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White Paper

Recovery of Key Metals in the Electronics Industry in the People's Republic of China: An Opportunity in Circularity

(Initial Findings)

Created as Part of the Platform for Accelerating the Circular Economy

January 2018

PACE
PLATFORM FOR ACCELERATING THE CIRCULAR ECONOMY

The Platform for Accelerating the Circular Economy (PACE)

This white paper has been created as part of PACE, a project accelerator and convening mechanism dedicated to decoupling resource use from economic growth. PACE is chaired by the heads of UN Environment, the Global Environment Facility and Royal Philips. The Ellen MacArthur Foundation, and Accenture Strategy are knowledge partners. It is hosted by the World Economic Forum.

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REF 291217

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Foreword

Zongguo Wen, Director, Tsinghua University Centre for Industry of Circular Economy, People's Republic of China

Dominic Waughray, Head of Public-Private Partnership, Member of the Executive Committee, World Economic Forum

Electronic devices are one of the pinnacles of human ingenuity. They encapsulate our ability to take and manipulate elements to create a range of products – from the personal computer to smart phones – that are having vast positive impact on people's lives and, more broadly, on society. The number of electronic devices is growing exponentially, with connected devices expected to grow to 25-50 billion globally by 2020, from around 10 billion in 2015.[1] Most of the growth is coming from emerging regions, which will bring connectivity, increased quality of life and convenience to billions of people.

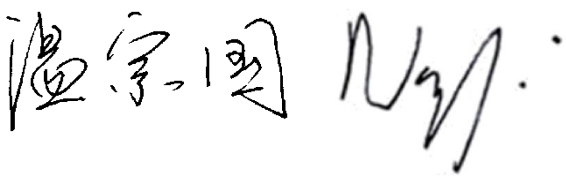
Innovation in electronics hardware is rapid. Fast improvements have led to shorter product upgrade cycles and therefore lifecycles. This means that many more of the devices we use end up as waste in an ever shorter period of time. This electronic waste, while not the largest waste stream, is the fastest growing globally.[2] Importantly, this waste also has significant economic value, containing many high value materials such as gold, platinum and high quantities of aluminum and tin. The UN estimates that each year, $52 billion worth of electronic waste is thrown away, with only 13% recycled. This represents an incredible economic opportunity.[3]

Recycled metals are also between two to 10 times more energy efficient than smelting the metals from virgin ore. In 2015, the extraction of raw materials accounted for seven percent of the world's energy consumption, meaning that moving towards the use of more secondary raw materials in production could help considerably in reaching the targets set out in the Paris Agreement.

A positive future vision for the industry would be one in which products are designed for longevity, repair and disassembly to facilitate recycling, and from which base materials can be constantly re-used in new products rather than discarded in landfill or extracted under hazardous conditions. A number of leading electronics companies are committing to the circular economy and taking steps to change business models, product design and setting targets to integrate recycled materials. Governments are also taking a lead, for example the Government of the People's Republic of China, has set targets to source 20% of raw materials for new electronics products from recycled content by 2025 and to recycle 50% of electronic waste.

What is clear, however, is that capturing this economic and environmental opportunity will require unprecedented levels of innovation and collaboration. The distributed nature of electronic device production and use; policy frameworks governing the flow and use of secondary materials; the economics of material recovery as well as the artisanal nature of waste collection and processing in many emerging markets are all challenges that need to be collectively addressed by a broad range of stakeholders. Multinationals, supply chain actors, regulators, recyclers, universities and consumers all have a role and a responsibility in this effort.

As the global manufacturing hub for electronics products, (producing some 70% of the world's mobile phones.[5] China is the key link in the global electronics manufacturing value chain, hence the focus of this work. This white paper draws together the preliminary findings from a longer study, as collaborative effort between Tsinghua University and the World Economic Forum. The study addresses the opportunities and necessary collaborative actions to progress the build out of a system in which the secondary raw materials from electronics products are recovered and re-integrated into production on an industrial scale.



Executive summary

- China has become the global centre for both the production and the consumption of electronics, a key driver in the growing demand for materials and increasing production of waste electrical and electronic equipment (WEEE)
- According to the most recent data, only $160 million of material value is recovered by the formal recycling industry of a potential $1.3 billion worth of materials, with this potential expected to rise to $4.4 billion by 2030
- The Chinese government has ambitious targets for recycling, including sourcing 20% of raw materials for new electronic products from recycled content as well as a 50% recycling target of all WEEE by 2025. Leading electronics companies also have significant internal targets for incorporating raw materials into their products
- To support the achievement of these goals, this study serves as a baseline and overview of the current state of recycling for four key metals and metal groups used in electronic devices: Aluminum, tin, cobalt and rare earths. Among these four, recycling rates vary, ranging from 10.7% and 6.1% for aluminum and tin to 0.6% for cobalt and 0% for rare earths
  - In the case of aluminum, the mixing of various scraps often produces a grade too low for the manufacture of high-end electronic goods such as mobile phones, creating a significant barrier to circular sourcing of materials
  - Metal in WEEE can be difficult to recover. For example, recovery rates for cobalt are only 30%, the rest being lost in processing, and close to 0% for rare earths, the technology for recovering these metals is still in its infancy
- The informal sector dominates the e-waste sector in China. On average across the four metals, 78% of waste was collected by the informal sector. Many of these metals are still treated but often in a rudimentary manner without measures to protect the health and safety of the workers or the environment. The quality of the recycled material is also significantly lower
- The industrialization of recycling to engage the informal sector is therefore a key goal to move towards a more circular system of electronics production. Recycling capacity will need to grow by 100% to reach the Chinese government's 2025 target of recycling 50% of WEEE
- Due to low metal prices and high recycling costs, waste metals are often stockpiled rather than recycled, in anticipation of future regulatory and economic incentives. The government is addressing this with new policy measures

