SCRREEN2

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

TIN

AUTHOR(S):

TABLE OF CONTENT

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TIN

OVERVIEW

Tin (chemical symbol Sn, from the Latin term 'stannum') is a soft, malleable, ductile and highly crystalline silvery-white metal. It has a low melting point (232 °C). It is one of the few metals which has been used and traded by humans for more than 5,000 years. The earliest record of its use was in 3,500-3,200 BC for weapons, and it was shortly after alloyed with copper to make bronze, notably by the Romans in the first century AD. Despite this prehistoric use, its abundance in the upper continental crust (2.1 ppm) is estimated lower than that of other industrial metals like aluminium, copper, and lead (Rudnick, 2003).

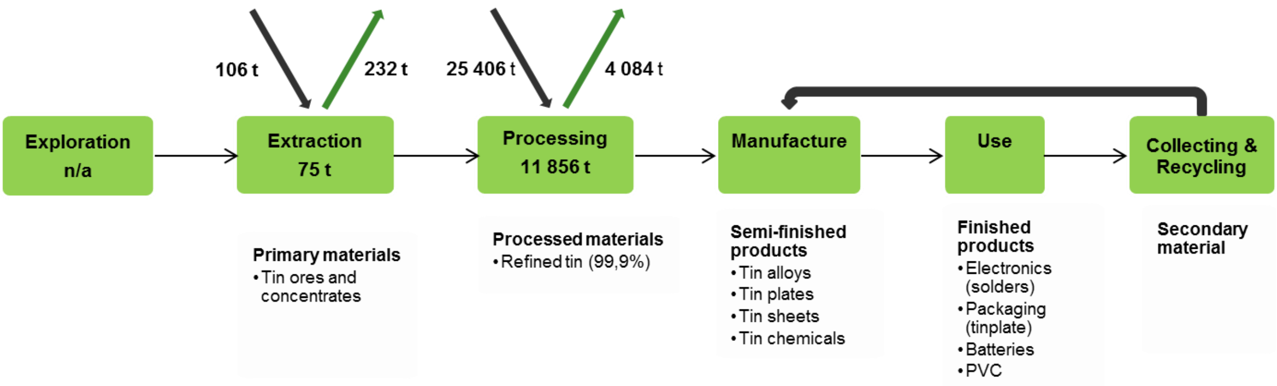

Figure 1. Simplified value chain for tin in the EU[1]

Table 1. Tin supply and demand in metric tonnes, 2016-2020 average

Global production	Global Producers	EU consumption	EU Share	EU Suppliers	Import reliance
300440	China 29% Indonesia 24% Myanmar 17% Peru 6%	49000	18%	Indonesia 46% Peru 15% Malaysia 9%	73%

Prices: Over the last years, different drivers of tin-price dynamics have been reported. These range from relatively small market size and concentration of supply on few countries with significant supply risk/instability, over weak market fundamentals (low production, low inventories, rising costs of production) and impacts of Covid-19 (e.g., supply disruptions in Indonesia and Malaysia) to growing demand. The use of

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

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tin in electronics and lead-free solders has been the main component and driver of tin demand in the past decades

Primary supply: During the period 2016-2020, 300,000 tonnes of tin were mined on average annually, in the world. China was the main producer and accounted for 29% of the global mine production, followed by Indonesia (24%) and Myanmar (17%). Experts noted that there is tin smuggling taking place between Myanmar and China, which hampers the quality of the related trade data.

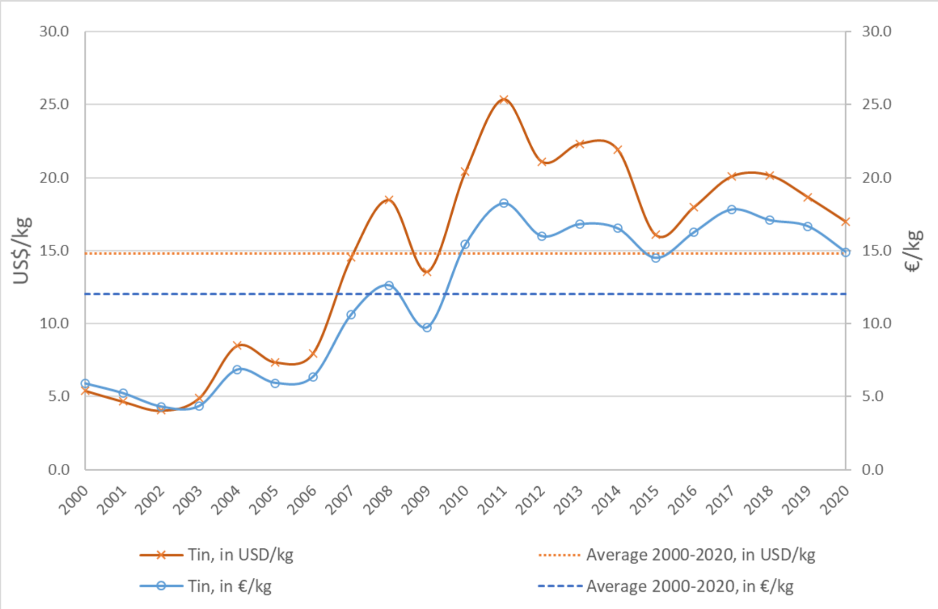

Figure 2. Annual average price of tin between 2000 and 2020 (USGS, 2021)[2].

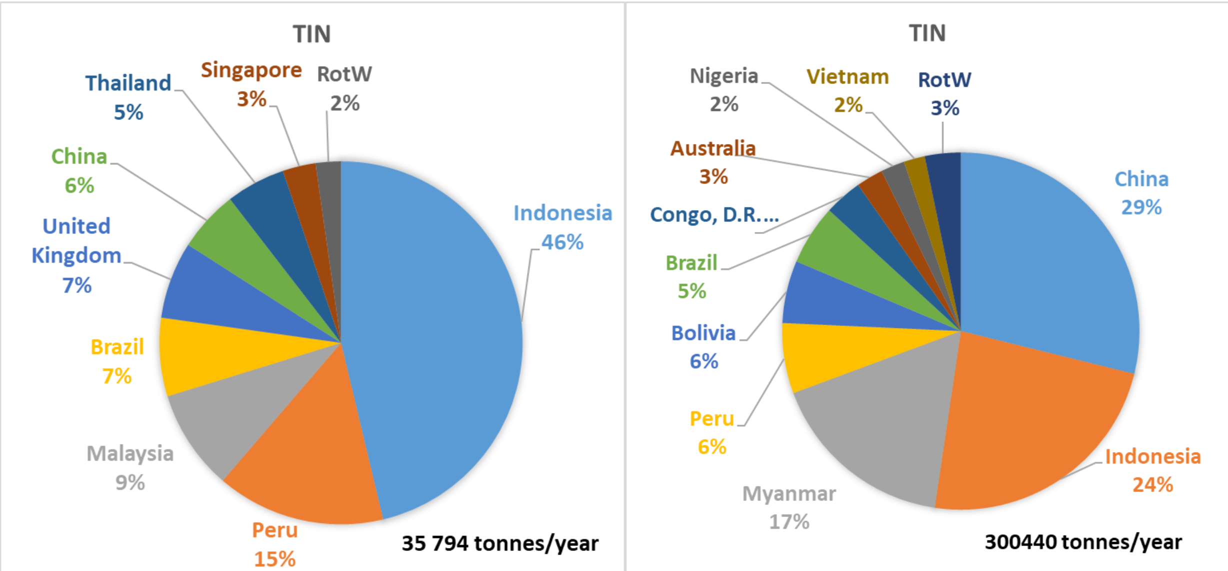

Figure 3. EU sourcing of tin and global mine production (tin content, average 2016-2020)

[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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Secondary supply: End-of-life recycling rate depends on the applications, with tinplate in food and beverages cans having the highest (around 65%), followed by solders in electronics (40%). The End-of-Life Recycling Input Rate (EoL-RIR) of tin, including refined and unrefined forms, was calculated as 30.7% in 2016, down from 31.4% in 2015, with re-refined tin contributing approximately 16% (ITRI, 2016; ITRI, 2017). The proven global tin reserves were reported to be approximately 4.7 million tons (Mtonnes) in 2016, and among these resources, only approximately 2.2 Mtonnes can be recovered economically.

Uses: Tin has been proved to be non-toxic and is used in a variety of applications, including solder, tinplate, tin chemicals and copper alloys. It is resistant to corrosion, and a good electrical conductor. Thanks to those properties, it is primarily used today as coating for steel sheet in tinplate (food containers, etc.) and for industrial solders in electronics.

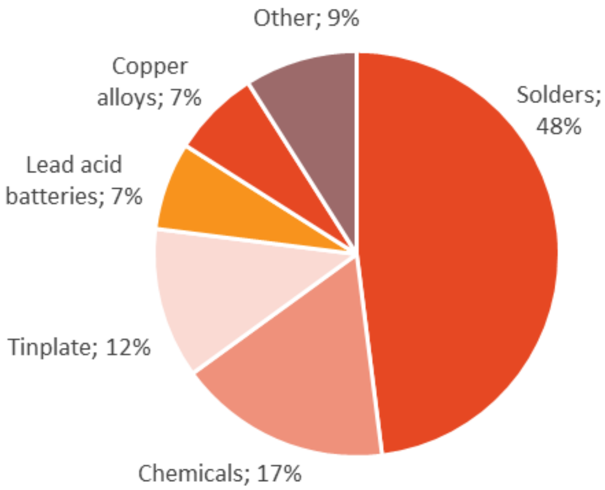

Figure 4: EU uses of tin

Substitution: Potential substitutes exist for most of the tin uses.

Table 2. Uses and possible substitutes

Application	Share	Substitutes	SubShare	Cost	Performance
Solders	47%	Epoxy Resin	20,00	Similar or lower costs	Reduced
Solders	47%	Lead-tin	5,00	Similar or lower costs	Reduced
Solders	47%	no substitute	75,00	Similar or lower costs	Similar
Chemicals	18%	Barium-Zinc	15,00	Similar or lower costs	Reduced
Chemicals	18%	Calcium-Zinc	75,00	Similar or lower costs	Reduced
Chemicals	18%	no substitute	10,00	Similar or lower costs	Similar
Tinplate	13%	Aluminum	30,00	Similar or lower costs	Similar
Tinplate	13%	Glass	30,00	Similar or lower costs	Similar
Tinplate	13%	Plastics	30,00	Similar or lower costs	Similar
Tinplate	13%	no substitute	10,00	Similar or lower costs	Similar
Lead acid batteries	6%	Lithium-ion battery	60,00	Very high costs (more than 2 times)	Similar
Lead acid batteries	6%	no substitute	40,00	Similar or lower costs	Similar
Copper alloys	6%	Aluminum	25,00	Similar or lower costs	Similar
Copper alloys	6%	Zinc	25,00	Similar or lower costs	Similar
Copper alloys	6%	no substitute	50,00	Similar or lower costs	Similar

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Other issues: Tin is one of the “conflict minerals” addressed by Directive (EU) 2017/821 („Conflict Minerals Directive“) requiring specific due diligence of importers, and by the US Dodd-Frank Act (2010). It is also in the scope of the OECD (2017) “Due Diligence Guidance for Responsible Supply Chains of Minerals from Conflict-Affected and High-Risk Areas” and the “ASM Code of Conduct” published by T.I.C. (2022). The shares of tin export values remain far below 1% of their total exports in all exporting countries. Only for Bolivia, Burundi and the Democratic Republic of the Congo, Tin exports represent more than 0.1 % of the value of their total exports in value. There are also reports about surging illegal mining activities, among others for tin, on indigenous peoples’ territories in Brazil (France24) and rising fears that the war in Ukraine driving the prices of raw materials may attract more such activities. (BBC 2022). According to (BGR, 2020), artisanal and small-scale mining activities represent around 27 % of the global tin production making the sector particularly relevant for social and economic development for example in Indonesia, Central Africa or Bolivia while at the same time offering poor working conditions.

