Disassembly-based bill of materials data for consumer electronic products

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Consumer electronic products have a complex life cycle, characterized by environmental, social, and economic impacts and benefits associated with their manufacturing, use, and disposal at end-of-life. Accurately analysing these trade-offs and creating sustainable solutions requires data about the materials and components that make up these devices. Such information is rarely disclosed by manufacturers and only exists in the open literature in disparate case study format. This study presents a comprehensive database of bill of material (BOM) data describing the mass of major materials and components contained in 95 unique consumer electronic products. Data are generated by product disassembly and physical characterization and then validated against external benchmarks in the literature. The study also contributes a reproducible framework for organizing BOM data so that they can be expanded as new products enter the market. These data will benefit researchers studying all aspects of electronics and sustainability, including material scarcity, product design, environmental life cycle assessment, electronic waste policy, and environmental health and safety.

Background & Summary
Consumer electronics have enabled a revolution in the way society accesses and shares information, education, and entertainment. But this transformation has come at a significant environmental cost. Satisfying society's hunger for new technology has led to concerns about energy- and resource-intense product manufacturing1, declining product lifespans2, and waste management systems that create risks to human and environmental health3. A major driver of these environmental risks are the vast and complex array of materials that enable the functionality and appearance that consumers demand, including valuable metals such as gold, silver, and platinum; scarce resources such as cobalt and rare earth elements; hazardous materials including lead and mercury; and difficult-to-recycle materials like polymers containing halogenated flame retardants4,5.

The ability to research and create sustainable solutions for electronic products hinges on the availability of high-quality data that accurately capture the materials and components contained in these devices. The environmental research field has made significant progress in developing comprehensive life cycle inventory databases describing environmental impacts associated with general processes associated with material extraction and refining (e.g., ecoinvent, GaBi, and U.S. LCI databases) and processes specific to electronics manufacturing6,7. These tools are typically applied to specific case study electronic products1,8, which makes it challenging to generalize to other product types, designs, or time periods.

To analyse the environmental footprint of an electronic product of interest, a first step is to establish the profile and quantity of materials, components, and assemblies present in that product (often called a bill of materials or BOM). These data can then be paired with existing environmental databases to determine the life cycle impact of electronic material procurement, product manufacturing, use, and disposal. For example, data on the mass of printed circuit boards (PCBs) contained in a computer could be coupled with life cycle inventory data, typically reported on a per mass basis, and used to estimate the resource use and environmental impacts of manufacturing circuit boards. BOM data are also vital for assessing the economic profile of electronic waste intended for recycling, the dependence of new technology on scarce minerals, and the human health risks associated with product handling during disassembly and recycling.

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Therefore, this study was carried out to collect, verify, and disseminate BOM data that describe the major materials and components contained in common consumer electronic products. The primary goal was creating a transparent database for a wide cross-section of technologies and time periods that could be used by other researchers studying sustainable solutions for consumer electronics. Thus, the study focused on empirical data, obtained by extensive product disassembly and physical material characterization and organized into a reproducible framework. Recognizing that consumer electronics will continue to evolve in the future, this data set can be updated following this framework as new products enter the market and as other researchers publish studies containing BOM data. To this end, the study also evaluated existing examples of BOM data available in the open literature, which were found to vary widely in quality and reproducibility. Select literature values were also included to supplement the empirical BOM data.

### Methods

This study estimated the average bill of materials for 25 common categories of consumer electronics products using a combination of empirical analysis via product disassembly and physical material identification and measurement and external validation via literature benchmarking. Product categories (Table 1) were selected for study based on high ownership rates in U.S. households and prevalence in the electronic waste stream. Within the 25 product categories analysed, a total of 95 individual products were disassembled, spanning a wide array of model years, product designs, and functional attributes (Table 1). These products were primarily obtained opportunistically or by request from donation events and e-waste recycling firms, although some were purchased as used devices from online resellers.