Introduction

Over the past two decades, China's growing economy has taken an increasingly leading role in electronics, with rapid development across the entire value chain. It has a developed infrastructure in mining and production of raw materials, and now supplies 46% of global aluminum[6] and 85% of rare earths.[7] Even so, China still relies on foreign imports of certain scarce metals such as cobalt and zinc. Raw materials are used for the production of electronic goods, in which China has become a leading global hub. Its global market share of manufactured goods (by value) reached 25% in 2015, and in some sectors it dominates, such as in manufacturing air conditioners (80% of global market share) and mobile phones (70%).[8] Altogether, Chinese exports of electronic machinery totalled $595 billion in 2015.[9] Concurrently, demand for these products is also growing rapidly in China. In 2012, China surpassed the United States as the largest market for personal computers[10]. In some cases, as regards aluminum, the electronics industry is not the single largest consumer of raw materials but the learnings from electronics serves as a practical review of the systems and approaches which could be replicated across all sectors.

China's growing consumption patterns, however, have also translated into growing generation of waste, of which WEEE or e-waste are some of the most difficult to deal with. In this respect, China's chief administrative authority (the State Council) has set clear targets for recycling 50% of e-waste and increasing the use of recycled materials in the production of electronics to 20% by 2025.[11] An interim target of 40% recycling is set for 2020.

Recycling has two major benefits. One: E-waste represents a major opportunity for resource recovery. It is rich in valuable metals including gold and platinum, in concentrations that can be 50 times greater than mineral ores[12]. The recycling potential of China's WEEE in 2010 was approximately $16 billion, and is projected to reach $73 billion by 2030[13]. Two: E-waste pollutant discharges have high concentrations of toxic substances, including chromium VI, cadmium and brominated flame retardants, for example.[14] If left unchecked, it can have adverse effects on human and environmental health especially when treated without environmental and safety measures, which is often the case in the informal recycling industry. The informal e-waste recycling sector in China has been characterized as the artisanal processing of waste usually by hand with rudimentary processes; it is often associated with environmental and health impacts and a poor quality material output.[15]

In the current WEEE sector, the recycling of three base metals – aluminum (Al), tin (Sn), cobalt (Co) – and the group of rare earth elements (RE) are lagging far behind these targets. They offer huge economic potential, however, and related development could see increased political support in the near future. This white paper, undertaken by Tsinghua University and the World Economic Forum, maps the current state of metals recycling in China, draws some key lessons and summarizes some of the actions being taken by the government to increase recycling in the country.
This white paper summarizes in brief a more in-depth study under the same title to be published in 2018. It will incorporate these findings along with the output of a series of workshops with public and private stakeholders in China and abroad.

Analysis of the current flows of Al, Sn, Co and rare earths in the electronics sector in China

Aluminum (Al)

Aluminum is used in a number of structural, electrical and thermotechnical functions in the electronics industry. In 2014, the quantity used in electroncis made up only 4% of total demand for the metal, but was still a significant 1.2 million tonnes. Post use, aluminum waste in electronics totalled 410,000 tonnes, with the majority (74.5%) found in four waste categories: Air conditioners, PCs, commercial printers and personal printers. These are large, bulky items in which aluminum is used primarily for structural purposes, and in the case of air conditioners, for condensing coils. As with all metals covered in this study, the major part of the aluminum in e-waste was collected and treated by the informal recycling sector (74%). Due to its unregulated nature, the informal sector does not collect data on amounts and quality of recycled output. These details in this study are therefore not accounted for. While use of secondary aluminum was 19% in 2014, only a small portion was sourced from WEEE (44,000 tonnes or 0.14%).

Metal Grade for Aluminum Recycling

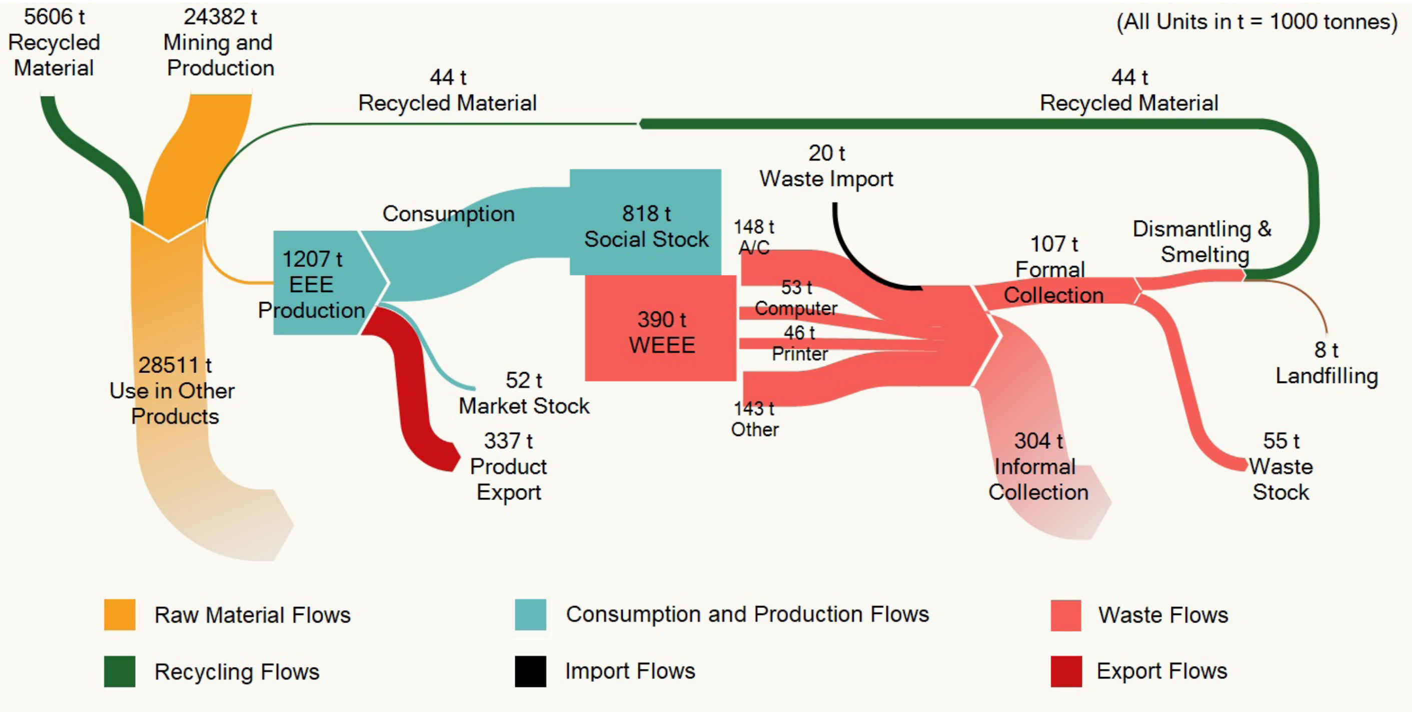
Based on policies in the PRC such as Made in China 2025 (2016) and the Circular Economy Leading Action Plan (2017), aluminum recycling is targeted to grow from 15-17% in 2015 to 22.5% by 2020.[16]