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MARKET ANALYSIS, TRADE AND PRICES

GLOBAL MARKET

Table 3. Tin supply and demand in metric tonnes, 2016-2020 average

Global production	Global Producers	EU consumption	EU Share	EU Suppliers	Import reliance
300440	China 28% Indonesia 23% Myanmar 17% Peru 6%	49000	16%	Indonesia 46% Peru 15% Malaysia 9%	73%

The largest net-exporters of tin (ores/concentrates) at the mining stage were Burma, Australia and Ruanda with global shares of ca. 89%, 5% and 2% in 2018 (Barazi et al., 2021). Country concentration, 'weighted country risk' (indicated by the Worldwide Governance Indicators) and, thus, overall 'supply risk' at the tin-mining stage can be characterised as 'medium' when referring to production statistics, respectively (Barazi et al., 2021). However, when referring to net-exports of tin at the mining stage, supply risk is significantly higher, since both, the country concentration of international trade in mining-stage tin ('net-exports concentration') and the corresponding 'weighted country risk' can be characterized as 'high' (Barazi et al., 2021).

Similarly, tin-supply risk at the refining stage is 'high' (regarding production and net-exports); this is primarily due to the high country concentration of tin refining, with 'weighted country risk' of tin refining being 'medium': the major refined-tin producers are China, Indonesia and Malaysia with ca. 48%, 20% and 8% of global refined-tin production in 2018; the major net-exporters of unwrought tin (not alloyed) are Indonesia, Malaysia and Peru, representing ca. 47%, 13% and 10% globally (Barazi et al., 2021). At firm level, the largest tin producer in 2020 was Yunnan Tin (China), followed by PT Timah (Indonesia), MCS (Malaysia), Minsur (Peru) and others (International Tin Association, 2021b).

The demand side of the tin market is dominated by solder applications, which account for 49% of global refined-tin use in 2020 (International Tin Association, 2020, 2021b). Chemicals, tinplate, batteries, alloys and others follow with 18%, 12%, 7%, 5% and 9%, respectively (International Tin Association, 2020, 2021b). China is the major tin consumer, and, like the production side, the consumption side is highly concentrated on few countries: the top-ten countries account for ca. 80% of global tin consumption (Li et al., 2021; Vasters & Franken, 2020). Substitution of tin is possible to varying degrees depending on the application (see the section on substitution and European Commission, 2020).

Overall, the tin market (in quantity terms) has been characterised by positive trend growth over the last 120 years (International Tin Association, 2021b). The use of tin in electronics and lead-free solders has been the main driver of this growth in the past decades (International Tin Association, 2021b, 2021c). China is an important demand driver currently (DERA, 2021). The short-to-medium-run dynamics of the tin market are affected by different factors, such as relatively small market size, supply concentration, supply risk, market fundamentals, political/regulatory aspects and others (see the prices section for details). Moreover, the

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forming of 'Regional Comprehensive Economic Partnership' in East Asia and Oceania covers a significant share of global tin supply, and, thus, bears potential effects on tin market dynamics (DERA, 2020a).

Negative effects of Covid-19 crisis on tin markets have been reported in the past, e.g., supply disruptions in Burma, Indonesia and Malaysia; decline of tin use/demand in China and globally; tin-sourcing difficulties in China; and transport disruptions (shortages in container-transport capacity) paired with low inventories engraving the undersupply of the last years (DERA, 2020b, 2021; International Tin Association, 2020, 2021a; MINING.com, 2021; USGS, 2021a). There are also reports/expectations of (partial) recovery from the Covid-19 crisis (Home, 2021; International Tin Association, 2020) and positive effects of Covid-19 crisis on, e.g., tinplate use (related to increased demand for canned foods) and battery use (from e-bikes) (International Tin Association, 2020; USGS, 2021a).

EU TRADE

Table 4. Relevant Eurostat CN trade codes for tin

Mining		Processing/refining	
CN trade code	**Title**	**CN trade code**	**Title**
26090000	Tin ores and concentrates	26209940	Slag, ash and residues containing mainly tin
		28273910	Tin chlorides
		80011000	Unwrought tin, not alloyed
		80012000	Unwrought tin alloys

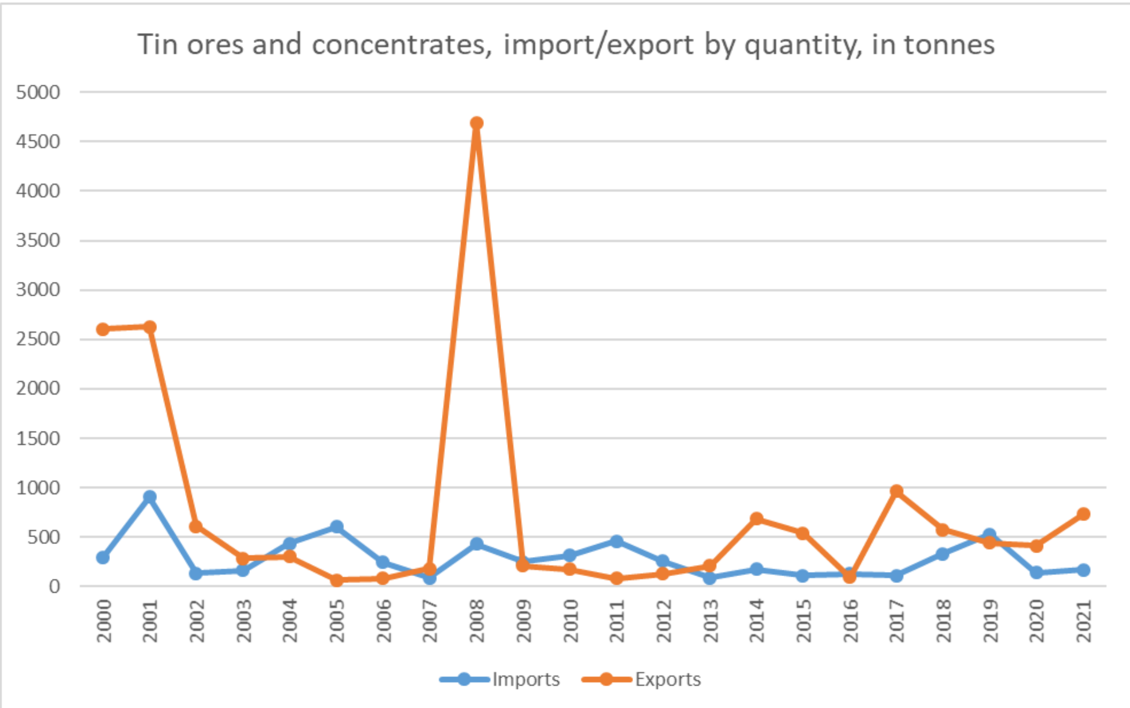

Figure 5. EU trade flows for the category 'tin ores and concentrates', between 2000 and 2021 (based on Eurostat, 2021).

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Figure 5 shows the EU trade in tin at mining stage between 2000 and 2021. EU's (mining-stage) tin-trade balance was mixed over the period, switching between surpluses and deficits. Imports varied between 86 tonnes and 907 tonnes p.a.; exports were in the range between 65 tonnes and 4,694 tonnes, the latter quantity representing a peak. Figure 6 presents the average EU imports of tin at mining stage, by country, for the period 2000-2021. The major EU suppliers of tin at mining stage were United States and United Kingdom, accounting for 30% and 29% of EU's imports in the category 'tin ores and concentrates', respectively. Thailand, Indonesia and Russia followed with 13%, 9% and 5%. While in the beginning of the period, EU's imports in the category 'tin ores/concentrates' were covered, for the greatest part, by United Kingdom (and Indonesia's peak supply), the middle of the period was dominated by US supply; by the end of the 2010s, supply from Thailand and Russia dominated EU's imports in the category 'tin ores and concentrates'.

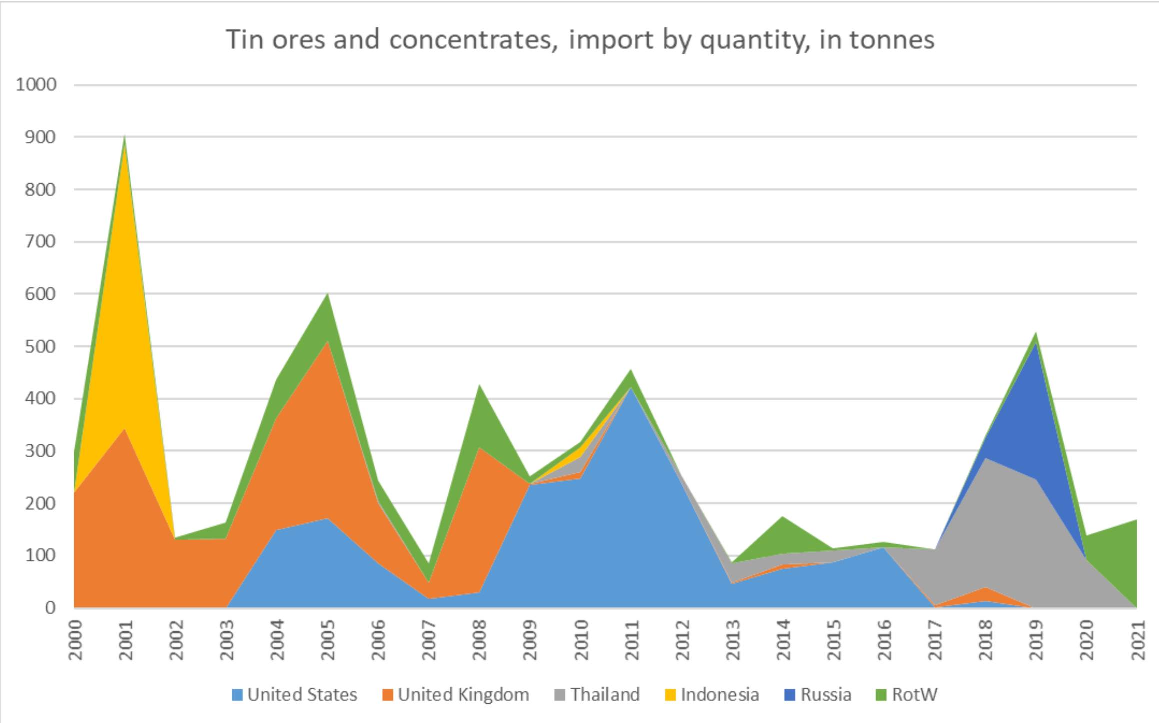

Figure 6. EU imports in the category 'tin ores and concentrates', by country, between 2000-2021 (based on Eurostat, 2021).

Figure 7 to Figure 10 show the EU trade in tin at processing stage, between 2000 and 2021. The EU was a net importer in three categories: 'unwrought tin (not alloyed)', 'unwrought tin alloys' and 'slag, ash and residues containing mainly tin'. The trade deficit with respect to the category 'unwrought tin, not alloyed' was large: imports were in the range of 38-68 ktonnes, while exports were in in the range of 3-8.4 ktonnes. The trade deficit with respect to the category 'slag / ash / residues' was relatively extreme: imports were ranging between 1 and 10 ktonnes, while exports were between 0 and 76 tonnes. Imports of unwrought tin alloys were between 2.1 ktonnes and 8.5 ktonnes, where the latter quantity represents rather a peak; exports were between 0.4 ktonnes and 9.2 ktonnes. The trade balance of tin chlorides was switching between surplus and deficit; imports were varying between 549t and 1,207 tonnes; exports were between 204 tonnes and 1,397 tonnes.