#### Collecting lab-scale bill of materials data via disassembly.

A standard disassembly procedure was designed based on examples of BOMs in the literature and followed to ensure consistent data collection across multiple researchers who contributed to the disassembly dataset. The process of disassembly started by recording the mass of the full product assembly. The full weight included product power cords if they were affixed to the product (as opposed to detachable). Subsequently, the product was disassembled to its major assemblies, which were assigned a unique number and description. The number and organization of unique assemblies varied by product, depending on the complexity of the product’s design and the logical way in which its internal components could be grouped.

| Product category     | Data points from lab (products disassembled) | Years covered by lab data | Data points from literature | Years covered by literature data |
|----------------------|---------------------------------------------|---------------------------|-----------------------------|----------------------------------|
| Basic mobile phone   | 9                                           | 1998–2010                 | 0                           | —                                |
| Blu-ray player       | 3                                           | 2006–2012                 | 0                           | —                                |
| CRT monitor          | 0                                           | —                         | 6                           | 1990*                            |
| CRT TV               | 0                                           | —                         | 3                           | 1987*                            |
| Desktop – integrated | 1                                           | 2011                      | 0                           | —                                |
| Desktop – traditional| 1                                           | 2009                      | 9                           | 1985–2010                        |
| Digital camcorder    | 1                                           | 1998                      | 2                           | Unknown                          |
| Digital camera       | 8                                           | 2002–2010                 | 2                           | Unknown                          |
| Drones               | 4                                           | 2013–2016                 | 0                           | —                                |
| DVD player           | 3                                           | 2004–2005                 | 4                           | Unknown                          |
| E-reader             | 2                                           | 2010–2014                 | 2                           | 2001–2010                        |
| Fitness tracker      | 6                                           | 2012–2014                 | 0                           | —                                |
| Gaming console       | 3                                           | 2005–2006                 | 3                           | Unknown                          |
| Laptop               | 16                                          | 1999–2011                 | 0                           | —                                |
| LCD monitor          | 2                                           | 2006–2008                 | 10                          | 2009*                            |
| LCD TV               | 1                                           | 2009                      | 12                          | 2002–2008                        |
| LED TV               | 1                                           | 2016                      | 1                           | 2011                             |
| LED monitor          | 2                                           | 2014–2016                 | 0                           | —                                |
| MP3 player           | 5                                           | 2004–2010                 | 1                           | 2009                             |
| Netbook              | 3                                           | 1998–2008                 | 1                           | 2009                             |
| Non-smart thermostat | 2                                           | 2011–2015                 | 0                           | —                                |
| Smart thermostat     | 2                                           | 2011–2015                 | 0                           | —                                |
| Plasma TV            | 0                                           | —                         | 8                           | 2002*                            |
| Printer              | 5                                           | 1999–2009                 | 5                           | 2001*                            |
| Smartphone           | 12                                          | 2004–2015                 | 0                           | —                                |
| Tablet               | 2                                           | 2011–2014                 | 1                           | 2009                             |
| VCR                  | 1                                           | 1990                      | 6                           | 1986–2002                        |

Table 1. List of 25 product categories analyzed. * Denotes products from published sources that have incomplete or uncertain information regarding production date. The year stated is the best approximation by those studies or by these authors based on model details or other specifications given.
Collecting literature bill of materials data. Because some BOM data already exist in the open literature, available sources were collected and assessed for potential to include in the BOM datasets (Table 1). One challenge was that literature BOM data are often presented in varied formats, according to the purpose of the study for

For example, a tablet (Fig. 1) was disassembled into five assemblies: battery (lithium-ion battery cells and associated connectors), motherboard (includes PCB), display (includes flat panel glass, cover glass, display bezel, PCBs, plastic films, and other connectors), casing (back cover including camera lens), and interior parts (includes small PCBs and miscellaneous metal and plastic parts). Screws and other small parts from the same major assembly were grouped and weighed together. On the other hand, smartphones were observed to have more streamlined designs that could be described within two assemblies: main body (includes motherboard, interior parts, and battery) and display (includes flat panel glass, cover glass, plastic films, bezel, and other connectors).

