From: DIGIT-CIRCABC@nomail.ec.europa.eu
To: Undisclosed recipients:
Subject: JRC Report on technical proposals for by-products - Version 2
Date: vendredi 27 novembre 2020 17:25:57
Attachments: Pièce jointe sans titre 00129.png

CIRCABC

You received a new message

As member of the interest group JRC by-product fertilisers (Category: Joint Research Centre), you received the following message.

Message

From the user Dries HUYGENS

Dear all,

The second version of the JRC draft report “**Technical proposals for by-products as component materials for EU Fertilising Products**” is now available on CIRCABC. The report updates version 1, and provides an assessment of candidate materials for CMC 11 – within the meaning of Directive 2008/98/EC. In addition, the JRC presentation given at the Commission Expert Group Meeting on 24 November 2020 is uploaded to CIRCABC.

The report includes a **questionnaire aimed at complementing the information database** on candidate materials for CMC 11. All aspects of the questionnaire, including question content and instructions for respondents, are outlined in section 10 of the report. Stakeholder input in response to the consultation is essential for the development of criteria proposals. The **members and observers of the**

Commission Expert Group on Fertilising Products are kindly invited to provide input by the **deadline of 25 January 2021**.

We are looking forward to receiving your feedback and support to progress with the development of the proposals on quality and safety criteria for CMC 11. For any further questions, please contact the JRC at JRC-B5-Fertilisers@ec.europa.eu

Kind regards,

Hans Saveyn & Dries Huygens

European Commission - Joint Research Centre

Circular Economy and Industrial Leadership Unit

Directorate B - Growth and Innovation

Edificio EXPO, Calle Inca Garcilaso 3

E-41092 Sevilla

Spain

Tel +34 954 488 349

http://ipts.jrc.ec.europa.eu

To access the CIRCABC Interest Group ‘JRC by-product fertilisers’, please click here, or go to CIRCABC -> Browse all groups -> European Commission -> Joint Research Centre -> JRC by-product fertilisers. For those organisations not yet listed as members of this Interest Group, please click on “Join the Group”, and indicate the name of your organisation in the submission form. Your application will be approved manually by the JRC in due course. Members' and observers' organisations of the Commission expert group on fertilising products will be given access to upload and manage their documents in the library.

Attachments:
By-products_JRC_draft_report_v2.pdf:

FWG_Presentation_November_2020.pdf:

Best regards,
The CIRCABC team
https://circabc.europa.eu

Change your notification settings

EUROPEAN COMMISSION
JOINT RESEARCH CENTRE

Directorate B - Growth and Innovation (Seville)
Circular Economy and Industrial Leadership

Technical proposals for by-products as component materials for EU Fertilising Products

Background document

Date:	27 November 2020
Version:	2
Authors:	Dries HUYGENS, Hans SAVEYN
Public:	Commission expert group for Fertilising Products consisting of Member State authorities, EU industry associations and environmental NGOs
Reference Number:	n/a

Table of Contents

Document History

Version	Date	Comment
1	24/04/2020	Background document on project framework directions
2	27/11/2020	Background document, updated with selection of candidate materials

1 PROJECT OBJECTIVE

Article 42(7) of the Fertilising Products regulation (EC) 2019/1009 (FPR) indicates that "the Commission shall adopt delegated acts [...] of component material category 11 in Part II of Annex II to this Regulation by laying down criteria on agronomic efficiency and safety for the use of **by-products within the meaning of Directive 2008/98/EC** in EU fertilising products. Such criteria shall reflect present product manufacturing practices, technological developments and the latest scientific evidence."

DG GROW has requested DG JRC to **formulate proposals that could serve as a technical basis for the implementation of Article 42(7)**, thus on agronomic efficiency and safety for by-products within the meaning of Directive 2008/98/EC as a Component Material Category (CMC 11 – Annex II).

Although the use of substances and chemicals in manufacturing and products is cautiously regulated within the EU, production process by-products to be used in sensible applications like the food chain may require additional controls compared to intentionally manufactured products. By-products may also be affected by incidental contamination throughout their lifecycle, and firms may not have access to information on the composition of goods other than the primary product. The general objective of this project is the task of **analysing, developing and proposing criteria** in line with the objective of enabling the use of **by-products as value-added components** for the EU agricultural sector, at the interface between chemicals, products and waste legislation.

2 AIM OF REPORT VERSION 2, DATED 27 NOVEMBER 2020

At two different occasions (March 2019; April 2020), DG GROW and DG JRC have invited the COM Expert Group on Fertilising Products to provide input for CMC 11 candidate materials. The current document (version 2) includes a first assessment for the materials proposed by the COM Expert Group (cfr. the newly added sections 6 and 7 in this version 2). In addition, some materials have been added to the proposals based on a screening of techno-scientific literature by JRC.

The criteria development approach of the JRC departs from a **basic technical understanding** of the production process and industries that produce candidate CMC 11 materials, as well as the composition in terms of main elements and potential contaminants. Such information facilitates the development of technical criteria proposals in terms of safety, agronomic value and "usability" for the private sector operators.

For each of the individual candidate materials, the JRC has progressed based on the information submitted by the stakeholders and publically available techno-scientific literature. Fertilising component materials that are "technical additives" (e.g. binding agents, fillers) will afterwards be considered once the analysis for materials that have "agronomic value" has been finished. The assessment involved an analysis of the **agronomic value** (e.g. as a fertiliser, soil improver, liming material, plant biostimulant) of the material, and the possible **impurities** that may be present in the material. **A list of materials for further assessment has now been developed ("priority materials")**, based on the criteria for the selection of candidate materials (i.e. alignment to the scope, current legal situation under Regulation (EC) No 2003/2003 and national rules in EU Member States, market potential and future outlook, data availability, straightforwardness for criteria settings; see section 5.3.2). In order to structure the report, the materials have been divided into different (sub-)groups (see section 7). Altogether, these materials represent a dominant share of the by-products that are used directly, without processing, as component materials for fertilising products. The materials are listed in sections 6 and 7.

JRC will progress with the analysis and possible criteria setting for these selected **“priority materials”, based on a positive list approach**. The Commission has to develop and adopt criteria for by-products by July 2022. Therefore, a necessity arises to develop draft criteria for these materials, taking into consideration possible challenges that may arise during the next project steps to criteria adoption. This might ensure continuity for many fertilising product components that are currently covered under Regulation (EC) No 2003/2003. The next project phase will therefore focus on development of criteria for the priority materials as proposed in section 7.

For the selected priority materials, JRC requests **data and information on the impurities and contaminants** that might potentially be present in these materials. JRC has already identified the nature of some impurities/contaminants, but this list needs to be complemented and information on their concentration in candidate materials needs to be added. Hence, a targeted questionnaire has been developed for stakeholders departing from a screening of techno-scientific knowledge from literature and other data sources. The questionnaire provides possibilities to flag and make available information on identified and currently non-identified impurities and contaminants (see section 10).

The **requested information is critical for the development of criteria proposals**. Without a clear understanding of the contaminant profiles of candidate materials, and the associated risks, it is impossible to develop adequate criteria for their safe release to the market. Proper information will enable a comparison between the levels of impurities typically observed in the candidate materials and the levels that may induce concerns and risks for human health and the environment. Note that the listing of a particular substance as an impurity does not necessarily imply that such a substance is of concern. After all, by-products, as well as products, often contain impurities, but as long as the concentration levels are below specific levels (e.g. associated to environmental risks or to accumulation in soils to undesired levels), no risks from their placing on the market would occur.

The JRC aims to develop proposals for simple and low-cost compliance schemes for CMC 11. It is re-iterated that the **precautionary principle applies, involving that data gaps need to be filled prior to enabling (minimal) compliance schemes** (associated to low costs and burdens for producers). Therefore, JRC welcomes at this stage all relevant information that can contribute to a full assessment of risks and stakeholder concerns. A lack of data on contaminants at this evaluation stage might involve that certain risks arising from the placing of the market of by-products cannot be dismissed, and may therefore lead to increases in the complexity and costs of the proposed compliance schemes, or even lead to the decision not to further consider certain materials. Moreover, it is emphasised that confidence in the materials by all stakeholders involved is requisite for a well-functioning internal by-product market.

3 SCOPE

The scope of this project is determined by the interplay between Waste Framework Directive (WFD, 2008/98/EC) and FPR (Figure 1). Actually, **by-products used as a component material (CMC 11) in EU fertilising products also have to comply with the national legislations setting criteria on the application of the conditions laid down in Article 5(1) of Directive 2008/98/CE**. The FPR will, however, enable free movement on the internal market for products containing CMC 11 by-products. Article 5(1) of this Directive sets cumulative conditions under which a substance resulting from a production process, other than the primary product, is to be considered a by-product and not a waste.

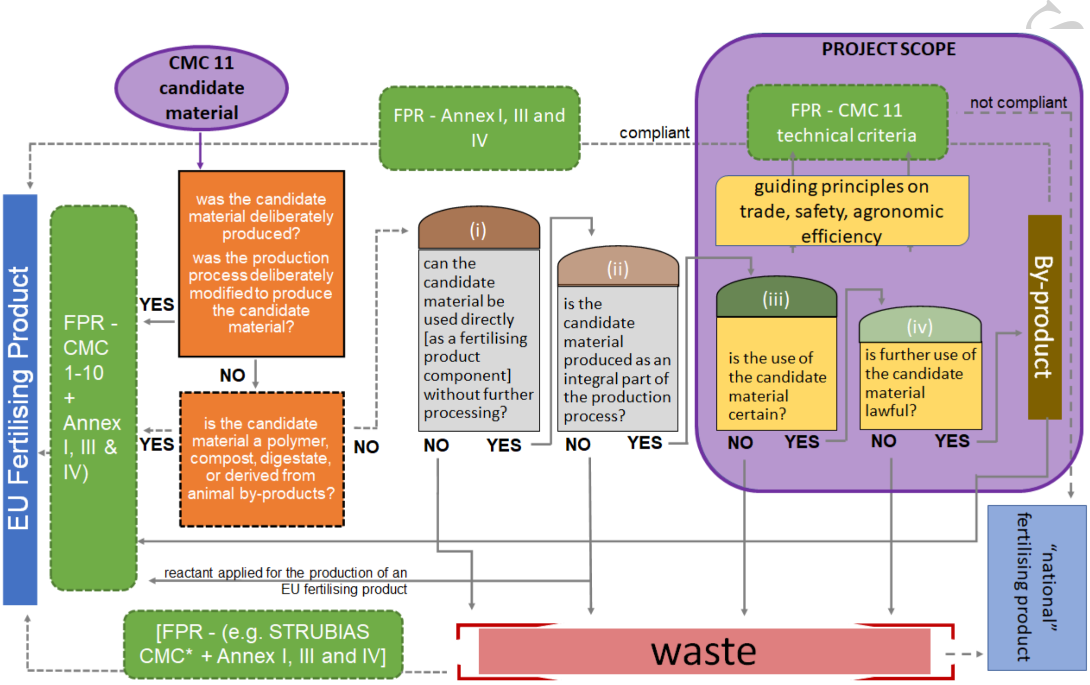

Figure 1: Schematic overview of the scope of this project (purple rectangle on the top of the right hand side) as well as possible routes for CMC 11 candidate materials (purple circle on the top of the hand left side) to become a fertilising product, either through the Fertilising Products Regulation (FPR) (blue rectangle on the left hand side) or through national provisions (blue rectangle on the bottom of the right hand side). The full arrows indicate a reclassification dependent on the rules of the Waste Framework Directive (2008/98/EC), the dotted arrows indicate a possible reclassification dependent on criteria of the FPR, dashed lines indicate a possible reclassification dependent on national rules (*Note: According to Art. 19 of the FPR, this Regulation lays down criteria in accordance with which material that constitutes waste, as defined in Directive 2008/98/EC, can cease to be waste, if it is contained in a compliant EU fertilising product; STRUBIAS CMCs could be an example hereof).

It is important to take into consideration that compliance with harmonised rules of the FPR is optional. The FPR does not prevent by-products **from being made available on the market as non-harmonised fertilisers** in accordance with national law and the general free movement rules of the Treaty on the Functioning of the European Union (TFEU) (Figure 1, “optional harmonisation principle”).

3.1 Product versus production residue

In first instance, a candidate CMC 11 material should classify as a **production residue** (Figure 1). The WFD guidance document[1,2] defines them as something other than the end product that the manufacturing process directly seeks to produce[3]. In many production processes, it is possibly to identify one or more "primary" products, this or these being principal materials(s) produced. Where the production of the material concerned is 'the result of a technical choice', it cannot be a production residue and is considered a product[4]. If the manufacturer could have produced the primary product without producing a material concerned but chose not to do so, this can be evidence that the material concerned is a product and not a production residue. Also, a modification of the production process in order to give the material concerned specific technical characteristics could indicate that the production of the material concerned was a technical choice. Primary products could fall under the scope of other CMCs, notably CMC 1 (virgin material substances and mixtures), CMC 2 (plants, plant parts or plant extracts), CMC 7 (micro-organisms), CMC 8 (nutrient polymers) and CMC 9 (polymers other than nutrient polymers).

Box 1. Indicative examples of possible classification: ammonium sulphate as a by-product from coke gas versus synthesis of ammonium sulphate

Ammonium sulphate is, amongst other routes, produced as a by-product during the removal of ammonia (NH_3) from the raw coke oven gas generated during the coking of the metallurgical coal. This process consists of absorption of ammonia in the coke oven gas in a solution of ammonium sulphate and sulphuric acid. The absorption reaction is $2NH_3 + H_2SO_4 = (NH_4)_2SO_4$. The ammonium sulphate produced by the reaction of NH_3 with H_2SO_4 is recovered by crystallization. The crystals are then centrifuged, washed and dried.

A second production route for ammonium sulphate involves the intentional synthesis by reacting Haber-Bosch derived anhydrous ammonia and sulphuric acid in a reactor of a fertiliser production plant.

In the first case, the end product that the manufacturing process directly seeks to produce is coke, and the production process has not been modified with the intention of producing the ammonium sulphate. The produced ammonium sulphate could here be considered as a production residue, thus possibly be included under CMC 11 of the FPR. This stands in contrast with the second process in the fertiliser plant, where the ammonium sulphate is deliberately created in a production process to be sold on the internal market as a product. The latter material will be assessed against the criteria of CMC 1 in the FPR. Note that the contaminant profile between both types of ammonium sulphate

---

[1] Available at: https://ec.europa.eu/environment/waste/framework/pdf/guidance_doc.pdf

[2] The guidance document refers to a number of Court of Justice of the European Union (CJEU) rulings related to previous Directives on waste 75/442/EEC or 2006/12/EC, respectively, where the impact of the rulings cited may still be applicable. The content of the guidance, including examples, reflects the views of Directorate-General Environment of the European Commission and as such is not legally binding. The binding interpretation of EU legislation is the exclusive competence of the CJEU. The views expressed in this guidance document cannot prejudge the position that the Commission might take before the CJEU.

[3] Case C-9/00 Palin Granit Oy (2002), para 32.

[4] Case C-235/02 Saetti (2004), para 45.

(i.e. CMC 1 and CMC 11 candidate materials) may differ because ammonium sulphate produced as a by-product during the recovery of ammonia from coke oven gas may contain greater concentrations of organic and inorganic impurities (e.g. HCN).

According to Article 5(1) of Directive 2008/98/EC, a production residue may be regarded as being a by-product only if the following conditions are met (Figure 1 & sections 3.3 - 3.5):

(i) the substance or object can be **used directly** without any further processing other than normal industrial practice;
(ii) the substance or object is produced as an **integral part of a production process**;
(iii) further **use** of the substance or object **is certain**; and
(iv) further **use is lawful**, i.e. the substance or object fulfils all relevant product, environmental and health protection requirements for the specific use and will not lead to overall adverse environmental or human health impacts.

The Guidance on the interpretation of key provisions of Directive 2008/98/EC on waste further specifies the interpretation of the concept of by-product as well as on the terminology applied in the definition.

3.2 Fertilising Product Regulation framework

Component materials for EU fertilising products are divided into different categories in the FPR. Differentiating requirements for each of the CMCs apply because different component materials warrant different process requirements and control mechanisms adapted to their different potential hazardousness and variability, in turn dependent on the quality of the input materials applied, production process conditions, etc. This principle is exemplified in Box 1, where different criteria could apply to ammonium sulphate derived as a product or as a by-product.

Point 1 of CMC 11 of Annex II of the FPR indicates that an EU fertilising product may contain by-products within the meaning of Directive 2008/98/EC, except:

(a) animal by-products or derived products within the meaning of Regulation (EC) No 1069/2009,

(b) polymers,

(c) compost, or

(d) digestate.

Hence, the current provisions of the CMC 11 of the FPR indicates that materials derived from **animal by-products (as defined in Regulation (EC) No 1069/2009), polymers, compost and digestates are excluded** from the scope because they have to meet the requirements in the designated CMCs (CMC 3-5, 8 -10) (Figure 1). In this respect, a clear definition of how polymers have to be interpreted may be required as differences in properties (e.g. biodegradability and risk profiles) may occur between plant-derived polymers (e.g. starch and other biodegradable proteins like those obtained after seaweed extraction) and petroleum-derived synthetic polymers.

The provisions of Component Material Category 6 (Food industry by-products) indicate that an EU fertilising product may contain component material consisting of one of the following substances:

(a) food industry factory lime, i.e. a material from the food processing industry obtained by carbonation of organic matter, using exclusively burnt lime from natural sources;

(b) molasses, i.e. a viscous by-product of the refining of sugarcane or sugar beets into sugar;

(c) vinasse, i.e. a viscous by-product of the fermentation process of molasses into ethanol, ascorbic acid or other products;

(d) distillers grains, i.e. by-products resulting from the production of alcoholic beverages;

(e) plants, plant parts or plant extracts having undergone only heat treatment or heat treatment in addition to processing methods referred to in CMC 2; or

(f) lime from drinking water production, i.e. residue which is released by production of drinking water from groundwater or surface water and consists, mainly, of calcium carbonate.

The sole requirement associated to these materials is that they are registered pursuant to Regulation (EC) No 1907/2006 (concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals - REACH), covering the use as a fertilising product. Hence, only specific materials with a **low risk profile that received a large and undisputed support** from the Commission expert group for Fertilising Products and the co-legislators have been included in this CMC 6 The scope of CMC 11 on by-products will complement these materials, and **also other food industry by-products,** possibly associated to supplementary environmental and health safeguard criteria, **could be covered under CMC 11**.

It is also clarified that some fertilising product components could possibly be covered in different CMCs. In such case, a manufacturer that places a fertilising product on the market will have to ensure that all its components are **compliant with the provisions of at least one selected CMC**. This should, however, not lead to the re-opening of discussions that were finalised during the evaluation of materials (also) covered under other CMCs (e.g. “STRUBIAS” CMCs).

3.3 Materials to be used directly [as a fertilising product component] without further processing

The scope of this CMC is limited to materials to be used directly as a fertilising product component without further processing other than ´normal industrial processing´, due to the following provisions from the WFD and the FPR (Figure 1, Box 2):

- According to Article 5(1)(b) of **Directive 2008/98/EC**, a production residue may be regarded as being a by-product only if, amongst other conditions, **the substance or object can be used directly without any further processing other than normal industrial practice** (Figure 1). Normal industrial practice can include all steps which a producer would take for a product, such as the material being screened, sized, agglomerated, pelletised, dried solely to remove free water, or adding materials necessary for further use through physical mixing without intentionally changing the chemical composition of the material contained in the mixture. Treatments usually considered as a recovery operation cannot, in principle, be considered as normal industrial practice in this sense. The title of this CMC “by-products within the meaning of Directive 2008/98/EC” implies that all materials should enable their direct use as a fertilising product component.
- According to the **FPR**, the provisions on product criteria for EU fertilising products contain requirements for the categories of end-products in accordance with their intended function (PFC), as well for the categories of component materials (CMCs). A fertiliser

manufacturer can place an EU fertilising product that is composed of one single ingredient, belonging to a specific CMC, on the market. A possible example is, for instance, ammonium sulphate as a by-product from coke production, compliant with all CMC 11 criteria. It is also possible to put an EU fertilising product on the market that is composed of several component materials from various CMCs, where each material complies with the requirements of a certain category. A condition is, however, that no intentional chemical reaction or transformation takes place between the different component materials that are contained in the EU fertiliser. Hence, an EU fertiliser producer may contain two or more substances or mixtures (provided that each of them complies with the description in one or more of the CMCs), **without any intentional chemical reaction taking place between the substances/mixtures**. The component materials are then ‘contained’ as such in the final EU fertilising product. This follows the presumption that if different component materials do not show unacceptable risks for human health and the environment, a physical mix of them constituting the final CE marked product will also be safe, subject to compliance with certain limit values defined in Annex I (i.e. PFC level) for the final product. An example of such route occurs when a fertiliser company mixes (e.g. combined in a 1:1 ratio in the same fertiliser bag) urea derived through the Haber-Bosh process (CMC 1) with ammonium sulphate as a by-product from caprolactam production (CMC 11).

Box 2. Indicative examples of possible classification: blast furnace slag versus calcium sulphite from flue-gas desulphurisation

Blast furnace slag is produced in parallel with hot iron in a blast furnace. Blast furnace slag can be used directly as a fertilising product at the end of the production process, without further processing that is not an integral part of this production process (such as crushing to get the appropriate particle size). This material can therefore be considered a by-product, and thus falls within the scope of this CMC 11 (subject to further assessment of safety and agronomic impacts).

Flue gas desulphurisation from facility A removes sulphur from the flue gases that are produced when sulphurous fossil fuels are burnt in power plants, in order to prevent these emissions contributing to air pollution and acid rain. The wet limestone flue-gas desulphurisation system generates a calcium sulphite sludge, which is processed via a recycling process inn a different economic entity to turn the (largely insoluble) calcium sulphite sludge into gypsum as a fertilising product component. Hence, the viscous sludge obtained cannot be used directly as a fertilising product component when not further processed using techniques (e.g. oxidation to induce further chemical reactions) that do not classify as “normal industrial processing”. Here, the calcium sulphite sludge is not considered a by-product for assessment under CMC 11, but a waste material.

3.4 Materials produced as an integral part of a production process

The wording of Article 5(1)(c) WFD requires that the substance or object ‘is produced’ as an integral part of a production process (Figure 1, Box 3 and Box 4). It can be taken from this that the process where the by-product is generated has to be an integral part of a production process. If a material leaves the site or factory where it is produced in order to undergo further processing, this may be evidence that such tasks are no longer part of the same production process, thus disqualifying it as a by-product. Specific manufacturing steps, that occur independent from the main product manufacturing line, and address typical waste-related characteristics of the production residue, such as its contamination with components which are hazardous or not useful, would prevent classification of the residue as a by-product. Materials obtained from the recycling facilities for waste materials fall beyond the scope of this project (Figure 1).

Box 3. Indicative examples of possible classification: gypsum from forced oxidation scrubbers versus gypsum recovered from calcium sulphite

Plant B has an integrated desulphurisation system that is based on forced oxidation techniques, pushing the chemical reaction towards producing gypsum (calcium sulphate dihydrate) that has the same properties as natural, mined gypsum (a product used in ameliorating high-sodium soils). The generation of gypsum from the residues from flue gas cleaning on the site of the power plant can be regarded as an integral part of a production process (energy generation), and the resulting flue gas desulphurisation gypsum as a by-product that falls under the scope of this project.

The viscous calcium sulphite sludge from wet limestone flue-gas desulphurisation system of plant A (see Box 2) is isolated and further subject to a recovery operation that has gypsum as a final product of the recovery process. The recovery operation is not considered an integral part of the (energy) production process. Therefore, the corresponding gypsum, derived from the calcium sulphite sludge of the desulphurisation system of plant A, cannot be considered as a by-product, and falls beyond the scope of this project.

In combination with the “direct use as a fertilising product component” requirement (section 3.3), it also becomes clear that by-products that are used as reactants to produce EU fertilising products fall beyond the scope of CMC 11 and thus this project.

Nonetheless, by-products could be used as reactants in production processes for other fertilising product component materials (e.g. CMC 1 production processes that use by-products as precursors, exemplified in Box 4)

Box 4. Indicative examples of possible classification: by-products as reactants for EU fertilising products

A fertiliser company would like to make continued **use of spent sulphuric acid (e.g. from the food industry) to produce single super phosphate** as an EU fertilising product under the FPR. The spent sulphuric acid meets all requirements to be classified as a by-product in line with Article 5(1) of Directive 2008/98/EC (i.e. not a waste material) and is thus used as *a reactant for the production of an EU fertilising products* (exemplified here to be single super phosphate as a CMC 1 material). In the production process at the fertiliser production plant, it is chemically reacted with rock phosphate to form single super phosphate.

The spent sulphuric acid is not “directly used as a fertilising product component”, so it cannot be considered as a CMC 11 material. On the other hand, whereas the single super phosphate can be directly used as a fertilising component, it is not a by-product, but a newly formed CMC 1 substance derived from reacting a by-product (spent sulphuric acid) with another substance (phosphate rock). For this reason, the single super phosphate should not be evaluated against the criteria for CMC 11, but itis eligible to be considered under CMC 1 when registered pursuant to the REACH Regulation for use as a fertilising product.

3.5 Materials with “certainty” of further “lawful” use

Article 5(1)(a) of the WFD requires that “further use of the substance or object is certain” in order to classify as a by-product (Figure 1). ‘Further use is certain’ means that it is not a mere possibility but a certainty; there should thus be solid evidence or an assurance that the material will be used. The purpose of this criterion is that if further use were not certain, there would be a risk of the material being disposed of as waste.

COM/2007/0059 (Communication from the Commission to the Council and the European Parliament on the Interpretative Communication on waste and by-products" COM/2007/0059 final) refers to the Avesta Polarit, Saetti and Spanish Manure cases as examples where use was regarded to be certain. Certainty of further use can, of course, be difficult to prove definitively in advance. However, following criteria may provide guidance elements for the assessment of 'certainty of further use' may, amongst others, be indicated through:

- Existence of contracts between the material producer and subsequent user;
- A financial gain for the material producer from the sales of the material;
- A solid market (sound supply and demand) existing for this further use;
- Evidence that the material fulfils the same specifications as other products on the market.

On the other hand, the following may be indications that future use is uncertain:

- There is no market for the material. Low sales volumes and/or long-term storage of the material may hint at this;
- Only part of the material is to be used, with the rest to be disposed of;
- The financial gain for the material holder does not arise from selling the by-product, but from avoiding substantial expenses due to treatment and disposal if the material were to be discarded as waste. Low sale prices, combined with free transport offered by the material holder, may hint at this.

These criteria are aligned to the need to limit CMC 11 materials to **materials of added value** for the extensive European agricultural sector. As a matter of fact, **Article 42(1)(a) of the FPR mentions the "potential to be the subject of significant trade on the internal market**" as one of the conditions for the adoption of delegated acts by the Commission.

Article 5(1)(d) WFD clarifies that the further use of the material **must be lawful**, i.e. the substance or object fulfils all relevant product, environmental and health protection requirements at EU and at Member States' level for the specific use (Figure 1). It ought to be demonstrated that it will not lead to overall adverse environmental or human health impacts, supplementary to those possibly associated to their primary raw materials equivalents. This is fully **aligned to the conditions of Article 42(1)(b) of the FPR** that mention the need for scientific evidence indicating that EU fertilising products:

(i) do not present a risk to human, animal or plant health, to safety or to the environment;
(ii) ensure agronomic efficiency; this aspect will here be considered in its broadest sense also including indirect agronomic impacts relating to technical functions of additives which improve the characteristics of the fertiliser product.

These conditions are particularly relevant for CMC 11 due to concerns that inappropriate or low-quality by-products will enter the market. It has been brought forward that some recycling companies, which are not fertilising products producers, may try to put low quality products (in terms of agronomic efficacy and contaminants levels) on the market to get rid of ineffective by-products as fertilising products.

3.6 Implications for project scope

Based on the information provided in sections 3.1 to 3.5, the scope of this project (Figure 1) is thus:

- limited to industrial or plant-derived **production residues** that can be **used directly** as fertilising product component without further processing other than normal industrial practice, and that are **produced as an integral part of a production process**, thus excluding any waste-based derived materials; and
- focussed on developing and proposing **safety and agronomic criteria** for CMC 11 materials. The focus will be on safety aspects not addressed in the REACH registration, relevant for by-products in particular.

In this respect, broadly accepted material criteria proposals will be developed to ensure similar specifications as for other CMCs within the FPR, clearly segregated from materials being perceived as waste within the different EU Member States.

For materials not fulfilling these principles, the FPR does not prevent by-products **from being made available on the market** as **non-harmonised fertilisers** in accordance with national law (Figure 1, “optional harmonisation principle”). Hence, compliance with harmonised rules is therefore optional. Finally, the FPR does not impact upon by-products being entered into the market for any other use than as a fertilising product.

4 LINK TO POLICY OBJECTIVES

4.1 By-products as an opportunity for the EU Circular Economy

Circular Economy initiatives and actions aim at contributing to "closing the loop" of product lifecycles and manufacturing processes through greater recycling and re-use to the benefit of both the environment and the economy. The aim is to **extract the maximum value** and use from all raw materials, products, by-products and waste, fostering resource efficiency and energy savings, and reducing greenhouse gas emissions.

The European Commission's 2015 **Circular Economy Action Plan** stressed the importance of developing a well-functioning single market for secondary raw materials, including those derived from by-products. One of the objectives is enabling recycling and improving the uptake of secondary raw materials by limiting unnecessary burdens and facilitating the cross-border circulation of secondary raw materials while ensuring their performance and safety in a toxic-free environment. The new 2020 Circular Economy Action Plan - one of the main blocks of the European Green Deal - explicitly refers to the need to create a well-functioning EU market for secondary raw materials, support cross-border initiatives for cooperation to harmonise by-products, and to restrict on the use of substances of very high concern in articles.

This is consistent with the priorities of the waste hierarchy that encourages re-use practices in an environmentally sound way while ensuring high standards of protection of the environment and health.

4.2 By-products as a risk to the EU Circular Economy

Friction at the interface between two policy objectives - circular economy and the protection of the environment and human health – may occur due to the **presence of certain substances that pose a risk to the environment and/or human health** in by-products. This holds particularly true for by-products as components for EU fertilising products since they are not the end product that a manufacturing process directly seeks to produce. Therefore, the control on the possible hazardous substances and other substances associated to a risk for the environment and health is intrinsically low. Moreover, the intended use of the primary product (e.g. intended use as a construction material) may possibly require less stringent controls and restrictions on contaminants than a by-product produced through the same production process but to **be used for more sensitive applications (in the food chain).** As our knowledge about the properties of many chemicals increases, more substantial concerns arise about the negative impacts that specific elements, chemicals and substances used in industrial processes may have on human health and the environment. Concerns for some substances such as lead and arsenic have been known or suspected for centuries, whereas for other substances, concerns are much more recent. Some substances, such as perfluorinated compounds, endocrine disrupting chemicals and rare earth metals, have only been coming under scrutiny in the last few years.

Hence, this study will assess the risk that by-products could pose to the environment and human health and propose correspondingly criteria to promote a toxic-free EU environment and circular economy.

5 PROPOSAL FOR A DIRECTIONAL FRAMEWORK

The JRC has developed a proposal for the directional framework of CMC 11. The JRC has listed and assessed the **main challenges and issues to consider** in this project, and proposed directional approaches to address those in view of the advantages and drawbacks of possible options.

5.1 Challenge A – Ensuring material safety

5.1.1 Overview

By-products to be used in the agri-food and environmental chain could contain contaminants that lead to environmental and health risks for food consumers. Whereas the boundary between by-products and waste is case-dependent and at times fuzzy, material holders might benefit from a financial gain when materials can be classified as a by-product due to the avoided cost of waste treatment. Therefore, a main challenge is to limit the CMC to **value-added materials that have been proven safe to the environment and to health when used as a fertilising product component**. Should the techno-scientific knowledge base be incomplete or divergence exists amongst techno-scientific opinions, **the precautionary principle** should apply.

5.1.2 Issue #1: listing approach

5.1.2.1 Background and options

When using a **positive list**, the proposals will explicitly ("positively") list materials, and possibly their production processes, that are eligible to be considered as a by-product under CMC 11. Additionally, exceptions or conditions (e.g. limits for contaminants) to these materials may apply. A **negative list** does not list materials, implying that all by-products are by default considered. In such case, the proposals only incur exceptions (e.g. materials from nuclear industries are not considered) or excluding conditions (e.g. contents of specific contaminants of concern exceeding a certain limit value).