Aluminum from WEEE, however, does not factor too heavily in overall recycling in China, as evidenced by its recycling rate (10.7%) compared to national aluminum recycling (17%).

According to Metal Recycling Branch Secretary General Guwei Wang of the China Nonferrous Metals Industry Association, the recycling industry is currently structured in a way that has most aluminum scraps mixed, recovered and recycled together to produce aluminum alloys. Their grade is lower than that produced from raw ores, but still finds application in many industries. For select applications that require high-grade aluminum, (e.g. mobile phone casings, aluminum foil), recycled aluminum under the current system is not suitable for the products themselves, but can still be applied for other uses such as to create industrial molds.

Figure 1: Material flow analysis for aluminum through the electronics life cycle, 2014

Note: The Sankey diagram has been separated into three sections – production (yellow), consumption (blue), waste disposal and recycling (red). Flows within each of these three sections are drawn to scale, but flows between sections are not proportional. Material flows were constructed using 2014 data, the year for which most recent data is available.



Sources: Zeng, 2016; China Household Electric Appliance Research Institute, 2015; China Ministry of Industry and Information Technology, 2015; Waste Electronics and Electrical Equipment Treatment Information Network, 2017; China Nonferrous Metals Network, 2015; China Nonferrous Metals Industry Association, 2015; China Ministry of Land Resources, 2015

Tin (Sn)

In China, 70% of all tin is used for the production of solder which is an essential component of electronic products. PCs, which require large quantities of solder, are therefore the largest source of tin in WEEE accounting for 55% of the total found (see Figure 2). This is followed by by air conditioners and refrigerators. Of the waste tin flowing into the formal recycling sector, 67% (5,600 tonnes) is stockpiled as a waste stock (saved in storage for future dismantling and recycling when conditions become more favourable, for example in the event the government were to introduce a new subsidy).

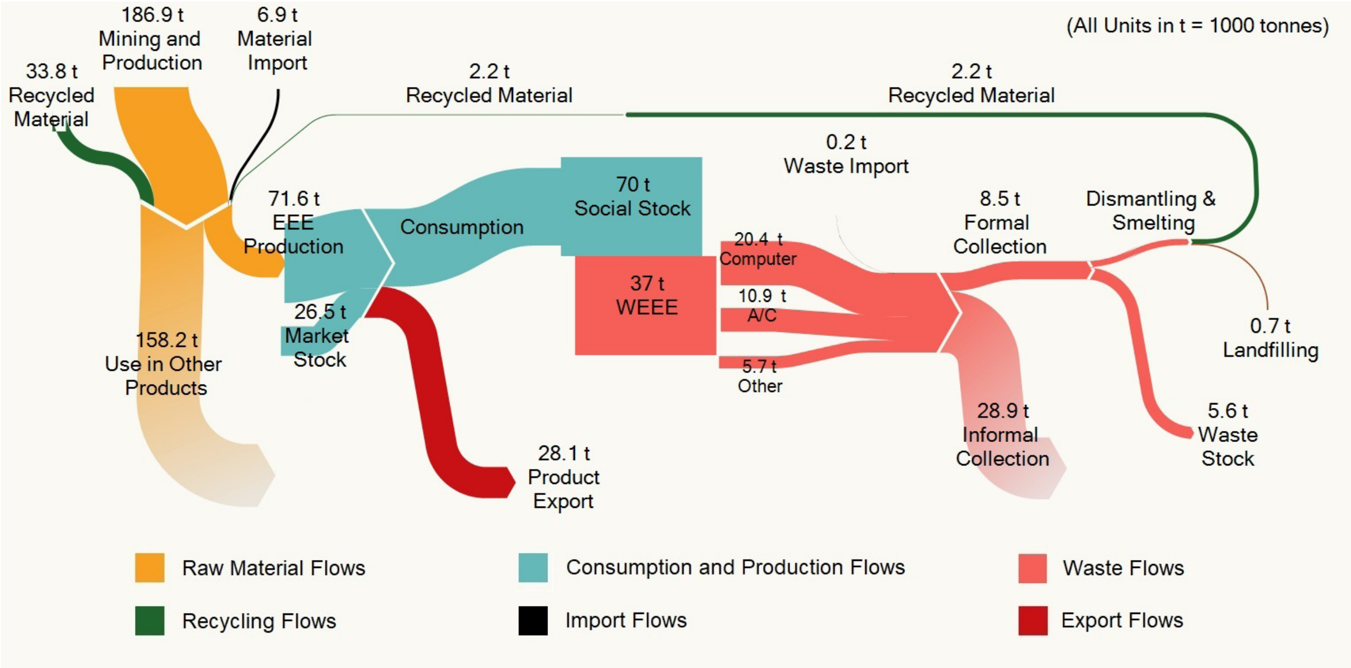
The remaining 33% (2,900 tonnes) of waste tin were sent for further processing, where recycling technologies are fairly mature and end-of-life recycling rates relatively high, capturing a full 75% of the material sent for processing with the remainder being lost in production.[17] Acordingly, the model yielded 2,200 tonnes of recycled tin in 2014. Conversely, some industry experts estimate the actual quantity of tin going back into the economy is closer to 35,000 tonnes, or roughly equivalent to the theoretical potential. This suggests that the informal recycling sector is incredibly dominant in the recycling of tin, with a market share of tin recycling from WEEE at over 95% of the total.

