CEN

WORKSHOP

AGREEMENT

CWA 18505

November 2026

ICS 13.020.20; 13.060.01

English version

Roadmap for the Evaluation of Product Quality Criteria for water related Circular Economy Products: Defining Product Types, Key Performance Indicators, and Methods of Proof for Product Certification

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Ref. No.:CWA 18505:2026 E

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Foreword

This CEN Workshop Agreement (CWA 18505:2026) has been developed in accordance with the CEN-CENELEC Guide 29 “CEN/CENELEC Workshop Agreements — A rapid way to standardization” and with the relevant provisions of CEN/CENELEC Internal Regulations — Part 2. It was approved by the Workshop CEN “Roadmap for the Evaluation of Product Quality Criteria for water related Circular Economy Products: Defining Product Types, Key Performance Indicators (KPIs), and Methods of Proof for Product Certification”, the secretariat of which is held by UNE (Spanish Association for Standardization) consisting of representatives of interested parties on 2025-10-13, the constitution of which was supported by CEN following the public call for participation made on 2025-07-14. However, this CEN Workshop Agreement does not necessarily include all relevant stakeholders.

The final text of this CEN Workshop Agreement was provided to CEN for publication on 2026-10-30.

Results incorporated in this CWA received funding from the European Union’s Horizon Europe research and innovation programme under grant agreement No 101135239 (BOOST-IN).

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Introduction

Droughts and water scarcity are becoming critical issues in Europe, with around 20% of the European territory and 30% of the population already experiencing water stress. This growing challenge is driven by a combination of factors, including climate change, agricultural intensification, tourism, and population density. As global temperatures rise, the frequency and intensity of water scarcity events are projected to increase, particularly in Southern and Western Central Europe. [1] These changes disrupt the natural water cycle and pose severe risks to energy production, food security, human health, and economic development.

Currently, most European water systems follow a linear model “take, make, consume and waste”, which leads to the overexploitation and degradation of freshwater resources. This unsustainable model not only intensifies environmental hazards but also depletes ecosystems, undermining their ability to provide essential services. For example, over 60% of European rivers, lakes, and wetlands are in poor ecological condition. [2]

To address these challenges, Europe is advancing the transition toward a circular economy (CE) - a model that emphasizes resource efficiency, waste minimization, and recovery. In the water sector, this means reusing treated water, recovering energy and materials from wastewater, and rethinking infrastructure and governance to support closed-loop systems. A circular economy helps to reduce pressure on natural resources, decrease greenhouse gas emissions, and improve resilience to the impacts caused by climate change.

The importance of CE for Europe lies in its potential to create sustainable growth while reducing dependency on imports and fragile global supply chains. According to the European Commission, applying circular economy principles across the EU economy has the potential to increase EU GDP by an additional 0.5 % by 2030 and create around 700,000 new jobs. [3] In the water sector specifically, CE solutions can contribute to achieving the objectives of the European Green Deal, which calls for a climate-neutral, resource-efficient, and pollution-free Europe by 2050. [4]

However, to effectively implement and scale CE practices, especially in the water and wastewater sector, Key Performance Indicators (KPIs) and certification schemes can play a crucial role. KPIs are essential to monitor progress, ensure transparency, and measure the environmental, economic, and social impacts of CE products and processes.[5] Without robust metrics, it is difficult to assess whether CE initiatives are truly sustainable or merely incremental improvements. Likewise, certification plays a crucial role in building trust among stakeholders, facilitating market access, and ensuring compliance with EU regulatory frameworks. [6,7] Certification systems also help to distinguish verified circular products from greenwashing and can support harmonization across EU member states.

The BOOST-IN project addresses these needs by implementing successful strategies to support the development and market uptake of CE products derived out of technical solutions related to circularity in the water sector. BOOST-IN aims to promote the market uptake of Water Circular Economy Solutions (WACES) that recover water, materials and energy and hence, close the water cycle. These efforts are being implemented at both EU and regional levels, particularly in “Regions of Opportunity” to promote knowledge exchange, build capacity, encourage entrepreneurship, and support policy development.

The resulting CEN Workshop Agreement serves as a practical output of the BOOST-IN project, illustrated with five specific CE products which are not well defined until now.

1 Scope

This document aims at developing guidance/a roadmap on evaluating product quality criteria for water related Circular Economy products, defining product types, related KPIs and relevant methods that can support product certification.

This document is applicable to researchers, public authorities, circular economy product owners, NGOs, water utilities, manufacturers and users or companies developing market-ready solutions.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 17892, *Water quality — Determination of selected per- and polyfluoroalkyl substances in drinking water — Method using liquid chromatography/tandem-mass spectrometry (LC-MS/MS)*

EN ISO 21675, *Water quality — Determination of perfluoroalkyl and polyfluoroalkyl substances (PFAS) in water — Method using solid phase extraction and liquid chromatography-tandem mass spectrometry (LC-MS/MS)*

ISO 18127, *Water quality — Determination of adsorbable organically bound fluorine, chlorine, bromine and iodine (AOF, AOCl, AOBr, AOI) — Method using combustion and subsequent ion chromatographic measurement*

DIN 3608, *Solids — Determination of perfluoroalkanoic acids by LC-MS/MS after oxidative digestion of soil leachates (TOP-Assay)*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at http://www.iso.org/obp/

— IEC Electropedia: available at http://www.electropedia.org/

3.1
quality criteria
measurable requirements for performance, safety, and sustainability of water-related circular economy products/technologies under defined conditions. Expressed as testable limits or ranges

3.2
product
products, that enable safe circular use of water and water-related materials. They reduce freshwater use, prevent pollution, support reuse/recycling, and recover value (e.g., nutrients and energy) across their life cycle

3.3
circular economy
combined practice of closed-loop material management (*sensu stricto*) and systemic transformation (*sensu lato*): it keeps resources in use at high value, minimizes waste and pollution, regenerates ecosystems and ensures safe, compliant, and economically viable solutions across design, operation, and

end-of-life. In the water sector, this means lowering freshwater abstraction, reusing and recovering water and co-resources such as nutrients and energy

3.4
circularity criteria
measurable indicators that demonstrate the circular nature of a product by quantifying the origin of input materials (e.g., recycled content, renewable content) and the recoverability of the product at end-of-life (e.g., recyclability, reusability)

3.5
technology
technical means (processes, equipment, controls) that perform circular functions in the water cycle: reclaiming, reusing, recovering and reducing. Includes unit operations and integrated treatment trains

3.6
key performance indicators
measurable metrics that demonstrate how a circular water-related product or technology performs against defined targets for function, safety, environment, operations, economics, and compliance

3.7
platform chemicals
substances of sufficient purity, defined chemistry and identified market demand

3.8
Water and Circular Economy Solutions
Water and Circular Economy Solutions specified in the frame of the BOOST-IN project. The project aims to advance and adopt the progress of those solutions enabling water sector becoming circular

3.9
Region of Opportunity
Region of Opportunity are specifically selected in frame of the BOOST-IN project. For total of six regions across Europe, BOOST-IN facilitates adapting solutions with the highest potential for success

3.10
End of Waste Criteria
EU legal framework that outlines when a recycled or recovered waste material ceases to be classified as "waste" and become a safe, usable product or secondary raw material

4 Abbreviated terms

For the purpose of this document, the following abbreviated terms apply:

AMD	Acid Mine Drainage
AOF	Adsorbable Organic Fluorine
CE	Circular Economy
CE marking	Conformité Européenne
CLP	Classification, Labelling and Packaging
CMC	Component Material Category
CPR	Construction Products Regulation
CRM	Critical Raw Materials

DIN	German Institute for Standardization
DW	Drinking Water
DWD	Drinking Water Directive
EDC	Endocrine Disrupting Chemical
EDR	Electrodialysis Reversal
EoW	End of Waste
EU	European Union
FPR	Fertilising Products Regulation
GAC	Granular Activated Carbon
IED	Industrial Emissions Directive 2.0
JRC	Joint Research Centre
KPI	Key Performance Indicator
LC-MS/MS	Liquid Chromatography with tandem Mass Spectrometry
LOQ	Limit of Quantification
OECD	Organisation for Economic Cooperation and Development
PAA	Peracetic acid
PAM	Polyacrylamide
PAH	Polycyclic Aromatic Hydrocarbon
PFA	Performic acid
PFAS	per- and polyfluoroalkyl substances
PFOA	Perfluorooctanoic acid
PFHxS	Perfluorohexanesulfonic acid
PHA	Polyhydroxyalkanoate
POPs	Persistent Organic Pollutants
ROp	Region of Opportunity
rGAC	Reactivated Granular Activated Carbon
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals
RO	Reverse Osmosis
STRUBIAS	STRUvite, BIochar and ASh-based products
TRL	Technology Readiness Level
WACES	Water Circular Economy Solutions
WFD	Waste Framework Directive
WWTP	Wastewater Treatment Plant
VFA	Volatile fatty acids
VOC	Volatile Organic Compound

5 Roadmap to quality criteria

5.1 General

This chapter provides step-by-step guidance on the quality criteria for water-related circular economy products. It covers the existing quality criteria framework (Clause 5.2), the product-specific quality criteria (Clause 5.3), which describe the criteria and parameters required for water-related circular economy products, and the methods of proof for product quality (Clause 5.4), which outline how to demonstrate that a product meets the quality requirements and expectations of water-related circular economy standards.

5.2 Criteria framework

5.2.1 General

The criteria framework covers the existing legislative framework, the standardisation/technical specification framework and requirements deriving from market and user requirements.

5.2.2 Existing regulative framework

The EU has a dedicated regulation for water reuse and several related frameworks that affect circular water-related products, risk management and certification pathways:

- **Water Framework Directive (2000/60/EC)**: This is a cornerstone of EU water policy, aiming to achieve good qualitative and quantitative status of all water bodies.

- **Urban Waste Water Treatment Directive (91/271/EEC)**: This directive sets standards for the collection, treatment, and discharge of urban wastewater.

- **Sewage Sludge Directive (86/278/EEC):** The directive aims both to prevent environmental harm and to promote the recycling of sludge in farming as part of a circular economy.

- **Fertilising Products Regulation (2019/1009):** This regulation harmonizes rules for making fertilizers available on the EU market, allowing products with a CE mark to be sold freely across member states. It expanded the scope beyond traditional mineral fertilizers to include organic and inorganic fertilizers, biostimulants, and products made from recovered waste.

- **Organic Products Regulation (2018/848):** Sets principles and rules for organic production, certification and the use of "organic" claims in labelling and advertising and additional control requirements to ensure consumer trust.

- **Industrial and Livestock Rearing Emissions Directive (IED 2.0):** The new rules are designed to strengthen the protection of human health and the environment by cutting harmful emissions from industrial facilities, including intensive livestock farms into air, water, soil, and through waste discharges. They also seek to enhance the reporting of environmental data by improving the current European Pollutant Release and Transfer Register (E-PRTR), creating a more complete and integrated industrial emissions portal.

- **Minimum requirements for water reuse (2020/741):** Establishes minimum water quality classes, monitoring, and risk management for the safe use of reclaimed urban wastewater in agricultural irrigation, supporting circular economy objectives and climate adaptation**.**

- **REACH Regulation (1907/2006):** If the product involves the recovery and reuse of materials from the water cycle (e.g., nutrients, by-products from wastewater), the regulations concerning registration, evaluation, authorization, and restriction of chemical substances will be applicable to

ensure environmental and human health safety. Article 2(7)(d) of the REACH Regulation states an exemption for recovered materials, in case where recovered material is the same as its virgin equivalent previously registered.

- **Circular Economy Action Plan:** The EU's commitment to a circular economy influences funding and policy directions.

- **Waste Framework Directive (2008/98):** Provides EU's overarching framework for waste management, aiming to protect human health and environment while moving towards circular economy. It establishes the waste hierarchy and key concepts like extended producer responsibility and rules when a material can be considered a by-product or reaches End of Waste (EoW) status.

