Electronic waste in Ontario:
Case study of a primary processing facility

by

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AUTHOR'S DECLARATION

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

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Abstract

Electronic waste (e-waste) is one of the fastest expanding, and valuable waste streams due to its content of precious, critical, and base metals. E-waste is comprised of electronic devices operated below 10,000 volts that have reached their end of useful life. While global production and consumption of electronic goods is increasing, in Ontario the electronic waste treatment program has reported decreasing collection under the provincial regulation. This raises questions of efficacy and function of the collection system and the electronic waste primary processors within Ontario.

This research employed both qualitative and quantitative methods to analyze material flows through an Ontario e-waste primary processor. Annual data for inputs and outputs provided three years of facility data from 2016 to 2018. At a more granular level, two days of material flow accounting were conducted at the primary processor, resulting in a single average “model day” of operation for the summer season. For this daily operation, the facility processed 25.3 Mg of input products, producing 23.3 Mg of outputs, the remaining 2 Mg entering facility stock. The main inputs for the primary processor were printers and peripheral devices, refurbishable flatscreen displays, cathode ray tube (CRT) televisions, small household appliances and complete desktop computers. The main outputs were leaded-glass from CRT, sorted shredded plastics, various pure and mixed copper-bearing materials, refurbished goods like flatscreen displays, clean shredded steel and clean shredded aluminum.

For the facility, the daily operations’ map of material flow describes the processes used to extract and sort materials, the relative flows of materials, the processing capacity of a single day, and provides a base for the representation of a day of sales. The resulting model of sales is presented and indicates the high comparative value of refurbished items to bulk shredded materials. The annual data indicates that, while CRT displays are both being displaced in the economy and sold or traded by the primary processor, for flat-screen displays, substantial outputs of low to negative value materials are still produced from the CRT processing on site. These materials include leaded glass, thin-film plastics, and low-quality black plastics. From 2016 to 2018, the composition of inputs indicated that CRT displays fell from 30% to 18%, printers and peripheral devices fell from 28% to 24%, flatscreen displays rose from 4% to 10%, and printed circuit board and computer components increased from 2.5% to 6%. The output composition regarding the desired processed material changed considerably

as well, with steel increasing from 20% to 31%, copper falling from 18% to 10%, and glass remaining somewhat stable at 14% to 18%.
Results indicate that the primary processor is adapting to shifts in e-waste streams as electronic product composition changes. The processor is implementing new technologies to shred and sort large quantities of material, and making changes including downsizing printer cartridge refurbishment capacity, the installation of a flat-screen display shredder, and an expanded shredding line, with enough processing capacity to replace personnel and therefore reduce operating costs.

More broadly, the adaptations at the primary processor are a reaction to the 2020 regulation changes that are expected to significantly increase inputs to the facility. The implementation of an extended producer responsibility regulatory system in 2020 is the cause of the expected increase in material flow at primary processors, and investments at such firms. This is through stricter reporting and a broadened categorization of e-waste in Ontario. The 2002 – 2016 regulatory implementation had serious issues regarding private industry self-governance and competition, and a restricted scope on e-waste categories resulting in falling overall collection of e-waste covered under that program from 2013 to 2018.

This research provides a case study of the primary processor entity in Ontario, situating it in a regulatory atmosphere that is in the process of major systematic change. This work provides knowledge that will aid in the understanding of the future of e-waste in Ontario as regulations change. It provides a point of reference for future work to indicate changes in processing methods, the targeting of materials and products at the firm, and the quantity and categories of materials processed at the primary processor entity.

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Chapter 1
Introduction and Background

Electronic waste (e-waste) is one of the fastest-growing and complex global waste streams. For the purpose of this thesis, e-waste is broadly defined as any electronic device that has reached the end of its useful life for any reason and is discarded as a waste product. Devices that run on more than 10,000 volts are not considered e-waste to differentiate from industrial machinery waste products. This waste stream contains base metals and materials such as steel, polystyrene, polyurethane and ABS plastics, as well as more valuable metals such as copper and aluminum. Gold and palladium are some of the precious metals found within such waste electronics, contributing to e-waste's relatively high-value as a waste stream. The global supply chain that produces electrical and electronic equipment (EEE), and collects and recycles waste electrical and electronic equipment (WEEE) is vast, complex, and poorly monitored. In 2016, it was estimated that global e-waste production was 44.7 million metric tonnes, with only 20% processed through formal systems despite 66% of the world's nations having some form of e-waste regulatory legislation (Baldé et al., 2017).

Global regions vary significantly in the production of e-waste, with ~~the~~ wealthier regions producing far more per capita due to their consumer purchasing power. E-waste generation in different parts of the world in 2016 was: Africa – 2.2 Mt (1.9 kg per capita), Americas – 11.3 Mt (11.6 kg per capita), Asia – 18.2 Mt (4.2 kg per capita), Europe – 12.3 Mt (16.6 kg per capita), Oceania – 0.7 Mt (17.3kg per capita). The United States and Canada were both reported to produce 20 kg of e-waste per capita, about double the average production in the Americas (Baldé et al., 2017).

The main problems with e-waste are twofold. First, informal and improper disposal of e-waste can lead to severe environmental and human health concerns, due to the materials contained in electronic products becoming toxic when heated or vaporized. Such hazardous materials may include arsenic, cadmium, chromium, mercury, and lead (Akram et al., 2019). Second, technical and economic challenges associated with the efficient recovery of materials from e-waste results in their partial recovery or disposal (Baldé et al., 2017, p. 2,7). The costs associated with the building of efficient e-waste processing infrastructure are high, limiting the capability for such enterprises, especially where funding is unavailable and regulation insufficient or non-existent. Informal processing is characterized as being the open burning of e-waste to extract valuable and precious metals, releasing toxic chemicals that can be inhaled or enter the soil and water systems (Daso, Akortia, & Okonkwo, 2016; Grant & Oteng-Ababio, 2016; Tue et al., 2016). Such processing methods are more common in developing nations which lack regulatory oversight or strictly enforced health and safety standards (Daso et al., 2016; Grant & Oteng-Ababio, 2016; Tue et al., 2016). This is contrasted with formal processing, which usually consists of the manual dismantling of e-waste products, automated shredding and sorting, shipping of shredded and sorted goods to smelters for final resource recovery. In such systems, health and safety standards for environment and workers are considered.

While e-waste contains valuable metals such as gold, it also contains critical materials such as rare earth elements (REEs) which have a variety of uses, usually in the high-tech sector. For example, dysprosium (Dy) is an REE used in neodymium-iron-boron (NdFeB) magnets in hard disk drives for electronic products, as well as the production of lasers. These REEs are needed for many high-tech and military sector applications, though many have relatively low values compared to gold or palladium (Sun, Xiao, Agterhuis, Sietsma, & Yang, 2016). Some of the targeted metals for recovery from e-waste include gold, palladium, platinum, cobalt, lithium, copper, aluminum, and less valuable metals such as steel and tin (Friege, 2012; Husiman, Leroy, & Tertre, 2017). The more valuable materials such as gold have often been associated with serious human rights concerns, are expensive to mine and refine, and are frequently sourced from unstable regions (Airike, Rotter, & Mark-Herbert, 2016). This creates a strong motivation to recover materials from e-waste, allowing not only a more circular economy that reduces environmental and social impacts from virgin resource extraction but also a more just and fair economy.

To address the social and environmental problem of transboundary movement and disposal of hazardous waste (including e-waste) in less developed nations from developed nations, the Basel Convention entered into force in 1992. The Basel Convention has 187 nations party to it, including Canada, though notably, the United States is absent, and both Canada and the United States have not agreed to the Basel Ban amendment. The Basel Ban is different from Basel Convention in that it outright bans the international shipment of hazardous waste, including e-waste. The Basel Convention requires that the waste categories covered in it have strict tracking, notice, and consent from both national parties shipping and receiving the waste products. Issues of compliance with the Basel Convention are still prevalent. For example, an e-waste tracking exercise in 2016 found that of 205 trackers attached to e-waste products in the USA, 34% (69) were exported, of which 96% (66) were exported illegally. Out of these 66 trackers, 93% (64) of exported e-waste items were shipped to developing nations, and the remaining 7% (5) were moved to other nations in the Americas, including 3% (2) to Canada (Hopson & Puckett, 2016).

Canada is no exception to the international shipping of e-waste issue. From 2010 to 2019, incidents of Basel Convention violations continue to surface. Canada is not a signatory of the Basel Ban ((Basel Action Network, 2011), and as such exports of recyclables from Canada are legal. However, the export of e-waste that is illegitimate and contaminated beyond expectation continues to occur (Basel Action Network, 2015; CBC news, 2010; Nair, 2019). Systemic and jurisdictional issues are especially challenging in Canada, as waste management is a responsibility of the provincial governments, and the federal government has no established domestic monitoring, tracking, categorization system, or collection targets (Giroux Environmental Consulting, 2014; Lepawsky, 2012). There is no national e-waste policy as there are in all European Union (EU) countries, though Canada is not necessarily an outlier with the USA and Australia in similar situations of state-level jurisdiction for almost all e-waste handling (Kumar, Holuszko, & Espinosa, 2017). Issues of jurisdiction and definition continue to plague efforts to address e-waste in both studies and practical measures; when there is no fixed international definition accepted by all parties, responsibility becomes a far murkier subject. In the abovementioned US study, it was stated that of the e-waste exported, “it is likely that 96% of the exports are illegal.” (Hopson & Puckett, 2016, p. 12).

Issues of e-waste collection rates, short product lifespan, public awareness, material composition, product design, producer responsibility, and consumer participation are prevalent (Baldé et al., 2017). In some Canadian provinces, only 62% of the polled population is aware of e-waste recycling programs (Electronic Products Recycling Association (EPRA), 2018). Ongoing concerns over the shortened lifespan of devices raise serious questions about the intent and impact of product design, and the planned obsolescence phenomenon. Regardless, the accelerated pace of electronics consumption, combined with the expanding global middle class in China and India is resulting in the production of more consumer electronics and e-waste than ever before, and more consumption of said electronics in both nations. This demographic shift, in combination with the Basel Ban, 2018 Chinese waste ban, and EU WEEE program capturing EU waste domestically implementation has seen the amount of e-waste processed in China switch from predominantly imported, to predominantly domestic (Zeng, Gong, Chen, & Li, 2016). If this is an indication of future trends, then the fields of e-waste management and design of devices for disassembly and material recovery are only going to become more pressing as Chinese domestic e-waste processing is increasing, and developed nations must expand e-waste processing to manage the waste flow as it too expands.

In many regions around the world, the recovery rates[1] and collection rates[2] of e-waste are not firmly set, or sometimes there are no targets (Baldé et al., 2017; US Environmental Protection Agency, 2012). This includes Ontario before 2008 and after 2014 (OES, 2009). The provinces of Canada, being the responsible jurisdiction for e-waste and waste management, have, since 2004, been implementing stewardship programs and a loosely defined extended producer responsibility (EPR) system (Hickle, 2013). Under these programs, consumers pay fees when purchasing a product and corporations pay based on the quantity of goods entering the province, in order to responsibly process e-waste (OES, 2019). The targets set for each of the Canadian provinces vary considerably, and some lack targets entirely (Maddock, 2017). Quebec and Ontario have had relatively progressive targets set, however, Ontario failed to meet its last set target in 2014, and Quebec postponed any financial penalties for failing to meet targets until 2020 (Maddock, 2017; Ontario Electronic Stewardship, 2015). Other provinces fare worse, only Newfoundland and Labrador have a target set out of the remaining provinces of approximately 2.3 kg per capita and failed to meet it as well collecting only 1.5 kg per capita (Electronic Products Recycling Association (EPRA), 2018; Maddock, 2017). This means that British Columbia, Alberta, Saskatchewan, Manitoba, Quebec, New Brunswick, Nova Scotia, Prince Edward Island, and all three Territories lack targets. Recovery rates from e-waste collected are mandated in the European Union under the WEEE program and have recently been raised from 45% to a target of 65% of EEE sold into the market, *or* 85% of WEEE generated (European Commission, 2012), contrasting sharply with the Canadian provinces.

[1] The amount of usable material produced from the processing of e-waste, represented as the percentage of material recovered from the total e-waste processed

[2] The amount of e-waste brought into the official and proper management system

Chapter 2
Literature Review and Research Questions

2.1 Policy Analysis

There have been many critiques, assessments, and comparisons of national and international electronic waste (e-waste) policy from academia, institutions and non-government organizations, and from the news media (Carter-Whitney, Webb, & Canadian Institute for Environmental Law and Policy, 2008; European Commission & DG Environment, 2013; Hestin, Pernot, Huranova, & Lecerf, 2016; Huisman, 2010; Lepawsky, 2012; Ongondo, Williams, & Cherrett, 2011; Salhofer, 2016). The realities of the impacts of developed nation's disposal of e-waste in the developing world have led to investigative reporting and the attention of the Basel Action Network[3] and social activists concerned with the externalization of our e-waste (Basel Action Network, 2015; Hopson & Puckett, 2016). Comparative analyses have been conducted comparing both developing and developed nations' treatment of e-waste, highlighting areas of concern, for instance comparing solid municipal waste management in Ghana and Canada, or waste electrical and electronic equipment (WEEE) management in Europe and China (Asase, Yanful, Mensah, Stanford, & Amponsah, 2009; Salhofer, 2016). Other policies and regulatory analyses are done by governmental organizations, such as the European Commission's report comparing the various global e-waste management systems to the EU WEEE program for equivalencies (European Commission & DG Environment, 2013). Some analyses were conducted on extended producer responsibility (EPR) policies such as those between Canada and the United States (Hickle, 2013), though the extent to which Canada has true EPR is questionable in the time frame of that study.

Such policy analysis allows for all parties to learn what is effective and what is not in terms of the collection and proper treatment of electronic waste. Where the shortcomings of the systems in varying jurisdictional sizes can be highlighted, the opportunity for improvement is presented. These analyses and this generally expanding field of research is happening at a time of international change in attitudes towards climate science and responsible resource management (Bezirtzoglou, Dekas, & Charvalos, 2011; Cohen, Affairs, International, & Affairs, 500; Section 2 Letcher & Vallero, 2019, Chapter 3; Renwick, Redman, & Maguire, 2013).

[3] A non-governemnetal organization that investigates and reports on possible and known violations of the Basel Convention (Jim Puckett, 1997)

2.2 Tracking and Characterization of Electronic Waste

The tracking of e-waste is an important component of both complying with international agreements such as the Basel Convention (1992) and ensuring that the e-waste generated and collected domestically and legally is properly and effectively processed for its component materials (Lee, Offenhuber, Duarte, Biderman, & Ratti, 2018). Studies show flows of e-waste through entire economies (Babbitt, Chen, & Althaf, 2017; Ohno, Fukushima, Matsubae, Nakajima, & Nagasaka, 2017), investigative analysis done tracking the illegal exports of e-waste from the United States and Canada (Hopson & Puckett, 2016; Puckett, Brandt, & Palmer, 2018) as well as globally (Baldé et al., 2017), and smaller-scale tracking on individual components of e-waste conducted in academic studies (Golev, Corder, & Rhamdhani, 2019; Habib, Parajuly, & Wenzel, 2015; Ueberschaar, Geiping, Zamzow, Flamme, & Rotter, 2017). Tracking of e-waste allows for chain-of-custody to be recognized and maintained thereby improving accountability (Lee et al., 2018). In North America, the R2[4] standard requires that the chain of custody be proven through the tracking of e-waste from upstream to downstream processors (Sustainable Electronics Recycling International, 2014). From a materials perspective it allows the products derived from the recycled products to be determined and quantified, thereby determining processing efficiencies and quantities of products produced.

Tracking the flows of e-waste products that move through the waste management systems to become recyclate and raw materials is valuable information in determining a predictable supply from the recycling market (Golev et al., 2019; Zeng et al., 2016). Studies conducted on the availability of precious metals in e-waste have been conducted for both the broad category of urban mining[5] solid municipal waste[6] and specifically e-waste (Pietrelli, Ferro, & Vocciante, 2019) looking at the availability of multiple common and precious metals (i.e. Copper, Tin, Iron, Aluminum, Lead, Zinc,

[4] The R2 standard is one of the few unifying factors across the North American e-waste processing landscape. The standard is used to ensure that waste materials are properly treated and not dumped or exported to improper recyclers. There remains a substantial amount of e-waste exported illegally from both Canada and the USA, though R2 compliant recyclers generally fare better in compliance (Hopson & Puckett, 2016)

[5] Urban mining is generally the process of mining waste products from existing landfill or directly from consumers for recoverable materials

[6] Solid municipal waste is defined for this thesis refers to municipal solid waste which includes recyclable, organic, and residual materials from residential and industrial, commercial and institutional (ICI) sources as well as materials generated by construction, renovation and demolition (CRD) activities. (Giroux Environmental Consulting, 2014, p. iii)

Nickle, Chromium, Solver, Gold, Palladium) (Sun et al., 2016). The need to quantify and describe the materials available is of increasing importance to the electronics manufacturing industry, tracking the e-waste is an integral part of proving supply security for many of the precious metals needed. A 2016 study concerning the Chinese WEEE recycling industry concluded that in order to close the loop and maintain the supply levels needed for the electronics manufacturing industry, industry and governments need to pay attention and increase research and development of the e-waste recycling industry (Zeng et al., 2016).

As mentioned above, there exist multiple scales at which e-waste can be tracked for varying reasons such as material recovery, ethical considerations for the dumping of e-waste, ensuring compliance with regulations. The smaller scale tracking of the products from the processing of e-waste in pre-processing[7] facilities is useful in assessing the efficiencies that personnel and machinery can dismantle e-waste, shred and sort the materials, and is often used in conjunction with elemental analysis (Habib et al., 2015; Sun et al., 2016; Ueberschaar et al., 2017). At a larger scale, the Urban Mine Project provides an easy-to-use interface for viewing estimates of European data for inputs of EEE, the output WEEE, and the products that are derived from the processing (Urban Mine Platform, 2018b). This project also incorporates other materials such as batteries and vehicles which are tracked in a similar fashion to e-waste through the European economies.

2.3 Canada and Ontario - Electronic Waste Regulation

Canada has emerging and in some cases, progressive e-waste laws, established at the provincial level and delivered through a combination of provincial, municipal, and private services (Alberta Recycling, 2019; EPRA, 2014; OES, 2018b). There is little academic research assessing the impacts, operations, or efficacy of the provincial systems. Globally, numerous studies have addressed e-waste management and regulation in the European Union (see for example, (Ibanescu, Cailean (Gavrilescu), Teodosiu, & Fiore, 2018; Román, 2012; Salhofer, 2016)), some studies have looked at the United States (Hickle, 2013; Kahhat & Williams, 2012; Liu, 2014), while few have focused on Canada

[7] Pre-processing facility for e-waste are generally facilities that: sort, shred, and ship the recyclable materials to smelting or plastics re-processing facilities downstream. They do not completely recycle the e-waste on site, with exception to refurbishment which may occur on site. In Ontario, pre-processors are referred to as “primary processors”.

(Lepawsky, 2012; Toyasaki, Boyacı, & Verter, 2011). E-waste literature in Canada has addressed some case studies of products such as cell phones (Noman & Amin, 2017) and efforts to measure the greenhouse gas emissions resulting from e-waste processing (Lakhan, 2016).

There is little in the way of national oversight from the Federal government. Thus collection and potential material recovery suffer from the lack of a unified regulation, definition and policy. There is no unified categorization of e-waste, and it falls entirely to industry groups to provide the stability of trade and standards nationwide (Lepawsky, 2012). This gap is filled by the industry group, Electronic Products Recycling Association (EPRA), which provides some level of homogeneity using the recycler qualification office (EPRA, 2014; Recycling Qualification Office, 2015). This acts as a form of regulation by which e-waste pre-processors, such as the primary processors in Ontario, can operate by the same standards of e-waste treatment and downstream/upstream certification. To understand e-waste management and regulation in Canada one must understand the relevant provincial regulations and the corporate self-regulation, as there is no unified governmental Canadian system of e-waste regulation.

Among the ten provinces and three territories in Canada, Ontario is the focus of this work. Ontario has had no specific scholarly assessment of its e-waste regulation or e-waste management system to date, though the broad description of the system is touched upon in Lepawsky's (2012) work, which provides an overview of the entire country from a legal geography perspective. Other industry group initiatives have summarized the provincial e-waste programs, such as board members from the Electronic Products Recycling Association (EPRA) who defined the e-waste programs as extended producer responsibility (EPR) programs and addressed the targets set, implementation, and costing until 2017 (Maddock, 2017).

Studies of specific e-waste processing such as cell phones have been conducted, though the degree to which this describes the primary processing facility is limited (Noman & Amin, 2017). The primary processor described is the same as the case study subject in this thesis and is described not only as an e-waste preprocessor, but also a recycler that *produces* "Valuable materials such as aluminum, steel, copper, plastics, and glass" (Noman & Amin, 2017, p. 195). This is somewhat problematic as it mischaracterizes the facility as producing the finished good, as well as what constitutes "valuable" materials. For example, glass is a cost rather than a source of revenue to the primary processor, as they have to pay downstream glass-lead separating facilities to safely process the material (Greentec Inc., 2019).

In 2002, Ontario passed the *Waste Diversion Act*, becoming a leader in Canada for the implementation of stewardship programs. Through its maturation, this program failed to implement full and individual producer responsibility programs (EPR Canada, 2017). In 2016, Ontario passed the *Waste Diversion Transition Act* and the *Resource Recovery and Circular Economy Act,* beginning the transition from the stewardship model of regulation to individual producer responsibility, effectively EPR regulatory model (Government of Ontario, 2017, 2019). The EPR model covers the same key product categories, including tires, some hazardous wastes, packaging, and waste electronics. These efforts aim to improve material recovery as well as overhaul the 2019 system of governance for electronic, hazardous, tires, and chemical wastes (Government of Ontario, 2016). It includes the development of regulations to make producers of specified EEE and batteries environmentally accountable and financially responsible for their products at end-of-life, as well as the formalizing and introducing tracking and reporting for the waste chain of collection, pre-processing, and downstream processing. This development appears to be part of a gradual trend towards EPR style governance and regulation of e-waste in North America, with the province of British Columbia in Canada, and 23 US states as of 2014 having E-waste EPR policies as per Hickle's US definition of EPR (Hickle, 2013). It should be noted that the products covered under the various state and provincial laws vary substantially (OECD, 2016).

2.4 Extended Producer Responsibility

Studies authored from academic, industry, and not-for-profit associations (EPR Canada, 2017; Hickle, 2013; Maddock, 2017) consider the Ontario-2019[8] regulations to be an extended producer responsibility (EPR) system This being said, some specific consideration must be paid to the definition and practical function of EPR. One body that has provided a fairly comprehensive overview of EPR is The Organisation for Economic Co-operation and Development (OECD). The OECD is an international body providing recommendations to policymakers at multiple levels,

[8] **The Ontario-2019 regulation references the method by which e-waste was managed from circa 2002 until February 1st, 2019**. This is based upon the 2002 *Waste Diversion Act* legislation and regulated under the OES. As of 2016 the system is managed under the *Waste Diversion Transition Act* and as of February 2nd 2019, the*Resource Recovery and Circular Economy Act,* though the regulations associated with the latter act will not come into force untill 2020.

usually with the intention to better the economic development of the region addressed. They provide guidance documents, best practice information and reviews of policies that can, and have been, implemented (OECD Publishing, 2019). These guidelines also have environmental and social policy guidance, such as the EPR guidance document (OECD Publishing, 2001). As a member of the OECD, Canada participates in the formation of these documents and can incorporate the voluntary recommendations into its own policy. As per the OECD definition, EPR must: shift responsibility (physically and/or economically; fully or partially) upstream toward the producer and away from municipalities and provide incentives to producers to incorporate environmental considerations in the design of their products.

Within the context of Ontario, the criteria under the OECD definition of EPR have not been met under the 2019 regulation. Though there is substantial investment from producers to process e-waste collectively, there is a disincentive for the individual electronics producers to reduce the e-waste generation once the requirements for processing have been met. In a 2019 review of EPR, three overarching assumptions of EPR are made clear:

1. The main goal of EPR is to induce design changes to reduce waste and encourage design for environment
2. Collective EPR implementations counter the first point
3. More stringent and specific EPR policy parameters will be more effective for environmental outcomes
   (Paraphrased from (Atasu, 2019)*)*

In this regard, the Ontario-2019 regulation may be an EPR scheme, if loosely, though it fails to achieve the first goal, as it is a more collective implementation of the program for producers operating under the EPRA umbrella, including almost all consumer device manufacturers (EPRA, 2019). Each electronics producer simply adds an environmental handling fee to the product which pays for most of the transport and processing of that product type, and the added cost is simply a cost of doing business with no incentive to design less wasteful products. The fee would be added to the product regardless. Though this makes them technically responsible for the products put of the market, there is no tracking of e-waste downstream at collection and processing, simply the finding distributed to primary processors. This funding can go into any product in the same category, not necessarily the products from the producer.