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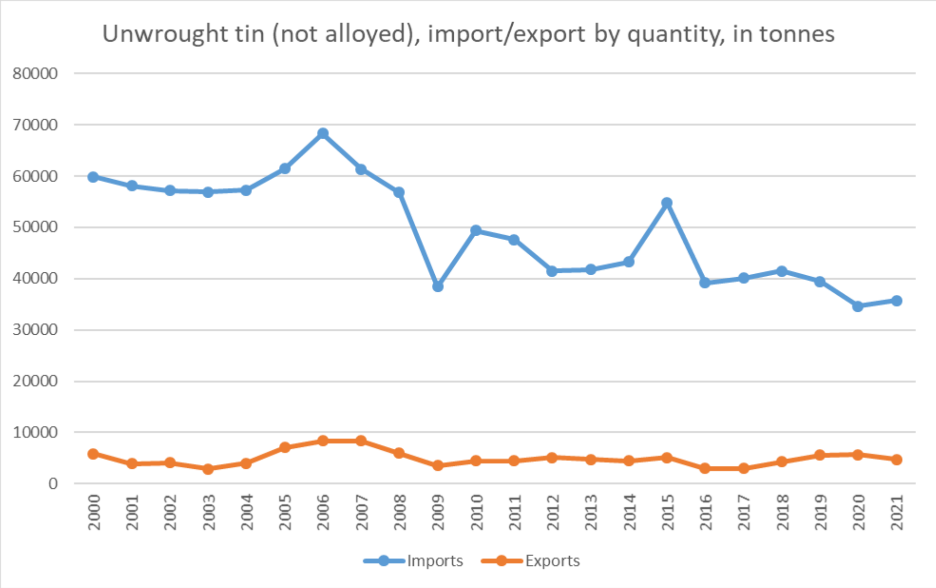

Figure 7. EU trade flows of unwrought tin (not alloyed), from 2000 to 2021 (based on Eurostat, 2021).

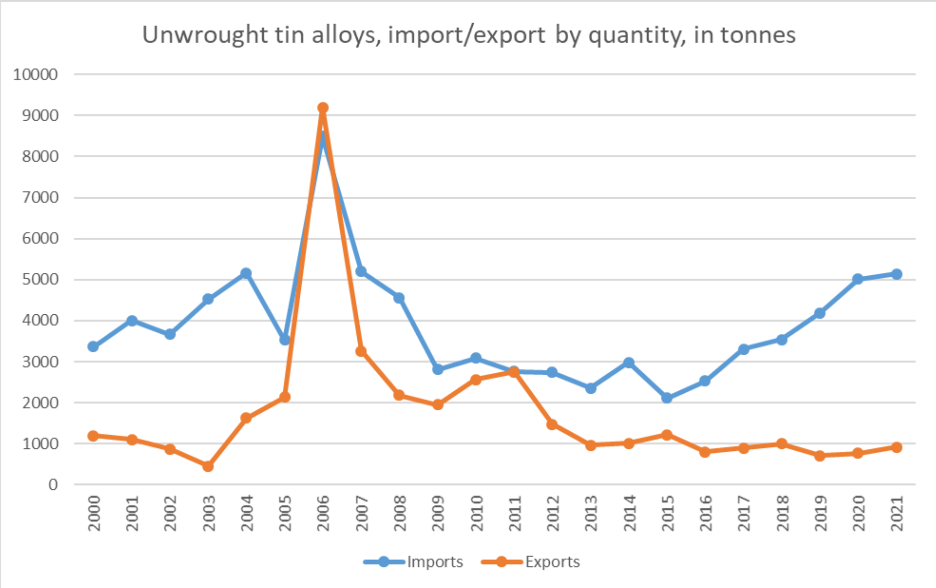

Figure 8. EU imports of unwrought tin alloys, by country, between 2000-2021 (based on Eurostat, 2021).

Figure 11 to Figure 14 present the average EU imports of tin at processing stage, by country, for the period 2000-2021. For unwrought tin (not alloyed), EU's import structure was relatively stable over the period, besides the fact that Chinas contribution to EU-imports in this category diminished in the beginning of the 2000s. The main suppliers were (import shares in parentheses): Indonesia (32%), Peru (16%), China (12%), United Kingdom (8%) and Malaysia (8%). A loss of significance of China is also visible in EUs import structure of unwrought tin alloys; in this category, EUs import structure is relatively diversified over the period as whole (import shares in parentheses): United States (21%), United Arab Emirates (14%), China (11%), United Kingdom (10%), Indonesia (9%). In the category 'slag, ash, residues containing mainly tin', United States is the largest supplier to the EU by far (import share 51%). EU supply of tin chlorides is dominated by United Kingdom and China, which cover 45% and 35% of EU imports in this category.

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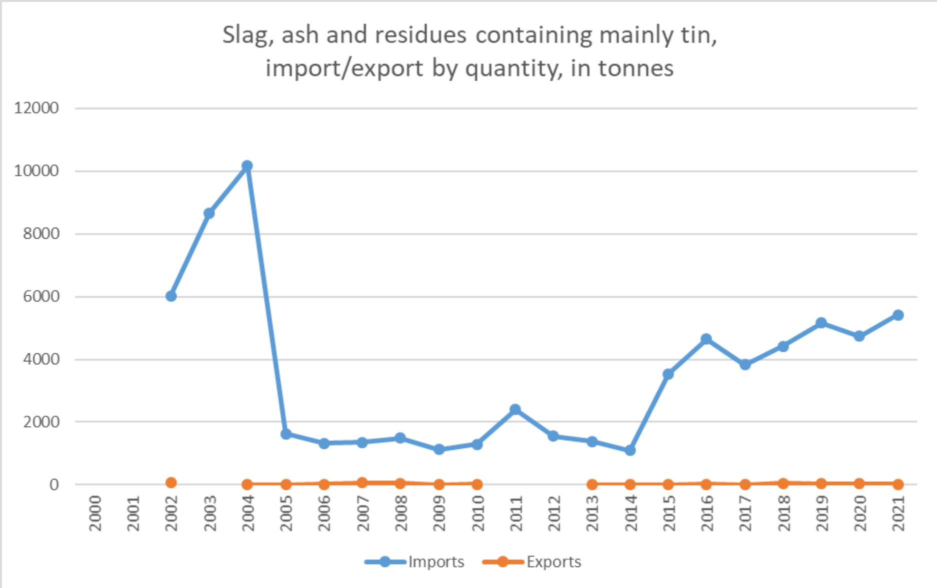

Figure 9. EU imports in the category 'slag / ash / residues containing mainly tin', by country, between 2000-2021 (based on Eurostat, 2021).

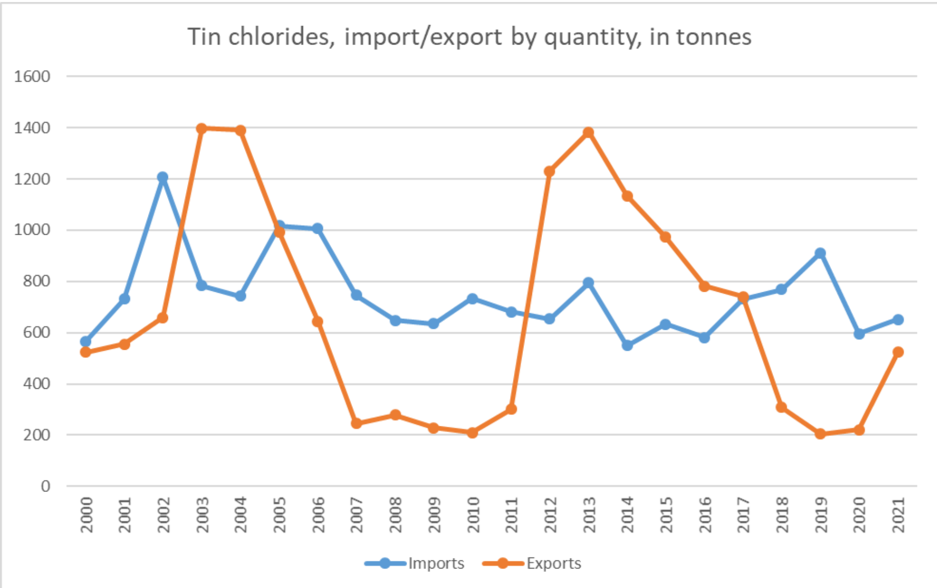

Figure 10. EU trade flows of tin chlorides, from 2000 to 2021 (based on Eurostat, 2021).

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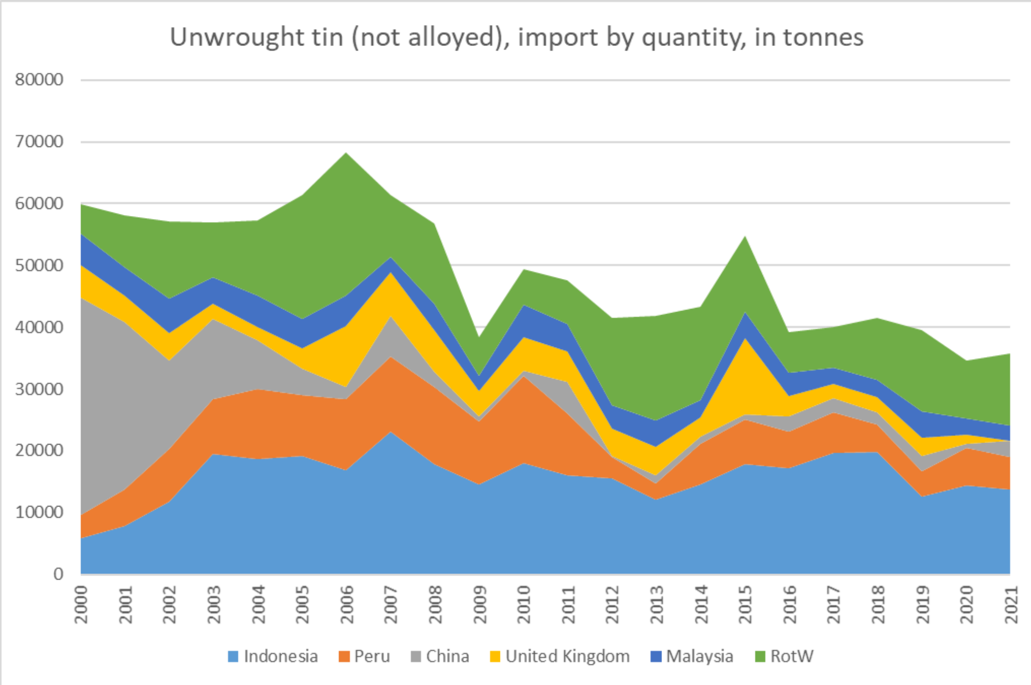

Figure 11. EU imports of unwrought tin (not alloyed), by country, between 2000-2021 (based on Eurostat, 2021).

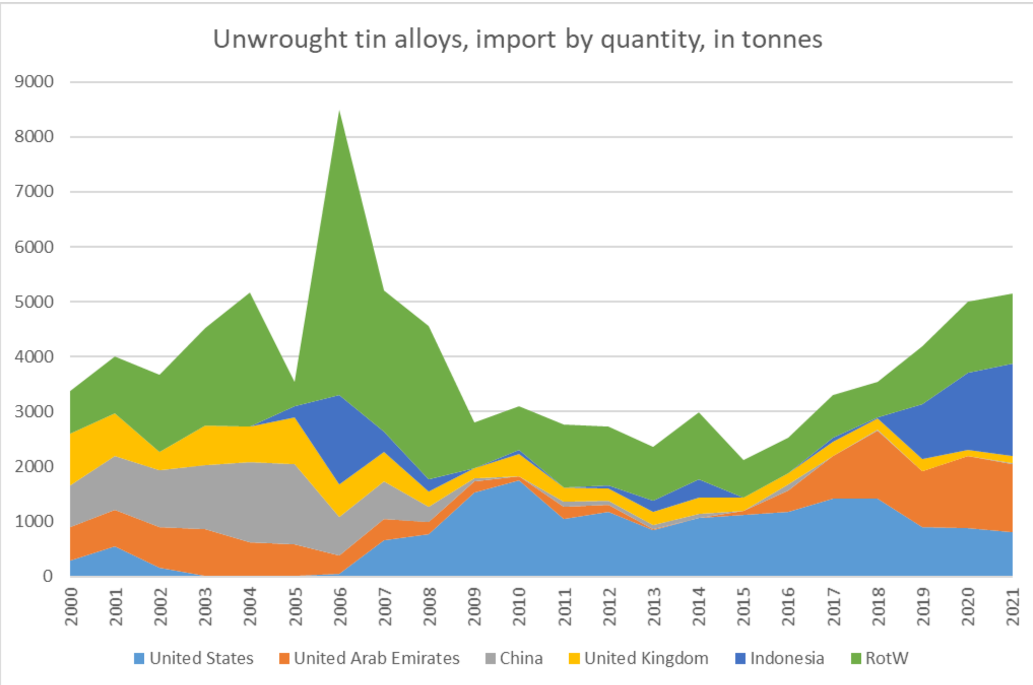

Figure 12. EU imports of unwrought tin alloys, by country, between 2000-2021 (based on Eurostat, 2021).