Cobalt (Co)

With only 1.1% of the world's reserves, China is a net importer of cobalt (see Figure 3). It is an important component of lithium batteries, constituting as much as 60% of the cathode (in lithium cobalt oxides). By contrast, lithium constitutes only 7% of those same cathodes by weight, and has similar concentrations in other types of batteries. As such, 39% of the cobalt in China goes to the production of electronics and electrical equipment. As a waste, cobalt is primarily found in computers and mobile phones, and there is a significant source of cobalt from waste imports. Here, the informal sector is extremely dominant, collecting 88% of the waste cobalt generated in 2014. Due to a combination of economics and inefficient recycling technologies[18], only 30 tonnes of cobalt were formally recycled in 2014 from WEEE (or 0.6% of the waste cobalt generated).

Figure 2: Material flow analysis for tin through the electronics life cycle, 2014

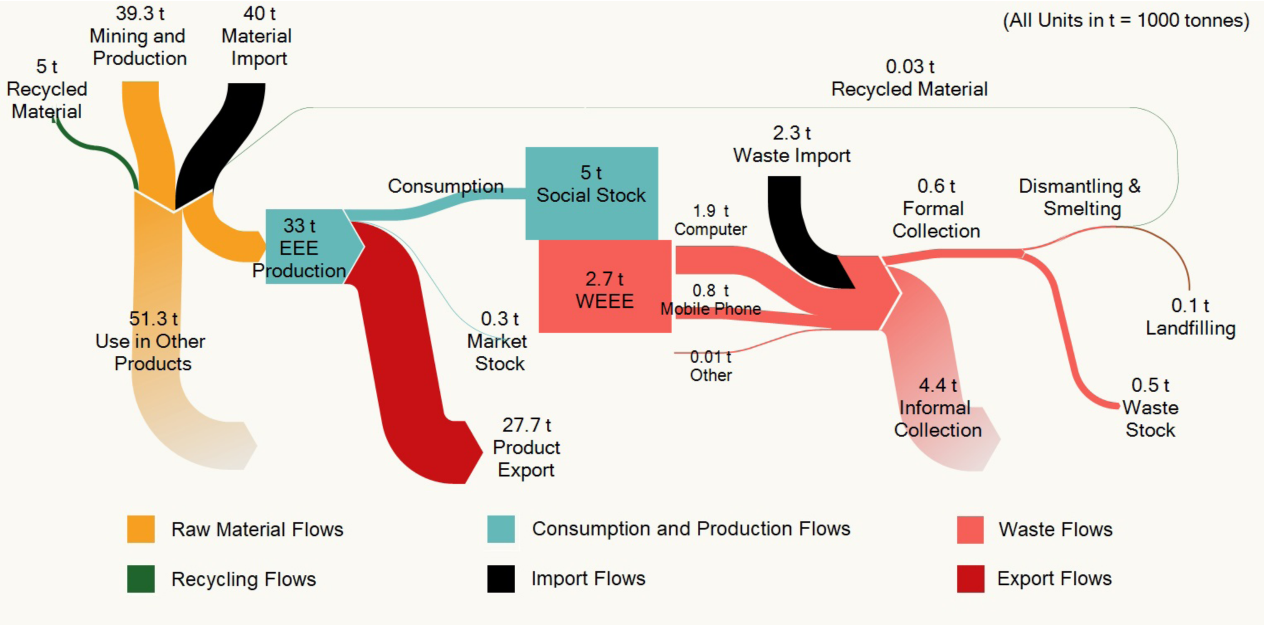
Note: The Sankey diagram has been separated into three sections – production (yellow), consumption (blue), waste disposal and recycling (red). Flows within each of these three sections are drawn to scale, but flows between sections are not proportional. Material flows were constructed using 2014 data, the most recent year for which a complete data set is available.



Sources: Zeng et al., 2016; China Household Electric Appliance Research Institute, 2015; Jiang et al., 2016; Wang, 2009; Zhao,2014; Li and Xia, 2016; China Industrial Information Network, 2017; China Nonferrous Metals Industry Association, 2015

Figure 3: Material flow analysis for cobalt through the electronics life cycle, 2014

Note: The Sankey diagram has been separated into three sections – production (yellow), consumption (blue), waste disposal and recycling (red). Flows within each of these three sections are drawn to scale, but flows between sections are not proportional. Material flows were constructed using 2014 data, the most recent year for which a complete data set is available.