The 2019 regulations are also not comprehensive, as not only they do not apply to all electronic goods, (see Appendices A and D) they also do not attach any requirements for producers to collect their own products (EPR Canada, 2017). This task falls to municipalities primarily, with some help from the Ontario Electronic Stewardship (OES) at the provincial level, and retailers of electronics as drop-off locations for consumers. It is therefore clear that the 2019 Ontario regulation is at best a poorly implemented EPR scheme, but more appropriately simply a stewardship program, whereby contributing funds derived from fees charged to consumers the producers of electronics aid in the collection and processing of e-waste.

Policymakers and regulatory authorities need qualitative and quantitative information to not only draft targets regarding collection and processing of e-waste, but also to report on the progress and status of e-waste collection and processing. The system of e-waste management and processing in Ontario has thus far been opaque and dominated by industry with little provincial and public reporting. There, therefore, exists a need to both describe the system in full, address stakeholders, movements of waste, existing conflicts of interest, and methods of self-regulation. Changes underway for Ontario's regulation of e-waste from the stewardship model to an extended producer responsibility model provide an excellent opportunity to analyze a primary processor (PP), the main entity responsible for the pre-treatment, aggregation and shredding or dismantling of e-waste in the province. Some primary processors also refurbish considerable amounts of electronic goods.

2.5 Research Aim

Based on the lack of literature regarding the practical function of the primary processor in Ontario, the general system in which it is situated, and the processes performed at the primary processor, the primary processor entity merits in-depth research. The material flows of an Ontario primary processor have not been examined before, and though broad data on pre-processing type entities is available internationally, it is not available in the Ontario context for total facility flows. In addition, the adaptations and changes made to these functions and processes that it performs as a result of changing regulations and fiscal realities relating to resource and product pricing are not broadly studied and are therefore also of interest.

The aim of this research is to examine a case study of a primary processor entity in Ontario and to provide a practical understanding of the processing system in place. This work aims to provide an understanding of the landscape of e-waste processing in Ontario in 2019. More specifically, it examines the role(s) the primary processor entity plays in the collection, refurbishment, processing, and regulation of e-waste in Ontario. The following research questions elaborate:

1. What activities and processes take place at a primary processor in Ontario?
2. What is the composition of the inputs and outputs of a primary processor in Ontario?
    a. In terms of product category?
    b. In terms of specific material composition?
    c. In terms of financial flows?

Chapter 3
Methodology

With the problem context now described, and the literature about electronic waste (e-waste) both in a general sense and in the specific circumstances of Ontario shown, this chapter will describe the methodology.

3.1 Methodological Background

3.1.1 Material Flow Analysis

The general approach provided by MFA was chosen for this study for the tracking of materials through the electronic waste primary processor. The MFA methodology lends itself well to this application, as will be expanded upon below. The history, previous and current applications of MFA, as well as the application of the Sankey flow diagram will be described. Following this, the research design will be laid out addressing the research aim and each of the research questions specifically. MFA is a methodology by which the stocks and flows of materials in a system that is physically and temporally bounded are quantified and balanced. This means that all inputs and outputs must be accounted for and the system therefore balanced. Flows are movements of materials through the processes of the system within the temporal and physical bounds i.e. wheat produced per year from a field. Stocks are materials that stay in residence of the system for longer than the defined temporal period, i.e. wheat siloed in storage from that field for *more* than a year.

The following is the general mass balance equation used for MFA:

$$Inputs = Outputs \pm Changes\ in\ Stock$$

In the e-waste management context, all inputs to a waste management facility must be represented in mass[9] added to the facility stock or leaving the facility to be incinerated, landfilled, sold or reprocessed. The materials in stock prior to the study that are processed or exit the facility are also considered. This methodology can be used to track material flows and stocks on a variety of scales

[9] This can also be in units, what matters is the consistent use of such quantifications. i.e. all "per unit" or all in kg, depending on the objective of the measurement.

(Brunner & Rechberger, 2004), for example: the flows of steel in Japan (Ohno et al., 2017), tracking rare earth elements in Europe (Guyonnet et al., 2015), or processing of hard disk drives at end-of-life stage in a pre-processing facility (Habib et al., 2015).

3.1.2 Brief Overview of Material Flow Analysis

MFA and the characterization of anthropogenic systems as metabolisms are fields of study that emerged gradually through the social and theoretical development of the study of human and environmental interactions. Advancing understanding of natural sciences and processes along with the cross-pollination of terminology and concepts between the natural and social studies created the language used. For example, industrial *metabolism* referring to the way in which an organism processes nutrients, whilst addressing the way an industry or facility processes materials. The field developed from the 1860s as sociology and anthropology advanced alongside biology and economics, allowing for the incorporation of economic theory. Sir Patrick Geddes' work in using an input-output table with energy and materials was an early application of the "flows" through a system, in that instance a macroeconomic view of societal metabolism. The 1900s brought about a gradual shift from the economic and natural sciences to a more environmental view of social metabolism and material flows. As early as 1912 the work of Wilhelm Ostwald viewed fossil fuel energies as a limiting factor and believed that solar energy was to be used for human industry. This contrasted sharply with the views of many at the time, including Max Weber, known for being a founder of the field of sociology, who criticized it as a theory full of "mischief". It would not be until the 1960s environmental movement before the environmental perspective began to re-emerge as prevalent in the field. (Fischer-Kowalski, 1998)

In the United States, the modern environmental movement that began in the 1960s and emerged properly in the 1970s did not originate from the 20th century, as mentioned above. Key tenants of environmentalism emerged in the late 19th century such as land and resource conservation (Rome, 2003), though these ideas evolve into the modern discourse until the late 1960s due to several key factors: the incredible affluence of the postwar era (1950s and 1960s), the large scale and rapid expansion and development of nuclear energy and weapons, chemical industries, farming fertilization, synthetic materials and mechanization technologies created new waste products not seen before. Finally, the impact of the field of ecology giving a new perspective on the impacts of human activity on nature created the circumstances which led to the widespread protest of environmental degradation. This helps to explain why the concepts and methodological applications of urban metabolism and the use of material flow analysis became much more popular from the 1970s onwards. (Rome, 2003)

Urban metabolism is a way of conceptualizing a city or region as functions of their inputs and outputs, similar to how organisms require certain nutrients and produce waste products (Fischer-Kowalski, 1998). The application of material flow analysis, described below, to measure an industrial ecology[10] system is an extension of this idea, with multiple industrial processes acting as organisms requiring "nutrients" and producing waste products. By using the waste products and using them as the "nutrient" input for another process, the overall waste produced from the system is reduced, the system rendered more circular and cost savings can be realized (CIRAIG, 2015). Resource conservation studies are interested in this concept for similar reasons to those who wish to create more efficient industrial ecosystems: the overall reduction in materials consumed, waste gases and products produced, and reducing overall environmental impacts.

3.1.3 Application of Material Flow Analysis to Electronic Waste Systems

The use of MFA studies for waste management practices is well documented, with the *Practical Handbook of Material Flow Analysis* even stating the "hidden" intent behind the publication is to encourage responsible materials management and expand the knowledge and technologies of resource management systems to move towards a more sustainable world (Brunner & Rechberger, 2004). As the concept of the urban metabolism is what started much of the systematic study of stocks and flows, originating from environmental roots, it is fitting that the method has evolved to be used in the industrial ecology and resource conservation fields. Studies such as those exploring electronic waste product composition transitions as a result of one technology superseding another (Gusukuma & Kahhat, 2018), and those focusing on specific facilities (Ueberschaar et al., 2017) use material flow analysis to categorize e-waste and elemental products of e-waste processing.

[10] Industrial ecology is a field of study where material and energy flows associated with products, processes, industrial sectors, and economies are systematically analysed at global, regional and local levels..

The MFA methodology is flexible in allowing for the compositional breakdown of single or multiple products or materials indicating end fates, processing methods, and efficiencies of the processes used. Visual representations of, for example, the macroeconomic national scale use of steel using broad categories of steel-consuming “processes” are relatively simple, as many sub-processes are nested within allowing easy comprehension. One of the best ways to represent such models is with a Sankey diagram, a weighted flow chart indicating the metric used (i.e. weight, unit count, energy) and ratios of materials/products/economic value stocked or flowing within the system under analysis. In this example, the processes are industries, such as automotive manufacturing or construction. Contrasting this, micro-level assessments of products and in-depth analyses of systems require the processes to be disaggregated for detail, thus the bounding of the system must be appropriate in order to show detail but still be understandable. Within this thesis are examples of the latter. How each process is defined and how granular the study wishes to be, therefore, determines the complexity of the diagram, and in turn, describes to varying detail the MFA it is based upon. Sankey diagrams have been used in multiple e-waste studies previously (Brunner & Rechberger, 2004; Habib et al., 2015; Husiman et al., 2017; Peeters et al., 2015) and are used in the resource management and industrial ecology fields extensively.

3.2 Research Design

In order to achieve the research aim as set out in section 2.5 the following goals and method to achieve them were set out. Following the planned research design are elaborations on changes made and practical methods used.

3.2.1 Processes Taking Place at the Primary Processor

Addressing research question 1

What activities and processes take place at a primary processor in Ontario?

Observation and assessment of the primary processor were planned in order to create the base upon which the material flow analysis model was to be built. Observing what processes took place at what phase in the facility was to be assessed, in addition to the daily operations that took place such as shipping, movement of goods, sorting, what machinery and manual labour processes were used, etc. This would be used to create a model of the linear and ad-hoc movement of products to processes within the facility based on the products and materials received and sold. The general order of processing, as well as diagrams representing the system, were to be described and generated. Once the general layout and order of processes were established, assessment of the processes was a matter of analyzing the machine type or the manual labour required and inspecting and photographing the outputs from the process.

The primary lines of enquiry into the operations of the primary processor included information from the company and collaboration with the staff, especially the compliance officer on staff. Speaking to the manager of operations, as well as personnel working on the floor would be the main methods to gain insight into the processes taking place from a functional perspective. Inquiring as to the effects of the policy change as the primary processor took part in the consultation process with government offices was to aid in understanding changes that could take place. Visiting the primary processor firm and observing the mechanical processing changes over the two years of study, as well as changes in the allocation of personnel for dismantling tasks would help to understand practical changes taking place.

3.2.2 Material Flow Analysis

Addressing research questions 2, 2a, 2b, 2c:

What is the composition of the inputs and outputs of a primary processor in Ontario?

In terms of product category?

In terms of specific material composition?

In terms of financial flows?

3.2.2.1 Daily Operation Material Flow Analysis

The daily operation material flow analysis (MFA) data collection was planned as a mass survey over three days; two to measure entire facility operations and one to measure the BluBox machine specifically. This was planned to be conducted with the aid of personnel on-site and measure all flows within the facility from opening at 5:30 am until approximately 5 pm. After the facility was assessed for the processes contained within, a database of labels was to be made and printed to attach to the boxes or bins of materials to keep track of the various outputs from the machinery and processing stations within the facility. These processes and the map they made was to be input into STaN (version 2.6.8, 2017) (Cencic & Kovacs, 2017), an MFA software tool used to track and balance mass flows through a system. With the mass collected, the data was to be entered into STAN, and that data later used to create Sankey diagrams to provide visual MFA models for ease of comprehension.

The first and second days of study were planned close together to facilitate the collection of data, maximize the time available to process it, and minimize the risk of processing techniques or machinery changing at the facility. The time of year for the first run (July 5th, 2018) was still considered early in the year, and as such a lower overall mass was measured on that day. Later in the summer, the second run (August 21st, 2018) was busier and thus more inputs arrived from the various sources for the Primary Processing Facility. The third day of study to specifically address the BluBox could not take place due to time constraints and staffing issues at the primary processor. The pyrometallurgical and spectroscopic analyses could likewise not be completed due to time and resource limitations. The paper slips used to track the goods internally were to be collected and the information input into a spreadsheet database. In order to create the Sankey diagrams, e!Sankey (version 4.5.3, 2018) (ifu Hamburg, 2016) was to be employed, using the information entered into the database. This software would be used alongside the database through to project completion.

3.2.2.2 Daily Operation Representation of Sales for Primary Processing Facility

The sales information was to be acquired from various sources in order to comply with the requirement of the primary processor to retain the majority of their financial information. The scrap prices were to be taken from Canadian scrap buyers' websites, indicated by the primary processor, or taken from market prices posted online. In this respect, the levels of error for the prices vary, with some information being updated hourly, as is the case with stock prices, or daily to monthly, as is the case with many scrap buyers. The prices for goods would be averaged across many dealers, with all being from North America (Avada, 2019; BN Steel and Metals Inc, 2019; CMC recycling, 2019; Premier Recycling Ltd., 2019; Rockaway Recycling, 2019), as the primary processor's goods are sold frequently across the US-Canada border depending on market conditions. Once the information was gathered, the daily MFA model would be repurposed with the inputs representing potential value in electronic and the outputs representing the sales value of materials and goods.

Due to time constraints, the input products could not be evaluated and instead a diagram representing only the sales information was created.

3.2.2.3 Annual Data Material Flow Analysis

The collection of the secondary data from the inventory management system's (IMS') at the primary processor was planned for the weeks after the initial daily operation MFA data collection. The information was to be input into a database, sorted by year, material and product type, and presented in much the same way as the daily information. In addition, this information was to be used for cross-checking the data gathered for the daily operations after some weeks had passed to allow the system to process all of the transactions taking place.

Due to data constraints the goal of creating Sankey diagrams could not be realized for the annual data material analysis, the information gathered was entered into the OriginPro version 2019b (OriginLab Corporation, 2019) graphing software in order to provide a visual representation that easily indicates year over year changes in the composition of the inputs and outputs from the facility. To facilitate general data analysis, database searching tools, a database of photos with a searchable index, and tables summarizing all goods processed over the three years with both mass and % composition were created.

Chapter 4
Results

Presented below are the results of the simplified process map and the description of processes operating within the facility, the daily map of material flow, annual data collected, and limitations of the study. Of note is Appendix A and B, which contain the tables of information for the annual material flow analysis and provide supplementary insight into the content in section 4.3.

4.1 Primary Processor General Operation

The electronic waste (e-waste) pre-processing facilities in Ontario are referred to as “primary processors”. Outside Ontario but still within Canada, the terminology varies (OES, 2017). The facility analyzed in this thesis is owned and operated privately, like all the primary processors in the Province of Ontario. The processor is located in the Waterloo Region in Southern Ontario, relatively close to the other primary processors, in and around the Greater Toronto Area. The processor is within 2km of the busiest highway in the country, facilitating the interprovincial and international shipments. The processor operates an approximately 6000m^2 facility near the busiest highway in the country, facilitating the interprovincial and international shipments from its integral multi-bay trucking terminal allowing for a large volume of material to arrive and ship out daily.

The facility accepts all kinds of e-waste, both from the official Ontario Electronic Stewardship (OES) lists and Schedule of e-waste (see Table 5 and Appendix D) from the depreciating 2019 regulation, as well as other items that are delivered. This means that the facility effectively processes e-waste categories: 2: Screens, monitors; (some of category) 3: Lamps; (some of category) 5: Small equipment; and 6: Small IT and telecommunication equipment as per the e-waste categories described in the WEEE directive and *the global e-waste monitor* 2017 (Baldé et al., 2017). Whilst the facility receives small and large appliances either accidentally or within shipments of goods, they only process those whose circuit board value merits shredding. Other items are shipped to more appropriate scrap dealers.

The material enters the facility via the trucking terminal at the rear of the building. This material is a mix of industrial, commercial and institutional (ICI) and household electronic waste (e-waste). This material is sourced from all over the province through the various collection sites operated by municipalities, private collection by the primary processor, and other e-waste aggregators who truck the waste to the primary processor. There is also e-waste from outside of Ontario that is bought or imported for the value of the materials derived from them, as well as through trades with other Canadian e-waste pre-processors.

The processes involved in the processing of e-waste are described in Table 1 below. This table provides information on what kind of labour and function each of the processes serves, as well as the end fate of the materials output from some processes.

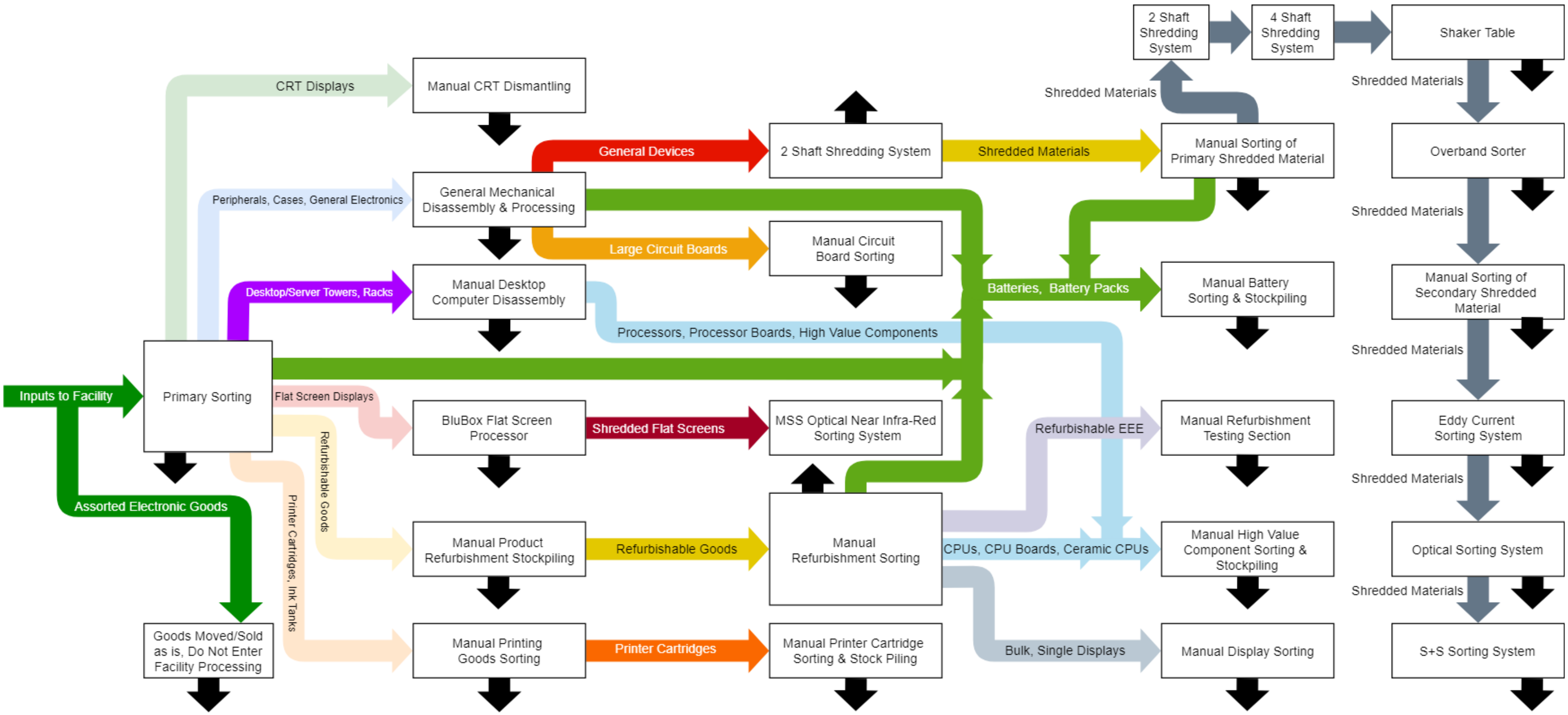
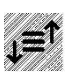
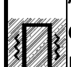
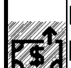


Figure 1 Simplified Process Map of Facility Indicating Majority of Product Flows from Each Process. Note: flow width has no bearing on the diagram, colours here represent different item and material flows as labelled, black arrows indicate that there are outputs from the process that are shipped, sold, or disposed of.

Table 1 Process and Icon Description from Daily Operation Map of Material Flow and Daily Operation Representation of Sales Diagrams

Icon	Description	Icon	Description
	*2 Shaft / 4 Shaft Shredder:* The 2-shaft shredder system shreds items from their largest size to large shred, then the 4-shaft shredder takes this large shred and reduced the particle size substantially. Most materials exiting the 4-shaft shredder are smaller than 12cm in any dimension.		*Near-Infrared Optical Air-Jet Sorter:* The sorting system takes the outputs from the BluBox or the entire shredder line (PCB mixed with plastic) and extracts the plastics, PCBs, metals, and thin films for improved quality.
	*Battery and Battery Backup System Sorting:* Manual sorting of batteries and battery systems in a section of the facility set aside.		*Optical Sorter:* A colour based optical sorter that extracts plastics.
	*BluBox Flatscreen Shredding System:* A standalone shred/sort system that can process CFL bulbs and flatscreen displays into various shredded products. Namely: steel and ferrous metals, 3 sizes of plastics/acrylic, 3 sizes of glass, etc.		*OverBand Sorter:* The overband sorter extracts steel from the shredded materials.
	*CRT dismantling Line:* A multi-station conveyor line of manual labourers who grind apart and then extract: stainless steel, cables and wires, phosphor powder, CRT copper yokes		*Primary Sorting and Received Goods Stockpile:* The initial manual offloading of items from trucks, in addition to the reading of labels, adding labels to pallets and shipments, and sending the items to the various sections of the facility. Items may wait here for some time.
	*Desktop and Server Line:* A multi-station setup located beside the main Shredder Line conveyor belt. Desktops are taken apart by hand, high-value components for resale or smelting are extracted, the remainder is thrown on the line or sorted into bins.		*Refurbishment Department:* Simultaneously a stockpiling of refurbishable items, and a sorting and refurbishment area for such items. A stockpile is located beside an entrance to a separate section of the facility allowing for repairs to be made to all manner of consumer products in a cleaner environment.
	*Disassembly and Pre-Shredding Line:* This is a manual sorting and stockpiling phase that takes place once items are removed from their shipping containers. Once removed, contaminants may be sorted out (hazards, garbage)		*S+S Optical Sorter:* An optical sorter than further extracts PCBs from plastics.
	*Eddy Current Sorter:* Magnetic sorting system, separates the aluminum from PCBs, plastics, and copper metals not separated already.		*Shaker Table:* A large perforated metal platform that shakes the outputs from the 4-shaft shredder to extract "Metal Fines" which contain high levels of precious metals. Metal Fines are one of the most profitable outputs from the shredder line.
	*First / Second Manual Picking:* The First Manual Picking is where large "Large Clip" steel, or large chunks of steel that should not be shredded, as well as batteries, are manually taken off the line.		*Sold Goods:* Items that are sold from the facility, or bought as it may be, resulting in revenue or expense. i.e. Metallic Fines are sold for profit, Panel and Funnel glass is an expense.

	The Second Manual Picking extracts batteries and copper coils from the shredder line.		
	*Hazardous Waste Stockpile:* A metal cart in a corner which holds all manner of hazards (fire extinguishers, airbags, broken batteries). This is taken to a hazardous waste disposal firm as needed.		*Sorted Facility Stock:* Many materials are not addressed on the day they arrive, some are added to the system and set aside, some labelled and placed in staging for their processing activity.
	*Incineration:* Waste that is not recyclable and is prohibitively voluminous to landfill is incinerated.		*Stockpiles of Materials:* Usually, a section of the floor or shelving set aside for the pallets of goods. Mixed-use areas are also common for bulk goods. It should be noted that this is considered a process for this thesis, meaning that each stockpile has flows and stock, as the stockpiles of goods processed and ready for shipment are separate from the stocks of materials *to be processed.* The notable exception is the *MSS Near Infrared Optical Air-Jet Sorter*, where materials may be re-run from the stockpile OR sold.
	*Ink Cartridge Sorting and Processing:* Printer cartridges, ink tanks, and some misc. electronics are sorted, input in the system, and sorted into their respective types. Boxes hold large quantities of each type of industrial or consumer cartridges until sold in bulk. This station has been downsized dramatically since this study took place.		*Waste to Landfill:* Items that are landfilled, usually packaging materials or foams.

4.2 Simplified Process Map

The simplified process map of the primary processing facility, as shown in Figure 1, is a rough outline of the functions and processes performed. This diagram indicates the most likely flows of materials as they move through the facility. All processes are marked with black arrows indicating an output material for sale or downstream processing, with exception to the shredder machinery, as at each processing step indicated there are outputs from the system. There is some discrepancy between the simplified process map and the map of material flow Sankey diagram, namely the aggregation of the refurbishment section and the inclusion in the map of material flow diagram of notable but small processes such as Hazards Stock. There are also no stockpile indicators, as stockpiling is not necessarily a "process" but is certainly important for the map of material flow model due to the fashion in which the facility stores goods pre/post-processing. The "Goods moved/sold as is, do not enter Facility Processing" is a notable process that is absent in the map of material flow. This is because, as is indicated by the title, the goods are simply turned around at the facility stockpile and shipped elsewhere. It should be noted that this process is represented in the annual data, as it is included in the inventory management system[11] (IMS) and could not be filtered out as easily as with the single day of operations. It is, however, a normal flow that deserves mention as a process that takes place. The various sections of this primary processing facility, as shown in Figure 1, are described further in Table 2 below to supplement Table 1, which indicates the specific processes taking place.