5.1.2.2 Proposal

The proposal is to rely on a **positive list of selected materials for this CMC**. It shall, however, be intended to formulate the criteria in order to account for safe innovation (see section 5.4.2). The main advantage of a positive list approach is that it ensures **a higher level of protection** because the screening on contaminants is limited to a set of identified materials. The producer has to be aware of the composition and potential contaminants of the product to be able to control them according to the conformity assessment requirements of FPR. This may be particularly pertinent for this CMC, covering production residues from very different industries, with different sorts and levels of contaminants, under the single umbrella "by-products". Since the materials and associated risks are clearly identified when using a positive list, analysis schemes can be limited to the most relevant parameters and hence **compliance costs can be kept to a minimum** (see section 5.4.4). A negative list approach involves a substantial risk for overlooking recognised or non-identified contaminants in material streams due to a lack of available information on the different possible materials, attention gaps during screening, and/or lack of information on use history as a fertilising product component within the EU. Such option may therefore open a backdoor for the marketing of unsafe by-products as CE marked products when contained in EU fertilising products. In addition, the way to address risks in a negative list approach would be through extensive, and therefore expensive, material analysis schemes. Moreover, it remains uncertain if risk assessment data would be available to derive “safe limit values” for all identified contaminants. Altogether, it would be largely impossible to develop criteria to exclude all possible contaminant loads in a material on the one hand and to limit the cost of analysing the candidate by-product at an economically acceptable level in the compliance scheme on the other hand.

5.1.3 Issue #2: screening of contaminants for evaluation

5.1.3.1 Background

Screening helps to identify contaminants for which data need to be collected and assessed. A difficulty lies in identifying information sources for screening and possible risk management evaluation. A well-defined list of potential contaminants of concern will, however, ensure that appropriate information on contaminants can be collected for candidate materials.

Contaminants are substances that have not been intentionally added to the by-product as a fertilising production component. General safety criteria in the Fertilising Products Regulation will apply to all EU fertilising products, depending on their product function category. Hence, the assessment of any additional or complementary safety criteria shall result from the identification of specific risks linked directly to the fact that the component materials are by-products, as opposed to intentionally manufactured products from virgin substances. Specific substances, of concern upon entering into the environment, might have been introduced unintentionally to by-products due to the complexities of the primary product supply chain and manufacturing process.

Point 3 of CMC 11 of the FPR requires in parallel that by-products are registered according to the REACH Regulation ((EC) No 1907/2006) for the use as a fertilising product. In order to avoid overlaps, the risk management in this report shall mainly focus on issues not addressed in the REACH registration, relevant for by-products in particular. This is particularly relevant as companies manufacturing and importing the same substance can register jointly, based on the “sameness” principle. For REACH registration, technical grades, analytical grades or pure substances are the same as long as they consist of the same main constituent(s). Hence, a product and its by-product equivalent, with different impurity profiles resulting from the production process (see Box 1 for indicative example), may register jointly. This brings along a challenge as impurities/contaminants present at trace (ppm or lower) level in fertilising products could induce a significant risk for the food chain.

The assessment shall cover both short-term effects (e.g. metal accumulation in soil) and longer-term effects (e.g. changes in soil quality, contamination of the food chain) of contaminants. The screening of possible contaminants may require a broader screening than for intentionally manufactured products, taking into consideration that by-products may be derived e.g. from intermediate processing steps as well as from industrial process streams, air cleaning or other liquid or solid purification systems.

5.1.3.2 Proposal

It is proposed to collect information on possible contaminants and other substances of concern (e.g. micronutrients supplied at excess levels) from different sources. Depending on the sector of origin and type of production process, the contaminant list could then be refined and grouped for similar materials (see section 5.3.3).

In first instance, technical experts from the private sector, and national and EU bodies will be consulted to provide information and expert judgement on risks (source 1). A second source of information are relevant contaminants in food and environmental legislation and national quality standards (source 2). Thirdly, sector specific contaminants are reviewed through revising sources such as the Best Available Techniques (BAT) reference documents (BREFs) and the European Pollutant Release and Transfer Register (E-PRTR)[5], a potentially important tool for tracking industrial pollutants (source 3). Finally, contaminants and substances taken up in the Stockholm convention on persistent organic compounds (POPs) and with particular provisions due to environmental or health concern in the REACH regulation will be screened (source 4). The information derived from those different sources should provide an extensive checklist as a starting point, which can then be narrowed further down to the elements relevant for every type of material.

Source 1: Expert knowledge from experts in the field

Experts' knowledge from experts from the Commission expert group for Fertilising Products (consisting of Member State authorities, EU industry associations and environmental NGOs), and other Commission departments will be sought to provide supplementary information on materials that have been identified as candidate by-products (see section 10). Any expert information can be communicated to the JRC through oral and/or written feedback consultation rounds (see section 9).

Source 2: contaminants from food and environmental legislation and national quality standards

Material criteria may also build upon Member States' implementation of the requirements for safe use, and any specific safety criteria adopted by Member States under Directive 2008/98/EC Furthermore, to identify possible contaminants of concern, a screening is proposed for substances regulated under specific sectorial/product legislation on food safety, water quality, air quality, and other national and EU environmental quality standards, including those for soils. A focus on water and air pollutants may also be relevant as some by-products may be produced from processing steps that aim to avoid pollutant emissions. Note that not necessarily all the contaminants taken up in these references may be relevant for all materials in this project. For instance, food contaminants that may be introduced through food contact with packaging may not be a relevant contamination route for many materials, whereas other food contaminants can be toxic for humans, but not for plants (e.g. nitrate).

Maximum levels for certain **contaminants in food** are set in Commission Regulation (EC) No 1881/2006. The food contaminant catalogue includes other substances (https://ec.europa.eu/food/safety/chemical_safety/contaminants/catalogue_en). Relevant substances are, for instance, metals, dioxins, polychlorinated biphenyls (PCBs) and polycyclic aromatic hydrocarbons (PAH).

Directive 2008/105/EC of the European Parliament and the Council on Environmental Quality Standards in the field of water policy (EQSD) established limits on concentrations of the **priority substances in surface waters** of 33 priority substances and 8 other pollutants (in its Annex I). The list includes selected existing chemicals and solvents (finding various applications in chemical, pharmaceutical, oil, and gas industries, including in chemical syntheses and purification processes), plant protection products, biocides, metals and other groups like Polyaromatic Hydrocarbons

---

[5] https://prtr.eea.europa.eu/

(PAH) that are mainly incineration by-products and Polybrominated Biphenylethers (PBDE) that are used as flame retardants.

Regulations and conventions related to **air quality** focus on reducing emissions from e.g. metals, persistent organic pollutants, and non-methane volatile organic compounds (e.g. benzene). The European Union has developed an extensive body of legislation which establishes health-based standards and objectives for a number of pollutants present in the air. These standards and objectives are summarised at https://ec.europa.eu/environment/air/quality/standards.htm.

Soil is not subject to a comprehensive and coherent set of rules in the Union. There is no EU-wide legislation on **soil protection**. However, soil screening values are generic quality standards that are used to regulate land contamination[6]. Soil screening values adopted in European countries are widely variable in multiple aspects. The use of screening values varies from setting long-term quality objectives, via triggering further investigations, to enforcing remedial actions. Derivation methods of screening values have scientific and political bases; they also differ from country to country, and, as a result, screening values display substantial variation across Member States. The number of substances for which soil screening values are provided widely vary across EU Member States, ranging from less than 20 to 234 substances, with about 60 as the most common substances. They include heavy metals and metalloids (e.g. As, Be, Cd, Co, Cr, Cu, Hg, Pb, Ni, Se, Tl, V, Zn), aromatic hydrocarbons (e.g., benzene, ethyl benzene, toluene), polycyclic aromatic hydrocarbons, chlorinated aliphatic hydrocarbons (e.g. dichloromethane, trichloroethylene, tetrachloromethane), chlorinated aromatic hydrocarbons (e.g. chlorobenzene, hexachlorobenzene), pesticides (atrazine, dieldrin), dioxins and dioxin like PCBs.

Source 3: sectorial reference documents

Information on **sector specific contaminants** may possibly be listed in the Best Available Techniques (BAT) reference documents, known as **BREFs** (as well as a few other reference documents) that have been adopted under the Industrial Emissions Directive (IED, 2010/75/EU). Amongst others, each document generally gives information on a specific industrial/agricultural sector in the EU, on the techniques and processes used in this sector, current emission and consumption levels, techniques to consider in the determination of the best available techniques (BAT) and emerging techniques. The IED has introduced provisions to ensure that the operation of an installation does not lead to a deterioration in the quality of soil (and groundwater). However, a large number of potentially polluting activities are not within the scope of the IED, which in any event only covers larger industrial installations. As well the **European Pollutant Release and Transfer Register (E-PRTR)** includes a list of sector-specific pollutants. It contains key environmental data from industrial facilities in European Union Member States. The new register covers 65 economic activities across Europe. Information is provided concerning the amounts of pollutant releases to air, water and land as well as off-site transfers of waste and of pollutants in wastewater from a list of 91 key pollutants including heavy metals, pesticides, greenhouse gases and dioxins for years 2007 onwards.

Source 4: other contaminants listed as POPs in the Stockholm Convention and substances of very high concern and restricted substances from the REACH Regulation

---

[6] https://esdac.jrc.ec.europa.eu/ESDB_Archive/eusoils_docs/other/EUR22805.pdf

Other substances of concern could be present in the candidate fertilising product component. In this respect, following lists are relevant:

i. Persistent Organic Pollutants (POPs) are organic chemical substances, that is, they are carbon-based. They possess a particular combination of physical and chemical properties such that, once released into the environment, they:
   - remain intact for exceptionally long periods of time (many years);
   - become widely distributed throughout the environment as a result of natural processes involving soil, water and, most notably, air;
   - accumulate in the fatty tissue of living organisms including humans, and are found at higher concentrations at higher levels in the food chain; and
   - are toxic to both humans and wildlife.

   The list contains over 30 chemicals, distributed over three categories in the annexes (Annex A - elimination, Annex B – restriction, Annex C – unintentional production) (http://chm.pops.int/TheConvention/ThePOPs/ListingofPOPs/tabid/2509/Default.aspx)

ii. the list of substances of very high concern from REACH (SVHC list, including roughly 200 substances, https://echa.europa.eu/candidate-list-table). This list covers substances meeting the criteria for classification as carcinogenic, mutagenic or reprotoxic (CMR) category 1 or 2; persistent, bio-accumulative and toxic (PBT) substances; or very persistent and very bio-accumulative (vPvB) substances; substances for which there is evidence for similar concern, such as endocrine disruptors.
   EU producers or importers of articles which contain substances on the SVHC list in a concentration above 0.1% (w/w) have a duty to communicate information of substances in articles (as per Article 33 of REACH) and have to notify ECHA (Article 7(2)). For specific contaminants, the threshold of 0.1% (10 000 mg kg^{-1}) for notification may, however, be unacceptably high for applications in fertilising products.

iii. Annex XVII of REACH regulation contains the list of restrictions of certain hazardous substances, mixtures and articles for their marketing and use on the European market (https://echa.europa.eu/substances-restricted-under-reach). There are 70 valid entries on REACH Annex XVII (updated on 19 Nov 2019), including for instance phthalates and Bisphenol A, but also by-products of refining lead ores obtained from cleaning systems and slurry from scrubbers, calcines (i.e. product of the roasting of cadmium-enriched lead smelting dusts to remove cadmium - consists primarily of oxides and sulphates of lead and zinc). The list is often known as REACH restricted substances list or simply as REACH annex XVII.

Many of the substances identified from sources 1-3 are also taken up as in source 4 (e.g. lead and its compounds). Contaminants that exclusively form part of source 4 may be originating from unintentional contamination (e.g. food industry by-product contaminated with pentachlorophenol and its salts and esters (PCP) as disinfectant) or containing degradation products of anthropogenic chemicals like perfluorooctanoic acid (PFOA) from food processing equipment. Moreover, it is noted that the Stockholm convention and the REACH Regulation provide additional guidance to phase out and restrict the use of particular substances. In general, this implies that a manufacturer has a high degree of control over the addition and presence of such substances in the production process, and can thus effectively ensure its absence in a corresponding candidate CMC 11 by-product.

Based on the information collected from the different sources, Table 1 provides a non-exhaustive list of selected substances that may be relevant for the screening of contaminants in specific candidate by-products. **Main sources of material contamination could include solvents,**

disinfectants, oil-derived substances, ores, combustion, metal working fluids, pathogens and pests, degreasing agents, plasticizers, and flame retardants.

Table 1: Non-exhaustive list of selected possible impurities for screening in candidate by-products

Examples of contamination sources	Contaminant group	Example of contaminant
solvents disinfectants oil-derived substances combustion ores pathogens and pests metal working fluids plasticizers degreasing agents biocides and pesticides flame retardants	Metals and metalloids	Arsenic and compounds (as As) Cadmium and compounds (as Cd) Copper and compounds (as Cu) Cobalt and compounds (as Co) Mercury and compounds (as Hg) Nickel and compounds (as Ni) Lead and compounds (as Pb) Thallium and compounds (as Tl) Vanadium and compunds (as V) Zinc and compounds (as Zn)
	Inorganic	Chlorides (as total Cl) Cyanides (as total CN) Fluorides (as total F)
	Hydrocarbons	Polyaromatic hydrocarbons (PAH) Benzene
	Chlorinated organic substances	Brominated diphenylether Chloroalkanes, C10-13 Dichloromethane Pentachlorobenzene PCDD/F Pentachlorophenol Tetrachloro-ethylene Per/polyfluoroalkyl substances (PFAS)
	Others	Linear alkylbenzene sulfonates (LAS) Di(2-ethylhexyl)phthalate (DEHP) Organotin compounds (as total Sn) Plant pests Plastics < 2 mm Biological pathogens Octylphenol
	Biocides/ pesticides	Trifluralin Hexachlorobenzene

5.1.4 Issue #3: bioavailability of contaminants

5.1.4.1 Background

Like some primary materials, the constituent substances of some types of materials may be retained, to a greater or lesser extent, in a matrix. It may therefore be claimed that – similar to e.g. nutrients (see section 5.2.2) – the bioavailability of the elements and substances of concern within this matrix is a relevant issue that is related to its actual risk.

5.1.4.2 Proposal

It is proposed that the **absolute concentration of contaminants**, without further consideration of bioavailability or bioaccessibility, shall be considered for the by-products. The end-points to be considered in the assessment will depend on the nature of contaminant, potentially including as assessment on the accumulation of substances of concern in the soil and other relevant end-points such as aquatic organisms. The "worst-case-scenario" is proposed to be considered to ensure environmental protection based on the precautionary principle. The underlying principle is that the "storage" of contaminants in agricultural soils as an everlasting sink is not good practice. After all, sooner or later the contaminants may become available again, thus posing a threat to sustainability in the long-term and for future generations. This may be particularly relevant as the agricultural soil environment may become subject to a different use (e.g. restoration of natural vegetation) and/or a different abiotic environment (e.g. due to climate change). In addition, it should be avoided that elements and substances of industrial origin - without a direct contribution to agronomic interests - build up to levels beyond the natural background levels observed in soils. This is particularly relevant as our techno-scientific understanding of the substance dynamics in soils and risks to different types of organisms may be incomplete. Moreover, no harmonised methodologies are available for the evaluation of contaminant bioavailability, and its potential changes in time during soil storage.

5.2 Challenge B – Ensuring agronomic value

5.2.1 Overview

A by-product is not the primary product a manufacturer seeks to place on the market and therefore its added value to enhance plant growth is not necessarily certain. A **main challenge is to limit the CMC to value-added materials that have been proven agronomically beneficial** for the EU agricultural sector. The competitive position of any by-product in the market, vis-à-vis the primary material it replaces, is strongest when it is as close as possible to the primary material in its performance and quality, ensuring that the recovered material may be suitable for a broad range of uses. This, however, does not necessarily mean direct equivalence to primary materials - rather, by-products, just like primary materials, can be marketed under different grades or qualities.

The framework of the FPR has minimal conditions for agronomic value at Product Function Category (PFC) level that vary as a function of the class or intended use. Hence, agronomic value shall be understood in the broad concept, securing that criteria-compliant by-products are incorporated in fertilising products for a useful purpose, i.e. as a nutrient source (fertiliser), a liming material, a soil improver, a growing medium, an inhibitor, a plant biostimulant or a blend of those. Also technical additives might be considered.

5.2.2 Issue #4: effectiveness of fertilising claims

5.2.2.1 Background

This section only focuses on materials that have a direct, intended function to sustain plant growth (i.e. as fertiliser, a liming material, a soil improver, a growing medium, an inhibitor, a plant biostimulant or a blend of those), and thus excludes by-products that are used to facilitate product handling, use and management (covered in section 5.2.3).

The possible lack of effectiveness of fertilising value through the minimum PFC requirements requires a detailed evaluation per category. For PFC 1, for instance, minimum total nutrient values have been listed as a criterion, regardless of the form in which the nutrient occurs. By-products may contain, for instance, a mixture of calcium sulphite and calcium sulphate (see for instance box 2, example of materials obtained from flue gas desulphurisation), with the former being a low-value insoluble compound and the latter a fertilising product that can serve as a calcium and sulphur source for plants. However, in spite of their difference in agronomic value, both may meet the minimum nutrients requirements of PFC 1(C)(I)(a)(i) (straight solid inorganic macronutrient fertiliser, minimum 12% CaO). Therefore, additional criteria (e.g. water-soluble or extractable nutrient content) for this material group could be considered. Also, the agronomic requirements for candidate by-products that could become part of other PFCs (e.g. PFC 3(B); inorganic soil improver) may possibly require re-evaluation in the light of the material proposed. Similar to the safety criteria, the agronomic efficiency criteria are to reflect present product manufacturing practices, technological development and the latest scientific evidence.

It should also be avoided that by-products are mixed together with other CMCs into a new PFC material with the sole intention of meeting the PFC limit values on agronomic efficiency (mixing and dilution as an untruthful practice).

5.2.2.2 Proposal

Although the FPR enables that physical mixing, without intentional chemical reaction, between by-products (CMC 11) and other CMCs may occur (see section 3.3), it is proposed that the added value in terms of agronomic value should be evident. This is in line with the by-product condition of materials to be used directly without further processing laid down in the WFD (see section 3.3).

It is proposed to verify for each of the candidate by-products (or groups of similar materials, see section 5.3.3) the intended use envisaged. This information should provide an indication of its corresponding PFC. Additional criteria may be proposed in the CMC 11 criteria to ensure agronomic value, if the agricultural value of the material is unclear or debated.

5.2.3 Issue #5: materials to facilitate product handling, use and management

5.2.3.1 Background

The added-value of a by-product may relate to the direct role in improving plant nutrition, or to an indirect role related to facilitate the handling, use and management of fertilising products. By-products could, for instance, play a role as filling agents or to promote a specific material hardness for fertiliser broadcasting.

5.2.3.2 Proposal

It shall be recognised that components may be added for technical, not agronomic, reasons. Fertilising products may be of higher quality (e.g. less clumping), safer for the handle, etc. due to specific by-products being present, although they may not directly affect the agronomic performance. In case the intended function relates to facilitating product handling, use and management, criteria will be evaluated to ensure the added-value for EU fertilising products at a later project stage. These may consist, for instance, in proposing a maximum relative concentration for the materials in the PFC material, or a REACH registration for this specific use.

5.3 Challenge C – Selection and prioritisation of materials for assessment

5.3.1 Overview

The starting point for the present study is the wide range of by-products and candidate by-products available for the fertiliser markets of the EU territory. However, the mandate of the JRC is limited in time as Article 42(7) of the FPR sets the obligation for the Commission to adopt, by 16 July 2022, a delegated act for CMC 11. The proposal to rely on a positive list for CMC 11 materials involves that the JRC will evaluate candidate materials on a case-by-case basis, implying a final selection and prioritisation of candidate materials in an early stage of the project, followed by possible elaboration of criteria for the selected candidate materials.

5.3.2 Issue #6: selection of materials for assessment by the JRC

5.3.2.1 Background

Depending on the number of candidate by-product materials, JRC may have to prioritise specific materials of interest based on objective conditions.

5.3.2.2 Proposal

It is proposed that the following issues will be taken into consideration when selecting candidate by-products for assessment:

- **Alignment to the scope** of this project as outlined in section 3. This implies that by-products should be a production residue, not be part of one of the material types excluded under point 1 of CMC 11 of Annex II of the FPR, can be used directly as a fertilising product component, and are the result of an integral part of a production process.
- **Current situation and possible inclusion under Regulation (EC) No 2003/2003** (outgoing legislation relating to fertilisers) **and national markets in EU Member States** (by-products used directly as fertilising materials on agricultural land, including products of PFC 2 -6 of the FPR such as liming materials, soil improvers, etc.). By-products already placed in the market could be associated to more readily available techno-scientific database and use experience in the EU. Experiences observed by EU Member States from this current framework will be taken into consideration (e.g. positive track-record). Due attention will also be paid to current limitations and restrictions to mutual recognition of by-products by Member States, as well as differences in recognition of materials as by-products or not across Member States. This will be important, given the fact that individual

Member States will not be able to override the product status of materials compliant with the FPR.

- **Market potential** and future **outlook** of candidate by-products materials on the EU-market and **trade on the EU single market**. Article 42(1)(a) of the FPR mentions the "potential to be the subject of significant trade on the internal market" as one of the conditions for the adoption of delegated acts by the Commission. The draft criteria shall reflect present product manufacturing practices and technological developments. Hence, a primary focus will be given to by-products that are produced in larger volumes (e.g. in terms of intentionally synthesised fertilising products they can replace, or in terms of alternative management that can be avoided if included under the FPR). Possibly, it is also relevant to consider the future market outlook of the technologies applied ("future-proofness") in view of any Commission priorities and action plans (e.g. Circular Economy action plan and EU Green Deal, focussing on (hazardous) waste prevention and reduced pollution, safe chemical use and design, increased resource efficiency, greenhouse gas emission reductions etc.).
- **Data availability**. A prerequisite for the evaluation of candidate by-products is that a sufficient amount of data is available to judge material safety and agronomic performance. This may involve a clear production process description, knowledge on the chemicals and reactants applied during the production process and their partitions during manufacturing steps, chemical characterisation of the candidate materials, a full contaminant profile of the candidate material, etc. Information can be obtained from techno-scientific literature sources, site visits and/or inputs provided by members of the Commission expert group for Fertilising Products consisting of Member State authorities, EU industry associations and environmental NGOs (see section 5.1.3).
- **Straightforwardness for criteria settings**. Some candidate materials and candidate material groups may enable a more straightforward assessment and be associated to lesser challenges during criteria setting (e.g. determination of limit values). This could be materials for which already (industry) standards are available or those associated to intrinsically low risks (e.g. from production processed having applied chemicals of little or no toxicity).

Hence, the JRC would appreciate receiving any information that demonstrates compliance with one or more of the abovementioned aspects for candidate by-products (see questionnaire, section 10).

5.3.3 Issue #7: grouping of materials

5.3.3.1 Background

The JRC shall strive to propose a generic set of agronomic efficiency and safety criteria for the by-products considered. However, based on preliminary evidence it seems reasonable to assume that the technical (composition, mainly impurity profiles) and agronomic characteristics of by-products diverge to the extent that such overall criteria would become irrelevant. Therefore, a grouping could be evaluated based either (i) on the similarity of the hazardousness profile, or (ii) on the chemical composition (presence of main elements, closely related to intended use and agronomic performance).

5.3.3.2 Proposal

Should the characteristics of candidate by-products diverge to the extent that such overall criteria would become irrelevant, then the JRC will **define subcategories** of by-products that each comprise **materials with a similar hazardousness profile**. This proposal will enable (i) a fair assessment of the material risks, and (ii) favour safe innovation within the respective material groups as long as the main risks are controlled and agronomic value is demonstrated (see section 5.4.2). After all, a material with the "same" chemical composition may show substantial differences in its contaminant profile, depending on the production process from which it is derived (e.g. lime as a residue from alkaline seaweed extraction versus lime as a residue of the production of aerated concrete). It is also important to note that a materials registration in REACH, in principle, already covers the impacts, hazards and risks originating from the main constituents present in the by-product material, but may not be extensive enough to cover the impacts from the contaminants present at trace level (see section 5.1.3, impurities resulting from the production process may differ for "same" substances). Additionally, focussing exclusively on by-product materials with a specific and narrow chemical composition (e.g. ammonium sulphate, lime, gypsum) may hinder safe innovation that generates by-products of a different chemical composition than the ones that are taken up in a positive CMC 11 material list. The proposal thus involves a significant change relative to the EC 2003/3003 legislative framework that listed by-products based on their chemical composition and main elements, without consideration of the contaminant profile. One of the intentions of the FPR (EU) 2019/1009 is, however, to the address the identified weakness related to the lack of consideration of environmental and public health concerns in the EC 2003/2003 Fertilisers Regulation[7]. This proposal does, however, not imply that the agronomic value of the materials is of a lesser importance. As indicated in section 5.2, criteria will be proposed to ensure the added value of the materials in terms of agronomic performance.

5.4 Challenge D – Ensure a well-functioning market

5.4.1 Overview

The harmonisation of criteria for by-products is expected to promote a greater level playing field with intentionally manufactured fertilising products by increasing legal certainty and opportunity to use harmonised rules in a cost-effective manner for access to the single market. Stakeholders request simple and cost-effective regulatory processes to enable sector innovation, to incentivise investment, and to demonstrate compliance for by-product materials.

5.4.2 Issue #8: safe innovation

5.4.2.1 Background

In the best possible scenario, the FPR shall apply a reasonable neutral stance towards all existing and future technological systems operating on the market. However, this technological neutrality principle may to a certain degree be restricted for CMC 11 due to the wide scope and possible contaminants that may be present in by-product materials. At the same time, it is important to point out that the FPR has been envisaged as a "living document", thus providing already intrinsic

---

[7] See Commission staff working document impact assessment accompanying the proposal for the FPR, http://ec.europa.eu/DocsRoom/documents/15949/attachments/4/translations/en/renditions/native

opportunities for safe innovation based on the possibility to adapt the Annexes through delegated Commission acts.

5.4.2.2 Proposal

The already proposed reliance on a combination of a **positive list** (section 5.1.2) combined with a possible **grouping of materials** (section 5.3.3) provides opportunities to formulate the group-specific criteria **as generically as possible** in order to accommodate for safe innovation. After all, materials within the same group may be derived from alike input materials and/or may have similar primary products as an objective (e.g. by-products resulting from air cleaning systems after material combustion/smelting). Therefore, innovation during specific manufacturing steps may not induce supplementary risk as long as criteria have been proposed that account for risks associated to the input material and/or prior processing steps (e.g. specific metals in input materials, combustion-specific contaminants). Prior to proposing more generic criteria, an overview of the possible by-product candidate materials that could form part of each group is required so as to have a better view on the characteristics and risks for the grouped materials.

For completely new kinds of materials, it is important to recall the "optional harmonisation" principle of the FPR. Therefore, innovative products could still be placed on national markets that could serve to build up a track record on safety and agronomic efficiency. At a later stage, these materials can then be evaluated for inclusion under CMC 11. After all, Article 42(b) of the FPR indicates that the Commission has been given the possibility to adapt the Annexes to technical progress over time so as to facilitate coverage of EU fertilising products on condition that there is available **scientific evidence** to support their inclusion.

5.4.3 Issue #9: legal certainty

5.4.3.1 Background

The decision on whether or not a particular substance or object is a by-product must in the first instance be made by the producer of the substance or object, together with the competent national authorities, based on the applicable national legislation transposing the Waste Framework Directive. Production residues may be classified dissimilarly in different Member States or in different regions of the same Member State, ultimately leading to uncertainty about the legality of management practices for certain by-product streams. The situation may also lead to uncertainty for operators and authorities in possible cross-border movement of by-products, resulting in delays or even refusal of entry and thereby resulting in an inefficient internal market in the EU. Furthermore, in some cases, inconsistent classification of materials (waste versus by-product) could lead to poor management of risks and to potential risks to human health and to the environment.

As already explained, by-products used as a component material in EU fertilising products have also to comply with the national legislations setting criteria on the application of the conditions laid down in Article 5(1) of Directive 2008/98/CE, i.e. under the waste legislation. The CMC 11 criteria will thus not replace the WFD requirements. The criteria can, however, **aid to demonstrate that** further use of the materials identified in the criteria is **"lawful"** as they do not present a risk to human, animal or plant health, to safety or to the environment, and that "**further use of the substance or object is certain**" (see section 3.5).

5.4.3.2 Proposal

The elaboration of EU-wide criteria for by-products targets to create a level playing field for fertilising products by increasing legal certainty for access to the single market. Therefore, it is required that the JRC evaluation and the proposed CMC 11 criteria inspire trust by national competent authorities, food safety authorities, European fertilising products manufacturers, EU farmers, and the general public. To this end, it is proposed that this work shall be based **on solid and widely accepted principles that depart from a high level of ambition with respect to safety standards and agronomic efficiency** (as outlined in section 5.1 and 5.2). Such evaluation - based on transparently available data - may promote a **true level playing field for those materials, regardless of the Member State in which they are produced**. This, however, does not imply that by-products that do not meet the FPR criteria will be excluded from the market. In any case, the FPR relies on the principal of optional harmonisation and is therefore parallel to EU Member State legislation. Finally, the fact that by-products meeting the FPR criteria will automatically have access to the EU market also requires a sufficient support base across Member States for any materials selected for inclusion on the proposed FPR positive list.

5.4.4 Issue #10: limiting compliance costs

5.4.4.1 Background

The CMC criteria may limit the introduction of unnecessary regulatory burden and cost to demonstrate compliance when fewer parameters have to be measured and reported by the responsible fertilising product manufacturer as responsible economic operator. In the best possible scenario, the CMC 11 criteria shall be simple and practical, associated to reasonable compliance costs, and facilitate a straightforward verification and monitoring system.

5.4.4.2 Proposal

Depending on the criteria development process, it may be an option to divide the materials within different groups so as to enable the development of a more targeted compliance scheme (see also section 5.3.3). The use of a positive list, will furthermore limit the possible parameters to test and hence limit compliance costs (see also section 5.1.2.2).

Regardless, manufacturers may have to carry out sample testing for a to-be-determined number of parameters. Since compliance is a of the economic operators, benefits may be obtained from omitting measurements when risks are absent so as to reduce the time and resource costs of compliance. Where (i) compliance with a given requirement (such as absence of a given contaminant or contaminant list, see section 5.1.3) follows certainly and uncontestably from the nature or manufacturing process of an EU fertilising product, and (ii) a manufacturer wishes to take responsibility for compliance, it may be evaluated if the frequency of compliance can be lower or even presumed in the conformity assessment procedure without verification through testing (similar to specific conditions for PFCs, see Annex I, Part II, point 4 of the FPR).

6 AGRICULTURAL VALUE FOR SINGULAR STREAMS

Although CMC 11 candidate materials are produced through a variety of manufacturing processes, the number of different substances and materials of different chemical composition is more limited. For instance, ammonium sulphate (EC No 231-984-1) is produced through about 10 production pathways outlined in this document. Hence, many substances listed as “priority materials” only differ in their impurity profile. On condition that impurities are reduced to acceptable levels, **the agronomic efficiency is largely determined by the chemical composition of the main elements present in the CMC candidate material**. Other elements that impact upon agronomic efficiency are e.g. physical characteristics such as particle size and moisture content that can be adjusted using “normal industrial practice” (e.g. screening, granulation, drying, rewetting, etc.).

The priority materials identified involve a large share of materials that are associated to a long-term use history in the EU. Farmers acknowledge their effectiveness to contribute to plant nutrition. These involve substances that have intended uses as (component materials for) fertilisers, liming materials and soil improvers. Others are more innovative materials (e.g. plant biostimulants). Note that multiple intended uses for specific materials can be envisaged, for which reason the use classification indicated below is only informative.

Materials added for technical reasons will not necessarily have an agronomic efficiency (e.g. binding agent, adjustment of hardness for broadcasting). Hence, these materials will not be evaluated with respect to their agronomic efficiency.

6.1 Fertilisers

A number of **well-defined substances** (pursuant the definition in Regulation No 1907/2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH)) has been proposed as CMC 11 candidate materials. Mostly, this involves salts of sulphate (SO_4^{2-}), ammonia (NH_4^+), nitrate (NO_3^-)-, or phosphate (PO_4^{3-}).

This mostly involves **mono-constituent well-defined substances** with one main constituent that makes up at least 80% of the substance, and any other substances present in concentrations between 1% and 10%.

- Ammonium sulphate (EC No 231-984-1), agronomic value demonstrated from long-term history on field, classification as a fertiliser under Regulation (EC) No 2003/2003, and scientific literature (e.g. Chien et al., 2011). The materials are produced as:
    - By-products from following production processes from the chemical industry: from cyclohexanone amine and caprolactam production, from acrylonitrile and hydrocyanic acid production, from methyl methacrylate production, from saccharin production, from methionine production, from coke production.
    - By-products from following production processes from the metal and mining industry: from ore processing, from metal surface treatment.
    - By-products from following production processes from gas cleaning systems: from flue-gas desulphurisation systems, from biomass gases.