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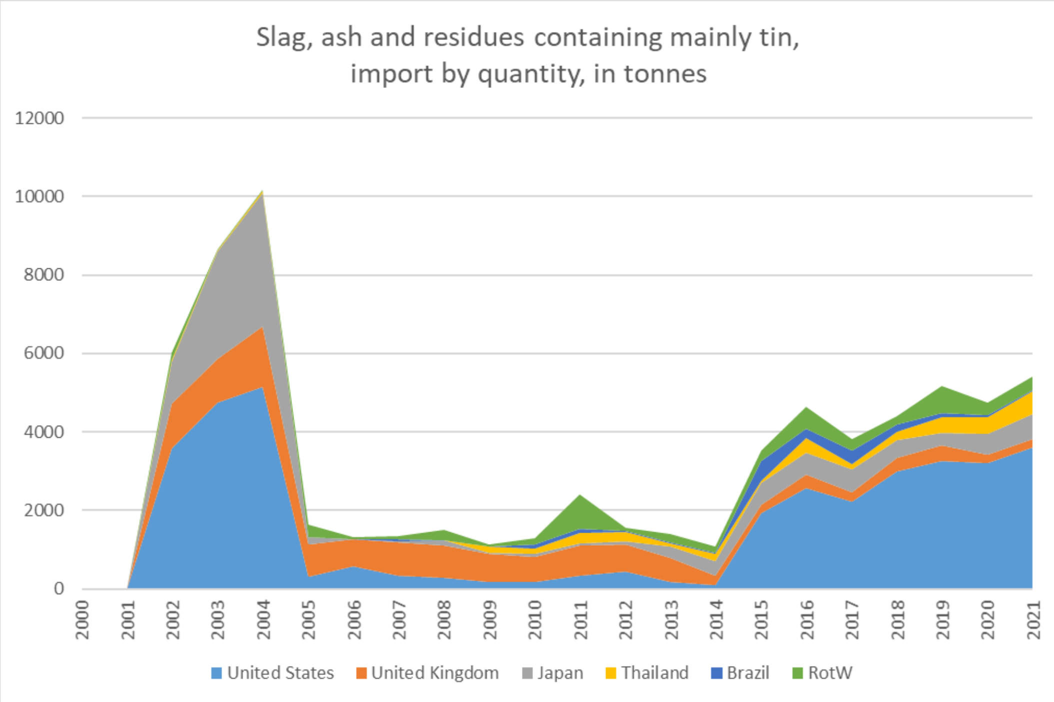

Figure 13. EU imports in the category 'slag, ash, residues containing mainly tin', by country, between 2000-2021 (based on Eurostat, 2021).

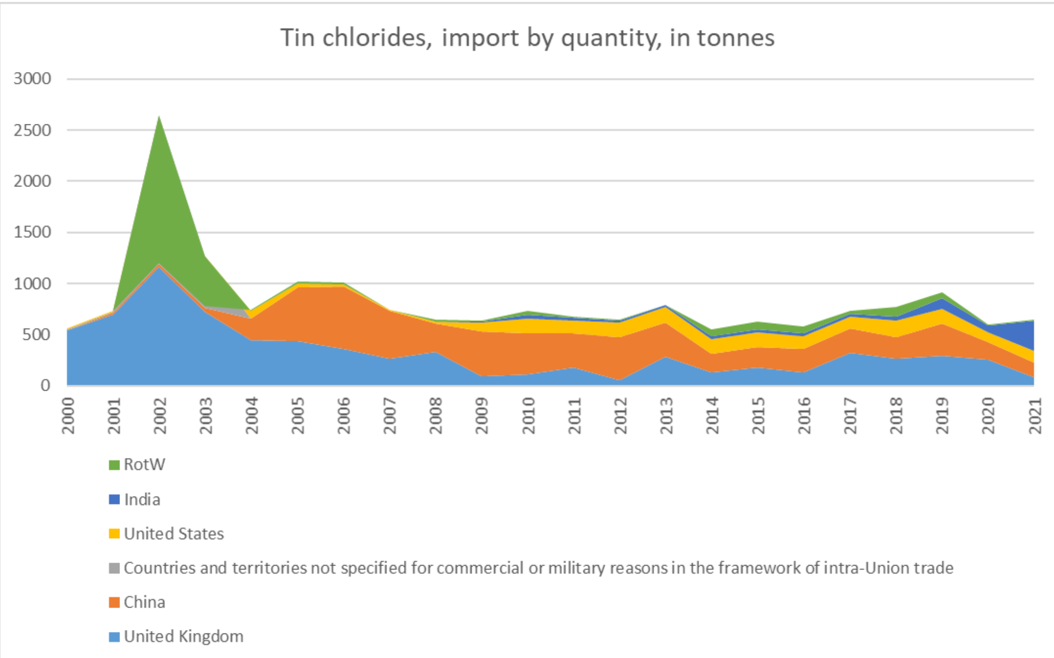

Figure 14. EU imports of tin chlorides, by country, between 2000-2021 (based on Eurostat, 2021).

PRICE AND PRICE VOLATILITY

Over the last years, different drivers of tin-price dynamics have been reported. These range from relatively small market size and concentration of supply on few countries with significant supply risk/instability, over

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weak market fundamentals (low production, low inventories, rising costs of production) and impacts of Covid-19 (e.g., supply disruptions in Indonesia and Malaysia) to growing demand (Burton, 2021; DERA, 2020b, 2021a; Edison, 2021; Home, 2021; International Tin Association, 2021a; Metalbulletin, 2019; MINING.com, 2021; Sainsbury, 2019; Singh, 2021; USGS, 2021a). The use of tin in electronics and lead-free solders has been the main component and driver of tin demand in the past decades (International Tin Association, 2021b, 2021c). The tin demand from China is an important price driver currently (DERA, 2021a). Political and regulatory aspects, e.g., the developments in the trade conflict between China and USA and the (relaxing of the) tin-export ban in Indonesia, had significant effects on the tin price – directly and via expectations forming (DERA, 2020a, 2020b).

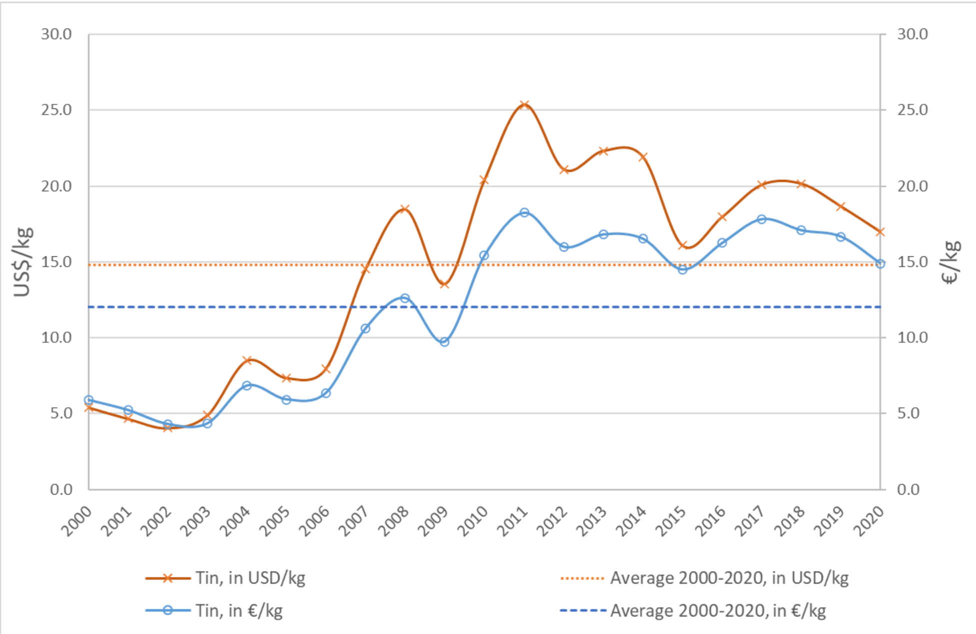

Figure 15. Annual average price of tin (LME, cash) between 2000 and 2020, in US$/kg and €/kg (based on USGS, 2021b)[3]. Dash lines indicate average prices for 2000-2020.

OUTLOOK FOR SUPPLY AND DEMAND

For the next five years, tin-demand growth is expected to be around 4%; and demand prospects in the medium-to-long-run are assessed as 'very positive' (DERA, 2021; European Commission, 2020; International Tin Association, 2021c). Future tin-demand growth is expected to be fuelled from the application areas 'computing and robotics', 'energy generation', 'autonomous and electric vehicles', 'energy storage' and 'energy infrastructure' (International Tin Association, 2021b). Demand growth in solder applications could be driven by 5G-related developments; the Covid-19 pandemic could intensify these developments (Edison, 2021; International Tin Association, 2020). Asia and Oceania are expected to be an important driver of tin-market

[3] 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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growth over the next 5 years (Mordor Intelligence, 2021). In the medium-to-long run, the negative effects of electronics miniaturization are expected to lose on (relative) importance for tin-demand development (International Tin Association, 2021c).

The demand-side dynamics of the tin market are expected to pose challenges on tin supply. Although new tin supply (from new projects) is expected to enter the market by 2025, supply is restricted by low prices (and duration of project implementation); thus, it is expected that supply will not be able to follow demand after 2023 or 2025, resulting in supply deficits (DERA, 2021; Home, 2021; International Tin Association, 2021c; MINING.com, 2021). Tin-supply growth could be relatively low (0.3% annually) after 2025 (MINING.com, 2021).

DEMAND

GLOBAL AND EU DEMAND AND CONSUMPTION

The world refined tin consumption was about 340,000 tonnes in 2020 (International Tin Association, 2021b). The EU annual apparent consumption of refined tin was 48,900 tonnes on average over the period 2016-2020.

Tin processing stage EU consumption is presented by HS code CN 80011000 Unwrought tin: tin, not alloyed (>99% tin). Trade data are extracted from Eurostat Comext (2021) and production data from Eurostat Prodcom (2021) using PRCCODE 24431330 Unwrought non-alloy tin (excluding tin powders and flakes).

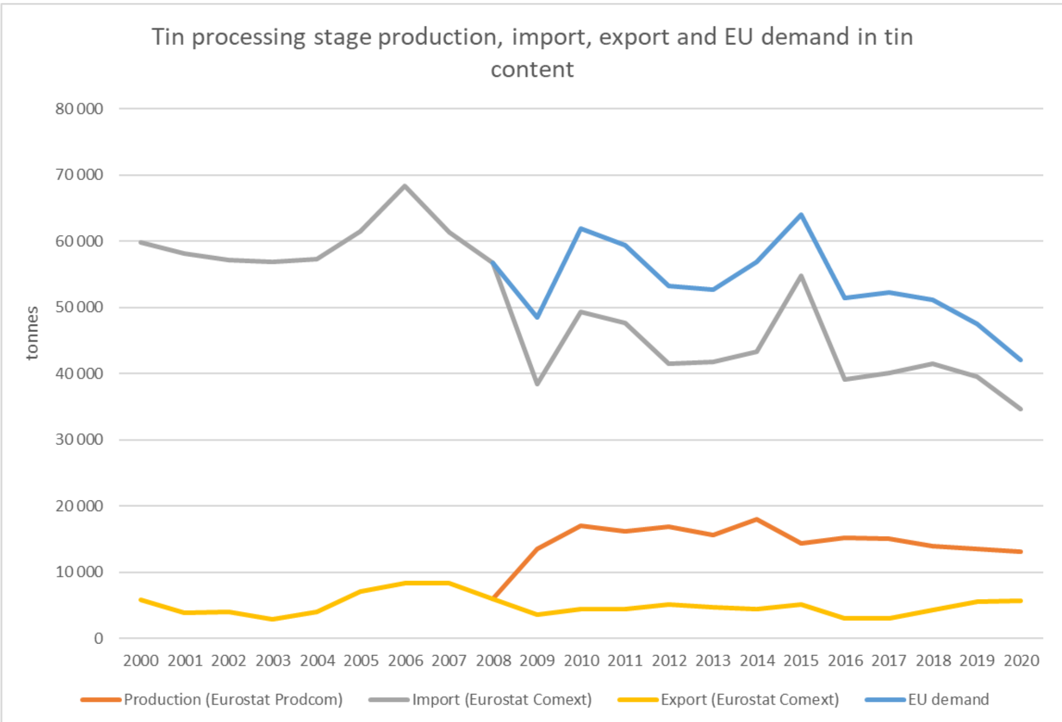

Figure 16. Tin (80011000 Unwrought tin: tin, not alloyed (>99% tin) processing stage apparent EU consumption. Production data from Eurostat Prodcom (2021) are available for 2008-2020. Consumption is calculated in tin content (EU production+import-export).

