SCRREEN2

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Start date: 2020-11-01 Duration: 36 Months

FACTSHEETS UPDATES **BASED ON THE EU FACTSHEETS 2020**

BORON

AUTHOR(S):

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BORON

OVERVIEW

Borates are naturally occurring minerals containing boron (B, atomic number 5). The industry defines borates as any compound that contains or supplies boric oxide (B_2O_3). Borates are thus inorganic salts of boron and refer to a large number of mineral and chemical compounds that contain borate anions. They have metabolizing, bleaching, buffering, dispersing, and vitrifying properties.

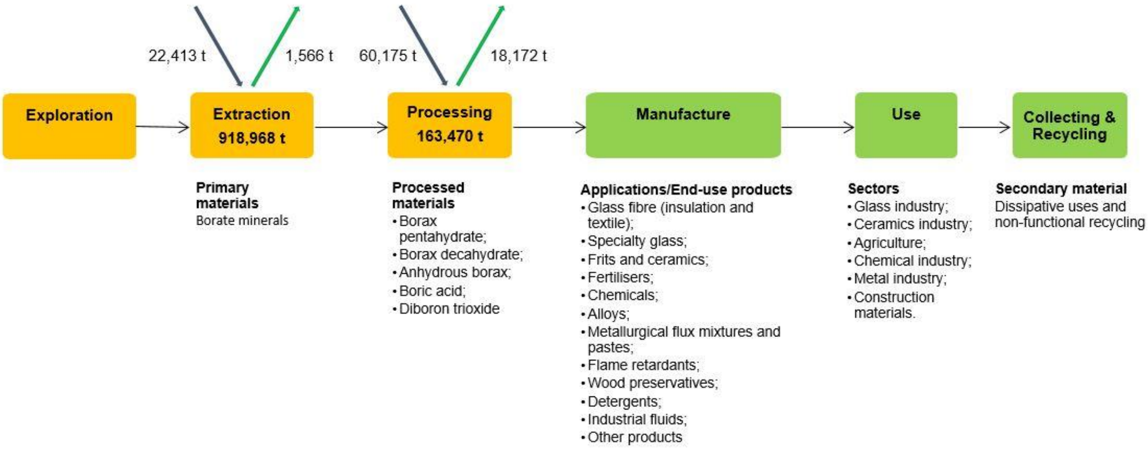

Figure 1. Simplified value chain for borates in the EU[1]

Table 1. Borates supply and demand in metric tonnes, extraction, 2016-2020 average (B content)

Global production	Global Producers	EU consumption	EU Share	EU Suppliers	Import reliance
1 287 469	Turkey 48% USA 25% Chile 11% Bolivia 5%	18 725	1.5%	Turkey 99%	100%

Table 2. Borates supply and demand in metric tonnes, processing, 2016-2020 average (B content)

Global production	Global Producers	EU consumption	EU Share	EU Suppliers	Import reliance
1 090 241	Turkey 45% USA 23% Chile 10% Bolivia 5%	75 447	6.9%	Turkey 47% Germany 25% USA 20% UK 4%	72%

[1] JRC elaboration on multiple sources (see next sections)

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Prices: Annual prices of borates, in B_2O_3 content tonne, fluctuated between € 386/t in 2012 and € 337/t in 2020 (USGS, 2021). Furthermore, the average price of borates in 2012-2020 was € 337/t. Borates price drivers are associated with demand changes in glass, fertilizer, ceramic, and detergents industries (OROCOBRE, 2021).

Primary supply: Turkey and United States are over time the main producers of borates minerals. China, Chile, Argentina and Bolivia present notable production. The borates world production, according to WMD, in 2020 was 3.6 Mtonnes significantly reduced in comparison to the average of the period 2016-2020 (4.13 Mtonnes of borate corresponding to 1.29 Mtonnes Boron content). There is no publicly available data on the production of refined borates. Based on estimation from the global trade data as reported by UN Comtrade (2019), US is the dominant supplier of refined borates accounting for 67% of the total world exports.

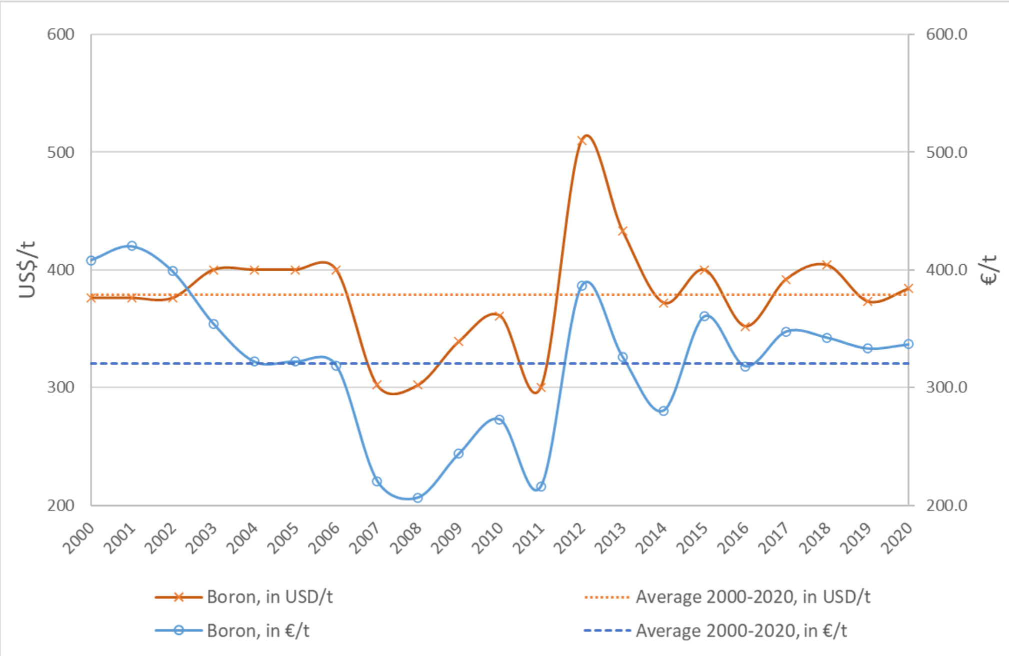

Figure 2. Annual average price of boron between 2000 and 2020 (USGS, 2021)[2].

Secondary supply: Because of the nature of end uses, boron/borates functional recycling is not possible as products are consumed with the use (e.g. fertilisers, chemicals and detergents), or because non-functional recycling only occurs. For instance, separation of borosilicate glass from the boron-free container and flat glass is not possible and, as a result, waste borosilicate glass will end up in the manufacture of normal glass, causing defects in the final product.

[2] Values in €/kg are converted from original data in US$/kg by using the annual average Euro foreign exchange reference rates from the European Central Bank (https://www.ecb.europa.eu/stats/policy_and_exchange_rates/euro_reference_exchange_rates/html/eurofxref-graph-usd.en.html)

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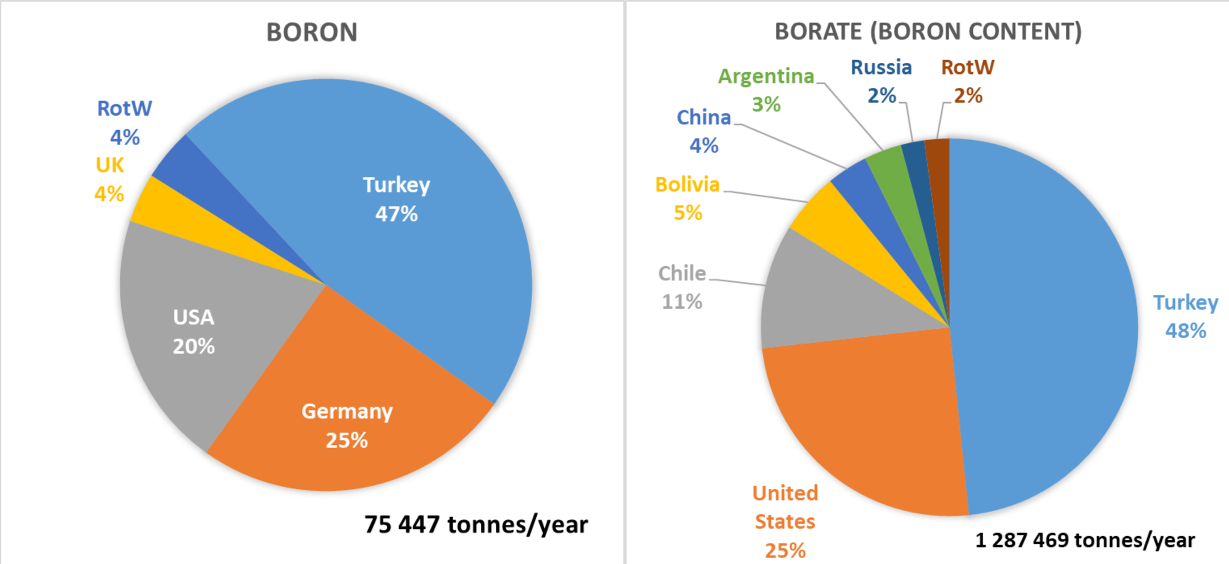

Figure 3. EU sourcing of boron (processing) and global mine production (extraction) average 2016-2020)

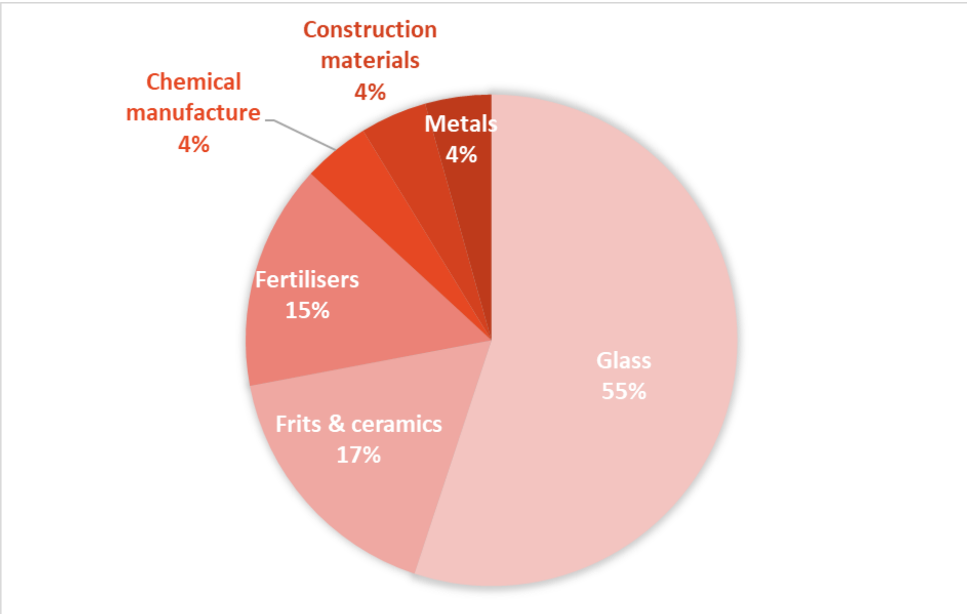

Figure 4: EU uses of borates

Uses: Borates are a key input material in the production of fibreglass insulation, textile fibreglass, borosilicate glass, ceramics and fertilisers. These applications account for over three-quarters of borates consumption. The borates imported in the EU are mostly embodied in glass products. The next common application of borates imports is the supply to ceramics and frits industry followed by fertilisers. Borates also have applications within the construction, metallurgy and chemicals industries. Other applications and uses include as construction materials, abrasives, catalysts, coatings, and detergents.

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Substitution: On a scale of 0 to 100[3], the substitution potential of boron has been assessed as 41 by (Graedel et al. 2015). Most uses cannot be substituted without compromising the performance / end quality of the final product. (SCRREEN Expert Workshop, 2021).

Table 3. Uses and possible substitutes

Application	Share	Substitutes	SubShare	Cost	Performance
Glass	55%	ECR glass fiber	1%	Slightly higher costs (up to 2 times)	Reduced
		Rock wool	2%	Slightly higher costs (up to 2 times)	Reduced
		Cellulose	2%	Similar or lower costs	Reduced
		Silica in CFRP	2%	Slightly higher costs (up to 2 times)	Reduced
		No substitute	93%		No substitute
Frits and ceramics	17%	Phosphate	2%	Similar or lower costs	Reduced
		No substitute	98%		No substitute
Fertilizers	15%	No substitute	100%		No substitute
Chemical manufacture	4%	Not assessed, below 10 %	100%		No substitute
Construction materials (flame retardants, plasters, wood preservatives)	4%	Not assessed, below 10 %	100%		No substitute
Metals	4%	Not assessed, below 10 %	100%		No substitute

Other issues: Naturally occurring boron is present in groundwater primarily as a result of leaching from rocks and soils containing borates and borosilicates (WHO 2022). Boron is a trace element that is naturally present in many foods and available as a dietary supplement. (NIH 2022). No data are available on adverse effects of high boron intakes from food or water. Short- and long-term oral exposures to boric acid or borax in laboratory animals have demonstrated that the male reproductive tract is a consistent target of toxicity (WHO 2022). Symptoms associated with accidental consumption of boric acid or borax (sodium borate), contained in some household cleaning products and pesticides, include nausea, gastrointestinal discomfort, vomiting, diarrhea, skin flushing, rash, excitation, convulsions, depression, and vascular collapse. On the other side, a few clinical studies in humans suggests that boron might be helpful for reducing the symptoms of osteoarthritis and might be important for bone growth and formation (NIH 2022). The oxide of boron, boron trioxide, is identified as toxic for reproduction. (REACH 2012). The limit value of boron oxide in air is estimated at 10 mg/m^3 in European countries, while according to the USA OSHA it is estimated at 15 mg/ m^3 (GESTIS 2022). (WHO 2022) developed a set of 'Guidelines for drinking water quality', where the guideline value for boron is set at 2.4 mg/l. Similar guidelines developed by the government of Canada, set the guideline value even lower, at 2 mg/l (Gov of Canada, 2020).