- Calcium sulphate – gypsum (EC 231-900-3), agronomic value as a fertiliser or soil improver demonstrated from long-term history on field, classification as a fertiliser under Regulation (EC) No 2003/2003, and scientific literature (e.g. Panday et al., 2018). The materials are produced as:
    - By-products from following production processes from metal mining industries: from sodium chloride brine purification, from ore processing (phosphogypsum, fluorogypsum, titanogyspum), from metal surface treatment;
    - By-products from following production processes from gas cleaning systems: from flue-gas desulphurisation systems, from ammonia scrubbing of biomass gases;
    - By-products from citric acid and tartaric acid production (from the processing of biomass and water for food, drink and biorefinery industries).
- Elemental sulphur (EC No 231-722-6), agronomic value demonstrated from long-term history on field, classification as a fertiliser under Regulation (EC) No 2003/2003, and scientific literature (e.g. Boswell and Friesen, 1993). The materials are produced as:
    - By-products from following production processes: from gas cleaning systems: from flue-gas desulphurisation, from sulphur recovery units, from biomass gases (biogas purification).
- Ammonium nitrate (EC No 229-347-8), agronomic value demonstrated from long-term history on field, classification as a fertiliser under Regulation (EC) No 2003/2003, and scientific literature (e.g. Lips et al., 1990). The materials are produced as:
    - By-products from caprolactam production (hydroxylamine phosphate oxime process);
    - By-products from ammonia scrubbing of biomass gases (gas cleaning systems).
- (Di-)ammonium phosphate (EC No 231-764-5 and 231-987-8), agronomic value demonstrated from long-term history on field, classification as a fertiliser under Regulation (EC) No 2003/2003, and scientific literature (e.g. Thomas and Rengel, 2002). The materials are produced as:
    - By-products from following production processes from ammonia scrubbing of biomass gases (gas cleaning systems).
- Sodium sulphate (EC No 231-820-9), agronomic value demonstrated from long-term history on field, classification as a fertiliser under Regulation (EC) No 2003/2003, and scientific literature (e.g. Solberg et al., 2007). The materials are produced as:
    - By-products from flue-gas desulphurisation systems.
- Magnesium sulphate – kieserite (EC No 231-298-2), agronomic value demonstrated from long-term history on field, classification as a fertiliser under Regulation (EC) No 2003/2003, and scientific literature (e.g. Craighead and Martin, 2001). The materials are produced as:
    - By-products from following production processes from flue-gas desulphurisation systems.
- Metal sulphates, including zinc sulphates (EC No 231-793-3), iron sulphate (EC No 231-753-5) and copper sulphate (EC No 231-847-6); agronomic value demonstrated from long-term history on field, classification as a fertiliser under Regulation (EC)

No 2003/2003, and scientific literature (e.g. Brennan, 1990; Lucena, 2003; Broadley et al., 2007). The materials are produced as:

  - By-products from metal surface treatment.

Note that with specific process modifications, the chemical composition of by-products can be modified (e.g. calcium sulphate to magnesium sulphate). This is because strong acids (sulphuric acid, nitric acid, phosphoric acid) used in neutralising processes, as well as counter-ions that bind to free sulphates (Ca, Mg, Na, etc.), can normally be exchanged during chemical processes that take place during product manufacturing. Hence, the combination of material – production process is indicative, but a common property is that they jointly classify as salts of sulphate (SO_4^{2-}), ammonia (NH_4^+), nitrate (NO_3^-), or phosphate (PO_4^{3-}).

In addition, **multi-constituent well-defined substances** can be produced, defined pursuant REACH as substances consisting of several main constituents that each will be present at a concentration of between 10% and 80% in the substance, and the sum of the remaining components together making up < 10%:

- Binary salts (EC No 914-103-1), defined as a reaction mass of ammonium sulphate, potassium sulphate and sodium sulphate. Examples include by-products from amino acid production, e.g. from the molasses left over after fermentation processes.
- Other manufacturing processes that result in materials that are not REACH registered may produce multi-constituent well-defined substances (e.g. possibly potassium and sodium sulphates from biodiesel production; concentrates from sodium acid pyrophosphate potato washing solutions consisting of different phosphate salts).

Finally, the “**Unknown or Variable composition, Complex reaction products or Biological materials” (UVCB**, pursuant REACH terminology) such as basic slags or Thomas slags can show high contents of phosphorous. Since most slags also have a high neutralising value, these will be discussed under section 6.2 (liming materials).

6.2 Liming materials

Some candidate materials are **well-defined substances** (pursuant the definition in Regulation No 1907/2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH)), due to their high content of carbonates, oxides and/or hydroxides of Ca and Mg (>80% of the total mass). This implies that their agronomic value as a liming material is intrinsic and can thus be assumed without further testing. This involves, for instance, following materials:

- Calcium carbonate (EC No 207-439-9), by-products from the processing of biomass and water for food, drink and biorefinery industries: from sodium chloride brine purification, from soda ash production (post-soda lime), from sugar production, from the paper and pulp industry (lime mud).
- Calcium oxide (EC No 215-138-9) from sugar production, from the paper and pulp industry (burnt lime);
- Calcium hydroxide (EC No 215-137-3): carbide lime from acetylene production (EC No 215-137-3);

Note that Regulation (EC) No 2003/2003 exclusively focused on fertilisers (materials with high nutrient content), and therefore the placing on the market of these materials was not regulated at EU level previously.

Steel slags, specifically "basic slags", also contain high amounts of P_2O_5 and possibly other nutrients and are listed as fertilisers under Regulation (EC) 2003/2003. The chemical composition of steel and iron slags includes a multi-fold of substances, and are therefore classified as "Unknown or Variable composition, Complex reaction products or Biological materials" (UVCB) substances in REACH:

- Slags, ferrous metal, blast furnace (EC No 266-002-0);
- Slags, steelmaking (EC No 266-004-1)
- Slags, steelmaking, converter (EC No 294-409-3)

The agronomic value of these materials, either as nutrient sources or as liming materials is well recognised. Basic slags are listed as fertilisers under Regulation (EC) No 2003/2003, and have a long-term use history in specific EU Member States such as Germany and Belgium. The neutralising value of some slags may be similar to limestone, and the effectiveness of slags as a nutrient source or to neutralise soil acidity is demonstrated in scientific publications (e.g. Algermissen et al., 2016)

Finally, the following material could possibly be classified as a **substance which occurs in nature**[8] and that is not chemically modified[9]:

- Dolomite fines (e.g. from MgO production)

As long as these conditions apply, these materials are exempted from registration in REACH (Annex V of Regulation (EC) No 1907/2006).

6.3 Soil improvers and plant biostimulants

A significant amount of by-products from the processing of biomass and water for food, drink and biorefinery industries are generated that can be used in agriculture as soil improvers or as plant biostimulants. Biostimulants are often composed of multiple components such as plant hormones, amino acids, betaines, peptides, proteins, sugars (carbohydrates, oligo- and polysaccharides), aminopolysaccharides, lipids, vitamins, nucleotides or nucleosides, humic substances, beneficial elements, phenolic compounds, furostanol glycosides, and sterols (Yakhin et al., 2017; Madende and Hayes, 2020). Many of the proposed CMC candidate 11 materials span different intended uses because they contain nutrients, organic matter, and easily decomposable plant building blocks in different quantities.

A solid body of scientific evidence (McHugh, 2013; Lonhienne et al., 2014; Canellas et al., 2015; du Jardin, 2015; Yakhin et al., 2017; Rouphael and Colla, 2018; Xu and Geelen, 2018) has demonstrated that **plant hydrolysates, seaweed extracts, humic/fulvic acids, and yeasts** can have

---

[8] naturally occurring substance as such, unprocessed or processed only by manual, mechanical or gravitational means, by dissolution in water, by flotation, by extraction with water, by steam distillation or by heating solely to remove water, or which is extracted from air by any means

[9] [=chemical structure remains unchanged, even if it has undergone a chemical process or treatment, or a physical mineralogical transformation, for instance to remove impurities

added value for agriculture. In addition, humic/fulvic acids have been shown to induce rates of seed germination, transfer micro-nutrients from soil to plants, improve water retention and enhance microbial biomass (Peña-Méndez et al., 2005). In line with the definition of plant biostimulants in the FPR, they may have the ability to stimulate plant nutrition processes independently of the product's nutrient content with the sole aim of improving one or more of the following characteristics of the plant or the plant rhizosphere: (a) nutrient use efficiency, (b) tolerance to abiotic stress, (c) quality traits, or (d) availability of confined nutrients in the soil or rhizosphere. Such innovative materials are potentially important for the EU agricultural sector, especially since new ways should be pursued to increase nutrient use efficiency in line with the priorities outlined in the EU Farm-to-Fork[10] and Biodiversity Strategy[11].

Based on the abovementioned scientific literature on plant biostimulating properties, possibly combined with high contents of organic carbon, it is proposed that the agronomic efficiency is implicit for following materials that are biomass residues from chemical and enzymatic refining processes (assuming that acceptable levels of impurities and other conditions are met):

- **plant expellers/cakes** mostly containing vegetable fibres and proteins as obtained after acid/alkaline/enzymatic/(solvent) extraction (e.g. oilseed cakes);
- **filter cakes** (e.g. protein fractions) obtained during the filtration of foodstuffs, beverages and biorefinery liquids (e.g. starch hydrolysates cake; brewers' grains)
- **protein residues obtained after acid/alkaline/enzymatic extraction processes of plants and seaweeds** from which primary products (e.g. amino acids, agar, pharmaceuticals) have been isolated (e.g. protein concentrates from which amino acids of interested have been extracted; alkaline extraction residues from agar production);
- **protein-rich residues** obtained in **fermentation** processes (using e.g. *Escherichia coli* K12, *Corynebacterium glutamicum*, yeasts) on substrates of vegetable (e.g. molassess) or chemical origin, natural gas, or mineral salts (e.g. ammonium sulphate) for the production of e.g. amino acids (e.g. methionine), aroma, syrupy, inulin, pharmaceuticals, vitamins;
- **surplus yeasts and parts thereof** obtained (e.g. *Saccharomyces cerevisiae*) for instance from beer brewing;
- **Humic/fulvic acids** from organic matter removal during drinking water production.

Note that (most) by-products from biomass processing are also eligible as an input material for compost and anaerobic digestate. This will provide for many materials an alternative route for their placing on the market as components for EU fertilising materials, especially since such materials are REACH exempted. However, for some smaller high-value streams with specific properties (e.g. concentrated protein fractions), it may be beneficial to keep them separate, rather than mix them with other materials (e.g. as part of a co-digestion process). All materials will have to comply with a set of criteria that ensures high levels of environmental protection (e.g. absence of biological pathogens, material stability, etc.).

---

[10] https://ec.europa.eu/food/farm2fork_en

[11] https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal/actions-being-taken-eu/eu-biodiversity-strategy-2030_en

6.4 Excluded materials due to presently uncertain agronomic value

Based on agronomic value, there are only two materials proposed by the COM Expert Group on Fertilising Products for which the JRC proposes that their knowledge base on agronomic value is at present not sufficiently developed to enable its inclusion under CMC 11. Therefore, JRC proposes to exclude these materials for further assessment. This does not imply that those materials have no future in agriculture. As outlined in the directional framework for this project, the selection and prioritisation of candidate materials is based on numerous criteria including amongst others market potential, available techno-scientific information, challenges to develop criteria in a straightforward manner, and possibilities to develop cost-effective compliance schemes. Additional materials have been excluded due to challenges to ensure environmental and human health safety through cost-effective compliance schemes that are straightforward to develop within this project (see section 7). It is re-iterated that alternative routes for their placing on the market may exist (e.g. in line with national rules and the FPR principle of optional harmonisation, other CMCs for specific materials (e.g. compost for biomass-derived materials)).

6.4.1 Residues from nepheline syenite production with a lurgi type of magnetic separation system

Nepheline syenite has about 48-54% albite ($NaAlSi_3O_8$, a Na-rich feldspar), 18-23% microcline ($KAlSi_3O_8$, a potassium-rich feldspar), and 20-25% nepheline ($Na_3KAl_4Si_4O_{16}$) (Cinar and Durgut, 2019), and can thus be classified as a K-rich silicate mineral. It serves as a raw material for ceramic body composition as a melting agent. However, impurities such as titanium, iron-bearing minerals, quartz (SiO_2), mica ($Al_2K_2O_6Si$), and calcite ($CaCO_3$) minerals in nepheline syenite can lead to quality problems on the surface of floor tile because of different sintering properties (Cinar and Durgut, 2019). Therefore, these impurities should be eliminated from syenite before the sintering process to increase its quality while reducing economic and environmental impacts. This is done via a lurgi type of magnetic separation system, and generates a nepheline syenite residue as a by-product.

Plant responses following the application of silicate minerals, such as residues from syenite, are rather low (approximately 10% of that of treatments with KCl; Manning et al., 2017), and often no difference is observed in plant growth with a negative control (Mohammed et al., 2014). Soils derived from glacial till or developed on granite contain K-feldspars and are common in many parts of Europe. Therefore, the addition of (residues from) silicate minerals to these temperate soils may not give a response (Manning et al., 2017). This indicates that the K present in the residues is largely in a stabilised form, and not available to plants in the short term. Evidence for other uses of this material (e.g. as liming materials) were not observed in literature. Hence, the agronomic efficiency for these materials is at present not sufficiently supported, and no further assessment of the material is proposed.

6.4.2 Glycerol

The predominant biodiesel production process involves a phase of transesterification that yields glycerol as a by-product. Glycerol is a material that contains organic carbon as well as impurities in the form of methanol, soaps, triglycerides, fatty acids, and salts. Since it is of low purity, few alternatives for its application have been identified (Pitt et al., 2019). The techno-scientific base for its use as a fertilising product remains thin and possibly limited to very specific application conditions and rates (Qian et al., 2011; Parker, 2013). Because its production volumes increase alongside biodiesel production (O'Connell et al., 2019) to levels potentially in excess to agricultural demands, there may be a risk of being returned to agriculture as a disposal route, without a clear associated benefit for EU agriculture. Nonetheless, valuable component fractions from glycerol (e.g. potassium concentrates) could be isolated as valuable by-products, as outlined elsewhere (see section 7.4.3.3).

6.4.3 Any other materials not part of the positive list

One of the main reasons for proposing the development of a **positive list is that enables restricting the CMC to materials that have a demonstrated agricultural value**. A more "open" input material approach (e.g. negative list) would open a door for the landspreading of materials of unknown or uncertain agronomic value as a low-cost route for their disposal.

7 IMPURITY PROFILES FOR SINGULAR STREAMS

7.1 Group A – by-products primarily obtained through the refining of fossil fuels (for chemical industry)

7.1.1 Scope

By-products primarily obtained from the transformation, refining and purification (e.g. through heating, steaming, thermal processing, extraction, distillation, condensation, crystallisation, stripping, filtration) of fossil fuels for the production and chemical synthesis of (fine) petrochemicals like synthetic polymers (for instance plastics, rubber, fiber raw materials), amino acids, and other organic compounds. Materials excluded involve:

- By-products from gas cleaning systems;
- By-products from chemicals produced through fermentation (e.g. citric acid) as covered under Group D (biomass-derived materials; see section 7.3.7).

7.1.2 Ammonium salts from cyclohexanone oxime and caprolactam production

Over the years, many routes for the manufacture of caprolactam have been developed. Of these routes, the bulk of manufacture is via cyclohexanone (as prepared from phenol or cyclohexane) and cyclohexanone oxime. The conversion of cyclohexanone to cyclohexanone oxime is brought about by the use of hydroxylamine sulphate. The produced sulphuric acid is neutralised with ammonia to ammonium sulphate and this is separated from the oxime. In the presence of fuming sulphuric acid, the oxime undergoes the process known as the Beckmann rearrangement to yield the crude caprolactam. After further neutralization with ammonia, the caprolactam and further ammonium sulphate are separated by solvent extraction. From the rearrangement section, two liquid phases result: an aqueous solution rich in ammonium sulphate (35-40%) containing 0.5-1.5% caprolactam, and crude caprolactam containing 25-30% water and a small amount (<1.5%) of ammonium sulphate. Both streams also contain organic and inorganic impurities. Caprolactam is recovered from both of these phases and further purified by solvent extraction, and the ammonium sulphate is combined with the phase separated from the oxime. The crude caprolactam layer is extracted with an organic solvent in the so-called forward extraction, which is followed by back-extraction with water. Benzene, toluene, alkanes or chlorinated hydrocarbons (e.g. trichloroethylene, chloroform) are examples of solvents used in the industry (van Delden et al., 2006). In 2011, the global annual production of caprolactam was more than 4.75 million tonnes. In the above process, 4-5 tonnes of ammonium sulphate are produced as a by-product per tonne of caprolactam.

Technological developments have attempted to reduce or eliminate by-product formation. These involve, for instance, the acidic oximation process, the BASF process based on the production of hydroxyl ammonium sulphate to be reacted with cyclohexanone and ammonia (~0.1 tonne of ammonium sulphate per tonne of cyclohexanone oxime produced); the hydroxylamine phosphate oxime process developed by DSM - a process that generates phosphoric acid and ammonium nitrate as a by-product, the EniChem process based on the production of the oxime through the reaction of hydroxylamine with ketone. One route that eliminates the production of ammonium sulphate is the photonitrosation process involving nitrosyl chloride.

Finally, different companies have attempted the production of caprolactam without cyclohexanone oxime as intermediate. For example, the SNIA viscosis process produces caprolactam and ammonium sulphate based on toluene, benzoic acid, cyclohexanoid acid, and nitrosulphuric acid as raw materials, intermediates and reactants. Alternative routes with butadiene (e.g. followed by hydrocyanation) and 6-aminocapronitrile as raw material have also been explored and commercialised in the past.

After effluent stripping with steam, the main residual contaminants in the by-product stream are **caprolactam, cyclohexanone** and **cyclohexanone oxime** (Falcke et al., 2017). In the neutralized Beckmann rearrangement mixture impurities of inorganic and organic nature are present (e.g. amines, alcohols, amides). Those could potentially be transferred to the ammonium sulphate stream, dependent on their affinity for the organic (solvent) phase versus the high ionic aqueous environment in the ammonium sulphate phase. Specifically, Zhao et al. (2001) identified **aniline** and **2-methylcyclopentanol** as main impurities present in the reaction system. Extraction solvents used in an extraction procedure during the processing are normally removed under conditions of good manufacturing practice. Nonetheless, at times the presence of solvent residues (e.g. **trichloroethylene**, **toluene** and **benzene**) in candidate CMC 11 materials may be unintentional or technically unavoidable (DOMO Caproleuna GmbH, 2014).

7.1.3 Ammonium sulphate from acrylonitrile and hydrocyanic acid production through ammoxidation

In chemistry, ammoxidation is an industrial process for the production of nitriles using ammonia and oxygen. Usually, the processes use alkenes as substrates. Nitriles are organic compounds that have a −C≡N functional group, and are referred to as “cyano” compounds. In the EU, acrylonitrile is produced through the ammoxidation of propylene at temperatures of 500°-650°C (Golodets, 1983). Hydrocyanic acid is commonly manufactured by reacting methane and ammonia at a temperature of around 1000°C, through the ammoxidation-like Andrussow process (Pirie, 1958). There are numerous variations in the methods of recovery of the excess ammonia in such processes, but most of them comprise the two basic steps of ammonia recovery by quenching/washing with acidified ammonia sulphate solution. The aqueous solution leaving the reactor dominantly consists of **acrylonitrile, hydrocyanic acid, ammonia sulphate**, **and acetonitrile,** as well as smaller quantities of **acrolein, acetic acid, acrylic acid, propionitrile, and methacrylonitrile** (Falcke et al., 2017). A recovery column removes bulk water, and separates the different products of interest by distillation and condensation, whereas crystallisation is applied to obtain reusable ammonium sulphate from the excess (unconverted) ammonia reacted with sulphuric acid. In another recovery process, hydrogen cyanide and ammonia are simultaneously absorbed in a medium based on a polyhydroxy boric acid complex— an aqueous solution of pentaerythritol and boric acid. Here, the hydrogen cyanide dissolves, but the ammonia combines with the polyhydroxy complex. The hydrogen cyanide can be recovered by vacuum distillation at moderate temperature; the cyanide-free solution is subsequently stripped at a higher temperature at which the ammonium salt is dissociated.

Impurities from the reaction of propylene and ammonia may include following compounds: **acrylonitrile, hydrocyanic acid, acetonitrile, acrolein, acetic acid, acrylic acid, propionitrile, and methacrylonitrile**. Following the addition of sulphuric acid, primarily **tarry** (containing polyaromatic hydrocarbons, **PAHs**) **and/or sulphur-containing organic substances** could then be produced. The addition of water during a possible basic quench step causes the formation of **(undefined) high-boiling oligomeric compounds** and organic ammonium salts which must be purged from the system, together with **organic acids** (Falcke et al., 2017). It is expected that most of these compounds end up in the effluent stream from the crystallisation process.

7.1.4 Ammonium sulphate from methyl methacrylate production

Methyl Methacrylate (MMA) is a methyl ester of methacrylic acid. Methyl methacrylate is a reactive resin, and the polymerized form is used e.g. as cement in dentistry, orthopaedic surgery and ophthalmology. A dozen technologies are under development and practiced commercially for MMA, the main one being the acetone cyanohydrin (ACH) route (Figure 2). Acetone and hydrogen cyanide (HCN) react to form acetone cyanohydrin. This intermediate then reacts with excess concentrated sulphuric acid to methacrylamide sulphate. Methacrylamide is then treated with excess aqueous methanol; the amide is hydrolysed and esterified forming a mixture of MMA and ammonium bisulphate (NH_4HSO_4).

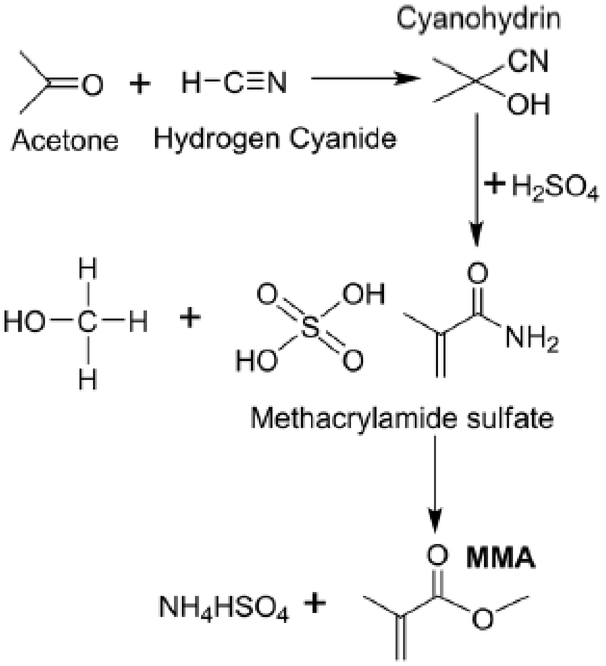

Figure 2: Overview of the methyl methacrylate (MMA) production process via the acetone cyanohydrin route

A less common alternative route is the methacrylonitrile (MAN) process. Here, methacrylonitrile as produced by ammoxidation from isobutylene is hydrated by sulphuric acid and reacted with methanol to methacrylamide. Similar to the ACH pathway, NH_4HSO_4 is produced as a by-product that can be further neutralised to ammonium sulphate in a subsequent step. Hence, the latter ammonium sulphate would be a by-product on condition that it is manufactured as an integral part of the MMA production process.

The MMA product is boiled of leaving an aqueous solution (spent acid) that contains ammonium sulphate (44%) and spent sulphuric acid (14%), as well as various organic compounds, such as **sulphonated organic products, tars, and light and heavy organics such as methanol and aldehydes (acetaldehyde), vinyl ether and methacrylic acid (vinyl actetate) (DKL Engineering, 2002)**. The solution flows into an ammonium sulphate crystallization feed tank and impurities are removed using purification techniques (CEFIC, 2014).

7.1.5 Ammonium sulphate from saccharin production

Saccharin was originally obtained by Fahlberg through the oxidation of o-methyl-benzenesulphonamide, a starting material obtained by chlorosulphonation of toluene with chlorosulphonic acid (O'Donnell and Kearsley, 2012). Sulphonation of toluene by chlorosulphonic acid results in sulfonyl chlorides. The ortho form, o-toluene-sulphonyl chloride, is treated with ammonia to give o-toluene-sulphonamide, which is then oxidized with potassium permanganate to produce o-sulphamido-benzoic acid. On heating, the latter yields saccharin.

The Maumee process is based on the common grape flavourant from phthalic anhydride or methyl anthranilate as starting material (O'Donnell and Kearsley, 2012). In this synthesis, the methyl anthranilate successively reacts with nitrous acid (from sodium nitrite and hydrochloric acid), sulphur dioxide, chlorine, and then ammonia to yield saccharin.

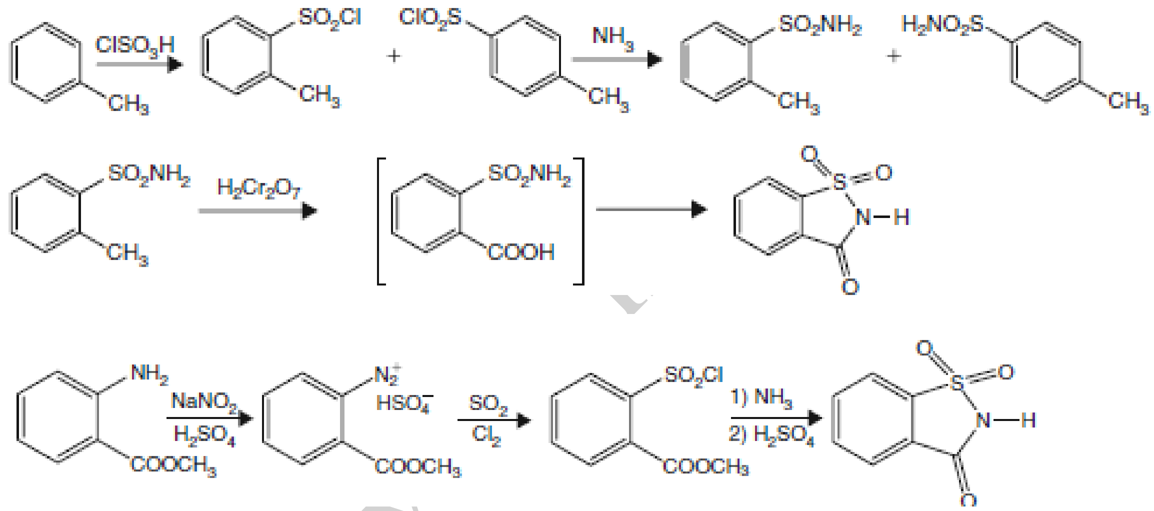

Figure 3: Production routes for saccharin through the Fahlberg-Remsen (top) and the Maumee process (bottom) (adopted from O'Donnell and Kearsley (2012).

No information could be retrieved on the process of ammonium sulphate purification, but it seems likely that excess ammonia is precipitated from the sulphuric acid solution.

Information on impurities in the recovered ammonium sulphate was not found from literature, but may possibly include intermediate reaction products, such as o-toluene-sulphonamide and o-sulphamido-benzoic acid (Fahlberg process), and methyl anthranilate, benzamide, methyl benzoate, and 2-chlorobenzamide (Maumee process).

7.1.6 Ammonium sulphate from methionine production through chemical synthesis

Amino acids are essential compounds for life metabolic processes, containing an amine and a carboxyl acid chemical functional group. Industrially produced amino acids are widely used in animal feed and human nutrition. Amino acids can be obtained through chemical synthesis (such as methionine), extraction from protein hydrolysates (such as cysteine), enzymatic synthesis and fermentation of sugars. This paragraph focusses on by-products from amino acids that are produced through chemical synthesis reactions, as the raw materials and manufacturing steps are similar to those from the petrochemical industry. Methionine is, to the best of our knowledge, the sole amino acid whose production process gives rise to sulphate salt-containing fertilising materials as by-product.

DL-Methionine is mainly produced by chemical synthesis from methyl mercaptan, acrolein and hydrogen cyanide (Willke, 2014). Acrolein is reacted with methyl mercaptan and the resulting product is treated with HCN to form beta-methylmercaptopropionaldehyde cyanhydrin. The latter compound is then subjected to amination by means of high pressure ammonia and the resulting methionine nitrile is hydrolysed with sulphuric acid to give a reaction product which, upon neutralization with aqueous ammonia, gives a solution containing methionine. This solution also contains **ammonium sulphate and/or bisulphate** (produced by hydrolysis of the nitrile), as well as certain (PAH-containing) **tarry impurities**. From this solution, methionine as primary product (generally by crystallization) and ammonium bisulphate as by-product will be isolated that can be further neutralised to ammonium sulphate in a subsequent step. Hence, the latter ammonium sulphate would be a by-product on condition that it is manufactured as an integral part of the methionine production process. Possible impurities in the by-product include cyanides, acrolein, methyl mercaptan, methionine nitrile, and tarry impurities.

7.1.7 Other well-defined substances (as defined pursuant regulation (EC) No 1907/2006) that are salts of ammonia (NH_4^+), nitrate (NO_3^-)-, phosphate (PO_4^{3-}), or sulphate (SO_4^{2-})

Additionally, different production processes for organic chemicals which apply excess ammonia or sulphuric acid in processing steps are potential production routes for salts of ammonia and sulphate, respectively. Though uncommon due to cost issues, sulphuric acid can also be replaced by other strong acids (phosphoric acid, nitric acid) in production processes. Although not brought forward by the Commission Expert Group, examples encompass **formic acid production** (involving the reaction of methyl formate with ammonia to give formamide ($HC(O)NH_2$), which is then hydrolysed with sulphuric acid to produce formic acid (HCO_2H) and ammonium sulphate), and **lactic acid production** (synthesised industrially by reacting acetaldehyde with hydrogen cyanide to produce lactonitrile, which is then hydrolysed the resultant with hydrochloric acid to produce lactic acid and ammonium chloride). Another possible process to recover ammonium sulphate as a by-product may involve the **production of hydroxylamine** (Raschig process). It cannot be ruled out that other production processes for organic chemicals result in the formation of by-products that are overlooked in this assessment.

7.1.8 Horizontal assessment

The envisaged by-products of this group involve salts of ammonia (NH_4^+), mostly ammonium sulphate. This is because underlying manufacturing processes apply acid-base reactions for neutralisation processes (e.g. neutralisation of ammonia with strong acids, such as sulphuric acid; though also other strong acids such as phosphoric acid or nitric acid could in principle be applied). By extension, **the products can thus be classified as salts of ammonia (NH_4^+), nitrate (NO_3^-)-, phosphate (**PO_4^{3-}**), or sulphate (**SO_4^{2-}**)**. The agronomic value for all these salts is intrinsic as outlined in section 6.1.

The greatest concerns associated to materials within the scope of this subcategory relate to the incomplete removal of reactants (e.g. solvents), final products and intermediate reaction products (e.g. coal tar obtained by cooling the gas that is formed during the destructive distillation of coal, residues from solvents applied for purification, residues of end products such as hydrocyanic acid).

Purification techniques (e.g. solvent extraction, distillation) are applied with the objective of recovering materials for re-use in the production process and to minimise the generation of waste. Therefore, by-products that are well-defined substances of **high purity** (>99%, with impurities being mostly organic compounds) can be obtained on condition that good management practices are applied with the objective of reducing the impurities in the by-product. Nonetheless, even for by-products of high purity, it cannot be excluded that trace amounts of highly hazardous substances (e.g. benzene at ppm levels) are present. The nature and hazardousness profile of potential impurities present may, however, vary widely depending on the manufacturing process, reactants applied and primary products produced. Taking into consideration the high degree of innovation in production processes (e.g. solvents applied, existence of different manufacturing process variants for a single primary product), it may be challenging to bring forward a comprehensive positive list of all possible contaminants.

As a way forward, it is proposed to proceed with the assessment of health and environmental risks for the different by-products outlined in sections 7.1.2 - 7.1.6. If supplementary data and high-quality feedback would be retrieved from stakeholders on additional materials, it can afterwards be evaluated to what extent possibilities exist to include additional salts of ammonia (NH_4^+), nitrate (NO_3^-)-, phosphate (PO_4^{3-}), or sulphate (SO_4^{2-}) under this group. Such work could then progress either on individual material basis, or through the development of more generic criteria proposals for this group.

7.2 Group B – By-products primarily obtained from the refining of minerals, ores, and metals

7.2.1 Scope

This subgroup involves materials produced during the processing of mineral, ores and metals that are generated during ore beneficiation, mineral purification, and ore and mineral processing through chemical reaction and synthesis. Materials resulting from metal finishing techniques are also considered. It also covers materials from chemical installations that process minerals and ores for the production of basic inorganic chemicals (soda ash and titanium dioxide) as well as organic chemicals (e.g. acetylene). Materials from gas cleaning systems are excluded.