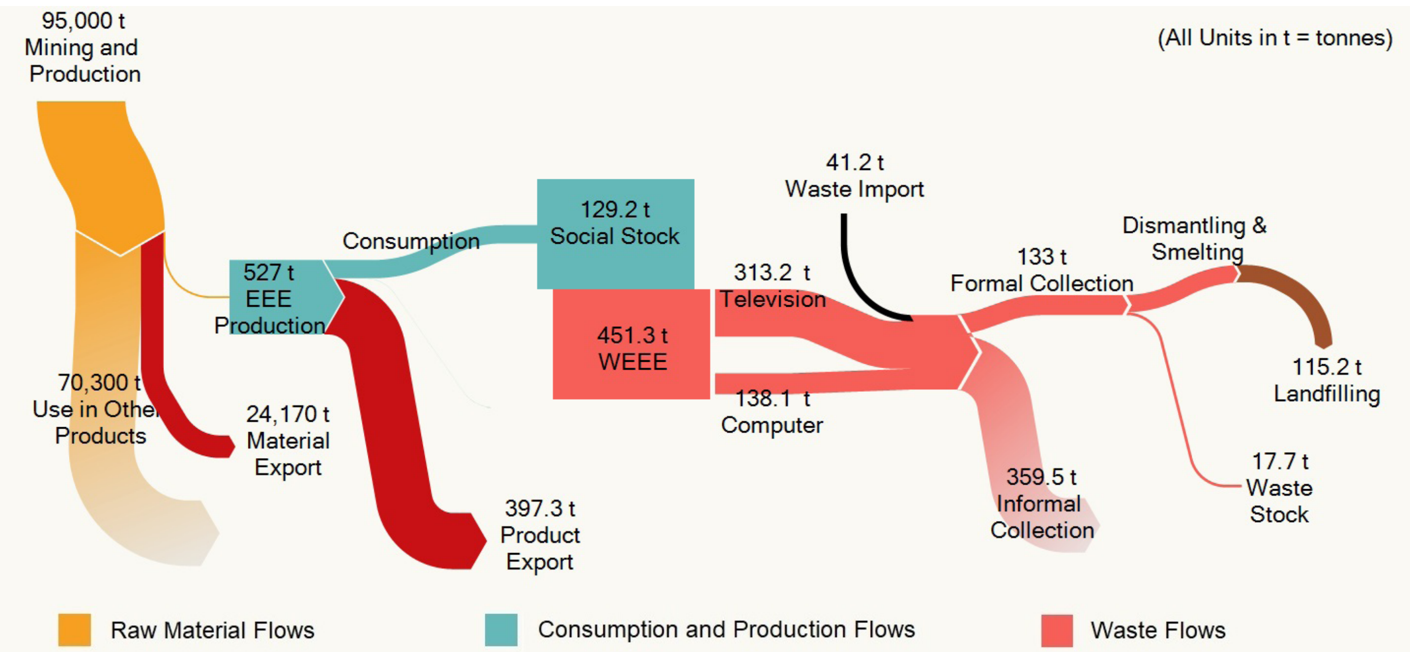
Sources: Zeng, 2016; China Household Electric Appliance Research Institute, 2015; China Ministry of Industry and Information Technology, 2015; Waste Electronics and Electrical Equipment Treatment Information Network, 2017; China Nonferrous Metals Industry Association, 2015; China Ministry of Land Resources, 2015

Rare earths (RE)

The group of rare earth elements includes 15 metals in the lanthanide series, scandium and yttrium. In electronics, they are valued for their magnetic properties, as well as in polishing powders for lighting. However, its concentration in electronics and thus WEEE is generally very small, making it costly and difficult to recover. For this reason, recycling of rare earths is virtually non-existent in China, and only reaches 1% globally.[19] In WEEE, rare earths are found primarily in televisions (as polishing powders) and computers (permanent magnets in hard disks). While they are also used in mobile phones, these quantities were considered negligible. Whether through formal or informal collection, the fate of rare earths in WEEE was either landfilling or waste stockpiling.

Figure 4: Material flow analysis for rare earths through the electronics life cycle, 2014

Note: The Sankey diagram has been separated into three sections – production (yellow), consumption (blue), waste disposal and recycling (red). Flows within each of these three sections are drawn to scale, but flows between sections are not proportional. Material flows were constructed using 2014 data, which is the most recent year that a complete set of data exists.



Sources: Zeng, 2016; China Household Electric Appliance Research Institute, 2015; China Ministry of Industry and Information Technology, 2015; Waste Electronics and Electrical Equipment Treatment Information Network, 2017; China Ministry of Land Resources, 2015; Liu, 2016

Key findings from the material flow analysis

Three critical junctures along the waste value chain determine recycling rates

Material flow analysis of the metal groups permitted identification of three major bottlenecks that contribute to low formal recycling rates. They range from negligible for rare earths to just under 11% for aluminum.

1. The informal sector dominates waste collection in China

WEEE are highly coveted on the Chinese market, sold to waste collectors that offer the highest price[20]. On average across the four metals, 78% of waste metal in WEEE ended up in the informal recycling sector. While metals are still treated, informal recycling has several challenges. Often, outdated technologies are used, which are extremely harmful to the environment; consisting of open-air burning, acid leaching without safety measures and indiscriminate dumping. Furthermore, resources are usually down-cycled into low-grade products, resulting in low efficiency of re-use. Recognizing that the informal processing of waste provides a basic livelihood for millions of workers, their transition towards safer and more efficient working conditions through technology, training and support can play an important role in enhancing the overall effectiveness and safety of the system while enhancing economic outcomes.