[3] *On this scale, zero indicates that exemplary substitutes exist for all major uses and 100 indicates that no substitute with even adequate performance exists for any of the major uses*

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MARKET ANALYSIS, TRADE AND PRICES

GLOBAL MARKET

Table 4. Borate supply and demand in metric tonnes, 2016-2020 average

Global production	Global Producers	EU consumption	EU Share	EU Suppliers	Import reliance
4 130 000	Turkey 48% USA 25% Chile 11% Bolivia 5%	51 450	1.1%	Turkey 70% USA 20% UK 5%	100%

The global market of borates is estimated at over 2 million tonnes of B_2O_3 equivalent in 2018 (Orocobre, 2021). Glass manufacturing, ceramics, modern medicines, agriculture and detergents are the main borates-consuming industries. Turkey and the United States continued to be the largest producers of boron minerals with 74% share of world's production. Asia remained the largest regional consumer of borates, accounting for more than 50% of total global consumption (Orocobre, 2021).

According to UN Comtrade's trade flow figures, an average of 1 million tonnes of natural borates per year was imported globally in 2016-2020. Turkey dominated the export of natural borates with 65% of share, while the main importer was China (38% of total imports) (Figure 5).

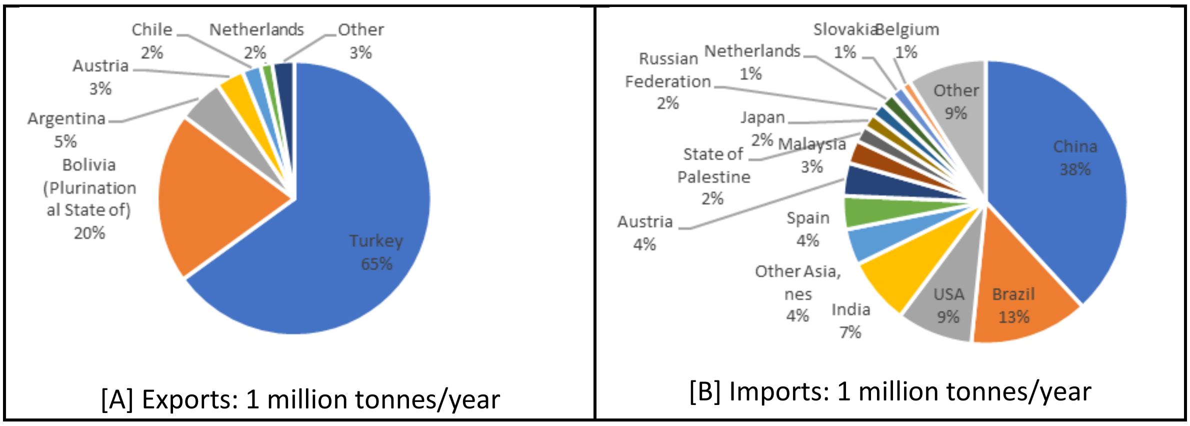

Figure 5. Share of natural borates world exporter and importer 2016-2020 by quantity of trade (elaborated from trade flows figures reported in UN Comtrade database, 2021)

The demand for refined borates was reported to increase at an equivalent to 344,000 Mt of Borax Pentahydrate and 201,000 Mt of Boric Acid (Orocobre, 2021). However, there is no official data on global supply of refined borates and borates products. Based on the analysis of the trade flow of borates products4,

4 The commodities covered in Figure 6 and the corresponding B content are the following: 281000 - oxides of boron, borics acids (B content: 17%); 284011 - anhydrous disodium tetraborate (refined borax) (B content: 21%); 284019 - Disodium tetraborate, not anhydrous (B content: 12%)).

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(excluding re-export), the United States was the major exporter with 68% of export share. China was the leading importer, followed by the United States, each with 30% and 13% of total import share (Figure 6). The trade of some specific borates-products was reported to have grown. For example, the trade of Borax Pentahydrate and Decahydrate have grown by 30% in the past two years from 1,371 Kilo Metric Tonnes (KMT) in 2016 to 1,781 KMT in 2018 (OROCOBRE, 2021).

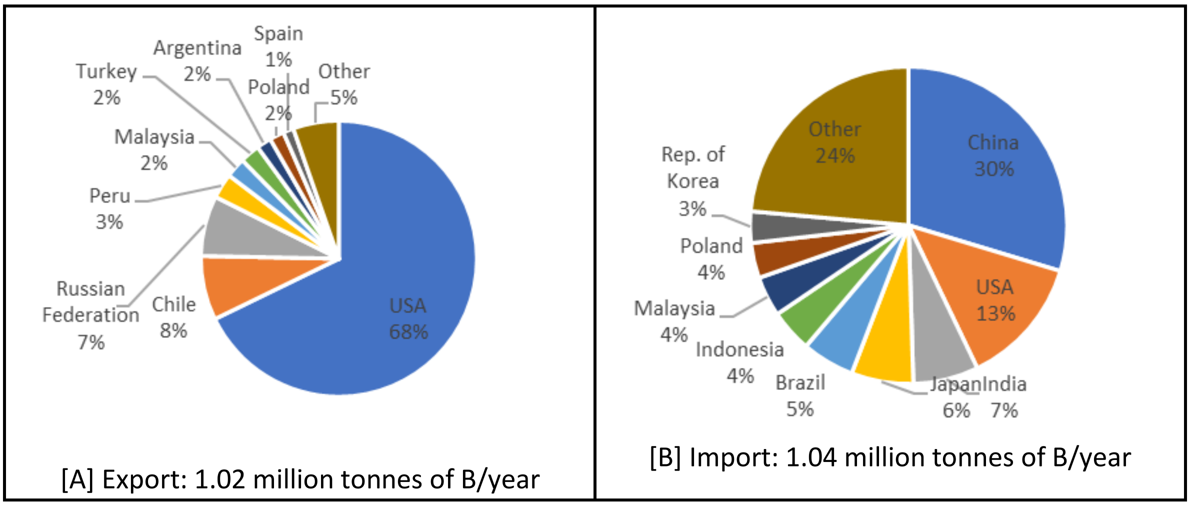

Figure 6. Share of refined borates world exporter and importer 2016-2020 by quantity of trade (elaborated from trade flows figures reported in UN Comtrade database, 2021)

EU TRADE

For the purpose of this assessment, borates are evaluated at both extraction and processing stage.

Table 5. Relevant Eurostat CN trade codes for borates

Mining		Processing/refining	
CN trade code	**Title**	**CN trade code**	**Title**
25280000	Borates, natural, and concentrates thereof, whether or not calcined, and natural boric acids containing <= 85% of H3BO3 calculated on the dry weight (excl. borates separated from natural brine)	28100010	Diboron trioxide
		28100090	Oxides of boron and boric acids (excl. diboron trioxide)
		28401100	Anhydrous disodium tetraborate "refined borax"
		28401910	Disodium tetraborate penthahydrate
		28401990	Disodium tetraborate "refined borax" (excl. anhydrous and disodium tetraborate pentahydrate)

Figure 7 shows the EU trade flows of borates at extraction stage, in tonnes (t), from 2012 to 2021. EU exports of borates at extraction stage increased continuously from 5,873 t in 2013 to 16,807 t in 2021; EU imports of borates at extraction stage ranged between 104,629 t (which is the import quantity reported for 2020) and 133,994 t (which is the import quantity reported for 2017). Between 2020 and2021, the exports were relatively small in comparison to the imports and, thus, the EU was a net importer of borates at extraction stage. Figure

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8 presents the average EU imports of borates at extraction stage, by country, for the period 2012-2021. By far, Turkey was the main EU supplier of borates at extraction stage in each year of the period, accounting for 99% of EU imports in this category. The contributions of Argentina, Bolivia, Chile and United Kingdom to these imports were rather marginal.

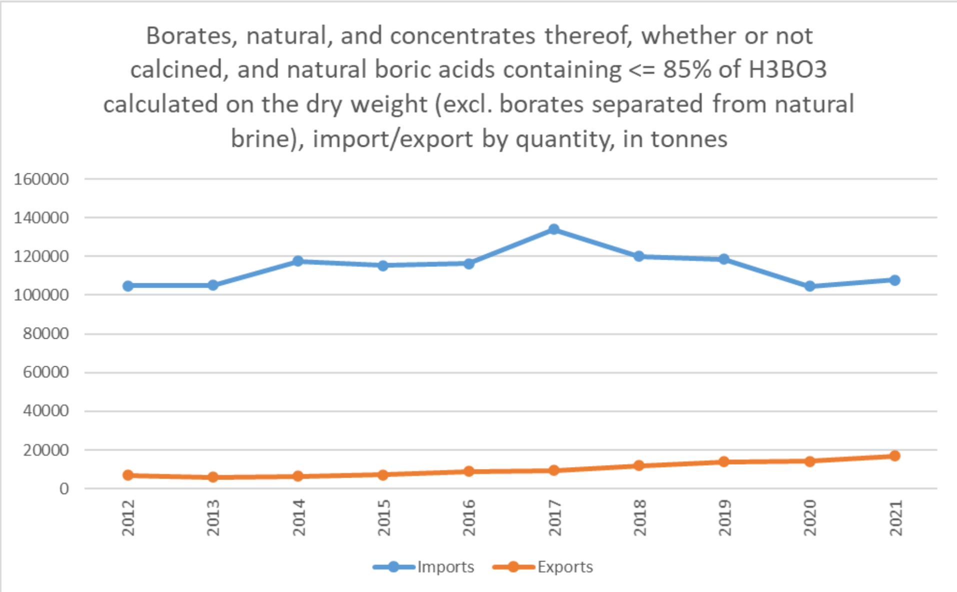

Figure 7. EU trade flows of 'natural borates and concentrates thereof' from 2012 to 2021 (based on Eurostat, 2022).

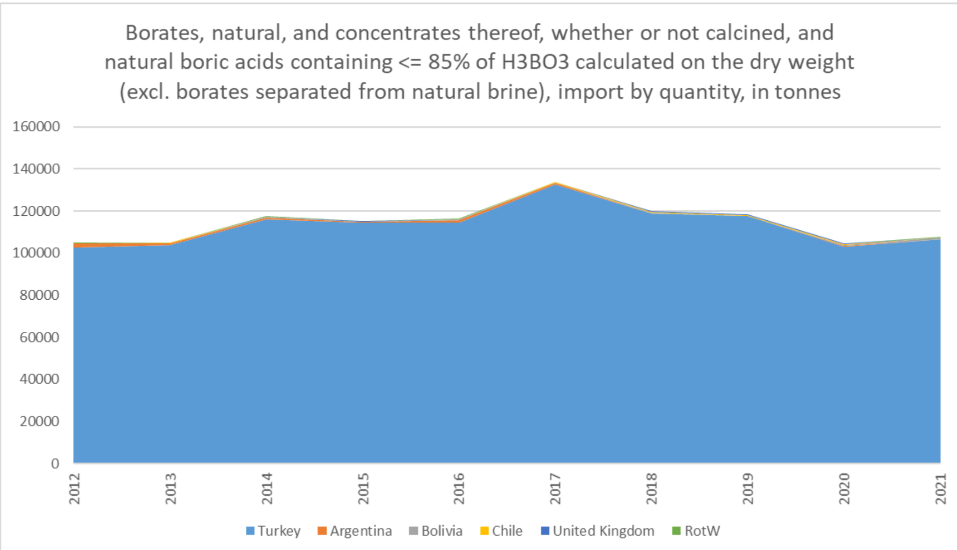

Figure 8. EU imports of 'natural borates and concentrates thereof' by country from 2012 to 2021 (based on Eurostat, 2022).

Figure 9 to Figure 13 show the EU trade flows of borates at processing stage (refined borates), in tonnes (t), from 2000 to 2021. In particular, data on five CN codes is depicted: CN 28100010 ('diboron trioxide'), CN 28100090 ('oxides of boron and boric acids excl. diboron trioxide'), CN 28401100 ('anhydrous disodium

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tetraborate'), CN 28401910 ('disodium tetraborate penthahydrate') and CN 28401990 ('disodium tetraborate excl. anhydrous and disodium tetraborate pentahydrate'). In each of these categories and in each year of the period 2000-2021, the EU was a net importer, and the exports were relatively small in comparison to the imports (except for diboron trioxide exports): Annual EU imports were in the ranges of ca. 0.4-7.7 kilotonnes (for 'diboron trioxide'), 62-127 kilotonnes (for 'oxides of boron and boric acids'), 11-31 kilotonnes (for 'anhydrous disodium tetraborate'), 157-324 kilotonnes (for 'disodium tetraborate penthahydrate') and 13-44 kilotonnes (for 'disodium tetraborate...'). The corresponding exports were in the ranges of ca. 42-340 tonnes, 2-16 kilotonnes, 0.1-5 kilotonnes, 3-19 kilotonnes and 1-3 kilotonnes, respectively.

