U.S. Department of Energy
Advanced Research Projects Agency – Energy (ARPA-E)

Request for Information (RFI)
DE-FOA-0002355
on
Identifications and Quantification of Electronic Waste (e-waste) in Municipal Solid Waste Streams

Introduction

The purpose of this RFI is to solicit input for ARPA-E consideration for potential future ARPA-E research programs focused on highly energy efficient conversion of e-waste into usable manufacturing materials. ARPA-E is interested e-waste management/conversion ideas across the entire supply chain of e-waste and its impact on municipal solid waste, including classification, collection, identification, sorting, and reclamation of materials. Such e-waste reclamation research and development could result in the development and deployment of advanced energy technologies, enhancing the economic and energy of the United States, while reducing imports of foreign-sourced energy, and reduction of energy-related emissions.

According to the U.S. Environmental Protection Agency (EPA), Municipal Solid Waste (MSW)[1](also called trash or garbage) consists of daily items such as product packaging, yard trimmings, furniture, clothing, bottles and cans, food, newspapers, appliances, electronics, and batteries. Sources of MSW include residential waste and waste from commercial and institutional locations, such as businesses, educational institutions, and hospitals. The appliances and electronics waste within the MSW stream are broadly classified as electronic waste often referred to as *e-waste* or *e-scrap*. While the definition of e-waste is quite complex, the widely adopted definition in different e-waste studies is by the European Union Waste Electrical and Electronic Equipment (EU WEEE) directive, defined as *"Electrical and Electronic Equipment (EEE) which is waste, including all components, sub-assemblies, and consumables, which are part of the product at the time of discarding"*[2]. It encompasses six different categories as per International Telecommunication Union[3]. They are listed below. Each product of the six e-waste categories has a different lifetime profile leading to different waste quantities, economic values, and potential environmental and health impacts, if recycled inappropriately. Evidently, the logistical processes including, and recycling technology differ for each category, in the same way as the consumers' attitudes when disposing of the electrical and electronic equipment also vary.

- **Temperature exchange equipment**, more commonly referred to as cooling and freezing equipment (e.g. includes refrigerators, freezers, air conditioners, and heat pumps etc.)
- **Screens, monitors** (e.g. includes TVs, monitors, laptops, notebooks, and tablets etc.)

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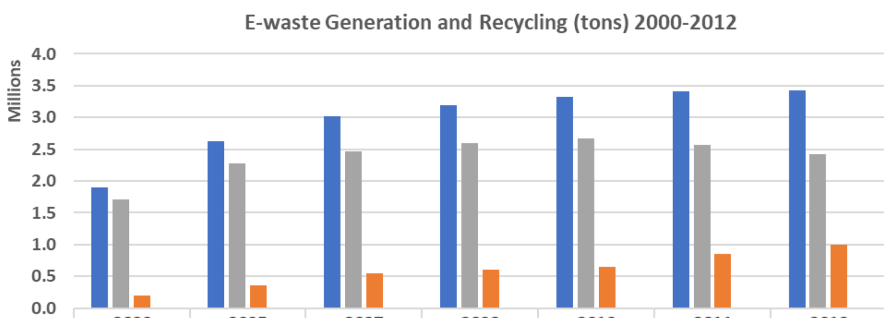
[1] https://archive.epa.gov/epawaste/nonhaz/municipal/web/html/

[2] D. Mmereki, B. Li, A. Baldwin, and L. Hong, "The Generation, Composition, Collection, Treatment, and Disposal System, and Impact of E-Waste", *Chapter 4* [http://dx.doi.org/10.5772/61332]

[3] "*What is E-waste*?" Chapter 1 [https://www.itu.int/en/ITU-D/Climate-Change/Documents/GEM%202017/Global-E waste%20Monitor%202017%20-%20Chapter%201.pdf]

- **Lamps** (e.g. includes fluorescent lamps, high intensity discharge lamps, and LED lamps etc.)
- **Large equipment** (e.g. washing machines, clothes dryers, dish-washers, large stoves, large printing/copying machines, and photovoltaic panels etc.)
- **Small equipment** (e.g. vacuum cleaners, microwaves, small electric and electronic tools etc.)
- **Small IT and telecommunication equipment** (e.g., mobile phones, Global Positioning Systems, and routers etc.)