- **Nitrates directive (91/676)**: Aims to protect ground and surface waters from agricultural nitrate pollution by requiring Member States to monitor waters, designate Nitrate Vulnerable Zones and apply action programmes including a key cap of 170 kg nitrogen per hectare per year from livestock manure in those zones. Adding the Recovered Nitrogen from Manure (RENURE) amendment aims to reduce waste and provide a more sustainable source of fertilisers used in agriculture.

- **Classification, Labelling and Packaging regulation (1272/2008)**: Harmonises how chemical substances and mixtures are classified, labelled and packed in the EU based on the UN GHS system, to ensure a high level of health and environmental protection. It requires companies to classify and communicate hazards appropriately.

- **Persistent Organic Pollutants regulation (2019/1021):** Protects human health and environment by prohibiting or restricting manufacturing, placing on the market and use of persistent organic pollutants. It also controls realizing waste contaminated by POPs. Recovered products entering the market are required to meet the thresholds set out in Annex I of this regulation.

- **Construction Products Regulation (305/2011):** Provides the legal basis for CE marking (Conformité Européenne), ensuring product performance is verified through harmonised test methods and factory production control.

5.2.3 Existing standardisation/technical specification frameworks

Generic management and technical frameworks apply across multiple sectors. These include, among others:

- **ISO 9000 series** for Quality Management Systems.

- **ISO 14000 series** for Environmental Management Systems.

- **ISO 55000 series** for Asset Management.

Similarly, established standardization frameworks exist for specific sectors such as water, wastewater, agriculture, construction, and petrochemical systems.

For the purposes of this CWA, relevant sector-specific specifications and standards are detailed in clause 2 (normative references). In addition, the specific standards applicable to each product reintroduced into the marketplace are provided within each factsheet referenced in Annex A.

5.2.4 Market and user needs

This section outlines market and user needs considered for ensuring not only technical criteria, but also other user criteria responding to market needs. Those needs may consist of such aspects as smell of the product, granularity or dryness.

Each of those aspects may be relevant for inserting products for circular processes at certain stage.

Potential market sectors:

- Fertilizer,
- Feed use,
- Non-food use,
- Food processing,
- Building/construction,
- Chemistry.

5.3 Product-specific quality criteria

5.3.1 Circularity criteria

For the effective marketing of circular products, the circular nature of the products shall be proven with well-defined indicators. Value-chain actors and end-users require verification regarding the circularity of recovered materials and the precise fraction that can be claimed as circular. Therefore, suitable circularity criteria shall be defined and assessed for circular products to facilitate customer information and market transparency.

The ISO 59020 (part of the ISO 59000 series on the circular economy) provides a standardized methodology to measure and assess circularity performance. Rather than acting as a static certification for a product, it establishes a framework of mandatory and optional indicators to measure how effectively resources are managed within a defined system (e.g., product, organization, or region).

In particular, resource inflow indicators measure the origin of the materials that make up the recycled product:

- **Recycled content indicator:** measures the average percentage of the product's total mass originating from recycled feedstock;
- **Renewable content indicator:** measures the fraction of material resources derived from sustainably produced renewable content (e.g. bio-based polymers).

On the other end, resource outflow indicators measure whether a product is recoverable to maintain its value at the end of its life. These indicators measure recyclability, reusability, or recirculation into the biological cycle. However, these indicators also relate to a specific function of the product and its use by the customer, extending beyond the sole responsibility of the producer.

5.3.2 Microbiological Parameters

For safe usage of water-related circular products, microbiological parameters shall be controlled to prevent risks to human and animal health. The presence of pathogens such as *Escherichia coli*, *Salmonella spp*. and other relevant human or animal pathogens, shall be monitored to ensure compliance with established safety standards (see clause 5.2.2).

Microbiological assessments are critical, especially for products entering the fertilizer, feed or food-related sectors (see Annex A), where microbiological contamination poses a direct health risk. To ensure safety throughout the product lifecycle, the following measures shall be implemented:

- **Treatment and monitoring:** implementation of validated treatment processes and monitoring schemes to maintain parameter values within specified limits during production, storage, and application.

- **Quality control and documentation:** continuous quality control and full traceability documentation to support compliance verification, product certification, and market acceptance.

5.3.3 Chemical Parameters

For safe usage and sustainable use of circular products, chemical parameters shall be monitored and controlled to prevent risks to human health and the environment, ensuring compliance with relevant regulatory and certification requirements. Furthermore, depending on the origin of the product, relevant sector-specific regulations and directives shall be taken into account.

A particular challenge in evaluating chemical parameters of water-related circular products lies in the variability of source streams.[8] The origin of recovered materials is often not exactly defined, which means that the chemical composition may vary over time between production sites. This variability creates uncertainty regarding the presence of desirable and undesirable substances. To ensure consistent product quality, the following measures shall be applied:

- **Regular monitoring:** continuous analytical control of incoming and outgoing material flows.

- **Input material documentation:** clear tracing and documentation of input streams.

- **Acceptance criteria:** establishment of defined quality acceptance thresholds.

Particularly, product purity defines overall its suitability for use and determine whether it meets the intended functional purpose. A clear distinction shall be made between:

- **Contaminants:** including heavy metals, residual chemicals, PFAS, pharmaceuticals, endocrine disrupting chemicals (EDCs), and pesticides.

- **Non-contaminants:** including inert substances and background material matrix.

The environmental persistence and residence time of these substances within the product system shall be also evaluated to assess potential long-time impacts. In addition, general properties of a product, including pH and conductivity, shall be monitored to predict product behaviour during use and the production as well. In certain cases, explosivity may also need to be considered, particularly for organic residues or volatile compounds, ensuring that handling and processing are conducted carefully. At the same time, the concentrations of nutrients and functional substances (e.g. as phosphorus, potassium or other active components) shall be quantified to ensure they remain within environmentally acceptable thresholds. Furthermore, biodegradability shall be evaluated:

- **High biodegradability:** indicates natural decomposition without leaving persistent residues.

- **Low biodegradability:** indicates potential risk of environmental persistence or bioaccumulation.

5.3.4 Physical Parameters

Physical parameters describe the measurable characteristics of water-related circular products that affect their functionality, handling and market acceptance, serving as key determinants for the performance within a circular system. Particle size distribution, liquid flow, and optical properties shall be evaluated according to end-use requirements:

- **Granularity:** particle size and distribution influence texture, flowability and mixing behaviour, particularly in fertilizer, construction, and chemical applications.

- **Viscosity:** determines fluid dynamics, affecting spreading or blending operations.
- **Turbidity:** measures optical clarity in water-based products, serving as an indicator for suspended solids concentration.

Physical contamination and safety risks shall be controlled during processing and final product evaluation:

- **Physical contaminants:** products shall be free from macro-impurities, including glass, plastics, metals, and other foreign debris that compromise structural integrity or quality.
- **Flammability:** thermal stability and ignition propensity shall be assessed for products exposed to elevated temperatures or thermal processing risks.

Finally, for products intended for construction, structural, or industrial applications, mechanical performance criteria shall be verified, including:

- **Thermal insulation capacity.**
- **Acoustic performance.**
- **Structural stability and mechanical strength.**

5.3.5 Application-Specific Quality Parameters

Beyond the microbiological, chemical and physical parameters, several application-specific quality criteria may play a critical role in determining the market acceptance and practical usability of water-related CE products. These parameters are closely interconnected with quality criteria as they often influence or are influenced by chemical composition, physical structure and microbiological safety of the product.

Typical application-specific parameters shall include, but are not limited to, the following:

- **Aesthetic and sensory properties**: Properties such as colour, odour and appearance, which directly affect user acceptance and indicate underlying quality issues.
- **Physical handling characteristics**: granularity, particle size distribution, moisture content and surface texture, which determine how a product can be handled, processed, transported and applied in practice.
- **Homogeneity**: Uniformity of composition to ensure consistent performance and user trust in CE products.
- **Additives**: The presence and type of additives, which shall be declared and assessed for compatibility with the intended application and regulatory requirements.

These application-specific parameters shall be defined taking into account the targeted application, requirements for use and user expectations.

5.3.6 PFAS as a cross-cutting constraint

Per- and polyfluoroalkyl substances are not a product-specific issue but a platform-level constraint: their persistence means that contamination travels through every recovery loop, accumulates in sludge- borne fractions, and concentrates in membrane reject streams alongside the target nutrients. Any market positioning of water-derived platform chemicals (see clause 7), and of circular auxiliaries shall anticipate future regulatory trajectories in addition to complying with current legal limits.

Process implications are direction-specific:

- **Thermal pathways** (e.g. Component Material Category (CMC) 13 thermal oxidation, CMC 14 pyrolysis above ~600–900 °C, Granular Activated Carbon (GAC) destruction-grade reactivation > 1000 °C) destroy the great majority of PFAS, including precursors.

- **Precipitation and crystallisation pathways** (e.g. CMC 12 struvite, calcium phosphate) do not degrade PFAS, although partitioning into the crystal phase is generally low.

- **Membrane pathways** (e.g. Reverse Osmosis, Electrodialysis Reversal for mineral concentrate) concentrate PFAS into the same stream as the target nutrients, requiring downstream destruction or removal.

In **Track B** (see clause 9), PFAS play a dual role:

1. As a contaminant to be excluded from regenerated adsorbents (Reactivated Granular Activated Carbon, ion-exchange resins) and recovered acids.

2. As a competitive lever for inherently PFAS-free bio-based alternatives - notably antiscalants (polyaspartates, polyepoxysuccinic acid), oxygen scavengers (erythorbic acid, tannins), and bio-based flocculants.

The substitution argument here is no longer only about resource circularity, but it is about positioning ahead of an inbound regulatory frontier.

The analytical baseline for declaration and verification shall be performed using the following standardized methods:

- **EN 17892,** for individual short- and long chain PFAS analysis with liquid chromatography and tandem mass spectrometry (LC-MS/MS)).

- **ISO 18127**, for determination of adsorbable organically bound fluorine, chlorine, bromine and iodine (AOF, AOCl, AOBr, AOI) using combustion and subsequent ion chromatographic measurement.

- **EN ISO 21675**, for PFAS in sludges and soils analysis with solid phase extraction and LC-MS/MS.

- **DIN 3608**, for determination of perfluoroalkanoic acids by LC-MS/MS after oxidative digestion of soil leachates (TOP-Assay).

For platform chemicals destined for food-chain or drinking-water-adjacent applications, target-list LC-MS/ MS to single-digit ng/L (water) or µg/kg (solids) is the de-facto market expectation.

5.4 Methods of Proof for Product Quality

Methods of proof define the procedure by which compliance with quality criteria shall be verified, ensuring that the results are credible, repeatable, and auditable. Establishing clear and transparent verification procedures is required to ensure trust among users, regulators and certification bodies, and for enabling the market acceptance of circular water-related products.

Applicable testing and verification methods should be selected from existing European and international regulatory frameworks, including:

- **End-of-Waste (EoW) criteria under Directive 2008/98/EC (Waste Framework Directive WFD):** Specifications defining the conditions under which recovered materials cease to be waste. Priority waste and by-product streams identified in relevant European Commission scoping studies should be taken into account.

- **Regulation (EC) 1907/2006 (REACH) and Regulation (EC) 1272/2008 (CLP):** Harmonised testing and classification methods for chemical composition, hazard identification, and risk assessment. Track A and Track B operators should monitor regulatory developments under REACH Annex XVII restrictions regarding PFAS, including sector-specific derogations for recovered streams and substitute substances (see clause 5.5).

- **Regulation (EU) 2019/1009 (Fertilising Products Regulation – FPR):** Conformity assessment procedures and testing methods establishing the basis for CE marking. Where numerical limits for specific contaminants (e.g. PFAS) are not explicitly set in FPR Annex I, compliance with applicable national requirements (e.g. German *AbfKlärV* for sludge-derived products) should be demonstrated.