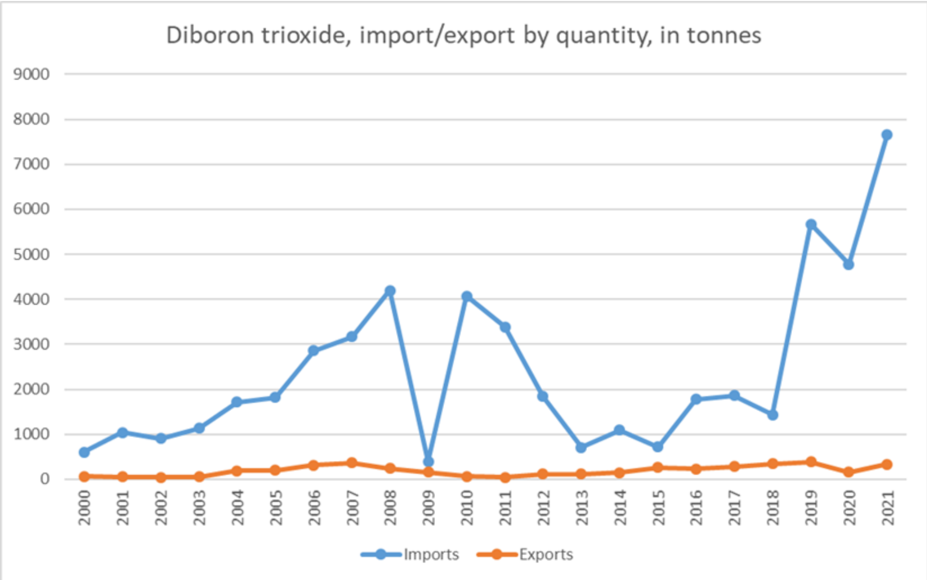

Figure 9. EU trade flows of 'diboron trioxide' from 2000 to 2021 (based on Eurostat, 2022).

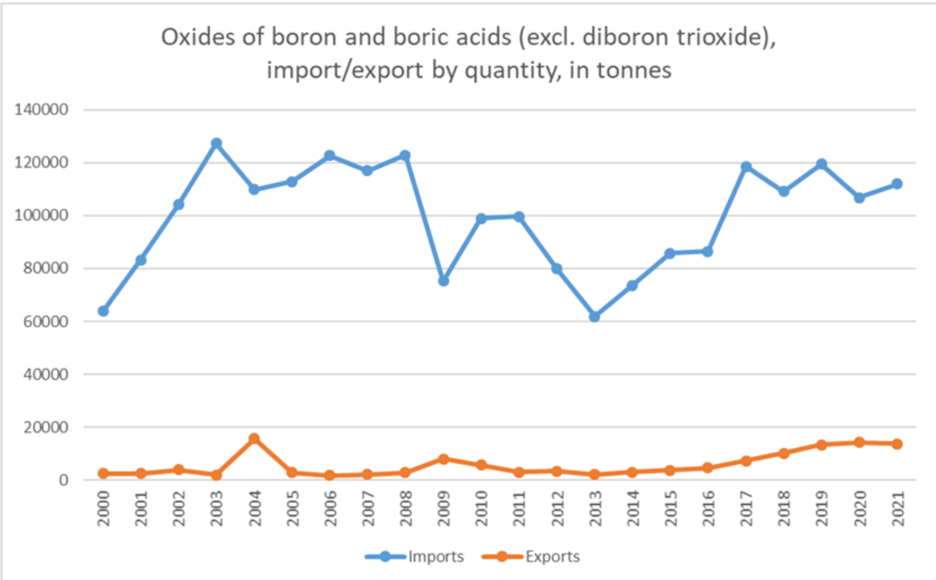

Figure 10. EU trade flows of 'oxides of boron and boric acids (excl. diboron trioxide)' from 2000 to 2021 (based on Eurostat, 2022).

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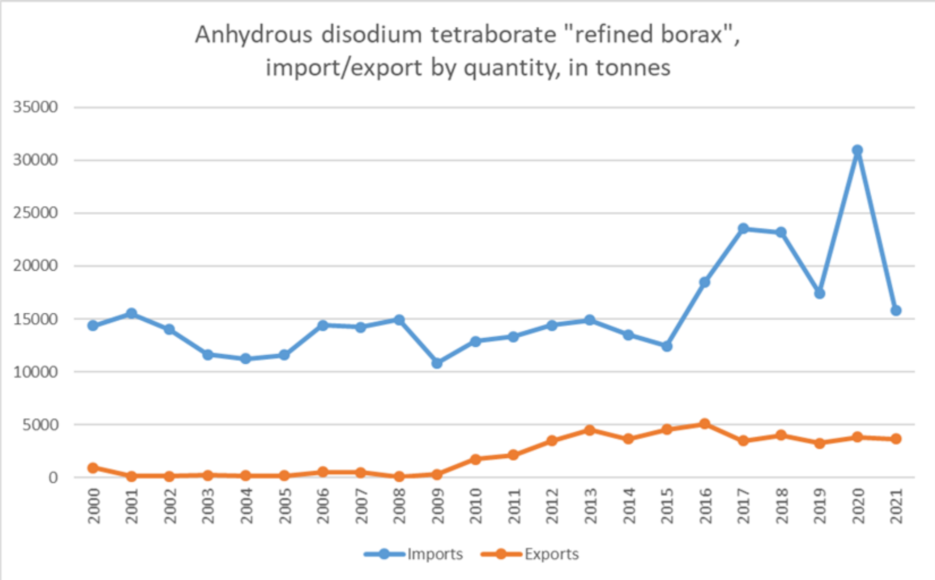

Figure 11. EU trade flows of 'anhydrous disodium tetraborate' from 2000 to 2021 (based on Eurostat, 2022).

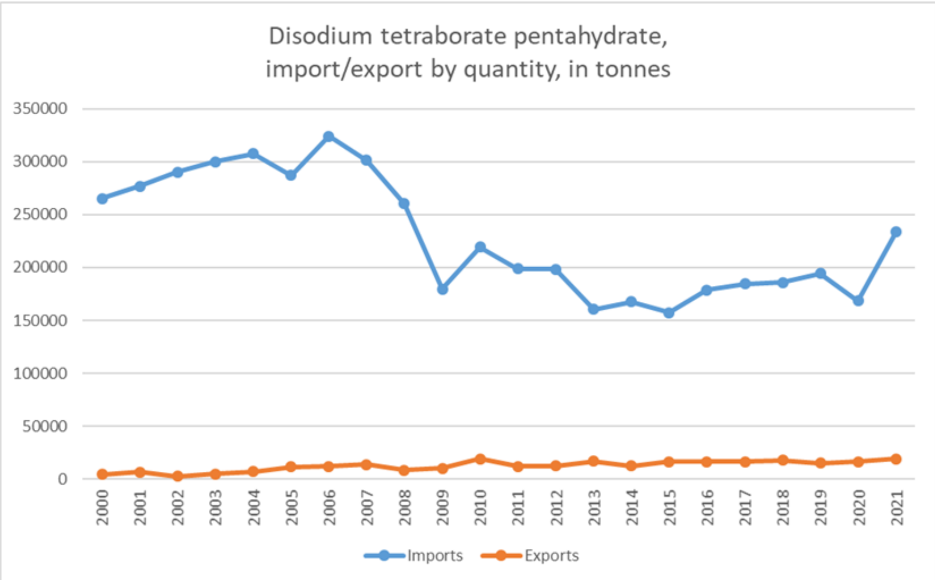

Figure 12. EU trade flows of 'disodium tetraborate penthahydrate' from 2000 to 2021 (based on Eurostat, 2022).

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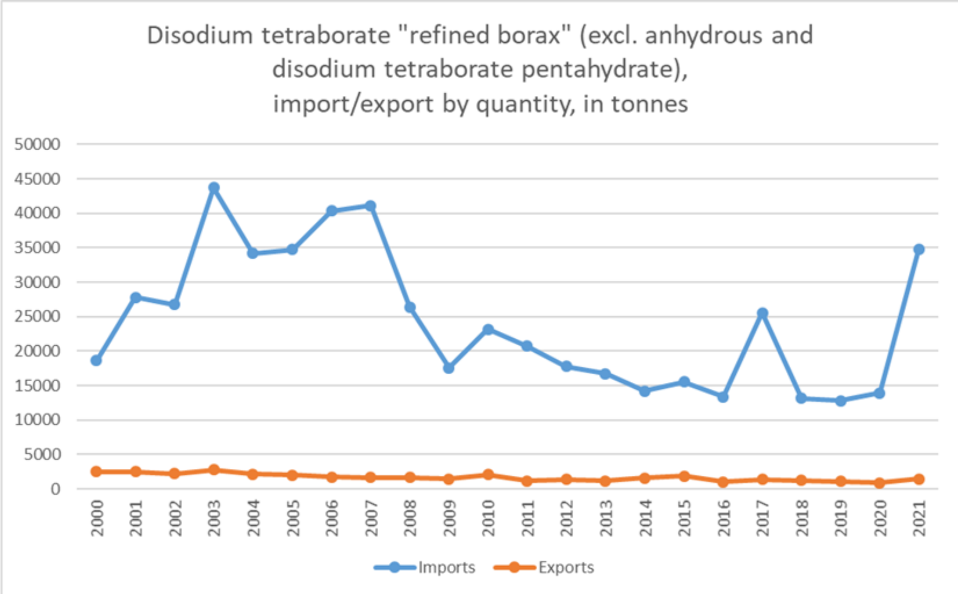

Figure 13. EU trade flows of 'disodium tetraborate (excl. anhydrous and disodium tetraborate pentahydrate)' from 2000 to 2021 (based on Eurostat, 2022).

Figure 14 to Figure 18 present the average EU imports of borates at processing stage (referring to the same five refined-borate categories / CN codes as above), by country, for the period 2000-2021. EU imports of refined borates were dominated by Turkey or United States in all five refined-borate categories (CN codes). Turkey was the main contributor to EU imports in the categories 'diboron trioxide, 'oxides of boron and boric acids', 'disodium tetraborate penthahydrate' and 'disodium tetraborate...', covering 29%, 49%, 72% and 64% of the corresponding imports over the period, respectively. United States were the main supplier of 'anhydrous disodium tetraborate' to the EU, covering 65% of the corresponding EU imports in the period. The dominance of Turkey and USA in refined-borate imports to the EU was relatively stable over the whole period. An exception are the imports of diboron trioxide: Peru dominated the EU import in this category in the middle of the period 2000-2021 and (following Turkey as the major supplier) and accounted for 26% of EU's 2000-2021 imports in this category. Other countries with significant shares (close to 20% or higher) in EU imports of refined borates include Russia (with a share of ca. 18% for 'diboron trioxide') and United Kingdom (with a share of ca. 19% for 'disodium tetraborate excl. anhydrous and disodium tetraborate pentahydrate').

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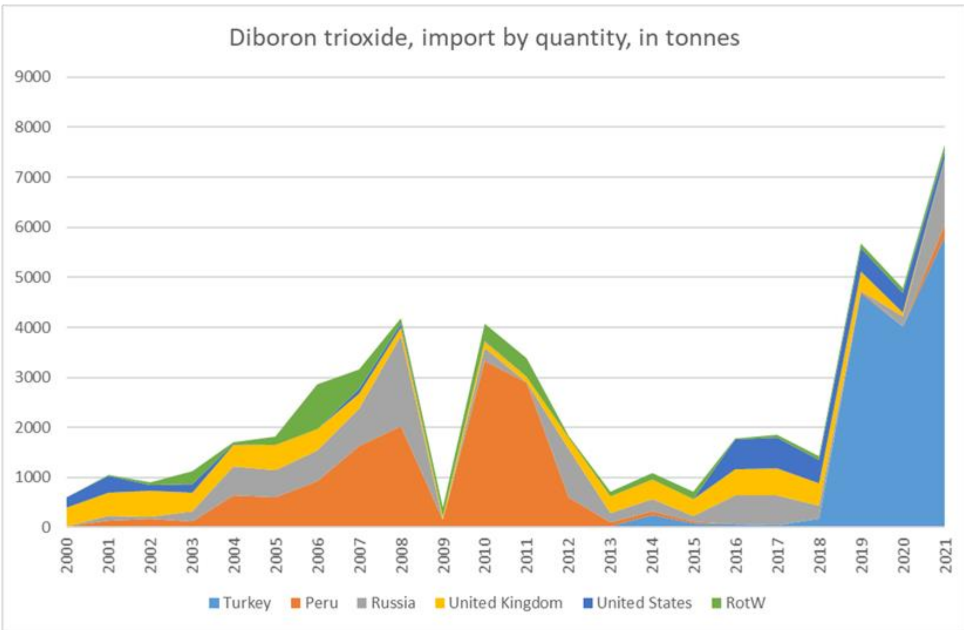

Figure 14. EU imports of 'diboron trioxide' by country from 2000 to 2021 (based on Eurostat, 2022).