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Based on Eurostat Comext (2021) and Eurostat Prodcom (2021) average import reliance of tin at processing stage is 72.7 % for 2008-2020.

EU USES AND END-USES

The main application of tin are solders and tinplating of steel. Tin chemicals are used in various applications. Further tin consumption can be attributed to production of lead acid batteries and copper alloys like bronze.

The right side of **Erreur ! Source du renvoi introuvable.** presents the shares of the main uses of tin on global scale in 2020 (International Tin Association 2021). The comparison with data on end uses in 2010 shows, that the shares of solders and tinplating did slightly decrease within the past decade, while the shares of chemicals, lead acid batteries and tin consumption for copper alloys increased.

Industry sectors relevant for tin demand analysis are described in **Erreur ! Source du renvoi introuvable.** using the NACE sector codes (Eurostat, 2021). The development of gross value added by these sectors since 2000 is shown in **Erreur ! Source du renvoi introuvable.**.

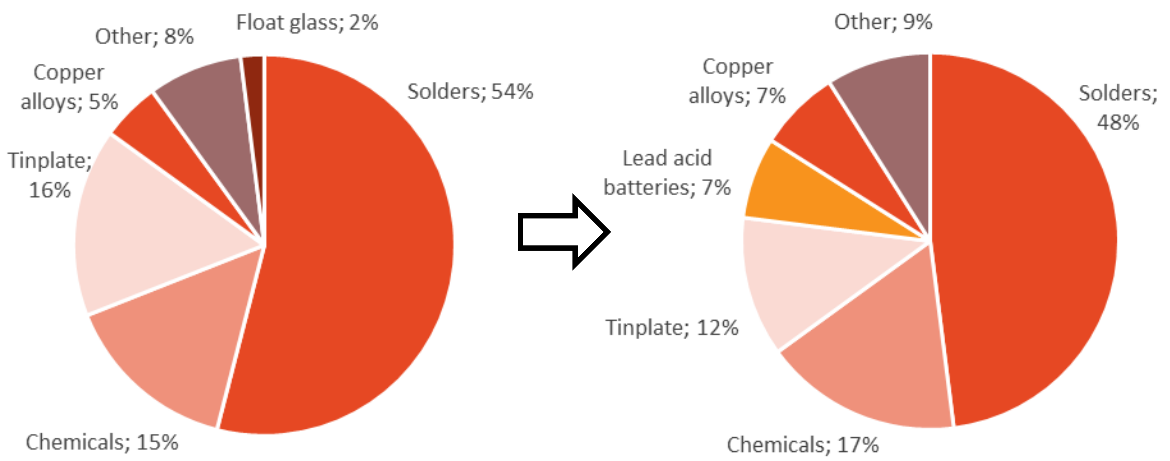

Figure 17. Global tin end uses in 2010 (left graph, European Commission 2014) and 2020 (right graph, International Tin Association (2021).

Table 5. Tin applications, 2-digit and associated 4-digit NACE sectors, and value added per sector for 2019 (*for 2014) (Eurostat, 2021).

Applications	2-digit NACE sector	Value added of NACE 2 sector (M€)	4-digit CPA
Solders	C26 - Manufacture of computer, electronic and optical products	84,074*	C26.10- Manufacture of electronic components
Chemicals	C20 - Manufacture of chemicals and chemical products	117,150*	C20.16- Manufacture of plastics in primary forms, main use is PVC in this category, but also used for glass coatings, pigments, etc.
Tinplate	C25 - Manufacture of fabricated metal products, except machinery and equipment	186,073	C25.92- Manufacture of light metal packaging

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Lead acid batteries	C27 - Manufacture of electrical equipment	97,292	C27.20- Manufacture of batteries and accumulators
Copper alloys	C24 - Manufacture of basic metals	63,700	C24.44- Semi-finished products of copper or copper alloys
Others	C25 - Manufacture of fabricated metal products, except machinery and equipment	186,073	C25.7 Others (including tin and bronze powders, wine capsules, pewter, tin coatings and float glass). These end-uses are mostly found in C25 - Manufacture of fabricated metal products, except machinery and equipment

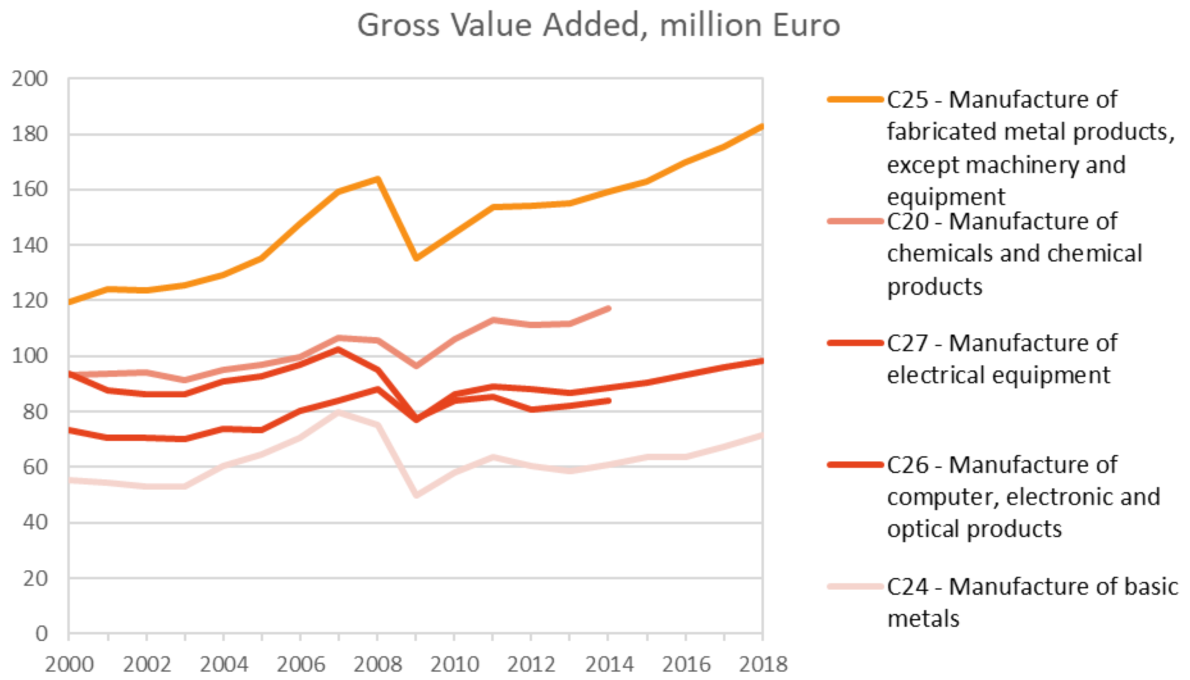

Figure 18. Value added per 2-digit NACE sector over time (Eurostat, 2021)

APPLICATIONS OF TIN IN THE EU:

SOLDERS

Almost half of the tin is used for solders on global scale. Solders are an essential part of modern life, joining together all of the electronic and electrical systems that society relies on today and in the future.

Around 85 % of the solder is for electronics, as solders can be found in electric circuits of the majority of electronic appliances. The remainder is consumed by industrial applications such as joining copper pipes, electrical joining, DIY/crafts and solar ribbon for PV.

Tin alloys have a low melting range and can be used to join other metals, notable copper, at lower temperature than brazing or welding.

Under regulatory pressure, mainly from Europe, 70 % of solders are now lead-free tin alloys with 95 % tin content. A residual amount of tin-lead solders with 60 % tin are still used in mainly industrial markets, but

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expected to shift to lead-free alloys over the 2020s. Lead-free alloys contain small amounts of other metals, commonly copper, silver, bismuth or other elements (International Tin Association, 2019).

CHEMICALS

Tin chemicals are used as catalysts for polyurethane and silicone production. There are numerous other uses including electroplating, ceramics, glass melting and coating, relay contacts, pharmaceuticals, fire retardants, catalysts etc., but also polyurethane foam used increasingly for building insulation (International Tin Association, 2019).

TINPLATE

Tinplate for packaging, especially food cans, remains an important sector of consumption. It is produced by coating steel with a thin layer of tin. Because of its non-toxicity and resistance to corrosion, tinplated steel is commonly used as containers and closures for packaging food, drink, dry products, oils, paints and chemicals. Compared to alternatives, tinplate packaging is highly recyclable, with high rates of collection. It is physically robust and able to provide long shelf-life, low-cost nutritious food, with little waste (International Tin Association, 2019).

LEAD ACID BATTERIES

Tin is added to lead-calcium lead-acid battery grids at up to 1.6 % to improve casting and cycling performance in high end maintenance-free products. These are notably used in automotive markets, especially start-stop hybrids. Up to 2 % tin may be contained in lead tin alloy posts and straps connecting the grids. These can replace lead-antimony alloys containing 0.2 % tin that are still widely used in flooded products. Stationary batteries for mobile communications, renewable energy and utility grid balancing typically use flooded products. Tin is also important in other mobile applications such as electric forklifts or e-bikes (International Tin Association, 2019).

COPPER ALLOYS

Copper alloys such as bronze and brass are used in many industrial applications like bearings, springs and electrical connectors for example, as well as sculpture, coins, bells and musical instruments. Bronze is an alloy of copper and tin and some brasses are an alloy of copper, zinc and tin. For both brass and bronze, varying the amount of copper and other elements in the composition will change the properties of the alloy. Tinned copper and bronze wire products are increasingly used in automotive and electrical components (International Tin Association, 2019).

OTHER

Beside the described applications, tin has a wide variety of further uses. Tin is used in the Pilkington process for making flat window glass, whereby molten glass is floated on top of molten tin at 1,100 °C. Other

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applications include pewter items, tin powders, wine and spirit capsules, and electroplating anodes (International Tin Association, 2019).

FURTHER TIN USES OUTSIDE THE EU

CHEMICALS

Globally, the largest use of tin chemicals is for polymer additives, especially PVC stabilizers that prevent PVC degrading to give a brittle plastic in the presence of light, heat or atmospheric oxygen. Many of these are organotin and have been largely phased out in Europe under regulatory pressure, but are still essential in some applications and in other regions (International Tin Association, 2019).

SUBSTITUTION

Potential substitutes exist most of the tin uses, as described for the following applications.

SOLDERS

Solders in some high-end uses may be substituted by alternate technologies such as conductive adhesives or embedded components, although these can be more expensive and less reliable, and their use is currently marginal. Conductive adhesives are used in some displays, RFID tags and LCD connections, typically with temperature-sensitive components. Embedded component technologies, using components built inside the circuit board, can be used in high-volume high-end uses such as mobile phones where capital costs can be justified. Other technologies exist including pressfit, printed electronics and copper-to-copper, but these are not likely to have a significant impact on mainstream electronics production. Leaded solders have been largely substituted by lead-free products (silver-copper and other alloys with higher tin content) due to health and safety concerns over the toxicity of lead. There has also been extensive economisation in solder use for electronics assembly, including conversion to miniaturised products, which has flattened solder use in the 2010s. More recently new low-temperature 58% bismuth-tin solders have been introduced but are limited by bismuth supply. Industrial solder use in copper pipes is impacted by the increasing use of plastic piping in construction markets (International Tin Association, 2019).