Table 2 Sections of the Primary Processing Facility and Associated Processes

Section	Section Description	Specific Processes Taking Place in Section
1. Primary Sorting and Facility Shipping / Receiving	Primary sorting is the separation of goods based on appearance, labelling, product composition, and quality. This takes place at the rear of the facility. The products arriving in bulk with little labelling or easy identification are dumped onto a conveyor system where they are separated manually into the various streams within the facility. Printers and peripheral devices are a large part of this "random" material that arrives. Other materials and products such as small appliances, wiring, computers, modems, and similar materials are sorted and sent to their respective processes or stockpiled for sale.	• Primary Sorting and Received Goods Stockpile
2. CRT Dismantling Line	The CRT processing entails the pulling of CRT displays and televisions onto a belt. The devices are moved to stations at which personnel pull the devices off, angle grind and pry the housings off, placing the large steel components in bins, the PCBs and control modules on the Shredder Line, and the glass separated into funnel and panel glass smashed in large bins. The cathode ray gun is placed in a bin destined for processing as stainless steel.	• CRT dismantling Line
3. General Mechanical Disassembly	The General Mechanical Disassembly is a string of stations where devices of all kinds, with exception to those with specific stations throughout the rest of the facility, are processed manually. The devices have their cables cut off, valuable components such as PCBs removed, housings removed, and are then placed on the Shredder Line. The PCBs are typically placed on the Shredder Line as well, though the housings	• Disassembly and Pre-Shredding Line Hazardous Waste Stockpile

[11] The inventory management system (IMS) is a business logistics system used to document materials entering the facility, processed within the facility, and sold or shipped from the facility. The system used at the primary processor was developed in-house, as such no reference to it is present.

	may be placed in the large steel clip bins as they are too large to shred. Included in this process is the manual pre-shredding line which is composed of a personnel who are “pickers”, removing Christmas lights, ethernet and household cables, mixed plastics, heat sinks made of copper and aluminum and other materials. This acts as a filter to the shredding line which cannot accept all materials	
4. Shredder Line	The Shredder line is the most comprehensive automated system in the facility. The materials loaded on from the other stations, in addition to many materials destined directly for shredding are placed onto the conveyor belt leading to the shredder systems. The materials pass through the shredding system, being broken down to products first medium, and then smaller particle sizes, existing the 4 shaft shredder approximately 6-12cm diameter maximum. The materials are sorted by machinery into plastics, PCBs and copper-bearing materials, steel, aluminum, and are manually picked for batteries and copper coils.	• 2 Shaft / 4 Shaft Shredder • First / Second Manual Picking • Shaker Table • OverBand Sorter • Eddy Current Sorter • Optical Sorter • S+S Optical Sorter
5. Desktop and Server Computer Dismantling Line	The desktop and server line is directly opposite the General Mechanical Disassembly area on the same conveyor belt line. This area has several stations for personnel to dismantle desktop and server computer towers and rack-mountable devices to extract the precious metal-bearing and refurbishable or directly reusable components. i.e. RAM, CPUs, Graphics Cards, Storage Media (HDD, SSD). The motherboards are sorted into the “PCB Sorting” area or are thrown on the shredder line if not easily categorized. Housings are recycled for steel or aluminum, many are not placed on the “Shredder Line” as they are too big.	• Desktop and Server Line
6. BluBox and MSS Flatscreen and Bulb Shredding and Sorting	The BluBox and MSS systems lie in the middle of the facility and operate largely separately from other processes. Depending on the day, inputs of flatscreens of fluorescent bulbs are loaded into the BluBox shred/sort machine, the outputs from the flatscreens then sorted again at the MSS Sorting machine. The bulbs do not require further processing. Large stockpiles of materials are kept at the inputs and outputs of the BluBox and MSS machines for processing and sale. The MSS machine is also used to sort material from the shredder line outputs to increase concentrations of copper-bearing materials. This was a trial run at the time of the study.	• BluBox Flatscreen Shredding System • MSS Near Infrared Optical Air-Jet Sorter
7. Product Refurbishment and Sales	Separated from the rest of a facility in a more secure area are the refurbishment and direct sales sections. The refurbishment starts with the sorting of materials into bulk sales or individual refurbishment. This occurs outside the refurbishment lab where personnel check bulk items such as desktops and laptops shipped explicitly for refurbishment, as well as other sent from different parts of the facility, for obvious defects. Screens are checked for power on at this point as well. Following this, the products that need some work and are valuable enough are repaired in the lab, which also contains the public sales area. Processors and chips sold for their precious metal value are also kept in a secure area near the refurbishment area.	• Refurbishment Department
8. Printer Cartridge Sorting and Assessment	The cartridge section occupied approximately 1/6th of the facility at the time of the study, and through manual labour sorted thousands of ink cartridges and ink tanks into boxes stockpiled for sale.	• Ink Cartridge Sorting and Processing
9. PCB Sorting	The PCB sorting took place beside the shredder line, along the wall of the facility. PCBs extracted from products were brought here to be sorted and stockpiled into buckets and pallets for sale when prices for the materials derived from the PCBs were at a premium.	• Not Represented
10. Battery Sorting and Assessment	The battery section resides beside the desktop and server line, easily accessible for the buckets of batteries picked off the various shredder, desktop and server and general disassembly lines. The batteries are sorted by type, some are checked for reparability and moved to the refurbishment section.	• Battery and Battery Backup System Sorting

4.3 Daily Map of material flow

4.3.1 Daily Operation Map of material flow for Primary Processing Facility

Figure 2, Figure 3 and Figure 3 show the material flows during an average day of operation taken from the two days measured. The stocks and flows represented are combined to create a reasonable representation of what a day could look like in the summer months of the year. The model indicates all processes that were taking place as of the summer of 2018, including mechanical disassembly and manual labour. The division of material processing between mechanized and manual labour is about 50/50 in terms of the processes present, with 10 of 23 processes being predominantly manual. In terms of material throughput on the days in question, the mass processed by manual labour and mechanized processes was about the same, the shredder line being the largest source of mechanized outputs.

The first day assessed processed approximately 16.7 Mg of inputs and produced 18 Mg of outputs, while the second day processed 18.3 Mg of inputs and produced 18.9 Mg of outputs. The map of material flow averages these two days and accounts for processes which had no inputs either on the first or second day by drawing on the other's information. This resulted in an averaged flow input of approximately 25.3 tonnes, and an output of 23.3 Mg. Most flows in this model can be interpreted as somewhat inflated due to the combining of the two separate days, however, the averaged quantities are more representative as there are more outputs from processes that on either of the measured days may not have had any present.

The inputs measuring over a tonne for the map of material flow were printers and peripheral devices (4.7 Mg), laser cartridges (3.1Mg), refurbishable flatscreen displays (2.2Mg), cathode ray tube televisions (2.1Mg), small household appliances (1.8Mg) and complete desktop computers (1.8Mg). The top outputs in excess of one tonne and their target materials for recovery were: panel glass [glass, lead] (4.5Mg), mixed plastics mixed low grade plastics] (3.7Mg), funnel glass [leaded glass] (3.1Mg), computer and communication wires [copper] (2.3Mg), Steel shred [clean steel] (1.7Mg), aluminum shred [clean aluminum] (1.3Mg), and the MSS black plastic shred [low grade plastics] (1Mg).

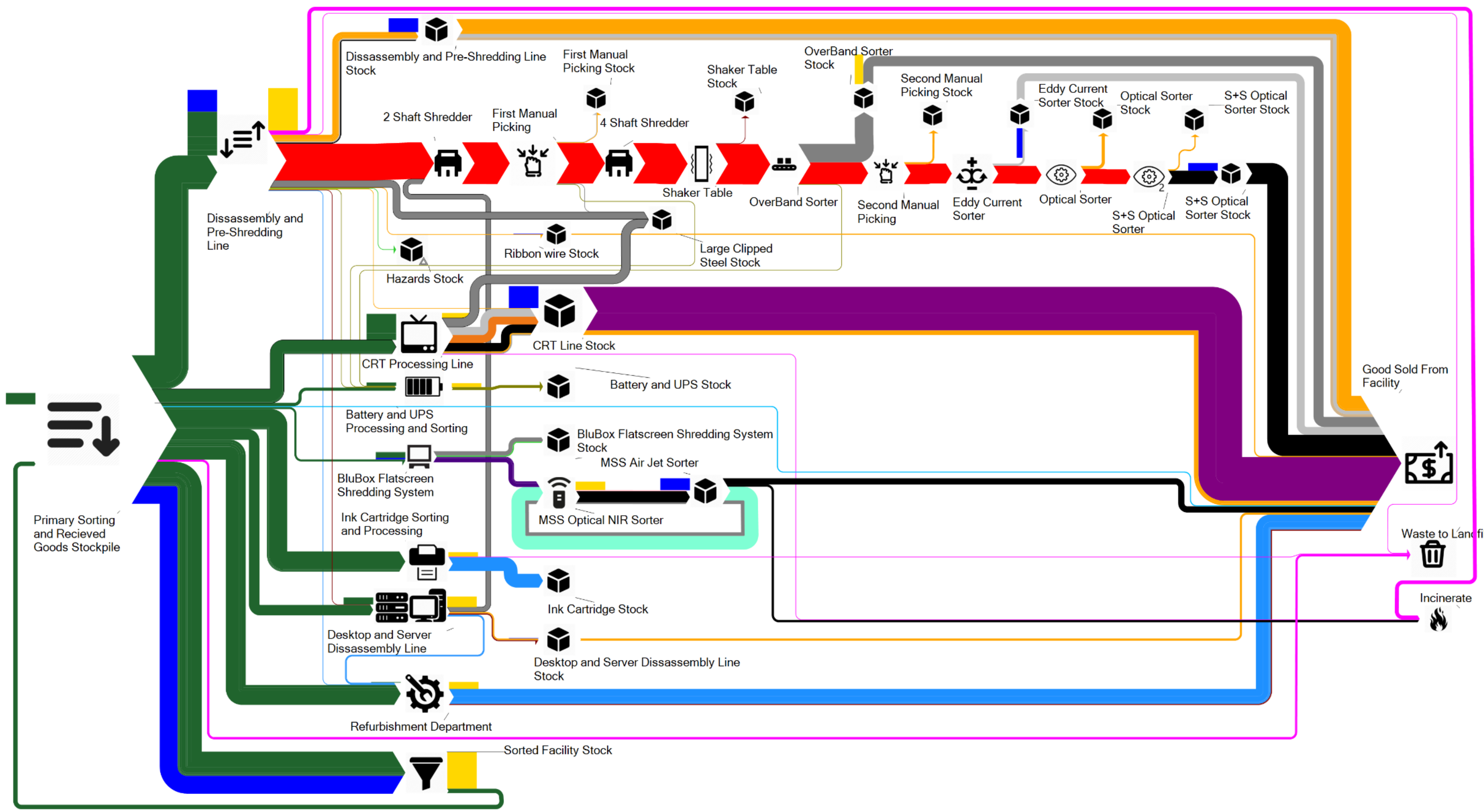


Figure 2 Daily Operation Map of Material Flow for the Primary Processing Facility. Note the colour coded outputs to the model, and the estimated stock inputs and outputs to each section in Gold and Dark Blue. Width is proportional to mass in this diagram, though small flows that would not be visible are enlarged for visibility.

Colour	Target Material or Product	Colour	Target Material or Product	Colour	Target Material or Product	Colour	Target Material or Product	Colour	Target Material or Product
	Inputs to System: Product not Material		Acrylic		Copper Aluminum Mix		Mixed Shred Materials		Shredded Flatscreens
	Stock Input for Model		Aluminum		CRT Leaded Glass		Plastics		Steel
	Stock Outputs for Model		Batteries and Battery Modules		Hazardous Materials		Precious Metals		Wood Waste and Garbage
			Copper		Mixed Plastics		Refurbished Products		

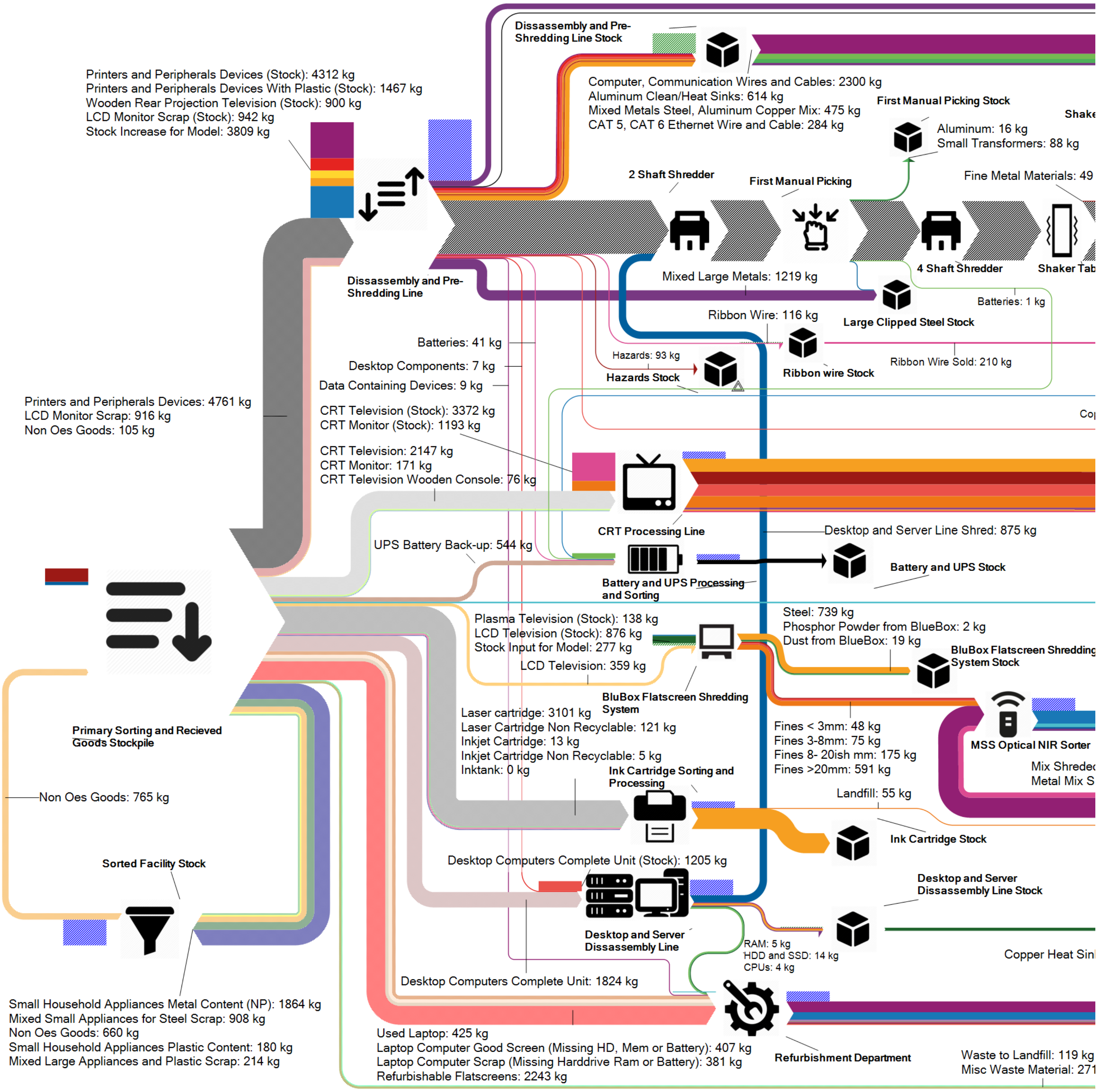


Figure 3 Left Side Disaggregated Daily Operation Map of Material Flow for the Primary Processing Facility Full Image. Note: 50% dot gradient flows are measured inputs, full colours are measured outputs and intermediary flows, upwards diagonal hatching is estimated based on other measured input-output flows.

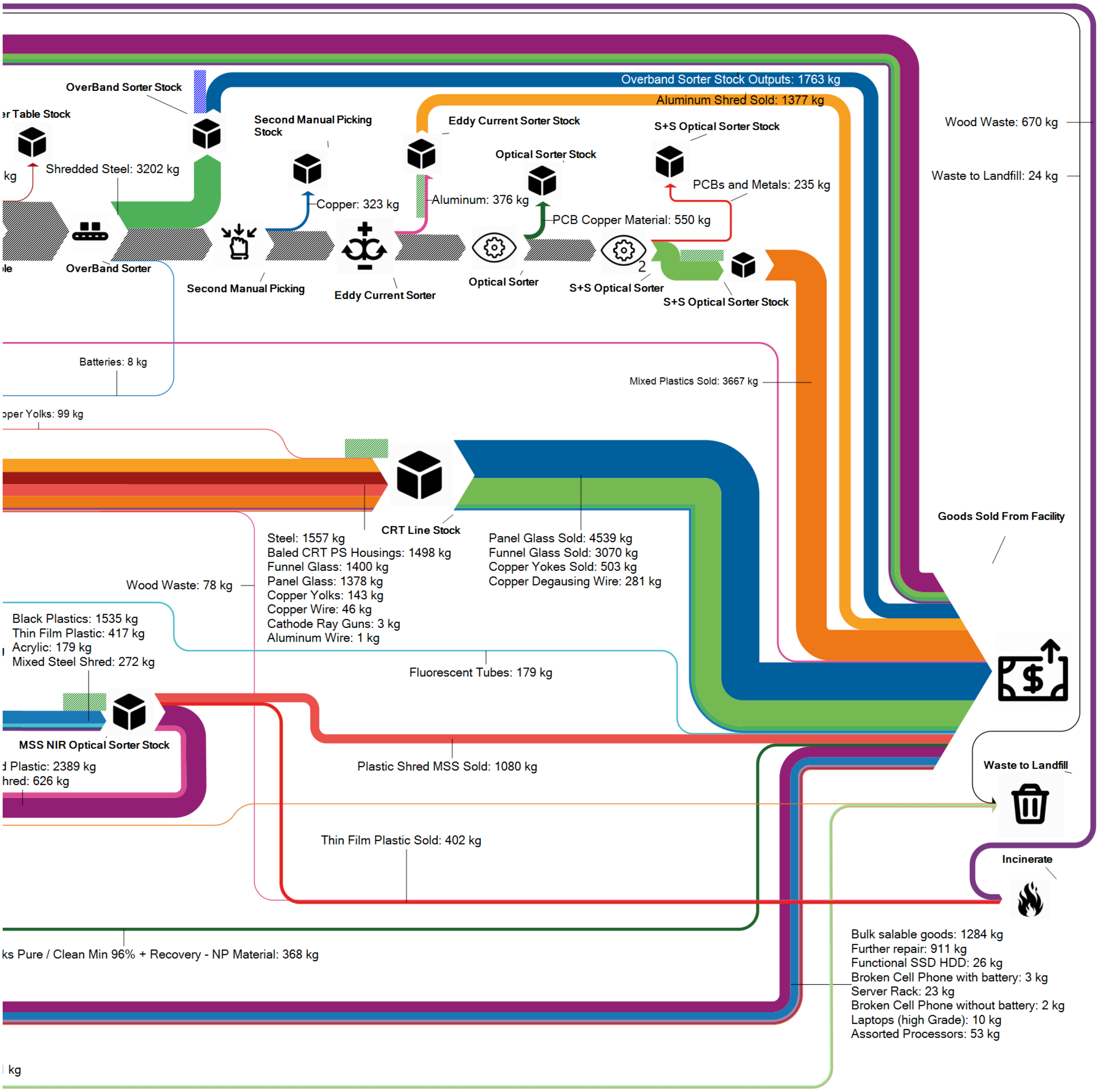


Figure 3 Right Side Disaggregated Daily Operation Map of Material Flow for the Primary Processing Facility Full Image. Note: 50% dot gradient flows are measured inputs, full colours are measured outputs and intermediary flows, upwards diagonal hatching is estimated based on other measured input-output flows. See Appendix B for a single image.

4.3.2 Variability of the Map of material flow

The daily operation material flow surveys that the map of material flow is based on varied substantially, mainly due to the factors like time of year, sales on the day measured, and the composition of the inputs and throughputs to the facility which can vary day to day. This is reflected in the overall larger Facility Input mass, approximately 18.3 Mg in the second run as opposed to approximately 16.7 Mg for the first. The lack of outputs from the facility on the day is not abnormal, for example, the Printer Cartridges that went to the refurbished goods section and were stockpiled.

The number of items delivered, and the date of operation was not, according to the staff, strongly linked. It was indicated that the likelihood of people returning items, especially larger items such as televisions and appliances increases with warmer weather (Greentec Inc., 2019). This is shown to be true for the period studied, if only just, with approximately 54%, 46%, and 53% of sales occurring in the warmer months (May-Oct) of 2016, 2017, and 2018 respectively. This is within the margins of error of this study and, therefore no conclusion of date difference impacting sales can be drawn. Information concerning inputs to the facility was not granular enough to allow for monthly comparison of inputs to the Primary Processor.

Colour	Flow Type	Colour	Flow Type	Colour	Flow Type
(grey)	Unaccounted Economic Value	(green)	Positive Sales Value	(red)	Negative Sales Value (expense

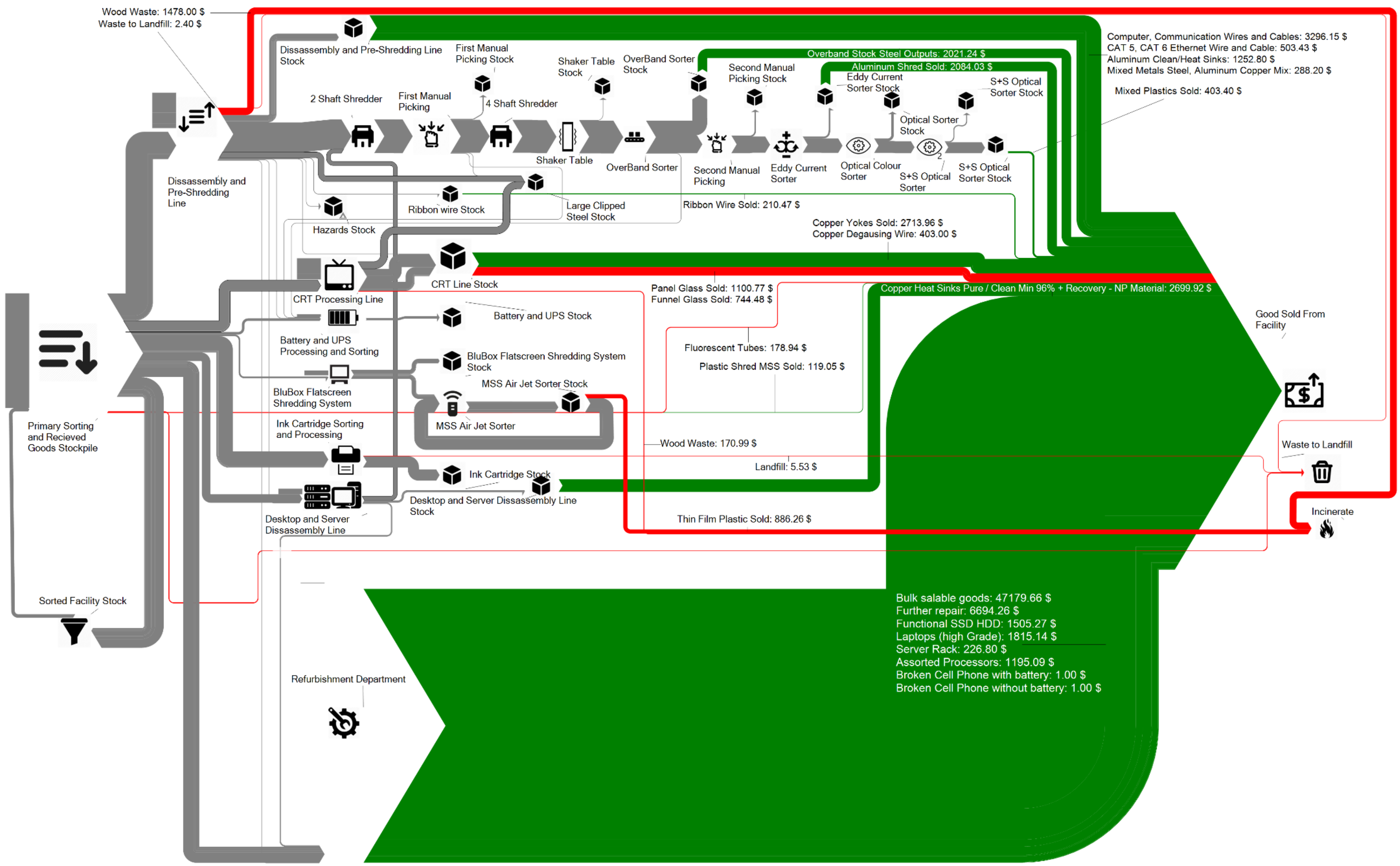


Figure 4 Daily Operation Representation of Sales for Primary Processing Facility, Using North American Market Prices

4.3.3 Daily Operation Representation of Sales for Primary Processing Facility

Figure 4 shows the daily operations sales model, which is a series of averages for the monetary revenues and costs associated with each of the materials sold, measured in 2019 Canadian dollars. This model is intended to give a sense of where the revenue is coming from for the various materials sold from the facility. All materials in the daily map of material flow were taken into account, though with varying degrees of certainty for the price the materials were sold for. The differing types of copper and other metals were accounted for, using lower grade prices for the more contaminated sources, for instance, copper shred from the PCB sorting system, and higher-grade prices for high qualities of copper, such as heat sinks of high elemental purity. Different types of wires such as ethernet or home use wiring, as well as grades of steel and types of plastics were other materials considered. Waste processing fees for landfill and incineration were also considered.