7.2.2 Residues from ore beneficiation processes

7.2.2.1 Fines from dolomite processing

The mineral dolomite is a double carbonate consisting of $CaCO_3$ and $MgCO_3$. It undergoes physical classification as well as processing steps (crushing and screening) to remove the undesirable impurities, especially silica, to make the dolomite to the desired specification for particular end uses, such as MgO production (Tripathy et al., 2018). Crushing and sizing are used for the preparation of the sized high-grade material for different applications, whereas a huge amount of the minerals is left out at the processing site (mostly low-grade fine fractions, e.g. < 3 mm) as fines. The main elements are mostly calcium and magnesium carbonates (both 20-30%), and SiO2 (< 10%) (Tripathy et al., 2018). Given the mechanical processing, impurities are natural constituents and will vary depending on the local environment during the formation of the dolomite. Assuming that these materials have not been chemically modified, and only been processed using mechanical machineries, the potential risks are limited. The sole impurities presently identified may relate to the presence of **mineral oils and lubricants** originating from cutting tools.

7.2.2.2 Natural stone processing sludge (proposed exclusion)

The processing stage involves splitting carbonate rocks (e.g. calcite, dolomite, marble, and limestone) and from silicate rocks into slabs and treating their surfaces. Cutting is performed by metal blade looms and abrasive pulp (rock dust, grit, and lime) or diamond wire looms, with water aspersion to avoid suspension of the dust (Uliana et al., 2015). This process generates large amounts of residual sludge, that has been identified as a possible by-product material candidates (carbonate sludge and silicate sludge; Careddu and Dino, 2016).

The use applications of this material are mostly outside agriculture (e.g. construction material, filler) (Manca et al., 2015; Rana et al., 2016), and a single study was found that investigated the potential use of silicate stone sludges in agriculture (Zichella et al., 2020). Silicate rocks are characterised by silicate, iron and aluminum contents, but reduced amounts of Ca, Mg, and their oxides and hydroxides. In general, a direct agricultural application of silicate sludge is seemingly hindered by their limited content of components with agricultural value (Careddu and Dino, 2016). Zichella et al. (2020) generally observed lower or similar responses in agronomic efficiency of silicate stone sludge amended soils compared to the control treatment, indicating that the added value of the material in agriculture was not supported. To the best of our knowledge, no information on the agricultural performance of carbonate stone sludge is available in public databases. However, for some materials a composition similar to nearly pure carbonate has been indicated (Marras et al., 2017), for which reason a high neutralising value for agricultural purposes can be assumed.

Little information is available in literature on the contaminant profiles from stone processing sludge. Stone processing sludge has chemical characteristics different from the original mineral material because of contamination from wear of cutting tools, use of grouting chemicals, resin (e.g. bisphenol A) and polishing materials (Careddu and Marras, 2015; Manca et al., 2015; Rana et al., 2016). The contaminant profile is dependent upon the characteristics of parent rock that influences the machinery and processing techniques applied, including cutting (e.g. diamond wire possible coated with elastomeric material such as rubber and lubricants, detonating, jet piercing, gel techniques) and polishing (possibly including the use of porous tools with silicon carbide and resin-based bonders) (Careddu and Marras, 2015; Rana et al., 2016). In addition, traditional anionic flocculants, based on acrylamide or polyacrylamide, may be deployed in sludge dewatering procedures that are possibly detrimental for the reuse of the stone waste (Careddu and Marras, 2015). Hence, the content of total petroleum hydrocarbon content, mineral oils from lubricants (C12–C40), Cr(VI), and possibly other contaminants in residual stone sludge can possibly be high (Careddu and Dino, 2016).

Altogether, it is indicated that criteria setting is challenging due to variety of production methods applied, resulting in a possibly wide spectrum of contaminants for the materials covered under the general umbrella "stone processing sludge". This involves that a possible compliance scheme, if already feasible to be developed, would involve an extensive list of possible contaminants leading to high compliance costs for the operator. At the same time, the added value and the magnitude of possible applications for the EU agricultural sector remain undemonstrated. Therefore, it is **proposed to exclude this material for further assessment by the JRC in this project**.

7.2.3 Gypsum and calcium carbonate from sodium chloride brine purification

The production of pure sodium chloride by evaporation of the saturated solution cropping out of saltwater springs requires purification of the crude brine in order to remove sulphate and potassium as well as the foreign Mg, Ca and Sr (O'Brien et al., 2005; Steinhauser, 2005). Traditional brine purification is performed in the two-step Schweizerhalle process (Steinhauser, 2005). At first, the addition of calcium hydroxide thus precipitating Mg^{2+} ions in the form of $Mg(OH)_2$ and producing calcium sulphate due to the increase of the concentration of Ca^{2+} in a solution already saturated with calcium sulphate:

$$Mg^{2+} + SO_4^{2-} + Ca(OH)_2 \rightarrow Mg(OH)_2 + CaSO_4$$

During the second stage, calcium is precipitated by adding soda ash or possibly carbon dioxide:

$$Ca^{2+} + Na_2CO_3 \rightarrow CaCO_3 + 2\ Na^+$$

Only purified brine is capable to be used in modern evaporators or for the production of soda ash in a Solvay process. The brine purification process causes the onset of solid precipitates in the form of sludge.

After these two reactions Mg^{2+}, Ca^{2+}, and Sr^{2+} ions are removed almost quantitatively (Steinhauser, 2005). The insoluble precipitates are removed from the brine after each purification step. The resulting basic sludge contains gypsum, calcium carbonate, magnesium hydroxide, strontium sulphates, chlorines, some unreacted $Ca(OH)_2$, and small amounts of clay minerals (O'Brien et al., 2005).

7.2.4 Sulphate salts and metal sulphates from ore processing

The presence of calcium, magnesium, phosphorus, iron and other impurities in the **hydrometallurgical processing of ores** containing base metals, alkaline earth metals, and calcium/sulphate-rich minerals may lead to the contamination of the final product. Therefore, the ores are treated with acids (e.g. hydrochloric acid, ammonium carbonate, sulphuric acid, phosphoric acid) to remove impurities (Gominsek et al., 2005; Pereira and Papini, 2015). Examples of processing routes that generate fertilising product components as by-products submitted through the Commission Expert Group on Fertilising Products involve:

- processing of phosphorus rich minerals (e.g. apatite) for the production of phosphoric acid via the "wet process," in which finely ground phosphate rock is dissolved in phosphoric acid to form a monocalcium phosphate slurry. Sulphuric acid is added to the slurry to produce phosphoric acid (H_3PO_4) and a **phosphogypsum** (hydrated calcium sulphate) by-product that can be dried in stacks. The main impurities present in the material include **radioactive substances** (e.g. radium) and **fluoride** up to 1.5% (Chesner et al., 1999; Grabas et al., 2019). In addition, high Cd levels are observed in phosphogypsum (Elloumi et al., 2015). The latter contaminant is, however, already regulated at PFC level in the FPR, and will therefore not be considered in this work.
- processing of fluorspar (a mineral composed of calcium fluoride), with the possibility to produce **fluorogypsum**. Fluorogypsum is discharged in slurry form and gradually solidifies into a dry residue after the liquid has been allowed to evaporate in holding ponds. This produces a sulphate-rich, sandy silt material with some gravel-size particles, and a fluoride content of ~ 1.5 – 2.5% F (Chesner et al., 1999);
- processing of e.g. ilmenite to produce TiO_2 (titanium dioxide) with the possibility to generate **iron(II)sulphate and/or** gypsum (referred to as **titanogyspum**) as a by-product following sulphuric acid addition (sulphate route); and
- processing of low to medium grade strontium sulphate containing ores to produce strontium carbonate, with the possibility to recover **ammonium sulphate** following ammonium carbonate addition to the purified ore residue.

Note that gypsum can also be obtained as a by-product from the processing of mined borax (e.g. colemanite) into boric acid. The obtained boro-gypsum contains, however, secondary diboron trioxide in high concentrations that render it toxic to plants and fauna. It is therefore excluded from further assessment.

The main impurities and substances of concern for this sub-group relate to the presence of **radioactivity, fluorides, titanium dioxide, and strontium**, with the specific substances being dependent on the production process.

7.2.5 Carbide lime from acetylene production

Carbide lime or carbide lime sludge is a by-product of acetylene production through the hydrolysis of the mineral calcium carbide (Cardoso et al., 2009). Calcium carbide production requires extremely high temperatures, around 2000°C, obtained in an electric arc furnace to transform a mixture of the raw materials lime and coke. Pure calcium carbide is colourless; however pieces of technical-grade calcium carbide are grey or brown and consist of about 80–85% of CaC_2 (the rest is CaO (calcium oxide), SiC (silicon carbide), as well as possibly toxic substances such as Ca_3P_2 (calcium phosphide), CaS (calcium sulphide), and Ca_3N_2 (calcium nitride)). In contact with water, calcium carbide instantly decomposes hydrolytically, yielding acetylene gas and calcium hydroxide.

$$CaC_2 + H_2O \rightarrow C_2H_2 + Ca(OH)_2$$

The carbide lime is generated as an aqueous slurry and is composed essentially of calcium hydroxide ($Ca(OH)_2 \approx$ 85–95%) with minor parts of calcium carbonate ($CaCO_3 \approx$ 1–10%), unreacted carbon and silicates (1–3%) (Cardoso et al., 2009). Although not being classified as dangerous/hazardous, its managing and disposal require special caution, since the highly basic sludge (pH 12) can also contain **metals** (Mg, Sr, Cd, Cu, Pb, Fe, Ni and Zn; note most of them are already regulated at PFC level in the FPR) (Ramasamy et al., 2002). Moreover, it seems possible that traces of Ca_3P_2 (**calcium phosphide**), CaS (**calcium sulphide**), and Ca_3N_2 (**calcium nitride**) could be present in case technical-grade calcium carbide is applied as input material. Finally, **flocculants** (e.g. acrylamide or polyacrylamide) may be deployed in sludge dewatering procedures. Ammonium hydroxide present in supernatant (100–300 ppm) and **acetylene** dissolved in the water fraction may also be an issue, requiring appropriate ventilation during handling and storage.

7.2.6 Post-soda lime (by-product from soda ash production)

In the EU, approximately 91% of sodium carbonate (soda ash) is obtained using the Solvay method (Czaplicka and Konopacka-Łyskawa, 2019). Soda ash is predominantly sodium carbonate (Na_2CO_3) used for the industrial production processes for glass, dyes, pulp and paper or detergents as well as water softening. Soda ash is mainly produced via the Solvay process by reacting limestone (as a source of calcium carbonate ($CaCO_3$) and brine (as a source of sodium chloride (NaCl)). The process generates a by-product called post-soda lime, which accounts for approximately 40% of the soda ash production volume. Post-soda lime is obtained by separating the solid phase present in the distillation fluid from the soda. Post-soda lime mainly contains calcium carbonate, calcium sulphate, magnesium hydroxide, silica, lime scale solids, and unreacted calcium hydroxide, calcium and sodium chloride. The main impurities involve **chlorides** and possibly **metals, especially mercury** (Steinhauser, 2005; Steinhauser, 2008). Post-soda lime contains about 80% calcium carbonate ($CaCO_3$) (Twerd et al., 2017), and is therefore an effective liming material.

7.2.7 Grinded steel slags from primary and secondary production of iron and steel

About 90% (by weight) of solid by-products that come from iron and crude steel production are slags (Thomas et al., 2019). The composition of the slags includes silica, calcium oxide, magnesium oxide, aluminium and iron and are the result of removing impurities from the molten steel. Steel slags are usually classified according to the type of furnace in which they are produced. The properties of the slag depend on the type of process used to produce the crude steel, the cooling conditions of the slag and the valorisation process (Thomas et al., 2019).

Steel is produced from ores by oxidizing sulphur (S), phosphorus (P), carbon (C), silicon (Si), manganese (Mn), and other impurities so that they can enter the slag or gas phases, thus separating from the metal phase. In a first process, “pig iron” is produced from fuel (coke), ores, and flux (limestone) in the blast furnace, and a by-product is obtained by milling and/or sieving of the air-cooled and granulated iron slag (**blast furnace slags**). At times, a hot metal desulphurisation process is applied, where reagents (usually Mg, CaO and/or CaC_2) are injected or added to react with the dissolved sulphur. The formed sulphides (CaS and MgS) end up in the slag layer that floats on top of the hot metal. This slag is then skimmed off to permanently remove the sulphur (**hot**

metal desulphurisation slag) (Schrama et al., 2020). In a further process step, the so-called basic oxygen steelmaking, remaining impurities (mostly carbon and sulphur) are oxidised by blowing oxygen onto the liquid pig iron to form crude steel in an oxygen converter. During this process, **basic oxygen furnace slag** is produced. Using a different method, slags are generated in the scrap-based steel industry. The first stage of the scrap-based steel industry production generates **electric arc furnace slag** and a second stage is performed to refine the molten steel.

To further refine the steel after coming out of the basic oxygen furnace and electric arc furnace, fluxes are added to the molten steel while in a ladle. The slag from this process is usually called **ladle slag** (Thomas et al., 2019). The chemical composition of ladle slag is significantly different from that of steel furnace slag in that the former has a very low FeO content, a higher Al_2O_3 content. The difference in chemical composition results in different mineral composition. Ladle slag has a CaO/SiO_2 ratio of around 2 and consists mainly of dicalcium silicate (Shi, 2002).

Potential substances of concern in slags may involve **mineral oil, metals like Be, V, Cr,** Zn, Pb, Mo, As, Hg, Cd (some of which already regulated in the FPR), other inorganic substances such as **chlorides** (Kobesen, 2009). Incomplete and/or inefficient combustion of fossil fuels may generate PAHs and **PCDD/F,** that could be trapped in slags (Almaula, 2005). Although Cr(III) is an essential element for animal and human health, both Cr(III) and V may be especially toxic to aquatic organisms in concentrations < 5 µg L^{-1} (see ECHA dossier for chromium trioxide) (Smit, 2012). The long-term use of steel slags in agriculture has also been shown to increase the bulk concentrations of Cr and V in soils, even in soil horizons below the ploughing layer (Kuhn et al., 2006; Hejcman et al., 2009; Algermissen et al., 2016). Most of the metals present in steel slags are tightly bound to the solid matrix, but the presence of easily-mobilisable and leachable Cr and V fractions have been observed in laboratory and field settings (Proctor et al., 2000; Hejcman et al., 2009; Hobson et al., 2017; Reijkonen, 2017). Slags may also contain high levels of titanium oxides, some of which are suspected of causing cancer, but little information is available on their possible release dynamics in the environment upon soil application.

Slags are also produced by other (metal) industries and processes. Nonetheless, materials such as non-ferrous (e.g. Cu, Ni, Pb, Zn) slags, ferrosilicon slag, ferrochromium slags and precious metal refining are not listed under the product category “Fertilisers (PC 12)” in the ECHA database, and will therefore not be considered in this assessment. Non-ferrous slag leachate generated during base metal extraction is commonly more metal-rich than leachate from ferrous slags (Piatak et al., 2015).

7.2.8 Inorganic salts from metal surface treatment (e.g. etching, staining, polishing, galvanising, cleaning, degreasing and plating)

Metal products require pre-treatment to remove rust or scale, impurities and inorganic contaminants, e.g. in the production of steel or copper alloys. Since lubricants and oils may have been applied in certain metal processing steps (e.g. cooling lubricants, cutting fluids), these are removed using solvents, emulsifiers, or surfactants, such as alcohols, oil-based substances and hydroxides (e.g. methylene chloride, propylene glycol) (Kuenen et al., 2009). After a rinsing step, the **pickling step** involves the removal of impurities, such as stains, inorganic substances, rust or scale, using hydrochloric acid, sulphuric acid, or phosphoric acid. This process generates a considerable quantity of spent (pickle) liquor containing the residual free acid as well as dissolved metal salts of iron, chromium, copper, nickel, zinc or other metals depending on the process applied

(Devi et al., 2014). After the picking step, the corrosion resistance of the metal can be increased using **phosphating** (formation of a layer of phosphate coating typically includes iron, zinc or manganese crystals; using phosphoric acid and e.g. zinc or manganese salts), **galvanisation** (applying a protective zinc coating to steel or iron, using molten zins and possibly fluxing solutions of zinc chloride and ammonium chloride), or **anodising processes** (i.e. the process of increasing the thickness of the natural oxide layer on the surface of metal using for example nitric acid or sulphuric acid). Finally, other industrial processes, such as **wet etching** rely on a similar principle of removing the top layer of a multilayer structure using etchants such as nitric acid, phosphoric acid, or potassium hydroxide.

In common, these processes involve putting into contact a metal in a (hot acidic) solution that can be recovered in a state that enables further use as a component for EU fertilising materials (e.g. **ammonium sulphate, gypsum, zinc sulphate, iron sulphate, copper salts**). Techniques applied to recover concentrated materials involve evaporation, precipitation, solvent extraction or membrane separation (Devi et al., 2014).

The possible impurities and/or contaminants are similar to those identified for steel slags (**mineral oils from grease and oils, metals including Cr, or V**). In addition, **other metals** may be present in trace amounts depending on the material that is processed (e.g. tungsten (W) can be present in alloys manufactured for aerospace and automotive applications). For agricultural purposes, the **free acids** should be reduced to acceptable levels. Finally, solutions are at times mixed with **substances (e.g. hydrofluoric acid, hydrogen peroxide, organic solvents) that are not used in agriculture** (Devi et al., 2014).

7.2.9 Horizontal assessment

The nature of the by-products proposed for this category vary widely in their nature, from sludges, over slags to ammonium salts from metal rinsing. Considering that the primary products of the manufacturing process are mostly intermediate and construction materials, the production techniques applied for this group are generally basic and well-established techniques (e.g. thermochemical processes, flocculation-coagulation, lime precipitation, leaching and acid rinsing). As a result of the process techniques applied, by-products are generally of a lower purity compared to group A. They often involve mixtures with different impurities that are present in substantial concentrations (% range). Also the agronomic value for the different materials is material-specific; from materials of high added value for agriculture to materials that have even been proposed for exclusion based on the incomplete knowledge base on their agronomic value (see section 6.4). The contaminants that could be present in the by-product materials are largely determined by the starting materials (e.g. metals and metal salts, inorganics (F^-, Cl^-), sulphides, radioactive substances). In addition, the processing techniques applied could introduce additional contaminants, such as mineral oils and flocculants.

Based on these observations, it seems appropriate to develop criteria based on **a positive list**. This will ensure that both the agronomic value as well the impurity profiles can be subject to a detailed screening.

7.3 Group C – By-products from gas cleaning systems, other than those from the chemical industry and waste management

7.3.1 Scope

The scope involves effluent gases and dust emissions from industrial facilities that can be recovered as a fertilising product component. Substances present in gases from thermal power plants, metal and mining industries, and (bio)gas plants, that have been transformed into materials such as gypsum, elemental sulphur, ammonia salts, etc. By-products will be considered whenever they are the result of a manufacturing process for commercial products (e.g. steel, electric power, biogas, fertilisers, compost; in line with the reference to "resulting from a production process" in EU legislation).

Materials that are produced during the processing and management of waste materials fall beyond the scope of this work. In our view[12], the treatment and management of waste materials cannot be considered a production process in the sense of Article 5 of Directive 2008/98/EC on waste, and any resulting materials can thus not be classified as a 'by-product'. This has important implications for the materials for group C because following feedstocks are waste materials:

- Bio-waste, defined as "biodegradable garden and park waste, food and kitchen waste from households, offices, restaurants, wholesale, canteens, caterers and retail premises and comparable waste from food processing plants'. It does not include forestry or agricultural residues, manure (on condition that it is not destined for incineration, landfilling or use in a biogas or composting plant), or other biodegradable waste such as natural textiles, paper or processed wood. It also excludes those by-products of food production that never become waste.
- Animal by-products (e.g. manure) including processed products (e.g. meat and bone meal) covered by Regulation (EC) No 1774/2002, that are destined for incineration, landfilling or use in a biogas or composting plant;
- Sewage sludge;
- Any other waste materials that are used as fuel for co-incineration plants.

Materials derived from waste can only be regarded as "not being waste" if they have obtained end-of-waste status. The recovery of components from such materials should occur via meeting national or EU End-of-Waste criteria, and any recovered materials from these waste streams will not be by-products.

Amongst others, this implies that following materials proposed by the COM Expert Group on Fertilising products are **excluded for further assessment under CMC 11**:

- Ammonia salts from the absorption of ammonia at anaerobic digestion plants that use bio-waste, sewage sludge, or any other waste material as (one of the) input materials;
- Elemental sulphur from the purification of biogas from anaerobic digestion plants that process bio-waste, sewage sludge, or any other waste material;
- Gypsum from thermal power plants that use waste as a fuel for co-incineration.

The air and **off-gases of livestock animals are not subject to Regulation (EC) No 1069/2009 on animal by-products**, and fall thus within the scope of CMC 11. Livestock derived NH_3-rich off-gases are subject to Regulation (EU) 2016/429 on transmissible animal diseases and its delegated acts (the Animal Health Law) that deal with virus born diseases that may be transmitted by aerosols.

---

[12] Reflecting the views of the team of the Joint Research Centre that has elaborated this document after consultation with the Directorate-General Environment of the European Commission.

Under normal circumstances, there is no limitation for farmers and operators to harvest ammonium from the air and produce ammonium salts. However, in case of suspicion of a category A disease referred to in Article 55 of Regulation (EU) 2016/429, all establishments in the restricted zone are closed and operators are prohibited to move animals and products from the restricted zone as laid down in Article 55(1)(e). This implies that – amongst others - following candidate materials fall **within the scope of CMC 11**:

- ammonia salts produced from the off-gases of stables (animal housing);
- ammonia salts produced from manure storage facilities (on condition that they are not destined for incineration, landfilling or use in a biogas or composting plant)

It is proposed to exclude by-products from the chemical industry (as defined in Annex I of Directive 2010/75/EU on industrial emissions (IED)). The chemical industry is responsible for only 4% of the SOx emissions (JRC, 2019), whereas the potential for NH_3 recovery is also low (~9%). In spite of its limited emissions and fertilising component recovery potential, the sector is responsible for e.g. >90% of the total amount of tetrachloromethane, vinyl chloride, dichloromethane, and ethylene oxide emitted to air by all installations covered by the E-PRTR (JRC, 2019). Likewise, many other volatile organic compounds of concern are emitted from by this industry as a whole (JRC, 2019). The character and scale of emissions across individual chemical plants are highly variable. Emissions may depend on factors such as raw material composition, product type, nature of intermediates, use of auxiliary materials, process operating conditions, type of process-integrated techniques to prevent or reduce emissions and type of end-of-pipe treatment (JRC, 2019). Hence, in view of the limited market potential for recovering by-products from this industry, the risk of increasing the complexity of the compliance scheme as well as the efforts required for risk assessment for by-product materials from this industry sector is high.

7.3.2 Materials from flue-gas desulphurisation of fossil fuels

7.3.2.1 Background

Across the EU, sulphur oxides (SO_2/SO_x) are principally being emitted by the energy industry (mainly power plants), and metal and mineral industries (energy for smelting of iron ores in steel industry, but also from the roasting of metal sulphide ores), that jointly emitted ~95% of the total emissions (after the application of abatement techniques; JRC, 2019). Fossil fuel combustion (e.g., coal, petroleum, natural gas) has been widely practiced in industry as a method of producing steam for the use of turbines in electricity generation, production of heat in concrete and paper industries, smelting of iron ores in steel industry, etc. The fossil fuel used typically contains 0.5–5% sulphur, which implicates that the burning of such materials will release sulphur oxides (SO_2 and SO_x) into the atmosphere (Hanif et al., 2020). Flue-gas desulphurization substances are materials of a process typically used for reducing SO_x emissions from the channelled emissions at thermal oxidation facilities.

Note that the scope of this group limits this sub-group to materials that are recovered from raw material fossil fuels (section 7.3.1), and that materials recovered from flue-gas desulphurisation systems of co-incineration plants that use waste as feedstock fall beyond the scope of CMC 11.

The physical nature of the materials produced from flue-gas desulphurisation systems varies from a wet sludge to a dry, powdered material depending on the process applied (Cheremisinoff, 2012). In general, absorption (wet scrubbers, based on the principle of an acid-base chemistry reaction) is the most common technique within flue-gas desulphurisation systems of large plants that produce fertilising materials as by-products (Brinkmann et al., 2016; Lecomte et al., 2017; JRC, 2019). Other desulphurisation techniques can be applied, including spray dry scrubber/absorber, circulating fluidised bed dry scrubber, duct sorbent injection, furnace sorbent injection (Lecomte et al., 2017). However, the typical resulting materials of these processes do not contain materials that can be directly used on land as components for fertilising products. Some of these materials can, however, be recovered in sulphur recovery units that are an integrated part of large industrial facilities.

7.3.2.2 Sulphate salts from SOx wet scrubbing techniques applied in forced oxidation mode

Absorption techniques are based on the principle of an acid-base chemistry reaction of an alkaline slurry with acidic sulphur dioxide ("wet scrubbing") (Brinkmann et al., 2016; Lecomte et al., 2017; JRC, 2019). The flue gases are channelled into a spray tower where an aqueous slurry is injected into the flue gas. As the gas comes in contact with the alkaline solution, sulphur dioxide absorbs into the liquid, after which a slurry is collected at the bottom of the absorber. Alkaline solutions are typically a slurry of alkaline sorbent, usually a mixture of limestone or hydrated lime and water to scrub gases. This technique removes sulphur from flue-gases through injection of a slurry of lime/limestone sorbent (liquid solution) into the scrubbing suspension to capture SO_2 and transform it into gypsum (Lecomte et al., 2017). Magnesium scrubbing systems are also used in relatively small industrial boilers, mainly due to the low capital costs involved. The reagent in magnesium scrubbing is magnesium hydroxide, which is produced by adding slaked lime to seawater in order to enhance alkalinity. In addition, ammonia, sodium hydroxide and sodium carbonate potentially can be applied with a view to produce by-products to be used as fertilising product components. Potential high-quality by-products generated through these processes are **Ca-, Mg-, NH_4-, and Na-sulphates** that can be used as components for fertilising products. The sulphate recovered from the absorber recycle slurry can, however, be high in unreacted reagents (e.g. limestone) and sulphite ash, depending on the alkaline reagent and oxidation mode applied.

In natural oxidation mode, sulphite is partly oxidised by the oxygen contained in the flue-gas, producing a mixture of sulphite hemihydrate and sulphate salts is in a sludge form that is not suitable for direct use on land as a fertilising product component. In forced oxidation mode, however, air is introduced into the bottom of the absorber to oxidise sulphite to sulphate, achieving over 99% oxidation (modern *in-situ* systems). Originally, the process was made up of two absorbers and an oxidation unit (*ex-situ*). SO_2 and the basic slurry are absorbed in the absorber, whereby a mixture of sulphites and sulphates are created. In the oxidation barrel under the absorber, this is then converted into sulphates at a relatively low pH (5.5 - 6) using air, **peroxide, or sodium hypochlorite**. In forced oxidation, dewatering is more simple due to the larger crystal sizes obtained with the primary dewatering is usually accomplished by hydrocyclones, followed by secondary dewatering in filters or centrifuges (Lecomte et al., 2017).

The solids can contain significant chloride concentrations, as **often the chloride levels** in the scrubber process slurry can reach or exceed as much as 3%. This is particularly true at plants burning eastern bituminous coal. This can be overcome by installing a freshwater wash at the beginning of either the vacuum drum or the belt filter process. Calcium chloride, and the much smaller concentrations of magnesium chloride, are soluble and quickly wash out of the filter cake.

7.3.2.3 Regenerable techniques

Specific technologies (e.g. amine units, sour water stripping units; see Brinkmann et al., 2016) adsorb H_2S gases. During the sorbent's regeneration, the sulphur compounds are released and treated in sulphur recovery units, which most often consists of a Claus process (see section 7.3.3).

7.3.2.4 Potential impurities from SOx wet scrubbing techniques

In fully oxidative incineration, the main constituents of the flue-gas are: water vapour, nitrogen, carbon dioxide and oxygen. Depending on the composition of the input material and on the operating conditions, smaller amounts of CO, HCl, HF, HBr, HI, NO_x, NH_3, SO_x, volatile organic carbon (VOC), PCDD/F, PCBs and metal compounds remain or are formed in the gas phase (Neuwahl et al., 2019).

Alkaline solutions may trap acidic compounds such as hydrogen halides, leading to the presence of **Cl^- and F^-** in the by-products (Chen et al., 2020). In addition, **sulphides** (e.g. calcium sulphide, entrapped hydrogen sulphide in sludges) could be present in case of incomplete oxidation (Raiswell and Bottrell, 1991; Lecomte et al., 2017). Sulphide is known to be able to hamper plant nutrient uptake, which is not surprising given its basic disturbance of cell metabolism and energy transfer (Lamers et al., 2013). In addition, root loss due to die-off and concomitantly decreased root to shoot ratios lead to an unbalanced nutrient uptake. Sulphide can impair the uptake of N, P and Fe (Lamers et al., 2013).

The term VOCs covers a diverse group of substances and includes all organic compounds released to air in the gas phase, whether hydrocarbons or substituted hydrocarbons (Falcke et al., 2017). Their properties, and hence need for control, vary greatly and so systems have been developed to categorise VOCs according to their harmfulness. Some VOCs may also be highly odorous, for example **mercaptans**, and **other organic sulphur-containing compounds**. Mercaptans, commonly referred to as thiols, are organosulphur molecules composed of carbon, hydrogen, and sulphur that are known for having a pungent odor similar to rotten cabbage or garlic.

Persistent organic compounds such as **(polyaromatic) hydrocarbons, PCDD/F, PCBs** are most likely not present in desulphurisation gypsum from wet scrubbing systems due to their low affinity for (alkaline) scrubbing solutions (Brinkmann et al., 2016), but measurements demonstrating their absence in the by-products is lacking.

Traces of metal compounds, including commonly regulated metals (e.g. As, Hg, Cd; also regulated at PFC level in the FPR) as well as metals that are more often excluded from regulatory frameworks for fertilisers (e.g. Cr, Se, Tl, V) could be present. Based on an initial literature review, the concentrations of Hg and of some other metals (e.g. Tl) that are not regulated at PFC level (and thus within the focus of this study) seem to be of possible concern for agricultural use (Lee et al., 2009; Panday et al., 2018; Torbert et al., 2018).

7.3.3 Elemental sulphur from thermal sulphide oxidation processes (sulphur recovery unit)

7.3.3.1 Elemental sulphur from the magnesium oxide process

The magnesium oxide process is a regenerable wet scrubbing process, which uses magnesium hydroxide solution as sorbent (Lecomte et al., 2017). The technique is essentially the same as for the limestone wet scrubber except for the regeneration step for the spent sorbent. The flue-gas then enters the scrubber, where the SO_2 is absorbed by aqueous slurry of magnesium sulphate, formed from the magnesium hydroxide sorbent. The reaction product, magnesium sulphite/sulphate, is bled continuously from the absorber and dried in a dryer. The magnesium sulphite/sulphate is calcined at high temperature in the presence of carbon, to regenerate magnesium oxide that is returned to the absorption system. As a by-product, elemental sulphur is obtained in the process, that can be used as a fertiliser (Boswell and Friesen, 1993).

7.3.3.2 Modified Claus process

The catalytic (modified) Claus process is amongst other central to gas plants and refineries that process off-gases from amine units, sour water (H_2S) strippers from steam stripping and quenching, and pulp/paper mills. Also for solid adsorption/regeneration processes that employ a solid sorbent or catalyst, the Claus process can be applied. Here, S or N species are liberated for reuse from the sorbent in the regeneration step, which generally requires a high temperature for reducing the gas for a sufficient residence time.

The Claus recovery unit includes thermal oxidation of H_2S in the gas phase with air (or air enriched oxygen) at high temperature (>850°C, often maintained above 1050°C) with the formation of elemental sulphur, SO_2, water and some impurities (mainly carbonyl sulphide and carbon disulphide). The thermal stage is followed by a waste heat boiler producing high-pressure steam, and a sulphur condenser where liquid sulphur is separated from the gas. Afterwards, the remaining gas is heated and sent to a series of two or three catalytic reactors (e.g. with activated aluminium (III) and/or titanium(IV) oxide) where the residual (unburned) H_2S and SO_2 react with each other to produce sulphur captured in either liquid (in hot region) or solid form (in cold region) (Speight, 2007; Lavery et al., 2019). Practically, the process is thus divided into two main stages consisting of thermal stage and some catalytic stages.

7.3.3.3 Sub-group assessment

The purity of the obtained elemental sulphur has been documented as very high (99.5% to 99.99%) (Scafe et al., 2005; Sofekun et al., 2018; Lavery et al., 2019), with minor impurities documented as hydrocarbons, embedded hydrogen sulphide gas and calcium sulphide. The impurity profile is expected to be similar to materials obtained from wet scrubbing techniques (see section 7.3.2.4).

7.3.4 By-products from biomass gases

7.3.4.1 Background and scope

All materials originating from facilities that process waste materials, including bio-waste and manure destined for composting or use in a biogas plant, are excluded from this sub-group (see section 7.3.1). This sub-category is limited to by-products from facilities that capture biomass-derived off-gases from (i) production processes starting exclusively from (by-)products (e.g. primary raw materials such as energy crops, by-products of food production that never become waste), and (ii) animal digestive tract and manure not destined for incineration, composting or digestion (present in e.g. stable ventilation air, manure storage tanks).