- **Regulation (EU) 305/2011 (Construction Products Regulation – CPR):** Harmonised test methods and factory production control requirements establishing performance verification for CE marking.

- **Directive (EU) 2020/2184 (Drinking Water Directive – DWD):** Quality parameters for water intended for human consumption, including the limit of 0.1 µg/L for the sum of 20 individual PFAS. Analytical methods used for feedstock characterisation should achieve limits of quantification compatible with these parametric values.

- **Regulation (EU) 2019/1021 (Persistent Organic Pollutants – POPs):** Low concentration limits set in Annex I for substances such as PFOS, PFOA, and PFHxS (including their salts and related compounds). Solid recyclates carrying potential historical contamination (e.g. STRUBIAS materials, biochar, reactivated granular activated carbon) should be verified against these thresholds.

These frameworks collectively offer a strong foundation for existing methods of proof for product quality, which can be adapted for water-related circular economy products. Wherever possible, alignment with these established systems ensures regulatory compatibility and recognition of testing results. The relationship between methods of proof and the criteria framework is outlined in clause 5.2.

It should be noted that for some parameters e.g., chemical purity or microbiological parameters, a broad range of accepted testing methods currently exists. If circular products are to be placed on the market, they shall undergo the same procedures and quality requirements and meet the same regulatory thresholds as first use products to also ensure fair competition and successfully enter the market.

6 Key Performance Indicators

In order to measure and improve the performance of the water-related CE products, this document proposes KPIs categories, which should be taken into account while evolving into a list of indicators. These categories facilitate comparability between products and support certification schemes across the life cycle (sourcing, production, use and end-of-life).

To ensure the comparability, KPIs should be reported per clearly defined functional unit. The selection and application of KPIs should follow a fit-for-purpose approach, meaning that not all indicators are relevant for every product type. Moreover, selection of additional KPIs may be selected depending on the intended application.

The KPIs categories should address the following aspects:

a) Material circularity and sourcing

This category should include indicators related to the proportion of secondary, recovered or recycled inputs, the traceability of input streams and the origin of raw materials. Indicators addressing product circularity and lifetime performance may include the number of reuse cycles, regeneration cycles and the retention of functional performance over time.

For structuring circularity assessment, ISO 59020 on circularity indicators may be used as an indicative reference (see clause 5.2.2). Relevant indicators may include reusability, recyclability and biodegradability (application-dependent), to describe what happens after use in a measurable way.

b) End-of-life and substance management

This category should include indicators related to the presence of hazardous substances or other problematic constituents that could limit safe reuse, recycling or disposal. Additional chemicals used in the production process should be listed for the specific application as they may have an impact for reuse.

c) Operational efficiency during use

Operational efficiency KPIs are essential, especially energy intensity, chemical use and water reuse rate.

d) Environmental impacts and emissions

This category should include indicators related to environmental impacts, such as carbon footprint and water use. The origin of the energy supply (e.g. renewable or fossil) and the water source (e.g. potable or reclaimed) should be explicitly reported where relevant.

KPIs should also address emissions to soil, water and air, distinguishing between emissions associated with production process and those arising during operation. Relevant substances may include carbon dioxide (CO_2), ammonia (NH_3) and nitrate (NO_3^-).

The detailed specification of KPIs, together with product-specific test methods, acceptance criteria and references to applicable product standards, should be provided in the corresponding product factsheets (see Annex A).

7 Future Perspective for Potential Circularity Routes — Platform Chemicals

For the purposes of this CWA, platform chemicals are substances of sufficient purity, defined chemistry and an identified market demand to function as building blocks tradeable between facilities, sectors and value chains — rather than as terminal products tied to a single end-use.

Their relevance for water-related circular economy is threefold:

- they offer market opportunities beyond niche applications;
- they are standardisable against established trading specifications,
- they enable a separation between the responsibility of the producer, who ensures product quality and purity at the point of delivery, and the responsibility of the downstream user, who ensures compliance with end-use requirements.

This decoupling is the precondition for tradeable circular-economy commodities. The scope adopted here is symmetric and broad: every residual stream is treated as a potential raw material, and every conventional chemical input is treated as a potential substitution target. The result is a two-track architecture or two complementary circularity pathways:

Track A: Recovery of platform chemicals from the water cycle

Track A covers substances recovered from water-related processes and subsequently placed on the market for use in chemical, agricultural, energy, materials and Critical Raw Materials (CRM) value chains.

Examples include:

- biorefinery-derived platform chemicals;
- recycled nutrient products;
- water-cycle co-products;
- recovered metals and minerals, including CRM-related materials;
- biogenic CO_2; and
- green hydrogen.

This track represents the primary focus of this CWA.

Track B: Circular substitution of operational chemicals

Track B addresses the substitution of conventionally sourced chemicals used in water treatment, process-water treatment and effluent treatment operations by circular alternatives derived from secondary resources.

Relevant chemical groups may include:

- acids and bases;
- coagulants and flocculants;
- oxidants and reductants agents;
- adsorbents;
- biocides;
- antiscalants;
- oxygen scavengers and conditioning agents; and
- nutrients used in biological treatment processes.

Where a circular alternative is inherently free of substances under regulatory pressure (e.g., PFAS, phosphonates, polyacrylamide), this substitution carries an additional compliance dividend. It is important to highlight that the main focus lays on Track A but under holistic consideration for circularity related management, Track B can be seen as future perspective for the circular economy market and reaches beyond the scope of this CWA.

The two tracks are linked: Track A outputs become Track B inputs at the points marked in the bridge subclause below (clause 8). PFAS is treated as a separate cross-cutting block because its regulatory trajectory affects every recovery and substitution loop independently of the specific substance. To provide an indication of technological readiness and market maturity, each circularity route may be assigned one of the maturity categories defined in Table 1:

- **I (Industrial deployment):** Technology Readiness Level (TRL) ≥ 8. Commercially deployed at industrial scale, with applicable standards available and implemented.
- **P (Pilot or pre-commercial deployment):** TRL 6-7. Demonstrated under relevant operating conditions at pilot or demonstration scale, with standards under development or only partially available.

- **R (Research stage):** TRL < 6. Laboratory-scale or early pilot-stage development, with no established product standard available.

The maturity classification is intended to support the assessment of implementation potential and should not be interpreted as a limitation on further innovation or market uptake.

Other recovered resources with more mature regulations can be found in Annex B.

Table 1 — Recovered platform chemicals with none or limited existing regulatory: origin, state, applicable standards, purity benchmarks, critical contaminants and maturity

Platform chemical	Origin in water cycle	Aggregate state	Existing standards/ specifications	Typical purity/ concentration benchmark	Critical contaminants	Maturity
Struvite ($MgNH_4PO_4 \cdot 6H_2$)	Controlled precipitation from digester supernatant or side-stream	Crystalline solid (granules, 0.5–3 mm)	FPR 2019/1009 CMC 12 (Precipitated phosphate salts and derivates); EN 15959 (P determination)	P_2O_5: 26–28 %; N: 5–6 %; Mg: 9–10 %; water-soluble P ≤ 15 %	Cd ≤ 60 mg/kg P_2O_5 (FPR Annex I), Hg, Ni, Pb, As; PFAS (typically below Limit of Quantification (LOQ)	I
Vivianite ($Fe_3(PO_4)_2 \cdot 8H_2O$)	Magnetic separation from Fe-dosed digested sludge; co- recovers Fe and P	Crystalline solid (blue-green)	No EU product standard yet; pre-commercial; potential dual pathway as FPR CMC 12 P-source and as LFP-battery cathode precursor	Fe: 28–30 %; P_2O_5: 30–32 %; magnetic susceptibility used for separation	Organic matter co- precipitates, PFAS partitioning under investigation	R
Volatile fatty acids (VFA)s: acetic, propionic, butyric)	Acidogenic fermentation of primary sludge or food-waste streams	Liquid (mixed fermenta te, 5–40 g COD/L)	No EU-harmonised EoW or product standard; REACH applies to isolated acids; CEN/TC 411 (bio- based products) partially relevant	Total VFA: 5–40 g/L; C2:C3:C4 profile process-specific	Heavy metals (Cu, Zn from feedstock), pathogens, residual macromolecule s, PFAS (process-dependent)	P
PHA (Polyhydroxyalkan oate)	Mixed-culture accumulation on VFA- rich streams; extraction from waste activated sludge	Solid powder / pellets after extraction	ISO 17088 (compostable plastics); EN 13432 (packaging compostability) ; ASTM D6866 (bio-based C); ISO 14855 (biodegradatio n)	PHA content > 95 % (extracted); thermal stability Td > 250 °C	Endotoxins, residual solvents from extraction, PFAS	P

Platform chemical	Origin in water cycle	Aggregate state	Existing standards/ specifications	Typical purity/ concentration benchmark	Critical contaminants	Maturity
			FPR CMC 9 for coatings (see factsheet Annex A)			
Cellulose Fibers (recovered)	Fine sieving (350 µm) of raw municipal wastewater	Solid (wet sludge → dried fibres)	No EU product standard; REACH; CEN/TC 411; food-contact (EU) 10/2011 not applicable for current uses (see factsheet Annex A)	Cellulose content > 75 % (dry); ash < 10 %	Microplastics, pathogens (pre-pasteurisation), PFAS, residual surfactants	P
Alginate-like exopolymers (ALE / Kaumera)	Alkaline extraction from aerobic granular sludge	Solid (dried flakes) or gel	No EU product standard; pre-commercial; REACH polymer exemption under review CE mark for soil improver FPR CMC 9, use as soil improver or plant biostimulant	Polymer content > 60 % (dry); uronic acid signature	Heavy metals, PFAS, pathogens, endotoxins	P

8 Bridge: from recovered outputs to substituted inputs

The two circularity tracks described in this CWA are not parallel and disconnected; they form a closed loop within the operating envelope of a single facility, between facilities, and across sector boundaries. This is the most direct form of resource closure available in resource-intensive industries: a recovered output of one process becomes the substituted input of another, often the same process.

Several representative linkages illustrate this concept and demonstrate the potential integration between Track A and Track B (see Annex B):

- **Recovered ammonia streams**, such as stripped ammonia (NH_3) solution or ammonium sulphate, may be reused as nitrogen sources for biological wastewater treatment processes (see Annex B, Table B.9). Such streams may be directly reinjected into the same wastewater treatment plant (WWTP), for example in nitrogen-deficient industrial co-treatment applications, or transferred to another facility requiring nitrogen supplementation.

- **Recovered phosphorus products**, including struvite and calcium phosphate, may serve as phosphorus sources for industrial biology (see Annex B, Table B.9). Such applications may be particularly relevant for food-processing, pulp-and-paper and other industrial sectors generating carbon-rich but phosphorus-deficient wastewater streams. It also may replace Magnesium and Nitrogen in nutrient mixes for industrial water treatment.

- **Volatile fatty acids (VFAs)** recovered from organic residual streams may be used as external carbon sources for denitrification (see Annex B, Table B.9). They may also serve as precursors for the production of acetic acid used in peracetic acid (PAA) disinfection systems (see Annex B, Table B.9), thereby reducing the demand for conventionally produced methanol and acetic acid.

- **Biogenic carbon dioxide (CO_2)** recovered from water-sector processes may be utilised as a feedstock for the production of formic acid, which can subsequently be used in performic acid-based disinfection systems and drinking water softening (see Annex B, Table B.6). In the longer term, recovered CO_2 may also contribute to alternative methanol-based pathways for the generation of external carbon sources.

- **Biochar derived from sewage sludge** may be processed into adsorbent materials for water treatment applications (see Annex B, Table B.5). Such materials may partially substitute virgin granular activated carbon in advanced treatment processes. Particular attention should be given to regeneration requirements where the removal of persistent substances, such as PFAS, is intended, as effective destruction-grade reactivation conditions.