The economic value of e-waste is significant. For example, as reported in 2019 Recycling Industry Yearbook by Institute of Scrap Recycling Industries[4] (ISRI Inc.), recycling 1 million cellphones will produce 33 lbs. of palladium, 75 lbs. of gold, 772 lbs. of silver, and 35,274 lbs. of copper. As per the *MarketWatch*, the e-waste recycling market revenue is expected to grow at 7.2% CAGR to exhibit $1.68 billion by 2024. It is one of the fastest growing waste streams. Despite significant economic value, only less than 30% of e-waste was recycled during 2000-2012, per Electronics TakeBack Coalition[5], as shown in Figure 1. It is to be noted that these EPA numbers are for “selected consumer electronics” which include products such as TVs, VCRs, DVD players, video cameras, stereo systems, telephones, and computer equipment. EPA estimates the consumer electronics in the waste stream based on the apparent consumption (apparent consumption equals U.S. manufacturer shipments plus U.S. imports minus U.S. exports).



	2000	2005	2007	2009	2010	2011	2012
E-waste Generated	1,900,000	2,630,000	3,010,000	3,190,000	3,320,000	3,410,000	3,420,000
E-waste Trashed	1,710,000	2,270,000	2,460,000	2,590,000	2,670,000	2,560,000	2,420,000
E-waste Recycled	190,000	360,000	550,000	600,000	650,000	850,000	1,000,000
Perecent Recycled	10%	14%	18%	19%	20%	25%	29%

E-waste Generated E-waste Trashed E-waste Recycled Perecent Recycled

Figure 1: EPA data from “Municipal Solid Waste Generation, Recycling and Disposal in the United States, 2012,” Feb 2014[6].

Including all the six electronic waste categories listed above, the U.S. was the second largest producer of e-waste after China. In other words the U.S. produced approximately 10 million tons[7] of e-waste in 2012, over 64 pounds per person (EPA data for more recent years are not available). According to one source, the U.S. generated roughly 11.7 million tons of e-waste[8] in 2014 and the global recycling rate

[4] https://www.isri.org/recycling-commodities/recycling-industry-yearbook
[5] http://www.electronicstakeback.com/wp-content/uploads/Facts_and_Figures_on_EWaste_and_Recycling.pdf
[6] https://www.epa.gov/sites/production/files/2015-09/documents/2012_msw_fs.pdf
[7] https://blogs.ei.columbia.edu/2018/08/27/growing-e-waste-problem/
[8] https://www.streamrecycling.com/e-waste-facts-statistics/

was between 15-20%. As per multiple other sources[9,10], the recycling rate in the U.S. is estimated to be only 12.5%. As shown in Fig. 1, 12.5% is less than half of the EPA estimation. There are two potential reasons for the reported lower number: a) inclusion of all the six categories of e-waste outlined above and b) what is thought to be recycled is in reality exported to developing countries in Asia[11]. As a matter of fact, United Nations estimates 10-40% of the U.S.'s e-waste is exported, even though there are international laws forbidding the transnational movement of electronic wastes[12]. Twenty-seven states and District of Columbia have passed laws to mitigate e-waste, but only federal legislation can ban exports. One of the major reasons for this export is the lack of sustainable solutions.

According to EPA, the trashed e-waste most likely ends up in landfills or Waste to Energy (WtE) facilities along with the MSW. In 2017, U.S. generated 267.8 million tons of MSW of which approximately 65%[13] were diverted to landfill and WtE facilities. In a nation of approximately 324 million people, the amount of MSW produced is enough to fill around 60,000 garbage trucks daily[14]. Essentially, the numbers speak to the scale of MSW produced in the U.S. Evidently, this MSW stream contains at least 80% of the total e-waste generated in the U.S.

According to the EPA and multiple other sources[15,16,17]e-waste makes up for more than two-thirds of the heavy metal waste in the U.S. Hence, it is extremely important to not only identify the e-waste in the MSW but also segregate them. In general, citizens must sort and segregate e-waste to divert e-waste from MSW. It needs to be sorted and transferred to either curbside or to an offsite collection site[18]. However, the curbside collections are regarded as expensive, time-consuming to design, implement, and operate[19]. Thus, the offsite drop-off option is attractive to waste management authorities. Post collection of e-waste, it is important to segregate and sort using new innovative technologies employing Artificial Intelligence (AI) and Machine Learning (ML).