7.3.4.2 By-products from biogas H_2S desulphurization technology

Biogas is a renewable energy consisting mainly of methane (CH_4) and carbon dioxide (CO_2). Other gases such as nitrogen (N_2), water vapour (H_2O), ammonia (NH_3), hydrogen sulphide (H_2S) and other sulphur compounds may also be present. Removal of H_2S is often required for reasons of health, safety, environment and corrosion of equipment such as gas engines, boilers and piping. Desulphurization is also is necessary when biogas is upgraded to natural gas quality and injected in the grid.

The hydrogen sulphide concentrations can vary from 200 ppm up to several volume percentage. The concentration of hydrogen sulphide in the gas is a function of the digester feed substrate and inorganic sulphate content. Protein rich materials containing sulphur-based amino acids (methionine and cysteine) can significantly increase biogas hydrogen sulphide levels (Rasi et al., 2007). Hence, the presence of manure as well as feedstock containing residues from specific plant (e.g. legumes) may show high H_2S levels (Rasi et al., 2007). Different techniques are applied for

H_2S removal, but only a limited set of techniques enables the recovery of H_2S as elemental S for possible use in fertilising products (Horikawa et al., 2004; Allegue and Hinge, 2014; Xiao et al., 2017).

7.3.4.2.1 Chemical absorption by catalytic oxidation with chelated-iron salt solutions

In processes based on iron chelating, H_2S is initially physically absorbed into water undergoing dissociation into sulphides (S^{2-}). A catalyst achieves the oxidation of hydrogen sulphide into elemental sulphur. Most commonly aqueous [Fe(EDTA)]− is used for conversion (Wubs and Beenackers, 1993; Allegue and Hinge, 2014):

$$[\mathrm{Fe(EDTA)}]^{-} + H_2S \rightarrow 2\,[\mathrm{Fe(EDTA)}]^{2-} + S + 2\,H^{+}$$

The chelating agents prevent the precipitation of iron sulphide or iron hydroxide such that the reduced (ferrous) iron can be re-oxidised to ferric iron by air stripping.

Catalytic scrubbing processes on the market are for example the LO-CAT® and MINI-CAT® redox chemistry technology (Gas Technology Products–Merichem), the SulFerox® (Shell), the Sulfothane® (Biothane corporation) and the Apollo Scrubber (Apollo Environmental Systems Corp.).

Little information is available on the composition of the sulphur slurry that is generated. Nagl et al. (2014) provided information on the LO-CAT® material, that has impurities in the form of thiosulphates and carbonates (both 1.2%), and trace levels of Fe (likely method-specific; here due to the use of Fe-EDTA) and organic C (both 85 mg/kg).

7.3.4.2.2 Biological and combined techniques

The process of biogas desulphurization can be divided into three stages: (1) the dissolution process of H_2S gas by gas-liquid double membrane transfer to the liquid phase; (2) the dissolved H_2S enters the desulphurization bacteria through the cell membrane; (3) the intracellular H_2S is converted into sulphate and elemental sulphur that can be recovered as a fertiliser (Xiao et al., 2017).

In **biofilters and biotrickling** filters, the biogas is forced through a moist, packed bed that contains microorganisms (Allegue and Hinge, 2014). Microbes grow on the surface and crevices of the support, forming a biofilm. The H_2S in the biogas is transferred from the gas phase into the biofilm, where it is used as energy source by the microorganisms producing mainly sulphur if the oxidation is partial or sulphate if it is total. The main difference between biofilters and biotrickling filters is the nature of the carrier material, organic in biofilters and inert in biotrickling filters. The bacteria normally used for H_2S removal are aerobic, and therefore they require oxygen. The conventional way of supplying oxygen into a biofilter/biotrickling filter is injecting directly air (4 – 10%) into the gas stream. Commercial systems involve the Biopuric process (DE) (https://cms.esi.info/Media/documents/134247_1474366489261.pdf), the BioSulfurex® system (https://www.dmt-et.com/products/sulfurex/) (NL), the EnviTec biological trickling filter (https://www.envitec-biogas.co.uk/fileadmin/media/pdf_downloads/subpage_infocenter/brochures/External-desulphurisation_EN.pdf), and the BiogasCleaner® desulphurization plants (https://www.biogasclean.com/CustomerData/Files/Folders/6-pdf-er/118_16-10-11-biogasclean-profile-eog.pdf) (DK) (Allegue and Hinge, 2014).

A **bioscrubber** consists of two reactors (Allegue and Hinge, 2014). The first part is an absorption tower, where pollutants are absorbed in a liquid phase. This liquid phase goes to a second reactor, the activated sludge unit. In the latter, microorganisms grow in suspended flocks in the water degrading the pollutants. The effluent of this unit is recirculated over the absorption tower. Nutrient addition, oxygen and pH are continually controlled to maintain microbial growth and high activity. The excess biomass and by-products are continually purged from the system. The most well-known scrubber system for removal of H_2S from biogas is the THIOPAQ™ Process licensed by Paques (https://en.paques.nl/products/featured/thiopaq-biogas-desulfurization), based on the principle of continuous regeneration of an alkaline solution (sodium hydroxide, pH 8-9) that is biologically oxidised to elemental sulphur in a bioreactor by natural occurring microorganisms and air.

7.3.4.2.3 Sulphur recovery unit

In addition to the above listed techniques, H_2S gases can also be removed using regenerative systems, after which the sulphur compounds can be recovered using the techniques outlined in section 7.3.3.

7.3.4.3 Materials from NH_3 scrubbing

Emissions of ammonia from >5800 industrial facilities covered by the E-PRTR to air amounted about 200 kilotonnes in the year 2010 in the EU (Brinkmann et al., 2016). By far, the largest share of ammonia emissions originated from the intensive rearing of poultry and pigs (>80%). Other possibilities to recover NH_3 in the form of ammonia salts from scrubbing units are located at manure storage and drying/pelletising units (Melse and Ogink, 2005; Serna-Maza et al., 2014; Ehlert et al., 2019).

The absorption principle based on acid-base chemistry can be applied to scrub NH_3, a basic gas, in an acid solution (mostly sulphuric acid, but possibly also nitric acid, phosphoric acid). Resulting materials from the wet scrubbing process, such ammonium sulphate, ammonium nitrate and ammonium phosphates, can be used as as fertilising product components. Alternatively, electrodialysis, biological techniques (biotrickling filters along the same principle as applied for biogas desulphurisation, but with ammonia oxidising bacteria) as well a combination of techniques, can be applied (Van der Heyden et al., 2015).

7.3.4.4 Sub-group assessment

The possible impurities that could be present in the elemental sulphur mud and ammonia salts is limited to the volatile compounds in the process feedstock. Therefore, the identity as well as the concentrations of impurities present are largely dependent on the input material stream (Papadias and Ahmed, 2012). With the exclusion of waste and chemical industry materials as part of the scope for this sub-group (see sections 7.3.1 and 7.3.4.1), the risks are limited.

Depending on the technology and operational conditions applied, the presence of **hydrogen sulphide** (in the range of < 10 to >1000 mg/L) has been indicated in elemental sulphur mud (Papadias and Ahmed, 2012). The concentrations of **mercaptans** (methyl mercaptan, ethyl mercaptan), VOCs, and other organosulphur compounds/sulphides (**dimethyl sulphide, dimethyl disulphide, carbonyl sulphide, carbon disulphide**) are low, in the range of 0-10 mg L^{-1} (Papadias and Ahmed, 2012). For materials from NH_3 scrubbing systems, trace impurities present could be fatty acids, dimethyl sulphides and volatile amines (e.g. methylamine, dimethylamine, ethylamine, and trimethylamine) (Schade and Crutzen, 1995; United Nations Economic Commission for Europe (UN ECE), 2009). Most likely, the presence of these compounds at trace levels result in negligible risks due to their low concentrations, ready biodegradability and relatively low toxicity for humans and the environmental. Finally, the presence of **airborne microorganisms** in biomass and bio-waste and manure processing plants has been observed (Sánchez-Monedero and Stentiford, 2003; Wéry, 2014), with no information on their possible occurrence in the candidate by-product. Regulation (EU) 2016/429 on transmissible animal diseases and its delegated acts (the Animal Health Law) already deal with virus born diseases that may be transmitted by aerosols.

7.3.5 Ammonium sulphate from coke production

When producing coke by coal carbonisation, a large volume of gas is produced; this gas is treated in the by-product plant to give a clean fuel gas after removing condensable, corrosive or economically valuable components. The gases contain minor quantities of ammonia, hydrogen sulphide, hydrogen cyanide, ammonium chloride, benzene, toluene, xylene and naphthalene and other aromatics, tar components, tar acid gases (phenolic gases), tar base gases (pyridine bases) and carbon disulphide (Wright, 2002).

The gas is sprayed with flushing liquor as it leaves the individual oven chambers, the objective being to reduce the temperature to a reasonably low value and to condense the most easily condensable (high boiling point) components. Spraying the gas with ammonia liquor will condense from the gas the high-boiling tar vapour compounds and ammonium chloride (Wright, 2002). The gases, together with flushing liquor and condensed tar, pass along the collecting main and through a butterfly control valve before leaving the battery area. The tar will form a separate liquid phase with the hot spray liquor and the ammonium chloride will dissolve in the liquor. The tar and liquor are separated from the gas stream at the downcomer and pass to the tar decanting plant. Following initial cooling and passage through the exhausters the coke oven gas flows in sequence through a number of vessels which incorporate means for removing undesired or saleable components (Wright, 2002).

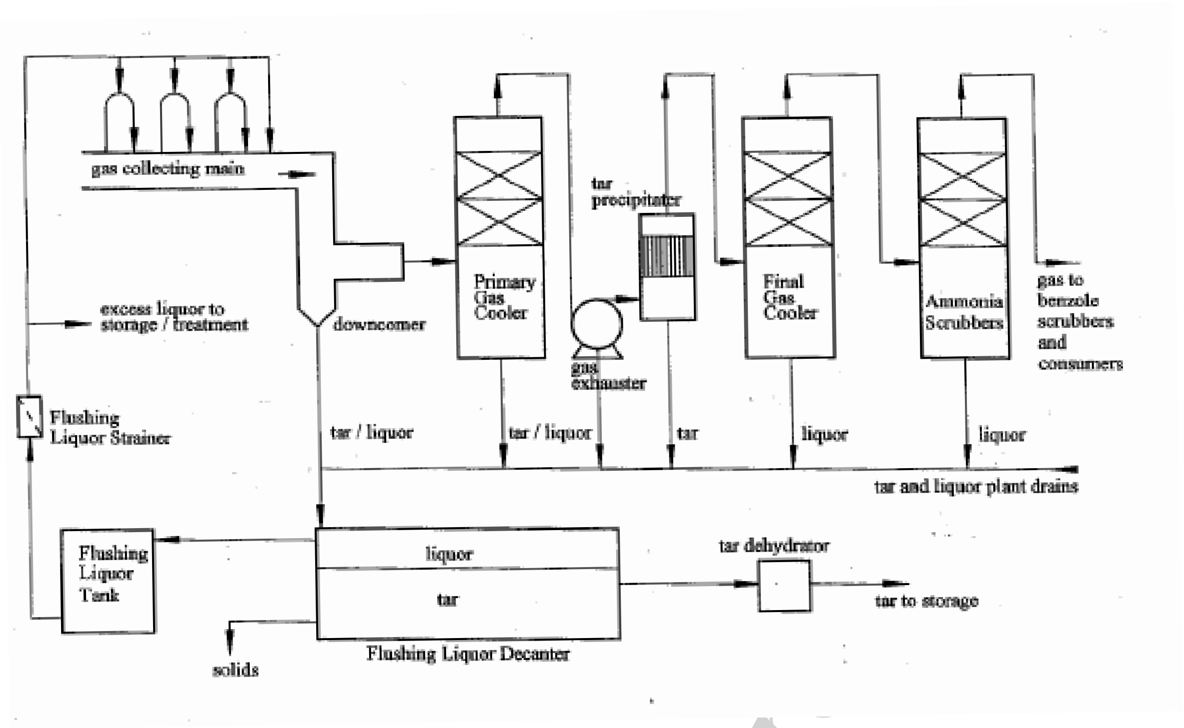

Figure 4: Overview of the coke production process (adopted from Wright et al., 2002)

The primary ammonia recovery equipment in the coke oven by-product plant deals with the removal and disposal of the ammonia present in the coke oven gas. However, these systems often include facilities to handle the ammonia arising in the excess flushing liquor after the application of “stripping” techniques in an alkaline environment. Methods for the removal of ammonia from the gas stream are the ammonium sulphate process, the water wash process and the **Phosam process** (Wright, 2002). The Phosam process is a means of producing a saleable, commercially pure anhydrous ammonia product from the ammonia present in raw coke oven gas. Since anhydrous ammonium should be further processed it is not a fertilising material that can be used “as such”, and thus beyond the scope of this work.

One of the simplest and most frequently used methods of removing ammonia from coke oven gas is to absorb it in water (water wash process). The rich ammonia solution formed, with a typical concentration of 5 to 8 g/L, is then fed to a distillation column where the ammonia is stripped from the aqueous liquor using steam, and scrubbed as described above. The ammonium sulphate process removes ammonia from the coke oven gas by absorption (“scrubbing”) in a solution of ammonium sulphate and sulphuric acid. Techniques may be in place to remove organic and inorganic impurities (e.g. froth flotation device, preheating liquors in vessels to cause vaporisation). The ammonium sulphate produced by the reaction of ammonia with sulphuric acid is recovered by crystallisation. The crystals are then centrifuged, washed and dried. Various ammonium sulphate systems in operation differ in the type of gas/liquor contacting device and the type of crystallisation equipment used. Brownish grey to white crystals are formed dependent to their degree of purity. Today`s commercial ammonium sulphate is generally of high purity (> 99 %), with a water content of < or = 0.2% w/w, heavy metals < or = 5 mg/kg and iron < or = 5 mg/kg, and free acid < or = 0.01% w/w.

The ammonium sulphate process can become contaminated by **tar** and by absorption of **acid gases** (HCN and H_2S) in solutions and chlorides that are recirculated within the N recovery system (Wright, 2002). The tar consists mainly of a mixture of numerous **heterocyclic organic** (e.g. pyridine) and **aromatic hydrocarbons** (from volatile benzene, toluene and xylene to polyaromatic compounds which are solids at room temperature, such as naphthalene). Also carbon disulphide can be present in the recovered ammonium sulphate (Wright, 2002).

7.3.6 Dust particles from limestone crushing plant, and flax/grain processing (proposed exclusion)

Filter dust, which builds up in lime kilns and at lime grinding mills, has very fine material with a composition similar to limestone (Lewis and Crocker, 1969). Flax (*Linum usitatissimum*) has been grown and its fibres have been spun and woven into linen fabrics since antiquity (Buick and Magee, 1999). The grinding process in the milling industry transforms grain into a variety of powders destined for human nutrition and animal feeding (Dacarro et al., 2005). **Dust may act as carriers of metals, microorganisms and toxins** (Lauf et al., 1982; Swan and Crook, 1998; Buick and Magee, 1999; Goluchowska et al., 2012). Concentrations in limestone dust of 165 and 290 mg kg^{-1} have been measured for nickel and lead, respectively (Goluchowska et al., 2012). Moreover, the fate and possible partition across materials of different particle sizes for other contaminants, such as (chemical) limestone grinding aids (Sohoni et al., 1991), remains largely unknown.

Hence, it is proposed to **exclude this material for further assessment in this study** due to its high adsorption capacity that induces risks for material contamination by trace metals and other impurities present during the processing of minerals and biological materials.

7.3.7 Horizontal assessment

By-products from gas cleaning systems that are possible components for fertilising materials encompass abated sulphur compounds (elemental sulphur and sulphate salts, such as gypsum), and recovered ammonia. For sulphur compounds, the main issue is to ensure that by-products are limited to materials of high purity and that any reduced compounds (e.g. sulphides) are transformed into plant available sulphur compounds. Therefore, different techniques have been listed that encompass flue-gas desulphurisation systems, sulphur recovery units, and chemical and biological biogas desulphurisation systems. Possible contaminants involve those present in the off-gasses, but their presence should be reduced to a few compounds due to the thermal oxidation process applied or the limitations on input materials. It is proposed to proceed with the assessment of materials resulting from these processes on a case-by-case basis. Based on the information and knowledge gained, it can be evaluated to what extent opportunities may exist to formulate “technological neutral” criteria proposals, if appropriate.

7.4 Group D – by-products from the processing of biomass and water for food, drink and biorefinery industries

7.4.1 Scope

This subcategory includes by-products obtained from the processing of biomass (biomass, including microorganisms and algae) for the production of food, feed, drinks and a spectrum of bio-based products from biorefineries (e.g. fine chemicals, bioenergy, pharmaceuticals, and paper). The term bio-refinery is used for a wide range of activities which have in common that biomass is separated into different functional components, which can be used as feedstock or directly as co-products (Croezen et al., 2006).

Some materials that fall within the scope of this subcategory are already covered under other CMCs:

- CMC 2: plants, plant parts or plant extracts having undergone no other processing than cutting, grinding, milling, sieving, sifting, centrifugation, pressing, drying, frost treatment, freeze-drying or extraction with water or supercritical CO_2 extraction. For the purpose of this point, plants include mushrooms and algae and exclude blue-green algae (cyanobacteria). These materials are also exempted from REACH registration as per Annex V of Regulation (EC) 1907/2006.
- CMC 6: selected food industry by-products:
  - (a) food industry factory lime, i.e. a material from the food processing industry obtained by carbonation of organic matter, using exclusively burnt lime from natural sources;
  - (b) molasses, i.e. a viscous by-product of the refining of sugarcane or sugar beets into sugar;
  - (c) vinasses, i.e. a viscous by-product of the fermentation process of molasses into ethanol, ascorbic acid or other products;
  - (d) distillers grains, i.e. by-products resulting from the production of alcoholic beverages;
  - (e) plants, plant parts or plant extracts having undergone only heat treatment or heat treatment in addition to processing methods referred to in CMC 2; or
  - (f) lime from drinking water production, i.e. residue which is released by production of drinking water from groundwater or surface water and consists, mainly, of calcium carbonate.

7.4.2 Biomass residues as by-products from chemical and enzymatic refining processes

7.4.2.1 Materials of interest and their production processes

The COM expert group on fertilising products indicated an interest to include by-products obtained through the processing of biomass via one or more of the following processes: **slicing and cutting**; **pressing and expelling** (the physical removal of liquids like fat, oil, water or juice from solids); **hydrolysis** of higher plants or algae (reduction of molecular size by appropriate treatment with water and enzymes or acid/alkali); **steaming** (the process using pressurised steam for heating and cooking to increase digestibility); **fermentation** (the process in which micro-organisms such as bacteria, fungi or yeasts either are produced or used on materials to modify their chemical composition or properties); **filtration** (the process of passing a liquid through a porous media or membrane filter in order to remove solid particles); and (hydrogenated) **oil/fats splitting** (the chemical reaction of fats/oils with water, carried out at high temperatures and pressures, allows obtaining crude fatty acids in the hydrophobic phase and sweet waters (crude glycerol) in the hydrophilic phase).

Examples of materials that have been proposed as candidate CMC 11 materials include:

- **oilseed expellers/cake** (edible and possibly non-edible oilseeds) mostly containing vegetable fibres, proteins, oils as obtained by solvent/acid/alkaline/enzymatic extraction; also including seaweed after (alkaline) extraction (note materials after oil extraction by pressing would be covered under CMC 2);
- **filter cakes** obtained during the filtration of foodstuffs, beverages and biorefinery liquids (e.g. protein fractions) including bleaching earth/filter aid (e.g. diatomaceous earth, amorphous silicates and silica, phyllosilicates and cellulosic or wood fibres);
- **protein residues obtained after acid/alkaline extraction processes** of plants and seaweeds from which primary products (e.g. amino acids, agar, pharmaceuticals) have been isolated (e.g. protein concentrates from which amino acids of interested have been extracted);
- **protein-rich residues** obtained through **fermentation** (e.g. *Escherichia coli* K12 or *Corynebacterium glutamicum*) on substrates of vegetable (e.g. molassess) or chemical origin, natural gas, ammonia or mineral salts (e.g. ammonium sulphate; that acts as the sources of nitrogen for microorganisms or as a pH adjuster) for the production of e.g. amino acids, aroma, syrup, inulin, vitamins.
- **surplus yeasts and parts thereof** obtained (e.g. *Saccharomyces cerevisiae*) for instance from beer brewing;
- **glycerol** from biodiesel production process; the process uses an alkaline hydrolysis reaction to convert vegetable oil into biodiesel using methanol, potassium hydroxide, and heat. A transesterification reaction splits the glycerol group from the triglyceride oils, producing methyl esters (biodiesel) and glycerol by-product (note see section 6.4.2 for an assessment of the agronomic value of this material).

It is noted that by-products of plant origin that are produced from plants (e.g. oilseed cake meal, coca husks, and malt culms) as well as seaweeds (e.g. as obtained by alkaline extraction or fermentation) are allowed for use as “fertilisers and soil conditioners” in **organic farming in the EU** (See Annex I of Regulation (EC) No 889/2008).

The scope of this subcategory is focussed on value added ingredients for EU fertilising products **derived from the biomass itself** applied as starting material for a manufacturing process (e.g. organic matter, peptides, proteins, amino acids, plant hormones or hormone-like lipids, vitamins). Therefore, the materials targeted in this subgroup are mostly envisaged to be used as organic soil improvers and plant biostimulants (see section 6.3). Nutrient concentrations in the envisaged materials are typically rather low when expressed on a fresh matter basis. By-products whose main functional components are derived from processing aids (e.g. CaO recovered from the washing or extraction of biomass) are covered in section 7.4.3.

7.4.2.2 Environmental and human health issues

The concerns associated to materials within the scope of this subcategory relate to **biological hazards** (e.g. microbiological pathogens, plant pests), the introduction of **non-native species**, including **genetically modified organisms** (GMOs) in the environment, and possibly **chemical substances**.

7.4.2.2.1 Microbiological hazards

The most prevalent animal and human diseases from food and feed contamination can still be attributed to the classic pathogens such as *Salmonella*, *Campylobacter*, *E. coli*, *Listeria* and in some cases *Clostridium* species. Insufficient hygienic barriers both at farm level as well as in processing and handling of biological materials account for the contamination risk (Doyle and Erickson, 2012). Possibly occurring contamination in feed materials can thus be widely transmitted between countries and continents in case HACCP (Hazard Analysis & Critical Control Point)-based programs and associated control measures are not in place (Wierup, 2017).

Data of biological pathogens in the envisaged by-products to be used in fertilising products is scarce, and the assessment of absolute numbers and trends is hindered by a lack of standardised sampling and testing procedures. Nonetheless, a large **share of the proposed material in this subgroup are also used as feed** material and therefore listed in the EU feed catalogue (Commission Regulation (EU) No 68/2013[13]). Because these materials are subject to monitoring and quality control schemes, more data on microbial hazards are available.

A relevant overview on *Salmonella* contamination is provided in Wierup (2017), although most **studies date from before 2010**. *Salmonellae* strains were isolated from approximately 30% of samples tested from dust of all lots of soy beans imported mainly from South America to Norway during 1994–2007 (Denofa, 2007; Liebana and Hugas, 2012). Long-term experiences and data from several countries have highlighted and verified that processed biological materials, such as vegetable proteins, cakes and meal, are regularly contaminated by *Salmonella*. In a comprehensive study from Poland, based on an annual examination of up to 80,000 batches of feed up to 15% of imported lots of soya bean and rapeseed meal were, respectively, found to be *Salmonella*-contaminated in 2005–2007 (Kwiatek et al., 2008). Swedish data from 2004–2005 report that 15% of the soybean meal and 10% of the rapeseed meal samples were contaminated (Wierup and Haggblom, 2010), and possible higher numbers have been reported for imported soy from South America (Häggblom, 1993). *Salmonella* is also frequently reported from rapeseed and palm kernel, with data from Sweden, the Netherlands, and the UK indicating an incidence of 2-12% for the period 1999-2006 (summarised in Liebana and Hugas, 2012). Moreover, EFSA reports the highest proportion of positive samples in individual investigations for the feed category ‘Feed material of oil seed or fruit origin’, mainly rape seed-derived, soya (bean)-derived, sunflower seed-derived and cotton seed-derived feed (data available for reporting periods 2013-2015) (Eurosurveillance Editorial, 2012; Boelaert et al., 2015; European Food Safety et al., 2015; Boelaert et al., 2016; European Food Safety et al., 2017; European Food Safety et al., 2018; European Food Safety et al., 2019). Grain is not often found to be contaminated unless as a result of contamination during storage and transport (Liebana and Hugas, 2012). It has been suggested that biomass may be contaminated by *Salmonella*-containing water used for irrigation or through the use of (animal and human-derived) faecal matter used as fertiliser (Greene et al., 2008). Moreover, in-house contamination in crushing plants and feed mills as well as contamination during transport and storage may occur (Wierup and Kristoffersen, 2014). In **recent years, feed materials show a lower incidence of microbial contamination** in feed (in the range of 1-4% for Salmonella in the years 2013-2018), compared to previous years (Boelaert et al., 2015; European Food Safety et al.,

---

[13] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:02013R0068-20200701

2015; Boelaert et al., 2016; European Food Safety et al., 2017; European Food Safety et al., 2018; European Food Safety et al., 2019). Possibly, this is due to stricter regulation and law enforcement in the EU, following the introduction of new legislation on feed hygiene (183/2005/EC) and the placing on the market for feed use of products derived from vegetable oils and blended fats. For such materials, specific requirements for production, storage, transport and dioxin testing of oils, fats and products derived thereof are laid down in Regulation (EU) No 225/2012 (amending Annex II to Regulation (EC) No 183/2005).

Microbiological hazards also comprise their toxins produced by a number of **pathogenic fungi** that are incompletely inactivated during the processing of biological materials (Fink-Gremmels, 2012). Mycotoxins are toxic secondary metabolites from some species of *Aspergillus*, *Fusarium Penicillium* and their related fungi. Many **mycotoxins** (e.g. aflatoxin B1, zearalenone (ZEA)) are already present in the crop during growth in the field. Nonetheless, their presence in processed biological materials (Pettersson, 2012; Sivamaruthi et al., 2018) may further exacerbate risks for animal and food safety.

The processing of biological materials often involves the disaggregation of biological materials (seeds, such as soybeans, palm kernels and rape and sunflower into crude vegetable oil, animal feed, and fiber). The crushing involves either the use of a screw/expeller or hydraulic press between plates. Due to friction in the screw, the temperature is raised up to 130–140°C. Generally, the material in the crushing plates reaches >100°C for 20 min (Himathongkham et al., 1996). The product after the crushing is called cakes which usually are ground to a meal. Solvent extraction is also applied, typically with hexane, resulting in refined extraction meal that is further toasted or **heat-treated**. Other processes, such as **acid or alkaline extraction** may lead to cell lysis (Pasupuleti and Braun, 2010; Ruiz-Hernando et al., 2014), but the effectiveness of hygienisation is largely dependent on the process conditions (pH, time, temperature) applied. At times, **pasteurisation** steps are also applied to sterilise the materials. Hence, relative to the biological input materials applied, the implementation of processing steps may lead to a proportional decrease in *Salmonella* contamination in the candidate by-product materials (e.g. oilseed cakes, protein hydrolysates) and the primary products of higher added-value (e.g. feed materials). Nonetheless, it is important to note that the p**urpose of these treatments is primarily to improve specific processing steps** (e.g. feed conversion and the handling qualities and feed intake), rather than the hygienic quality of the process (Pasupuleti and Braun, 2010; Liebana and Hugas, 2012). Temperature, alkalinity/acidity range and time limits for the process are selected to meet also nutritional requirements and exposure of the feed to too high temperature may have negative effects on certain feed ingredients, such as amino acids and vitamins. Moreover, available data may be insufficient to specify a minimum temperature, time range and pH range that under all conditions would be sufficient to eliminate contaminations for all industrial processes.

To limit microbiological hazards, **Hazard Analysis & Critical Control Point** (HACCP) programmes and associated control measures are critical. At all relevant stages of production, processing and distribution of food and feed, European legislation is in force to ensure that proper and effective measures are taken to detect and control biological pathogens (e.g. EC Regulation 2160/2003 on the control of *Salmonella* and other specified food-borne zoonotic agents; Regulation (EC) No 2073/2005 on microbiological criteria for foodstuffs; Regulation (EC) No 183/2005 on feed hygiene).

In the same way as it is important to prevent and reduce contamination at all steps during manufacturing, it is equally important to prevent multiplication of possibly contaminating microbes which can survive for considerable time in various materials once production has reached the end stage (Jones, 2011; Wierup, 2017). This is particularly relevant for this sub-group as carbon sources are abundantly available microorganisms. For instance, **adequate storage conditions** (e.g. under dry conditions) is one effective measure to prevent recontamination and microbial regrowth and mycotoxin production (Liebana and Hugas, 2012; Pettersson, 2012). In order to avoid microbial multiplication, grain-derived materials should be dried to approximately 13–14% and oilseeds to 7–9% moisture content corresponding to a water activity of around 0.4–0.65 (Eisenberg, 2007; Jones, 2011).

In EC Regulation No 2160/2003, the general rules on monitoring of zoonoses and zoonotic agents in animals, food and feed are laid down in Article 4 of Chapter II ‘Monitoring of zoonoses and zoonotic agents’ of the Directive. Specific rules for coordinated monitoring programmes and for food business operators are, respectively, in Articles 5 and 6 of Chapter II. In addition, international initiatives exist (e.g. *Codex Alimentarius).* In the same way as it is important to prevent and reduce contamination at all steps during manufacturing, it is equally important to prevent multiplication of possibly contaminating microbes which can survive for considerable time in various materials **once production has reached the end stage** (Jones, 2011; Wierup, 2017).

7.4.2.2.2 Plant pests

With regard to the concerns for maintaining plant health inside the European Union as laid out in Directive 2000/29/EC, manufacturers must demonstrate that any products containing plant-based raw materials have been verified to be not containing any of the plant pathogens or diseases listed in the annexes to that directive or shall demonstrate that the manufacturing process of the raw material and/or final fertilising product eliminates any risk of contamination.

7.4.2.2.3 Introduction of alien organisms

The accidental release into the environment of genetically modified microorganisms (GMMs) and other (alien) species that are not present in the EU soil environment may have adverse consequences on biodiversity. Hence, it is important to avoid the release of production cultures that are not already present in natural habitats and could proliferate under the outside abiotic conditions.

Whereas the risk of the introduction of alien species in the environment is limited for most candidate materials, hydrolysed proteins and fermentation residues are at times produced using GMMs. GMMs are regulated under Directive 2009/41/EC on the contained use of genetically modified microorganisms. Whereas the fermentation process itself is clearly contained use, marketing for example the fermentation residues as components for EU fertilising products, if **potentially still containing any living GMOs**, would be subject to the Part C **notification procedures** of Directive 2001/18/EC (regulating the deliberate release of GMOs into the environment). This procedure would thus also apply to CMC 11 materials that might contain still viable GMOs. Materials that do not contain genetically modified biological entities capable of replication or of transferring genetic material, e.g. after inactivation procedures, are not subject to the notification procedure.

In addition, producers who introduce a product in the supply chain must provide an indication that the product - or certain ingredients – contains, consists of, or is obtained from GMOs. Regulation 1830/2003 provides a framework for the **traceability and labelling** of feed and food products produced from genetically modified organisms (GMOs), but not for any other product produced from GMOs (produced from GMOs means “derived, in whole or in part, from GMOs, but not containing or consisting of GMOs). Nonetheless, the rules for organic farming in the EU set out in Regulation (EC) No 889/2008 indicate that organic products should not be produced from GMOs and thus not be derived in whole or in part from GMOs (even if the food production does not contain or consists of GMOs).

7.4.2.2.4 Stability

Material stability facilitates the safe handling, transport and storage, and ensures a constant quality in between the time of production and further downstream use. Component materials such as compost and digestate (CMC 3-5) have to meet minimum requirements on biological stability.

7.4.2.2.5 Residues of pesticides

In the EU, the application and use of pesticides is legally controlled to minimise risks and residue levels occurring in both food and feed. The authorisation of active substances in plant protection products is laid down in Regulation (EU) No 540/2011. Where they are used according to good agricultural practice, residues of these pesticides should not exceed maximum residue levels in food and feed (see Annex II of Regulation (EC) No 396/2005), which are set on the basis of a toxicological risk assessment and in consideration of what is achievable by best practice, i.e. correct application rates and minimum harvest intervals. These measures also apply to similar by-products that are used as fertilising materials within the FPR (e.g. oilseed cakes resulting from mechanical techniques such as pressing, a CMC 2 material). Altogether, these measures should limit the occurrence of pesticide residues in the candidate by-product materials. Moreover, Annex I of the FPR indicates that “where the EU fertilising product contains a substance for which maximum residue limit values for food and feed have been established in accordance with Regulation (EC) No 396/2005 on pesticides the use of the EU fertilising product as specified in the use instructions must not lead to the exceedance of those limit values in food or feed”.