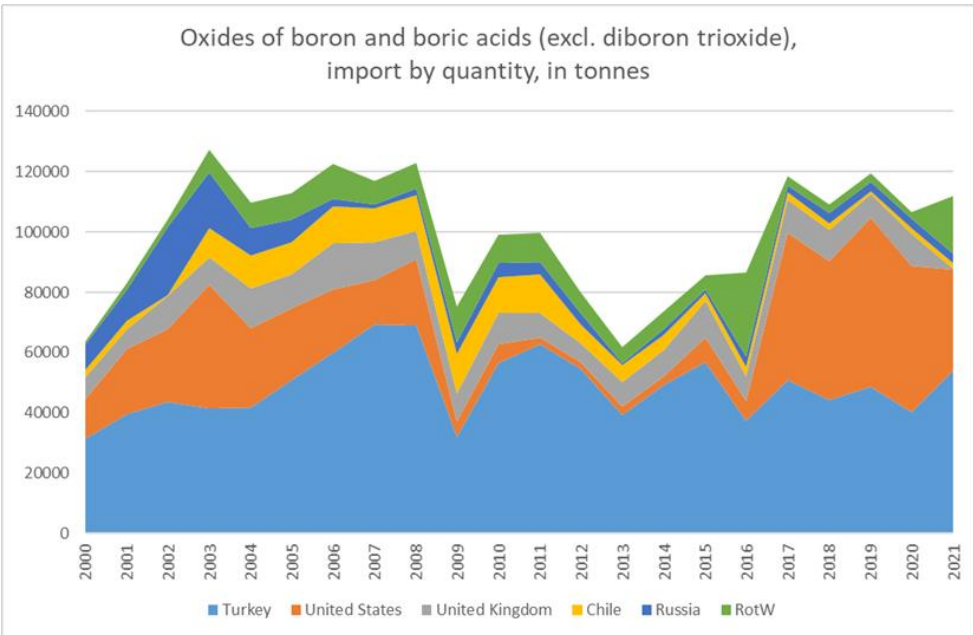

Figure 15. EU imports of 'oxides of boron and boric acids from 2000 to 2021 (excl. diboron trioxide)' by country (based on Eurostat, 2022).

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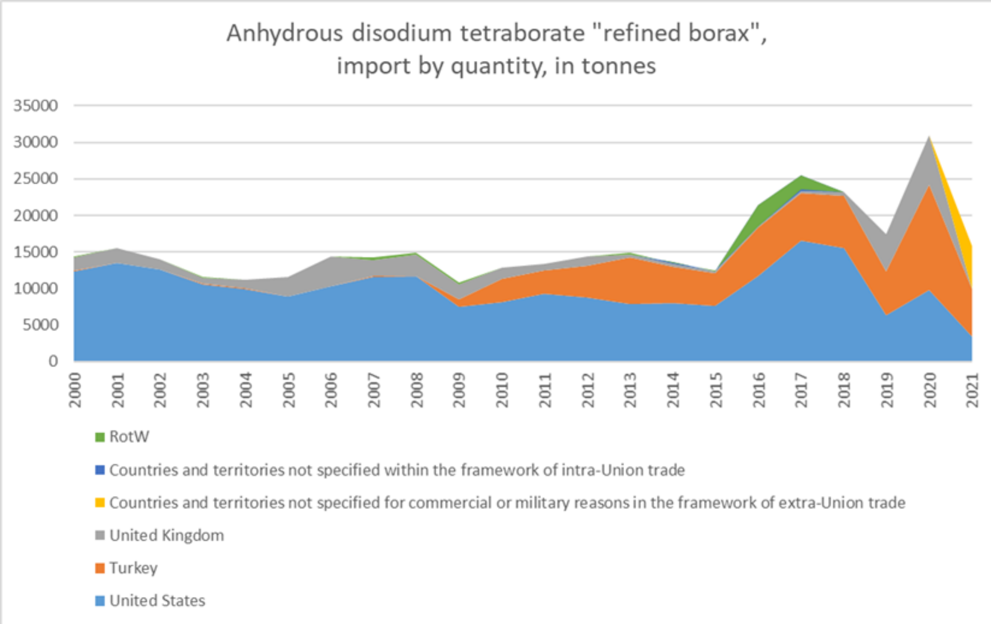

Figure 16. EU imports of 'anhydrous disodium tetraborate' by country from 2000 to 2021 (based on Eurostat, 2022).

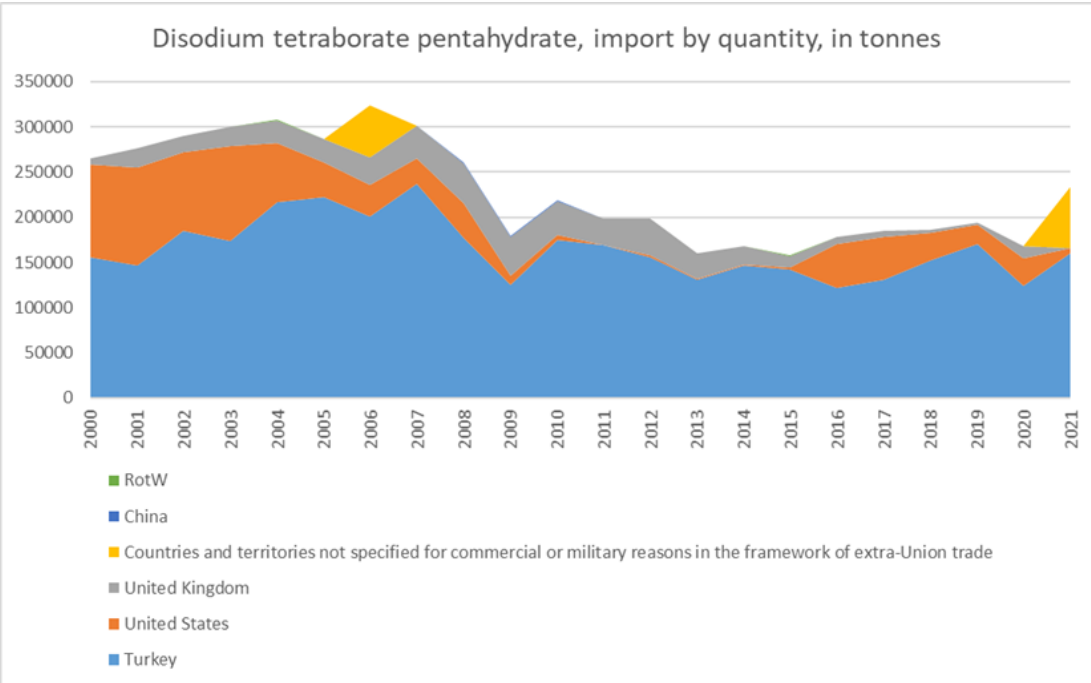

Figure 17. EU imports of 'disodium tetraborate penthahydrate' by country from 2000 to 2021 (based on Eurostat, 2022).

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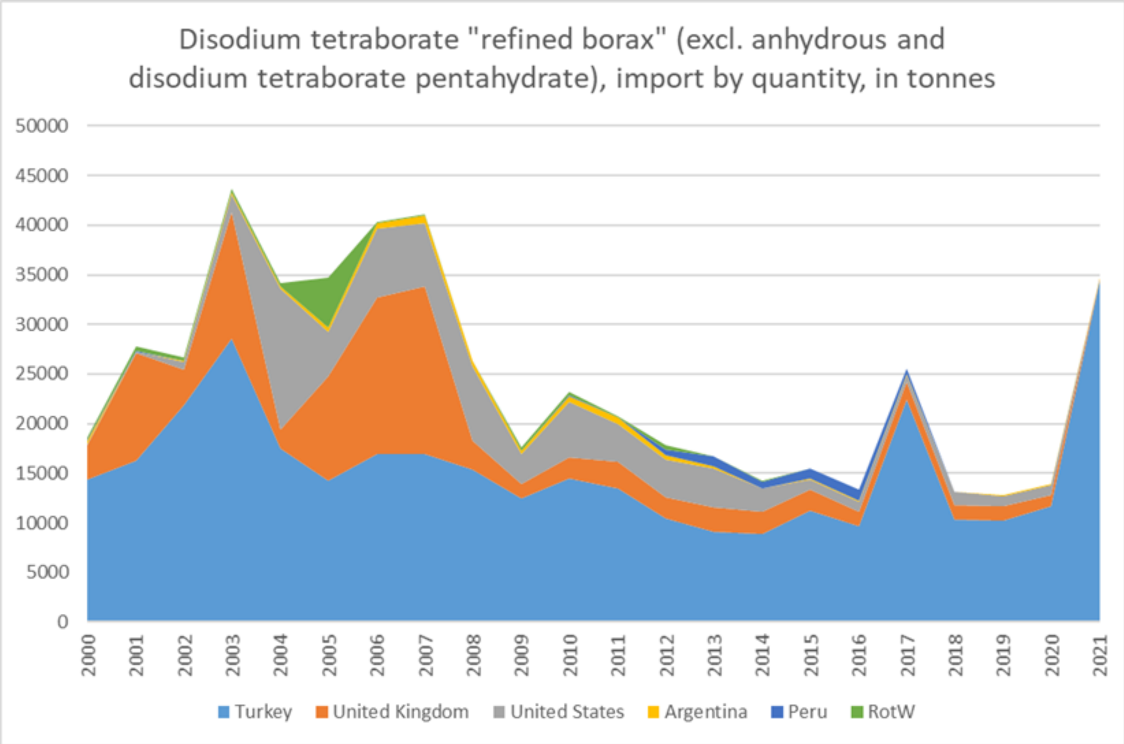

Figure 18. EU imports of 'disodium tetraborate (excl. anhydrous and disodium tetraborate pentahydrate)' by country from 2000 to 2021 (based on Eurostat, 2022).

PRICE AND PRICE VOLATILITY

Annual prices of borates, in € B2O3 content tonne, fluctuated between € 386/t in 2012 and € 337/t in 2020 (USGS, 2021). Furthermore, the average price of borates in 2012-2020 was € 337/t. Despite the decrease of prices in mid-2000s (see European Commission, 2020), the average return between 2016 and 2020 was around 2%, which shows a slightly stable trend for this period.

Borates price drivers are associated with demand changes in glass, fertilizer, ceramic, and detergents industries (OROCOBRE, 2021). Furthermore, new markets are expected to contribute significantly to the borates demand (e.g., borates applications in renewable energy technologies), which could influence prices in the next 2-3 decades (Bobba et al., 2020; Widmer et al., 2015). However, prices changes are expected to remain marginal because there is an ongoing investment in new borates factories that will contribute to maintain enough supply for the future demand (USGS, 2021). The price volatility of borates was around 8% between 2016 and 2020. In this period, price volatility was mostly disturbed by the 2012 price that resulted from the decreasing trend in the mid-2000s. From 2018 to 2020, borates price volatility remains relatively low, which might indicate a breaking point of the price trend from mid-2000s.

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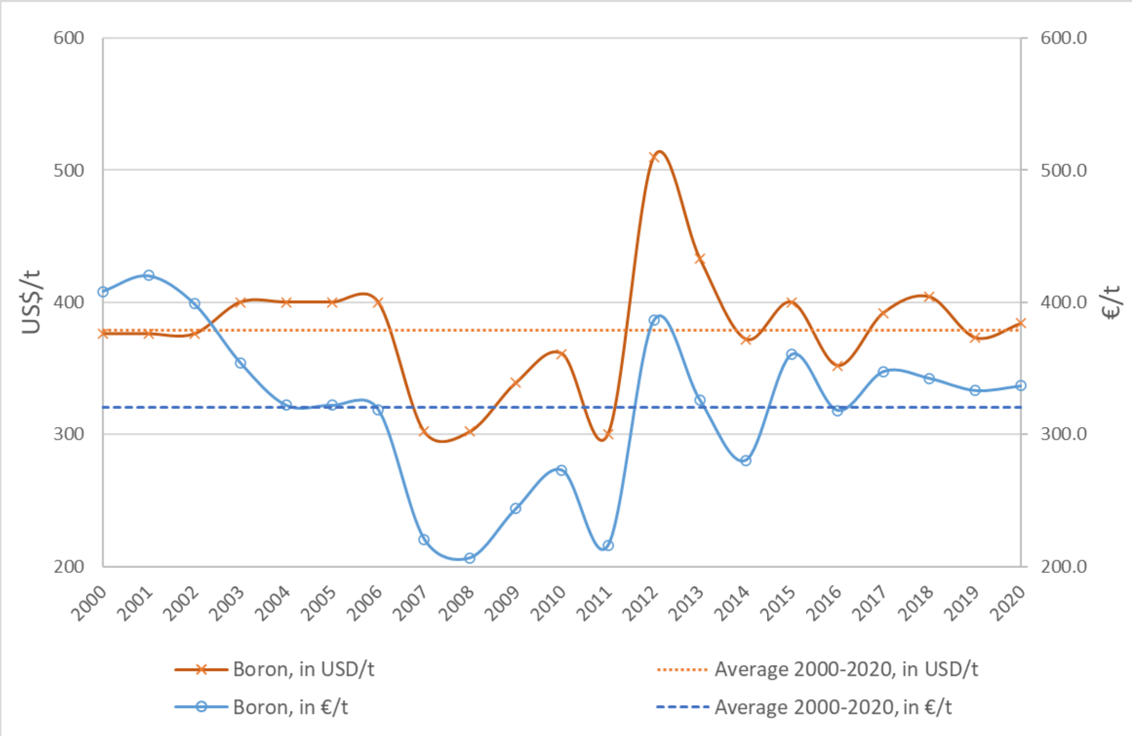

Figure 19. Annual average price of borates between 2000 and 2020 in US$/ per B2O3 content tonne and €/ per B2O3 content tonne (based on USGS, 2021)[5]. Dash lines indicates average price for 2000-2020.