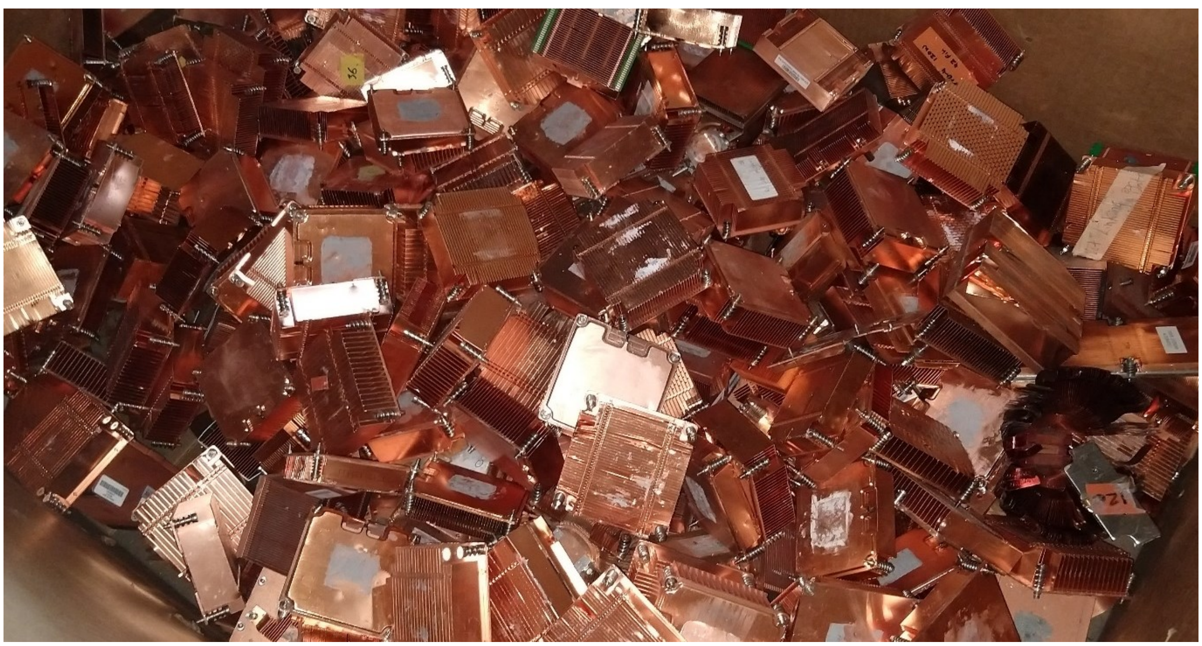


Figure 5 Copper Heat Sinks
Note the high purity of the copper and the small amount of thermal interface material (grey squares on the copper blocks). These heat sinks are almost 100% pure copper.

On the day examined, in total, the firm earned a revenue of approximately $72,000 (CAD) and paid approximately $4,400 in expenses for the processing of materials downstream. The refurbished goods accounted for the largest source of revenue at approximately $57,200, followed by copper-bearing materials such as wires, heatsinks, and copper yokes from cathode ray tube displays at approximately $9,810. Other target materials such as aluminum, steel, precious metals, plastics, and mixed metals earned $3,300, $2,000, $1,200, $522 and $300 respectively. The materials that cost the primary processor for downstream processing were cathode ray tube glass (-$1,800), wood wastes (-$1,600) and thin-film plastics (-$900).

4.3.3.1 Revenue

While by mass about 50% of the sold items were negative or close to break-even priced items, the high revenue per unit for the refurbished items, as well as some of the copper-bearing materials made the measured day strongly net positive for items sold. Of note is the largest flow, the "bulk salable goods" from the refurbished department process. In this case, this is predominantly laptops that are shipped off for further assembly, as all are missing one or two major components, usually RAM and an SSD or HDD[12] as indicated by the material label in the IMS'. These refurbished goods were calculated to have a value approximately one-third of the value of a comparable era laptop sold used from OEMs, this lower value accounting for the profits that the downstream resellers intend to make.

The various copper-bearing materials yielded some revenue, but the most profitable items sold for copper value are the pure copper heatsinks (Figure 5). These machined pieces of metal are almost 100% pure copper, with the potential for some screws made of different materials to be present. These items, therefore, sell for close to the full market value for copper, categorized by scrap dealers as "#1 copper" and are recovered from desktop PCs and servers. Copper heatsinks are placed over the central processing unit(s) and are used to dissipate heat as the computers are running.

[12] RAM or random-access memory is a computer component used for temporary storage. It is comprised of chips which each hold a set amount of temporary data and are made of valuable metals including gold. SSD are solid state drives, so named for their lack of moving parts. These long-term storage media use chips similar to that of the RAM, though built for longer data residency. The HDD or hard disk drive is a series of spindle mounted disks in an enclosure. These disks have small arms which write information to them using powerful small magnets which contain valuable materials that can be recovered.

4.3.3.2 Costs

The highest cost item, which has been one of the most processed items for decades, is leaded glass. This glass comes in two types: non-leaded panel glass and leaded-funnel glass. The panel glass from cathode ray tube (CRT) monitors is recovered from the front-facing section of the CRT display, while the funnel glass makes up the sides of the display and is more opaque. These glass types are separated at the facility and sent to a downstream glass processor at a cost of approximately 375$ per tonne, not counting labour. Other costs calculated were the plastics, predominantly thin-film black plastics, output from the MSS Air Jet Sorter. The primary processor incinerates this material as it cannot be easily processed or recycled as it degrades rapidly in the re-melting process and yields low-quality products when processed. This results in other plastics being targeted by the plastics reprocessing industry, and little market demand for such lower quality products. For this reason, the MSS sorter extracts it from the relatively high value printed circuit board copper-bearing material, and other plastics that may be more valuable (Greentec Inc., 2019). The remaining waste from the facility as accounted was wood materials sent for incineration from the CRT processing line, these being older housings from televisions.

Figure 6 Starting Top Left Moving Clockwise: Wood Waste from CRT Display Processing, Thin Film Plastics from Flatscreen Display Processing, Panel Glass from CRT Display Processing, Hazards Taken from all Processes, all examples of items that incur downstream processing costs to the primary processor

4.4 Annual Data and Adaptations at the Primary Processor

The annual data indicates the volatility of the received products, mass, and composition of the e-waste over three consecutive years. Figure 6 indicates the mass imbalance of the facility, making balanced mass equations calculations impossible. The mass balance indicated that the outputs exceeded the inputs by 2000, 3000, and 500 Mg over the inputs for 2016, 2017, and 2018 respectively. The likely reason being lack of mass data, items measured as "each" and having no references the mass per unit, inconsistent labelling and the IMS' not being designed for such work. For this reason, the information from the Facility Outputs should be considered the “most correct” of the information collected as this is the information that tracked well in the sales IMS and is the most important aspect to revenue and profitability at the primary processor. Goods indicated in the sales IMS suffer from less of the aggregation in the labelling process as they must be sold to consumers and downstream recyclers necessitating a higher degree of specificity.

Figure 6 Flow Totals for the Case Study Primary Processor

The other flows and subcategories of flows measured and described are useful as they indicate the composition of the inputs and internal Facility processing. For the detailed flow composition by category, see Appendix A. The mechanical and manual disassembly and processing are described in the daily processing more in-depth. The compositional shift in the products flowing into the facility and being processed are somewhat in line with the products seen entering waste streams in Europe (Huisman, 2010; Urban Mine Platform, 2018a), such as a dramatic fall in CRT displays, an increase in the number of flat-panel displays, and an increase in portable computers entering the Processing Facility. Whilst the mass of the inputs is known, the error indicated by the mass discrepancies makes it unreliable, see Appendix B for graphs of the mass information. Figure 8 shows the percentage composition of such inputs, the percentage composition which in this case, tells the most important transitional story avoiding the confusion of the high variability of the regular mass numbers.

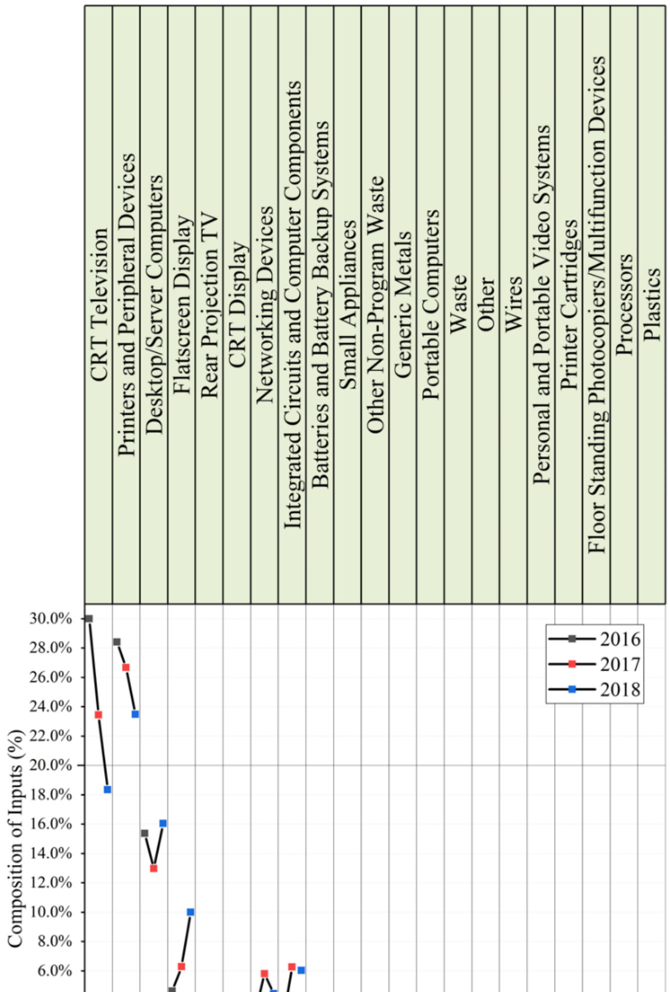


Figure 8 Composition of Facility Inputs by Product Categories, in percentages of the total composition, 2016-2018.

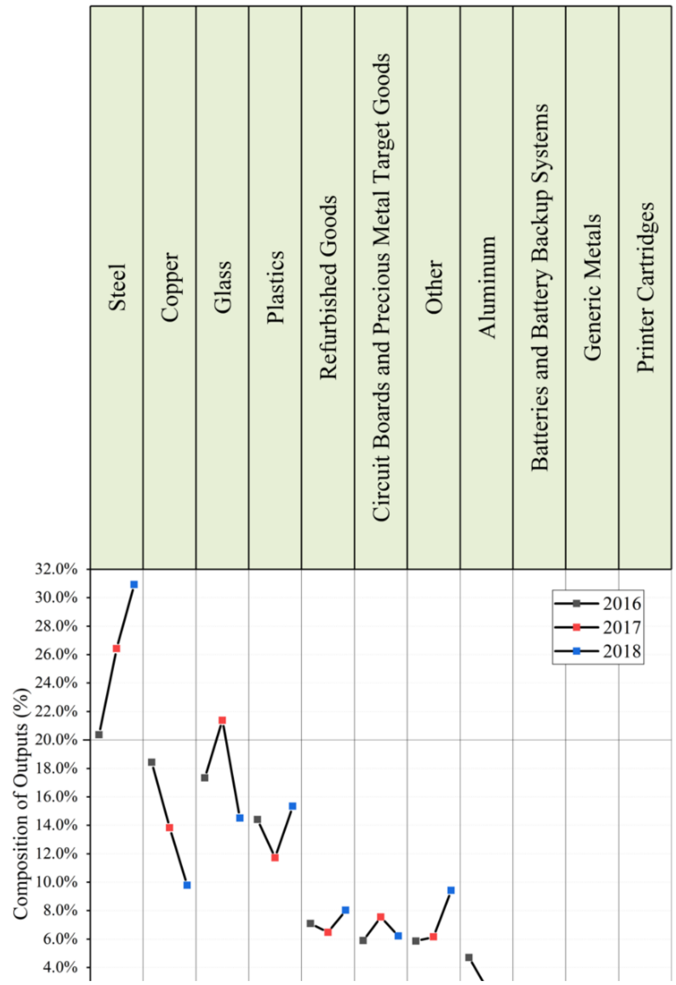


Figure 9 Composition of Facility Outputs by Product Categories, in percentages of the total composition, 2016-2018.

4.4.1 Composition

The above graphs indicate both the inputs and outputs of the facility as measured in percentage composition of the totals for each year. The dataset is also available in much higher detail in Appendix A. This information is useful in ascertaining possible trends and looking at what valuable materials may be of interest to the processor and industry in the future. Most importantly it indicates the changes taking place in terms of e-waste sourced and sold from the facility as it changes for a different regulatory landscape and increased processing capacity. Of note is the "Other" category that is predominantly CRT sales to other businesses. Waste shipments both coming in and exiting may be several times larger than indicated due to measurements not being kept as they happened off-site, though the measured mass was incorporated into the "other" output for the facility outputs due to its small percentage representation. Other notable outputs not represented are the high-value items processed primarily for gold and palladium, as well as some copper. Some of the most notable and precious outputs are seen below in Table 3, the processor outputs, in particular, are associated with the highest recovery rates of gold and as such are stockpiled in a vault in the primary processing facility.

Table 3 Circuit Boards and Precious Metal Target Goods, by Percentage and Mass, Sold per Year

Product Type Sold	2016 (kg)	2016 (% of Circuit Boards and Precious Metal Target Goods Sold)	2017 (kg)	2017 (% of Circuit Boards and Precious Metal Target Goods Sold)	2018 (kg)	2018 (% of Circuit Boards and Precious Metal Target Goods Sold)
Motherboards	18,8698	36%	221826	29%	87,721	22.1%
Shred	44,105	8.5%	84,934	11%	140,905	35.4%
Gold Finger Boards	27,270	5.3%	45,620	6.0%	24,187	6.1%
RAM	12,063	2.3%	11450	1.5%	11,930	3.0%
CPU	6,596	1.3%	5,146	0.7%	2,915	0.73%
Other PCBs	239,480	46%	389,541	51%	129,967	32%

4.4.2 Business to Business and Commercial Trading

Through the annual data and staff remarks the Processing Facility indicated that while there are general product trends being followed, other active measures are being taken to target certain markets, devices and product types to increase profitability. As of 2018, the Facility operated a dismantling and sorting machine called a BluBox to process flat-screen devices and fluorescent bulb products. This machine has allowed them to target flat-screen displays aggressively in the marketplace and led to selling and buying of e-waste products with other Ontario and Canadian primary processors, thus allowing the processor to trade away CRT displays for flat screen devices. This trading has decreased further the CRT displays entering the Facility. Other strategies that are exemplified by the data are targeting the Business-to-Business and Institutional (B2BI), sometimes known as Industrial Commercial Institutional (ICI) waste streams, and gradually pulling out of the printer cartridge refurbishment and processing waste stream. This has resulted in a significant drop in the outgoing Refurbished Printer Cartridges (see Figure 7,) though they still account for the largest mass of refurbished materials sold as of 2018.

The B2BI waste stream has provided larger quantities of refurbishable materials to be sold in bulk, such as Portable Computers, which rose by 14% from 2017 to 2018 and account for substantial revenue to the Primary Processor. This is also reflected in the substantial increase of 3.9% for Refurbished Desktop Computers from 2017 to 2018. Figure 4 indicated the profitability of this revenue stream, namely refurbishable laptops sold. The targeting of high-value refurbishable items was an excellent move as the value degradation, even with cheaper electronics, is simply much more favourable for the Primary Processor.

Chapter 5
Discussion

The case study of a primary processor entity in Ontario provided a practical understanding of the processing system in place. Both major and minor activities and processes were identified and characterized at the primary processor in Ontario and were outlined and their functions described in Table 2. The order of operations, nature of the labour used, and the general facility functions were described. Using the Sankey diagrams presented, the approximate physical flow of goods is also modelled through the facility, in addition to the sales information as a result of a single day of operation. The primary processor is situated as a versatile entity that ships, sorts, shreds, dismantles, refurbishes, and sells both bulk materials and products as well as individual materials. The studied primary processor operates as a transporter, aggregator, drop off location for the public, processor, and refurbisher.

This multi-roll is a somewhat unique position as many other processors do not focus on refurbishment to the extent that the subject of this thesis does. According to the primary processor and the listed activities at other firms, many focus more on shredding and dismantling, shipping reparable goods to refurbishment specialists. This focus on refurbishment positions the primary processor studied as a more versatile entity, capable of weathering poor economic conditions regarding bulk material pricing with the better returns from bulk and individual refurbished device sales. Despite the mass of goods entering and exiting the refurbishment section being comparatively small, the value of the items processed exceeds all others for the daily data collected and extrapolating this to annual data indicates that this revenue stream is valuable and expanding.

The composition of the flows to and from the processor for both the annual data and the average day was categorized and calculated by target material. The average day information was sorted based on product and material type and presented in Figure 2 in its aggregated target material type. For the annual data, a more detailed analysis was performed for the categorization in regards to the searchable database of materials within the various broad categories, though the data presented is also in an aggregated format, consistent with the categorization of the daily information. The daily data was also created with more granularity, see Figure 3 and Figure 3, as well as Appendix B for the disaggregated flows.

5.1 Comparison to literature

One of the most similar studies conducted in relation to the work done regarding material flow analysis of the primary processor within this thesis is *Assessment of element-specific recycling efficiency in WEEE pre-processing* (Ueberschaar et al., 2017). This study contains several commonalities and key differences to this thesis' work, but the overarching results and scale are very similar. The objective of the Ueberschaar et al. study was to harmonize methodologies and provide guidance to further plant level pre-processing study, making it directly relevant to this work. The goal of this thesis was broader, to provide insight not only into the material throughput of the Ontario primary processor but also the general operations and adaptations being made to account for regulatory and e-waste product composition changes.

Both Ueberschar et al. and the current study considered an e-waste pre-processing facility. Under the Ueberschaar et al. study, the quantity of e-waste assessed was approximately 40 Mg over a single 11-hour operation, whilst at the primary processor in Ontario, approximately 35 Mg were assessed over two days of operation, each approximately 10 hours in length. Both studies provided simplified maps of the material flow as it moves through the facility. Under Ueberschaar et al. the processes taking place are significantly simpler to display as there was no refurbishment section, sorting of refurbished material such as cartridges, or secondary automated systems such as the BluBox for specialized goods. This is due to the study using pre-measured sample loads such that the inputs of materials at an elemental level could be estimated, and the output fractions sampled against that estimate.

The most obvious and prominent difference is the elemental analysis conducted, as this is the focus of the Ueberschar et al. (2017) study. Chemical analyses were conducted to determine precisely the composition of the various output fractions, a task that was not possible within the constraints of this work. Where the work within this thesis provides insight that is not the focus of the Ueberschaar et al. work is the broader function of the primary processing facility. The processes taking place at the Ontario primary processor are more varied, with significant flows moving into the refurbishment section along with flat-screen displays routed though the BluBox processing line, the primary processor lacks the linearity of the pre-processor described by Ueberschaar et al. This creates a more complex system, one that is both more interesting but also difficult to assess with the same sampling methodology. While the CRT, BluBox, and shredder lines, alone with the PCB sorting could all be assessed on an elemental basis fairly using the same methodology presented in Ueberschaar et al, the printer cartridge sorting, refurbishment, and reshipping aspects of the Ontario primary processor are not so easily described. The elemental composition of a functional laptop sold as a refurbished product is irrelevant when the goals of refurbishment and resale are met.

Comparing the output fractions from the mixed inputs of both this thesis and Ueberschaar et al., the key difference lies in the CRT processing line and the use of stockpiles. By removing the CRT line and accounting for the outputs from the processes entering the stockpiles, the composition of the outputs increases in similarity. The dominant outputs for both become mixed plastics, steel and copper fractions. Curiously, the aluminum output from the Ueberschaar et al. study is quite low compared to the amount produced at the primary processor in this work (approx. 3.35% vs 11%). Other differences include the lack of landfill waste generated. While in the supplementary material it alludes to a fraction of the manually sorted material could be categorized under “metal-poor material” and further to “commercial and residual waste”, none is reported in the study. This contrasts with the admittedly low quantity measured for the material flow accounting at approximately 9.5%, though as per the limitations section this should be taken as a conservative estimate.

The work conducted in this thesis may appear lacking in the sense that the inputs were not predetermined and analyzed, as is the case in other studies. Instead, the inputs were effectively random as to what arrived on the two days of study. The eventual real limitation is the specific product identification, for example, the make and model of television, ie. “SONY Bravia 23 inch” CRT, vs the general description such as “CRT television”. The input goods indicated on the map of material flow were presented disaggregated for specificity, and aggregated for ease of understanding, as the data gathered specified the goods in detail. Though using the inventory management system in addition to manual measurement did not allow for a full accounting of the goods, the issues arising from an incomplete data indicated above, it did allow for these input products to be easily identified by type. This allows for further analysis of the material outputs should the opportunity arise to study the sampled materials, as comparisons to existing studies of the material composition of the inputs could be drawn upon to address the input elemental composition information using product category averages.

Another European study of the pre-processing efficacy and function is presented by Chancerel Meskers, Hagelüken, & Rotter in 2009. Though somewhat dated, this work is similar to the study conducted by Ueberschaar et al. as it measured a baseload for input, processed it through a pre-processor, and used the material assay from a smelter to determine the mass of metals and materials contained in the output fractions. Comparisons with this study are limited, but for the output fractions, copper-bearing materials, precious metals, and plastics are all similar percentage compositions. Other materials vary substantially, ferrous metals such as steel accounted for 32% of the 2009 study's outputs, whereas the Ontario primary processor produced only 7% within the day. This study did, however, track significant production of garbage, though substantially less at 2.4% as compared to 6.4% by Chancerel Meskers, Hagelüken, & Rotter (2009).

This study uses assumed quantities of precious metals and base materials in products flowing into the pre-processor and reaches the conclusion that regarding printed circuit boards, which contain many of the valuable and rare metals targeted in e-waste processing, the shredding system reduces the concentration significantly (Chancerel, Meskers, Hagelüken, & Rotter, 2009). This is notable as the Ontario primary processor is as of 2019 preparing to expand shredding capacity, as well as expand the types of goods being placed on the shredder line. With the goals of the new regulation explicitly encouraging a more circular economy, it remains to be seen whether the higher throughput of materials through the Ontario primary processors will result in less-than-expected outputs of materials such as silver, gold, and palladium.

5.1.1 Cathode Ray Tube Analysis

Of the processes tracked within the facility, the CRT line presented one of the easiest comparisons to other studies. The daily operation material flow analyses indicate that the efficiency for the dismantling of CRT monitors was similar to that of other studies conducted on CRTs specifically. The main differences lie in the quantity of steel produced, though it was clear from the dismantling process that the steel extracted from the CRT had some contaminants, but this does not account for the large discrepancy. Reasons for the discrepancy also include the methodology of disassembly. The *Common CRT Display* information was taken from a Chinese language study concerning efficient dismantling in a “scrapping” environment, similar to that of the primary processor (Jinhui & Yonghong, 2003). In a lab environment, care is taken to extract each of the components and categorize them, whereas the speed and volume at which the dismantling occurs at the primary processor do not allow for such methods in order to maintain profitability.

Table 4 CRT Composition Comparison to a Lab Environment Disassembly, and Common CRT Display Circa 2002

	Ferrous Metals	Aluminum	Copper	Other metals	Plastic	Printed Circuit Board	CRT Glass	CRT Lead	Other
CRT Monitor[1]	*3.00%*	*1%*	*4%*	*1%*	*17%*	*12%*	*56%*	*6%*	*0%*
CRT TV[1]	*6%*	*1%*	*2%*	*0%*	*21%*	*10%*	*54%*	*6%*	*0%*
Common CRT Display[2]	*30.5%*	*2.2%*	*3.1%*	*0%*	*18.7*	**0%*	*46.3%*		*1.8*
Measured outputs from CRT dismantling line[3]	23.5%	0.02%	3.5%	0%	22.5%	**0%	49.3%	*0%	1.2%

Note:
[1] Source: (Babbitt et al., 2017) from a lab-based study of the composition of e-waste products disassembled individually
[2] Source: (Niu, Wang, Song, & Li, 2012) with information from 2002 CRT study, similar bulk dismantling to Ontario primary processor
[3] From this thesis
* not measured
** the outputs of the PCBs were put through the conveyor shredding system on-site, and as such were not measured at the CRT station

CRTs are a diminishing waste flow and have a low value, as the majority of their outputs from the dismantling process are of low economic value for recycling. In the case of the leaded and unleaded glass, the value is negative as the glass is a cost to process safely. The plastics derived from the process are also low value, the black polystyrene housings are especially hard to find a good market for, and even baled at high purity the value was indicated to be extremely low (Greentec Inc., 2019). This is partially a result of cheap oil and the poor economics of plastics recycling (Gelles, 2016; Markets Insider, 2019).