ARPA-E is interested in surveying e-waste management ideas across the entire supply chain of e-waste and its impact on municipal solid waste, including classification, collection, identification, sorting, and reclamation of materials. This information complements the efforts within the Department of Energy being pursued by the Office of Science, Office of Energy Efficiency and Renewable Energy's (EERE)

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[9] https://earth911.com/eco-tech/20-e-waste-facts/

[10] https://turtlewings.com/blog/11_facts_about_e-waste

[11] "Scam Recycling - E-dumping on Asia by Recyclers" – The e-Trash Transparency Project by Basel Action Network group; http://wiki.ban.org/images/1/12/ScamRecyclingReport-web.pdf

[12] https://bpr.berkeley.edu/2019/12/05/out-of-sight-out-of-mind-how-the-united-states-discards-e-waste/

[13] https://www.epa.gov/facts-and-figures-about-materials-waste-and-recycling/national-overview-facts-and-figures-materials

[14]https://www.salon.com/2016/07/15/america_is_a_wasteland_the_u_s_produces_a_shocking_amount_of_garbage_partner/

[15] https://www.nytimes.com/2018/07/05/magazine/e-waste-offers-an-economic-opportunity-as-well-as-toxicity.html

[16] https://www.cawrecycles.org/

[17] https://www.scientificamerican.com/article/earth-talk-recycling-e-equipment/

[18] Q. Liu, Q. Li, H. Zhao, G. Li, and F. Fan, "The Global Challenge of Electronic Waste Management". Environmental Science and Pollution Research 2009; 16(3)L 248-249

[19] P. Chancerel, "Substance Flow Analysis of the Recycling of Small Waste Electrical and Electronic Equipment: An Assessment of the Recovery of Gold and Palladium, Papier-flieger 2009

Advanced Manufacturing Office (AMO) and Bioenergy Technologies Office (BETO). ARPA-E requests responses solely focusing on the e-waste that is contained in and can be segregated from the MSW and thus be avoided from going to landfill.

Please carefully review the REQUEST FOR INFORMATION GUIDELINES below. Please note, in particular, that the information you provide will be used by ARPA-E solely for program planning, without attribution. **THIS IS A REQUEST FOR INFORMATION ONLY. THIS NOTICE DOES NOT CONSTITUTE A FUNDING OPPORTUNITY ANNOUNCEMENT (FOA). NO FOA EXISTS AT THIS TIME.**

Purpose and Need for Information

The purpose of this RFI is solely to solicit input for ARPA-E consideration to inform the possible formulation of future research programs. ARPA-E will not provide funding or compensation for any information submitted in response to this RFI, and ARPA-E may use information submitted to this RFI without any attribution to the source. This RFI provides the broad research community with an opportunity to contribute views and opinions.

REQUEST FOR INFORMATION GUIDELINES

No material submitted for review will be returned and there will be no formal or informal debriefing concerning the review of any submitted material. ARPA-E may contact respondents to request clarification or seek additional information relevant to this RFI. All responses provided will be considered, but ARPA-E will not respond to individual submissions or publish publicly a compendium of responses. **Respondents should clearly mark any information in the response to this RFI that might be considered proprietary or confidential. Information labeled proprietary or confidential will not be released by DOE but may be used to inform ARPA-E's planning.**

Depending on the responses to this RFI, ARPA-E may consider the rapid initiation of one or more funded collaborative projects to accelerate along the path towards commercial deployment of the energy technologies described generally above.

Responses to this RFI should be submitted in PDF format to the email address **ARPA-E-RFI@hq.doe.gov** by **5:00 PM Eastern Time on June 5, 2020**. Emails should conform to the following guidelines:

- Please insert "Responses for e-waste RFI" in the subject line of your email, and include your name, title, organization, type of organization (e.g. university, non-governmental organization, small business, large business, federally funded research and development center (FFRDC), government-owned/government-operated (GOGO), etc.), email address, telephone number, and area of expertise in the body of your email.
- Responses to this RFI are limited to no more than 10 pages in length (12-point font size).
- Responders are strongly encouraged to include preliminary results, data, and figures that describe their potential methodologies.
- ARPA-E is not interested in information related to topics such as process logistics improvement, manual separation etc.

Questions

The questions posed in this section are classified into several different groups as appropriate. Please provide responses and information about any of the following. We do not expect any one respondent to answer all, or even many, of these prompts. Simply indicate the group and question number in your response. Citations are encouraged as appropriate. Respondents are also welcome to address other relevant avenues/technologies that are not outlined below.

E-waste Classification

1. ***What are different classes of e-waste?***
    a) What other e-waste can be included to expand the above six categories?
        - Rare earth magnets, copper wires and shield etc.?
        - There are products that overlap with universal waste program for e.g. mercury containing devices and batteries. Are there any other overlapping products to be considered?