7.4.2.2.6 Other chemical contaminants

7.4.2.2.6.1 PCBs and PCDD/F

Polychlorinated biphenyl (PCB) and polychlorinated dibenzo-p-dioxins and furans (PCDD/Fs) PCDD/F are polychlorinated aromatic compounds with similar structures, chemical and physical properties. These persistent organic pollutants are not biodegradable so they are persistent and bio-accumulate in the food chain. Contamination can occur during biomass processing and dioxin contamination is of particular note because chemicals in this group are highly toxic (Crawshaw, 2012). Isolated incidents have traditionally been the main reason for exceeding maximum levels of PCDD/Fs and PCBs in food and feed (Crawshaw, 2012; Malisch, 2017), such as the feeds containing citrus pulp pellets from Brazil which had high dioxin levels as a result of the use of heavily contaminated lime used for neutralization, or the use of contaminated marl clay from a German quarry in a potato processing operation (Veerman, 2004). Moreover, contamination during the processing of biomass has occurred due to malpractice (e.g. contamination of feed with transformer oil containing dioxins, furans and PCBs). In addition, improper drying of biomass to reduce the moisture content to permissible levels for storage or processing (e.g. fire drying, use of contaminated fuels) may induce dioxin contamination.

7.4.2.2.6.2 Polyaromatic hydrocarbons

Polycyclic aromatic hydrocarbons (PAHs) are a group of persistent, semi-volatile organic pollutants. Polycyclic aromatic hydrocarbons represent a broad group of physicochemically different molecules made of two or more unsubstituted benzene rings fused together when a pair of carbon atoms is shared between them. The most frequent PAHs are anthracene, fluoranthene, naphthalene, pyrene, phenantrene and benzopyrene. Similar to PCBs and PCDD/Fs, processing of biomass (such as drying) could be major sources generating PAHs (Guillen et al., 1997; Phillips, 1999).

7.4.2.2.6.3 Cyanides

Cyanogenic glycosides are produced as secondary metabolites by various plant species (oil seeds, fruits) and include compounds such as amygdalin, dhurrin, linamarin, linustatin, lotaustralin, neolinustatin, prunasin and sambunigrin (Rietjens et al., 2005). **Hydrogen cyanide (HCN)** is formed from these cyanogenic glycosides by hydrolytic enzymes following by the crushing of plant materials (Monbaliu et al., 2012; Sivamaruthi et al., 2018)

7.4.2.2.6.4 Chlorine

Salinity is a generic term used to describe elevated concentrations of soluble salts in soils and water. Comprised primarily of the most easily dissolved ions - sodium (Na^+) and chlorine (Cl^-), and to a lesser extent calcium, magnesium, sulphate, and potassium - salinity in the environment adversely impacts water quality, soil structure, and plant growth. Excess salinisation might constrain crop productivity and can cause clays to deflocculate, thereby lowering the permeability of soil to air and water. Especially seaweed-derived materials may contain high levels of natural chlorine.

7.4.2.2.6.5 Chloropropanols

Chloropropanols are formed in protein hydrolysates by the reaction of hydrochloric acid with residual lipids associated with the proteinaceous materials used in their production (Collier et al., 1991). Production of two of these derivatives, 3-monochloropropane-1,2-diol (3-MCPD) (1,3-DCP) and 3-monochloropropane-1,2-diol (3-MCPD) (3-MCPD), are carcinogenic contaminants in processed foods. 3-MCPD is listed in Regulation (EC) No 1881/2006 that sets maximum levels for certain contaminants in foodstuffs with a limit value of 20 µg kg^{-1}.

7.4.2.2.6.6 Processing residues

In industrial processes, foams pose serious problems. They cause defects on surface coatings and prevent the efficient filling of containers. **Antifoaming** substances are chemical additives that reduce and hinder the formation of foam in process liquids. Commonly used agents that could end up in by-products (e.g. molasses, vinasses, fermentation by-products) are insoluble oils, polydimethylsiloxanes and other silicones, certain alcohols, stearates and glycols. **Disinfection products** are used for cleaning of surfaces and food processing reactors. In case **solvents** would have been applied during refining steps, it should be assured that any potentially toxic solvent residues are removed from the candidate by-product materials.

7.4.2.3 Sub-group assessment

This assessment has brought forward following issues:

- A **delineation of the scope of this subgroup**, either via a positive or a negative list, is highly **challenging** because the processing of biomass materials may involve an enormous amount of processing steps and lead to a vast range of possible primary products. A full assessment of the whole range of individual materials goes beyond the timeframe and resources available at JRC. A need exit to identify specific materials of interest under this sub-group so as to narrow the scope.
- The most pressing risks for this group identified relate to the presence of **microbiological pathogens and toxins**. The spectrum of microbiological hazards; is a main **challenge for the development of cost-effective compliance schemes** as part of the FPR. However, it is imperative that these risks are appropriately controlled, especially due to the envisaged storage and cross-border transport of EU fertilising products that may induce microbial re-growth;
- It is reiterated that **different routes for the placing of the market** of the candidate materials exist, including their possible use as an input material for **composting and digestion processes** (with both end materials exempted from REACH registration) or placement on **national markets**. Moreover, many of the proposed target materials for this group **have already been listed under CMC 2** (e.g. mechanically processed biomass materials and water extracts, such as oilseed cakes). These alternative routes may be a more suitable choice for the many voluminous material streams (i) for which operators are not willing to undertake the procedure of REACH registration; (ii) that envisage use on land as a fertilising products in nearby areas, e.g. due to the high transport costs of high volume materials or materials with a low stability, and/or (iii) for which strict hygienisation measures cannot always be garantueed, especially under conditions of storage and (long-distance) transport.
- Nonetheless, it may be beneficial to **collect certain by-product streams in a separate manner** without mixing them with other types of organic materials due to the specific composition (concentrated peptides, hormones, amino acids, etc.) that may be present in high concentrations in by-products from specific industries. If not collected separately, these valuable compounds could be highly diluted due to mixing with other streams, e.g. in a co-digestion plant where large materials volumes are being processed.
- Many candidate materials could also serve a function **as animal feed**, and many of the proposed materials are thus listed on the EU feed catalogue (Regulation (EU) No 68/2013). The EU feed market already produces large amounts of materials in the EU, and a fraction of the about 166 million tonnes of feed in the EU (about 70% grain, followed by about 25% oil meals; RaboResearch, 2017) are by-products. These materials are already subject to the requirements on feed hygiene as laid down in Regulation (EC) No 183/2005 (including procedures to control microbial hazards based on the hazard analysis and critical control point (HACCP) principles laid down in Article 6(2) that also applies to all stages of production, processing and distribution). Moreover, maximum residue levels of pesticides as per Regulation (EC) No 396/2005 already apply to these materials. The rules on the marketing of feed materials and compound feed are established in EC Regulation 767/2009, indicating that feed may only be placed on the market if it does not have a direct adverse effect on the environment. Hence, reliance on **already implemented control**

mechanisms and available data for specific materials of interest would provide **synergies** because the JRC can build upon previous assessments and well-functioning legal frameworks, and thus avoid a repeated assessment of possible risks from a broad spectrum of materials. Finally, this may bring forward possibilities to develop **compliance schemes of marginal added costs** for operators due to the already established quality control mechanisms in place for the sector.

Given these arguments and starting from the candidate materials proposed by the Commission Expert Group on Fertilising products, it is **proposed to focus the detailed assessment on by-products from this subcategory** to the following materials:

- **plant expellers/cake** (including cakes from edible and possibly non-edible oilseeds including soapstocks from degumming/neutralisation; cakes from other crops and fruits) mostly containing vegetable fibres, proteins, and oils as obtained by solvent/acid/alkaline/enzymatic extraction (note materials after oil extraction by pressing would be covered under CMC 2);
- **filter cakes** obtained during the filtration of foodstuffs, beverages and biorefinery liquids (e.g. protein fractions). A relevant aspect for further assessment is if and to what extent **bleaching earth/filter aid** (e.g. diatomaceous earth, amorphous silicates and silica, phyllosilicates and cellulosic or wood fibres) should be further considered. After all, filter cakes are applied for the removal of impurities and thus show a substantial risk to accumulate e.g. metals, microbial pathogens, etc;
- **protein residues obtained after acid/alkaline extraction processes of plants** and from which primary products (e.g. amino acids, pharmaceuticals) have been isolated (e.g. protein concentrates from which amino acids of interested have been extracted);
- **protein-rich extracts obtained after acid/alkaline extraction processes of seaweeds** (e.g. from agar production). Agar is mainly produced from *Gelidium* and *Gracilaria* seaweeds following acid/alkali extraction at elevated temperatures (Qin, 2018). In a first step, the seaweed is washed and extracted so as to the increase jelly strength. The alkaline extraction treatment (e.g. NaOH solution at 80–90°C for 3–5 h) causes the hydrolysis of sulphate groups and transforms important quantities of l-galactose 6-sulphate into 3,6-anhydro-l-galactose (Qin, 2018). In a second step, the agar is dissolved as part of a heating treatment with water for several and the mixture is filtered to remove the residual seaweed. Then, the water is removed from the gel, either by a freeze-thaw process or by squeezing it out using pressure. Seaweed by-products from this agar extraction are protein sources and contain amino acids, such as aspartic acid, glutamic acid, arginine, and lysine (Laohakunjit et al., 2014).
- **protein-rich residues** obtained in **fermentation** processes (using e.g. *Escherichia coli* K12, *Corynebacterium glutamicum,* yeasts) on substrates of vegetable (e.g. molassess) or chemical origin, natural gas, or mineral salts (e.g. ammonium sulphate) for the production of e.g. amino acids (e.g. methionine), aroma, syrupy, inulin, pharmaceuticals, vitamins;
- **surplus yeasts and parts thereof** obtained (e.g. *Saccharomyces cerevisiae*) for instance from beer brewing.

Following materials are **proposed for exclusion** from further assessment:

- Other materials not listed above for further assessment.

It is reiterated that the fact that particular by-products from biomass processing are not listed above in the list for further assessment does not imply that those materials are of low quality for agriculture. As outlined in the directional framework for this project, the selection and prioritisation of candidate materials is based on numerous criteria including amongst others market potential, available techno-scientific information, challenges to develop criteria in a straightforward manner, and possibilities to develop cost-effective compliance schemes.

7.4.3 By-products derived from manufacturing and processing aids

7.4.3.1 Gypsum from citric acid and tartaric acid production

One of the production routes for citric acid is based on the growth of the fungus *Aspergillus* spp., yeasts of the genus *Candida* or other organisms on glucose-containing medium (e.g. corn steep liquor, molasses, hydrolysed corn starch, technical and pure glucose, oils and fats, syrups of beet, etc.) (Berovic and Legisa, 2007). The method of citric acid recovery from the fermentation broth may vary depending on the technology and raw materials used for the production. After the mold is filtered out of the resulting solution, one of the methods for isolating citric acid is by precipitating it with calcium hydroxide to yield calcium citrate salt ($2C_6H_8O_7 + 3Ca(OH)_2 = (C_6H_5O_7)_2Ca_3.4H_2O + 2H_2O$), from which citric acid is regenerated by treatment with sulphuric acid ($(C_6H_5O_7)_2Ca_3.4H_2O + 3H_2SO_4 = 2C_6H_8O_7 + 3CaSO_4.2H_2O + 2H_2O$). This results in the precipitation of **calcium sulphate** (“citrogypsum”) as a by-product of the reaction. The low pH value during the production phase ($pH < 2$) reduces the risk of contamination by other microorganisms and inhibits the production of unwanted organic acids (gluconic and oxalic acids) (Max et al., 2010). The gypsum may, however, contain impurities especially when used as a filter aid in citric acid purification, with hexacyanoferrate (applied as an inhibitor of non-acid-forming *A. niger* mycelium) as a possible relevant contaminant (cyanide) when applied as a fertiliser.

Also the production of tartaric acid is obtained by converting potassium bitartrate-rich lees, the solid by-product of fermentations, to calcium tartrate ($CaC_4H_4O_6$) upon reaction with $Ca(OH)_2$. In a following process step, calcium tartrate is transformed into tartaric acid following sulphuric acid addition ($Ca(O_2CCH(OH)CH(OH)CO_2) + H_2SO_4 \rightarrow HO_2CCH(OH)CH(OH)CO_2H + CaSO_4$.

7.4.3.2 Concentrates from sodium acid pyrophosphate potato washing solutions

Effluent waters from potato processing facilities contain large amounts of phosphate. During preparation of the prebaked frozen product, potatoes are treated with sodium acid pyrophosphate ($Na_2H_2P_2O_7$) after the blanching treatment. Sodium acid pyrophosphate prevents that iron in the potato reacts with chlorogenic acid during the heating processes (Rossell, 2001). The oxidation of the Fe^{2+}-chlorogenic acid complex by oxygen from the air would otherwise result into a grayish-colored substance that causes after-cooking gray discoloration (Rossell, 2001). The blanching treatment also causes leaching of phosphate from the potatoes. The best available techniques (BAT) conclusions for the food, drink and milk industries, under Directive 2010/75/EU, indicate that phosphorus recovery from P-rich waters (> 50 mg L^{-1}), in order to reduce emissions to water, is a suitable technique. The P-rich concentrates formed are often referred to as struvite, though they may not classify as CMC ‘precipitated phosphate salts’ due to their high organic C content. As a matter of fact, the process taking place is likely more an adsorption/coagulation process to the natural potato-derived polymer present in the solution than a precipitation process from free ions in solution in mineral forms (Huygens et al., 2019). The main concerns associated to the P-rich concentrates relate to the presence of biological pathogens and plant pests derived from the potato substrates (e.g. potato cyst nematodes (*Globodera rostochiensis*)).

7.4.3.3 Potassium and sodium sulphates from glycerol purification

Biodiesel is produced from a process whereby the processed fat is separated from the protein. Processed fat is subsequently submitted to transesterification, possibly after esterification. It involves the breaking of the triglyceride structure and the exchange of alkyl groups with the hydroxide groups of the alcohol to obtain the new ester (biodiesel) (Pitt et al., 2019). Transesterification is carried out in the presence of a catalyst (usually sodium hydroxide or potassium hydroxide). This process is then followed by the separation of biodiesel from the glycerol/glycerine rest fraction. The latter also contains excess alcohol, catalyst and fatty acid (soaps) residue, making it a product of low commercial value with restricted applications and thus it is usually discarded (Nasir et al., 2017). Further applications for glycerol (e.g. in the food and pharmaceutical sectors) require the elimination of impurities. Usually, the crude glycerol is reacted with concentrated sulphuric acid to convert soap impurities into insoluble fatty acids. Afterward, potassium hydroxide, sodium borohydride or sodium hydroxide solution is added to neutralise the excess acid and to remove coloured impurities (Wan Isahak et al., 2015). In the end, potassium sulphate or sodium sulphate can be removed by decantation and filtration. Concerns may relate to the presence of **methanol**, and to smaller extent other impurities, such as fatty acids.

7.4.3.4 Calcium oxide or calcium carbonate from sugar production (excluded since covered under CMC 6)

Lime is used in sugar production when purifying the juice from beet or cane. Sugar beet is sliced up and passed through a diffusor to extract the sugar juice. Calcium oxide or calcium carbonate is used in this process to remove impurities, and could be recovered for applications as a liming material in agriculture. Commonly, high quality grade lime is applied for which reason the risk of the introduction of foreign impurities from the lime applied is low. The material is already covered under CMC 6 and thus excluded for further assessment under CMC 11.

7.4.3.5 Harvested mushroom growing media (proposed exclusion)

Mushrooms and their mycelia grow in a number of different types of growing mediums including straw, grain, sawdust and manure that are normally sterilised prior to mushroom cultivation. Contamination of the mushroom growing medium can, however, occur. The most common contaminants are yeast cultures and bacteria, although other chemical or biological contaminants are not infrequent during mushroom growth. After mushroom removal, a mass consisting of the growing media and mycelia remains. Given the risk of biological contamination, and the possible inclusion of animal by-products, it is suggested that more **suitable outlets (e.g. composting, anaerobic digestion) exist and this material will no further be assessed in this project**.

7.4.3.6 Sub-group assessment

By-products of this sub-group contain a variety of materials, of different chemical compositions that mostly reflect the processing aid applied. The contaminant profile is process-specific, though biological pathogens are a returning concern. It is proposed to evaluate these materials proposed by the COM expert group on a case-by-case basis to ensure an in-depth evaluation of the agronomic value and contaminant profiles.

7.4.4 Calcium carbonates, iron hydroxide and humic/fulvic acids as by-products from the production of drinking water

7.4.4.1 Humic/fulvic acids from organic matter removal

The humic and fulvic acids are natural acidic organic polymers, produced during de-colorization of drinking water. Some ground and surface waters are rich in humic and fulvic acids that are removed during the drinking water production process using ion exchange technologies. The resin used for removal of the humic and fulvic acids is regenerated with sodium chloride. The humic and fulvic acids are recovered from the brine solution by a combination of nanofiltration, diafiltration, forward osmose and/or electrodialysis. Ion exchange systems are used for the removal of dissolved ions from water. Therefore, the expected levels of contamination are generally lower than for e.g. calcium carbonate sludges, but dependent on the operation configuration and technologies applied. Hence, in principle, the expected contaminant load may include compounds of a similar nature to calcium carbonate sludges (listed as fertilising product components under CMC 6), though the risks are expected lower due to the selectivity of the ion exchange technology applied. Possibly, **chlorine** from column regeneration agents may be an issue. The risk of other chemical substances, such as pesticides and other priority substances in the field of water policy such as chlorinated organic solvents seems low due to the strict control on the placing on the market of pesticides within the EU, and the EU framework on the protection of the quality of EU fresh- and surface waters. Finally, many compounds (e.g. microorganisms, pesticides, metals) are typically removed during other processing steps of water purification (e.g. adsorption to powdered activated carbon).

7.4.4.2 Calcium carbonate sludges from water softening (excluded since covered under CMC 6)

In Europe, on average, surface water is used for one third of drinking water supplies and two thirds are provided by ground water (Roccaro et al., 2005). **Water softening** of ground and surface waters for human consumption (drinking water) is the process of removing the dissolved calcium and magnesium salts. Water can be chemically softened on a large scale by calcium hydroxide, soda ash (sodium carbonate, Na_2CO_3) and/or sodium hydroxide. The calcium carbonate and magnesium hydroxide precipitates are typically removed in a clarifier before the water is filtered (WHO, 2017). When $Ca(OH)_2$ and Na_2CO_3 are added, hardness-causing minerals form nearly insoluble precipitates, such as calcium carbonate ($CaCO_3$) and magnesium hydroxide ($Mg(OH)_2$). These precipitates are then removed by conventional processes of coagulation/flocculation, sedimentation, and filtration, leading to a sludge that mainly consists of calcium carbonate and impurities. Alternatively, **ion exchange techniques** could be applied. Here, the water is passed through a bed of cationic resin, and the calcium ions and magnesium ions in the water are replaced by sodium ions. The by-products are already listed as CMC 6 materials.

7.4.4.3 Iron hydroxide from iron removal (proposed exclusion)

Anaerobic groundwater may contain ferrous iron at concentrations of up to several milligrams per litre without discoloration or turbidity in the water when directly pumped from a well (Chaturvedi and Dave, 2012). **Iron removal** is among the problematic issues for making potable water. Its main issues involve taste, visual effects, and clogging. There are several methods for removal of iron used in water purification processes (Chaturvedi and Dave, 2012). The majority of iron treatment systems employ the processes of oxidation/filtration. The oxidant chemically oxidizes the iron, and inactivates iron bacteria and any other disease-causing agents that may be present. Oxidation involves the transfer of electrons from the iron or other chemicals being treated to the oxidizing agent. Ferrous iron (Fe^{2+}) is oxidized to ferric iron (Fe^{3+}), which readily forms the insoluble iron hydroxide complex $Fe(OH)_3$ that can subsequently be filtered out (Vigneswaran and Visvanathan, 1995). The most common chemical oxidants in water treatment are chlorine, chlorine dioxide, potassium permanganate, ozone and oxygen present in air in a tray aerator (Chaturvedi and Dave, 2012). The impurity profile is similar to the one for calcium carbonate sludges from drinking water production, though lower contents of biological pathogens may be present due to the use of chemical oxidants such as chlorine or ozone.

Iron hydroxide is not used as a fertilising product as such in EU agriculture. The use of iron(hydr)oxide from drinking water in digester as a sulphur binder is, however, allowed in some EU Member States (e.g. NL, BE, DE). Possibly, such material could be applied as a digestion additive under CMC 4-5. Because this CMC 11 focused on materials that can be used as such as components for EU fertilising products without intentional chemical reactions taking place between the different CMCs, **this material is proposed to be excluded for further assessment**.

7.4.5 By-products from the pulp and paper industry

7.4.5.1 Fiber sludge (proposed exclusion)

Various types of sludge (biosludge from waste water treatment, fibrous sludge, deinking sludge, etc.) from both virgin pulp production and/or processing paper for recycling and own pulp or paper mill residues are produced. Sludges can originate from either pulp milling, paper milling or from integrated installations where pulp and paper are produced in the same plant. Pulp can be manufactured using mechanical or chemical methods (kraft and sulphite processes). Sludges include wood in the form of solid and dissolved substances, bark residues, alkaline substances, **polyaromatic hydrocarbons** and **possibly chlorinated organic compounds** (expressed as Adsorbable Organic Halides, AOX; present in sulphite and some kraft market pulp mills that apply chlorine containing (e.g. ClO_2) bleaching stages). Particular care should also be exercised in the case of addition of chemicals that are designed to have a biological effect such as **biocides, disinfectants** and **slimicides**.

Paper is afterwards made by draining a low consistency dispersion of cellulose fiber pulp, fillers, and additives (fillers, coatings, resins, etc.) through a paper machine “wire” (Hsu and Hu, 1998). The drained liquid suspension, known generally as “white water,” carries entrained solid material. The treatment of unused white water normally involves passing the effluent through a clarifier, prior to which flocculants are added to promote sedimentation of solid material suspended in the water. A biological treatment with microorganisms is also commonly performed to reduce the biological oxygen demand of the liquid effluent before it is discharged. The sediment accumulated in the clarifier is a sludge composed of pulp fibers, fiber particles or fines, fillers, pigments, and other miscellaneous debris (Grönfors, 2010). Sludge from deinking and waste paper mills may be relatively high in **metals** due to the formulations used in ink removal. Depending on the type of paper manufactured and the technological choices of the plant operator, **a large variety of product aids that may environmental risks is applied that could end up in the sludge (Table 2)**.

Of the substances used previously in the pulp and paper industry, certain substances are prohibited in current legislation. Nonylphenols and nonylphenol ethoxylates have been used as tensides and dispersion agents. Now the use of these substances is prohibited. Some substances regulated in legislation and used in large quantities, e.g. in slimicides and sizing agents, have been found at paper mills in low concentrations (Suhr et al., 2015). However, none of the listed priority substances to protect environmental quality as listed in Directive 2008/105/EC is used in the pulp and papermaking processes (e.g. nonylphenols, inorganic compounds, DEHP). Although not used, it is however possible for these priority substances to be present in the emissions from waste water treatment plants, due to either entering the site via **imported pulps** or via upstream abstracted surface water used within the papermaking process (Suhr et al., 2015).

Table 2: Main process and product aids and their application in the paper industry

Product aids	Purpose	Examples	Remarks
Fillers	Improve printability properties, opacity, brightness, smoothness and gloss; replace (saving) fibres	Kaolin or clay, talc, lime, gypsum, titanium dioxide, calcium carbonate	
Sizing agents	Improve surface quality; make paper hydrophobic	Modified starch, modified natural resins, wax emulsions, synthetic products like alkyl ketene dimers and maleic acid anhydride copolymers	Some may be toxic to bacteria when they are cationic; however, they have high retention to the fibre
Fixing agents	Improve adsorption of additives to fibres	Alum [$Al_2(SO4)_3$], cationic amines	Mostly cationic products which may be toxic to bacteria
Dry strength agents	Improve strength properties in dry conditions	Modified starch	Some may be toxic to bacteria when they are cationic
Wet strength agents	Improve strength properties under wet conditions	Urea formaldehyde polymer, melamine formaldehyde polymer, Epichlorohydrin condensates	Usually toxic to bacteria, some increase the AOX
Dyes	Give paper a certain colour and/or brightness	Azo compounds, quaternary ammonium compounds	Difficult to eliminate; some are toxic; may contain heavy metals
Optical brighteners	Give paper a white impression	Chemicals based on 4,4-diaminostilbene-2,2-disulphonic acid	Some cationic substances may be toxic
Coating chemicals	Give paper certain surface properties	Pigments, binders, wet strength agents, dispersion and lubrication agents, defoaming agents, slimicides	Binders must be destabilised before mixing with other WW, otherwise they may disturb the clarification
Greaseproof or waterproof agents	Give paper grease- or water-repellent properties, e.g. baking papers, coated drink cups, fast food wrappers and pizza boxes	Perfluorinated compounds (PFC, e.g. based on fluorocarbon resins and perfluoropolyether are applied to impregnate some papers; for adhesive labels, fluorocarbon resins are used to prevent the penetration of the adhesive. The fluorochemicals are designed so that they bind to the fibres	Persistent and bioaccumulative; PFCs used for paper impregnation do not contain perfluorooctane sulphonate but may contain fluorotelomer alcohols and perfluorooctanoic acid in the lower ppm range, trace contaminants

Retention aids	Retention of fibres, fines and fillers; increased production by improving dewatering; decreased emission of pollutants	Alum, sodium aluminate, polyaluminiumchloride, starch products, gums, anionic polyacrylamides, nonionic polyacrylamides, cationic polymers, bentonite	Mostly cationic products
Surfactants	Cleaning of felts, wires and machinery; cleaning of water circuit system; dispersion of substances	Acidic and alkalic surfactants	May cause floating sludge
Defoaming agents	Prevention and destroying of foam	Fatty acid ethoxylates, poly-oxi-ethylene, fatty acid derivates, higher alcohols, phosphoric acid esters, vegetable oil products	De-aeration agents may lower the oxygen input in waste water treatment plant
Biocides (slimicides)	Prevention of growth of microorganisms	Organic bromine, sulphur or nitrogen compounds, quaternary ammonium compounds, chlorine dioxide, hydrogen peroxide	Some contain AOX, they are toxic when reaching the waste water treatment plant in higher concentrations

With respect to agronomic value, some studies have highlighted the potential of fibrous sludge as a soil improver. Chemical characterisation of paper mill sludge has shown that cellulosic materials represent more than 50% of the sludge content (Ochoa de Alda, 2008). As a result, the C:N ratio in the sludge is very high (C/N ratio of 50 to 200) (Monte et al., 2009; Likon and Trebše, 2012) and the sludge has a very low hydraulic conductivity (permeability) (Kuokkanen et al., 2008). The envisaged use may include limiting losses of mobile elements, such as nitrates in soils (Kirchmann and Bergstrom, 2003).

In conclusion, it is indicated that recycling possibilities of pulp and paper sludge depend on the papermaking process considered, the raw materials used and consequently the type and physico-chemical properties of the generated residues. Altogether, it is indicated that:

(i) a possible broad spectrum of contaminants (such as biocides, slimicides, and organic pollutants) may be present in the (fibrous) sludges, even though some of them may be present only in minor concentrations;
(ii) the necessary science (e.g. publically available risk assessments in scientific literature or in REACH registrations) demonstrating the absence of impacts on human health and the environment is not in place;
(iii) the risk to increase complexity and measurement costs for a possible compliance scheme is high;
(iv) demand for the material in agriculture remains uncertain.

Therefore, it is proposed **not to focus on these by-product materials**. Possibly, more suitable mechanisms for the placing on the market of specific sludges may exist (e.g. national rules, based on plant- or country-specific assessments that consider local use demands for this material).

7.4.5.2 Lime mud

In the Kraft (sulphate) pulping process, wood chips are combined in a digester with white liquor, an aqueous solution comprising principally sodium sulphide (Na_2S) and sodium hydroxide ($NaOH$), which breaks down lignin and, to a lesser extent, hemicelluloses under elevated temperature and elevated pressure, freeing the cellulose fibers (pulp) (World Bank, 2007). Following digestion, the resulting black liquor, which contains dissolved organic substances, is separated from the pulp. In many kraft pulp mills the inorganic chemicals' contribution to black liquor dry material amounts to 45 – 50 % (Suhr et al., 2015). Approximately one third of the dry material of the black liquor consists of dissolved organic substances. The chemical feedstocks are recovered in what is referred to as the liquor cycle. Black liquor is typically concentrated (to levels as high as 70 – 85 %) by evaporation of water and then incinerated at temperatures of 800°C - 1050°C in a recovery furnace, which destroys the organic constituents and generates heat used to make steam for other facility uses. Smelt, a molten salt mixture consisting principally of sodium carbonate (Na_2CO_3) and sodium sulphide, is formed at the bottom of the recovery boiler, and is dissolved in an aqueous solution, forming green liquor. In the causticizer, CaO is added to the green liquor, which converts sodium carbonate back to sodium hydroxide that - in combination with the sodium sulphide - forms the white liquor that is used again in the digesters. **Lime mud**, principally comprising calcium carbonate ($CaCO_3$), is separated from the white liquor and washed. Often, it is calcined afterwards in a lime reburning kiln to regenerate the lime (World Bank, 2007) (see section 7.4.5.3). The lime mud is highly alkaline, and has a high proportion of fine particles; it can therefore potentially be used as a liming material in agriculture (Muse and Mitchell, 1995).

7.4.5.3 Burnt lime (calcium oxide)

In the lime reburning process, the lime mud formed during the recausticising process is thermally converted back to calcium oxide according the reaction equation $CaCO_3 \rightarrow CaO + CO_2$. The reaction takes place in a rotary kiln where wet lime mud is dried, heated up to the reaction temperature, calcinated and cooled again. The calcination reaction starts at 800 °C and to complete the reaction temperatures up to 1 000 – 1 100 °C are required in the hot end of the kiln. This calcination is a high-temperature, endothermic reaction requiring external fuel (Suhr et al., 2015). The cooling is done by air in heat exchangers.

7.4.5.4 Sub-group assessment

Lime mud may and burnt lime may contain **metals and metalloids** such as As, Cd, Cr, Cu, Hg, Mn, Ni, Pb and Zn (most of these already regulated at PFC level in the FPR), although measured values are mostly below the limit values that are set in the FPR (He et al., 2009; Pérez-López et al., 2010). It may also contain high levels of **chlorides** (Pérez-López et al., 2010; Zhang et al., 2015). Due to the prior oxidation step, also **PCDD/Fs** and **PCBs** are a potential risk, especially in case chlorine containing bleaching agents have been applied.

7.4.6 Horizontal assessment

Group D materials include a set of materials with a very heterogeneous composition. It is proposed to evaluate these materials on their preliminary classification in the four sub-groups outlined in sections 7.4.2 - 7.4.5. A need exists to delimit “Biomass residues as by-products from chemical and enzymatic refining processes (section 7.4.2)” to added-value materials for which an interest exists to have them listed under CMC 11 as REACH registered materials. For the other sub-groups, it is proposed to evaluate the (limited set of) materials on an individual basis to control for any risks associated to their placing on the market.

7.5 Group E – by-products as fertilising product components added for technical reasons

The criteria proposals for this group will be developed based on the outcomes and lessons learned from the groups A – D.

7.5.1 Examples of materials envisaged

[to be developed in a later stage]

7.5.2 Concentrations of these materials in envisaged EU fertilising products

[to be developed in a later stage]

8 CERTAINTY OF FURTHER USE WITHIN THE MEANING OF WASTE FRAMEWORK DIRECTIVE (2008/98/EC)

As outlined in section 3.5, Article 5(1)(a) of the Waste Framework Directive (2008/98/EC) requires that "further use of the substance or object is certain" in order to classify as a by-product (Figure 1). 'Further use is certain' means that it is not a mere possibility but a certainty; there should thus be solid evidence or an assurance that the material will be used. For many of the identified materaisl outlined in section 7, the use of the by-product may be difficult for many reasons, including distance to re-use and transport costs, competition with existing sources, compatibility of by-product volumes with market requirements, etc. Hence, in spite of some materials meeting requirements on agronomic value and possible contaminant limits, there is still no certainty that these materials will actually be applied as value-added materials within the EU agricultural sector. Under conditions of a limited market, at times only part of the by-product can be re-used according to sound management practices.

The principle of this criterion laid down in Article 5(1)(a) is that if further use were not certain, there would be a risk of (i) adverse impacts for the environmental and human health resulting from (long-term) storage, and (ii) the material is ultimately being disposed of on agricultural land when storage capacity is exceeded. In addition, it may not make business sense to be dependent on a volatile market of a low-cost by-products, unless a long-term strategy towards re-using the by-product is in place.