OUTLOOK FOR SUPPLY AND DEMAND

The demand for borates is influenced by the world's growing population and the development of emerging economies (Eti Maden, in Eurolithium, 2021). The demand drivers in the borates market are growth in urbanization (global housing market), global population, sustainable food supply and energy production (Orocobre, 2021). The global market of borates is expected to grow at 3% CAGR and reach 2.65 million tonnes (Mt) B_2O_3 equivalent by 2023 (Orocobre, 2021).

On the supply side, Jadar project in Serbia could potentially supply a significant proportion of global demand for borates. Jadar lithium-borate deposit in Serbia, estimated to contain 21 million t of B_2O_3 as an equivalent borate remains subject to receiving all relevant approvals, permits and licenses and ongoing engagement with local communities, the Government of Serbia and civil society (Rio Tinto, 2021). The Environmental Impact Assessment is required for the commencement of works, with construction targeted to start in 2022 (Rio Tinto, 2021). The first saleable production will be expected in 2026. In addition, two Australia-based mine developers confirmed that production of high-quality boron products would be possible from their projects in California and Nevada. The project in California was expected to begin production in 2021, and the project in Nevada was expected to begin production in 2023 (USGS, 2021).

[5] Values in €/kg are converted from original data in US$/kg by using the annual average Euro foreign exchange reference rates from the European Central Bank (https://www.ecb.europa.eu/stats/policy_and_exchange_rates/euro_reference_exchange_rates/html/eurofxref-graph-usd.en.html)

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DEMAND

GLOBAL AND EU DEMAND AND CONSUMPTION

World borates consumption was about 2,290 ktonnes in B_2O_3 content or 821 ktonnes in B content in 2018 (Orocobre, 2021).

Total EU apparent consumption of borates between 2016 and 2020 was estimated at 33,000 t per year (B content). Natural borates account for one-third of the total consumption and processed/refined borates for two-thirds.

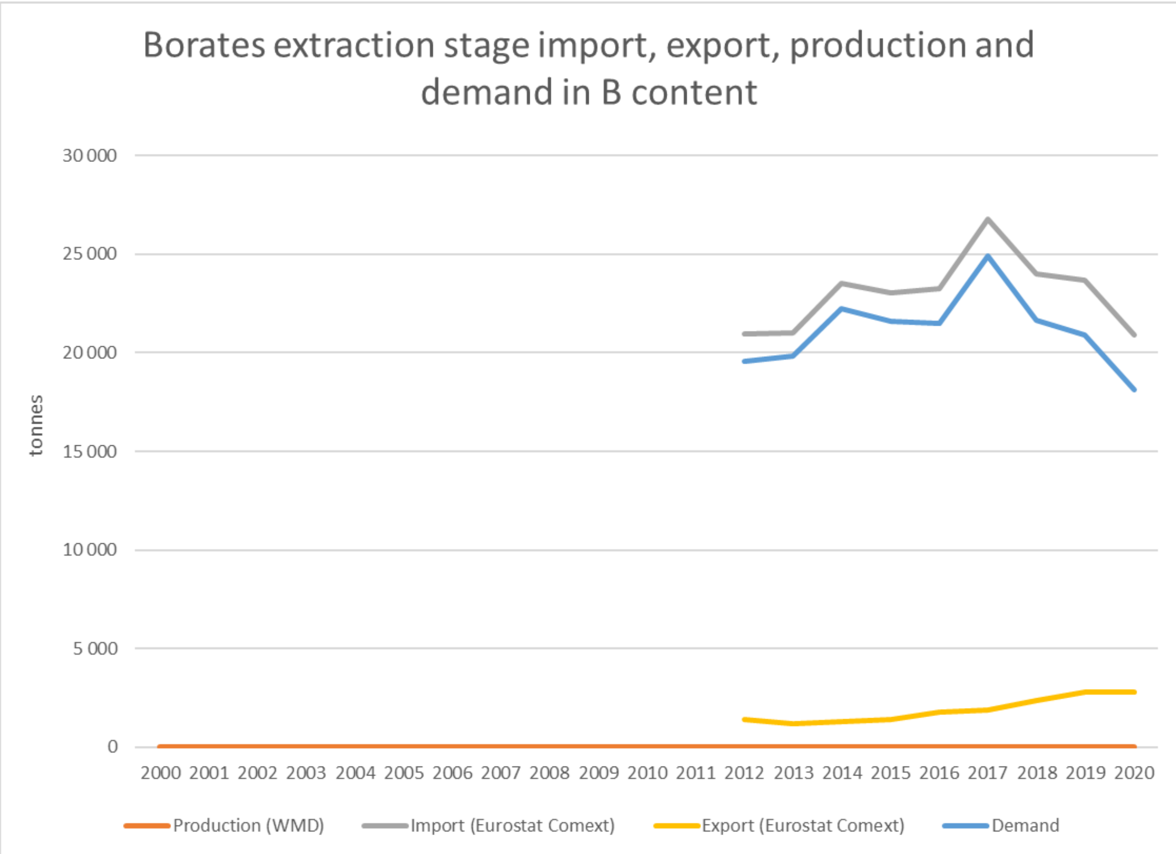

Figure 20. Borates (CN 25280000 Natural borates and their concentrates) extraction stage apparent EU consumption. Import and export data is available for 2012-2020 from Eurostat Comext (2022). Production data is available for 2000-2020 from WMD (2022). Consumption is calculated in B content (EU production+import-export).

Borates extraction stage EU consumption is presented by HS code CN 25280000 Natural borates and their concentrates. Import and export data is extracted from Eurostat Comext (2022). Production data is extracted from WMD (2022).

Based on Eurostat Comext (2021) and WMD (2022) average import reliance of borates at extraction stage is 100% for 2016-2020.

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Borates processing stage EU consumption is presented by HS codes CN 28100010 Diboron trioxide, CN 281000 Oxides of boron, boric acids, CN 284011 Anhydrous disodium tetraborate “refined borax” and CN 284019 Disodium tetraborate, not anhydrous. Import and export data is extracted from Eurostat Comext (2022). Production data is extracted from Eurostat Prodcom (2022) using PRCCODE 20136230 Borates; pexoborates, PRCCODE 20132465 Oxides of boron and boric acids (excl. diboron trioxide) and PRCCODE 20132462 Diboron trioxide.

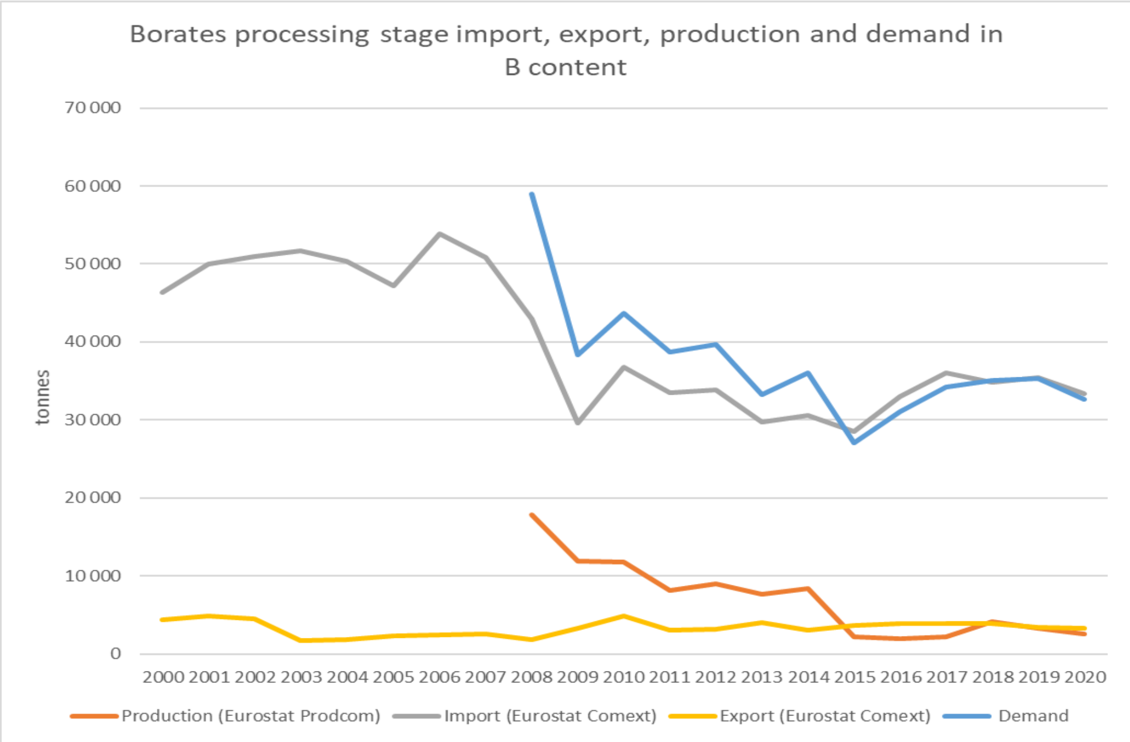

Figure 21. Borates (CN 28100010 Diboron trioxide, CN 281000 Oxides of boron, boric acids, CN 284011 Anhydrous disodium tetraborate “refined borax” and CN 284019 Disodium tetraborate, not anhydrous) processing stage apparent EU consumption. Production data from Eurostat Prodcom (2022) for diboron trioxide and oxides of boron, boric acids are available only for 2019-2020. Production data of CN 2840 Borates; pexoborates (B2O3) is available for 2008-2020 and is used as a proxy for EU processing stage production 2008-2018. Consumption is calculated in B content (EU production+import-export).

Based on Eurostat Comext (2022) and Eurostat Prodcom (2022) average import reliance of borates at processing stage is 53.5% for 2008-2020.

4.2 USES AND END-USES

Borates are a key input material in the production of fibreglass insulation, textile fibreglass, borosilicate glass, ceramics and fertilisers. These applications account for over three-quarters of borates consumption. The borates imported in the EU are mostly embodied in glass products.

The next common application of borates imports is the supply to ceramics and frits industry followed by fertilisers. Borates also have applications within the construction, metallurgy and chemicals industries.

Other applications and uses include construction materials, abrasives, catalysts, coatings, and detergents.

The EU end-uses of borates in 2012 are shown in Figure 22

Relevant industry sectors are described using the NACE sector codes in Table 6.

Table 6. Borate applications, 2-digit and examples of associated 4-digit NACE sectors, and value-added per sector (2019 figures stated, Eurostat 2022)

Applications	2-digit NACE sector	Value added of NACE 2 sector (M€) - 2019	Examples of 4-digit NACE sector(s)
Glass	C23 - Manufacture of other non-metallic mineral products	72,396	C2314 - Manufacture of glass fibres C2319 - Manufacture and processing of other glass, including technical glassware
Frits and Ceramics	C23 - Manufacture of other non-metallic mineral products	72,396	C2331 - Manufacture of ceramic tiles and flags
Fertilisers	C20 - Manufacture of chemicals and chemical products	117,150*	C2015 - Manufacture of fertilisers and nitrogen compound
Chemicals manufacture	C20 - Manufacture of chemicals and chemical products	117,150*	C1610- Sawmilling and planing of wood
Construction materials (flame retardants, plasters, wood preservatives)	C20 - Manufacture of chemicals and chemical products	117,150*	C2059- Manufacture of other chemical products n.e.c.
Chemicals manufacture	C20 - Manufacture of chemicals and chemical products	117,150*	C2059- Manufacture of other chemical products n.e.c.
Metals	C24 - Manufacture of basic metals	63,700 ** Data to 2014 only*	C2410- Manufacture of basic iron and steel and of ferro-alloys

Relevant industry sectors in the EU for value added (up to 2019) are described using the NACE sector codes (Eurostat, 2022), presented in Figure 23.