Moreover, close attention shall be also given to the following products:

- **Calcite pellets** from pellets softening as seed material for softening, remineralisation and/ or hardening of water. Raw material may be used for the production of calcium oxide / calcium hydroxide as known as lime milk, which is currently in the development in the Netherlands.

- **Iron sludge from drinking water** for direct dosing in digesters WWTPS for sulphur binding. Raw material for the production or iron salts (like $FeCl_3$) and for the production of adsorption pellets (e.g. adsorption of phosporus, arsenic).

- **Cellulose** as raw material for biobased activated carbon which is currently under development (see Annex A).

- **Activated carbon sludge from drinking water production** as reuse from WWTPS for removal of organic micropollutants.

Beyond these directly identified linkages, the architecture invites systematic exploration of further pairings, including recovered acid streams (e.g., biological H_2SO_4 from desulfurisation, see Annex B, Table B.1) feeding back into the same plant's pH-regulation needs, and Fe-bearing vivianite serving simultaneously as P-recovery product and as Fe-coagulant source.

The methodological point is that the longer-term value of the CWA framework lies in standardising not only individual recovery products but the transfer protocols between recovery loops.

9 Track B — Auxiliary and operating chemicals: circular substitution routes

The substances in Track B are the chemicals that water, process-water and effluent treatment operations currently procure linearly. The market is large and the existing product specifications are mature, which means that the methodological challenge differs from Track A: it is not about defining new product types, but about documenting equivalence between a circular recovery route and the established specification. Each subtable in the annex lists one function group, the conventional source it replaces, the circular recovery route, the applicable standard, purity and contaminant criteria, and the maturity code.

Scope clarification: this CWA contribution focuses on auxiliaries used within the water sector (water treatment, wastewater treatment, cooling-water and boiler-water management, Cleaning-in-Place). Most of the circular alternatives listed are equally applicable in other industrial chemical operations, but the water sector use case provides the organising principle.

10 Regulatory closure, open gaps and linkage to the CWA framework

The regulatory and standardisation landscape applicable to the circularity pathways described in this CWA is currently heterogeneous and varies considerably depending on the substance, market sector and level of technological maturity.

In **Track A**, three substances are regulatorily closed for the EU internal market via established CE-marking or harmonised standards (e.g. STRUBIAS-pathway phosphates, biomethane, calcite pellets); four are partially closed, governed by REACH but lacking a harmonised water-sector-specific EoW or product standard (e.g. recovered ammonium salts, VFAs, PHA, elemental sulfur); the remainder operate under Member-State derogations or are at pilot/research maturity. The CRM-related rows (e.g. battery metals, specialty metals, green hydrogen) are governed by the CRM Act 2024 and sector-specific quality specifications, but no integrated water sector- to-CRM standardisation pathway yet exists.

In **Track B**, the situation is structurally different: harmonised EN standards exist for most major auxiliaries (e.g. $FeCl_3$, PACl, NaOH, H_2SO_4, GAC, ozone, H_2O_2, ClO_2), and the circular substitution challenge is primarily about documenting equivalence — not about creating new product categories. The exceptions are bio-based flocculants, antiscalants and conditioners, where standard-level harmonisation is incomplete.

The methodological implications for this CWA are consistent with the approaches described in Clauses 5.2, 5.3 and 5.4.

a) Methods of proof (Clause 5.4)

Where a harmonised European or International standard exists, it should be used as the verification baseline for both Tracks.

For Track A residual gaps, the CWA should specify a minimum protocol across the three layers (chemical, microbiological, physical) defined in Clause 5.3.

For Track B equivalence documentation, the test plan should match the conventional product's verification scheme (e.g., the test battery of EN 935 for $FeCl_3$, applied to any Acid Mine Drainage (AMD)-derived equivalent).

b) KPI design (Clause 6):

The KPI framework described in Clause 6 should include contaminant monitoring as a mandatory category for:

- all platform chemicals recovered from water-cycle processes (Track A); and
- all circular auxiliary chemicals intended for use within the water sector (Track B).

For Track B substances, an additional mandatory KPI category should address substitution equivalence, demonstrating that the circular alternative achieves functional performance comparable to that of the conventional reference product under the applicable standard.

c) Closed-loop accounting:

where a Track A output is re-used as a Track B input within the same facility (the bridge cases in clause 8), the CWA should support paired KPI reporting – i.e., not counting the output and the substituted input twice, and recognising the avoided import as an explicit KPI dimension.

This positions the CWA framework defensibly against future regulatory tightening – particularly the expected EU REACH Annex XVII PFAS entry – and provides the methodological infrastructure for circular economy operations to evidence resource closure across both directions of the chemical-water interface.

The European Commission has announced a Circular Economy Act for 2026. Its stated aim is a single market for waste and secondary raw materials, raising the Union's circularity rate from around 12 % today to 24 % by 2030, with critical raw materials among its priorities. A single market requires comparability, and comparability requires a common declaration. The division of labour is therefore straightforward: regulatory framework supplies the knowledge, this agreement supplies the language and the Act opens the market. What the Act does not address is the chemical identity of a recovered substance and the evidence that it is equivalent to its primary counterpart. That is the gap this agreement fills, and it is worth filling whatever the legislative timetable turns out to be.

Annex A
(informative)

Factsheets

Table A.1 — Purified lithium concentrate from industrial brines and recycling streams

Purified Lithium Concentrate from Industrial Brines and Recycling Streams
General Description Purified lithium concentrate produced using Amovion's patented Flow-Electrode Capacitive Deionization (FCDI) technology. The process selectively separates, concentrates and recovers lithium ions from industrial brines, battery recycling streams, geothermal waters and other saline process waters. The technology enables continuous lithium enrichment with high selectivity, high concentration factors and reduced energy demand compared to conventional concentration technologies.
Origin The technology was developed at RWTH Aachen University and DWI – Leibniz Institute for Interactive Materials, project Amovion (Aachen, Germany). The underlying FCDI technology has been demonstrated for lithium-containing streams and forms the basis for circular lithium recovery concepts for the European battery value chain.
Available quality grades • Lithium-enriched concentrate (process intermediate) • Battery precursor grade lithium concentrate • High-purity lithium salt feedstock for further refining • Application-specific lithium streams according to customer requirements
List of application fields • Lithium-ion battery manufacturing • Battery recycling • Geothermal lithium extraction • Industrial brine processing • Resource recovery from wastewater • Circular raw material supply chains • Strategic battery materials production
Description of production process Lithium-containing feed streams are introduced into an electrochemical FCDI module. Under an applied electric field, lithium and accompanying ions migrate through ion-exchange membranes into circulating flow electrodes. Due to the continuous transport and regeneration of the flow electrodes, lithium can be selectively concentrated and recovered in a separate concentrate stream. The process combines ion separation, concentration and recovery within a continuous operation scheme while maintaining low energy consumption and high water recovery.
Additional compounds added in the production process (if quality relevant) Activated carbon slurry (flow electrodes), ion-exchange membranes, conductive additives, aqueous electrolyte solutions.

Product Owner Contact
Dr. Christian Linnartz
Amovion / DWI e.V.
Forckenbeckstraße 50,
52074 Aachen, Germany

1. Field of Application

The product is intended for the sustainable production of lithium feedstocks and lithium concentrates required for lithium-ion battery manufacturing. The technology supports recovery of lithium from industrial wastewater, geothermal brines, battery recycling streams and other saline process waters. It contributes to the establishment of circular battery material value chains and reduced dependence on primary lithium mining.

2. Quality Criteria

2.1 Circularity Criteria

- Recovery of critical raw material lithium from secondary resources.
- Recovery and reuse of process water.
- Water recovery typically above 80–95%, depending on feed composition.
- Reduction of waste brine generation.
- Recovery of lithium from industrial side streams and recycling processes.
- Recovered lithium can be reintroduced into battery-material production.
- Flow electrodes are continuously reused during operation.
- Expected industrial lifetime of flow-electrode materials exceeds five years under normal operating conditions.

2.2 Microbiological Parameters

No relevant microbiological quality parameters for the lithium product. Standard industrial water quality monitoring may apply depending on feed source.

2.3 Chemical Parameters

- Lithium concentration (application dependent)
- Feed salinity range: 0.01–5 mol/L
- Concentrate streams up to 80% of salt solubility limit
- High lithium selectivity relative to competing ions
- Low contamination with multivalent ions after downstream polishing
- Controlled chloride, sulfate and sodium content according to customer specification

2.4 Physical Parameters

- Continuous operation
- Pilot-scale throughput approximately 1000 L/h
- Industrial scale-up possible through modular design
- High concentration factors achievable in a single process step
- Reduced fouling and scaling compared to membrane-only technologies
- Low operating voltage (approximately 1–1.4 V)

3. Regulations & specific standards to comply with

- EU Critical Raw Materials Act (CRMA)
- EU Battery Regulation (EU) 2023/1542
- REACH Regulation (EC 1907/2006)
- EU Water Framework Directive (2000/60/EC)
- Industrial Emissions Directive (IED)
- Machinery Regulation and CE conformity requirements
- ISO 9001 Quality Management Systems
- ISO 14001 Environmental Management Systems
- ISO 59020 Circular Economy Performance Indicators
- Applicable battery-grade lithium specifications according to customer requirements
- National and regional wastewater discharge regulations

4. Key Performance Indicators

Emissions to soil, water and air

- No direct process emissions of CO_2, NH_3 or N_2O during operation.
- No thermal evaporation required.
- Reduced indirect CO_2 emissions due to significantly lower electricity demand compared with thermal concentration technologies.
- Reduced environmental burden through lower brine disposal volumes.

Energy use

- Approximately 51% lower energy demand than comparable electrodialysis operation
- Energy recovery during electrode regeneration up to 36%.
- More than 70% energy reduction demonstrated through advanced multi-cell FCDI designs.
- Fully compatible with renewable electricity sources.

Water use

- Water recovery rates typically between 80% and 95%.
- Significant reduction of freshwater demand through internal water recycling.
- Enables simultaneous water reuse and lithium recovery.

Circular use and lifetime

- Recovery of lithium as a critical raw material.
- Recovered lithium can be reintroduced into battery production.
- Continuous reuse of activated-carbon flow electrodes.
- Expected electrode lifetime >5 years.
- Reduced generation of waste brines.
- Supports closed-loop battery material supply chains.

End-of-Life and substance management

- Main materials: activated carbon, ion-exchange membranes, polymer housings and electrolyte can be separated and recycled
- No intentionally added critical hazardous substances.
- End-of-life treatment according to local waste and chemical regulations.

Additional chemicals used in the production process

- Flow electrode slurry
- Conductive additives
- Ion-exchange membranes
- Electrolyte solutions

Table A.2 — Polyhydroxyalkanoates

Polyhydroxyalkanoates (PHA) / Caleyda®
General Description PHA is a biobased polyester produced from organic matter, such as present in wastewater sludge, industrial wastewater, solid organic waste, and food industry sidestreams. It can function as a replacement for fossil plastics in applications where biodegradability is required. The polymer combines ready biodegradability with mechanical and thermal properties that can be comparable to those of conventional plastics, depending on composition and application.
Origin Organic material in municipal and industrial aqueous residual streams is anaerobically converted to volatile fatty acids (VFAs). Mixed microbial cultures convert VFAs into intracellular PHA. Sources may include municipal wastewater sludge and streams from paper, brewing, starch and food production.
Available quality grades No formally standardised commercial grades are identified yet. Intermediates and endproduct: • dried PHA-rich biomass (approximately 50–70% PHA); • recovered PHA powder (>98.5% PHA); extruded Caleyda® granulate (>98.5% PHA). Application-specific specifications should cover purity, copolymer composition, molecular weight, thermal properties, moisture, residual solvent, elements and non-intentionally added substances (NIAS).
List of application fields • agricultural mulch films and plant pots; • fertiliser coatings, including controlled-release coatings; • paper coatings and paper or cardboard binders; • packaging and other plastic articles; • moulded products and 3D-printing applications; • foam plugs; • selected engineering applications, including research into self-healing concrete. Food-contact and biomedical applications require separate demonstration of compliance with stringent application-specific requirements, including requirements relating to purity, migration and biological safety.
Description of production process Organic carbon is fermented to VFAs. A mixed microbial culture accumulates PHA. The biomass is harvested, stabilised, dewatered and dried. PHA is selectively extracted with a heated higher alcohol, separated from residual biomass, crystallised by cooling, filtered, solvent-washed, vacuum-dried, extruded and pelletised.
Additional compounds added in the production process (if quality relevant) Sulphuric acid is used for biomass stabilisation. A green solvent (biodegradable higher alcohol) is used for extraction and washing and is recovered after use. Cooling water is used indirectly. No fillers, plasticisers, pigments or stabilisers are described for the neat granulate.
Product Owner Contact Paques Biomaterials BV (https://www.paquesbiomaterials.nl/)
1. Field of Application

PHA is a thermoplastic for applications where biobased content and biodegradability provide functional value. See list of application fields.