The time frame in which the study was conducted, in addition to the limitations, makes it difficult to assess trends in processing at the facility. While the annual data is not long-term in the sense that trends over the past decade of the evolution of the composition of electronic waste (e-waste) can be reflected. It is instead more accurately a snapshot of the primary processor's activity as it prepares for changes to both regulation and quantity of e-waste to be processed. The targeting of products for processing is of particular interest, as the primary processor entities in Ontario are few in number, and with the targeting of certain goods, the capacity for the system to processes all goods may change. If, for example, the primary processors simply began to outsource the processing of CRT displays in their entirety, to a much greater extent than is being done by the subject of this thesis, the purpose of both proposed and existing legislation would be defeated. This information will be valuable in comparing the composition of the annual flows through the processor in a post-2020 Ontario regulatory system when the extended producer responsibility regulations have come fully into effect.

Though the primary processor is the focus of this work, the literature review and regulatory overview presented to aid in situating the processor within the web of e-waste processing in Ontario. Chancerel et al. presented a paper which situated the European pre-processor in the network of waste electrical and electronic equipment (WEEE) processing (Chancerel et al., 2009). The regulation of e-waste in Ontario is as of August 2019 quite literally in a state of transition, moving from the *Waste Diversion Transition Act (2016)* to the *Resource Recovery and Circular Economy Act (2016)* under new regulatory operation from the resource productivity and recovery authority. In order to situate the Ontario primary processor, the regulatory framework in which the firm operates is described in detail below in Section 5.2.

5.1.2 Printed Circuit Boards and "Other" materials

As indicated in European data viewed in the *Urban Mine Platform*, the amount of PCBs used in electronics is stable or falling, and a good portion of this is due to lightweighting and miniaturization (Urban Mine Platform, 2018a). The social trends in using tablets, phones, and ultra-slim and compact computers, in addition to cost reduction because of more powerful system on a chip have meant that the same tasks are accomplished with a smaller PCB, smaller processor die, and overall fewer physical resources (Kasulaitis, Babbitt, Kahhat, Williams, & Ryen, 2015, p. 9). This trend of smaller and lighter PCBs continue with consumer and office products. As screens become thinner, laptops slimmer, and desktop personal computers (PCs) enter a new era with compact motherboards, and ultra-compact desktops such as the one-litre-and-less internal volume PCs (Intel Corporation, 2019; Lenovo, 2019; Via embedded, 2008).

The "Other" category in both the inputs and the outputs can be quite confusing, many materials in this category are inputs or products that were such a small percentage on their own they did not warrant a category such as random single products, for example, air conditioning units that arrive spuriously. There was a large amount of materials not labelled at all with masses measured and attached to the label name they are, these and others that such as those that used catch-all labels (i.e. names such as "product destruction and recycling") are indicated in this category. Many of the outputs for the "Other" category were sales of CRTs, the majority of which in 2018 were sold to other Primary Processors nationwide.

5.2 Ontario Electronic Waste Regulation

The Ontario provincial government is responsible for the regulation of most waste materials within its boundaries, with some financial and guidance support from the Federal Government (Environment and Climate Change Canada, 2017). The regulation of e-waste in 2019 for Ontario (Ontario-2019) is based on the legislation *O. Reg. 393/04: Waste Electrical and Electronic Equipment Under Waste Diversion Act, 2002, S.O. 2002, C. 6*, and through this legislation the Ontario provincial government has mandated Ontario Electronic Stewardship (OES) with managing the e-waste program. The OES has been, as of 2013, managed and operated by the Electronic Product Recycling Association (EPRA), an electronics producer's industry group, which is led by a board of directors composed of representatives from Samsung, Apple, Dell, and other electronics and electronic retailer corporations[13].

The OES acts as an intermediary for funds, enforcing the requirements for e-waste processing at the primary processors with the option to withhold funding. This funding is derived from two sources: the environmental handling fee charged to consumers at the time of product sale, and the fees paid by the producers of electronic goods proportional to the sale of those goods into the province of Ontario

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[13] 2018 composition of the board of directors: Jeff Van Damme, Chair: Samsung Electronics Canada Inc., Chris Gouglas: Best Buy Canada Ltd., Peter Maddock: Panasonic Canada Inc., Elena Papakosta: Dell Canada, Kristyn Rankin: Apple Canada Inc., Giro Rizzuti: Costco Wholesale Canada, Mark Shanahan: Staples Canada Inc., Cedric Tetzel: London Drugs Limited

(OES, 2009). For further information on the targets for collection from 2009 to 2014, as well as a list of the environmental handling fee covered product categories, see Table 5.

Table 5 Ontario Electronic Stewardship Environmental Handling Fee (EHF) Final Product Categories and Consumer Fee Price Table

Ontario EHF	**May 1st, 2015 - February 1, 2019**	**As of February 1, 2019**
Product Category	Price	Price
Display Products ≤ 29”	$12.25	$0.00
Display Products 30-45"	$24.00	$0.00
Display Products ≥ 46"	$39.50	$0.00
Desktop/Countertop Computers	$1.40	$0.00
Portable Computers	$1.00	$0.00
Desktop/Countertop Print, Copy, Fax & Multi-Function Products (and Scanners)	$8.00	$0.00
Floor-Standing Printing, Copying and Multi-Function Devices	$31.75	$0.00
Computer Peripherals	$1.00	$0.00
Home Audio/Video Systems	$5.00	$0.00
Personal/Portable Audio/Video Playback and/or Recording Systems	$0.75	$0.00
Home Theatre in a Box (HTB) Systems	$5.00	$0.00
Vehicle Audio & Video Systems	$4.00	$0.00
Non-Cellular Telephones and Answering Machines	$1.50	$0.00
Cellular Devices & Pagers	$0.07	$0.00
Source: (OES, 2015, 2019)		

Inspection and monitoring of primary processors and other OES approved entities is conducted by the OES. Provincial inspectors conduct many of the health and safety audits required by law for waste processing facilities. It should be noted that Ontario takes a more active approach in regard to e-waste management with the use of a provincial level regulatory body, as opposed to the EPRA run models in other provinces, such as Quebec, Nova Scotia, and British Columbia. Ontario-2019, therefore, operates in a hybrid industry-provincial model of regulation enforcement.

5.2.1 Regulation 2020 +: Resource Recovery and Circular Economy Act

With the passing of the *Resource Recovery and Circular Economy Act, 2016* the previous act was rescinded, and the target to wind up the operations of the OES set for December 31st, 2020. The new entity responsible for the regulation of e-waste, as well as other waste streams, in Ontario, was established as the Resource Productivity and Recovery Authority (RPRA) (Government of Ontario, 2019). This new regulatory oversight body had the board of directors set out as being appointed by the Minister of the Environment, Conservation and Parks (formerly Minister of the Environment and Climate Change) as well as appointed by the government-appointed members of the board itself. This differs from the Ontario-2019 regulation, where the board of directors of the OES was a set group of industry and retail representatives.

With the RPRA in place and guided by the defining principals of the 2016 Act, the consultation of stakeholders for, and implementation of, extended producer responsibility (EPR) programs began. First, the new vehicle tire EPR program was rolled out, ensuring that tire manufacturers were responsible for the recovery of the products. Following this, a consultation phase was opened for the drafting of e-waste and battery EPR regulation.

Proposal summary

We are proposing regulations that will make producers of electronics and batteries environmentally ***accountable and financially responsible*** *for the waste generated from products they supply into Ontario. The regulations will set requirements for collection, management and consumer education,* ***as well as incenting waste reduction activities.***

(Ontario Ministry of the Environment, Conservation and Parks, 2019)

Between the battery and e-waste regulations, the new language of "Individual Producer Responsibility" has been used to describe an EPR style system of regulation, putting the responsibility for the collection and processing of e-waste on producers. This system fills the requirements as set out in Atasu (2019) whereby: the EPR system explicitly incentivizes waste reduction activities as is indicated in the proposal summary quoted above, the individual aspect of the EPR regulation make if far less collective and more specific, and there are much more stringent requirements for collection and reporting (Atasu, 2019). This proposed regulation is by these qualities a significant improvement over the previous stewardship model.

5.2.2 Stakeholders

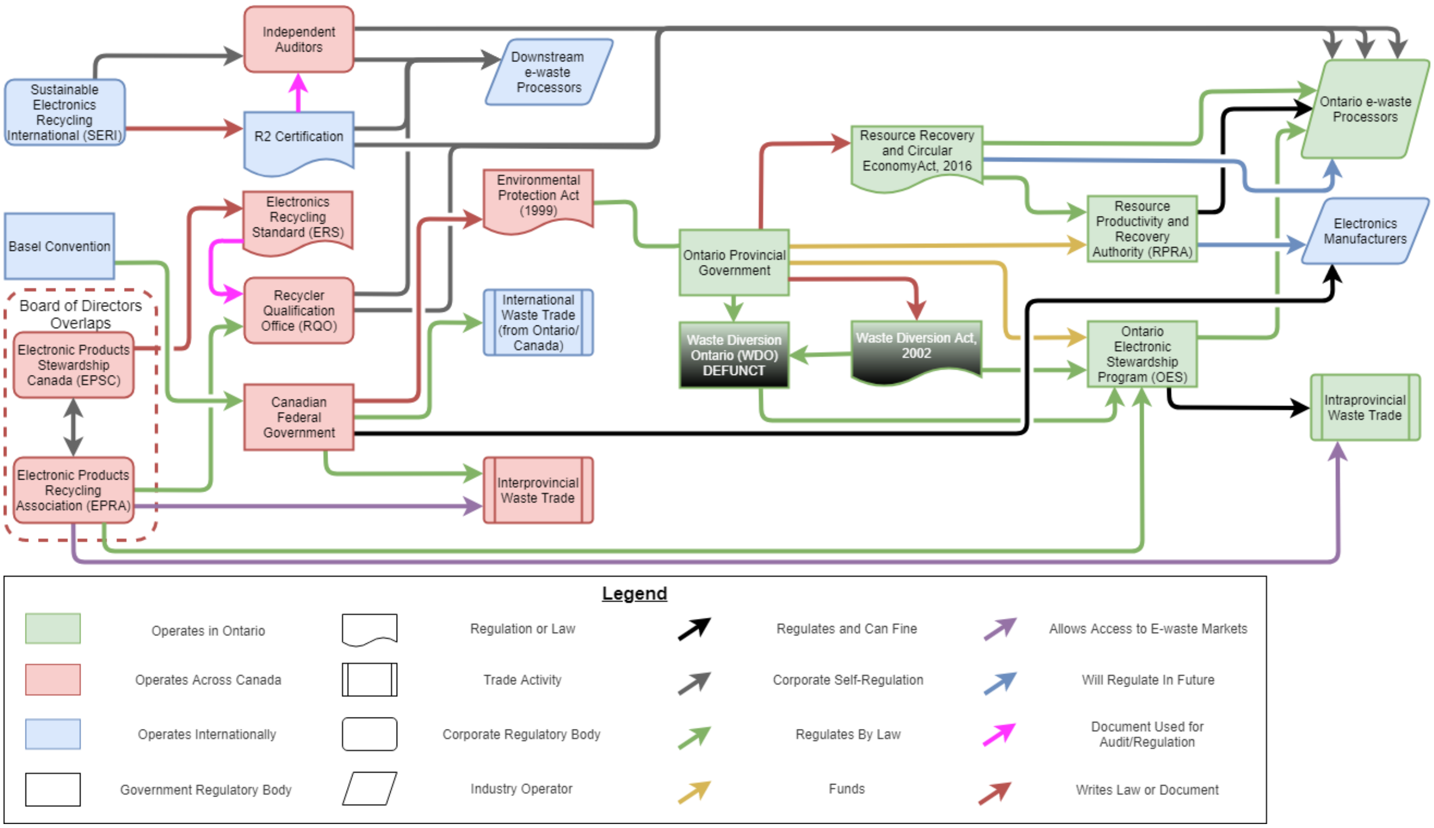

Figure 7 Ontario E-waste Regulatory Authority Flow

Figure 7 is a simplified summary of the Ontario regulatory map or the "flow" of authority regarding e-waste management. This map indicates which actors govern others, and what authority they hold over others. The "Corporate Self-Regulation" can be interpreted as mandatory regulation for the intent of this figure, though in reality, e-waste processors can exist outside of it. Under Ontario-2019 no primary e-waste processor type actor exists outside of the OES system as the access to interprovincial e-waste markets and trade is too valuable. The most notable changes indicated in this figure are that the new system under the RPRA will have expanded abilities to fine non-compliant processors, and through the EPR program hold the producers accountable to the required collection and processing targets. The future regulatory system is indicated in light blue. Another factor that is notable but less important directly to Ontario is the Electronic Product Stewardship Canada (EPSC) body. In function, it is simply a national electronics producer association like the EPRA, including the board of directors overlap. The EPSC advocates explicitly for a non-regulatory approach, spearheaded and operated by EPRA type industry actors at the provincial level. The EPRA functions nationally nested under the EPSC.

5.2.3 Collection of Electronic Waste in Ontario

There is no set collection service for electronic waste in the province. The Ontario-2019 system uses an amalgamation of city-wide collection services such as municipal collection from roadside pickup and drops off collection days and OES run collection sites. In addition, there are privately-run collection services run by e-waste processors themselves and other waste aggregators. As such the flow of e-waste in Ontario is neither uniform nor linear, as there is no predetermined path for the e-waste to follow. i.e. the path of *Collector/Collection Day* → *Transporter* → *Aggregator* → *Transporter* → *Primary Processor* would represent only some of the e-waste collected. This makes a summary of the flows through the province difficult, if not impossible to attach concrete values to, as not all actors follow R2 or Basel style tracking methods where a chain of custody must be maintained. Figure 9 indicates the broad nature of the electronics and e-waste flows in Ontario and some of the highly circular flows of the system at each phase. Though indicative of a circular economy of goods in that there is demand for reuse and refurbishment of electronics, this more indicates a lack of organization and pursuit of profit at each phase of an electronic product's life. The multiple roles that each actor plays complicate the system further: manufacturers are even now processing some of their own products, are requesting components back from refurbishers, and are further beginning to target consumers in order to maintain the intellectual property and value of goods. For example, server systems that enter into the e-waste system are treated specially, occasionally to ensure destruction of hardware or return of components such that the used market does not cut into their sales.

Other flows are less clear, and not easily represented: there is international waste trade especially imported from the USA, there is trade between provinces of electronics both reparable and waste products, and there is inter-corporate trade between primary processors for maximizing product yield depending on the e-waste processors specialty. The specialist e-waste processors are international and Canadian, such as those that process cell phones for metals. The scrappers and metal recovery businesses also act as aggregators and may be inserted into this model under the "scrapper" category. Aggregator corporations compete directly with returns to stores, e-waste processor collection, citywide collection and personal storage of goods to get their products into their waste streams.

Under the OES guidelines, there are “Re-user or Refurbishers” that refurbish goods for resale, however, on company websites, they refer loosely their ability to “recycle” goods as well (OES, 2018a; RDLong Computers, n.d.; Tech Wreckers Inc., 2013). This can lead to further competition for the OES payments that cover transportation and some processing costs, as the initial receiver of the goods receives the stipend. In summary, many of the actors in this waste stream share rolls, compete for e-waste and Provincial funding through the OES and must compete with Canadian’s habits of storing their electronics, see Figure 8 for example.

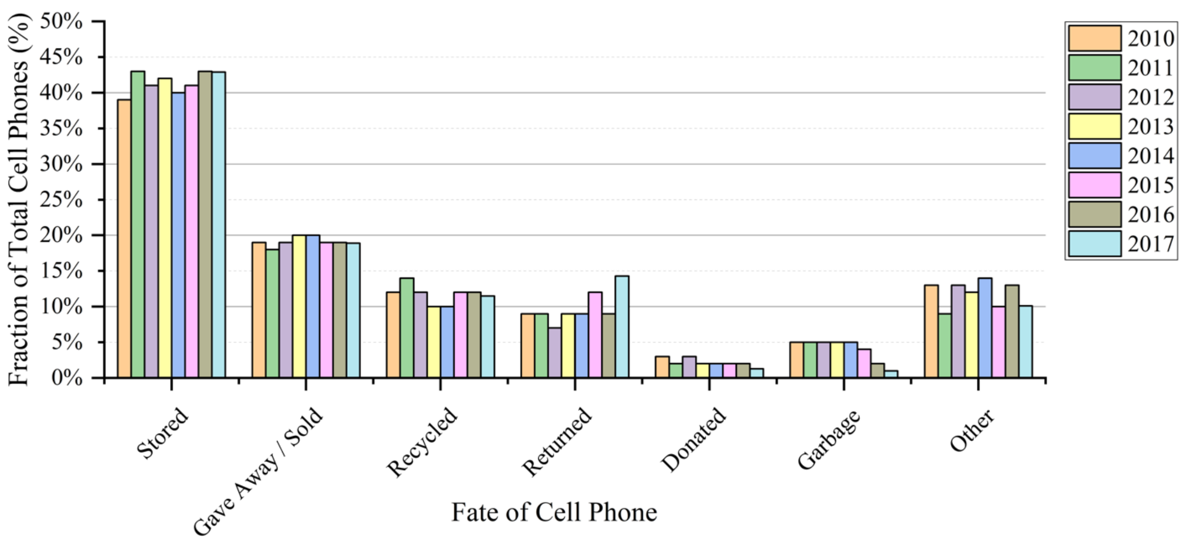

Figure 8 Fate of Cell Phones in Canada 2010-2017. Data from Canadian Wireless Telecommunication Association Surveys sourced from Way Back Machine (archive.org/web/). The current website for Recycle my Cell found here (www.recyclemycell.ca/facts-and-figures/)

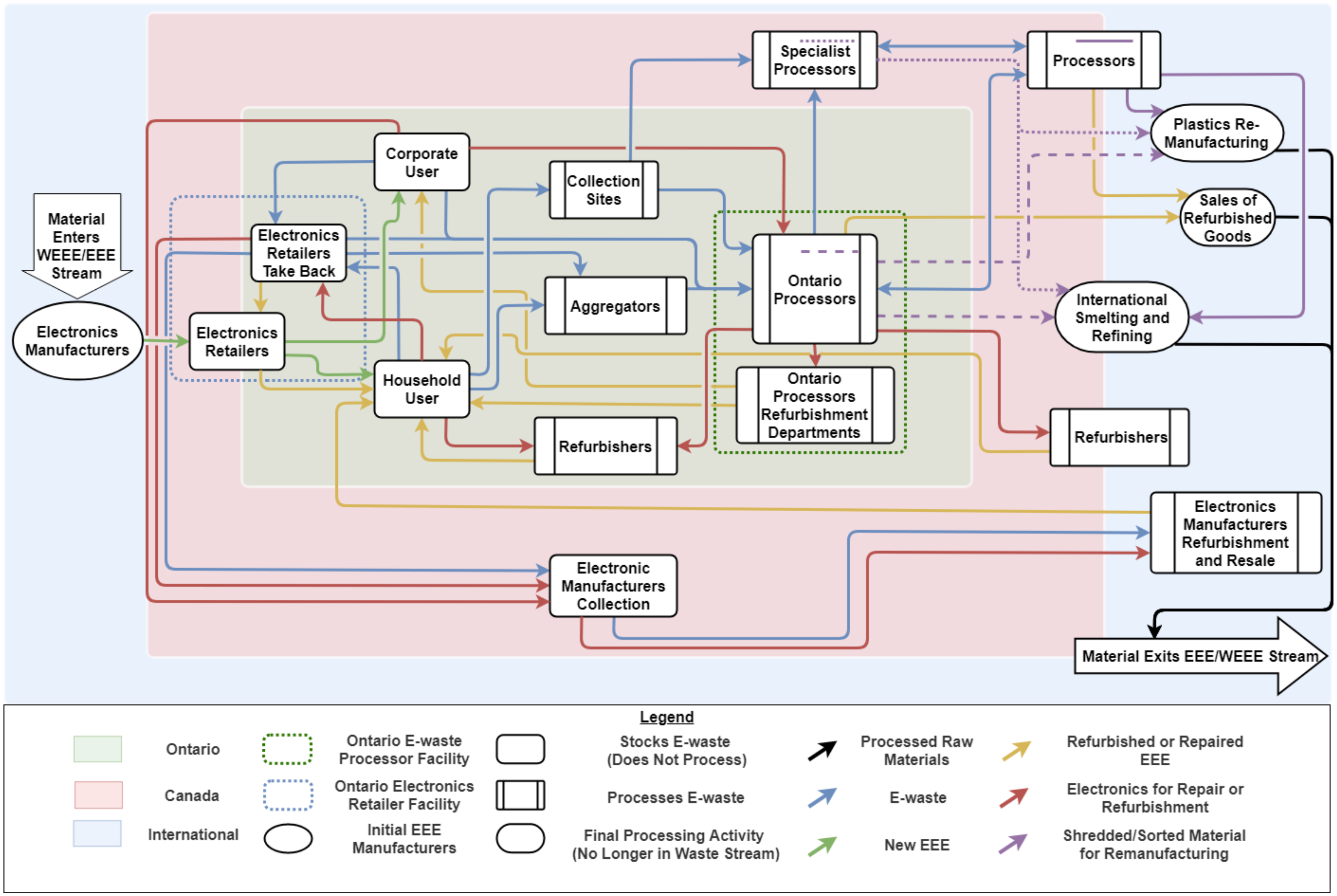

Figure 9 Typical Provincial Material Flow of E-waste

5.3 Future of the Primary Processor in Ontario

The context for the primary processor in Ontario is changing with the new 2020 regulations, with new regulatory entities and a new contractual chain of agreements to process the e-waste. With the implementation of the 2020 extended producer responsibility regulation, the burden of funding and proof of processing will fall to the electronics producers. This means that though primary processors will be contracted either through producer responsibility organizations or directly from electronics producers to ensure that the can and do process the electronics and quantity of electronics required by the 2020 regulation. The facility is responding to the expected increased processing demand for processing with larger and more automated processes to handle the waste flow. This includes expanding the shredding technology, as well as dismantling the printer cartridge section to allow for more space to store and processes other goods.

These decisions are motivated primarily by economic reasons, as increasing the shredding capacity allows for fewer employees to be present to process the same quantity of products. The focus on the refurbishment, as indicated in Figure 4, allows for disproportionate revenue to mass benefits compared to other bulk materials. The refurbishment counts on industrial, commercial and institutional (ICI) and other large entity contracts to maintain the bulk refurbished item sales, though items recovered from the standard e-waste stream also afford opportunities for refurbishment. Large shredding lines appear to be the norm in Ontario for primary processors, as the established network of refurbishers through the OES approved refurbishing firms allows them to ship electronics worth repairing to these locations. The extraction of valuable processors, as well as other gold, palladium, silver and high purity copper items for individual processing and sale also appears to be the norm.

The context of Ontario's primary processors is an interesting overlap of the mandated functions and responsibilities associated with two generations of regulation, and the underlying profit motive which forces change upon the industry in sometimes severe and sudden ways. The dependence upon the international resource markets, international and domestic metals and plastics refining and reprocessing results in this volatile system that is now seeking more automation and leaner function. The risks associated with the increasing shredding automation of formerly manual pre-shredding and manual disassembly are that there will be less critical and precious metals such as gold, silver, and palladium collectable even if they are targeted in the smelting process. The trade-off of better recovery is mitigated somewhat by sorting machinery that decreases contamination of plastics contained in many of the shredded outputs. This is still somewhat problematic, as within the purpose of the regulation is to recover the purest and highest quantity of precious and valuable metals. Without more specific regulation and funding to address the issue of volume processed over quantity of precious and valuable metals recovered, the primary processors have little choice but to increase automation to keep up with demand.

5.4 Limitations of This Work

The limitations of this work are listed as follows:

- Detailed material characterization of each output with similar processes as mentioned in Ueberschaar et al. (2017) was not achieved due to time constraints and lack of access to testing equipment. Such detailed analysis would allow for a comparison of the two systems - a step towards analyzing the effectiveness of the Ontario primary processing facility as compared to European pre-processors. (Ueberschaar et al., 2017)
- Though the IMS data provided by the facility incorporated many aspects of the flows analyzed, other information was fundamentally flawed, be it through lack of labels, aggregated data lacking clarity, or data not measured in the IMS and tracked separately.
- One of the most notable missing mass flows is waste to landfill. The reason for this information not being recorded in this thesis is because the mass is only measured at the landfill for the dumping fee. This information was not made available as it was not found in the timeframe necessary for this study.
- Some masses measured on-site for the daily operation mass flow mapping had to be averaged as the tare weight was not taken. Other materials were not measured due to human error. The issues with the IMS and the fluidity with which the label names of certain materials and items changed over the three years considered was also problematic. It remains entirely possible that some items were missorted or placed in the wrong broader categories due to this. Researcher mislabelling is also a concern, as all data was manually categorized, and sorted into constituent broader categories, in about two-thirds of cases this was done using an automatic system that searched for the product were manually labelled and re-used the category given.