In this respect, an interesting approach undertaken by quality insurance schemes for recycled materials (Waste & Resources Action Programme - UK (WRAP-UK), 2011; Saveyn and Eder, 2014) involves criteria that limit indefinite storage of materials in time and define storage conditions to limit adverse impacts (e.g. emissions of dust particles, leachates, greenhouse gas emissions) resulting from the temporary storage of materials.

9 NEXT STEPS

9.1 Mode of interaction with stakeholders

The JRC will collaborate exclusively on the **Commission expert group for Fertilising Products** to collect expert knowledge and techno-scientific data during the development of the project. Opportunities for feedback on interim deliverables during project developments will be provided through **oral and written consultations rounds** (see section 9.2). Meetings will be organised either virtually as webinars or physically through the physical presence of the JRC team at the Commission facilities (e.g. in combination with Commission expert group meetings).

9.2 Tentative timeline

A tentative project timeline is provided in Table 3.

Table 3: Tentative project timeline with the different project steps and stakeholder consultations

Tentative date	Project step	Stakeholder consultation
April 2020	webinar: presentation of project	
	report draft 1 – scope and directional framework questionnaire 1: feedback on directional framework and requests for proposals for candidate CMC 11 materials	written consultation - deadline 4 June
(June 2020)	(webinar/meeting: discussion of report draft 1 and directional framework)	(oral consultation)
Autumn 2020	webinar/meeting: selection of candidate materials for CMC 11 questionnaire 2: additional data requests for selected materials	oral and written consultation - deadline autumn 2020
Spring 2021	webinar/meeting: presentation of draft criteria	
	report draft 2 – updated report, draft criteria for CMC 11 questionnaire 3: feedback on draft criteria	oral and written consultation - deadline spring 2021
Autumn 2021	report draft 3 – full report this report will take into account the feedback from stakeholders and the Commission on the report draft 2, and include a proposal for the draft delegated acts that will be presented to the Fertilisers Working Group in autumn 2021	oral consultation
Spring / Summer 2022	decision on the implementation of the delegated act for CMC 11	oral consultation (DG GROW)

The tentative project timing has been developed taking into consideration Article 42(7) of the FPR: "By 16 July 2022, the Commission shall adopt delegated acts in accordance with Article 44 supplementing point 3 of component material category 11 in Part II of Annex II to this Regulation by laying down criteria on agronomic efficiency and safety for the use of by-products within the meaning of Directive 2008/98/EC in EU fertilising products".

Apart from the consultation round on this document, JRC will collect feedback from the stakeholders on the selection of candidate materials from CMC 11 (autumn 2020), and the proposed draft criteria for by-products (spring 2021). The JRC will strive to deliver the final proposals by Autumn 2021 to DG GROW.

10 STAKEHOLDER FEEDBACK

10.1 Objective of the questionnaire

The objective of this questionnaire is to **complement the information database** on "priority materials" for CMC 11. The requested information is critical for the development of criteria proposals. Without a clear understanding of the contaminant profiles of candidate materials, and the associated risks, it is impossible to develop adequate criteria for their safe release to the market. Therefore, JRC welcomes at this stage all relevant information that can contribute to a full assessment of risks and stakeholder concerns. A lack of data on contaminants at this evaluation stage might involve that certain risks arising from the placing of the market of by-products cannot be dismissed, and may therefore lead to increases in the complexity and costs of the proposed compliance schemes, or even lead to the decision not to further consider certain materials. Moreover, it is emphasised that confidence in the materials by all stakeholders involved is requisite for a well-functioning internal by-product market.

10.2 Information exchange

The **Commission expert group for Fertilising Products is now invited to provide their feedback** on this report (version 2). JRC will take into account relevant and credible techno-scientific information for the final report from these different stakeholders. However, to ensure a structured and time-efficient consultation process, the feedback will be based on a structured approach. The expert group members shall provide any feedback in a concise, constructive and structured form to enable the rapid understanding of the key messages.

The feedback should be provided in English, in order to facilitate the exchange of feedback among all stakeholders.

It is required that organisations provide a consolidated opinion; one contribution per organisation will be accepted. Umbrella organisations (e.g. EU wide industry associations or Member States) with daughter organisations (e.g. national industry associations or regional authorities) should compile the feedback of their daughter associations into one consolidated reply.

The JRC is pleased to take into account any feedback from the Commission expert group for Fertilising Products **until the deadline of Monday 25 January 2021** through the European Commission's CIRCABC platform.

10.3 Procedure

The CIRCABC platform is the preferred exchange information platform between experts and the JRC. Therefore, JRC has created a new CIRCABC interest group, entitled "JRC by-product fertilisers". Note that the information posted in the interest group is available to all stakeholders. An open exchange of information is preferred to ensure transparency. Please contact JRC (JRC-B5-FERTILISERS@ec.europa.eu) for the provision of any confidential information that, on an exceptional basis, cannot be shared with other stakeholders.

10.3.1 Accessing the CIRCABC "JRC by-product fertilisers" Interest Group

JRC will invite the experts from the Commission expert group for Fertilising Products in due course. Alternatively, experts can also apply for membership. The interest group can be accessed, as follows:

Step 1: Access CIRCABC

Open an internet browser and go to the CIRCABC homepage https://circabc.europa.eu/

In EU Login, your credentials and personal data remain unchanged. You can still access the same interest groups (e.g. "Fertilisers", the interest group managed by DG GROW) and applications as before. You just need to use your e-mail/password address for logging in.

Step 2: Access Interest Group "JRC by-product fertilisers"

https://circabc.europa.eu/ -> Browse Public Groups -> European Commission -> Joint Research Centre > JRC by-product fertilisers

Click on ´Browse Public Groups' in the top header, and choose 'European Commission'. Inside the European Commission, click on 'Joint Research Centre', and then "JRC by-product fertilisers".

Step 3: Fill in Membership Application Form

If you are not yet listed as a group member, click on 'Join the Group' and fill in the Membership Application Form and then click 'submit'. After the manual approval by the JRC by-product fertilisers team, you will be admitted as full member of the Interest Group. You will receive an e-mail with the link to the Interest Group confirming your access. Note that **permission to upload documents in the library is restricted to experts of the Commission expert group for Fertilising Products**.

10.3.2 Uploading feedback on the draft report version 2

The library is the place where all documents are stored, managed and shared. Once logged into the 'JRC by-products fertilisers' Interest Group, the library can be accessed by clicking on the icon in the header.

The report can be downloaded from the CIRCABC Interest Group: EUROPA > European Commission > CIRCABC > Joint Research Centre > JRC by-product fertilisers > Information distributed by JRC.

Expert feedback can be uploaded via: CIRCABC Interest Group: EUROPA > European Commission > CIRCABC > Joint Research Centre > JRC by-product fertilisers > Feedback Commission expert group > version 2 - November 2020 (top right green icon "ADD +"). The document name should start with the country code or acronym of the member organisation.

Please structure your reply in an organised manner to ensure that feedback is task-focused, clear, to the point, and does not contain redundant or marginal information to safeguard time efficiency. Any **opinions should be supported by objective and evidence-based arguments**. No template for the feedback is provided by the JRC. You are welcome to join technical or scientific documents (e.g. reports, databases, peer reviewed journal articles) with your feedback. These supporting documents should also be in English or accompanied by at least an English translation of the relevant section. For any document of more than 10 pages in length, clear indications should be given on where the relevant information can be found (e.g. "See contaminant concentrations of candidate by-product A in Table X on page Y of the enclosed document entitled ZZZ.pdf").

The JRC is pleased to take into account any feedback from the stakeholders **UNTIL THE DEADLINE OF MONDAY 25 JANUARY 2021.**

In case of any further questions, please contact the JRC team at: JRC-B5-FERTILISERS@ec.europa.eu

10.4 Questionnaire on version 2 of this draft

10.4.1 General questions

As outlined in section 8, it should be ensured that the storage and handling of by-products should not lead to risks for the environment and human health, e.g. as a result of long-term storage under inappropriate conditions.

> Q G.1: What is the typical storage time for components to be used in (EU) fertilising materials?

> Q G.2: Please provide examples of "good management practices" related to storage and handling of components to be used in (EU) fertilising products. Have (voluntary) industry standards or codes of good practice on storage/handling been developed by industry? Do EU Member States impose minimal conditions or rules related to the storage of by-products and components for fertiliser products so as to avoid adverse environmental and human health impacts?

Additional questions will be requested for identified "priority materials", based on the group they fit in (see below).

10.4.2 Group A - By-products primarily obtained through the refining of fossil fuels (for chemical industry)

Please provide any information on the materials listed in the first row of Table 4 (covered in section 7.1 of this document).

Q A.1: The JRC welcomes more details from manufacturers on the production processes description, with a particular view on identifying or discarding the presence of impurities and contaminants. Please describe the processes (i) as general and broad as possible with a view of capturing possible differences in manufacturing methods and techniques applied across industry, and (ii) in such a manner that no confidential information is included (else, please contact JRC to safeguard confidentiality during the assessment process).

Q A.2: Are all materials from this group REACH registered (see also section 6)? If so, what is their European Community number / List number assigned by ECHA (EC No)?

Q A.3: Are industry standards/minimum requirements applicable for by-products that will be placed on the fertilising market (e.g. purity, moisture content, minimum nutrient content, free acid content, etc)?

Q A.4: Do EU Member States impose specific requirements related to the placing on the market for these by-product materials? Do EU Member States have limit values for any of the impurities/contaminants listed in Table 4 (or any other relevant properties of the by-product materials)? If so, please specify.

Q A.5: Please complete Table 4 according to following instructions:

- Complete any green cells for which information is available on concentrations of impurities/contaminants present in the candidate CMC 11 materials;
- Provide as much information as possible on data distribution (average values, minimum-maximum value, number of measurements; all individual measurement values of series, etc.)
- Express all data on a dry matter basis. In case no such information would be available, please specify the contaminant concentrations relative to the nutrient content of the material (e.g. mg / kg total N) and ensure that the unit is clearly indicated;
- Specify in case contaminants are absent and why. For instance: because measurements are below limit of detection or due to technical reasons (e.g. specific process steps applied, no risk of formation in manufacturing process, not used as a reactant);
- Focus on the “open” questions (dark green boxes) that aim at identifying additional contaminants (including PBT substances and CMR substances), and provide any relevant qualitative or quantitative information you might have;
- Please be as specific as possible when adding substances to the Table (e.g. methyl mercaptan instead of “organosulphur compounds”, 1,3-butadiene instead of “volatile organic carbon compounds”);
- No template is provided for feedback, but please ensure that all feedback (preferentially in editable file formats such as MS excel or MS-word) is well structured and understandable to JRC.

Table 4: Information request for group A materials. Please carefully read the instructions for completing the Table outlined above. All concentration data should be expressed as mg kg^{-1} dry material (with the exception of free acid content).

	Ammonium salts from cyclohexanone oxime and caprolactam production (section 7.1.2)	Ammonium sulphate from acrylonitrile and hydrocyanic acid production through ammoxidation (section 7.1.3)	Ammonium sulphate from methyl methacrylate production (section 7.1.4)	Ammonium sulphate from saccharin production (section 7.1.5)	Ammonium sulphate from methionine production through chemical synthesis (section 7.1.6)	Other well-defined substances (as defined pursuant regulation (EC) No 1907/2006) that are salts of ammonia (NH_4^+), nitrate (NO_3^-)-, phosphate (PO_4^-), or sulphate (SO_4^-), and fall within the scope of this group as outlined in section 7.1.7 (please specify materials, production process and impurities)
Bulk organic carbon (mg kg^{-1} dry material)						
Total nitrogen content (%, dry matter basis)						
Water content (%)						
Free acid content (% by mass)						
Purity (%) (please specify measurement method)						
Tarry substances and sulphur-containing organic substances (please specify substance, mg kg^{-1} dry matter)						

Polyaromatic hydrocarbons (PAH, mg kg^{-1} dry matter)						
PCDD/F (ng WHO toxicity equivalents kg^{-1} dry matter) and PCBs (mg kg^{-1} dry matter)						
Cyanides (total, mg kg^{-1} dry material)						
Process-specific organic impurities, including intermediate reaction products (mg kg^{-1} dry material)						
	caprolactam	acrylonitrile	vinyl ether	o-toluene-sulphonamide,	acrolein,	(please specify substance)
	cyclohexanone	acetonitrile	methanol	o-sulphamido-benzoic acid	methyl mercaptan	(please specify substance)
	cyclohexanone oxime	acrolein	methacrylic acid (vinyl actetate)	methyl anthranilate	methionine nitrile	(please specify substance)
	aniline	acrylic acid	aldehydes (e.g. acetaldehyde, please specify substance)	benzamide		(please specify substance)
	2-methylcyclo-pentanol	propionitrile		methyl benzoate,2-chloro-benzamide		(please specify substance)
		methacrylo-nitrile		chlorine		(please specify substance)
Solvents (mg kg^{-1} dry material)						

	Benzene	If used as reactant/solvent
	Toluene	If used as reactant/solvent
	Trichloroethylene	If used as reactant/solvent
	Other solvent residues (please specify)	If applicable
(v)PBT substances*, other than those listed above (mg kg^{-1} dry material)		(please specify substance)
CMR substances**, other than those listed above (mg kg^{-1} dry material)		(please specify substance)
Any other impurities that could be considered hazardous to health or the environment (mg kg^{-1} dry material)		(please specify substance)

*Persistent, Bioaccumulative and Toxic substances based on criteria set out in REACH annex XIII

**Known or suspected human carcinogen, mutagen or reproductive contaminant based on human evidence or animal studies (H340, H341, H350, H351, H360 or H361) listed in the table 3.1 of annex VI to CLP regulation

10.4.3 Group B – By-products primarily obtained from the refining of minerals, ores, and metals

Please provide any information on the materials listed in the first row of Table 5 (covered in section 7.2 of this document).

Q B.1: Which materials from this group REACH are registered (see also section 6)? If so, what is their European Community number / List number assigned by ECHA (EC No)?

Q B.2: Are industry standards/minimum requirements applicable for by-products that will be placed on the fertilising market?

Q B.3: Do EU Member States impose specific requirements related to the placing on the market for these by-product materials? Do EU Member States have limit values for any of the impurities/contaminants listed in Table 5 (or any other relevant properties of the by-product materials)? If so, please specify.

Q B.4: Please complete Table 5 according to following instructions:

- Complete any green cells for which information is available on concentrations of impurities/contaminants present in the candidate CMC 11 materials;
- Provide as much information as possible on data distribution (average, minimum-maximum value, number of measurements; all individual measurement values of series, etc.)
- Express all data on a dry matter basis (with the exception of radioactivity to be expressed as Becquerel kg^{-1}). In case no such information would be available, please specify the contaminant concentrations relative to the nutrient content of the material (e.g. mg / kg total N) and ensure that the unit is clearly indicated;
- Specify in case contaminants are absent and why. For instance: because measurements are below limit of detection or due to technical reasons (e.g. specific process steps applied, no risk of formation in manufacturing process, not used as a reactant);
- Focus on the “open” questions (dark green boxes) that aim at identifying additional contaminants (including PBT substances and CMR substances), and provide any relevant qualitative or quantitative information you might have;
- Please be as specific as possible when adding substances to the Table (e.g. methyl mercaptan instead of “organosulphur compounds”, 1,3-butadiene instead of “volatile organic carbon compound”);
- No template is provided for feedback, but please ensure that all feedback (preferentially in editable file formats such as MS excel or MS-word) is well structured and understandable to JRC.

Table 5: Information request for group B materials. Please carefully read the instructions for completing the Table outlined above. All concentration data should be expressed as mg kg^{-1} dry material (with the exception of radioactivity and free acids).

		Fines from dolomite processing (section 7.2.2.1)	Gypsum and calcium carbonate from sodium chloride brine purification (section 7.2.3)	Sulphate salts and metal sulphates from ore processing (section 7.2.4)	Carbide lime from acetylene production (section 7.2.5)	Post-soda lime from soda ash production (section 7.2.6)	Grinded steel slags (section 7.2.7)	Inorganic salts from metal surface treatment (section 7.2.8)
Metals (mg kg^{-1} dry material)								
	Cr(total) (mg kg^{-1} dry material)						🟩	🟩
	V (mg kg^{-1} dry material)						🟩	🟩
	Sr (mg kg^{-1} dry material)		🟩	🟩	🟩			
	Be (mg kg^{-1} dry material)						🟩	🟩
	Titanium dioxide (mg kg^{-1} dry material)			🟩			🟩	🟩
Purity (%) (please specify measurement method)								🟩
Chloride (Cl-) (mg kg^{-1} dry material)			🟩			🟩	🟩	

Fluoride (F-) (mg kg^{-1} dry material)			🟩				🟩
Mineral oil (mg kg^{-1} dry material)	🟩					🟩	🟩
Polyaromatic hydrocarbons (PAH, mg kg^{-1} dry matter)						🟩	🟩
PCDD/F (ng WHO toxicity equivalents kg^{-1} dry matter) and PCBs (mg kg^{-1} dry matter)						🟩	🟩
Radioactive substances (e.g. radium, expressed as Bq/kg^{-1} dry matter)			🟩				
Flocculant residues (please specify substance, mg kg^{-1} dry material)				🟩			
Free acids (% by mass)							🟩
Process-specific organic impurities, including intermediate reaction products (mg kg^{-1} dry material)							
				Ca_3P_2 (calcium phosphide), CaS (calcium sulphide), Ca_3N_2 (calcium nitride)			organic solvents (please specify substance)
				Dissolved acetylene			hydrogen peroxide
							Application-specific metals (e.g. W for metal surface

							treatment of alloys containing W)
(v)PBT substances*, other than those listed above (mg kg^{-1} dry material)	(please specify substance)						
CMR substances**, other than those listed above (mg kg^{-1} dry material)	(please specify substance)						
Any other impurities that could be considered hazardous to health or the environment (mg kg^{-1} dry material,)	(please specify substance)						

*Persistent, Bioaccumulative and Toxic substances based on criteria set out in REACH annex XIII

**Known or suspected human carcinogen, mutagen or reproductive contaminant based on human evidence or animal studies (H340, H341, H350, H351, H360 or H361) listed in the table 3.1 of annex VI to CLP regulation

10.4.4 Group C – By-products from gas cleaning systems, other than those from the chemical industry and waste management

Please provide any information on the materials listed in the first row of Table 6 (covered in section 7.3 of this document).

Q C.1: Are all materials from this group REACH registered (see also section 6)? If so, what is their European Community number / List number assigned by ECHA (EC No)?

Q C.2: Are industry standards/ minimum requirements applicable for by-products that will be placed on the fertilising market (e.g. moisture content, minimum nutrient content, etc)?

Q C.3: Do EU Member States impose specific requirements related to the placing on the market for these by-product materials? Do EU Member States have limit values for any of the impurities/contaminants listed in Table 6 (or any other relevant properties of the by-product materials)? If so, please specify.

Q C.4: Please complete according to following instructions:

- Complete any green cells for which information is available on concentrations of impurities/contaminants present in the candidate CMC 11 materials;
- Provide as much information as possible on data distribution (average, minimum-maximum value, number of measurements; all individual measurement values of series, etc.)
- Express all data on a dry matter basis. In case no such information would be available, please specify the contaminant concentrations relative to the nutrient content of the material (e.g. mg / kg total N) and ensure that the unit is clearly indicated;
- Specify in case contaminants are absent and why. For instance: because measurements are below limit of detection or due to technical reasons (e.g. specific process steps applied, no risk of formation in manufacturing process, not used as a reactant);
- Focus on the “open” questions (dark green boxes) that aim at identifying additional contaminants (including PBT substances and CMR substances), and provide any relevant qualitative or quantitative information you might have;
- Please be as specific as possible when adding substances to the Table (e.g. methyl mercaptan instead of “organosulphur compounds”, 1,3-butadiene instead of “volatile organic carbon compound”);
- No template is provided for feedback, but please ensure that all feedback (preferentially in editable file formats such as MS excel or MS-word) is well structured and understandable to JRC.

Table 6: Information request for group C materials. Please carefully read the instructions for completing the Table outlined above. All concentration data should be expressed as mg kg^{-1} dry material.

		Materials from SOx absorption from flue-gas desulphurisation of fossil fuels (section 7.3.2)	Elemental sulphur from thermal sulphide oxidation processes (section 7.3.3)	By-products from biomass gases (section 7.3.4)	Ammonium sulphate from coke production (see section 7.3.5)
Bulk organic carbon (mg kg^{-1} dry material)		🟩	🟩	🟩	🟩
Purity (%) (please specify measurement method)		🟩	🟩	🟩	🟩
Moisture content (%)		🟩	🟩	🟩	🟩
Chloride (Cl-) (mg kg^{-1} dry material)		🟩	🟩		🟩
Fluoride (F-) (mg kg^{-1} dry material)		🟩	🟩		🟩
Cyanides (CN-) (mg kg^{-1} dry material)		🟩	🟩		🟩
Polyaromatic hydrocarbons (PAH, mg kg^{-1} dry matter)		🟩	🟩		🟩
PCDD/F (ng WHO toxicity equivalents kg^{-1} dry matter) and PCBs (mg kg^{-1} dry matter)		🟩	🟩		🟩
sulphides (e.g. calcium sulphide, carbon disulphide, dimethylsulphide, dimethyldisulphide, dissolved hydrogen sulphide) (mg kg^{-1} dry material)		🟩	🟩		🟩
Process-specific organic impurities (mg kg^{-1} dry material)					
		mercaptans and other organic sulphur-containing compounds (please specify substances)		amines (methylamine, dimethylamine, ethylamine, and trimethylamine)	BTEX (benzene, toluene, ethylene, xylene)
		Cr (total)		airborne microorganisms	PAH and naphthalene as individual compound

	Se		tarry substances (please specify substance)
	Tl		
	V		
	Other metals		
	Oxidant residues (e.g. sodium hypochlorite, peroxides)		
(v)PBT substances*, other than those listed above (mg kg^{-1} dry material)	(please specify substance)		
CMR substances**, other than those listed above (mg kg^{-1} dry material)	(please specify substance)		
Any other impurities that could be considered hazardous to health or the environment (mg kg^{-1} dry material)	(please specify substance)		

*Persistent, Bioaccumulative and Toxic substances based on criteria set out in REACH annex XIII

**Known or suspected human carcinogen, mutagen or reproductive contaminant based on human evidence or animal studies (H340, H341, H350, H351, H360 or H361) listed in the table 3.1 of annex VI to CLP regulation

10.4.5 Group D – By-products from the processing of biomass and water for food, drink and biorefinery industries

Please provide any information on the materials listed in the first row of Table 7 (covered in section 7.4 of this document).

Q D.1: What materials from this group are REACH registered or pre-registered (see also section 6)? What is their European Community number / List number assigned by ECHA (EC No)?

Q D.2: What is the interest of manufacturers to register materials classified as "biomass residues as by-products from chemical and enzymatic refining processes" under REACH so as to become CMC 11 materials? For what specific candidate materials would a REACH registration be envisaged, and what would be proposed substance name for registration? For what specific materials would processing routes through composting or anaerobic digestion be more suitable options?

Q D.3: Are industry standards/ minimum requirements applicable for by-products that will be placed on the fertilising market (e.g. moisture content, minimum nutrient content, etc)?

Q D.4: Do EU Member States impose specific requirements related to the placing on the market for these by-product materials? Do EU Member States have limit values for any of the impurities/contaminants listed in Table 7 (or any other relevant properties of the by-product materials)? If so, please specify.

Q D.5: Please complete according to following instructions:

- Complete any green cells for which information is available on concentrations of impurities/contaminants present in the candidate CMC 11 materials;
- Provide as much information as possible on data distribution (average, minimum-maximum value, number of measurements; all individual measurement values of series, etc.)
- Express all data on a dry matter basis. In case no such information would be available, please specify the contaminant concentrations relative to the nutrient content of the material (e.g. mg / kg total N) and ensure that the unit is clearly indicated;
- Specify in case contaminants are absent and why. For instance: because measurements are below limit of detection or due to technical reasons (e.g. specific process steps applied, no risk of formation in manufacturing process, not used as a reactant);
- Focus on the "open" questions (dark green boxes) that aim at identifying additional contaminants (including PBT substances and CMR substances), and provide any relevant qualitative or quantitative information you might have;
- Please be as specific as possible when adding substances to the Table (e.g. methyl mercaptan instead of "organosulphur compounds", 1,3-butadiene instead of "volatile organic carbon compound");
- No template is provided for feedback, but please ensure that all feedback (preferentially in editable file formats such as MS excel or MS-word) is well structured and understandable to JRC.

Table 7: Information request for group D materials. Please carefully read the instructions for completing the Table outlined above. All concentration data should be expressed as mg kg^{-1} dry material.

	Biomass residues as by-products from chemical and enzymatic refining processes (please specify material, see 7.4.2)	bleaching earth/filter aid (e.g. diatomaceous earth, amorphous silicates and silica; included under section 7.4.2)	By-products derived manufacturing and processing aids (see section 7.4.3)	Humic/fulvic acids from drinking water production (see section 7.4.4.1)	Lime mud and burnt lime from paper and pulp industry (see section 7.4.5)
Bulk organic carbon (mg kg^{-1} dry material)			🟩		🟩
Purity (%) (please specify measurement method)			🟩		
Moisture content (%)	🟩		🟩	🟩	🟩
Cyanides (CN-) (mg kg^{-1} dry material)	🟩		🟩		
Chloride (Cl-) (mg kg^{-1} dry material)	🟩			🟩	🟩
Biological pathogens (*Salmonella*, *Campylobacter*, *E. coli*, *Listeria*, *Clostridium*, plant pests, others – please specify) (colony forming units (CFU) g^{-1} material)	🟩	🟩	🟩		
Hazard Analysis & Critical Control Point Analysis programmes	🟩 In place for production process, and by-products generated?				
Stability (e.g. oxygen uptake rate, expressed as mmol O_2 /kg organic matter/h)	🟩				

PCDD/F (ng WHO toxicity equivalents kg^{-1} dry matter) and PCBs (mg kg^{-1} dry matter)	🟩	🟩	🟩		🟩
PAH (polyaromatic hydrocarbons, mg kg^{-1} dry matter)	🟩	🟩	🟩		🟩
Chloropropanols (µg kg^{-1})	🟩	🟩			
Processing residues (e.g. hexane from solvent use, antifoaming substances, disinfectants) (mg kg^{-1} dry matter)	🟩	🟩			🟩
Methanol (mg kg^{-1} dry matter)			🟩		
Metals (mg kg^{-1} dry matter)					🟩 Cr(total)
(v)PBT substances*, other than those listed above (mg kg^{-1} dry material)	(please specify substance)				
CMR substances**, other than those listed above (mg kg^{-1} dry material)	(please specify substance)				
Any other impurities that could be considered hazardous to health or the environment (mg kg^{-1} dry material)	(please specify substance)				

*Persistent, Bioaccumulative and Toxic substances based on criteria set out in REACH annex XIII

**Known or suspected human carcinogen, mutagen or reproductive contaminant based on human evidence or animal studies (H340, H341, H350, H351, H360 or H361) listed in the table 3.1 of annex VI to CLP regulation

10.4.6 Group E – By-products as fertilising product components added for technical reasons

Q E.1: What materials are envisaged for this group? Please provide information on the identity and production process of candidate materials.

Q E.2: What is the mass proportion of these materials in the fertilising products that will be placed on the market

11 REFERENCES

Accettola F., Guebitz G.M. & Schoeftner R. (2008) Siloxane removal from biogas by biofiltration: biodegradation studies. *Clean Technologies and Environmental Policy* **10**: 211-218.

Algermissen D., A. Morillon, K.-J. Arlt, N. Wolsfeld, M. Rex, M. Mauhart, . . . S. Tuo-Mikoski S. (2016) Impact of long-term application of blast furnace and steel slags as liming materials on soil fertility, crop yields and plant health (SLAGFERTILISER). European Commission, Research Programme of the Research Fund for Coal and Steel, TG9, 1. Juli 2011 - 30. June 2015, RFSR-CT-2011-00037, Draft Final Report.

Allegue L.B. & Hinge J. (2014) Biogas upgrading - Evaluation of methods for H2S removal. Technical Report for the Danish Technological Institute. .

Almaula S. (2005) Polycyclic Aromatic Hydrocarbons from Steelmaking. *Environmental Forensics* **6**: 143-150.

Berovic M. & Legisa M. (2007) Citric acid production. *Biotechnology Annual Review*, Vol. 13, El-Gewely M.R. (ed.), pages. 303-343. Elsevier.

Boelaert F., Rizzi V., Amore G., Stoicescu A., Riolo F., Nagy K., . . . European Centre Dis P. (2015) The European Union summary report on trends and sources of zoonoses, zoonotic agents and food-borne outbreaks in 2013. *Efsa Journal* **13**.

Boelaert F., Amore G., Van der Stede Y., Nagy K., Rizzi V., Mirena I., . . . European Ctr Dis P. (2016) The European Union summary report on trends and sources of zoonoses, zoonotic agents and food-borne outbreaks in 2015. *Efsa Journal* **14**.

Boswell C.C. & Friesen D.K. (1993) Elemental sulfur fertilizers and their use on crops and pastures. *Fertilizer research* **35**: 127-149.

Brennan R. (1990) Effectiveness of some copper compounds applied as foliar sprays in alleviating copper deficiency of wheat grown on copper-deficient soils of Western Australia. *Australian Journal of Experimental Agriculture* **30**: 687-691.

Brinkmann T., Giner Santonja G., Yükseler H., Roudier S. & Delgado Sancho L. (2016) Best Available Techniques (BAT) Reference Document for Common Waste Water and Waste Gas Treatment/Management Systems in the Chemical Sector Industrial Emissions Directive 2010/75/EU (Integrated Pollution Prevention and Control). Available at: https://eippcb.jrc.ec.europa.eu/sites/default/files/2019-11/CWW_Bref_2016_published.pdf.

Broadley M.R., White P.J., Hammond J.P., Zelko I. & Lux A. (2007) Zinc in plants. *New Phytologist* **173**: 677-702.

Buick J.B. & Magee T.R.A. (1999) Microbial contamination of flax dust. *Resources, Conservation and Recycling* **27**: 99-104.

Canellas L.P., Olivares F.L., Aguiar N.O., Jones D.L., Nebbioso A., Mazzei P. & Piccolo A. (2015) Humic and fulvic acids as biostimulants in horticulture. *Scientia Horticulturae* **196**: 15-27.

Cardoso F.A., Fernandes H.C., Pileggi R.G., Cincotto M.A. & John V.M. (2009) Carbide lime and industrial hydrated lime characterization. *Powder Technology* **195**: 143-149.

Careddu N. & Marras G. (2015) Marble Processing for Future Uses of CaCO3-Microfine Dust: A Study on Wearing out of Tools and Consumable Materials in Stoneworking Factories. *Mineral Processing and Extractive Metallurgy Review* **36**: 183-191.

Careddu N. & Dino G.A. (2016) Reuse of residual sludge from stone processing: differences and similarities between sludge coming from carbonate and silicate stones—Italian experiences. *Environmental Earth Sciences* **75**: 1075.

CEFIC (2014) Methyl methacrylate (MMA) Eco-profiles and Environmental Product Declarations of the European Plastics Manufacturers.

Chaturvedi S. & Dave P.N. (2012) Removal of iron for safe drinking water. *Desalination* **303**: 1-11.

Chen S., Jiang T., Zhang H., Kong K. & Bie L. (2020) Emission reduction process for dechlorinating flue-gas desulfurization gypsum and reducing wastewater effluents: Application prospects from laboratory-scale studies. *Energy Science & Engineering* **8**: 2662-2679.

Cheremisinoff N.P. (2012) 2 - Solid Wastes. *Clean Electricity Through Advanced Coal Technologies*, Cheremisinoff N.P. (ed.), pages. 31-61. William Andrew Publishing, Oxford.

Chesner W.H., Collins R.J. & MacKay M.H. (1999) User guidelines for waste and by-product materials in pavement construction. Chesner Engineering, P.C. and US Federal Highway Administration, Report Number: FHWA-RD-97-148

Chien S.H., Gearhart M.M. & Villagarcía S. (2011) Comparison of Ammonium Sulfate With Other Nitrogen and Sulfur Fertilizers in Increasing Crop Production and Minimizing Environmental Impact: A Review. *Soil Science* **176**: 327-335.

Cinar M. & Durgut E. (2019) Mineral beneficiation of nepheline syenite with combination of dry magnetic separation and flotation methods. *Physicochemical Problems of Mineral Processing* **55**: 1227-1238.

Collier P.D., Cromie D.D.O. & Davies A.P. (1991) Mechanism of formation of chloropropanols present in protein hydrolysates. *Journal of the American Oil Chemists Society* **68**: 785-790.

Craighead M.D. & Martin R.J. (2001) Responses to magnesium fertilisers in wheat in Mid Canterbury. *Agronomy New Zealand, Proceedings*, Vol. 31, Hampton J.G. & Pollock K.M. (eds.), pages. 63-70.