2. Quality Criteria

Quality criteria should be application-specific and linked to controlled feedstock, production and recovery. Important influences are biomass quality and PHA content, copolymer composition, molecular weight, extraction conditions, removal of contaminated solvent, washing and drying. Representative batch specifications and monitoring are required.

Product quality should include verification of residual contaminants, residual extraction solvent, heavy metals, NIAS and other trace substances. The required parameters and acceptance limits should depend on the intended application and exposure scenario.

2.1 Circularity Criteria

The carbon feedstock is derived from organic residual streams. PHA articles are recyclable in principle, but actual recyclability depends on design, additives, collection and infrastructure. Unmodified PHA is biodegradable in microbially active environments, including soil and ocean; rate depends on composition, crystallinity, geometry, environment and additives. Claims must be proven under the application-specific standard.

2.2 Microbiological Parameters

Upstream biomass may contain bacteria, fungi, viruses and spores. Acidification, drying, hot-solvent extraction, washing, vacuum drying and melt extrusion are expected to reduce viable microorganisms, but validated microbiological specifications or accredited absence data are not available yet. Depending on use, control total viable count, yeasts/moulds, spores and relevant indicators/pathogens. Endotoxins are especially relevant for biomedical use.

2.3 Chemical Parameters

The chemical quality of recovered PHA should be characterised by:

- PHA/PHBV content, polymer purity and monomer composition;
- molecular weight and molecular-weight distribution;
- moisture content;
- residual extraction solvent;
- residual process chemicals
- volatile, semi-volatile and non-volatile organic impurities;
- residual biomass components, including proteins and lipids;
- elements, heavy metals and other inorganic contaminants;
- trace organic contaminants originating from the wastewater-derived feedstock or recovery process;
- non-intentionally added substances (NIAS);
- application-specific substances of concern;
- migration or leaching behaviour, where relevant to the intended application.

2.4 Physical Parameters

Control form and appearance, colour/odour, particle or pellet size, bulk and polymer density, melting and glass-transition behaviour, crystallinity, thermal stability, rheology/melt flow and application-relevant mechanical properties.

3. Regulation & specific standards to comply with

Potentially relevant, depending on application: REACH Regulation (EC) No 1907/2006; CLP Regulation (EC) No 1272/2008; EN 13432 for industrially compostable packaging; EN 17033 for

biodegradable agricultural mulch films; Regulation (EU) No 10/2011 for food-contact plastics; and application-specific fertilising-product rules for coatings. Current Caleyda® conformity/certification was not demonstrated. Verify current legal texts and standards before publication.

For biodegradable agricultural applications such as mulch films and fertiliser coatings, compliance with relevant biodegradability and application-specific standards should be demonstrated for the intended market. The required standards depend on the final application.

4. Key Performance Indicators

Emissions to soil, water and air

- No validated data are currently available emissions to soil, or emissions to water.

Energy

- no complete energy balance per kilogram of PHA is available;

Improvement Potential

- Use of renewable electricity reduces environmental costs
- Use of sustainable heat reduces environmental costs
- Additional optimisation potential exists through heat recovery and process optimisation.

Process performance

- PHA content in PHA-rich biomass;
- conversion efficiency from organic matter to VFAs;
- conversion efficiency from VFAs to PHA;
- PHA recovery yield;
- solvent recovery rate;
- percentage of off-specification material.

Circular use and lifetime

PHA is a fully biodegradable biopolymer and can be used in applications where biological degradation after use is a desired functionality. PHA may in principle be mechanically recycled. Practical recyclability depends on polymer composition, additives, product design, contamination, collection and sorting systems, reprocessing conditions and the availability of suitable recycling routes.

End of Life and substance management

Potential benefits associated with avoiding persistent microplastic pollution are not included in LCAs because the long-term environmental effects of microplastics cannot yet be adequately quantified. Consequently, LCA assessments do not quantify this potential benefit of PHA in applications where unintended release to the environment may occur.

Table A.3 — Calcite pellets

Calcite pellets
General Description Calcite pellets are a granular calcium carbonate by-product formed during drinking-water softening in pellet reactors. They consist of calcium carbonate or calcium carbonate around a small sand seed core. The pellets typically have a diameter of 1–2 mm.
Origin Calcite pellets originate from the removal of calcium hardness during the production of drinking water from groundwater or surface water. Calcium carbonate precipitates on fine seed material after dosing sodium hydroxide or lime milk.
Available quality grades • Calcite-seeded pellets: up to 100% calcite. • Sand-seeded pellets: calcium carbonate around a quartz, silver-sand or garnet-sand core; a small sand core of approximately 5% w/w is reported for a typical sand-seeded pellet. • Application-specific grades may differ in seed material, colour, iron content, moisture and particle-size distribution.
List of application fields • Seed material in drinking-water softening and mineral material for remineralisation/hardening of water. • Raw material for the lime industry and lime-milk production. • Mineral filler or raw material in carpet tiles, sanitary ware, tiles, glass and paint. • Aggregate or filler in concrete products and other construction applications. • Floor covering in crawl spaces. • Soil improvement and horticultural applications. • Animal feed, cosmetics and food-industry applications where the relevant location-specific and application-specific requirements are met.
Description of production process Raw water is softened in a pellet reactor. Sodium hydroxide (NaOH) or lime milk [$Ca(OH)_2$] is dosed, causing calcium carbonate to precipitate on fine seed material. The pellets remain suspended in the upward water flow and grow until they reach approximately 1–2 mm and settle into the discharge zone. They are removed to storage. At many sites, storage and dewatering measures are used to deliver clean and dry pellets. Unprocessed pellets can be transported directly to customers or a depot. For reuse as seed material, selected pellets are milled and sieved before being returned to the softening process.
Additional compounds added in the production process (if quality relevant) • Sodium hydroxide or lime milk is used in the softening process. Sodium from sodium hydroxide remains in the water and is not incorporated into the calcium carbonate pellet. Calcium from lime milk becomes part of the pellet. • Fine calcite or sand is used as seed material. Reported sand types include quartz, silver sand and garnet sand. • No other deliberately added compounds.

Product Owner Contact
AquaMinerals B.V.
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3433 PE Nieuwegein
The Netherlands
www.aquaminerals.com
info@aquaminerals.com

1. Field of Application

Calcite pellets are used as a circular mineral raw material in several application fields. The applicable quality criteria, certification and legal requirements depend on the intended use. A grade must therefore be matched to the specific application, particularly for drinking water, food, feed, cosmetics and construction products.

2. Quality Criteria

2.1 Circularity Criteria

- Calcite pellets are a by-product of drinking-water softening.
- Existing circular routes include milling and sieving pellets for reuse as seed material in the same softening process and replacing primary quarried calcium carbonate in other applications.
- Recyclability after use depends on the application and cannot be stated generically.

2.2 Microbiological Parameters

Drinking-water sources and production are controlled. With a few exceptions water is not treated (hygienised) after the softening process as it meets microbiological drinking water standards. GMP+ and ISO 22000 certification can guarantee microbiological acceptance for feed and food applications. Some production sites have been certified.

2.3 Chemical Parameters

Composition in % w/w dry matter:

- Calcium carbonate ($CaCO_3$): 85–99.9%.
- Inert material (SiO_2): <0.1–15%.
- Iron: <0.1–0.75%.
- Aluminium: <0.1–0.3%.
- Magnesium: <0.1–0.5%.
- Manganese: <0.1–0.3%.

Heavy metals are regularly analysed and are not found above the applicable limits, PFAS is not detected.

2.4 Physical Parameters

- Granular solid; typical pellet diameter: 1–2 mm.
- Moisture content: <1–5% w/w.
- Colour, particle-size distribution, iron content and seed type may vary by production location and grade.
- Calcite pellets have high hardness and are not dust-sensitive.
- The bulk-density is 1450 kg/m3.

3. Regulations & specific standards to comply with

- REACH registration for calcium carbonate/calcite pellets: Calcium carbonate is classified as non-hazardous under CLP and report no Candidate List substances of very high concern above 0.1% and no CMR substances above applicable thresholds.
- Safety Data Sheets are available for calcite pellets.
- Application-specific schemes include GMP+ for animal feed and ISO 22000 for the food industry at selected production locations.
- For Belgian use as a non-shaped construction material, an OVAM raw-material declaration may be producer- and application-specific.
- The calcite pellets have been Cradle to Cradle Gold certified, but this certification is not renewed since 2023.
- Other standards and legal requirements must be determined for the intended application and production location.

4. Key Performance Indicators

These numbers are representative for the calcite pellets from the Dutch and Flemish drinking water companies. Source: LCA made for the EPD for the calcite pellets.

Emissions to soil, water and air

- No direct process emissions to air, soil or water were identified for the production of calcite pellets in the assessed production stage (A1-A3).
- During pellet formation, CO_2 is captured from water and air and incorporated into calcium carbonate. The LCA refers to literature reporting approximately 0.2 kg CO_2 uptake per kg calcite during softening.
- The EN 15804+A2 climate change indicator (GWP-total) equals 1.72 kg CO_2-eq per tonne of calcite pellets.

Energy use

For production of 1 tonne of calcite pellets:

- Purchased renewable electricity (green electricity with Guarantees of Origin): 0.779 kWh/t.
- On-site photovoltaic electricity: 0.00619 kWh/t.
- The LCA states that electricity is primarily used for pumping water to the pellet reactor during the drinking-water softening process

Water use

No additional water is intentionally added for calcite pellet production. Calcite pellets are formed during the softening of drinking water in pellet reactors. The only water involved is the raw water stream that already passes through the drinking-water treatment process.

Circular use and lifetime

- Calcite pellets are a by-product of drinking-water softening and replace primary calcium carbonate from quarrying in multiple applications.
- Milled calcite pellets are also reused as seed material in pellet reactors, creating a circular loop within the drinking-water softening process.
- Product lifetime depends on the specific application.

End of Life and substance management

- The product contains no substances classified as SVHCs according to the Candidate List.
- No hazardous process additives remain in the final product.

Additional chemicals used in the production process for the specific application

- Sodium hydroxide or lime milk is used during softening, and calcite or sand is used as seed material.
- No additional chemicals are used for delivery of unprocessed pellets.