The above-mentioned limitations mainly affect the annual material flow data due to lack of information regarding the individual products sold by unit, therefore not being represented by mass in such mass-based quantification and analysis. The overall picture of the annual data is still more or less accurate, with the bulk of the data aligning with the primary processor's sales reports and internal auditing, mass balances, and practices. This is especially true of the sales and output information, which after a comparative analysis was the most correct and most similar to the internal tracking at the facility.

5.5 Future Avenues of Research Regarding the Primary Processor

Future work on the subject of primary processors should focus on providing elemental analyses of the output fractions from the various processes with the facilities. Ensuring compatibility with existing studies by using similar sampling methodology, such as those compared to above, would be advantageous, as the efficacy of material extraction could be measured against different systems. Comparisons between primary processors within Ontario would also be advantageous in determining the most suitable destinations for the various e-waste products processed within Ontario, allowing for effective distribution of processing responsibilities and potentially increasing recovered material yields. This would also aid in determining if the primary processor studied is an outlier or the norm. Future study of the impact of changes to Ontario's e-waste regulation on the primary processor, post Ontario-2020 regulation implementation would allow for the longer-term changes to be identified. This could focus both on the processes used in the facility and the composition of the inputs and outputs.

Chapter 6
Conclusion

This research focused on the processing of electronic waste (e-waste) at an e-waste primary processor in the Region of Waterloo, Ontario. It assessed the facility using material flow analysis of daily operations in a map of material flow, annual material flow data, and the effect of market and regulatory developments at the facility. The work presented provides a snapshot of operations at a primary processor and background information on the changing regulation of e-waste in Ontario.

This information helped to build a profile of what the firm can process in a day of operation. The variety of inputs and outputs indicate that while efforts are being made to reduce inputs of CRT displays and printer cartridges, large flows of these products continue to be processed. The product categories arriving at the facility largely constitute the Ontario Electronic Stewardship materials list, the same as the products listed in the environmental handling fee lists. The products gathered are processed targeting higher value materials such as copper, aluminum, and gold, with lower value materials such as plastics and steel recovered and sold at varying purities. The majority of the outputs are low-value or negative value materials such as large steel pieces, leaded glass, and black plastics. The elemental composition of the output materials was not determined, though the samples were taken and labelled.

The large quantity and focus on refurbished goods output from the facility is advantageous both environmentally and financially, as the shredding of goods massively lowers the value per unit mass. These refurbished items are sourced from industrial, commercial and institutional (ICI) clients, indicating that the direct relationships between primary processors and ICI clients are highly valued.

Another aspect learned from the study is the variability in the flows to and from the primary processor. This leaves much to be desired from a business perspective, with the volatility of bulk goods markets for metals and plastics shadowing the recycling industry. Changes to the e-waste regulations could provide needed stability to industry actors, such as primary processors, and could lead to the long-term viability and increased business interest in the e-waste material recovery industry, one required to address this growing and complex waste stream.

This work sought to describe, quantify, and describe qualitatively the flows for the daily and annual operation of a primary processor, in addition to the processes taking place at the facility in order to situate the primary processor in the chain of e-waste management in Ontario. Overall, this work achieved these goals, surpassing some with the additional information made available to the primary processor. This thesis did not describe the outputs to the specificity originally intended, though it did incorporate more information from discussions and observation of the primary processor that eventually provided useful context and described the practical changes taking place at the time of the study. It described the primary processor's rolls, processing capabilities, and the processes used on site. Input and output flows were calculated for the daily information in both precise and aggregated formats (product and exact material description vs target material) providing detailed graphics of the processed goods. It is the researchers hope that this information is useful in moving the discussions of the rolls, funding, and regulation of primary processors and electronic waste in Ontario as this waste stream and the processing methods continue to evolve.

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Appendix A

Supplementary Tables

Table A1 Categorical Breakdown of Facility Inputs

Facility Input Category	2016 kg of Category	2017 kg of Category	2018 kg of Category	% of 2016 Facility Input Mass (kg)	% of 2017 Facility Input Mass (kg)	% of 2018 Facility Input Mass (kg)	% change in % composition 2016-2017	% change in % composition 2018-2018
CRT Television	2,032,148.76	1,634,364.86	1,081,494.16	29.99%	23.45%	18.34%	-6.54%	-5.11%
Printers and Peripheral Devices	1,925,677.34	1,858,786.96	1,385,379.47	28.42%	26.67%	23.49%	-1.75%	-3.18%
Desktop/Server Computers	1,040,740.03	903,842.00	946,405.28	15.36%	12.97%	16.05%	-2.39%	3.08%
CRT Display	242,694.31	216,025.00	136,069.59	3.58%	3.10%	2.31%	-0.48%	-0.79%
Rear Projection TV	270,774.11	223,610.93	159,643.20	4.00%	3.21%	2.71%	-0.79%	-0.50%
Networking Devices	215,379.38	403,963.28	262,331.51	3.18%	5.80%	4.45%	2.62%	-1.35%
Flatscreen Display	314,090.61	438,711.36	589,260.31	4.63%	6.29%	9.99%	1.66%	3.70%
Batteries and Battery Backup Systems	167,138.77	134,207.38	128,226.53	2.47%	1.93%	2.17%	-0.54%	0.25%
Other Non-Program Waste	85,223.13	120,147.75	82,418.37	1.26%	1.72%	1.40%	0.47%	-0.33%
Small Appliances	93,747.59	139,978.19	237,685.58	1.38%	2.01%	4.03%	0.63%	2.02%
Portable Computers	50,009.22	88,996.73	146,910.68	0.74%	1.28%	2.49%	0.54%	1.21%
Generic Metals	70,029.79	105,111.45	60,803.17	1.03%	1.51%	1.03%	0.47%	-0.48%
Integrated Circuits and Computer Components	174,465.33	437,186.79	355,694.52	2.57%	6.27%	6.03%	3.70%	-0.24%
Waste	35,091.74	93,254.49	62,383.01	0.52%	1.34%	1.06%	0.82%	-0.28%
Wires	16,002.21	31,366.90	40,913.33	0.24%	0.45%	0.69%	0.21%	0.24%
Personal and Portable Video Systems	11,070.83	8,805.59	9,067.31	0.16%	0.13%	0.15%	-0.04%	0.03%
Printer Cartridges	10,106.49	8,099.57	923.51	0.15%	0.12%	0.02%	-0.03%	-0.10%
Other	20,656.46	96,536.78	209,552.90	0.30%	1.39%	3.55%	1.08%	2.17%
Floor Standing Photocopiers/Multifunction Devices	1,045.98	1,947.27		0.02%	0.03%		0.01%	-0.03%
Processors	415.38	1,559.40	1,795.75	0.01%	0.02%	0.03%	0.02%	0.01%
Plastics	201.07	23,150.01		0.003%	0.33%	0.00%	0.33%	-0.33%
TOTALS	*6,776,708.54*	*6,969,652.69*	*5,896,958.19*					

Table A2 Categorical Breakdown of Facility Outputs

Mechanically Processed Goods (MPG) Category	2016 kg of Category	2017 kg of Category	2018 kg of Category	% of 2016 MPG Category Mass (kg)	% of 2017 MPG Category Mass (kg)	% of 2018 MPG Category Mass (kg)	% change in % composition 2016-2017	% change in % composition 2018-2018
CRT Television	1,980,042.68	1,556,769.20	1,072,434.06	33.98%	29.29%	22.60%	-4.69%	-6.69%
Printers and Peripheral Devices	1,622,695.17	1,565,954.04	1,309,168.96	27.84%	29.46%	27.58%	1.62%	-1.88%
Desktop/Server Computers	978,477.00	833,905.73	799,788.08	16.79%	15.69%	16.85%	-1.10%	1.16%
CRT Display	249,099.78	211,111.01	116,561.35	4.27%	3.97%	2.46%	-0.30%	-1.52%
Rear Projection TV	267,564.11	216,014.75	127,405.02	4.59%	4.06%	2.68%	-0.53%	-1.38%
Networking Devices	144,013.90	282,440.85	216,264.68	2.47%	5.31%	4.56%	2.84%	-0.76%
Other Non-Program Waste	116,464.80	105,230.96	60,960.14	2.00%	1.98%	1.28%	-0.02%	-0.70%
Flatscreen Display	159,411.14	230,042.47	519,454.93	2.74%	4.33%	10.94%	1.59%	6.62%
Small Appliances	89,926.07	90,297.09	197,535.39	1.54%	1.70%	4.16%	0.16%	2.46%
Batteries and Battery Backup Systems	99,290.37	47,441.23	52,713.87	1.70%	0.89%	1.11%	-0.81%	0.22%
Integrated Circuits and Computer Components	82,695.06	119,119.29	125,660.87	1.42%	2.24%	2.65%	0.82%	0.41%
Portable Computers	26,849.71	27,715.82	50,709.81	0.46%	0.52%	1.07%	0.06%	0.55%
Personal and Portable Video Systems	5,216.31	9,948.19	7,399.91	0.09%	0.19%	0.16%	0.10%	-0.03%
Generic Metals	3,125.44	3,057.34	1,124.46	0.05%	0.06%	0.02%	0.00%	-0.03%
Other	1,335.56	12,725.17	88,236.73	0.02%	0.24%	1.86%	0.22%	1.62%
Floor Standing Photocopiers/Multifunction Devices	1,021.94	735.73		0.02%	0.01%		0.00%	-0.01%
Wires	482.69	973.04	688.10	0.01%	0.02%	0.01%	0.01%	0.00%
Waste	74.84	53.34		0.00%	0.00%		0.00%	0.00%
Processors	37.65	298.76		0.00%	0.01%		0.00%	-0.01%
Printer Cartridges		1,238.08	143.34		0.02%	0.00%	0.02%	-0.02%
Plastics		6.71	29.48		0.00%	0.00%	0.00%	0.00%
TOTALS	*5,827,824.23*	*5,315,078.80*	*4,746,279.20*					

Table A3: Categorical Breakdown of Facility Outputs

Facility Outputs Category	2016 kg of Category	2017 kg of Category	2018 kg of Category	% of 2016 Facility Outputs Category Mass (kg)	% of 2017 Facility Outputs Category Mass (kg)	% of 2018 Facility Outputs Category Mass (kg)	% change in % composition 2016-2017	% change in % composition 2018-2018
Glass	1,521,771.56	2,147,866.92	928,568.00	17.33%	21.38%	14.50%	4.05%	-6.88%
Steel	1,788,599.99	2,654,740.07	1,980,675.04	20.37%	26.43%	30.93%	6.06%	4.50%
Copper	1,618,491.06	1,389,471.36	626,217.83	18.43%	13.83%	9.78%	-4.60%	-4.05%
Plastics	1,264,727.56	1,176,683.93	982,808.12	14.40%	11.71%	15.35%	-2.69%	3.63%
Refurbished Goods	622,367.13	649,950.48	513,483.17	7.09%	6.47%	8.02%	-0.62%	1.55%
Circuit Boards and Precious Metal Target Goods	518,212.95	758,520.74	397,628.59	5.90%	7.55%	6.21%	1.65%	-1.34%
Other	514,845.48	618,539.42	603,017.04	5.86%	6.16%	9.42%	0.29%	3.26%
Aluminum	412,297.32	257,865.90	102,872.94	4.70%	2.57%	1.61%	-2.13%	-0.96%
Batteries and Battery Backup Systems	226,770.33	180,870.86	143,767.47	2.58%	1.80%	2.24%	-0.78%	0.44%
Generic Metals	210,705.00	116,893.02	56,705.40	2.40%	1.16%	0.89%	-1.24%	-0.28%
Printer Cartridges	81,009.33	93,111.63	68,435.75	0.92%	0.93%	1.07%	0.00%	0.14%
TOTALS	*8,779,797.72*	*10,044,514.32*	*6,404,179.35*					

*Note: **BOLDED** items are explored further in Table 4, Table 5 and Table 6*

Table A4: Sub Categorical Breakdown of Facility Outputs "Other" Category

Facility Outputs "Other" Sub-Category	2016 kg of Category	2017 kg of Category	2018 kg of Category	% of 2016 Facility Outputs "Other" Category Mass (kg)	% of 2017 Facility Outputs "Other" Category Mass (kg)	% of 2018 Facility Outputs "Other" Category Mass (kg)	% change in % composition 2016-2017	% change in % composition 2018-2018
Other Non-Program Waste	187,116.38	113,598.58	23,547.34	36.34%	18.37%	3.90%	-17.98%	-14.46%
Other	255,678.68	335,961.80	141,133.46	49.66%	54.32%	23.40%	+4.65%	-30.91%
CRT Display	34,527.45		91,263.69	6.71%		15.13%	-6.71%	+15.13%
Portable Computers	18,400.43	39,270.21	118,558.16	3.57%	6.35%	19.66%	+2.77%	+13.31%
Printers and Peripheral Devices	5,153.26	7,885.70	35,784.81	1.00%	1.27%	5.93%	+0.27%	+4.66%
Small Appliances	2,894.83	3,961.22		0.56%	0.64%		+0.08%	-0.64%
Computer Peripherals	3,623.75	2,002.16	9,680.11	0.70%	0.32%	1.61%	-0.38%	+1.28%
Hazardous Materials	4,419.35	3,220.51	19,479.07	0.86%	0.52%	3.23%	-0.34%	+2.71%
Flatscreen Display	1,107.22	1,854.74	78,031.95	0.22%	0.30%	12.94%	+0.08%	+12.64%
Desktop/Server Computers	1,764.47	704.43	1,445.15	0.34%	0.11%	0.24%	-0.23%	+0.13%
Computer Components	102.06	93,219.58	53,494.42	0.02%	15.07%	8.87%	+15.05%	-6.20%
Waste	42.64	150.14	1,750.87	0.01%	0.02%	0.29%	+0.02%	+0.27%
Cellular Devices	14.97		15,397.65	0.00%		2.55%	-0.00%	+2.55%
Non-Cellular Telephones		15,846.70	12,832.58		2.56%	2.13%	+2.56%	-0.43%
Desktop Computers		863.64	91.17		0.14%	0.02%	+0.14%	-0.12%
Printer Cartridges			526.62			0.09%		+0.09%
TOTALS	*514,845.48*	*618,539.42*	*603,017.04*					

Table A5: Sub Categorical Breakdown of Facility Outputs "Refurbished Goods" Category

Facility Outputs "Refurbished Goods" Sub-Category	2016 kg of Category	2017 kg of Category	2018 kg of Category	% of 2016 Facility Outputs "Refurbished Goods" Category Mass (kg)	% of 2017 Facility Outputs "Refurbished Goods" Category Mass (kg)	% of 2018 Facility Outputs "Refurbished Goods" Category Mass (kg)	% change in % composition 2016-2017	% change in % composition 2018-2018
Printer Cartridges	455579.33	467503.37	336075.89	73.20%	71.93%	65.46%	-1.27%	-6.47%
WIP Refurb Stock	88464.12	39183.12	5507.97	14.21%	6.03%	1.07%	-8.19%	-4.96%
Portable Computers	44031.12	76693.85	132428.56	7.07%	11.80%	25.80%	+4.73%	+14.00%
Desktop/Server Computers	21765.63	17890.14	34169.57	3.50%	2.75%	6.66%	-0.74%	+3.90%
Computer Peripherals	10021.67	291.21		1.61%	0.04%		-1.57%	-0.04%
Refurbished Goods	2327.84	272.16		0.37%	0.04%		-0.33%	-0.04%
Cellular Devices	177.43	181.91	590.63	0.03%	0.03%	0.12%	-0.00%	+0.09%
Networking Devices		47320.12	1263.25		7.28%	0.25%	+7.28%	-7.03%
Batteries and Battery Backup Systems		614.62	2560.08		0.09%	0.50%	+0.09%	+0.40%
Computer Components			781.99			0.15%		+0.15%
TOTALS	*622367.13*	*649950.48*	*513377.94*					

Table A6: Sub Categorical Breakdown of Facility Outputs “Circuit Boards and Precious Metal Target Goods" Category

Facility Outputs “Circuit Boards and Precious Metal Target Goods" Sub-Category	2016 kg of Category	2017 kg of Category	2018 kg of Category	% of 2016 Circuit Boards and Precious Metal Target Goods" Category (%) Mass (kg)	% of 2017 Circuit Boards and Precious Metal Target Goods" Category (%) Mass (kg)	% of 2018 Circuit Boards and Precious Metal Target Goods" Category (%) Mass (kg)	% change in % composition 2016-2017	% change in % composition 2018-2018
Circuit Boards	351110.89	592865.18	374335.26	67.75%	78.16%	94.14%	+10.41%	+15.98%
Computer Components	67744.93	87443.54	253.10	13.07%	11.53%	0.06%	-1.54%	-11.46%
Networking Devices	71126.46	33961.37	16336.13	13.73%	4.48%	4.11%	-9.25%	-0.37%
Shredded Circuit Boards	21381.44	38560.79	2039.35	4.13%	5.08%	0.51%	+0.96%	-4.57%
Processors	6849.24	5688.50	3084.88	1.32%	0.75%	0.78%	-0.57%	+0.03%
Other		1.36	1579.86		>0.01%	0.40%		
TOTALS	*518212.95*	*758520.74*	*397628.59*					

Table A7 Ontario Electronic Stewardship Phase 1 and Phase 2 Material Categories, Management Targets and Environmental Handling Fee Schedule 2015 (latest version)

Material Category		Collection Targets (kg/capita)						EHF 2015-2019
		Baseline (2009)	Year 1 (2010)	Year 2 (2011)	Year 3 (2012)	Year 4 (2013)	Year 5 (2015)	
Display Devices	Computer Monitors	*0.40*	*0.53*	*0.61*	*0.76*	*0.91*	*0.97*	--
	Display Devices <18"	*0.06*	*0.06*	*0.06*	*0.06*	*0.06*	*0.06*	$12.25
	Display Devices 18"-29"	*0.79*	*0.79*	*0.76*	*0.75*	*0.74*	*0.73*	--
	≤29" Screen Total	1.25	1.39	1.44	1.57	1.70	1.75	--
	Display Devices 29"-45"	*0.31*	*0.35*	*0.37*	*0.40*	*0.43*	*0.47*	$24.00
	Display Devices >45"	*0.14*	*0.18*	*0.22*	*0.26*	*0.32*	*0.40*	$39.50
	> 29" Screen Total	0.46	0.52	0.58	0.66	0.76	0.86	--
Desktop Computers		0.37	0.45	0.52	0.62	0.74	0.88	$1.40
Portable Computers		0.07	0.09	0.10	0.13	0.16	0.19	$1.00
Computer Peripherals		0.04	0.05	0.06	0.07	0.08	0.09	$1.00
Printing, Copying & Multi-Function Devices	Desktop and Portable Printing, Copying and Multi-Function Devices	0.37	0.46	0.54	0.67	0.83	1.07	$8.00
	Floor-Standing Printing Devices	0.01	0.01	0.01	0.02	0.02	0.03	$31.75
	Floor-Standing Copying Devices	0.02	0.02	0.03	0.03	0.04	0.05	$31.75
Telephones and Telephone Answering Machines		0.08	0.09	0.10	0.11	0.12	0.14	$1.50
Cellular Devices and Pagers		0.01	0.02	0.02	0.02	0.03	0.04	$0.07
Image, Audio & Video Devices	Personal/Portable	0.03	0.03	0.04	0.04	0.04	0.04	$0.75
	Home/Non-Portable	0.21	0.27	0.35	0.45	0.58	0.75	$5.00
	Home Theatre in a Box (HTB)	0.11	0.12	0.15	0.18	0.21	0.25	$5.00
	Aftermarket Vehicle	0.02	0.02	0.03	0.03	0.04	0.05	$4.00

Phase 1 Materials Total *	2.56	2.96	3.24	3.71	4.26	4.84
Growth		***0.16***	***0.09***	***0.14***	***0.15***	***0.14***
Phase 2 Materials Total	0.49	0.59	0.72	0.88	1.08	1.34
Growth		***0.21***	***0.22***	***0.22***	***0.23***	***0.24***
Phase 1 and 2 Materials Total	3.05	3.55	3.96	4.58	5.35	6.18
Growth		***0.17***	***0.11***	***0.16***	***0.17***	***0.16***

Table A8: "Other" Category outputs 2016-2018 from Sales Data. Note the increasing number of CRTs sold, these are going to other Primary Processors around Ontario and Canada

2016		**2017**		**2018**	
Material or Product	**Kg**	**Material or Product**	**Kg**	**Material or Product**	**Kg**
Mixed Non Program Material	185080	SECURELY DESTROY AND RECYCLE ELECTRONICS & SKIDS	184828	CRT Television	79008
PRODUCT DESTRUCTION AND RECYCLING	99299	PRODUCT DESTRUCTION AND RECYCLING	113856	Scrap Laptop Computer	59813
SECURELY DESTROY AND RECYCLE ELECTRONICS	53673	Mixed Non Program Material	65975	PRODUCT DESTRUCTION AND RECYCLING	44613
SECURELY DESTROY AND RECYCLE ELECTRONICS & SKIDS	39784	Optical Disc Drive	48998	Hard Drives All Makes and Model	41879
CRT Television	34527	Hard Drives All Makes and Model	43963	Laptop Computer Scrap (Missing Hard drive Ram or Battery)	33070
SECURELY DESTROY AND RECYCLE ELECTRONICS & SKID HANDLING FEE	28946	Laptop Computer Scrap (Missing Hard drive Ram or Battery)	34766	Secure Bulk Shred-Capture Weight - SOW Item 3 - With Battery Non Welded Assy	22679
Scrap Laptop Computer	18400	Non-program TVs	18069	Printers and Peripherals Devices	22299
LCD Monitor Scrap	8020	Multi Line Phone Scrap	15846	4 ft Fluorescent Tubes	18753
Certified Material Destruction	4483	End of Life Processing - NON OES Material & Waste with 5% allowance	15131	SECURELY DESTROY AND RECYCLE ELECTRONICS & SKIDS	18207
Printers and Peripherals Devices	3965	Printers and Peripherals Devices	7714	Secure Bulk Shred-Capture Weight	15702

Appendix B

Supplementary Figures

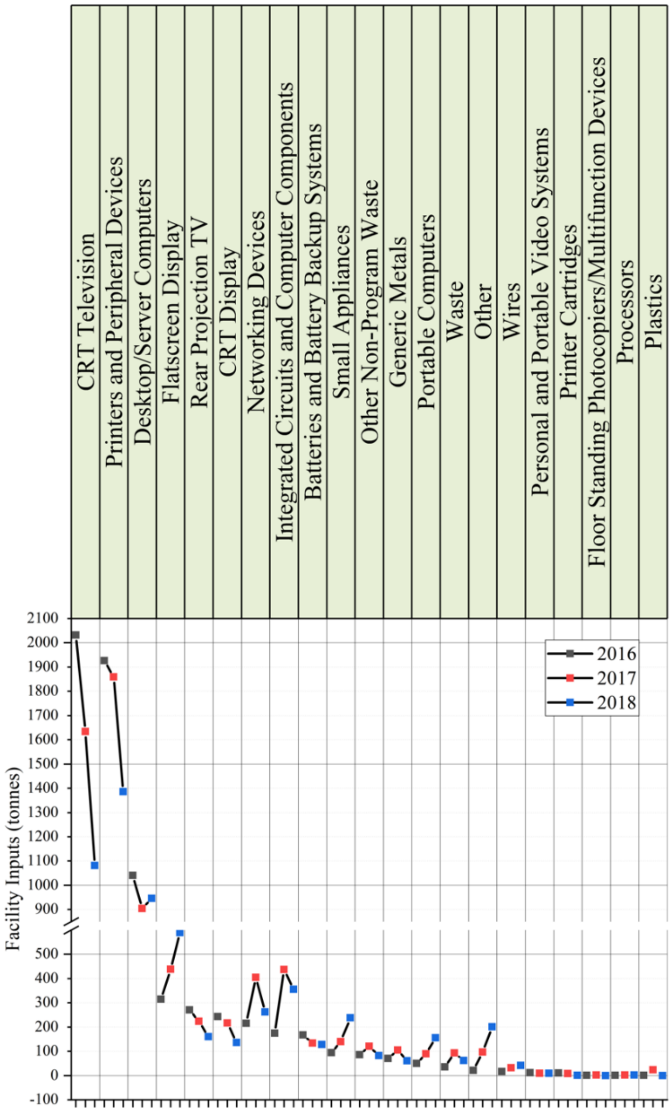


Figure B1 Composition of Facility Inputs by Product Categories, by mass (tonnes), 2016-2018.