2. ***How has e-waste changed over time? How can the industry be best prepared for future change?***

3. ***At what point in the e-waste life cycle would it be best to perform measurements and identify the different classes of e-waste?***
    a) During manufacturing
    b) Before disposal
    c) Curbside
    d) Dumpsters
    e) On garbage trucks
    f) Transfer Stations (TS)/Collection Facilities
    g) Tipping floor of Waste to Energy facilities or landfills

E-waste Technology (Identification, Quantification, and Sorting etc.)

1. ***What are the current practices for e-waste identification, quantification, and segregation from MSW streams?***

2. ***What are the potential observation and characterization methods to determine presence, identity, and quantity of e-waste?***
    a) Electromagnetic Imaging and Spectroscopic Methods
        - Near-infrared spectroscopy (NIR) (currently used in processing plastic waste)
        - Millimeter wave scanner (currently used in airport body scanners)
        - Terahertz wave scanner – nonionizing (currently used in material characterization)
        - Soft X-ray – Ionizing (currently used to produce images of very small objects for e.g. in airport baggage scanners) both spectroscopic (XRF) and imaging
        - Z backscatter – very low dose ionizing (currently used in cargo scanners) imager
        - Radiofrequency - conducting material detection
        - Laser Induced Breakdown Spectroscopy[20] (LIBS)
    b) Computer vision
        - Robots relying on artificial intelligence and taking advantage of machine learning (deep learning)

[20] V. Costa, F. Aquino, C. Paranhos, E. Pereira-Filho, "Identification and Classification of Polymer E-Waste using Laser Induced Breakdown Spectroscopy (LIBS) and Chemometric Tools", Polymer Testing 2017, 59: 390-395

c) Ultrasound vision
   - Guided ultrasound waves (currently used in Non-Destructive Testing of materials)

d) Chemical markers and digital watermarks[21]

e) Data fusion techniques which combine two or more inspection methodologies to improve detection and reduce false alarms.

3. ***What is the degree of accuracy and precision of the various identification technologies? For all cases, indicate how the probability of detection (PD) and false positives (FP) scale with inspection time (IT). For example, as the square root of IT? Ideally, provide the receiver operating characteristic curve (ROC) for each detection technique.***

4. ***Are there any specifications or demonstration of similar technologies in an adjacent application area (i.e. not necessarily in MSW) that should be considered?***

5. ***What metrics can be applied to identify e-waste in MSW? A few examples are stated below. Further recommendations are solicited.***
   a) 50% identification of presence by type with very low (e.g. < 10^{-3}) false positives (for curbside pickup)
   b) 75% identification on garbage trucks
   c) 90% identification at transfer station tipping floor

6. ***One of the barriers for recycling of small size e-waste is high recycling costs including labor and logistics costs which far exceeds the material cost. Potentially, outsourcing of such operations like Remote Recycling[22] is feasible and promising in terms of reducing recycling costs. Can this concept be adopted and modified depending on the needs in U.S.? How can the concept be implemented?***

<u>**E-waste Technology-to-Market**</u>

1. ***Not all e-waste is created equal: there is a wide variance in the value of recovered e-waste and potential harm of the failure to recover e-waste from the waste stream. How to prioritize e-waste identification, quantification, recovery and sorting in the best possible manner?***

2. ***Re-cycling of e-waste is valuable. What are the current and evolving business models?***

3. ***As per Bloomberg New Energy Finance[12] one of the biggest drivers of sorting technology adoption will be an uptick in new Material Recovery Facility (MRF) and recycling capacity where the facilities can be built around automation and integrated from the start to fully optimize operations. What are some of the other barriers to adoption of sorting technologies?***

4. ***What should be the range of the cost of the identification and quantification technologies to make the adoption quicker and the business profitable?***

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[21] Bloomberg New Energy Finance. "1H 2020 Advanced Materials Market Outlook" – January 16, 2020

[22] N. Mishima, J. Oki, A. Oikawa, K. Torihara, and Y. Kadowaki, "Service Outsourcing in Recycling of Used Small Electronics". *Procedia* CIRP 47 (2016), pp 424-429

E-waste compliance and certification

1. ***What are the barriers to compliance for the separation of e-waste from MSW?***

2. ***How can technology drive the change in social behavior towards increased compliance?***

3. ***Significant efforts have gone into developing e-waste certification standards (for e.g. e-steward, R2 etc.). What are the remaining risks to the industry?***