Table A.4 — Value – Added Compound - Polyphenols

Value – Added Compound - Polyphenols
General Description Value-Added Compounds (VACs) are high-value substances recovered from agro-industrial streams that would otherwise be discarded, treated as waste, or subjected to low-value disposal. Through selective extraction and, where required, purification, these compounds can become valuable secondary raw materials. Polyphenols are secondary plant metabolites naturally present in fruits and vegetables. Agroindustrial processing streams, including fruit and vegetable processing wastewater and other residual biomass streams, can contain significant quantities of these compounds. Polyphenols are of particular interest due to their biological activity and antioxidant properties. Depending on their chemical structure, polyphenols may also exhibit anti-inflammatory, anticancer and antimicrobial properties. High-purity compounds can have significant market value, particularly where they are suitable for applications such as pharmaceuticals, nutraceuticals, cosmetics and other products.
Origin The polyphenols originate from agro-industrial processing streams, particularly side streams generated during fruit and vegetable processing. Examples include process wastewater, washing and processing streams, fruit residues and pomace. Instead of being treated as waste requiring disposal or conventional wastewater treatment, these streams can be valorised as secondary raw material sources for the recovery of Value-Added Compounds.
Available quality grades • Crude Polyphenol Extracts: Extracts containing a mixture of polyphenols and other naturally occurring compounds. • Selected Mixtures: High-purity mixtures enriched in selected target polyphenols, with reduced levels of non-target compounds. • Pharmaceutical-Grade Compounds: Isolated individual polyphenols of very high purity, suitable for pharmaceutical applications.
List of application fields • Pharmaceuticals • Nutraceuticals and Dietary Supplements • Food & Beverages • Cosmetics
Description of production process Greener than Green Technologies has developed a product, VesperX, a mobile, modular wastewater treatment unit, particularly designed to address the needs of the food processing sector. It has the capability to remediate and recycle the industry's water byproduct and at the same time to extract purify and commercially exploit VACs.

Polyphenols are extracted from the production stream using green extraction technologies, mainly supercritical fluid extraction followed by separation and purification steps to reach the desired quality.

Additional compounds added in the production process (if quality relevant)

Not applicable

Product Owner Contact

Name: Dimitri Iossifidis, Myrto Foteini Touloupi

Organisation: Greener than Green Technologies S.A.

Contact details: d.iossifidis@greenerthangreen.co, m.touloupi@greenerthangreen.co

1. Field of Application

The method has been developed for the food processing sector, enabling the valorisation of agro-industrial side streams through the recovery of value-added compounds. The recovered polyphenols can be used as secondary raw materials for several applications, including nutraceuticals, dietary supplements, functional foods, cosmetics and pharmaceuticals, depending on their purity.

2. Quality Criteria

2.1 Circularity Criteria

The product contributes to circularity through the recovery and valorisation of high-value polyphenolic compounds from agro-industrial secondary resources and side streams that would otherwise require treatment or disposal.

Key circularity characteristics include:

- Recovery of high-value compounds from secondary (waste) resources.
- Recovery and reuse of process water, with water recovery typically exceeding 80–95%, depending on feed composition.
- Recovery of Value-Added Compounds from industrial side streams and by-products of up to 75%.
- Reduction, and potentially significant elimination, of agro-industrial waste volumes requiring disposal.
- Reintroduction of recovered polyphenols into high-value production chains, including food, cosmetic and nutraceutical applications, depending on the quality grade and regulatory requirements.
- Further treatment of residual wastewater to enable its safe reuse within the process or for other suitable applications.

2.2 Microbiological Parameters

Relevant microbiological parameters depend on the intended application and may include:

- Total aerobic microbial count
- Total yeast and mould count
- Enterobacteriaceae
- Escherichia coli
- Salmonella spp.
- Staphylococcus aureus
- Other application-specific pathogens or indicator organisms

For pharmaceutical, food, nutraceutical or cosmetic applications, microbiological specifications should be established according to the relevant product category and applicable legislation.

2.3 Chemical Parameters

Relevant chemical quality parameters may include:

- Total polyphenol content (for crude extracts and mixtures)
- Concentration of target polyphenolic compounds
- Individual polyphenol profile
- Purity of target compound(s)
- Pesticide residues, where relevant
- Other contaminants relevant to the original agro-industrial feedstock
- Antioxidant activity, where relevant to the intended application

For high-purity compounds, identity should be confirmed using appropriate analytical techniques such as HPLC/MS-MS.

2.4 Physical Parameters

- Physical state: liquid, concentrated liquid, powder or solid fraction, depending on formulation
- Appearance and colour
- Odour
- Solubility
- Particle size, where applicable
- Bulk density, where applicable
- Moisture content
- Stability and shelf life
- Hygroscopicity, where applicable

3. Regulations & specific standards

- Regulation (EC) No 1924/2006 on nutrition and health claims (incl. EFSA Article 13/14 claim types)
- Regulation (EU) 2015/2283 on Novel Foods (where applicable)
- Regulation (EC) No 1223/2009 on cosmetic products (for cosmetic-grade extracts)
- REACH Regulation (EC 1907/2006)
- EU Water Framework Directive (2000/60/EC)
- Industrial Emissions Directive (IED)

4. Key Performance Indicators

Emissions to Soil, Water and Air

The production of polyphenols through the VesperX approach is embedded within a broader circular economy framework for the treatment and valorisation of food-processing side streams.

Rather than generating a separate waste stream for polyphenol production, VesperX uses food-processing wastewater as a resource from which both water and Value-Added Compounds (VACs) can be recovered. The integrated treatment and recovery approach helps reduce the pollution burden associated with untreated or insufficiently treated food-processing wastewater, particularly the potential impact on water and soil. By treating the wastewater and enabling water recovery and reuse, VesperX addresses the environmental challenge of the original industrial side stream while simultaneously recovering valuable compounds.

Energy Use The VesperX process is designed to operate with low energy requirements, particularly compared with conventional approaches. **Water Use** Water reuse is the fundamental principle of the VesperX application. Water recovery is not an additional benefit of the process but the basis upon which the integrated resource-recovery concept is developed. VesperX treats food-processing wastewater to recover water for reuse while simultaneously creating the opportunity to extract valuable polyphenolic compounds from the same side stream. In this sense, water reuse acts as the entry point for VAC recovery: an environmental challenge faced by food-processing industries, wastewater generation and water consumption, is addressed while creating an additional value stream through the recovery of polyphenols. This integrated approach reduces freshwater demand, improves water efficiency and enables the same industrial side stream to provide both reusable water and value- added compounds. **Circular Use and Lifetime** Both the recovered water and compounds form part of a circular economy approach. The recovered water can be returned to irrigation or appropriate industrial uses, reducing the need for freshwater abstraction. The recovered polyphenols can be further processed and introduced into high-value value chains, including food, nutraceutical, cosmetic and other applications, subject to the applicable quality and regulatory requirements. The VesperX concept therefore supports industrial symbiosis, by connecting different resource flows within the food-processing value chain and converting an industrial side stream into useful resources.

Table A.5 — Fine screenings/cellulose

Fine screenings/cellulose
General Description Recovered cellulose-rich fibre material from municipal wastewater, also referred to as sewer cellulose or fine screenings. It is separated from municipal wastewater at an early stage of the wastewater treatment process with fine sieves. The main source of the cellulose fibres is toilet paper in the influent. Depending on the recovery and upgrading process, the material may be supplied as wet cellulose-rich screenings or as cleaned, hygienised and dried cellulose fibres.
Origin Municipal wastewater at wastewater treatment plants (WWTPs). Cellulose fibres mainly originate from toilet paper and are recovered near the beginning of the treatment process by fine screening.
Available quality grades • Raw screenings / recovered sewer cellulose: untreated, wet cellulose-rich material separated at a WWTP. • Hygienised or further treated recovered wet cellulose: cellulose-rich material that has undergone treatment to reduce pathogens and improve suitability for specific applications. • Clean, dry, hygienised cellulose fibres: upgraded cellulose fibres produced from raw screenings (e.g. Cellvation process: Recell fibres), suitable for higher-value material applications. • Converted products: products derived from cellulose conversion, including glucose (e.g. Recell glucose), fatty acids and other downstream chemicals. These are separate products and require product-specific assessment. • Exact commercial specifications and acceptance limits are application- and customer-specific and are still under development.

List of application fields

- drain-inhibiting fibres in asphalt;
- paper and cardboard;
- insulation materials;
- composite materials, including decking boards, façade panels and sheet piling;
- board materials as potential alternatives to MDF or gypsum board;
- mycelium-based products;
- activated carbon;
- conversion into glucose and fatty acids;
- downstream conversion into bioethanol, detergents, bioplastics and other biobased chemicals.

Description of production process

Municipal wastewater → fine screening at the beginning of wastewater treatment → separation and pressing of a wet cellulose-rich fraction → collection → optional hygienisation and/or further upgrading → application-specific use. The STOWA 2023 LCA distinguishes untreated screenings, a wet hygienised cellulose product from Meri technology using performic acid, and clean, dry, hygienised cellulose fibres from the CellCap process. Electricity is required for screening and pressing. Further upgrading may include washing, additional screening, pressing, heating, drying and hygienisation. Alternative routes include separate digestion for biogas or conversion into other materials and chemicals.

Additional compounds added in the production process

No additives are identified for the basic recovery step on the WWTP. Application-specific downstream processing may use additives, binders, enzymes or other chemicals.

Product Owner Contact

Raw fine screenings:

AquaMinerals BV

www.aquaminerals.com

info@aquaminerals.com

1. Field of Application

Recovered cellulose (raw screenings) from municipal wastewater treatment plants is intended for use as a secondary, biobased raw material in material and biochemical applications. Potential applications include asphalt additives (drain inhibitor fibers), paper and cardboard products, composite materials, insulation products, board materials, mycelium-based products, activated carbon production, and conversion into glucose and other bio-based chemicals. Depending on the intended application, additional treatment steps such as cleaning, dewatering, drying and/or hygienisation may be required. The specific quality requirements depend on the intended end use and relevant legislation.

2. Quality Criteria

2.1 Circularity Criteria

The cellulose originates from a secondary, biogenic feedstock in municipal wastewater. The wet recovered fraction also contains water and non-cellulosic components and should therefore not be characterised as pure cellulose without further processing and verification. Its actual cellulose content, biobased content and recycled content should be determined for the supplied product form.

Reuse routes substitute virgin cellulose or other primary feedstocks. Recyclability depends on the final application: cellulose in paper/cardboard may re-enter fiber recycling; cellulose in asphalt or composites is encapsulated and follows the end-of-life route of the host material; conversion to chemicals creates new value chains.

2.2 Microbiological Parameters

Relevant microbiological parameters include pathogens and the effectiveness of hygienisation. Pathogens have been detected in sewer cellulose. Because no safe threshold can be assumed for certain pathogenic microorganisms, hygienisation is considered an important control measure for applications involving potential human exposure. Application-specific monitoring parameters and microbiological limit values are not yet specified in the available information.

2.3 Chemical Parameters

Relevant groups are heavy metals, pharmaceutical residues, pesticides, substances of very high concern (SVHCs) and persistent organic pollutants (POPs). In the Netherlands these parameters are currently assessed as part of an end-of-waste trajectory. The measurement program uses selected indicator substances and bioassays for hormonal and combined effects. Approximately 50 substances or substance groups were selected as a worst-case indicator set. POP thresholds in Annex I of the POP Regulation apply to products placed on the market. The analytical results and the risk assessment for different application is not available yet.

The chemical quality of recovered cellulose should be characterised by:

- cellulose content and the proportion of non-cellulosic material;
- dry-solids and moisture content;
- organic matter and ash content, where relevant;
- Non-intentionally added substances (NIAS), such as heavy metals, pharmaceutical residues, pesticides, persistent organic pollutants (POPs), substances of very high concern (SVHCs) and other application-specific substances of concern.
- migration, leaching or bioavailability, where relevant to the intended application.

In the Netherlands, a monitoring programme has been developed as part of the end-of-waste assessment for recovered cellulose from municipal wastewater. The programme focuses on non-intentionally added substances (NIAS) that may be present as a result of the wastewater-derived feedstock. Approximately 50 substances or substance groups were selected as a worst-case indicator set, complemented by bioassays to assess hormonal activity and combined effects. The analytical results and application-specific risk assessments are not yet available. Consequently, generic contaminant limits cannot currently be derived from the available information.

