and-utilization-plant.

38 World Resources Institute and WBCSD (2023). Greenhouse Gas Protocol Survey on Need and Scope for Updates or Additional Guidance. Retrieved from: https://ghgprotocol.org/sites/default/files/Market-based%20accounting%20Survey%20Memo.pdf.

39 Zero Waste Europe (2021). Recycled content in plastics: The mass balance approach. Retrieved from: https://zerowasteeurope.eu/wp-content/uploads/2021/05/rpa_2021_mass_balance_booklet-2.pdf.

40 Petrochemicals Europe (n.d.). Flowchart – Petrochemicals Europe. Retrieved from: https://www.petrochemistry.eu/about-petrochemistry/flowchart/.

41 Morseletto, P. (2020). Targets for a circular economy. Resources, Conservation and Recycling, 153, 104553. Retrieved from: https://www.sciencedirect.com/science/article/pii/S0921344919304598.

42 Applies specifically to the technical sphere.

43 This means a permanent small-scale operation, using a minimum of permanent facilities, following the standards for semi-industrial methods. This is inspired from the EU Commission definition: "at a scale that allows to take economical and technical decisions for a first of a kind (FOAK) plant." (Source: European Commission (2023). Turning CO2 emissions from the process industry to feedstock (Processes4Planet partnership) (IA). Retrieved from: https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/opportunities/topic-details/horizon-cl4-2024-twin-transition-01-35.)

44 Clariant (n.d.). Recycling. Retrieved from: https://www.clariant.com/en/Business-Units/Care-Chemicals/Aviation/Recycling.

45 Finavia (2023). Finavia to start using recycled de-icing fluid at Helsinki Airport. Retrieved from: https://www.finavia.fi/en/newsroom/2023/finavia-start-using-recycled-de-icing-fluid-helsinki-airport?trk=feed-detail_main-feed-card_feed-article-content.

46 Syensqo (n.d.). An upcycling loop for used medical instruments. Retrieved from: https://www.syensqo.com/en/article/reducing-environmental-footprint-medical-devices.

47 Arkema (n.d.). The Pragati Sustainable Castor Initiative. Retrieved from: https://hpp.arkema.com/en/sustainability/pragati-sustainable-castor-initiative/.

48 Arkema (n.d.). The Virtucycle® Program. Retrieved from: https://hpp.arkema.com/en/sustainability/virtucycle/.

49 Ellen MacArthur Foundation (n.d.). Circulate products and materials. Retrieved from: https://www.ellenmacarthurfoundation.org/circulate-products-and-materials.

50 Rosenboom, J. G., Langer, R., & Traverso, G. (2022). Bioplastics for a circular economy. Nature Reviews Materials, 7(2), 117-137. Retrieved from: https://www.nature.com/articles/s41578-021-00407-8#Bib1.

51 Levis, J. W., & Barlaz, M. A. (2011). Is biodegradability a desirable attribute for discarded solid waste? Perspectives from a national landfill greenhouse gas inventory model. Environmental science & technology, 45(13), 5470-5476.

52 Lambert, S. & Wagner, M. (2017). Environmental performance of bio-based and biodegradable plastics: the road ahead. Chem. Soc. Rev. 46, 6855–6871.

53 Quantis & EA (2020). Plastic Leak Project – Methodological Guidelines. Retrieved from: https://incp.org.co/Site/publicaciones/info/archivos/Guia-Plastic-Leak-Project-17042020.pdf

54 Organisation for Economic Co-operation and Development (OECD) (1992). OECD Guidelines for Testing of Chemicals, Section 3 (updated 2023).

55 Rosenboom, J. G., Langer, R., & Traverso, G. (2022). Bioplastics for a circular economy. Nature Reviews Materials, 7(2), 117-137. Retrieved from: https://www.nature.com/articles/s41578-021-00407-8#Bib1.

56 Strotmann, U., Thouand, G., Pagga, U. et al. (2023). Toward the future of OECD/ISO biodegradability testing-new approaches and developments. Appl Microbiol Biotechnol 107, 2073–2095 (2023). https://doi.org/10.1007/s00253-023-12406-6.

57 European Commissions (n.d.). Biobased & biodegradable plastics. Retrieved from: https://environment.ec.europa.eu/topics/plastics/biobased-biodegradable-and-compostable-plastics_en.

58 Rosenboom, J. G., Langer, R., & Traverso, G. (2022). Bioplastics for a circular economy. Nature Reviews Materials, 7(2), 117-137.

59 WBCSD Circular Chemical Project (2023). Industry transformation roadmap.

60 Syensqo (n.d.). Rhodiasolv® IRIS. Retrieved from: https://www.syensqo.com/en/brands/rhodiasolv-iris.

Endnotes

61 Systemiq (2022). Planet Positive Chemicals: Pathways for the chemical industry to enable a sustainable global economy. Retrieved from: https://www.systemiq.earth/wp-content/uploads/2022/10/Main-report-v1.22.pdf.

62 Including reuse, repair, refurbish, remanufacture, repurpose as per Piero Morseletto (2020). Target for a Circular Economy. Institute for Environmental Studies (IVM), Faculty of Earth and Life Sciences, VU University of Amsterdam, De Boelelaan 1087, HV, Amsterdam, the Netherlands. Retrieved from: https://doi.org/10.1016/j.resconrec.2019.104553.