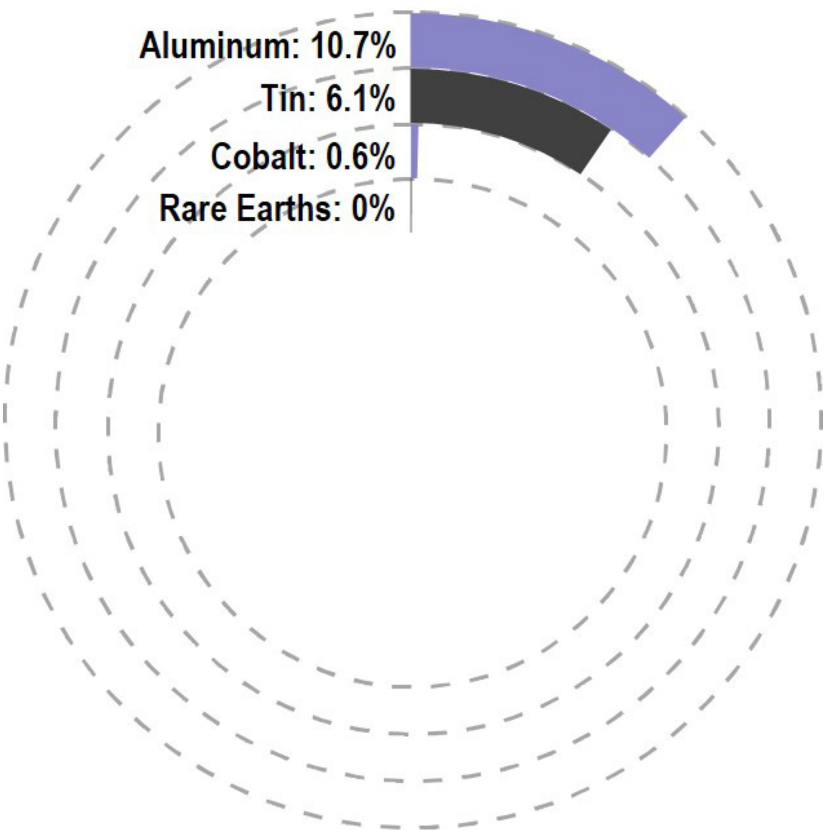
2. Due to lack of economic incentives, waste metals are stockpiled rather than recycled

Low metal prices and high recycling costs create an unprofitable environment for recyclers, acting as a major barrier to end-of-life recycling. While the Chinese government has introduced subsidies to incentivize recycling, the system is fiscally unsustainable due to the high cost to government, and is currently undergoing improvements driven by new policy measures.

3. Metal concentrations in WEEE are very low, making them difficult to recover

While technologies for aluminum and tin recovery are quite mature with high end-of-life recovery rates (85% and 75% respectively), recovery of cobalt and rare earths are still in their technological infancy. Recovery rates of cobalt are thus only 30% and virtually non-existent for rare earths.

Figure 5: Recycling rates of key metals and metal groups represent huge potential for improvement in the recycling industry

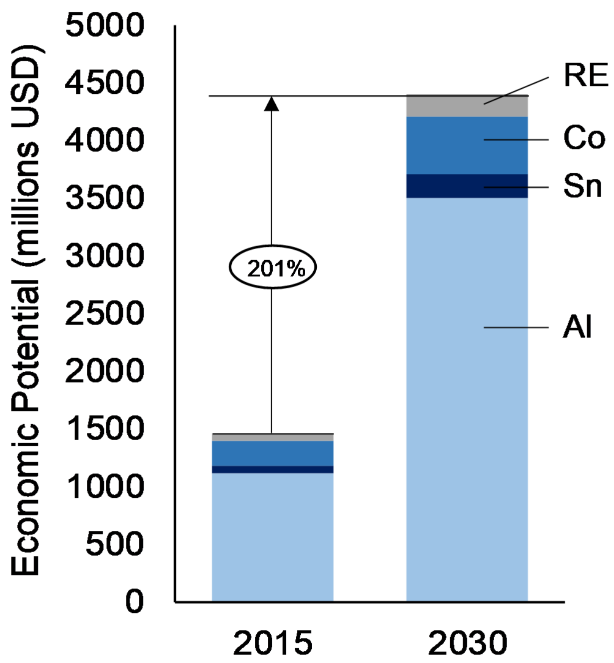


Circular potential of the four metal groups: Al, Sn, Co, RE

By 2030, the quantity of the selected metals in WEEE will reach 1.6 million tonnes. Using 2017 metal prices, its value is estimated to grow from $1.3 billion in 2014 to $4.4 billion by 2030. Much of this value is related to aluminum, which has one of the lowest prices of the four metal groups, but occupies a much larger volume in the waste stream.

Assuming that 75% of the value can be recovered after losses from collection and recycling, the economic potential in 2030 becomes a more conservative $3.3 billion, but still a significant difference from the $160 million currently recovered, and a huge potential to develop the WEEE recycling industry.

Figure 6: Total economic potential of the four metal groups will grow by almost three times by 2030



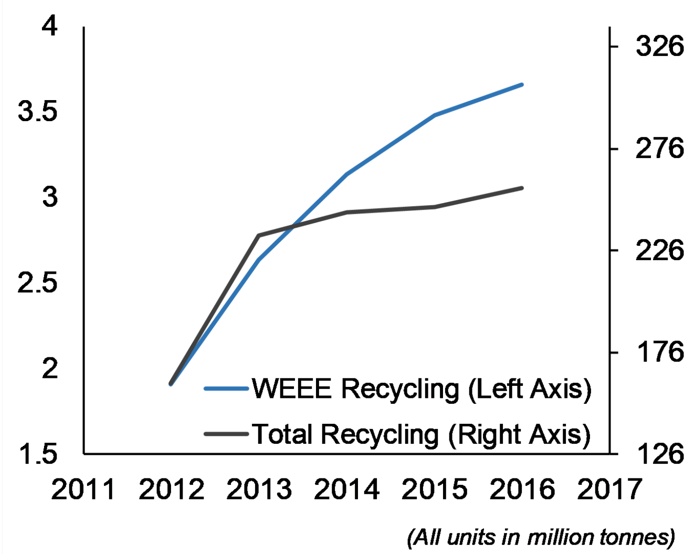
The state of China's recycling Industry

Recent development in China's recycling sector started from the top down

The past five years have seen faster growth in WEEE recycling as compared to other waste types (comprised of 10 categories including cars, paper, and plastics among others) ,[21, 22, 23], due in large part to a boost from the government's "Old for New" programme. The programme offered subsidies for collection and recycling of WEEE. Since then, the number of formal WEEE recycling enterprises registered with China's Ministry of Environmental Protection has grown from 36 in 2012 to 109 in 2017[24,25].