CHEMICALS

Alternatives to some tin chemicals have been developed. Calcium-zinc products can be used as PVC stabilizers and are cheaper than tin stabilizers. Iron sulphate is an alternative to tin sulphate or chloride in cement additives applications. However, inferior properties of these alternatives have prevented them from penetrating deep into the market (Coherent Market Insight 2019, International Tin Association 2019, USGS 2019).

TINPLATE

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In tinplate, tin can be replaced by other packaging materials including glass, plastic, aluminium, pouches, tin-free steel or cartons depending on price, quality, or manufacturer preference. Aluminium is largely replacing tinplate in beverage markets and competes in aerosol products. Food cans is typically a robust market for tinplate, with strong sustainability credentials, although this has recently been challenged by producers of polymer-laminated steel (International Tin Association, 2019).

LEAD ACID BATTERIES

The shift from lead-acid batteries to lithium-ion batteries in several sectors does impact tin usage, especially in the important China e-bikes market. The share of Lithium-ion batteries is estimated to be 40-80 % (International Tin Association, 2019).

COPPER ALLOYS

Substitutes of tin-containing copper alloys are aluminium alloys, alternative copper-base alloys like zinc-copper alloys, and plastics (USGS, 2019).

Table 6. Uses of tin and possible substitutes

Application	Substitutes	SubShare*	Cost	Performance
Solders	Epoxy Resin	20%	Similar or lower costs	Reduced
Solders	Lead-tin	5%	Similar or lower costs	Reduced
Solders	no substitute	75%	Similar or lower costs	Similar
Chemicals	Barium-Zinc	15%	Similar or lower costs	Reduced
Chemicals	Calcium-Zinc	75%	Similar or lower costs	Reduced
Chemicals	no substitute	10%	Similar or lower costs	Similar
Tinplate	Aluminium	30%	Similar or lower costs	Similar
Tinplate	Glass	30%	Similar or lower costs	Similar
Tinplate	Plastics	30%	Similar or lower costs	Similar
Tinplate	no substitute	10%	Similar or lower costs	Similar
Lead acid batteries	Lithium-ion battery	60%	Very high costs (more than 2 times)	Similar
Lead acid batteries	no substitute	40%	Similar or lower costs	Similar
Copper alloys	Aluminium	25%	Similar or lower costs	Similar
Copper alloys	Zinc	25%	Similar or lower costs	Similar
Copper alloys	no substitute	50%	Similar or lower costs	Similar

*sub-share validated by SCRREEN experts, 2022

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SUPPLY

EU SUPPLY CHAIN

Primary tin production in EU is negligible. There are reports of a small production until 2016 which was taking place in Portugal (59 tonnes per year) and Spain (15 tonnes per year) (BGS, 2018; Eurostat, 2019; International Tin Association 2019b). EU imports and production of refined tin (using non-primary resources) in the period 2016-2020 range between 34.6-41.5 thousand tonnes and about 13-14 thousand tonnes, respectively (Eurostat, 2021). The notable production of refined tin renders EU a relevant player in the global tin supply chain, in contrast to the mine stage (BGS, 2018; Eurostat, 2019).

In the past, Europe was an important supplier of tin ores and concentrates. Western and central-eastern Europe host an outstanding tin-tungsten mineral belt. Deposits of this belt were intensely used in the past until most of these tin mines were closed, mainly before the 1980s when tin prices went very low. To exploit the full tin mining potential in Europe, the project iTARG3T172 was funded by the EIT on Raw Materials173, running from 2019 to 2020. It is deployed in Spain and looks at the whole value chain of Sn-W-Ta in Europe, addressing the various problems arising during the early and advanced stages of W-Sn-(Ta-Li) exploration, effective ore targeting, and ore processing. iTARG3T estimates that based on the methods proposed, around ten new mines can be developed and opened, reaching the European self-production on a mid-term time scale.

SUPPLY FROM PRIMARY MATERIALS

GEOLOGY, RESOURCES AND RESERVES OF TIN

GEOLOGICAL OCCURRENCE

The estimated abundance of tin in the upper continental crust is 2.1 ppm (Rudnick, 2003), which is low compared to other industrial metals. Tin is invariably found in association with granitic rocks, either in situ or as alluvial or eluvial deposits resulting from the weathering of the original tin-bearing rock. Cassiterite (SnO2) is by far the most important tin ore. Small quantities of tin have also been recovered from complex sulphide minerals such as stannite (Cu_2FeSnS_4). Primary deposits can occur within the granite or within pegmatities or aplites associated with the granite. Deposits occur also in rocks surrounding the margins of the intrusions as veins, disseminations, skarns or carbonate replacements generated by tin bearing fluids derived from the granite magmas. Secondary deposits also known as placers result from the weathering and erosion of primary tin deposits. Cassiterite is chemically resistant, heavy and readily forms residual concentrations. Deposits in oceanic submerged river channels are important sources of tin. More than half of the world's tin production come from this type of deposits which are mostly located in Malaysia, Indonesia and Thailand (Geoscience Australia, 2016; Thompson, 2001). Global resources and reserves174: Global reserves of tin at the end of 2018 were estimated at around 4,700,000 tonnes (USGS, 2019), with China accounting for a quarter of the global total, followed by Indonesia and Brazil (**Erreur ! Source du renvoi introuvable.**).

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Table 7. Global reserves of Tin in 2021 (USGS, since 2000)

Country	Estimated Tin Reserves (tonnes)	Country	Estimated Tin Reserves (tonnes)
China	1,100,000	Congo D.R.	130,000
Indonesia	800,000	Burma	700,000
Brazil	420,000	Peru	150,000
Bolivia	400,000	Vietnam	11,000
Australia	560,000	Nigeria	n/a
Russia	560,000	Rwanda	n/a
Malaysia	81,000	Other countries	310,000
Thailand	170,000	Russia	200,000
World Total (rounded)	**4,900,000**		

According to the International Tin Association (2016), the world's reported tin resources at the end of 2015 totalled some 11,700,000 tonnes, including 2,200,000 tonnes of reserves i.e. about half of the USGS estimate.

EU RESOURCES AND RESERVES

Resource data for some countries in Europe are available at the European Minerals Yearbook (Minerals4EU 2019) but cannot be summed as they are partial and they do not use the same reporting code. Tin resources have identified in Czech Republic, Finland, France, Germany, Spain and Sweden (see**Erreur ! Source du renvoi introuvable.**).

Table 8. Resource data for the EU compiled in the European Minerals Yearbook of the Minerals4EU website (Minerals4EU, 2019).

Country	Reporting code	Quantity	Unit	Grade	Code Resource Type
Czech Republic	National reporting code	164,299	tonnes	0.22%	*Potentially economic*
Finland	None	0.11	Mt	0.32%	Historic Resource Estimate
France	None	47,341	tonnes	Metal content	Historic Resource Estimates
Portugal	None	101.137	Mt	0.11%	Historic Resource Estimates
Sweden	None	0.6	Mt	0.07 %	Historic Resource Estimates

In Spain, exploration for tin is active since 2010. The Oropesa Tin Project in Andalucia has a JORC measured and indicated resource of 9,340,000 tonnes (0.55% tin), and JORC inferred resource of 3,200,000 tonnes (0.52% tin, at 0.15% tin cut-off); for a total contained JORC resource of 67,520 tonnes of tin (Elementos, 2019). International Tin Association indicated higher resources for the Czech Republic (278,000 tonnes, 0.04% tin).

The Cinovec lithium-tin deposit located in Prague, Czech Republic is considered the biggest lithium deposit in Europe and one of the biggest tin resources in the world. Pre-feasibility study for the Cinovec lithium-tin project was completed in April 2017. The deposit is associated with the Cinovec Zinnwald granite cupola and comprises irregular metasomatic greisen, which hosts quartz, zinnwaldite, fluorite, and adularia-K feldspar. The minerals contained in the deposit are cassiterite, scheelite, zinnwaldite, and wolframite. The main target-product of the mining project is lithium carbonate contained in the lithium bearing micas zinnwaldite. The

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mining project is expected to have a 21 years life time. About 1.7 mt of ores will be extracted annually. The deposit has 0.09 wt.% average Sn concentration and 262,600 tonnes total Sn content. A Tin-rich concentrate will be produced as by product. A complex beneficiation system including flotation, electrostatic precipitation and magnetic separation will be used for the processing of the ore. After the Li-bearing mica separation, electrostatic precipitation will be used to separate wolframite and cassiterite from the scheelite. Dry magnetics will separate the wolframite from the cassiterite to give the final saleable concentrates (European Metals, 2017).

Various small-medium Sn resources have been reported in Spain, some of them were being exploited in the past. In Presqueiras (Ourense) site 0.2Mt of Ta-Sn resources/deposits were identified with a Sn concentration reaching 600 ppm, while 4 Mt of inferred resources are expected. Tailings in Penouta (Ourense), with a total amount of 8.8 Mt, contain Sn at concentrations around 450 ppm. Tin concentrations ranging between 0.2 and 0.8 wt.% have been measured in Oropesa and La Graña deposits near Seville. Santa Maria project located in Cáceres, which was mined during the first half of the 1980s, contains tin at concentrations to 560 ppm (Sáenz de Sicilia, 2013).

Sn concentrations to 0.08 wt.% have been reported in Cabeço do Pião tailings (total volume: 730,000 m^3) originated by the processing of W-Sn ore in the industrial complex of Panasqueira mine (Dinis et al. 2020). The metallurgical processing of Cabeço do Pião tailings aiming to the recovery of Zn and As has been studied, however there no data concerning the possibility of Sn recovery. Several tin resources have been described in Centro Region-Portugal where the Panasqueira district is also located. Metallic values exist into granitic rocks and metasedimentary rocks. Gonçalo-Vela-Benespera-Belmonte-Sabugal and Sátão-Mangualde-Viseu are the most promising areas for the identification of notable tin reserves (Almeida et al. 2018).

WORLD AND EU MINE PRODUCTION

During the period 2016-2020, 305,000 tonnes of tin were mined on average annually, in the world. China was the main producer and accounted for 27% of the global mine production, followed by Indonesia (23%) and Myanmar (17%). Experts noted that there is tin smuggling taking place between Myanmar and China, which hampers the quality of the related trade data. Nearly all Myanmar output, which soared from 5,000 tonnes in 2012 to a maximum of 67,300 tonnes in 2017, is further processed in China. Indonesian production, in contrast, has plummeted by a third since the government banned exports of unprocessed tin concentrates in 2014.

With an annual average production of 153 tonnes, the EU accounted for less than 1% of global tin ore production but has doubled its production compared to 2012-2016. Average annual tin extraction was in Portugal (92 tonnes per year, 60% of EU production) and a smaller output in Spain (62 tonnes per year, 40%), from the W-Sn San Finx mine in Galicia, and the Lousame, La Coruña, mine. Experts considered the production figures as uncertain.

Two mines are expected to start soon tin extraction in Europe. First, the Cinovec mine extending across the Czech-German border hosts one of the worldwide largest undeveloped tin resources. Second, the South Crofty mine in Cornwall, UK, is located in an ancient tin mining region and awaits permission for the dewatering before it can be reopened.