2.4 Physical Parameters

Application-specific physical parameters may include supplied form, dry-solids content, moisture content, cellulose or fibre content, particle/fibre characteristics, bulk density, ash content, dewaterability and relevant mechanical properties. For biochemical conversion routes, parameters such as cellulose accessibility, homogeneity, pumpability and supplied concentration may also be relevant.

3. Regulation & specific standards to comply with

- Waste Framework Directive end-of-waste criteria
- REACH: unmodified cellulose pulp/naturally occurring polymers may be exempt under the cited REACH provisions, subject to applicable conditions. Recovered substances may use Article 2(7)(d) where sameness and access to required safety information are demonstrated.
- CLP Regulation (EC) No 1272/2008 where classification is relevant.

- POP Regulation, including Annex I thresholds.
- Asphalt: production certification based on BRL 9320 and inclusion on the OPWA list.
- Paper/cardboard: EN 643; for food-contact paper, Regulation (EC) No 1935/2004, GMP Regulation (EC) No 2023/2006 and BfR Recommendation XXXVI.
- Biofuel: RED II/RED III sustainability requirements and recognised chain certification; the memo notes NEA registration for sales.
- Detergents: Regulation (EC) No 648/2004.
- Optional bio-based content certification/analysis: ISO 16620, EN 16785-1, EN 16640, ASTM D6866 and related schemes.

4. Key Performance Indicators

Emissions to soil, water and air

The recovery of raw sceenings from influent does not result in direct emissions during operation.

Water use

Recovery of the sceenings from influent does not affect the water quality and does not use extra water during operation; determine reclaimed/fresh water use per tonne and report process-water discharge.

Energie use

- Recovery of cellulose results in energy savings on the wwtpp for aeriation that partly compensates the energy use of recovery.
- STOWA 2023-08 gives following values for the net energy use: CellCap (clean dry cellulose fibres) 0,19 kWh/kg DM cellulose, band screen 0.68 kWh/kg DM cellulose product, drum-screen 0.68 kWh/kg DM cellulose product, Meri technology 0.85-1.37 kWh/kg DM cellulose product.

LCA

STOWA 2023-08, “LCA van acht grondstoffen uit rioolwater”. Negative values indicate net avoided impact within the study boundaries. The production of cellulose results in less sewage sludge and thus less impact in sludge treatment that way taken into account:

- Climate impact of untreated screenings: band screen −0.11 kg CO_2-eq./kg DM; Meri technology −0.51 kg CO_2-eq./kg DS. No net result was available for the drum-screen plus curved-screen combination because avoided aeration electricity and sludge reduction were unknown
- Wet hygienised cellulose product (Meri + performic acid): −0.30 kg CO_2-eq./kg DM and −2 eurocent/kg DS environmental costs. Reference pulps: recycled-paper pulp 0.32 kg CO_2-eq./kg DS and 16 eurocent/kg DM; virgin pulp 0.14 kg CO_2-eq./kg DM and 2 eurocent/kg DM
- Clean dry cellulose fibres (CellCap): −0.55 kg CO_2-eq./kg DM and −4 eurocent/kg DM environmental costs. Reference fibres: recycled-paper cellulose 0.21 kg CO_2-eq./kg DM and virgin softwood cellulose 0.14 kg CO_2-eq./kg DM. Both reference routes have 2 eurocent/kg DM environmental costs in the report.
- Indicative combined environmental-cost benefit when dry CellCap cellulose replaces recycled or virgin fibres: about 6 eurocent/kg DM. A similar benefit of about 6 eurocent/kg DS is reported for wet hygienised Meri cellulose when it displaces recycled-paper use.
- Separate digestion: the report concludes that digestion of screenings for biogas has a 200% lower environmental impact than the reference. The added benefit was about 2

eurocent/kg DM cellulose for band-screen screenings and almost 4 eurocent/kg DM for untreated Meri screenings.

- Important limitations: results depend strongly on screening yield, sludge-treatment route and the product actually replaced. The environmental costs use the MKI method "Bepalingsmethode, jan. 2021 (NMD 3.3) v3.04".

End of Life and substance management

Current studies in progress show the possible presence of trace contaminants originating from the wastewater-derived feedstock in the raw screenings. Additional assessment may be required for application-specific substances of concern and non-intentionally added substances (NIAS).

Circular use and lifetime

Cellulose is fully biodegradable and can be used in applications where biological degradation after use is a desired functionality. Practical recyclability depends on additives, product design, contamination, collection and sorting systems, reprocessing conditions and the availability of suitable recycling routes.

Additional chemicals

No added chemicals except formic acid for hygienisation with one of the recovery technologies (Meri).

Annex B
(informative)

Recovered Platform Chemicals

Table B.1 — Recovered platform chemicals: origin, state, applicable standards, purity benchmarks, critical contaminants and maturity

Platform chemical	Origin in water cycle	Aggregate state	Existing standards/ specifications	Typical purity/ concentration benchmark	Critical contaminants	Mat.
Ammonium sulfate ($AmSO_4$) solution	Air- or steam-stripping of reject water from sludge dewatering; acid scrubber	Liquid (≈30–40 % w/w)	FPR 2019/1009 PFC 1(C) (I)(a)(i) inorganic N fertiliser; REACH registered substance; DüMV (DE) Typ 4.1	N: 7–8 % (w/w); pH 4–6; turbidity < 50 NTU	PFAS (carry-over from feed), heavy metals (Cd, Hg), residual H_2SO_4 acidity	**I**
Ammonia water / stripped NH_3 solution (also energy carrier)	Direct stripping without acid scrubber; feedstock for Selective Catalytic Reduction /DeNOx and increasingly for NH_3- based energy storage	Liquid (≈10–25 % NH_3)	EN 12126 (NH_3 for industrial use); REACH; DIN EN ISO 7103 for analysis	NH_3: 10–25 % (w/w); free of suspended solids; for energy use: trace impurity targets emerging	Amines, organic N volatiles, PFAS (volatile precursors)	**I**
Mineral concentrate ($NH_4^+/NO_3^-/K^+$)	EDR / RO of nitrified urine or reject water	Liquid concentrate	FPR 2019/1009 (pending CMC for membrane concentrates); national pilot derogations (NL, CH)	N: 3–8 % (w/w); K: 1–3 %; EC: 100–250 mS/cm	Pharmaceutical residues, hormones, PFAS, micropollutants	**P**
Calcium phosphate / hydroxyapatite	Fluidised-bed crystallisation; lime precipitation	Crystallin e solid / pellets	FPR 2019/1009 CMC 12; ISO 6878 (P analysis)	P_2O_5: 30–40 %; CaO: 45–55 %	Heavy metals (Cd, U from rock-P co-processing), PFAS	**P**
P-ash recyclates (sewage-sludge ash derivates)	Mono-incineration of dewatered sludge + thermo-chemical or wet-chemical processing	Solid (powder/ granules)	FPR 2019/1009 CMC 13 (Thermal oxidation materials and derivates); AbfKlärV (DE) §3a	P_2O_5: 15–35 %; plant-available P > 50 % (citric acid soluble)	Cr(VI), Cd, U, As; PFAS destroyed at > 900 °C; PAHs if process T inadequate	**P**

Platform chemical	Origin in water cycle	Aggregate state	Existing standards/ specifications	Typical purity/ concentration benchmark	Critical contaminants	Mat.
Biogenic CO_2	Off-gas from biogas upgrading (Pressure Swing Adsorption, membrane, amine, water scrubbing); 35–45 % of raw biogas mass	Gas (compressed) or liquefied	ISBT / EIGA food-grade CO_2; EN ISO 18936; growing carbon-credit traceability frameworks (International Sustainability and Carbon Certification, Renewable Energy Directive III)	CO_2 > 99.5 % (food grade) / > 99.9 % (liquid food grade); residual O_2 < 30 ppm; H_2S, NH_3, siloxanes < 1 ppm	Siloxanes, Volatile Organic Compounds (VOC)s, H_2S, NH_3 traces; PFAS not relevant	**I**
Biomethane (upgraded biogas)	Anaerobic Digestion of sewage sludge + upgrading	Gas (compressed)	EN 16723-1 (grid injection); EN 16723-2 (vehicle fuel); ISO 6976 (calorific value)	CH_4 > 96 %; CO_2 < 2.5 %; H_2S < 5 mg/ m^3; H_2O dew point < −10 °C	Siloxanes (D4, D5), VOCs, H_2S, NH_3 traces; PFAS not relevant	**I**

EN 12678 / 939 / 896 / 12518 are CEN drinking-water-treatment chemical standards; for non-DW applications, REACH and sector specific aspects apply:

Table B.2 — pH regulators (acids, bases)

Substance	Conventional source	Circular recovery route	Standard / specification	Purity / concentration benchmark	Critical contaminants	Mat.
Sulfuric acid (H_2SO_4)	Sulfur burning / Claus process	Biological H_2S oxidation in biogas desulfurisation followed by SO_2/SO_3 conversion; pickling-bath spent acid regeneration	EN 12678 (H_2SO_4 for drinking-water treatment); EN 889 ($FeSO_4$, if downstream); REACH	H_2SO_4: 78–96 % (w/w); Fe < 50 ppm; As < 1 ppm	Heavy metals from feedstock, organics, residual S species	**P**
Hydrochloric acid (HCl)	Chlor-alkali by- product	Recovery from ion-exchange regeneration brines; pickling-line spent HCl regeneration (spray roasting)	EN 939 (HCl for drinking-water treatment); REACH	HCl: 28–35 % (w/w); Fe < 30 ppm; free Cl_2 < 5 ppm	Heavy metals (Fe, Zn, Cu), residual organics	**P**
Sodium hydroxide (NaOH)	Chlor-alkali electrolysis	Membrane electrolysis of saline RO/EDR concentrates; spent caustic streams from refineries	EN 896 (NaOH for drinking-water treatment); REACH	NaOH: 30–50 % (w/w); Hg < 0.1 ppm; Na_2CO_3 < 0.5 %	Mercury (legacy mercury-cell carry- over), heavy metals	**P**

Calcium hydroxide / lime ($Ca(OH)_2$)	Limestone calcination	Recovery from water- softening sludge (calcite pellets reactivation); white- water clarification residues	EN 12518 ($Ca(OH)_2$ for drinking-water treatment); EN 459 (building lime); REACH	$Ca(OH)_2$ > 90 %; CO_2 uptake (carbonation) < 5 %	Mg, Al, Si carry-over; trace heavy metals from feedwater	**I**

Bio-based flocculants face a regulatory gap: no harmonised EN standard for water-treatment use of chitosan, tannins or modified starches, though individual approvals exist (e.g., chitosan in some Member States for DW treatment):

Table B.3 — Coagulants and flocculants

Substance	Conventional source	Circular recovery route	Standard / specification	Purity / concentration benchmark	Critical contaminants	Mat.
Ferric chloride / ferric sulfate ($FeCl_3$, $Fe_2(SO_4)_3$)	Steel-mill spent pickling liquor; primary Fe ore	Recovery from acid mine drainage (AMD) / coal-mine effluents; spent pickling- bath regeneration; municipal water-treatment sludge	EN 888 ($Fe_2(SO_4)_3$), EN 889 ($FeSO_4$), EN935 ($FeCl_3$) — all for drinking-water treatment; REACH	Fe: 12–14 % (liquid $FeCl_3$); Mn< 1 %; As, Pb, Hg, Cd at EN limits	Heavy metals (Mn, Zn, Cu, Cr), organics, sulfate excess	**I**
Polyaluminium chloride (PAC) / aluminium sulfate	Bauxite-based primary Al	Acid extraction of waterworks sludge (KEMICOND, ELAN, ReAl, Aquaviva); Al recovery from anodising baths	EN 881 (PACl), EN 883 ($Al_2(SO_4)_3$), EN 882 (PASS) — for drinking-water treatment; REACH	Al_2O_3: 9–18 % (PAC liquid); basicity 35–85 %; Fe < 0.3 %	Heavy metals (Fe, Mn), Si carry-over, residual organic flocculants	**P**
Bio-based Flocculants (chitosan, tannin-, starch-based) Vivianite	Synthetic polyacrylamide (PAM) from acrylonitrile	Chitosan from crustacean shell waste (food industry side-stream); tannins from bark and leather industry; modified starch	REACH; food-contact (EU) 10/2011 (for chitosan); no harmonised EN standard for these specific applications	Chitosan: deacetylation degree > 75 %; MW 50–300 kDa	Acrylamide residues only relevant in PAM substitution claims; pathogens in raw biological feedstocks	**P**
($Fe_3(PO_4)_2 \cdot 8 H_2O$)- dual use as Fe-coagulant precursor	Synthetic Fe-P products	Magnetic separation from Fe-dosed sludge (see Track A); on-site reuse as combined Fe-source for coagulation and P-recycling	No specific standard; covered by REACH for Fe-P substances	Fe: 28–30 %; P_2O_5:30–32 %	Organic carry-over, PFAS partitioning under study	**R**