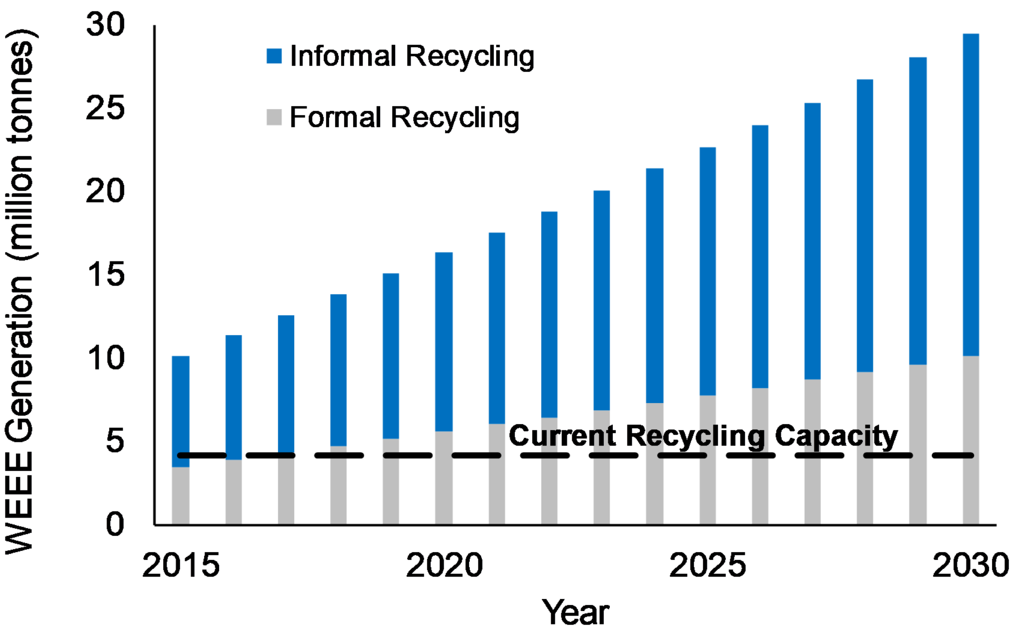
As a result, China's annual recycling capacity for WEEE has grown to 4.2 million tonnes – a slight overcapacity given the amount currently processed through formal recycling channels, but still far from the 11 million tonnes theoretically produced in 2016. The remaining 6.8 million tonnes are collected by the informal sector, some of which is recycled and some of which is disposed of. The informal sector lacks the health, safety and environmental standards of the formal sector in turn reducing its costs. As both sectors compete for the same WEEE from consumers, this allows the informal sector to undercut the formal on price and convenience by providing convenient door-to-door collection services.

Figure 7: Growth in recycling: WEEE vs 10 major waste categories



Sources: Ministry of Commerce Circulation Development Division, 2013,2015,2017

Figure 8: China's formal recycling capacity against projected growth in WEEE generation



Sources: Zeng et al., 2016; Cao et al., 2016

With WEEE generation set to grow to almost 30 million tonnes annually by 2030, recycling capacity will need to grow considerably to keep up. Even under a scenario of linear growth with formal recycling maintaining its proportion of total WEEE treated, capacity will need to more than double to 10 million tonnes. For its part, the Chinese government is targeting even greater growth to displace more of the informal sector and more ambitiously meet its recycling and environmental protection targets. 50% WEEE recycling by 2025, for example, translates into 9.4 million tonnes of treatment, necessitating 100% growth of the industry from present day capacity.

Key policies and actors in WEEE recycling in China

Political support is strong for WEEE recycling, with new policies pushing circular economy in the electronics industry even further

Several ministries are involved in the policy-making and management of formal WEEE recycling in China. At the highest levels, the State Council and National Development Reform Commission set the overall tone and direction for WEEE management. Five ministries are also involved in management and oversight of WEEE flows from the consumer to recyclers (see figure 9).

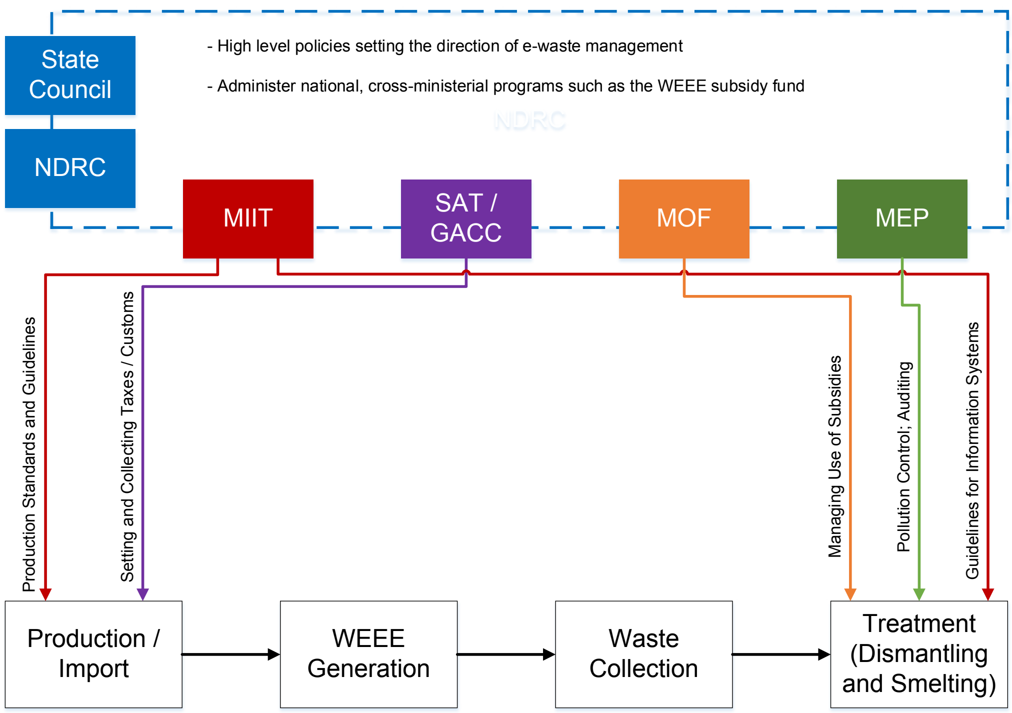
As electronic products are used, discarded and recycled, they pass through several actors from producers and importers; to consumers then waste collectors and eventually recycling enterprises, where they are disassembled and recycled. Five key ministries each play a unique role in managing this value chain:

- Producers and Importers are monitored by the *Ministry of Industry and Information Technology (MIIT)* who ensure adherence to local regulations and standards.
- *The State Administration of Taxation (SAT)* and *The General Administration of Customs China (GACC)* then levy *extended producer responsibility* (EPR) fees on producers and importers, these are paid in the form of taxes or customs charges and calculated according to the quantity of domestic sales and/or import volume.
- The proceeds of these fees are then transferred to the *Ministry of Finance* and allocated towards waste management.
- MIIT again, is responsible for implementing the data collection systems used for auditing recyclers
- Data itself is submitted to the Ministry of Environmental Protection (MEP) which it then uses to calculate and distribute subsidies.
- The MEP is also responsible for auditing dismantling and recycling enterprises to ensure they comply with environmental standards

Two new policies, in particular, are set to drive further development in WEEE recycling. The *Extended Producer Responsibility System Implementation Plan (2017)* lays out a roadmap to 2020, with a focus on four sectors: Electrical appliances, automobiles, lead-acid batteries and packaging products. One of the major goals is to achieve the aforementioned 50% recycling rate, and source 20% of raw materials from recycled products by 2025. The *Circular Economy Leading Action Plan* was also released in 2017. It is a broader policy piece that presents development of the recycling industry as a whole. Several parts of the plan have laid out development of WEEE recycling, improvements to the EPR system, policy support for remanufacturing, and supporting regional recycling systems. While no specifics were given for either policy, they will start with several demonstration projects prior to full-scale dissemination. Together, these plans point to a supportive policy environment for WEEE recycling and a government willing to adopt new trends in circularity.

Figure 9: Layout of regulatory bodies on the management of WEEE in China

Note: NDRC – National Development and Reform Commission; MIIT – Ministry of Industry and Information Technology; SAT – State Administration of Taxation; GACC- General Administration of Customs China; MOF – Ministry of Finance; MEP – Ministry of Environmental Protection



Next steps

This white paper assessed the current state of recycling across four metals and metal groups; identified systemic barriers to greater recycling; and cited key government policies aiming to increase recycling in China. The wide variance in recycling rates for different metals; a large capacity gap in between the capacity of the recycling sector and the amount of waste and the dominance of the informal sector points to nebulous and diverse challenges to scaling recycling in the country. However, the policy push from government and increasing commitment and investment from the private sector demonstrates a strong alignment of ambition to jointly overcome these challenges.

This study will serve as a baseline contribution for a larger project aiming to create a space for public-private collaboration in the field of WEEE recycling in China. Future research on the topic could examine other key materials such as plastics, or metals such as nickel or lithium, as well as the role of refurbishment and remanufacturing of products. In the coming 12 months, the Platform for Accelerating the Circular Economy, a project accelerator and platform for public- private collaboration, will convene workshops with key stakeholders and experts from the electronics and recycling industry, industry associations, academia and government to create tailored recommendations to industry and government on how to jointly build a more circular electronics industry in China and globally, while also creating a platform for ongoing collaboration in reaching China’s ambitious goals for 2025.

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Contributors

Zongguo Wen, Professor, Tsinghua University School of Environment

Jinhui Li, Professor, Tsinghua University School of Environment

Jason Lee, Project Manager, Tsinghua University Centre for Industry of Circular Economy

Quanyin Tan, Post-Doctoral Researcher, Tsinghua University School of Environment

Jinghan Di, Doctoral Candidate, Tsinghua University School of Environment

Yuting Zhang, Doctoral Candidate, Tsinghua University School of Environment

James Pennington, Specialist, Circular Economy, World Economic Forum

Mathy Stanislaus, Senior Advisor, Circular Economy Policy, World Economic Forum & Senior Fellow, World Resources Institute, USA

Antonia Gawel, Head, Circular Economy, World Economic Forum, Geneva

Lauren Joseph, Lead, Electronics Industry, World Economic Forum

Experts Consulted

Keli Yu, Secretary General of Electronics Recycling Division, China National Resources Recycling Association

Jiwei Wang, Secretary General of the Metal Recycling Division, China Nonferrous Metals Industry Association

Merisha Enoe, Environmental Initiatives, Apple

Yu Yang, Environmental Initiatives, Apple

Ruize Ma, Senior Manager of Policy and Alliance Development, Phillips China

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World Economic Forum
91–93 route de la Capite
CH-1223 Cologny/Geneva
Switzerland

Tel.: +41 (0) 22 869 1212
Fax: +41 (0) 22 786 2744

contact@weforum.org
www.weforum.org