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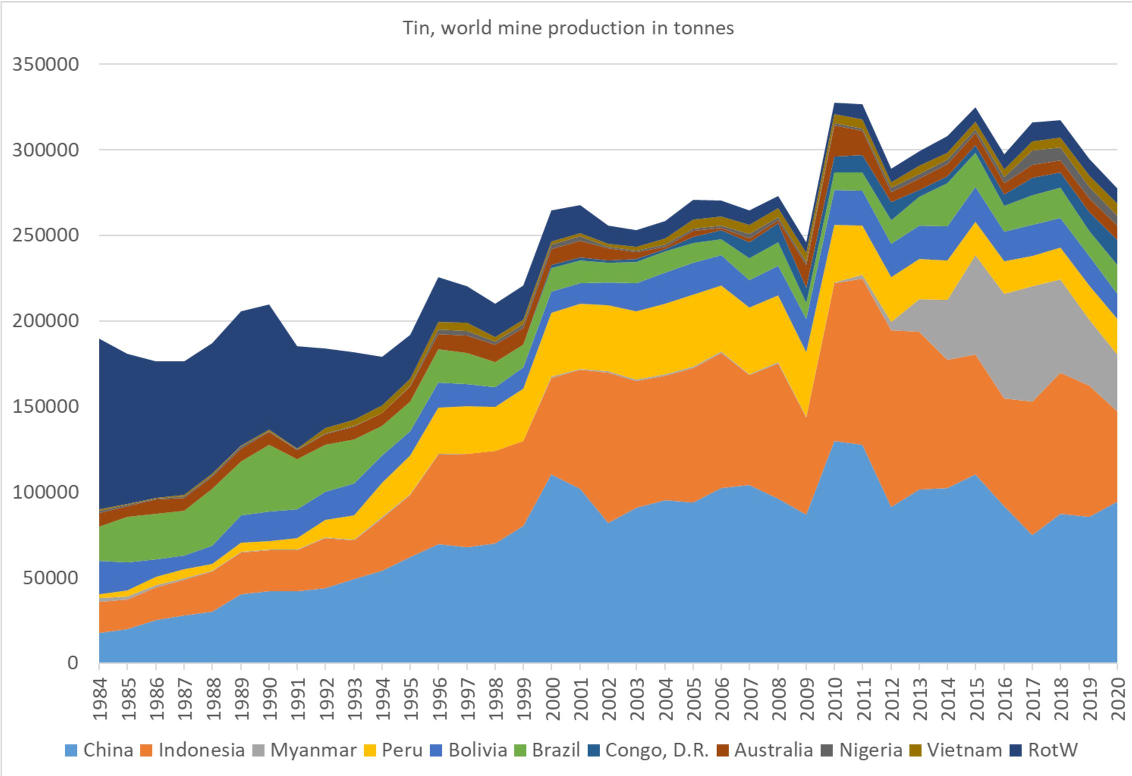

Figure 19. Tin mine production by country since 1984 (WMD, since 1984).

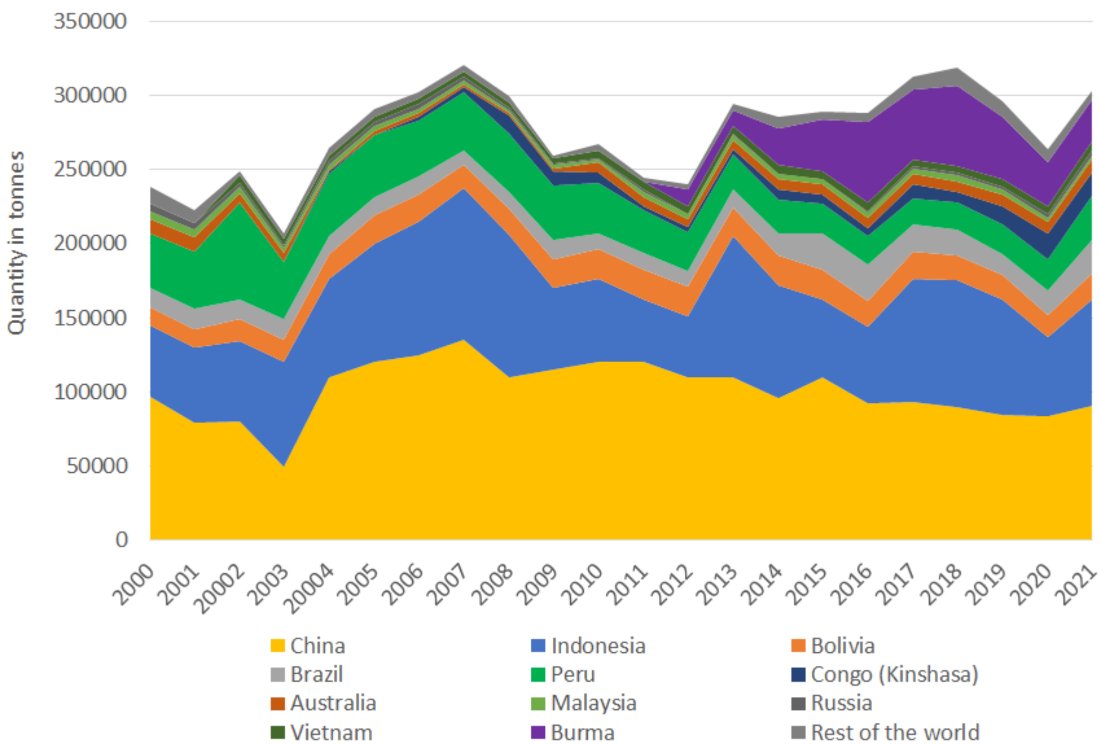

Figure 20. Tin mine production by country since 2000 (USGS, since 2000).

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The metallic world tin production by country since 1984 according to WMD and since 2000 according to USGS can be seen in **Erreur ! Source du renvoi introuvable.** and **Erreur ! Source du renvoi introuvable.** , respectively (WMD, since 1984; USGS, since 2000). China, Indonesia, Peru and Bolivia remain the major producers the last two decades.

OUTLOOK FOR SUPPLY

Covid-19 pandemic measures and border restrictions had an important impact on the supply of tin as refined tin production in Burma, Indonesia, Malaysia, and Rwanda was affected. Smelters were temporarily closed for repair and annual maintenance in China and Malaysia. The supply was increased in 2021 and this trend is expected to be continued due to the demand increase for alloys, chemicals, solder and tinplate (USGS, 2022).

SUPPLY FROM SECONDARY MATERIALS/RECYCLING

POST-CONSUMER RECYCLING (OLD SCRAP)

End-of-life recycling rate depends on the applications, with tinplate in food and beverages cans having the highest (around 65%), followed by solders in electronics (40%). The End-of-Life Recycling Input Rate (EoL-RIR) of tin, including refined and unrefined forms, was calculated as 30.7% in 2016, down from 31.4% in 2015, with re-refined tin contributing approximately 16% (ITRI, 2016; ITRI, 2017). The proven global tin reserves were reported to be approximately 4.7 million metric tons in 2016, and among these resources, only approximately 2.2 Mtonnes can be recovered economically. The last years, significant efforts have been done on the optimization of Sn recovery by secondary resources. The most notable Sn secondary resources are:

TIN-BEARING ALLOYS

Global tinned steel sheet consumption is more than 18 Mtonnes, in which the average tin content is approximately 0.5–2 wt.%. Electro-alkali dissolution and alkali detinning are used for recovering tin from these wastes. Before electro-alkali dissolution, the recyclable tin-plated steel sheet initially is cleaned and then used as the anode, whereas sheet iron is used as the cathode. Both sheets are placed in a Na_2SnO_3 solution, while a direct current is passed through the electrolyte at room temperature (Su et al. 2017). The technique is industrially applied.

TIN ANODE SLIME

Tin anode slime is a by-product of the electrolytic refining process of crude tin. The recovery of Sb, Bi, Cu, Ag, and Au contained as impurities is the recycling target, while Sn is obtained as by-product. The process comprises an oxidation roasting step in air at 600–900 °C to convert metallic tin to acid-insoluble SnO_2, and then Pb, Ag, and Cu can be leached and recovered from the oxidized products. Tin oxide is finally enriched in the leaching residue and collected for the smelting process (Su et al. 2017). The technique is industrially applied.

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ELECTRIC-WASTES

In this case, precious metals such as Au, Ag, Pt, etc. are the main recycling targets. Sn is mainly contained in electric contacts. The waste after various pre-processing steps, such as pyrolysis, are leached using various acids and Sn^{4+} exist in the leaching solution, usually with Cu^{2+} and Pb^{2+}. Both Cu^{2+} and Pb^{2+} are removed as sediments by adding metallic tin and Na_2S to the solution. The tin-bearing solution is prepared for use as an electrolyte (a Na_2SnO_3 solution), or SnO_2 is precipitated out for the smelting process (Su et al. 2017). The technique is industrially applied. A high-temperature (150 °C) alkaline pressure oxidation leaching–purification–electrowinning process is proposed for the optimization of Sn recovery by electronic wastes (printed circuit boards) has been proposed. The leaching efficiency of tin is increased to over 98% (Yan et al. 2017).

COPPER DROSS

Tin is contained at high amounts SnO_2 >60 wt.% in copper dross – a by-product of the copper refining industry. Metallic Sn has been successfully obtained through leaching with HCl at 60-80 °C followed by electrowinning. Alternatively, Sn oxide was produced through leaching at same conditions followed by precipitation (Jabit et al. 2019).

TIN-BEARING TAILINGS

A large number of tin-bearing tailings with 0.1– 1.0 wt.% tin content are discharged as solid wastes. Large amounts of tin secondary reserves in old tailing ponds have been reported in: Gejiu of China (reserve of 250 Mtonnes), Chenzhou of China (50 Mtonnes), Renison of Australia (19.2 Mtonnes), and Catavi of Bolivia (20 Mtonnes) with an average tin content is in the range of 0.10 wt.% and 0.50 wt.%. Gravity concentration is the most successful method to recover tin minerals as the specific gravity of cassiterite is significantly higher than those of other gangue minerals. Various types of gravity separators have been employed, such as a jig, heavy media cyclone, spiral, shaking table, and cross-belt separator. However, tin recovery ratio decreases with the decrease of cassiterite particle size (<45 μm). The multigravity separator and centrifugal separator have been used to recover fine cassiterite in the particle size range of 20– 45 μm. Furthermore, collector reagents with a better selectivity and applicability have been developed, and the recovery ratio of ultrafine particle cassiterite in the particle size range of 20– 45 μm increased drastically when hydroxamic acids are used. An alternative beneficiation process that has been tested involves the roasting of the tailings at 625 °C, followed by magnetic separation. The methodology is based on the cassiterite enrichment through the hematite content conversion to magnetite which subsequently is removed (Su et al. 2017).

TIN SLAGS

Sn recovery by tin slags from Penouta tin mine – Spain was examined by a techno-economical point of view. Sn is extracted through a complex pyro-hydrometallurgical techniques aiming mainly to the recovery of niobium and tantalum. Tin is obtained in the first carbothermal reduction step. The results showed that the methodology is economically feasible (Magdalena et al. 2021).

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PROCESSING OF TIN

The recovery of an impure cassiterite concentrate leads to further concentration by gravity methods which involve passing the concentrate in a stream of water over equipment such as jigs, spirals, or shaking tables. This separates the heavy cassiterite from the lighter minerals such as quartz. Magnetic or electrostatic separation removes the heavy mineral impurities. It results in the production of a cassiterite concentrate containing about 70% tin (Geoscience Australia, 2016). Although cassiterite is the main mineral, tin is also mined through other minerals.

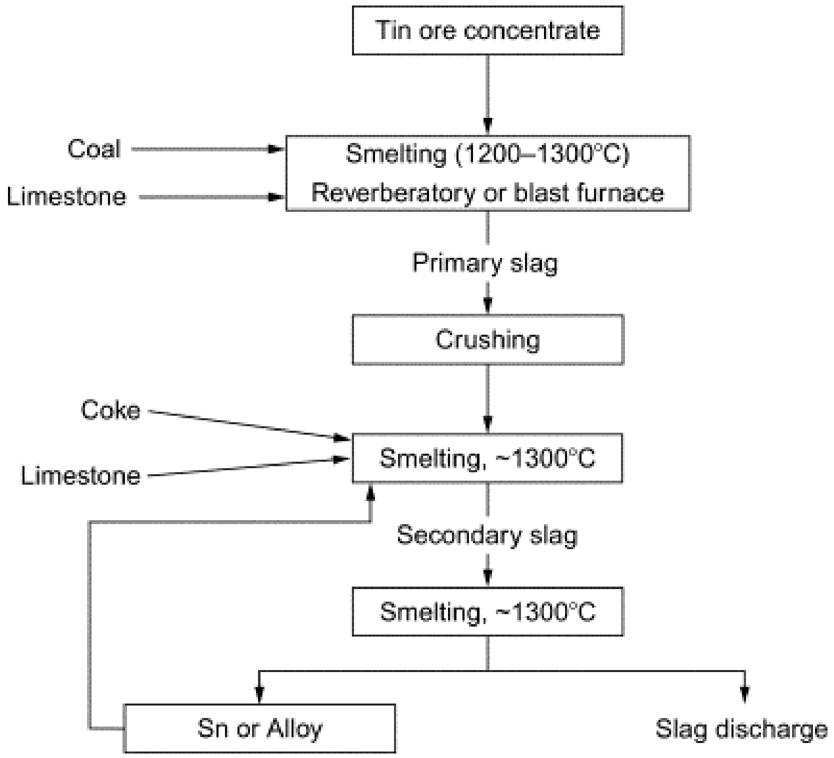

Figure 21. Simplified flowsheet of metallic tin production by cassiterite (Süli, 2003).