Crawshaw R. (2012) Animal feeds, feeding practices and opportunities for feed contamination: an introduction. *Animal Feed Contamination: Effects on Livestock and Food Safety*, FinkGremmels J. (ed.), pages. 11-32.

Czaplicka N. & Konopacka-Łyskawa D. (2019) Studies on the utilization of post-distillation liquid from Solvay process to carbon dioxide capture and storage. *SN Applied Sciences* **1**: 431.

Dacarro C., Grisoli P., Del Frate G., Villani S., Grignani E. & Cottica D. (2005) Micro-organisms and dust exposure in an Italian grain mill. *Journal of Applied Microbiology* **98**: 163-171.

de Arespacochaga N., Valderrama C., Raich-Montiu J., Crest M., Mehta S. & Cortina J.L. (2015) Understanding the effects of the origin, occurrence, monitoring, control, fate and removal of siloxanes on the energetic valorization of sewage biogas—A review. *Renewable and Sustainable Energy Reviews* **52**: 366-381.

Denofa (2007) Isolation of Salmonella from imported soy beans and associated environment of subsequent crushing procedure during the period 1999–2007. Denofa AS, Fredrikstad, Norway.

Devi A., Singhal A., Gupta R. & Panzade P. (2014) A study on treatment methods of spent pickling liquor generated by pickling process of steel. *Clean Technologies and Environmental Policy* **16**: 1515-1527.

DKL Engineering (2002) Acid Regeneration - Methyl Methacrylate (MMA) Spent Acid. Available at: http://www.sulphuric-acid.com/techmanual/AcidRegen/mma.htm.

DOMO Caproleuna GmbH (2014) Analysis of alternatives - Industrial use as an extraction solvent for the purification of caprolactam from caprolactam oil (public version). Available at: https://echa.europa.eu/documents/10162/18584504/afa_tce-0020-01-aa_en.pdf/44e6e42b-884e-46e9-b842-ca488ecb2200 (accessed 05/08/2020)

Doyle M.P. & Erickson M.C. (2012) Opportunities for mitigating pathogen contamination during on-farm food production. *International Journal of Food Microbiology* **152**: 54-74.

du Jardin P. (2015) Plant biostimulants: Definition, concept, main categories and regulation. *Scientia Horticulturae* **196**: 3-14.

Dumont E. (2015) H2S removal from biogas using bioreactors: a review. . *International Journal of Energy and Environnement* **6**: 479-198.

Ehlert P., Sigjurnak I., Meers E., Verbeke M., Adani F., Zilio M., . . . Schoumans O. (2019) Nitrogen fertilising products based on manure and other organic residues. Supporting literature of the SYSTEMIC factsheets. Wageningen, Wageningen Environmental Research, Report.

Eisenberg S. (2007) Relative stability of selenites and selenates in feed premixes as a function of water activity. *Journal of Aoac International* **90**: 349-353.

Elloumi N., Zouari M., Chaari L., Abdallah F.B., Woodward S. & Kallel M. (2015) Effect of phosphogypsum on growth, physiology, and the antioxidative defense system in sunflower seedlings. *Environmental Science and Pollution Research* **22**: 14829-14840.

European Food Safety A., European Food Safety A. & European Ctr Dis Prevention C. (2015) The European Union summary report on trends and sources of zoonoses, zoonotic agents and food-borne outbreaks in 2014. *Efsa Journal* **13**.

European Food Safety A., European Food Safety A. & Ctr Dis Prevention Control E. (2018) The European Union summary report on trends and sources of zoonoses, zoonotic agents and food-borne outbreaks in 2017. *Efsa Journal* **16**.

European Food Safety A., European Food Safety A., European Ctr Dis P. & Co (2017) The European Union summary report on trends and sources of zoonoses, zoonotic agents and food-borne outbreaks in 2016. *Efsa Journal* **15**.

European Food Safety A., European Food Safety A., European Ctr Dis Prevention C. & Ecdc (2019) The European Union One Health 2018 Zoonoses Report. *Efsa Journal* **17**.

Eurosurveillance Editorial T. (2012) The European Union summary report on trends and sources of zoonoses, zoonotic agents and food-borne outbreaks in 2010. *Eurosurveillance* **17**: 21-21.

Evans T.D. (2007) Recovering ammonium and struvite fertilisers from digested sludge dewatering liquors. In: Proceedings of Specialist Conference. IWA: Moving Forward – Wastewater Biosolids Sustainability, Canada.

Falcke H., Holbrook S., Clenahan I., Lopez Carretero A., Sanalan T., Brinkmann T., . . . Delgado Sancho L. (2017) Best Available Techniques (BAT) Reference Document for the Production of Large Volume Organic Chemicals. Industrial Emissions Directive 2010/75/EU (Integrated Pollution Prevention and Control). Available at: https://eippcb.jrc.ec.europa.eu/sites/default/files/2019-11/JRC109279_LVOC_Bref.pdf.

Fink-Gremmels J. (2012) 1 - Introduction to animal feed contamination. *Animal Feed Contamination*, Fink-Gremmels J. (ed.), pages. 1-10. Woodhead Publishing.

Golodets G.I. (1983) Chapter XXIV: The Ammoxidation of Organic Substances. In: Heterogeneous Catalytic Reactions Involving Molecular Oxygen. *Studies in*

Surface Science and Catalysis, Vol. 15, Golodets G.I. (ed.), pages. 767-792. Elsevier.

Goluchowska B., Strzyszcz Z. & Kusza G. (2012) Magnetic Susceptibility and Heavy Metal Content in Dust From the Lime Plant and the Cement Plant in Opole Voivodeship. *Archives of Environmental Protection* **38**: 71-80.

Gominsek T., Lubej A. & Pohar C. (2005) Continuous precipitation of calcium sulfate dihydrate from waste sulfuric acid and lime. *Journal of Chemical Technology and Biotechnology* **80**: 939-947.

Grabas K., Pawełczyk A., Stręk W., Szełęg E. & Stręk S. (2019) Study on the Properties of Waste Apatite Phosphogypsum as a Raw Material of Prospective Applications. *Waste and Biomass Valorization* **10**: 3143-3155.

Greene S.K., Daly E.R., Talbot E.A., Demma L.J., Holzbauer S., Patel N.J., . . . Painter J.A. (2008) Recurrent multistate outbreak of Salmonella Newport associated with tomatoes from contaminated fields, 2005. *Epidemiology and Infection* **136**: 157-165.

Grönfors J. (2010) Use of fillers in paper and paperboard grades. Tampere University of Applied Sciences.

Guillen M.D., Sopelana P. & Partearroyo M.A. (1997) Food as a source of polycyclic aromatic carcinogens. *Reviews on environmental health* **12**: 133-146.

Häggblom P. (1993) Monitoring and control of Salmonella in animal feed. NVI/WHO International course on Salmonella control in animal production and products, Aug. 21–27. Ed. National Veterinary Institute, Uppsala, Sweden, pp. 127–137.

Hanif M.A., Ibrahim N. & Abdul Jalil A. (2020) Sulfur dioxide removal: An overview of regenerative flue gas desulfurization and factors affecting desulfurization capacity and sorbent regeneration. *Environmental Science and Pollution Research* **27**: 27515-27540.

He J., Lange C.R. & Dougherty M. (2009) Laboratory study using paper mill lime mud for agronomic benefit. *Process Safety and Environmental Protection* **87**: 401-405.

Hejcman M., Szaková J., Schellberg J., Šrek P. & Tlustoš P.J.N.C.i.A. (2009) The Rengen Grassland Experiment: soil contamination by trace elements after 65 years of Ca, N, P and K fertiliser application. **83**: 39-50.

Himathongkham S., Pereira M.D. & Riemann H. (1996) Heat destruction of Salmonella in poultry feed: Effect of time, temperature, and moisture. *Avian Diseases* **40**: 72-77.

Hobson A.J., Stewart D.I., Bray A.W., Mortimer R.J.G., Mayes W.M., Rogerson M. & Burke I.T. (2017) Mechanism of Vanadium Leaching during Surface Weathering of Basic Oxygen Furnace Steel Slag Blocks: A Microfocus X-ray Absorption Spectroscopy and Electron Microscopy Study. *Environmental Science & Technology* **51**: 7823-7830.

Horikawa M.S., Rossi F., Gimenes M.L., Costa C.M.M. & da Silva M.G.C. (2004) Chemical absorption of H2S for biogas purification. *Brazilian Journal of Chemical Engineering* **21**: 415-422.

Hsu J.C. & Hu S.-H. (1998) Recovery of fibers from a fiber processing waste sludge. US patent US6372085B1.

Huygens D., Saveyn H., Tonini D., Eder P. & Delgado Sancho L. (2019) Technical proposals for selected new fertilising materials under the Fertilising Products Regulation (Regulation (EU) 2019/1009) - Process and quality criteria, and assessment of environmental and market impacts for precipitated phosphate salts & derivates, thermal oxidation materials & derivates and pyrolysis & gasification materials. Publications Office of the European Union, Luxembourg.

Jones F.T. (2011) A review of practical Salmonella control measures in animal feed. *Journal of Applied Poultry Research* **20**: 102-113.

JRC (2019) Best Available Techniques (BAT) Reference Document for Common Waste Gas Management and Treatment Systems in the Chemical Sector Industrial Emissions Directive 2010/75/EU

(Integrated Pollution Prevention and Control) (Draft 1), JOINT RESEARCH CENTRE Directorate B – Growth and Innovation Circular Economy and Industrial Leadership Unit European IPPC Bureau. Available at: https://eippcb.jrc.ec.europa.eu/reference.

Kirchmann H. & Bergstrom L. (2003) Use of paper-mill wastes on agricultural soils: Is this a way to reduce nitrate leaching? *Acta Agriculturae Scandinavica Section B-Soil and Plant Science* **53**: 56-63.

Kobesen H. (2009) Legal Status of Slag Valorisation, Proceeding of the First International Slag Valorisation Symposium, Leuven, Belgium, April 6-7, 2009

Kuenen J., Trozzi C., Berdowski J., van der Most P., Verhoeve P. & Woodfield M. (2009) Degreasing - EMEP/EEA emission inventory guidebook

Kuhn M., Spiegel H., Lopez F.A., Rex M. & Erdmann R. (2006) Sustainable agriculture using blast furnace and steel slags as liming agents. ECSC/RFCS Final Report for Contract No 7210-PR/267 for Directorate-General for Research, European Commission.

Kuokkanen T., Nurmesniemi H., Pöykiö R., Kujala K., Kaakinen J. & Kuokkanen M. (2008) Chemical and leaching properties of paper mill sludge. *Chemical Speciation & Bioavailability* **20**: 111-122.

Kwiatek K., Kukier E., Wasyl D. & Hoszowski A. (2008) Microbial quality of feed in Poland (In Polish with an English summary) *Medycyna Weterynaryjna* **64**: 183-188.

Lamers L.P.M., Govers L.L., Janssen I.C.J.M., Geurts J.J.M., Van der Welle M.E.W., Van Katwijk M.M., . . . Smolders A.J.P. (2013) Sulfide as a soil phytotoxin-a review. *Frontiers in plant science* **4**: 268-268.

Laohakunjit N., Selamassakul O. & Kerdchoechuen O. (2014) Seafood-like flavour obtained from the enzymatic hydrolysis of the protein by-products of seaweed (Gracilaria sp.). *Food Chem* **158**: 162-170.

Lauf R.J., Harris L.A. & Rawlston S.S. (1982) Pyrite framboids as the source of magnetite spheres in fly ash. *Environmental Science & Technology* **16**: 218-220.

Lavery C.B., Marrugo-Hernandez J.J., Sui R., Dowling N.I. & Marriott R.A. (2019) The effect of methanol in the first catalytic converter of the Claus sulfur recovery unit. *Fuel* **238**: 385-393.

Lecomte T., Ferrería de la Fuente J.F., Neuwahl F., Canova M., Pinasseau A., Jankov I., . . . Delgado Sancho L. (2017) Best Available Techniques (BAT) Reference Document for Large Combustion Plants Industrial Emissions Directive 2010/75/EU (Integrated Pollution Prevention and Control). Available at: https://eippcb.jrc.ec.europa.eu/sites/default/files/2019-11/JRC_107769_LCPBref_2017.pdf.

Lee J.-Y., Cho K., Cheng L., Keener T.C., Jegadeesan G. & Al-Abed S.R. (2009) Investigation of a Mercury Speciation Technique for Flue Gas Desulfurization Materials. *Journal of the Air & Waste Management Association* **59**: 972-979.

Lewis C.J. & Crocker B.B. (1969) The Lime Industry's Problem of Airborne Dust. *Journal of the Air Pollution Control Association* **19**: 31-39.

Liebana E. & Hugas M. (2012) Assessment of the microbiological risks in feedingstuffs for food-producing animals. *Animal Feed Contamination: Effects on Livestock and Food Safety*, FinkGremmels J. (ed.), pages. 66-93.

Likon M. & Trebše P. (2012) Recent Advances in Paper Mill Sludge Management. *Industrial Waste*, Show K.-Y. & Guo X. (eds.), pages. IntechOpen, Rijeka.

Lips S.H., Leidi E.O., Silberbush M., Soares M.I.M. & Lewis O.E.M. (1990) Physiological aspects of ammonium and nitrate fertilization. *Journal of Plant Nutrition* **13**: 1271-1289.

Lonhienne T., Mason M.G., Ragan M.A., Hugenholtz P., Schmidt S. & Paungfoo-Lonhienne C. (2014) Yeast as a Biofertilizer Alters Plant Growth and Morphology. *Crop Science* **54**: 785-790.

Lucena J.J. (2003) Fe Chelates for Remediation of Fe Chlorosis in Strategy I Plants. *Journal of Plant Nutrition* **26**: 1969-1984.

Madende M. & Hayes M. (2020) Fish By-Product Use as Biostimulants: An Overview of the Current State of the Art, Including Relevant Legislation and Regulations within the EU and USA. . *Molecules* **25**: 1122.

Malisch R. (2017) Incidents with dioxins and PCBs in food and feed-investigative work, risk management and economic consequences. *Journal of Environmental Protection* **8**: 744-785.

Manca P.P., Orru G. & Desogus P. (2015) Recycling of sludge from ornamental stone processing as resource in civil constructions. *International Journal of Mining Reclamation and Environment* **29**: 141-155.

Manning D.A.C., Baptista J., Sanchez Limon M. & Brandt K. (2017) Testing the ability of plants to access potassium from framework silicate minerals. *Science of The Total Environment* **574**: 476-481.

Marras G., Bortolussi A., Peretti R. & Careddu N. (2017) Characterization methodology for re-using marble slurry in industrial applications. *Energy Procedia* **125**: 656-665.

Max B., Salgado J.M., Rodriguez N., Cortes S., Converti A. & Dominguez J.M. (2010) Biotechnological production of citric acid. *Brazilian Journal of Microbiology* **41**: 862-875.

McHugh D.J. (2013) A Guide to the Seaweed Industry. Rome: Food and Agriculture Organization of the United Nations.

Melse R.W. & Ogink N. (2005) Air scrubbing techniques for ammonia and odour reduction at livestock operations: REview of on-farm research in the Netherlands. *Transactions of the ASAE* **48**: 2303-2313.

Mohammed S.M.O., Brandt K., Gray N.D., White M.L. & Manning D.A.C. (2014) Comparison of silicate minerals as sources of potassium for plant nutrition in sandy soil. *European Journal of Soil Science* **65**: 653-662.

Monbaliu S., Van Peteghem C. & De Saeger S. (2012) Detection and determination of natural toxins (mycotoxins and plant toxins) in feed. *Animal Feed Contamination: Effects on Livestock and Food Safety*, FinkGremmels J. (ed.), pages. 286-325.

Monte M.C., Fuente E., Blanco A. & Negro C. (2009) Waste management from pulp and paper production in the European Union. *Waste Management* **29**: 293-308.

Muse J.K. & Mitchell C.C. (1995) Paper mill boiler ash and lime by-products as soil liming materials. *Agronomy Journal* **87**: 432-438.

Nagl G.J., Bermel C.L. & Choong G.C. (2014) LO CAT®– The Green Solution to Sulfur Recovery. 19th annual Joint Conference Calgary, Alberta, November 14, 2012.

Nasir N.F., Mirus M.F. & Ismail M. (2017) Purification of crude glycerol from transesterification reaction of palm oil using direct method and multistep method. *IOP Conference Series: Materials Science and Engineering* **243**: 012015.

Neuwahl F., Cusano G., Gómez Benavides J., Holbrook S. & Roudier S. (2019) Best Available Techniques (BAT) Reference Document for Waste Incineration Industrial Emissions Directive 2010/75/EU (Integrated Pollution Prevention and Control). EUR 29971 EN; doi:10.2760/761437. Available at: https://eippcb.jrc.ec.europa.eu/sites/default/files/2020-01/JRC118637_WI_Bref_2019_published_0.pdf.

O'Donnell K. & Kearsley M.W. (2012) *Sweeteners and Sugar Alternatives in Food Technology*. JohnWiley & Sons, Ltd,, Sussex, UK.

O’Brien T.F., Bommaraju T.V. & Hine F. (2005) Brine Preparation and Treatment. *Handbook of Chlor-Alkali Technology: Volume I: Fundamentals, Volume II: Brine Treatment and Cell Operation, Volume III: Facility Design and Product Handling, Volume IV: Plant Commissioning and Support Systems, Volume V: Corrosion, Environmental Issues, and Future Development*, pages. 465-703. Springer US, Boston, MA.

O’Connell A., Prussi M., Padella M., Konti A. & Lonza L. (2019) Sustainable Advanced Biofuels Technology Market Report 2018, EUR 29929 EN, European Commission, Luxembourg, 2019, ISBN 978-92-76-12585-3, doi:10.2760/487802, JRC118309.

Ochoa de Alda J.A.G. (2008) Feasibility of recycling pulp and paper mill sludge in the paper and board industries. *Resources, Conservation and Recycling* **52**: 965-972.

Panday D., Ferguson R.B. & Maharjan B. (2018) Flue Gas Desulfurization Gypsum as Soil Amendment. *Soil Amendments for Sustainability - Challenges and Perspectives*, Rakshit A., Sarkar B. & Abhilash P. (eds.), pages. chapter 14. CRC Press, Boca Raton.

Papadias D. & Ahmed S. (2012) Biogas Impurities and Cleanup for Fuel Cells. Presented at the Biogas and Fuel Cells Workshop Golden, CO June 11-13, 2012.

Parker S. (2013) Biodiesel Transesterification Byproducts as Soil Amendments. MsC thesis, University of Arkansas. Theses and Dissertations. 685.

Pasupuleti V.K. & Braun S. (2010) State of the Art Manufacturing of Protein Hydrolysates. *Protein hydrolysates in biotechnology*, pages. 11-32. Springer, Dordrecht.

Peña-Méndez M.E., Havel J. & Patočka J. (2005) Humic substances - compounds of still unknown structure: applications in agriculture, industry, environment, and biomedicine. *Journal of Applied Biomedicine* **3**: 13-24.

Pereira A.C. & Papini R.M. (2015) Processes for phosphorus removal from iron ore - a review. *Rem: Revista Escola de Minas* **68**: 331-335.

Pérez-López R., Castillo J., Quispe D. & Nieto J.M. (2010) Neutralization of acid mine drainage using the final product from CO2 emissions capture with alkaline paper mill waste. *Journal of Hazardous Materials* **177**: 762-772.

Pettersson H. (2012) 11 - Mycotoxin contamination of animal feed. *Animal Feed Contamination*, Fink-Gremmels J. (ed.), pages. 233-285. Woodhead Publishing.

Phillips D.H. (1999) Polycyclic aromatic hydrocarbons in the diet. *Mutation Research-Genetic Toxicology and Environmental Mutagenesis* **443**: 139-147.

Piatak N.M., Parsons M.B. & Seal R.R. (2015) Characteristics and environmental aspects of slag: A review. *Applied Geochemistry* **57**: 236-266.

Pirie J.M. (1958) The Manufacture of Hydrocyanic Acid by the Andrussow Process. *Platinum Metals Reviews* **2**: 7.

Pitt F.D., Domingos A.M. & Barros A.A.C. (2019) Purification of residual glycerol recovered from biodiesel production. *South African Journal of Chemical Engineering* **29**: 42-51.

Proctor D.M., Fehling K.A., Shay E.C., Wittenborn J.L., Green J.J., Avent C., . . . Zak M.A. (2000) Physical and Chemical Characteristics of Blast Furnace, Basic Oxygen Furnace, and Electric Arc Furnace Steel Industry Slags. *Environmental Science & Technology* **34**: 1576-1582.

Qian P., Schoenau J. & Urton R. (2011) Effect of soil amendment with thin stillage and glycerol on plant growth and soil properties. *Journal of Plant Nutrition* **34**: 2206-2221.

Qin Y. (2018) 3 - Production of Seaweed-Derived Food Hydrocolloids. *Bioactive Seaweeds for Food Applications*, Qin Y. (ed.), pages. 53-69. Academic Press.

RaboResearch (2017) The European Feed Mix: Successful Ingredients for the World's Second-Largest Feed Market. Available at: https://research.rabobank.com/far/en/sectors/grains-oilseeds/the_european_feed_mix.html (consulted on 12/11/2020).

Raiswell R. & Bottrell S.H. (1991) The disposal of flue gas desulphurisation waste: sulphur gas emissions and their control. *Environmental Geochemistry and Health* **13**: 119-126.

Ramasamy P., Periathamby A. & Ibrahim S. (2002) Carbide sludge management in acetylene producing plants by using vacuum filtration. *Waste Management & Research* **20**: 536-540.

Rana A., Kalla P., Verma H.K. & Mohnot J.K. (2016) Recycling of dimensional stone waste in concrete: A review. *Journal of Cleaner Production* **135**: 312-331.

Rasi S., Veijanen A. & Rintala J. (2007) Trace compounds of biogas from different biogas production plants. *Energy* **32**: 1375-1380.

Reijkonen I. (2017) Chemical bioavailability of chromium and vanadium species in soil: risk assessment of the use of steel industry slags as liming materials. PhD thesis, University of Helsinki, Finland.

Reinhart D.R. (1993) A Review Of Recent Studies On The Sources Of Hazardous Compounds Emitted From Solid Waste Landfills: A U.S. Experience. *Waste Management & Research* **11**: 257-268.

Rietjens I., Martena M.J., Boersma M.G., Spiegelenberg W. & Alink G.M. (2005) Molecular mechanisms of toxicity of important food-borne phytotoxins. *Molecular Nutrition & Food Research* **49**: 131-158.

Roccaro P., Mancini G. & Vagliasindi F.G.A. (2005) Water intended for human consumption - Part I: Compliance with European water quality standards. *Desalination* **176**: 1-11.

Rossell J.B. (2001) *Frying: improving quality*. Woodhead, Cambridge, England.

Rouphael Y. & Colla G. (2018) Synergistic Biostimulatory Action: Designing the Next Generation of Plant Biostimulants for Sustainable Agriculture. *Frontiers in Plant Science* **9**.

Ruiz-Hernando M., Martin-Diaz J., Labanda J., Mata-Alvarez J., Llorens J., Lucena F. & Astals S. (2014) Effect of ultrasound, low-temperature thermal and alkali pre-treatments on waste activated sludge rheology, hygienization and methane potential. *Water Research* **61**: 119-129.

Sánchez-Monedero M.A. & Stentiford E.I. (2003) Generation and Dispersion of Airborne Microorganisms from Composting Facilities. *Process Safety and Environmental Protection* **81**: 166-170.

Saveyn H. & Eder P. (2014) End-of-Waste criteria for biodegradable waste subjected to biological treatment (compost and digestate) - technical proposals. Publications Office of the European Commission.

Scafe E., Nardella A. & De Filippis D. (2005) Elastic properties of polycrystalline elemental sulphur. *Journal of Materials Science* **40**: 3813-3816.

Schade G.W. & Crutzen P.J. (1995) Emission of aliphatic amines from animal husbandry and their reactions: Potential source of N2O and HCN. *Journal of Atmospheric Chemistry* **22**: 319-346.

Schrama F.N.H., Ji F., Hunt A., Beunder E.M., Woolf R., Tuling A., . . . Yang Y. (2020) Lowering iron losses during slag removal in hot metal desulphurisation without using fluoride. *Ironmaking & Steelmaking* **47**: 464-472.

Serna-Maza A., Heaven S. & Banks C.J. (2014) Ammonia removal in food waste anaerobic digestion using a side-stream stripping process. *Bioresource Technology* **152**: 307-315.

Shi C. (2002) Characteristics and cementitious properties of ladle slag fines from steel production. *Cement and Concrete Research* **32**: 459-462.

Sivamaruthi B.S., Kesika P. & Chaiyasut C. (2018) Toxins in Fermented Foods: Prevalence and Preventions-A Mini Review. *Toxins* **11**: 4.

Smit C.E. (2012) *Environmental risk limits for vanadium in water - A proposal for water quality standards in accordance with the Water Framework Directive.* . RIVM Letter Report 601714021/2012, Bilthoven, the Netherlands.

Sofekun G.O., Evoy E., Lesage K.L., Chou N. & Marriott R.A. (2018) The rheology of liquid elemental sulfur across the lambda-transition. *Journal of Rheology* **62**: 469-476.

Sohoni S., Sridhar R. & Mandal G. (1991) The effect of grinding aids on the fine grinding of limestone, quartz and Portland cement clinker. *Powder Technology* **67**: 277-286.

Solberg E.D., Malhi S.S., Nyborg M., Henriquez B. & Gill K.S. (2007) Crop Response to Elemental S and Sulfate-S Sources on S-Deficient Soils in the Parkland Region of Alberta and Saskatchewan. *Journal of Plant Nutrition* **30**: 321-333.

Speight J.G. (2007) CHAPTER 7 - Processes. *Natural Gas*, Speight J.G. (ed.), pages. 161-192. Gulf Publishing Company.

Steinhauser G. (2005) Split-precipitation — An ecological alternative in the purification of crude sodium chloride brine. *BHM Berg- und Hüttenmännische Monatshefte* **150**: 283-286.

Steinhauser G. (2008) Cleaner production in the Solvay Process: general strategies and recent developments. *Journal of Cleaner Production* **16**: 833-841.

Suhr M., Klein G., Kourti I., Gonzalo M.R., Giner Santonja G., Roudier S. & Delgado Sancho L. (2015) Best Available Techniques (BAT) Reference Document for the Production of Pulp, Paper and Board Industrial Emissions Directive 2010/75/EU (Integrated Pollution Prevention and Control).

Swan J.R. & Crook B. (1998) Airborne microorganisms associated with grain handling. *Ann Agric Environ Med* **5**: 7-15.

Thomas B.M. & Rengel Z. (2002) Di-ammonium phosphate and mono-ammonium phosphate improve canola growth when banded in a P-fixing soil compared with triple superphosphate. *Australian Journal of Agricultural Research* **53**: 1211-1218.

Thomas C., Rosales J., Polanco J.A. & Agrela F. (2019) 7 - Steel slags. *New Trends in Eco-efficient and Recycled Concrete*, de Brito J. & Agrela F. (eds.), pages. 169-190. Woodhead Publishing.

Torbert H.A., Watts D.B. & Chaney R.L. (2018) Impact of Flue Gas Desulfurization Gypsum and Manure Application on Transfer of Potentially Toxic Elements to Plants, Soil, and Runoff. *Journal of Environmental Quality* **47**: 865-872.

Tripathy S.K., Angadi S.I., Patra N.K. & Rao D.S. (2018) Comparative separation analysis of direct and reverse flotation of dolomite fines. *Mineral Processing and Extractive Metallurgy Review* **39**: 339-350.

Twerd L., Krzyżyński M., Waldon-Rudzionek B. & Olszewski P. (2017) Can soda ash dumping grounds provide replacement habitats for digger wasps (Hymenoptera, Apoidea, Spheciformes)? *PloS one* **12**: e0175664-e0175664.

Uliana J.G., Calmon J.L., Vieira G.L., Teixeira J.E.S.L. & Nunes E. (2015) Heat treatment of processing sludge of ornamental rocks: application as pozzolan in cement matrices. *Revista IBRACON de Estruturas e Materiais* **8**: 100-123.

United Nations Economic Commission for Europe (UN ECE) (2009) 4.B Animal husbandry and manure management. *Recent Results and Updating of Scientific and Technical Knowledge: Health Risks of Air Pollution from Biomass Combustion. Report by the Task Force on Health, Executive Body for the Convention on Long-range Transboundary Air Pollution, ECE/EB.AIR/WG.1/2009/12.* , pages. United Nations Economic Commission for Europe (UN ECE); , Geneva, Switzerland.

van Delden M.L., Kuipers N.J.M. & Haan d.A.B. (2006) Selection and evaluation of alternative solvents for caprolactam extraction. *Separation and Purification Technology* **51**: 219 - 231.

Van der Heyden C., Demeyer P. & Volcke E.I.P. (2015) Mitigating emissions from pig and poultry housing facilities through air scrubbers and biofilters: State-of-the-art and perspectives. *Biosystems Engineering* **134**: 74-93.

Veerman C. (2004) Dioxin contamination of potato by-products, answers to actual questions, letter to the [Dutch] parliament 09-11-2004 (http://www.minlnv.nl/portal/page?_pageid=116,1640363&_dad=portal&_schema=PO).

Vigneswaran S. & Visvanathan C. (1995) *Water Treatment Processes: Simple Options,* . CRC Press, New York.

Wan Isahak W.N.R., Che Ramli Z.A., Ismail M., Mohd Jahim J. & Yarmo M.A. (2015) Recovery and Purification of Crude Glycerol from Vegetable Oil Transesterification. *Separation & Purification Reviews* **44**: 250-267.

Waste & Resources Action Programme - UK (WRAP-UK) (2011) Quality control schemes: recycled gypsum from waste plasterboard - End of waste criteria for the production and use of recycled gypsum from waste plasterboard. Environment Agency UK.

Wéry N. (2014) Bioaerosols from composting facilities--a review. *Frontiers in cellular and infection microbiology* **4**: 42-42.

WHO (2017) Guidelines for drinking-water quality: fourth edition incorporating the first addendum.

Wierup M. (2017) Production of Soybean-Derived Feed Material Free from *Salmonella* Contamination: An Essential Food Safety Challenge. *Soybean - The Basis of Yield, Biomass and Productivity*, Kasai M. (ed.), pages. 977-1070. InTechOpen, London.

Wierup M. & Haggblom P. (2010) An assessment of soybeans and other vegetable proteins as source of salmonella contamination in pig production. *Acta Veterinaria Scandinavica* **52**.

Wierup M. & Kristoffersen T. (2014) Prevention of Salmonella contamination of finished soybean meal used for animal feed by a Norwegian production plant despite frequent Salmonella contamination of raw soy beans, 1994-2012. *Acta Veterinaria Scandinavica* **56**.

Willke T. (2014) Methionine production—a critical review. *Applied Microbiology and Biotechnology* **98**: 9893-9914.

World Bank (2007) Environmental, health, and safety guidelines for pulp and paper mills. Draft technical document Environment and Social Development Department, International Finance Corporation, Washington, DC.

Wright K. (2002) Coke oven gas treatment - tar, liquor and ammonia. Notes for inclusion in the COMA By-Products Textbook (unpublished). Available at: https://www.researchgate.net/file.PostFileLoader.html?id=538497add039b1c4408b45fe&assetKey=AS:273543999229954@1442229379326 (accessed on 07/08/2020).

Wubs H.J. & Beenackers A. (1993) KINETICS OF THE OXIDATION OF FERROUS CHELATES OF EDTA AND HEDTA IN AQUEOUS-SOLUTION. *Industrial & Engineering Chemistry Research* **32**: 2580-2594.

Xiao C., Ma Y., Ji D. & Zang L. (2017) Review of desulfurization process for biogas purification. *IOP Conference Series: Earth and Environmental Science* **100**: 012177.

Xu L. & Geelen D. (2018) Developing Biostimulants From Agro-Food and Industrial By-Products. *Frontiers in Plant Science* **9**.

Yakhin O.I., Lubyanov A.A., Yakhin I.A. & Brown P.H. (2017) Biostimulants in Plant Science: A Global Perspective. *Frontiers in plant science* **7**: 2049-2049.

Zhang J., Zheng P. & Wang Q. (2015) Lime mud from papermaking process as a potential ameliorant for pollutants at ambient conditions: a review. *Journal of Cleaner Production* **103**: 828-836.

Zhao Y.-y., Jing Z.-z., Li H.-p. & Zhang H.-s. (2001) The determination of impurities in caprolactam by capillary gas chromatography-mass spectrometry. *Microchemical Journal* **69**: 213-217.

Zichella L., Dino G.A., Bellopede R., Marini P., Padoan E. & Passarella I. (2020) Environmental impacts, management and potential recovery of residual sludge from the stone industry: The piedmont case. *Resources Policy* **65**: 101562.