63 Systemiq and the Center for Global Commons (2022). Planet Positive Chemicals. Retrieved from: https://www.systemiq.earth/wp-content/uploads/2022/10/Main-report-v1.22.pdf, p.98

64 Systemiq (2022). Planet Positive Chemicals: Pathways for the chemical industry to enable a sustainable global economy. Figure 40, pp. 98-99. Retrieved from: https://www.systemiq.earth/wp-content/uploads/2022/10/Main-report-v1.22.pdf. The potential for these solutions in the report are analyzed in the context of net-zero decarbonization only; other benefits to nature and equity imperatives may not be represented.

65 Chertow, M. R. (2000). Industrial symbiosis: literature and taxonomy. Annual review of energy and the environment, 25(1), 313-337.

66 Evonik (n.d.). Next Generation Solutions: Their contribution to the sustainability focus areas. Retrieved from: https://files.evonik.com/shared-files/evonik-ngs-broschu-re-a4-gb-2023-8579.pdf.

67 Arkema (n.d.). DMDS Evolution® E2, the most efficient sulfiding and anticoking polysulfide. Retrieved from: https://www.arkema.com/global/en/products/product-finder/product/thiochemicals/dimethyl_disulfide/dmds-evolution-e2-anti-coke-sulfiding-agent/.

68 International Union of Pure and Applied Chemistry (IUPAC) (1997). Compendium of Chemical Terminology, 2nd ed. (the "Gold Book"). Compiled by A. D. McNaught and A. Wilkinson. Blackwell Scientific Publications, Oxford (1997). Online version (2019-) created by S. J. Chalk. ISBN 0-9678550-9-8. Retrieved from: https://goldbook.iupac.org/.

69 In 2024, Solvay spun off its subsidiary Syensqo, which we have also included here.

70 Reduce, reuse and refurbish.

71 For example: The CTI methodology supports a circularity assessment in a portfolio sustainability assessment that uses a product-application-region combination (PARC) as scope. Instruction on how to define PARC as a unit of analysis for CTI is available in WBCSD (2023). Portfolio Sustainability Assessment v2.0. Retrieved from: https://www.wbcsd.org/Programs/Circular-Economy/Resources/Portfolio-Sustainability-Assessment-v2.0.

Acknowledgements

Disclaimer

This report is released in the name of WBCSD. Like other reports, it is the result of collaborative efforts by WBCSD staff and experts from member companies. WBCSD's Circular Chemicals project participants reviewed drafts, ensuring that the document broadly represents the majority of project members' views. It does not mean, however, that every member company of WBCSD agrees with every word. Please note that the data published in the report date back to September 2022.

Attribution

WBCSD Circular Products and Materials co-authors:

Anne-Laure Brison, Senior Manager, Circular Chemicals; Larissa van der Feen, Associate, Circular Transition Indicators; Quentin Drewell, Director, Circular Products and Material

WBCSD would like to extend special thanks to:

WBCSD companies that contributed to this Report (Circular Metrics Working Group):

Noel Zilberfarb (Arkema), Wibke Loelsberg (BASF), Jenny Reuber (BASF), Talke Schaffrannek (BASF), Christoph Jäkel (BASF), Carolina Fontes (Clariant), Bettina Siggelkow (Clariant), Angelina Prokofeva (Covestro), Burcu Unal (Covestro), Tara Nitz (Covestro), Susann Wiechers (Evonik), Ralf Kelle (Evonik), Simon Tage Jespersen (Dow), Andy Liu (Chemours), Ambica Koushik Pegall (Chemours), Emily Thomas (Huber), Nadine Dissemond (IFF), Daniel Gambus (Sabic), Jonna Fry (Infineum), Minea Holm (Sika) Julien Armadet (Sika), Guy-Noel Sauvion (Solvay), Thierry Delplanche (Syensqo), Carla Caldeira (Syensqo).

WBCSD Circular Transition Indicators for their guidance throughout the work:

WBCSD: Jeff Turner, Irene Martinetti.

Circular Transition Indicators Advisory group for their input and feedback:

African Circular Economy Network, CIRAIG, Circle Economy, Cradle to Cradle Products Innovation Institute, Ellen MacArthur Foundation, European Remanufacturing Council, MVO Nederland, Platform for Accelerating the Circular Economy, Sitra

Circular Transition Indicators co-authors

WBCSD: Jeff Turner, Irene Martinetti, Larissa van der Feen
KPMG: Arnoud Walrecht, Suzanne Kuiper, Julius Groenendaal
THE BIODIVERSITY CONSULTANCY: Hollie Booth, Graham Prescott, Alice Boucheza Brendan Edgerton, Carolien van Brunschot

Acknowledgements

About the Circular Transition Indicators

In recent years, the circular economy has increasingly appeared as the new model to pursue sustainable economic growth. Companies require consistent measurement processes and metrics to assess their circular performance. To address this need, we have worked with our members and stakeholders to jointly develop a universal framework to measure circularity. The Circular Transition Indicators (CTI) is a transparent, objective and evolving framework that is applicable to businesses of all industries, sizes, value chain positions and geographies.

About the WBCSD

The World Business Council for Sustainable Development (WBCSD) is a global community of over 225 of the world's leading businesses driving systems transformation for a better world in which 9+ billion people can live well, within planetary boundaries, by mid-century. Together, we transform the systems we work in to limit the impact of the climate crisis, restore nature and tackle inequality.

We accelerate value chain transformation across key sectors and reshape the financial system to reward sustainable leadership and action through a lower cost of capital. Through the exchange of best practices, improving performance, accessing education, forming partnerships, and shaping the policy agenda, we drive progress in businesses and sharpen the accountability of their performance.

Follow us on **X** and **LinkedIn**

www.wbscd.org

World Business
Council
for Sustainable
Development

Geneva | Amsterdam | London | New York City | Singapore