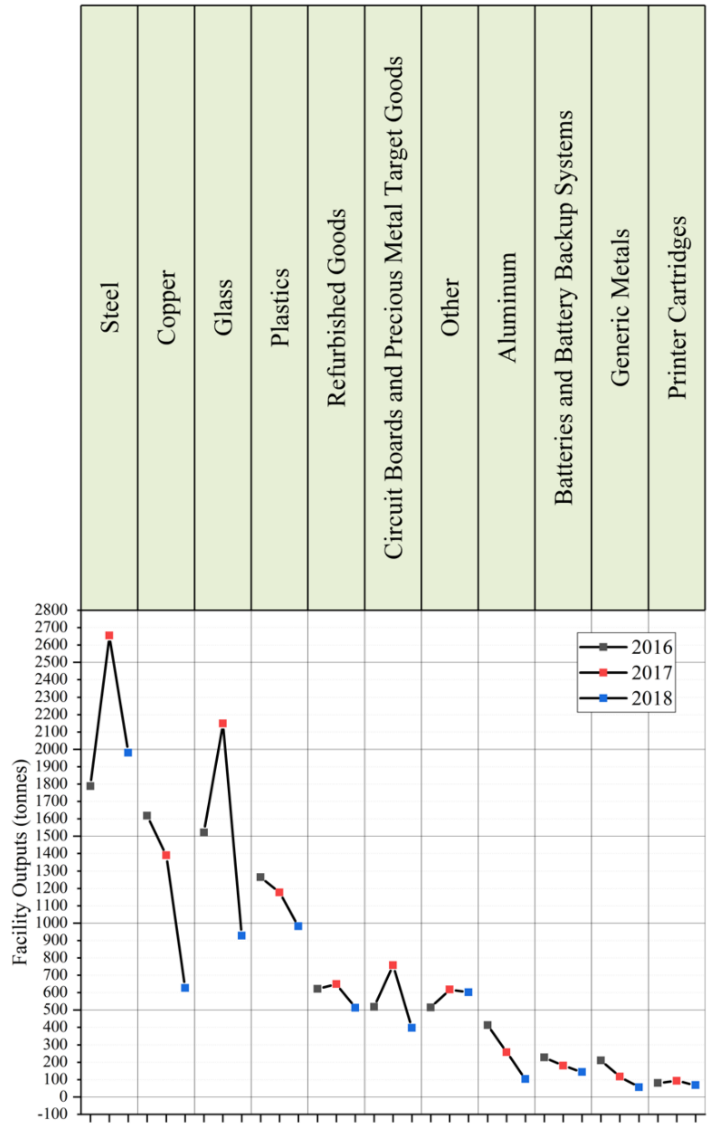


Figure B2 Composition of Facility Outputs by Product Categories, by mass (tonnes), 2016-2018.

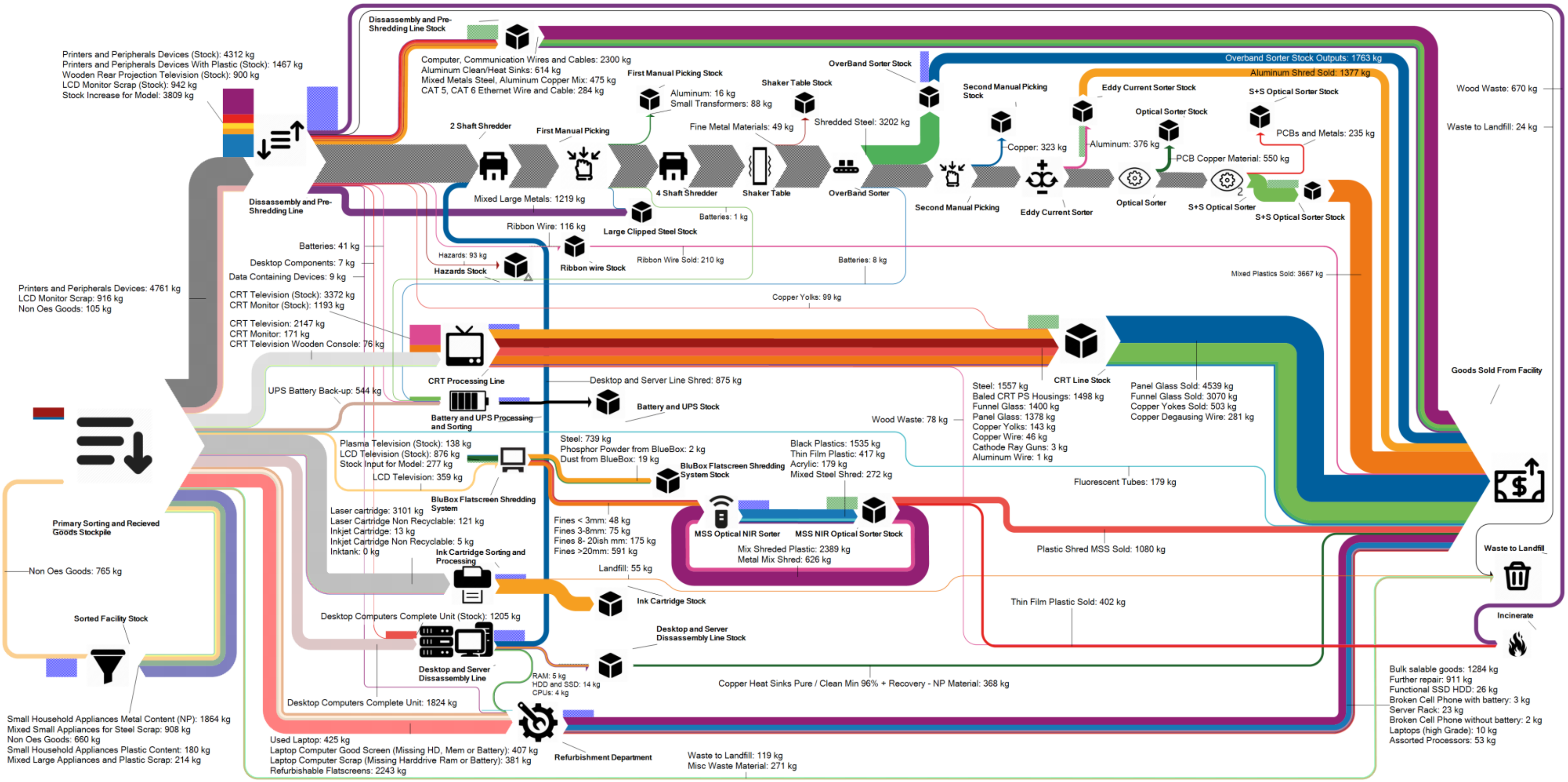


Figure B3 Disaggregated Daily Operation Map of Material Flow for the Primary Processing Facility Full Image. Note: 50% dot gradient flows are measured inputs, full colours are measured outputs and intermediary flows, upwards diagonal hatching is estimated based on other measured input-output flows.

Appendix C
Flows Not Shown in Material Flow Mapping

In a mostly linear order of e-waste processing through the facility these flows were not documented on either of the days but do exist:

1. *Modems and Routers:* Modems and Routers are common small electronic appliances that are dismantled for their relatively high value printed circuit boards.
2. *Small sub-flows of plastics:* There are a series of small sub-100kg flows of mixed plastics that are landfilled, scrap plastics, and other such plastic materials that were unreliably recorded, or it was indicated by the staff present that the flow was "abnormal". For this reason, the flows were left out. Other reliably recorded flows were listed, such as many of the waste to landfill and incinerated flows.
3. *Expected flows:* Some flows that were expected did not occur, for example, the printed circuit board sorting that normally occurs did not. This would have resulted in a measurable flow of PCBs being stockpiled in the facility from the desktop and server line, but in this case, those machines did not have their outputs recorded or the machines were set aside for later processing.
4. *Outputs from stocks:* Many of the stockpiles listed have no outputs, this is due to nothing being sold from these locations on the measured days. Outputs from stocks of materials are dependant on market conditions (material price), availability of buyers, predetermined contract dates, and transport availability.

Unnecessary flows: Some flows were deemed redundant or unnecessary, such as the stockpiling of valuable CPUs and chips that are smelted for gold and precious metals. This stockpile is physically in the same location as the refurbishment, and the precious metals flowing from the Disassembly and Pre-Shredding Line are already indicated, though by a very small flow. Other flows were very small or were proven to be inaccurate in representing a "normal operational day" as stated by staff.

Appendix D

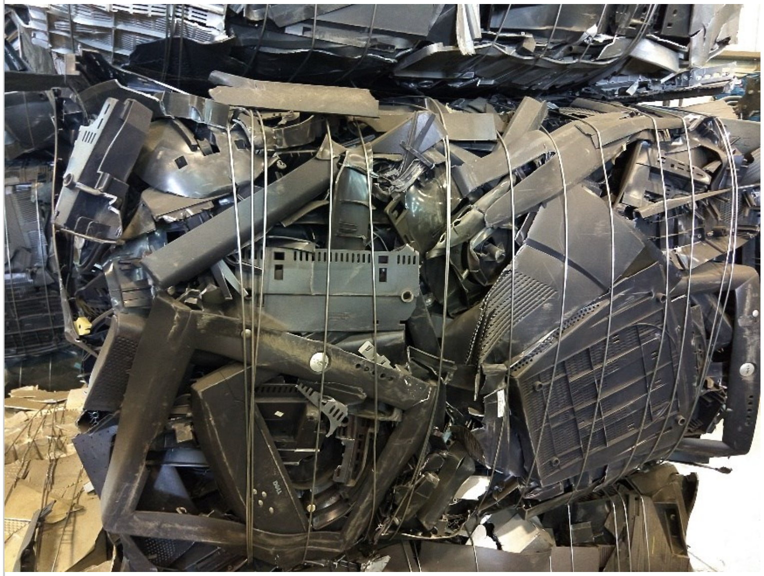
Table of Photographs of Outputs from Primary Processor Processes

Material and Description	Image
Section # - 1 - Primary Sorting and Facility Shipping / Receiving - Output # 1 - Material Output: Mixed Household Wires - Description: Diverse household wires, mostly power cables - Processing: Sold for copper content - Labour Type: Manual Labour - Notes: NA - Final Output: Yes	
Section # - 1 - Primary Sorting and Facility Shipping / Receiving - Output # 2 - Material Output: Mixed Large Appliances and Steel Scrap - Description: Large appliances like microwaves and vacuum cleaners - Processing: Sold for steel content - Labour Type: Manual Labour - Notes: NA - Final Output: Yes	

Section # - 1 - Primary Sorting and Facility Shipping / Receiving - Output # 3 - Material Output: Christmas Lights - Description: Christmas lights of all makes and age - Processing: Sold for copper content - Labour Type: Manual Labour - Notes: NA - Final Output: Yes	
Section # - 1 - Primary Sorting and Facility Shipping / Receiving - Output # 4 - Material Output: Mixed Coloured Plastic - Description: Plastics that are coloured, excluding white ABS and PCABS or black polystyrene. - Processing: To be stored and then shredded at a time when it will not contaminate higher value shredded goods - Labour Type: Manual Labour - Notes: NA - Final Output: Yes	NA
Section # - 1 - Primary Sorting and Facility Shipping / Receiving - Output # 5 - Material Output: Verified Materials - Description: Materials that enter the facility sorted and are sold immediately - Processing: Verified and sold - Labour Type: Manual Labour - Notes: No photo - Final Output: Yes	Just boxes or pallets of goods, stay on trucks usually.

Section # - 2 - CRT Dismantling Line - Output # 1 - Material Output: Copper Wire - Description: Copper wire from the internals of the CRTs, this is thick gauge wire - Processing: Sold - Labour Type: Manual Labour - Notes: NA - Final Output: Yes	
Section # - 2 - CRT Dismantling Line - Output # 10 - Material Output: Black ABS Housings - Description: Baled black ABS Housings - Processing: Baled and sold as plastic to be recycled - Labour Type: Baler - Notes: NA - Final Output: Yes	

Section # - 2 - CRT Dismantling Line - Output # 11 - Material Output: White ABS Housings - Description: Baled White ABS Housings - Processing: Baled and sold as plastic to be recycled - Labour Type: Baler - Notes: NA - Final Output: Yes	
Section # - 2 - CRT Dismantling Line - Output # 12 - Material Output: Wood Waste - Description: Wood frames from CRT housings - Processing: Sold for waste to energy to be burned - Labour Type: Manual Labour - Notes: NA - Final Output: Yes	

Section # - 2 - CRT Dismantling Line - Output # 13 - Material Output: CRT PS Housings - Description: Baled Polystyrene Housings - Processing: Baled and sold as plastic to be recycled - Labour Type: Baler - Notes: NA - Final Output: Yes	
Section # - 2 - CRT Dismantling Line - Output # 2 - Material Output: Copper Yolks - Description: Copper Yolks from the CRT process - Processing: Sold - Labour Type: Manual Labour - Notes: NA - Final Output: Yes	

Section # - 2 - CRT Dismantling Line - Output # 4 - Material Output: TV Shred - Description: Mixed TV materials including PCBs, housings, large pieces of aluminum, etc. - Processing: Shredded - Labour Type: Manual Labour - Notes: NA - Final Output: No	
Section # - 2 - CRT Dismantling Line - Output # 5 - Material Output: CRT Phosphorus Powder - Description: Phosphorus powder vacuumed out of monitors, disposed of by secondary firm downstream. - Processing: bagged and canned - Labour Type: Manual Labour - Notes: Cost to process, not done on-site - Final Output: Yes	

Section # - 2 - CRT Dismantling Line - Output # 6 - Material Output: Funnel Glass - Description: Removed and smashed - Processing: Sold (cost?) - Labour Type: Manual Labour - Notes: NA - Final Output: Yes	
Section # - 2 - CRT Dismantling Line - Output # 7 - Material Output: Panel Glass - Description: Removed and smashed - Processing: Sold (cost?) - Labour Type: Manual Labour - Notes: NA - Final Output: Yes	

Section # - 2 - CRT Dismantling Line - Output # 8 - Material Output: Steel - Description: Steel from TV internals, frames, etc. - Processing: Sold for steel content - Labour Type: Manual Labour - Notes: NA - Final Output: Yes	
Section # - 2 - CRT Dismantling Line - Output # 9 - Material Output: CRT Guns - Description: Collected for stainless steel content - Processing: Sold for Stainless Steel Content - Labour Type: Manual Labour - Notes: NA - Final Output: Yes	

Section # - 3 - General Product Dismantling and DisassemblyGeneral Product Dismantling and Disassembly - Output # 1 - Material Output: Mixed Large Metals - Description: Not shredded, low quality steel, appliances and other strange items - Processing: Sold for steel content - Labour Type: Manual Labour - Notes: NA - Final Output: Yes	
Section # - 3 - General Product Dismantling and DisassemblyGeneral Product Dismantling and Disassembly - Output # 10 - Material Output: Christmas Lights - Description: Christmas lights of all make and model - Processing: Sold for reprocessing for copper content - Labour Type: Manual Labour - Notes: NA - Final Output: Yes	

Section # - 3 - General Product Dismantling and DisassemblyGeneral Product Dismantling and Disassembly - Output # 11 - Material Output: Mixed Coloured Plastics - Description: Airflow cowlings from Desktops, toys, bins, misc. coloured plastic - Processing: Retained and then processed with rest of Mixed Coloured Plastic at a later time - Labour Type: Manual Labour - Notes: NA - Final Output: No	
Section # - 3 - General Product Dismantling and DisassemblyGeneral Product Dismantling and Disassembly - Output # 13 - Material Output: Hazards - Description: Batteries, Aerosol cans, other dangerous components - Processing: Batteries are then directed to - Labour Type: Manual Labour - Notes: NA - Final Output: Yes	

Section # - 3 - General Product Dismantling and DisassemblyGeneral Product Dismantling and Disassembly - Output # 17 - Material Output: Transformers - Description: Small and medium transformers - Processing: Processed for copper content - Labour Type: Manual Labour - Notes: No image file - Final Output: Yes	
Section # - 3 - General Product Dismantling and DisassemblyGeneral Product Dismantling and Disassembly - Output # 18 - Material Output: Ethernet Wire - Description: Communication wire, more valuable for copper content - Processing: Sold for copper content - Labour Type: Manual Labour - Notes: NA - Final Output: Yes	

Section # - 3 - General Product Dismantling and DisassemblyGeneral Product Dismantling and Disassembly - Output # 19 - Material Output: Digital Cameras - Description: Sold for PCB and PM content - Processing: Sold - Labour Type: Manual Labour - Notes: NA - Final Output: Yes	
Section # - 3 - General Product Dismantling and DisassemblyGeneral Product Dismantling and Disassembly - Output # 2 - Material Output: Pure Copper - Description: Not intended to be here, set aside and sent to clean copper bin, heatsinks etc. - Processing: Sold for copper content - Labour Type: Manual Labour - Notes: REMOVED - Final Output: No	

Section # - 3 - General Product Dismantling and DisassemblyGeneral Product Dismantling and Disassembly - Output # 20 - Material Output: Smoke Detectors - Description: Collected and stored for a long period, considered hazardous by some - Processing: Cost? - Labour Type: Manual Labour - Notes: NA - Final Output: Yes	
Section # - 3 - General Product Dismantling and DisassemblyGeneral Product Dismantling and Disassembly - Output # 4 - Material Output: Copper Yolks - Description: If not caught earlier, is sorted out into bin - Processing: Sold for copper content - Labour Type: Manual Labour - Notes: NA - Final Output: Yes	

Section # - 3 - General Product Dismantling and DisassemblyGeneral Product Dismantling and Disassembly - Output # 5 - Material Output: Copper Mix - Description: Classified as CAM, copper aluminium mix, sold as mixed material - Processing: Sold for mixed Al Cu content - Labour Type: Manual Labour - Notes: REMOVED - Final Output: Yes	
Section # - 3 - General Product Dismantling and DisassemblyGeneral Product Dismantling and Disassembly - Output # 6 - Material Output: Pure Aluminum - Description: Heatsinks and chunks of aluminium - Processing: Sold for high-value aluminium content - Labour Type: Manual Labour - Notes: NA - Final Output: Yes	

Section # - 4 - Shredder Line and Sorter Systems - Output # 1 - Material Output: Small Transformers - Description: Small copper transformers not caught in the initial General Product Dismantling and DisassemblyGeneral Product Dismantling and Disassembly teardown - Processing: Sent to copper bin, sold for copper, (not the final residency place) - Labour Type: Manual Labour - Notes: Not final location, moved to copper mix bin - Final Output: No	
Section # - 4 - Shredder Line and Sorter Systems - Output # 10 - Material Output: Aluminum - Description: Some mix, sorted by non-Fe sorter, some PCB as well - Processing: Sold - Labour Type: Eddy Current - Notes: NA - Final Output: Yes	

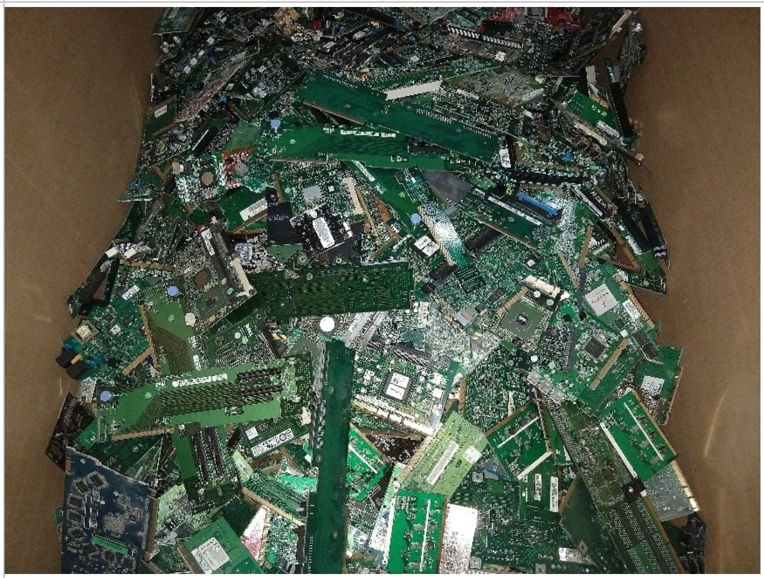
Section # - 4 - Shredder Line and Sorter Systems - Output # 11 - Material Output: PCBs and Metals - Description: Mix of copper materials, PCBs - Processing: Sold - Labour Type: Optical Sorter - Notes: NA - Final Output: Yes	
Section # - 4 - Shredder Line and Sorter Systems - Output # 12 - Material Output: PCBs and Metals - Description: Mix of copper materials, ferrous materials PCBs - Processing: Sold - Labour Type: S+S - Notes: NA - Final Output: Yes	

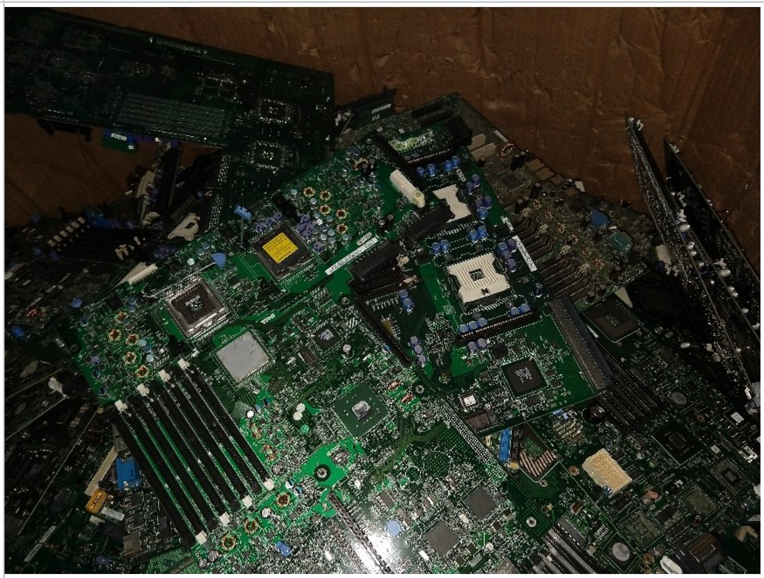
Section # - 4 - Shredder Line and Sorter Systems - Output # 13 - Material Output: Mixed Plastics - Description: Mixed plastics, all sorts - Processing: Sold - Labour Type: S+S - Notes: NA - Final Output: Yes	
Section # - 4 - Shredder Line and Sorter Systems - Output # 2 - Material Output: Aluminum - Description: Mostly Aluminum, heat sinks and large components, partially shredded with some mix - Processing: Sold for Al content - Labour Type: Manual Labour - Notes: NA - Final Output: Yes	

Section # - 4 - Shredder Line and Sorter Systems - Output # 3 - Material Output: Batteries - Description: Mixed Batteries - Processing: Sent to battery bin, not a finished product - Labour Type: Manual Labour - Notes: NA - Final Output: No	
Section # - 4 - Shredder Line and Sorter Systems - Output # 4 - Material Output: Steel, Large Shred - Description: Large steel parts, poorly shredded, large, printer components, steel chunks, etc. - Processing: Sold in the Large Steel scrap bin, less money - Labour Type: Manual Labour - Notes: NA - Final Output: Yes	

Section # - 4 - Shredder Line and Sorter Systems - Output # 5 - Material Output: Waste on Belt - Description: Waste dropped from belt, rerun - Processing: Rerun in system - Labour Type: Belt Drop - Notes: NA - Final Output: No	
Section # - 4 - Shredder Line and Sorter Systems - Output # 6 - Material Output: Fines - Description: Fine shredded metals and plastics - Processing: Sold for copper and gold content, PMs, etc. - Labour Type: Shaker Table - Notes: NA - Final Output: Yes	

Section # - 4 - Shredder Line and Sorter Systems - Output # 7 - Material Output: Second Shred Shredded Steel - Description: Fairly pure shredded steel - Processing: Sold - Labour Type: OverBand Sorter - Notes: NA - Final Output: Yes	
Section # - 4 - Shredder Line and Sorter Systems - Output # 8 - Material Output: Copper - Description: Copper mix, some transformers that made it through - Processing: Sold for Copper - Labour Type: Manual Labour - Notes: NA - Final Output: Yes	

Section # - 4 - Shredder Line and Sorter Systems - Output # 9 - Material Output: Batteries - Description: Mixed Batteries - Processing: Sent to battery bin, not a finished product - Labour Type: Manual Labour - Notes: NA - Final Output: No	
Section # - 5 - Desktop Line - Output # 1 - Material Output: Fingerboards - Description: Smaller Boards, Valuable - Processing: Sold - Labour Type: Manual Labour - Notes: Written on note as Section 10 - Final Output: Yes	

Section # - 5 - Desktop Line - Output # 2 - Material Output: Large Socket Server Boards - Description: Older large socket server boards, worth $$$ - Processing: Sold - Labour Type: Manual Labour - Notes: Written on note as Section 10 - Final Output: Yes	
Section # - 5 - Desktop Line - Output # 3 - Material Output: Small Socket Server Boards - Description: Older small socket server boards, worth $$ - Processing: Sold - Labour Type: Manual Labour - Notes: Written on note as Section 10 - Final Output: Yes	

Section # - 5 - Desktop Line - Output # 4 - Material Output: Standard Pc Motherboards - Description: Standard PC motherboards of many eras, varying but high value - Processing: Sold - Labour Type: Manual Labour - Notes: Written on the note as Section 10 - Final Output: Yes	
Section # - 5 - Desktop Line - Output # 5 - Material Output: Large Socket Standard PC motherboards - Description: Standard large EATX or ATX+ PC motherboards of many eras, varying but high value - Processing: Sold - Labour Type: Manual Labour - Notes: Written on note as Section 10 - Final Output: Yes	