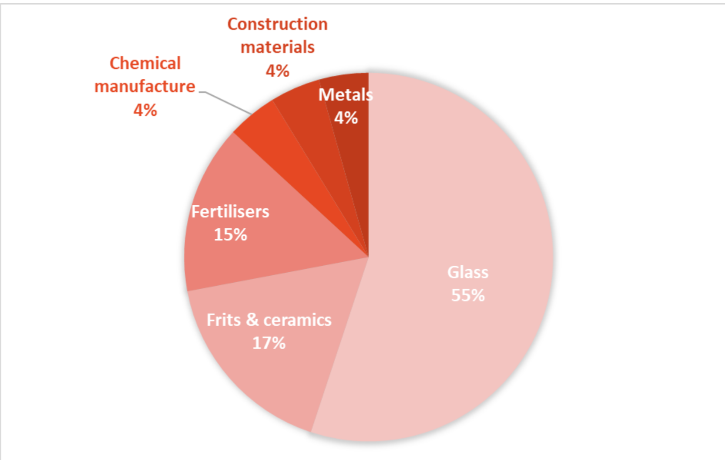

Figure 22. EU end uses of Borates 2012-2016 (IMA Europe 2016; (RMIS, uses - accessed 2022) - (no update from SCRREEN expert workshop, 2022

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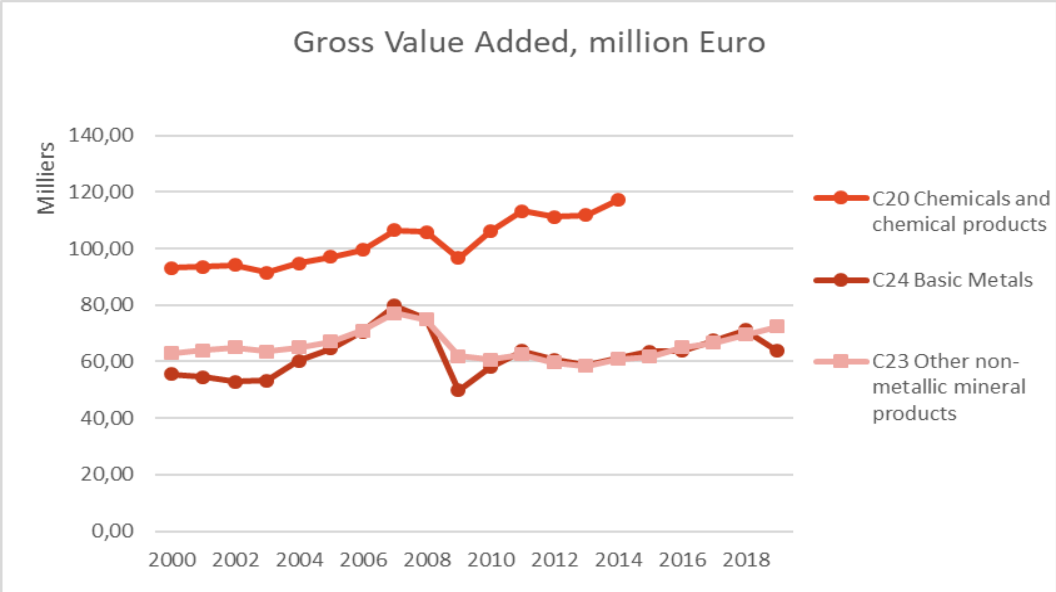

Figure 23. Value added per 2-digit NACE sector over time (Eurostat, 2022).

APPLICATIONS OF BORATES IN THE EU:

GLASS

The glass industry dominates the demand for borates worldwide.

Natural (e.g. colemanite concentrates, ulexite) or refined borates (e.g. borax pentahydrate, boric acid) can be added as raw materials during **the manufacturing of glass** depending on the application and the required quality.

In Europe, borax pentahydrate is the dominant raw material for boron addition to the glass melt (BIO Intelligence Service 2015).

The boron in **borosilicate glass** imparts increased mechanical strength and resistance to chemical corrosion, as well as improved resistance to high temperatures and thermal shocks due to a low coefficient of thermal expansion. In borosilicate glasses the B_2O_3 content typically ranges between 7% and 15% (Scalet et al. 2013), but can be as high as 30% (USGS 2018).

Glass fiber production includes **insulation glass fiber** (glass wool) and **continuous filament glass fiber** (textile grade). E-glass composition typically ranges from 5% to 10% of B_2O_3 content (Scalet et al. 2013) (RPA 2008). Furthermore, boron addition to the glass melt facilitates the production process as it lowers the glass batch melting temperature, favours fiberisation and inhibits crystallisation of the glass.

Glass products can be grouped in two categories:

- ***Insulation glass***: Insulation fibreglass (IFG) used in construction, vehicles, appliances and machinery for thermal and acoustic insulation;

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- ***Other glass (excl. insulation)***: Textile fiberglass (TFG) used in the manufacture of composite materials (glass-reinforced plastics), and borosilicate glass used in heat-resistant glass cookware and glass panels (e.g. for oven doors), laboratory glassware, pharmaceutical packaging, light bulbs, solar panels, and LCD screens.

FRITS AND CERAMICS

Borates are essential ingredient to produce frits used by the ceramic industry in ceramic glazes and enamels for chemical, thermal cycling, and wear resistance.

FERTILISERS

Boron is an essential micronutrient for plant growth, crop yield and seed development. Although only low amounts of boron are required, its deficiency in soil can have severe effects on crops.

CHEMICALS MANUFACTURE

Borates are used in laundry detergents, household and industrial cleaning products. Borates enhance stain removal and bleaching, provide alkaline buffering, soften water and improve surfactant performance.

CONSTRUCTION MATERIALS (FLAME RETARDANTS, PLASTERS, WOOD PRESERVATIVES)

Borates are used to treat wood to ward off insects and other pests (as wood preservatives) and in fire retardants.

METALS & OTHERS

Used for metalworking fluids, and other fluids used in cars, antifreeze, braking fluid, etc.

SUBSTITUTION

Most uses cannot be substituted without compromising the performance / end quality of the final product. (SCRREEN Expert Workshop, 2021).

Table 7. Uses and possible substitutes

Application	Share	Substitutes	SubShare	Cost	Performance
Glass	55%	ECR glass fiber	1%	Slightly higher costs (up to 2 times)	Reduced
		Rock wool	2%	Slightly higher costs (up to 2 times)	Reduced
		Cellulose	2%	Similar or lower costs	Reduced
		Silica in CFRP	2%	Slightly higher costs (up to 2 times)	Reduced
		No substitute	93%		No substitute

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Frits and ceramics	17%	Phosphate	2%	Similar or lower costs	Reduced
		No substitute	98%		No substitute
Fertilizers	15%	No substitute	100%		No substitute
Chemical manufacture	4%	Not assessed, below 10 %	100%		No substitute
Construction materials (flame retardants, plasters, wood preservatives)	4%	Not assessed, below 10 %	100%		No substitute
Metals	4%	Not assessed, below 10 %	100%		No substitute

GLASS

Borates may be substituted in fibreglass (boron-free E-glass), or fibreglass insulation may itself be replaced by alternative materials such as cellulose, foams, and mineral wool (Tercero et al. 2018) (USGS 2021). According to (IMA Europe 2016), eliminating boron from fibreglass production is not possible without affecting the glass fibre properties and increasing production costs.

Substitute materials for TFT-LCD glass include rare earth elements such as lanthanum, yttrium, cerium, or Erbium. The rare earth elements are added to reduce the boron content in flat panel display glass (Borates today).

No practical substitutes are available for heat-resistant glass.

In the criticality assessment, no substitution is considered available for the use of borates in the applications of 'Glass'.

FRITS & CERAMICS

In the criticality assessment, no substitution is considered available for the use of borates in the applications of 'Frits and Ceramics'.

For frits and ceramics used in tiles and floors, substitution is theoretically possible (Tercero et al. 2018) but no information is available on technically or economically viable alternative applications.

There are no substitutes in ceramic, or enamel glazes, as the benefits provided by boron trioxide (B_2O_3) in glaze production cannot be replaced by other oxides (IMA Europe 2016).

FERTILISER

In the criticality assessment, no substitution is considered available for the use of borates in the applications of 'Fertiliser' (due to the unique biological function of boron (Tercero et al. 2018).

OTHERS

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Other applications were not assessed due to less than 10 % share in total end uses.

However, substitutes exist for wood preservatives (Tercero et al. 2018), soaps (sodium and potassium salts of fatty acids), detergents (sodium percarbonate which requires a lower temperature to undergo hydrolysis) and bleaches (chlorine) (USGS 2019a)(Graedel et al. 2015b).

Boron replacement in metal applications seems impractical due to the numerous uses (Tercero et al. 2018a).

SUPPLY

EU SUPPLY CHAIN

The boron flows through the EU economy in 2012 are demonstrated in Figure 24. The average amounts of imported and produced intermediate boron-containing materials in EU during the period 2016-2020 were 31.000 tonnes and 66.000 tonnes, respectively. The intermediate refined borates include: diboron trioxide, oxides of boron and boric acids excluding diboron trioxide, anhydrous disodium tetraborate, disodium tetraborate penthahydrate and disodium tetraborate decahydrate (Eurostat, 2022).

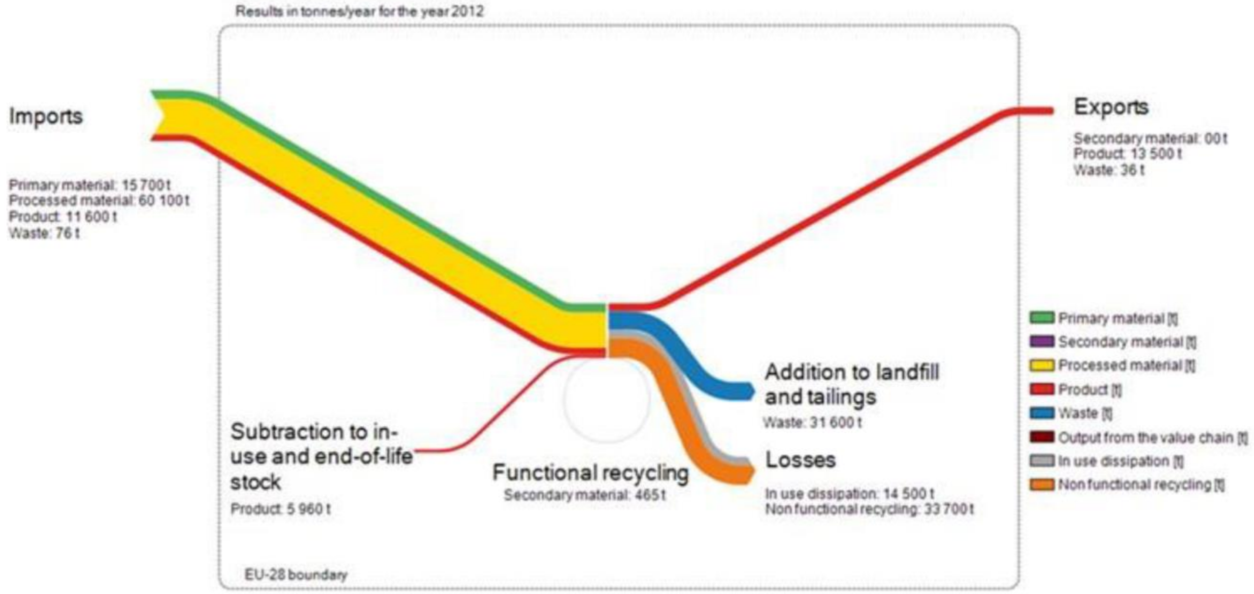

Figure 24. Simplified MSA of boron flows in the EU in 2012 (BIO Intelligence Service 2015).

The EU does not extract borates (WMD 2019) and has no known reserves (BIO Intelligence Service 2015a). Therefore, the EU is entirely reliant on imports of primary products (import reliance of 100%). Likewise, there are no manufacturing/processing plants to refine borates in the EU (IMA-Europe, 2016) (SCRREEN workshops 2019). However, it has to be mentioned that boric acid is produced in Italy from geothermal springs. Although it was the sole source of natural boric acid in the mid-19th century, the current contribution to the EU borates supply is minimal (RPA 2008) (Helvaci 2005). The leading supplier of the EU for both natural and refined borates is Turkey, with a share of 99% and 47% of the EU sourcing, respectively. The US is a significant supplier

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of refined borates with a share of 20% of EU supply after Germany (35%) (

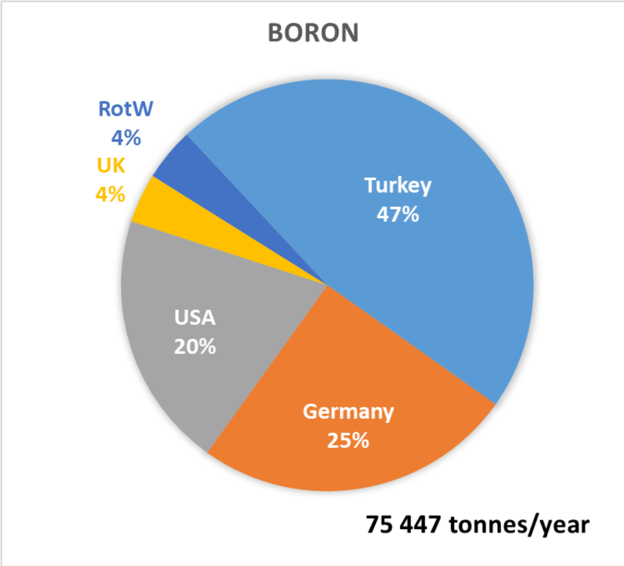

Figure 25).