The next step is smelting. The objective is to reduce cassiterite into tin by heating it with carbon at 1,200-1,300 °C in reverberatory furnaces together with a carbon-reducing agent, limestone and silica fluxes. Smelting takes 10-12 h. The molten batch is tapped into a settler from which the slag overflows into pots. The molten tin from the bottom of the settler is cast into slabs or pigs (of about 34 kg) for refining, and the cooled slag, which contains 10-25% tin, is crushed and re-smelted. High-grade tin-oxide concentrate is smelted in reverberatory or electric furnaces, while low-grade concentrate is smelted in blast furnaces, kilns, or horizontal furnaces. The slag produced by the reductive smelting step has a typical chemical composition of: 30–40% SiO_2, 15–25% FeO, 5–15% CaO, and 5–25% SnO_2 and it is further processed/recycled via reduction by the addition of further amount of flux, limestone, coal, and iron scrap (Erreur ! Source du renvoi introuvable.). The second slags contains only impurities of tin and after tapping of the furnace, the molten slag is quenched, granulated in water, and solidifies into glass-like material (Süli, 2003). Before the tin is put on the market, refining is necessary to remove metallic impurities contained after smelting. As there is not a great demand for tin of extremely high-purity (typically 99.85%-99.9%) pyrometallurgical techniques are the most widely used

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(Geoscience Australia, 2016). In this process, tin slabs are heated to a temperature slightly above the melting point of pure tin but below the one of the impurities. The “pure” tin melts and flows into a kettle, leaving impurities in the residue or slag. Some of these slags contain other valuable elements such as tantalum, niobium or REEs and can be re-processed specifically. The slag also contains naturally occurring radioactive materials such as uranium and thorium (Süli, 2003). Primary tin metal grading 99.85% tin is cast and sold as bars, ingots, pigs and slabs. High-purity tin with up to 99.999% purity may also be produced using electrolytic refining.

World refined tin metal production amounted to 361,000 tonnes per year on average during the period 2012-2016 (BGS, 2018). China was the world leading supplier with 47% (169,000 tonnes per year) of the global production, followed by Indonesia contributing 68,000 tonnes per year, and Malaysia (32,000 tonnes per year). The world top 3 refined tin producers are Yunnan Tin in China, PT Timah in Indonesai and Malaysia Smelting Corp in Malaysia.

The EU produced at an annual average for the period 2012-2016 around 12,000 tonnes, by refineries in Belgium (10,000 tonnes) and Poland (2,000 tonnes) from primary and secondary material (BGS, 2019). The tin production in Belgium declined by 25% from 2012 to 2016, whereas the Polish production more than doubled. The International Tin Association (International Tin Association 2019b) reports higher EU production of 14,100 tonnes per year (Belgium 9,300 tonnes, Poland 3,800 tonnes and Spain 1,000 tonnes).

OTHER CONSIDERATIONS

HEALTH AND SAFETY ISSUES RELATED TO TIN OR SPECIFIC/RELEVANT COMPOUNDS AT ANY STAGE OF THE LIFE CYCLE

At the EU level, workers’ and employers’ organizations should be kept informed by member states about the indicative occupational exposure limit values (IOELVs), which are set for tin (inorganic compounds) at the Community level by Directive 91/322/EEC: 2 mg/m3 (measured or calculated in relation to a reference period of eight hours).

Fairphone and Alpha Assembly Solutions were commissioned about the recycling of tin (Anthesis 2020). The report looked specifically at China, which is the most important hub of electronics production, as well as the world’s largest consumer of tin and concludes that tin waste and waste electronics are often collected by informal actors, who do not take appropriate health, safety and environmental precautions when handling waste materials. This substance is not restricted under REACH Regulation (EC) No 1907/2006 Annex XVII (Deutsche Forschungsgemeinschaft and Commission for the Investigation of Health Hazards of Chemical Compounds in the Work Area, 2002).

ENVIRONMENTAL ISSUES

No specific environmental restriction is known for tin.

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The quantity of tin extracted in Europe is not very significant (average of 75 tonnes per year for the period 2012-2016, less than 1% of global production) and does not generate environmental implications other than those associated with any mining project (landscape impact, waste treatment, etc.). Research project iTarg3T aims to provide solutions for the exploration of new Tin (also W–Ta-Li) deposits (iTarg3T 2019). Several actions have been carried out to remediate old mining areas (EMD 2018).

STANDARDS AND NORMATIVE REQUIREMENTS RELATED TO THE USE AND PROCESSING OF TIN

Tin is one of the "conflict minerals" addressed by Directive (EU) 2017/821 („Conflict Minerals Directive") requiring specific due diligence of importers, and by the US Dodd-Frank Act (2010). It is also in the scope of the OECD (2017) "Due Diligence Guidance for Responsible Supply Chains of Minerals from Conflict-Affected and High-Risk Areas" and the "ASM Code of Conduct" published by T.I.C. (2022). Technical rules for the use of tin can be found in the GESTIS Substance database[4].

SOCIO-ECONOMIC AND ETHICAL ISSUES

ECONOMIC IMPORTANCE OF THE TIN FOR EXPORTING COUNTRIES

Table 9 lists the countries for which exports of phosphate and/or phosphate rocks represent a considerable share of the total value of their exports.

Table 9: Share of tin exports in total exports

Country	Export value (USD)	Share in total exports (%)
Bolivia (Plurinational State of)	30,101,115.00	0.43
Burundi	687,815.00	0.42
The Democratic Republic of the Congo	39,983,509.00	0.28

Source: COMTRADE (2022), based on data for 2020

The shares of tin export values remain far below one per cent of their total exports in all exporting countries. Only for Bolivia, Burundi and the Democratic Republic of the Congo, Tin exports represent more than 0.1 % of the value of their total exports in value.

SOCIAL AND ETHICAL ASPECTS

Tin mining and trade are related to armed conflicts and severe human rights violations and is therefore considered a conflict mineral in legislation (c.f. section "Standards and normative Requirements related to use and processing of the material").

[4] See https://gestis-database.dguv.de/data?name=007020

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There are also reports about surging illegal mining activities, among others for tin, on indigenous peoples' territories in Brazil (France24) and rising fears that the war in Ukraine driving the prices of raw materials may attract more such activities. (BBC 2022). According to (BGR, 2020), artisanal and small-scale mining activities represent around 27 % of the global tin production making the sector particularly relevant for social and economic development for example in Indonesia, Central Africa or Bolivia while at the same time offering poor working conditions.

RESEARCH AND DEVELOPMENT TRENDS

RESEARCH AND DEVELOPMENT TRENDS FOR LOW-CARBON AND GREEN TECHNOLOGIES

- H2020 project FREENERGY (2019 – 2024)

The most efficient solar cells to convert solar into electrical energy are designed using halide perovskites, crystalline semiconducting materials that absorb high quantities of solar energy and generate an effective electric charge. The EU-funded FREENERGY project intends to re-design halide perovskite as an environmentally friendly photovoltaic material, in the form of a tin-based perovskite solar cell with high power-conversion capacity and long-term stability. FREENERGY will propose these cells as an alternative to existing lead-based ones and establish a solvent-free method for preparing the perovskite.

- Energy storage systems (TRL=4)

Tin is a strong candidate as a performance-enhancing component of anodes for next-generation lithium-ion batteries due to their higher volumetric capacity and relatively low working potential" (F. Xin and M.S. Whittingham, 2020). The traditional graphite (carbon) anode of lithium-ion batteries will be upgraded with pure silicon and silicon-carbon anodes, which are theoretically capable of tripling specific energy capacity and increasing overall cell capacities by up to 40 %. Tin can dramatically improve the performance of silicon by speeding up lithium ions inside the electrodes (A. Ruderman et al., 2021). Tin in such lithium-ion batteries could represent up to 60,000 tonnes per year by 2030. (International Tin Association, LIB-1) and (International Tin Association, LIB-2).

Whilst the current focus is on lithium ion batteries, post lithium ion batteries based on cheaper and safer products are already in development. Tin, its alloys and compounds are prominent candidates for anode materials in zinc and sodium batteries: tin stabilizes zinc-ion batteries (W. Guo at al., 2021) and enhances the performance of sodium batteries (H. Song et al., 2020).

A number of other battery technologies are under development, particularly for larger-scale utility power storage. Tin may be applied in liquid metal technologies or as a catalyst in redox flow batteries, for example, and in ion-exchanging technologies including tin as a possible metal ion candidate. Moreover, tin oxide nanoparticles can store electrical energy in wearable fabrics. Researchers incorporated these tiny particles into graphene-based, wearable supercapacitors (Taegun Kim et al., 2021). The energy storage technology could be used in smart sportswear, heated clothing, or even medical devices.

- Thermoelectrics (TRL=4)

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Thermoelectric materials are materials developed to convert heat energy, especially waste heat, into useful electricity for example in electricity generation. Tin compounds such as zinc tin oxides or tin sulphides and 'Huesler' alloys such as nickel manganese-TIN, TIN-selenide are candidates for thermoelectric materials (Shuhao Liu et al., 2018). Since more than 65 % of the globally produced energy is lost as waste heat (Gingerich & Mauter, 2015), thermoelectrics could have significant environmental and economic benefits, improving energy efficiency and decreasing CO_2 emissions.

- Hydrogen production (TRL=4)

Tin can significantly reduce the costs and sustainability of hydrogen production technologies, notably in use as a liquid metal to strip carbon from methane (I.V. Kudinov et al., 2021), and as an oxide or sulphide photocatalyst to split water in sunlight (W. Cheng et al., 2018). Further developments enable renewable hydrogen production, splitting water in sunlight using platinum-doped tin sulphide. Moreover, according to two recent discoveries, tin can enable the conversion of waste formaldehyde and alcohols into hydrogen, using just sunlight (Hongxia Liu et al., 2020 and Toyokazu Tanabe et al., 2020).

Strong hydrogen demand growth and the adoption of cleaner technologies for its production will enable hydrogen and hydrogen-based fuels to avoid up to 60 Gt CO_2 emissions in 2021-2050.

- Fuel cells (TRL=4)

New research highlights tin as 'promising alternative' for cheaper hydrogen fuel cell technology. Liquid tin was first used as an electrode in a type of fuel cell that was able to convert any type of hydrocarbon gas feed and at the same time act as catalyst for the recombinant reaction. Other developments have used tin, its alloys and compounds in various physical parts of the fuel cell, including tin pyrophosphate as a medium temperature fuel cell membrane (William A. G. McPhee et al., 2009).

Fuel cells convert the chemical energy of different fuels directly into electrical energy at a much higher efficiency, both theoretically and practically, compared to conventional power generation sources (Sayed *et al*., 2019; Abdelkareem et al., 2021). However, the main challenge remains sourcing of green fuels, e.g. green hydrogen, to avoid environmental impacts, in particular greenhouse gas emissions.

- CO2 capture catalysts (TRL=4)

Tin-based electrocatalysts are one of the most promising material classes for active components, or promotors, in catalyst systems to convert greenhouse gases, notably carbon dioxide, to useful industrial chemicals, e.g. valuable formic acid, using sunlight or electrochemistry. (Qiang Hu et al., 2020; Ying Zhang et al., 2018; M. Schreier et al., 2017).

OTHER RESEARCH AND DEVELOPMENT ACTIVITIES

- Research project iTarg3T[5]

[5] See https://www.itarg3t.eu

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The project iTarg3T supported by EIT Raw Materials aims to provide solutions for the exploration of new tin (also W–Ta-Li) deposits (iTarg3T 2019). Several actions have been carried out to remediate old mining areas (EMD 2018).

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