Section # - 5 - Desktop Line - Output # 6 - Material Output: Power Supplies - Description: Varying consumer and sever grade pc power supplies - Processing: Sold - Labour Type: Manual Labour - Notes: Written on note as Section 10 - Final Output: Yes	
Section # - 5 - Desktop Line - Output # 7 - Material Output: RAM - Description: Sent to the Refurb Storage section where it is stocked and then sold later - Processing: Stocked and sold - Labour Type: Manual Labour - Notes: Written on the note as Section 10 - Final Output: No	

Section # - 5 - Desktop Line - Output # 8 - Material Output: HDD and SSD - Description: Sent to the Refurb Storage section where it is stocked and then sold later - Processing: Stocked and sold - Labour Type: Manual Labour - Notes: Written on note as Section 10 - Final Output: No	
Section # - 5 - Desktop Line - Output # 9 - Material Output: CPUs - Description: Sent to the Refurb Storage section where it is stocked and then sold later - Processing: Stocked and sold - Labour Type: Manual Labour - Notes: Written on the note as Section 10 - Final Output: No	

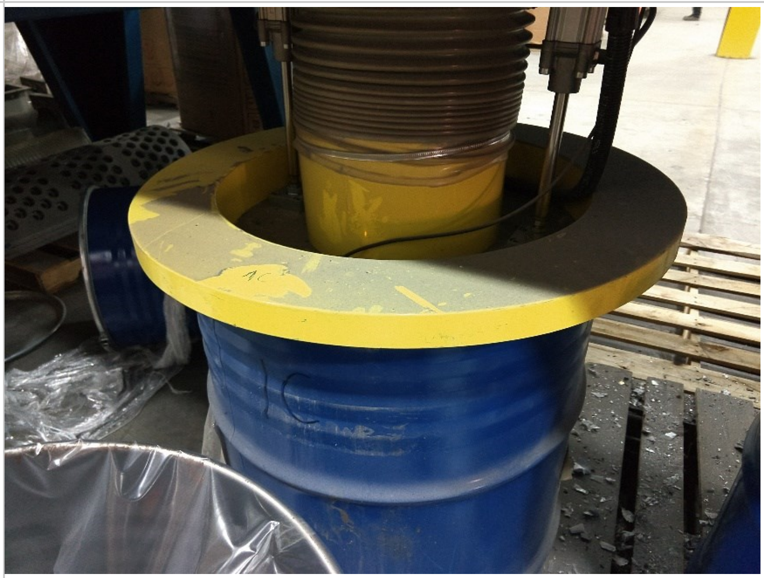
Section # - 6 - BluBox and MSS Flatscreen and Bulb Shredding and Sorting - Output # 1 - Material Output: Fluff from BluBox - Description: Thin plastics in a bag in a barrel - Processing: processed for mercury content - Labour Type: BluBox - Notes: 2C on Machine - Final Output: Yes	
Section # - 6 - BluBox and MSS Flatscreen and Bulb Shredding and Sorting - Output # 10 - Material Output: ferrous Metallic Ends of Bulbs - Description: Steel ferrous ends of bulbs (component that sockets in) - Processing: Sold for steel content - Labour Type: BluBox - Notes: Number 1 on BluBox Output - Final Output: Yes	

Section # - 6 - BluBox and MSS Flatscreen and Bulb Shredding and Sorting - Output # 11 - Material Output: Glass Fines < 3mm - Description: Glass from bulbs - Processing: Sold for concrete and other filler applications - Labour Type: BluBox - Notes: Number 2 on BluBox Output - Final Output: Yes	
Section # - 6 - BluBox and MSS Flatscreen and Bulb Shredding and Sorting - Output # 12 - Material Output: Glass Fines 3-8mm - Description: Glass from bulbs - Processing: Sold for concrete and other filler applications - Labour Type: BluBox - Notes: Number 3 on BluBox Output - Final Output: Yes	

Section # - 6 - BluBox and MSS Flatscreen and Bulb Shredding and Sorting - Output # 13 - Material Output: Glass Fines 8- 20ish mm - Description: Glass from bulbs - Processing: Sold for concrete and other filler applications - Labour Type: BluBox - Notes: Number 4 on BluBox Output - Final Output: Yes	
Section # - 6 - BluBox and MSS Flatscreen and Bulb Shredding and Sorting - Output # 14 - Material Output: Non ferrous Ends of Bulbs, Mixed Materials - Description: Non ferrous ends of bulbs (component that sockets in) - Processing: Sold for aluminum or copper content - Labour Type: BluBox - Notes: Number 5 on BluBox Output - Final Output: Yes	

Section # - 6 - BluBox and MSS Flatscreen and Bulb Shredding and Sorting - Output # 15 - Material Output: Large Acrylic - Description: Reprocessed from MSS - Processing: Sold - Labour Type: MSS - Notes: NA - Final Output: Yes	
Section # - 6 - BluBox and MSS Flatscreen and Bulb Shredding and Sorting - Output # 16 - Material Output: Small Acrylic - Description: Reprocessed from MSS - Processing: Sold - Labour Type: MSS - Notes: NA - Final Output: Yes	

Section # - 6 - BluBox and MSS Flatscreen and Bulb Shredding and Sorting - Output # 17 - Material Output: Black Plastics - Description: Rerun of initial plastics (2nd pass) - Processing: Sold - Labour Type: MSS - Notes: NA - Final Output: Yes	
Section # - 6 - BluBox and MSS Flatscreen and Bulb Shredding and Sorting - Output # 18 - Material Output: Thin Film Plastic - Description: Thin "fluff" Plastic - Processing: Waste to energy, sold and burned - Labour Type: MSS - Notes: NA - Final Output: Yes	

Section # - 6 - BluBox and MSS Flatscreen and Bulb Shredding and Sorting - Output # 19 - Material Output: PCBs Shred - Description: Low grade PCB shred, some mixed plastic - Processing: Sold for PM content, gold, etc. - Labour Type: MSS - Notes: NA - Final Output: Yes	
Section # - 6 - BluBox and MSS Flatscreen and Bulb Shredding and Sorting - Output # 2 - Material Output: Phosphor Powder from BluBox - Description: Powdered phosphor in bag in barrel - Processing: processed for mercury content - Labour Type: BluBox - Notes: 1C on BluBox Machine - Final Output: Yes	

Section # - 6 - BluBox and MSS Flatscreen and Bulb Shredding and Sorting - Output # 20 - Material Output: Mixed Steel Shred - Description: Potentially rerun for PCB extraction and further plastic purification - Processing: Sold for metal content, Cu, Fe, core metals - Labour Type: MSS - Notes: NA - Final Output: Yes		
Section # - 6 - BluBox and MSS Flatscreen and Bulb Shredding and Sorting - Output # 21 - Material Output: High Grade PCB Shred - Description: Shredded modems, satellite receivers, worth far more individually - Processing: Sold for PM content, gold, etc. - Labour Type: MSS - Notes: Does not exist except recently - Final Output: Yes		

Section # - 6 - BluBox and MSS Flatscreen and Bulb Shredding and Sorting - Output # 22 - Material Output: Mix Shredded Plastic - Description: Higher grade plastic, from modems, sat receivers, high-grade products - Processing: Sold for plastic recycling, high-value plastic - Labour Type: MSS - Notes: NA - Final Output: Yes	
Section # - 6 - BluBox and MSS Flatscreen and Bulb Shredding and Sorting - Output # 23 - Material Output: Small Mix Plastic - Description: from acrylic reruns, similar to Sect 6 output 17 - Processing: Sold for plastic content - Labour Type: MSS - Notes: NA - Final Output: Yes	

Section # - 6 - BluBox and MSS Flatscreen and Bulb Shredding and Sorting - Output # 3 - Material Output: Dust from BluBox - Description: Dust composite from BluBox processing, mixed materials - Processing: processed for mercury content - Labour Type: BluBox - Notes: F on Machine - Final Output: Yes	
Section # - 6 - BluBox and MSS Flatscreen and Bulb Shredding and Sorting - Output # 4 - Material Output: Steel - Description: Steel magnetically sorted in BluBox - Processing: finely shredded steel, sold as is - Labour Type: BluBox - Notes: Number 1 on BluBox Output - Final Output: Yes	

Section # - 6 - BluBox and MSS Flatscreen and Bulb Shredding and Sorting - Output # 5 - Material Output: Fines < 3mm - Description: Mixed plastics, acrylic, abs, PS, metals of all kinds from the shredding process, PCBs, all products from flat panels except steel or large ferrous materials - Processing: Send to MSS - Labour Type: BluBox - Notes: Number 2 on BluBox Output - Final Output: No	
Section # - 6 - BluBox and MSS Flatscreen and Bulb Shredding and Sorting - Output # 6 - Material Output: Fines 3-8mm - Description: Mixed plastics, acrylic, abs, PS, metals of all kinds from the shredding process, PCBs, all products from flat panels except steel or large ferrous materials - Processing: Send to MSS - Labour Type: BluBox - Notes: Number 3 on BluBox Output - Final Output: No	

Section # - 6 - BluBox and MSS Flatscreen and Bulb Shredding and Sorting - Output # 7 - Material Output: Fines 8- 20ish mm - Description: Mixed plastics, acrylic, abs, PS, metals of all kinds from the shredding process, PCBs, all products from flat panels except steel or large ferrous materials - Processing: Send to MSS - Labour Type: BluBox - Notes: Number 4 on BluBox Output - Final Output: No	
Section # - 6 - BluBox and MSS Flatscreen and Bulb Shredding and Sorting - Output # 8 - Material Output: Fines >20mm - Description: Mixed plastics, acrylic, abs, PS, metals of all kinds from the shredding process, PCBs, all products from flat panels except steel or large ferrous materials - Processing: Send to MSS - Labour Type: BluBox - Notes: Number 5 on BluBox Output - Final Output: No	
Section # - 6 - BluBox and MSS Flatscreen and Bulb Shredding and Sorting - Output # 9 - Material Output: Fine Fraction Metals - Description: Mixed metals, wire, PCBs, high metal content - Processing: processed for copper, metals, gold, etc. - Labour Type: BluBox - Notes: Small boxes attached to underside of BluBox - Final Output: Yes	In the metal box

	
Section # - 7 - Product Refurbishment and Sales - Output # 1 - Material Output: Batteries - Description: Mixed batteries from all laptops and computers - Processing: Stockpiled and sold - Labour Type: Manual Labour - Notes: NA - Final Output: No	

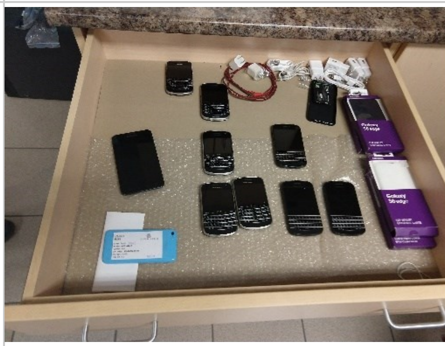
Section # - 7 - Product Refurbishment and Sales - Output # 11 - Material Output: High value Components - Description: Older CPUs, chips, components extremely high in gold and PM content - Processing: Sold to smelter - Labour Type: Manual Labour - Notes: NA - Final Output: Yes	

	  
Section # - 7 - Product Refurbishment and Sales - Output # 2 - Material Output: Broken HDD SSD - Description: Mixed new/old HDDs and SSDs, clearly broken - Processing: Stocked and then sold for PM and Al content - Labour Type: Manual Labour - Notes: NA - Final Output: Yes	

<table>
<tr>
<td>Section # - 7 - Product Refurbishment and Sales - Output # 3 - Material Output: Broken Cell Phone with battery - Description: Usually phones with integrated battery - Processing: Sold to another repair company - Labour Type: Manual Labour - Notes: NA - Final Output: Yes</td>
<td></td>
</tr>
<tr>
<td>Section # - 7 - Product Refurbishment and Sales - Output # 4 - Material Output: Broken Cell Phone without battery - Description: Mixed cell phones for disposal and possibly repair, mostly disposal - Processing: Sold for smelting or for repair - Labour Type: Manual Labour - Notes: NA - Final Output: Yes</td>
<td>NA</td>
</tr>
<tr>
<td>Section # - 7 - Product Refurbishment and Sales - Output # 6 - Material Output: Bulk salable goods - Description: Laptops, cell phones, tablets, Bulk-in-->Bulk-Out - Processing: Laptops and other goods sold around the world to resellers - Labour Type: Manual Labour - Notes: NA - Final Output: Yes</td>
<td>




</td>
</tr>
</table>

Section # - 7 - Product Refurbishment and Sales - Output # 7 - Material Output: Functional SSD HDD - Description: SSDs and HDDs - Processing: Sold in bulk or in store - Labour Type: Manual Labour - Notes: NA - Final Output: Yes	
Section # - 7 - Product Refurbishment and Sales - Output # 8 - Material Output: In Store Sales - Description: Individual components and products sold in store - Processing: Sold - Labour Type: Manual Labour - Notes: NA - Final Output: Yes	 

Section # - 7 - Product Refurbishment and Sales - Output # 9 - Material Output: Externally Processed electronic waste - Description: Ram Components, CPUs, newer - Processing: Sold to smelter - Labour Type: Manual Labour - Notes: NA - Final Output: Yes	 
Section # - 8 - Printer Cartridge Sorting and Assessment- Output # 1 - Material Output: Laser Cartridges for Refurbishment - Description: Printer cartridges for refurbishment and refill - Processing: Sold in pallets of similar/identical cartridges - Labour Type: Manual Labour - Notes: NA - Final Output: Yes	 

Section # - 8 - Printer Cartridge Sorting and Assessment- Output # 2 - Material Output: Inkjet cartridges for Refurbishment - Description: Printer cartridges for refurbishment and refill - Processing: Sold in pallets of similar/identical cartridges - Labour Type: Manual Labour - Notes: NA - Final Output: Yes	
Section # - 8 - Printer Cartridge Sorting and Assessment- Output # 3 - Material Output: Ink Bottles - Description: Large bottles resold for refurbishment, refill - Processing: Sold in bulk of similar ink bottles - Labour Type: Manual Labour - Notes: NA - Final Output: Yes	

Section # - 8 - Printer Cartridge Sorting and Assessment- Output # 4 - Material Output: Waste to Energy - Description: Sent to be burned for energy - Processing: Bagged/binned and disposed of - Labour Type: Manual Labour - Notes: NA - Final Output: Yes	
Section # - 8 - Printer Cartridge Sorting and Assessment- Output # 5 - Material Output: Landfill - Description: Sent to landfill - Processing: Bagged/binned and disposed of - Labour Type: Manual Labour - Notes: NA - Final Output: Yes	

Section # - 8 - Printer Cartridge Sorting and Assessment- Output # 6 - Material Output: Cardboard Goods - Description: Cardboard from packaging, recycled through paper waste streams - Processing: Baled and disposed of - Labour Type: Manual Labour - Notes: NA - Final Output: Yes	
Section # - 9 - PCB Sorting - Output # 1 - Material Output: Medium Grade Mainboards - Description: Various medium grade boards - Processing: - Labour Type: Manual Labour - Notes: Are these boards all shredded and sold or simply sold? - Final Output: Yes	

Section # - 9 - PCB Sorting - Output # 10 - Material Output: Gold Pin Server Power Supply Units - Description: - Processing: Sold for Gold Content - Labour Type: Manual Labour - Notes: Are these boards all shredded and sold or simply sold? - Final Output: Yes	
Section # - 9 - PCB Sorting - Output # 11 - Material Output: Tablet Boards - Description: - Processing: Sold for PM content - Labour Type: Manual Labour - Notes: Are these boards all shredded and sold or simply sold? - Final Output: Yes	

Section # - 9 - PCB Sorting - Output # 12 - Material Output: LCD Gold Strip Boards - Description: - Processing: Sold for Gold Content - Labour Type: Manual Labour - Notes: Are these boards all shredded and sold or simply sold? - Final Output: Yes	
Section # - 9 - PCB Sorting - Output # 2 - Material Output: High Grade Telecom Boards - Description: - Processing: Sold for PM content - Labour Type: Manual Labour - Notes: Are these boards all shredded and sold or simply sold? - Final Output: Yes	

Section # - 9 - PCB Sorting - Output # 3 - Material Output: Med High Grade Telecom Boards - Description: - Processing: - Labour Type: Manual Labour - Notes: Are these boards all shredded and sold or simply sold? - Final Output: Yes	
Section # - 9 - PCB Sorting - Output # 4 - Material Output: Low Grade Telecom Boards - Description: - Processing: - Labour Type: Manual Labour - Notes: Are these boards all shredded and sold or simply sold? - Final Output: Yes	

Section # - 9 - PCB Sorting - Output # 5 - Material Output: Power Supply Boards - Description: older style PCBs used for supplying power to other devices, large amounts of PMs - Processing: - Labour Type: Manual Labour - Notes: Are these boards all shredded and sold or simply sold? - Final Output: Yes	
Section # - 9 - PCB Sorting - Output # 6 - Material Output: Modem and Router Boards MRP - Description: Contains some plastics - Processing: - Labour Type: Manual Labour - Notes: Are these boards all shredded and sold or simply sold? - Final Output: Yes	

Section # - 9 - PCB Sorting - Output # 7 - Material Output: Satellite Receiver Boards - Description: High value, some of these are shredded at the end for fines - Processing: - Labour Type: Manual Labour - Notes: Are these boards all shredded and sold or simply sold? - Final Output: Yes	
Section # - 9 - PCB Sorting - Output # 8 - Material Output: TV Boards Loose - Description: Arrive loose occasionally, are also sorted from Deman - Processing: - Labour Type: Manual Labour - Notes: Are these boards all shredded and sold or simply sold? - Final Output: Yes	

Section # - 9 - PCB Sorting - Output # 9 - Material Output: Server Power Supply Units - Description: - Processing: Sold for Copper content - Labour Type: Manual Labour - Notes: Are these boards all shredded and sold or simply sold? - Final Output: Yes	
Section # - 10 - Battery Sorting and Assessment - Output # 1 – Batteries, mixed - Description: - Processing: Sold for refurbishment or reprocessing - Labour Type: Manual Labour - Notes: high variety though many laptop batteries and small cells - Final Output: Yes	Buckets and boxes of batteries, assorted, backup power supplies common

Appendix E
Categorization of E-waste in Ontario

Definition of e-waste in Ontario

Excerpt 1 from O. Reg. 393/04: WASTE ELECTRICAL AND ELECTRONIC EQUIPMENT

1. In this Regulation,

"waste electrical and electronic equipment" means a device that is waste, that required an electric current to operate and that is,

(a) a household appliance, whether used inside or outside a home, including any device listed in Schedule 1,

(b) information technology equipment, including any device listed in Schedule 2,

(c) telecommunications equipment, including any device listed in Schedule 3,

(d) audio-visual equipment, including any device listed in Schedule 4,

(e) a toy, leisure equipment or sports equipment, including any device listed in Schedule 5,

(f) an electrical or electronic tool, including any device listed in Schedule 6, but not including a large-scale stationary industrial tool, or

(g) a navigational, measuring, monitoring, medical or control instrument, including any device listed in Schedule 7, but not including any implanted or infected medical instrument. O. Reg. 393/04, s. 1.

Excerpt 2 from O. Reg. 393/04: WASTE ELECTRICAL AND ELECTRONIC EQUIPMENT

Schedule 1
household appliances

1. Air purifier
2. Air conditioner
3. Answering machine
4. Barbeque starter
5. Blender
6. Bottle or can dispenser
7. Can opener
8. Carpet sweeper
9. Clock
10. Clothes dryer
11. Clothes washer
12. Coffee grinder
13. Coffee maker
14. Curling iron
15. Dehumidifier
16. Dishwashing machine
17. Electric hot plate
18. Fan
19. Food processor
20. Freezer
21. Fryer
22. Glue gun
23. Hair dryer
24. Heat gun
25. Heater
26. Hot drink dispenser
27. Humidifier
28. Iron
29. Kettle
30. Knitting machine
31. Microwave oven
32. Mixer
33. Radiator
34. Razor
35. Refrigerator
36. Scissors
37. Sewing machine
38. Slicing machine
39. Solid product dispenser
40. Stove
41. Toaster
42. Toaster oven
43. Toothbrush
44. Vacuum cleaner
45. Vacuum sealer
46. Watch
47. Water purifier
48. Weaving machine
49. Weigh scale

O. Reg. 393/04, Sched. 1.

Schedule 2

INFORMATION TECHNOLOGY EQUIPMENT

1. Analog computer
2. Automatic teller machine (ATM)
3. Bar code scanner
4. Calculator
5. CD-ROM drive
6. Computer disk drive
7. Computer keyboard
8. Computer mouse
9. Computer terminal
10. Copier
11. Joystick
12. Mainframe computer
13. Microcomputer
14. Minicomputer
15. Monitor (CRT)
16. Monitor (LCD)
17. Monitor (Plasma)
18. Personal computer (Desktop)
19. Personal computer (Handheld)
20. Personal computer (Laptop)
21. Personal computer (Notebook)
22. Personal computer (Notepad)
23. Personal digital assistant (PDA)
24. Point-of-sale (POS) terminal
25. Printer
26. Computer router
27. Computer flatbed scanner
28. Typewriter

O. Reg. 393/04, Sched. 2.

Schedule 3

TELECOMMUNICATIONS EQUIPMENT

1. Antenna, transmitting or receiving
2. Broadcast equipment (including studio), for radio or television
3. Cable television transmitting or receiving equipment
4. Citizens' band (CB) radio
5. Closed circuit television equipment
6. Fax machine
7. Global positioning system (GPS)
8. Infrared wireless device
9. Intercom system
10. Local area network (LAN) communication equipment
11. Modem
12. Pager
13. PBX (private branch exchange)
14. Satellite television transmitting or receiving equipment
15. Switching equipment
16. Telephone (Cellular)
17. Telephone (Cordless)
18. Telephone (Wire line)
19. Telephone answering machine
20. Telephone carrier line equipment
21. Telephone carrier switching equipment
22. Telex machine
23. Traffic signal
24. Wide area network communications equipment

O. Reg. 393/04, Sched. 3.

Schedule 4

AUDIO-VISUAL EQUIPMENT

1. Amplifier
2. Audio player (tape, disk, digital)
3. Audio recorder (tape, disk, digital)
4. Camera (film, tape, disk, digital)
5. Equalizer
6. Headphone
7. Microphone
8. Mixing board
9. Musical instrument
10. Preamplifier
11. Public address system
12. Radio
13. Receiver
14. Speaker
15. Television (CRT)
16. Television (LCD)
17. Television (Plasma)
18. Television (Rear projection)
19. Tuner
20. Turntable
21. Video player or projector (tape, disk, digital)
22. Video recorder (tape, disk, digital)

O. Reg. 393/04, Sched. 4.

Schedule 5

TOYS, LEISURE EQUIPMENT AND SPORTS EQUIPMENT

1. Action figure and accessories
2. Arts, crafts or hobby device
3. Building set
4. Doll
5. Game or puzzle
6. Infant or preschool toy
7. Learning or exploration toy
8. Outdoor or sports toy

9. Plush toy
10. Vehicle
11. Video game and accessories
O. Reg. 393/04, Sched. 5.

Schedule 6
ELECTRICAL AND ELECTRONIC
TOOLS

1. Bender
2. Blower
3. Cutter
4. Disperser
5. Drill
6. Fastener
7. Folder
8. Grinder
9. Hammer
10. Joiner
11. Lathe
12. Lawn mower
13. Mill
14. Nail gun
15. Nibbler
16. Planer
17. Polisher
18. Punch
19. Riveter
20. Router
21. Sander
22. Saw
23. Screwdriver
24. Shear
25. Soldering gun
26. Sprayer
27. Spreader
28. Staple gun
29. Trimmer
30. Vacuum
31. Welder
32. Wrench
O. Reg. 393/04, Sched. 6.

Schedule 7
NAVIGATIONAL, MEASURING, MONITORING, MEDICAL OR CONTROL INSTRUMENTS

1. Alarm system
2. Analyzer
3. Automatic environmental controller or regulator
4. Cardiology equipment
5. Dialysis equipment
6. Drafting instrument
7. Fertilization tester
8. Fire detection and alarm system
9. Freezer
10. Hearing aid
11. Heating regulator
12. Humidistat
13. Instrument for industrial process control
14. Irradiation equipment
15. Laboratory analytical instrument
16. Laboratory equipment for in-vitro diagnosis
17. Medical equipment, ultrasonic
18. Medical radiation therapy equipment
19. Meteorological instrument
20. Meter
21. Nuclear medicine equipment
22. Oscilloscope
23. Process controller
24. Pulmonary ventilator
25. Radiation detection or monitoring instrument
26. Radiotherapy equipment
27. Refractometer
28. Scanner (CT/CAT)
29. Scanner (MRI)
30. Scanner (PET)
31. Smoke detector
32. Soil testing or analysis instrument
33. Surgical support system
34. Surveying instrument
35. Temperature instrument
36. Thermostat
O. Reg. 393/04, Sched.