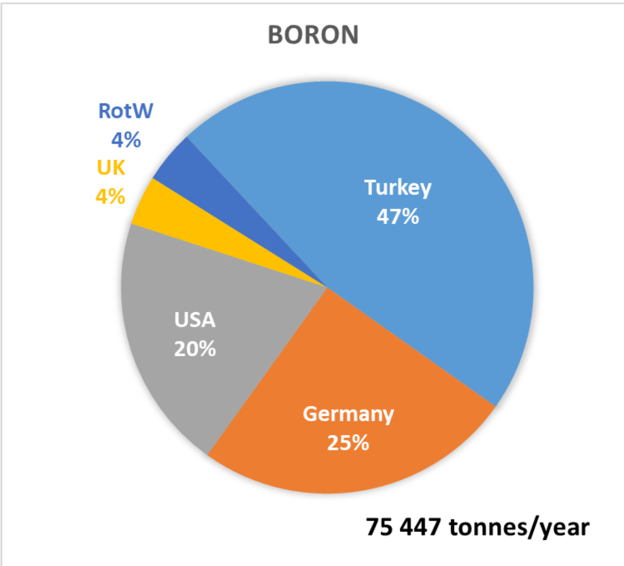

Figure 25. EU sourcing of refined borates. Average 2016-2020 (Eurostat Comext 2022).

SUPPLY FROM PRIMARY MATERIALS

GEOLOGY, RESOURCES AND RESERVES OF BORATES

GEOLOGICAL OCCURRENCE

Borates are naturally occurring minerals containing boron (B). Boron does not occur naturally as a native element but is found in combination with oxygen and other elements in salts, commonly called “borates”. Boron is a relatively rare element in nature, and the average content in the Earth’s crust is reported between

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10 (Helvacı 2017) and 17 ppm (Rudnick and Gao 2014). There are over 250 borate minerals occurring naturally, the most common being sodium, calcium, or magnesium salts (Helvacı 2017). Four of these account for 90% of the minerals used by the industry: the sodium borates tincal and kernite, the calcium borate colemanite, and the sodium-calcium borate ulexite (USGS 2021). Ore quality is typically measured as a function of its diboron trioxide (B2O3) equivalent content.

Deposits of borates are generally associated with arid climates and volcanically active areas; the largest are found in Turkey and the Mojave Desert in California of the United States. In the Puna region of the Andean belt of South America, which includes parts of Argentina, Peru, Bolivia, and Chile, commercial deposits of borates occur in brines (USGS 2021).

There is no information available on deposits of borates in the EU. In the geothermal springs of the Maremma region of Tuscany in Italy (Lardarello), natural steam carries boric acid recoverable as sassolite (Helvaci 2005).

GLOBAL RESOURCES AND RESERVE

The estimated known reserves of borates worldwide are about 1,093,000 kt in boron content (USGS 2021). Approximately 75-80% of the global boron reserves are located in Turkey, which are the world's highest-grade deposits of colemanite, ulexite and tincal with grades ranging from 25 to 30% of B_2O_3 (boric oxide) (Helvacı 2017).

Table 8. Global reserves of borates in 2022 (USGS, since 2000)

Country	Reserves (kt of boron)		Country	Reserves (kt of boron)
Turkey	1200,000		Peru	4,000
Unites States	40,000		Argentina	NA
Russia	40,000		Bolivia	NA
Chile	35,000		Kazakhstan	NA
China	24,000			

Valjevo B-Li occurrence in Serbia isthe only exploitable boron deposit in Europe. Identified borates cover a basin area over 9.3 km2 to 14.7km2 with a thickness of preserved borate that ranges from 1.3 m to 20.9 m. The highest measured B_2O_3 concentration through drilling was found to be 15.1%. The planned Valjevo mining project is owned by Canada-based Euro Lithium. The company is planning to extract lithium from clay. The Valjevo lithium deposits have a relatively low lithium concentration, similar to geothermal brines (borates.today, 2022; GeoMin Consulting).

EU RESOURCES AND RESERVES

There are no known reserves of borates in the EU. Table 9 presents available borate resources in Europe.

Table 9. Resources of borates in Europe

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Country	Classification	Quantity (million t of ore)	Grade (% B_2O_3)	Reporting code	Reporting date	Source
Serbia	Indicated	5.6	30.8	NI 43-101	04/2015	(Minerals4EU 2019)
	Inferred	6.2	28.8			
	Indicated	52.4	19.2	JORC	12/2016	(Rio Tinto 2017)[46]
	Inferred	83.3	13.0			

MINING AND REFINING OF BORATES

Most of the world's commercial borate deposits are mined by open-pit methods, generally using truck and shovel or backhoe equipment (Carpenter and Kistler 2006).

Some applications allow the use of unrefined borates, such as colemanite and ulexite. However, natural borates often require refining as the ores are not of sufficient quality. High purity borax or boric acid are the main forms consumed by manufacturing industries for most applications.

Processing techniques depend on both the scale of the operation and the ore type (Helvaci 2005). The basic processing steps used to convert natural borates to refined products consist of ore crushing, leaching the ore in either hot water or acid, filtration to -remove insoluble impurities, cooling the concentrated borate solutions, dewatering to produce a moist cake of boric acid, washing and drying (Carpenter and Kistler 2006). Several commercial forms of refined borates (or primary boron chemicals) exist:

- high purity sodium borates (borax pentahydrate, borax decahydrate, anhydrous borax);
- high-purity boric acid and boron oxide (anhydrous boric acid).

WORLD AND EU PRODUCTION OF NATURAL BORATES

The global primary production of borate minerals by country since 1984 according to WMD data and since 2000 according to USGS data can be seen in Figure 26 and Figure 27, respectively (WMD, since 1984; USGS, since 2000). Turkey and United States are over time the main producers. China, Chile, Argentina and Bolivia present notable production. The borates world production, according to WMD, in 2020 was 3.6 million tonnes– significantly reduced in comparison to the average of the period 2016-2020 (4.13 million tonnes). Statistical data of production differ between WMD and USGS. USGSindicates a notable escalation of production in the period 2013-2017 driven by a rapid production increase in Turkey which is the major boron producer worldwide However, it should be noted that the extent of this increase is not imprinted in the respective WMD factsheet. The primary production of borates in both diagrams refers to a wide number of materials including: crude ore (Peru), ulexite (Bolivia, Chile), boric oxide equivalent (China), refined borates (Turkey) and datolite (Russia)

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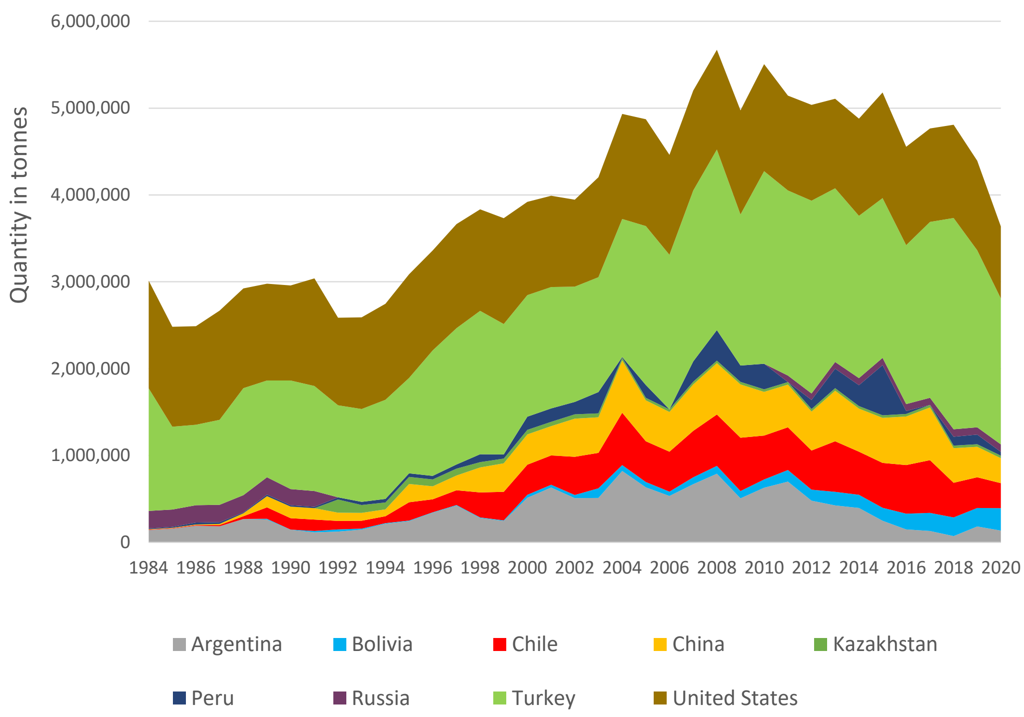

Figure 26. Global primary production of borate minerals between since 1984 (WMD, since 1984).

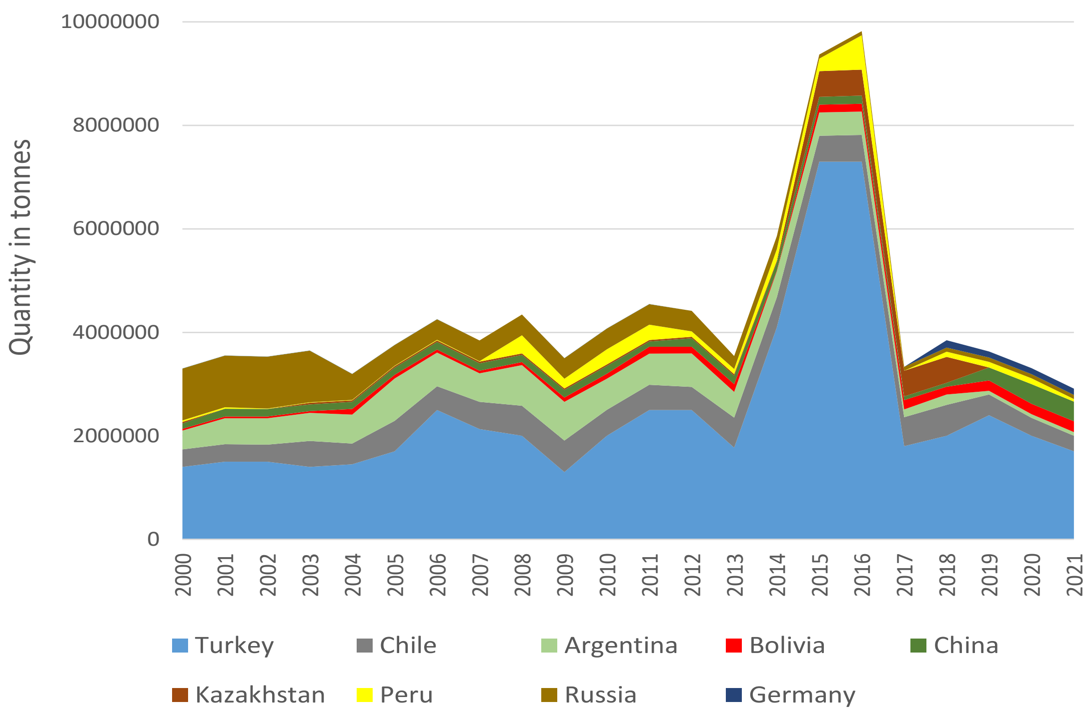

Figure 27. Global primary production of borate minerals between since 2000 (USGS, since 2000).

WORLD AND EU PRODUCTION OF REFINED BORATES

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There is no publicly available data on the production of refined borates. Based on estimation from the global trade data as reported by UN Comtrade (2019), US is the dominant supplier of refined borates accounting for 67% of the total world exports. The average annual quantity of the processed borate products traded over 2012-2016 is around 163,500 tonnes of borate content. The trade codes used for the indirect estimation of world production shares are:

- Oxides of boron, boric acids (HS6 281000, B content 17%). World exports 508,125 tonnes.
- Borates, disodium tetraborate (refined borax), anhydrous (HS6 284011, B content 21%). World exports 68,896 tonnes.
- Borates, disodium tetraborate (refined borax), other than anhydrous (HS6 284019, B content: 12%). World exports 701,756 tonnes.

Refined borates are not produced in the EU (IMA-Europe, 2016) (SCRREEN workshops 2019).

OUTLOOK FOR SUPPLY

Between 80% - 85% of the world's borates are produced by two companies in two countries: US Borax (Rio Tinto) in California, USA, and Eti Maden in Turkey. Eti Maden is a significant supplier of borates to the European Union, providing the 99% of concentrated borates and the 86% of refined borates. Borates supply in medium term is uncertain taking into account the reduction market share by Rio Tinto due to the lower quality of ore feedstock material and consequently higher cost of production at the US Borax operation in Boron, California. According to company filings, the mine will end production in 2042 or sooner. New mining projects of borates are planned to begin in Serbia including Valjevo and Jadar regions and in Rhyolite Ridge in Nevada, USA. Both projects in Serbia and US are in the stage of the feasibility study (Euro Lithium, 2020). Rhyolite Ridge is schedulte to start production in 2024. Currently (since 2022), the Serbian Government revoked the exploration licences of the mining company Rio Tinto for the Jadar project after the protests by green activists who concern that the mining projects will cause more pollution to Serbia which is one of Europe's most polluted countries (euractiv, 2022).