Ozone and on-site H_2O_2 are inherently distributed: their circularity is determined by upstream energy and feedstock-O_2 sourcing, not by product-take-back:

Table B.4 — Oxidants and reductants

Substance	Conventional source	Circular recovery route	Standard / specification	Purity / concentration benchmark	Critical contaminants	Mat.
Ozone (O_3)	On-site corona-discharge generation from O_2 + electricity	Inherently on-site; circularity depends on renewable electricity and on O_2 from electrolysis side- stream (closes the H_2 loop in Track A)	EN 1278 (ozone for drinking-water treatment); REACH	O_3 dose 1–10 mg/ L typical; off-gas < 0.1 ppm	NOx co-formation; no PFAS destruction at typical doses (requires advanced oxidation)	**I**
Hydrogen peroxide (H_2O_2)	Anthraquinone autoxidation process (high energy, palladium-catalysed)	On-site electrochemical generation from O_2 + water; recovery from semiconductor industry rinses (pre-commercial)	EN 902 (H_2O_2 for drinking-water treatment); REACH	H_2O_2: 35–50 % (w/w); stabilisers (phosphates, stannates) < 1 %	Stabiliser residues, heavy metals (catalyst carry-over)	**P**
Ferrous sulfate ($FeSO_4 \cdot 7H_2O$) as reductant for Cr(VI)	Primary smelting by-product	Recovery from steel-mill pickling baths; co-product of $FeCl_3$ recovery in B.2	EN 889 ($FeSO_4$ for water treatment); REACH	Fe(II): 19–20 %; Fe(III) < 0.5 %	Heavy metals (Mn, Zn, Cu), free acid	**I**
Sodium bisulfite / metabisulfite ($Na_2S_2O_5$) for dechlorination	Sulfur-burning route via SO_2	Recovery from flue-gas desulfurisation gypsum-alternative routes; spent acid regeneration	EN 12120 ($Na_2S_2O_5$ for water treatment); REACH	$Na_2S_2O_5$ > 96 %; SO_2 active content > 64 %	Heavy metals, residual acidity	**R**

Reactivated GAC has the most mature standard framework (EN 12915-2), but is consistently underused across Europe; PFAS-loaded GAC requires destruction-grade reactivation conditions, which not all commercial reactivation services currently guarantee:

Table B.5 — Adsorbents

Substance	Conventional source	Circular recovery route	Standard / specification	Purity / concentration benchmark	Critical contaminants	Mat.
Reactivated granular activated carbon (rGAC)	Virgin coconut-shell or coal-based GAC	Thermal reactivation of spent GAC at 800-1000 °C; PFAS-loaded GAC requires destruction-grade reactivation > 1000 °C	EN 12915-1 (virgin GAC), EN 12915-2 (reactivated GAC); NSF/ANSI 61; REACH	Iodine number > 800 mg/g; BET surface > 800 m^2/ g; ash < 8 %	PFAS retention if reactivation T inadequate; loss-on- reactivation 5–15 %	**I**

Biochar-based adsorbents	Activated carbon from fossil precursors	Activation of biochar from sludge pyrolysis (Track A link); biomass-derived activated carbons	EN 12915 series partially applicable; EBC for biochar; ASTM D5158	BET surface 200– 800 m^2/g; ash content variable (sludge-derived 20–40 %)	Heavy metals from feedstock, PAH residues if pyrolysis T inadequate	**P**
Regenerated ion-exchange resins	Polystyrene-divinylbenzene base, virgin	Regeneration with recovered acid/base (links to B.1); life-extension via off-site reconditioning	EN 12902 (5ilter media); resin-specific manufacturer specs; REACH	Exchange capacity > 90 % of virgin; cross-linked structure intact	Organic fouling, leached monomers (styrene, DVB), trace metals	**I**
Lignin-, biopolymer- and zeolite-based novel adsorbents	Virgin synthetic adsorbents	Lignin from kraft black liquor; chitosan-based composites; zeolites from coal-fly ash; framework materials from agro- industrial residues	No harmonised EN standard; REACH; application-specific specs	Application-dependent; selectivity for specific micropollutants prioritised over surface area	Feedstock contaminants, residual processing chemicals	**R**

Biocides are the function group with the weakest current circularity profile: on-site generation dominates, and precursor sourcing is rarely circular. Performic acid via biogenic formic acid (linked to CO_2 recovery) is a longer-term research pathway:

Table B.6 — Biocides and disinfectants

Substance	Conventional source	Circular recovery route	Standard / specification	Purity / concentration benchmark	Critical contaminants	Mat.
Chlorine dioxide (ClO_2)	On-site generation from $NaClO_2$ + acid; or Cl_2 + $NaClO_2$	Inherently on-site; precursor $NaClO_2$ has no established circular source; circular linkage limited	EN 12671 (ClO_2 for drinking-water treatment); REACH	ClO_2 0.5–2 mg/L typical dose; residual ClO_2^- < 0.2 mg/L	Chlorite (ClO_2^-) and chlorate (ClO_3^-) by-products	**I**
Peracetic acid (PAA)	Acetic acid + H_2O_2 equilibrium synthesis	Biogenic acetic acid from VFA fermentation (links to Track A) + electrochemical H_2O_2 (links to B.3)	EN 12931 (PAA for emergency drinking- water treatment); REACH	PAA: 5–15 %; H_2O_2: 10–25 %; acetic acid: 10–40 %	Acetic acid residue (taste/odour), H_2O_2 stabiliser residues	**R**
Performic acid (PFA)	Formic acid + H_2O_2 on-site	Formic acid from CO_2 hydrogenation (links to CO_2 recovery in Track A); biogenic formic acid routes pre-commercial	No EN standard yet; regulatory pathway via biocidal products regulation (EU 528/2012)	PFA: 0.1–1.5 %; rapid decomposition (half-life minutes)	Formic acid residue, H_2O_2 residue	**R**

Antiscalants are the function group with the strongest substitution dividend: bio-based polyaspartates and polyepoxysuccinic acids are inherently PFAS- and phosphonate-free, which positions them ahead of regulatory tightening in both directions:

Table B.7 — Antiscalants

Substance	Conventional source	Circular recovery route	Standard / specification	Purity / concentration benchmark	Critical contaminants	Mat.
Polyaspartate (PASP)	Synthetic phosphonates (HEDP, ATMP, PBTC) from PCl_3 route	Microbial fermentation from biogenic amino acid feedstocks; thermal polymerisation of L-aspartic acid	No specific EN standard; manufacturer specs; OECD 301 biodegradability tests; REACH	Active polymer 35–40 %; biodegradability > 60 % (OECD 301)	Residual monomers; inherently PFAS-free (substitution advantage)	P
Polyepoxysuccinic acid (PESA)	Synthetic non-P antiscalants	Bio-based maleic anhydride route; closed-loop solvent recovery in synthesis	Manufacturer specs; REACH; OECD 301F	Active polymer 40 %; calcium tolerance > 1000 ppm $CaCO_3$	Residual maleate, heavy metals trace; inherently PFAS-free	P
Carboxymethyl inulin (CMI) and tannin-based antiscalants	Conventional phosphonates / phosphino-carboxylic acids	Inulin from chicory/ Jerusalem artichoke side- streams; tannins from tanning and forestry residues	Manufacturer specs; REACH; food-grade precursor regulations partially applicable	Active content 30–50 %; biodegradability > 80 %	Pesticide residues from agricultural feedstock, allergen carry-over	R

This group offers direct substitution for hydrazine — one of the most safety- and disposal-critical conventional chemicals in industrial water treatment:

Table B.8 — Oxygen scavengers and conditioners

Substance	Conventional source	Circular recovery route	Standard / specification	Purity / concentration benchmark	Critical contaminants	Mat.
Erythorbic / ascorbic acid (oxygen scavenger)	Synthetic hydrazine, sulfite, carbohydrazide	Fermentation from glucose (D-erythorbic via Penicillium); food-industry side-streams	Manufacturer specs; REACH; food-grade precursor regulations (E315)	Activity > 99 %; pH 2–3 (1 % solution)	Inherently PFAS- and hydrazine-free; oxidation residues	**P**
Tannin-based oxygen scavengers and corrosion inhibitors	Hydrazine; benzotriazole; phosphonates	Tannins from bark, leather industry residues, agro-forestry side-streams	Manufacturer specs; REACH; biocidal products regulation if used as such	Active polyphenol content > 60 %; tannin number > 600	Allergen carry-over, pesticide residues from feedstock	**P**
Bio-based sludge conditioners (chitosan, modified starch)	Cationic polyacrylamide (cPAM)	Chitosan from crustacean shell waste (links to B.2); cationic starch from food- industry residues	REACH; manufacturer specs; no harmonised EN for conditioner use	Charge density 1– 4 meq/g; MW 100–500 kDa (chitosan)	Acrylamide-free by design (substitution advantage); pathogens in raw feedstock	**P**

This is the function group where Track A and Track B merge directly: every entry has its primary circular source in a Track A recovery product. The CWA should treat this group as the methodological anchor for transfer protocols between recovery loops:

Table B.9 — Biology nutrients (bridge group to Track A)

Substance	Conventional source	Circular recovery route	Standard / specification	Purity / concentration benchmark	Critical contaminants	Mat.
Phosphorus dosing for industrial WWTPs	Phosphoric acid (food-grade or technical) from primary rock phosphate	Struvite or calcium phosphate from Track A; on- site or inter-facility transfer	FPR 2019/1009 CMC 12; ISO 6878; site-specific permits for waste-stream transfer	P content matched to BOD:N:P stoichiometry (100:5:1 nominal)	Heavy metals (Cd, U from rock-P legacy), PFAS partitioning	**P**
Nitrogen dosing for industrial / methanogenic biology	Urea or ammonia from Haber-Bosch	Stripped NH_3 solution or ammonium sulfate from Track A; direct re-injection within same plant or inter- facility transfer	EN 12126; REACH; site-specific permits	N content matched to stoichiometry; chloride < 100 mg/L for sensitive biologies	PFAS volatile precursors, amines	**I**
External carbon source for denitrification	Methanol (natural-gas-derived)	VFAs from acidogenic fermentation (Track A link); ethanol from food-industry side-streams; glycerol from biodiesel co-product	No specific standard for denitrification use; REACH for substances	Soluble COD content; absence of inhibitory compounds; C/N ≥ 4	Heavy metals, residual fermentation products, pathogens	**P**
Trace elements for anaerobic digestion (Co, Ni, Fe, Se, Mo)	Mineral salts from primary mining	Co-recovery from spent catalysts and industrial process waters (links to Track A CRM rows); siderophore-mediated recovery (research)	No harmonised EN standard for AD- grade trace elements; manufacturer specs	Bioavailable fraction (chelated forms preferred); dose 0.1–1 mg/L per element	Trace metal interferences, organic matrix	**R**

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