SUPPLY FROM SECONDARY MATERIALS/RECYCLING

Because of the nature of end uses, boron/borates functional recycling is not possible as products are consumed with the use (e.g. fertilisers, chemicals and detergents), or because non-functional recycling only occurs. For instance, separation of borosilicate glass from the boron-free container and flat glass is not possible and, as a result, waste borosilicate glass will end up in the manufacture of normal glass, causing defects in the final product. Moreover, waste from ceramics is mostly used as a construction material (BIO Intelligence Service 2015). As an exception, the recycling of biogenic wastes (e.g. manure or other animal by-products, bio- and food wastes) can be considered as functional recycling because it may replace boron from industrial fertilisers (Mathieux et al. 2017). As a consequence, he EoL-RIR (End-of-Life Recycling Input Rate) for boron is less than 1% (SCRREEN workshops 2019).

Recently, specific attention has been drawn to the recovery of elemental B by spent end-of-life Nd-Fe-B magnets. The methodology, which is not applied commercially so far, achieves the simultaneous recovery of

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REEs, iron and boron through a process that comprises: (a) the pre-treatment-roasting of the magnet scrap at 800 °C, (b) the dissolution using HCl acid under pressure and (c) the separation of REEs, Fe and B using a combination of precipitation with oxalic acid and solvent extraction. Under these conditions, boron as sodium borate with >97% purity is obtained (Liu et al. 2020).

Table 10. Material flows relevant to the EOL-RIR of borates in 2012 (BIO Intelligence Service 2015).

MSA Flow	Value (tonnes)
B.1.1 Production of primary material as the main product in EU sent to processing in EU	0
B.1.2 Production of primary material as by-product in EU sent to processing in EU	0
C.1.3 Imports to EU of primary material	15,739
C.1.4 Imports to EU of secondary material	0
D.1.3 Imports to EU of processed material	60,050
E.1.6 Products at end of life in EU collected for treatment	65,778
F.1.1 Exports from EU of manufactured products at end-of-life	36
F.1.2 Imports to EU of manufactured products at end-of-life	75
G.1.1 Production of secondary material from post-consumer functional recycling in EU sent to processing in EU	0
G.1.2 Production of secondary material from post-consumer functional recycling in EU sent to manufacture in EU	464

PROCESSING OF BORATES

Boric acid consists the main intermediate material for the technological applications in which the use of B is taking place. Boric acid is industrially produced based on the reaction of colemanite ($Ca_2B_6O_{11} \cdot 5H_2O$) and sulfuric acid at 88–90 °C according to the following reaction:

$$Ca_2B_6O_{11} \cdot 5H_2O + 2H_2SO_4 + 6H_2O \rightarrow 6H_3BO_3 + 2CaSO_4 \cdot 2H_2O$$

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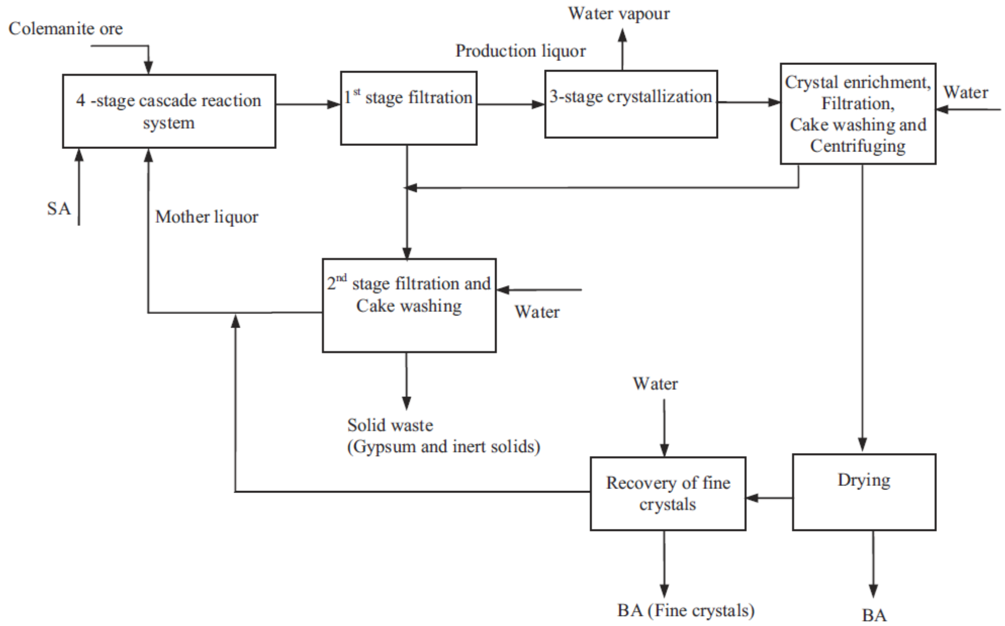

Figure 28 Flowsheet of colemanite processing for the production of boric acid (Kuskay and Bulutcu, 2011).

Reaction is carried out in a 4-stage cascade reaction system and its duration is 3–3.5 h in order to eliminate supersaturation of gypsum ($2CaSO_4 \cdot 2H_2O$) and to avoid its precipitation during boric acid crystallization (Figure 29). At the end of each successive reaction step, precipitated gypsum and inert solids are filtered. The cakes obtained at each step are washed and the filtrate is recycled to the next reaction step. The produced liquor (boric acid content is approximately 18%) is crystallized in a 3-stage crystallization unit composed by adiabatic vacuum crystallizers. The moisture content is reduced approximately to 7% through centrifugation. The final product is crystallized via drying in a fluidized bed drier (Kuskay and Bulutcu, 2011).

OTHER CONSIDERATIONS

HEALTH AND SAFETY ISSUES

Boron compounds are used in the manufacture of glass, soaps and detergents and as flame retardants. Naturally occurring boron is present in groundwater primarily as a result of leaching from rocks and soils containing borates and borosilicates (WHO 2022). Boron is a trace element that is naturally present in many foods and available as a dietary supplement. (NIH 2022)

No data are available on adverse effects of high boron intakes from food or water. Short- and long-term oral exposures to boric acid or borax in laboratory animals have demonstrated that the male reproductive tract is a consistent target of toxicity (WHO 2022). Symptoms associated with accidental consumption of boric acid or borax (sodium borate), contained in some household cleaning products and pesticides, include nausea, gastrointestinal discomfort, vomiting, diarrhea, skin flushing, rash, excitation, convulsions, depression, and vascular collapse. On the other side, a few clinical studies in humans suggests that boron might be helpful for reducing the symptoms of osteoarthritis and might be important for bone growth and formation (NIH 2022). The oxide of boron, boron trioxide, is identified as toxic for reproduction. (REACH 2012). The limit value of

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boron oxide in air is estimated at 10 mg/m^3 in European countries, while according to the USA OSHA it is estimated at 15 mg/ m^3 (GESTIS 2022). (WHO 2022) developed a set of 'Guidelines for drinking water quality', where the guideline value for boron is set at 2.4 mg/l. Similar guidelines developed by the government of Canada, set the guideline value even lower, at 2 mg/l (Gov of Canada, 2020).

ENVIRONMENTAL ISSUES

According to (Turkbay et al. 2022), "the environmental impact of the refinement process [of boron] is critical compared to the mining and beneficiations processes. Sulphuric acid, steam, hydrogen peroxide, and sodium perborate which are used in refined boron production cause most of the impact and emission into the environment. Among the refined boron products investigated, the impact of sodium perborate is quite high".

(Jun Wu et al. 2021) found "no information is currently available on potential environmental impact of boric acid solvent extraction from salt-lake brine, although boron production is important for industry, agriculture, and human well-beings".

NORMATIVE REQUIREMENTS

No specific applicable normative requirements could be identified.

SOCIO-ECONOMIC AND ETHICAL ISSUES

ECONOMIC IMPORTANCE OF THE BORON/BORATES FOR EXPORTING COUNTRIES

Table 11 lists the countries for which the economic value of boron product exports represents more than 0.1 % in the total value of their exports.

Table 11: Countries with highest economic shares of BORON exports in their total exports

Country	Export value (USD)	Share in total exports (%)
Bolivia	11153668924.57	0.7 %
Turkey	225424500642	0.1 %
Chile	94738365163.28	0.1 %

Source: COMTRADE (2023), based on data for 2021

Boron product exports are most relevant for Bolivia (0.7 %), Turkey (0.1 %) and Chile (0.1 %).

SOCIAL AND ETHICAL ASPECTS

No specific information was found.

RESEARCH AND DEVELOPMENT TRENDS

RESEARCH AND DEVELOPMENT TRENDS FOR LOW-CARBON AND GREEN TECHNOLOGIES

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- The Role of Borates in the European Green Deal and Digital Transformation (Schubert 2020)

Borates and materials made from them are integral to many technologies required to reach the goals of the European Green Deal. These include applications in electric vehicles, clean energy, digital transformation etc., some research for which is described in more detail below.

- Preparation of spherical amorphous boron particles via a green silicothermic reduction method (Pang et al., 2022)

Spherical amorphous boron with an average particle size of 380 nm have been successfully prepared by a novel silicothermic reduction method using silicon, alkali borate and silicate as raw materials. The low-viscosity R2O-B2O3-SiO2 melt that exist in the above reaction system could be used to facilitate the silicothermic reduction and absorption of silica, a water-insoluble by-product formed in conventional silicothermic reduction. In contrast to silica, the by-product of improved silicothermic reduction is alkali silicate which could be separate easily by washing. Besides, the alkali silicate aqueous solution is an important recyclable industrial material. The results reveal that this is a simple and environment-friendly way to prepare sub-micron amorphous boron particles with intact sphericity.

OTHER RESEARCH AND DEVELOPMENT TRENDS

- Multi BB[6] project: Boron-boron multiple bonding (2016-2021, EU)

Multiple bonding between atoms is immensely important to chemistry, biology, physics and their associated industries; multiple bonds are both ubiquitous in everyday products and extremely useful functionalities for effecting chemical transformations. The Multi BB project aimed to: (A) comprehensively explore the syntheses of these unique compounds and the limits thereof, and to (B) exploit the unusual reactivity of these electron-rich boron molecules in synthesis, small-molecule activation and materials science.

- PHOTO-BORAD[7] project: Boron chemistry in a new light: exploring the radical reactivity of boronate complexes through photochemical strategies (2017 – 2019, EU)

In the last decade photoredox reactions have emerged as tremendously versatile processes for organic synthesis, enabling reactive radical species to be generated at specific positions in an organic molecule under very mild conditions (visible-light irradiation). Over the same decade, a suite of transformations was developed exploiting the fundamental chemistry of boron, many of which involve 1,2-metallate rearrangement of boronate complexes. The project seeked to merge these two major pillars of synthetic methodology, which were unconnected, to create a new field which is believed has significant potential for organic synthesis.

[6] https://cordis.europa.eu/project/id/669054
[7] https://cordis.europa.eu/project/id/744242

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- WHITEMAG[8] project: Engineering magnetic properties of hexagonal boron nitride - based hybrid nanoarchitectures (2020 – 2022, EU)

Two-dimensional hexagonal boron nitride (hBN) has a similar structure like graphene. It is used extensively as an insulator and is known for its high thermal stability, inertness and mechanical robustness. Like graphene, it also has exotic optoelectronic properties and is attracting interest in applications such as field effect transistors and photoelectric devices. To fully exploit the potential of hBN nanostructures, the project planned to develop methodologies to enable the controlled magnetic functionalisation of hBN at the nanoscale. To do so, it characterised the structural, electronic and magnetic properties of various hBN-based engineered materials at the atomic level. Tailoring of magnetic properties could spur applications in numerous fields, from spintronics to molecular electronics.

- FRESCO[9] project: Efficient, Flexible Synthesis of Molecules with Tailored Shapes: from Photo-switchable Helices to anti-Cancer Compounds (2015-2021, EU)

Difficulties associated with chemical synthesis limit new molecular entities and subsequent exploitation of their properties in a broad spectrum of research disciplines from medicine to materials which needs a fundamentally new strategy to conduct complex organic synthesis. The basic C–C bond-forming step involves the reaction of a lithiated carbamate with a boronic ester to give a homologated boronic ester with complete stereocontrol. Furthermore, the reaction shows >98 % efficiency in most cases and can be conducted iteratively and in one pot. This method was extended to more functionalised carbamates enabling rapid synthesis of polypropionates, which are amongst the most important classes of biologically active molecules. The robust methodology is ripe for transfer to the solid phase for the preparation of libraries of these molecules. Applying an assembly-line-synthesis method to complex molecules with diverse structures, the method enables stereochemistry to be 'dialled in' to a carbon chain, which in turn controls the conformation. This approach was exploited in the shape-selective synthesis of molecules. We will explore how the sense of helical chirality of these molecules can be switched (M to P) just with light. The project targeted helical molecules with specific groups at specific places for optimum binding to disrupt protein–protein interactions involved in cancer. Finally, the approach provides ready access to a family of building blocks that represent common repeat units found in polyketides. By combining these building blocks iteratively using lithiation-borylation, it should be possible to rapidly and reliably prepare complex natural products.

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