Each of the major assemblies was weighed and then disassembled as far as possible with physical separation techniques (hand and power tools). Ideally, disassembly led to parts that were comprised of a single type of material, which could be classified as copper, steel, aluminum, other metals (typically magnesium), glass, or plastics (Fig. 1). These classifications were made based on visual inspection, physical properties, manufacturer labels, and recycling codes. Metal identification was verified using a Delta handheld XRF analyzer (Model DP-2000CC, >99% accuracy for Fe and Al and 95% accuracy for Mg, determined by repeated measurements using a reference alloy with known composition). For example, metals were first tested for ferrous content using a magnet. If magnetic properties were not observed, the metal is assumed to be either stainless steel or aluminum, and then verified with XRF. Copper was primarily identified based on visual inspection (e.g., copper wiring), and magnesium was identified using manufacturer label (parts stamped with a label indicating “Mg”) and verified with XRF.

The small fraction of material that could not be classified into these material types, including paper films, rubber, adhesives, or epoxies, was classified as “others.”

The disassembly process also resulted in components that were composites of multiple materials that were partially or totally inseparable by physical means alone. For example LCD display modules could be separated to the point where some materials were individually identifiable, such as the display frame (plastic or steel), the polarizer and optical films (plastic and paper/others), and in some cases a tempered glass cover (other glass). However, the flat panel glass itself is a composite made up of multiple layers and materials, including a glass substrate, liquid crystal layer, transparent electrode, and other films, which were not further separable. Components like lithium-ion batteries and printed circuit boards (PCBs) themselves contain many of the same materials reported in the BOM, such as aluminium, copper, steel, and plastic, as well as other elements, including gold, silver, cobalt and lithium, all of which would only be separable by chemical or thermal techniques that are outside the scope of this study.

Thus, the total mass of the component, at a point where it was no longer separable by physical disassembly, was recorded and reported in the BOM. As a result, the total amounts of individual materials in the BOM only represent the content of those materials present in a distinct, separable form in the product. The reported mass of components may include additional amounts of those materials and other elements that are not reported here but that can be estimated by connecting this study’s data with literature that has reported elemental concentrations, such as the mass of precious metals contained in PCBs or the mass of indium contained in flat panel display glass.

All of the above mentioned mass measurements were collected using three balances, which were selected according to the size and weight of the part or material being weighed: 50 kg capacity (Acculab bench scale, model SVI-50C, with 5 g resolution), 30 kg capacity (Measurtek high precision counting scale, model EHC-CF-30, with 1 g resolution), and 200 g capacity (Fisher Science compact balance, model CLF201, with 0.1 g resolution). The final mass of all the assemblies, and their respective sub-assemblies, components, and materials were compiled into a BOM for each product.

Collecting literature bill of materials data. Because some BOM data already exist in the open literature, available sources were collected and assessed for potential to include in the BOM datasets (Table 1). One challenge was that literature BOM data are often presented in varied formats, according to the purpose of the study for
which the material data were collected. Therefore, selection of literature sources\textsuperscript{10–23} to include alongside empirical data was based on three parameters: traceability, level of detail, and category consistency. Traceability refers to the degree of transparency in an article’s methodology with respect to how product disassembly and BOM construction were carried out, or in other words, the ability to trace reported material composition data back to methods as they were explained in the paper. Level of detail refers to the degree of disaggregation in the reported data, ranging from studies that only report final cumulative mass percent (low detail) to detailed component-level disassembly data (high detail). Finally, category consistency refers to the degree of similarity between the material categories considered in this study and those reported by the published sources. For example, some literature BOMs report “metals” content as opposed to breaking this down into specific types of metals (steel, aluminum, copper). Each parameter is rated as high, medium, or low depending on the published source (Table 2).

Based on this assessment, one of three scenarios was typically observed, which determined how the literature data were treated and whether they were ultimately included in the final average BOM values (Online-only Table 1):

Scenario 1: Literature reported a transparent product disassembly methodology, fully detailed bill of materials with major component assemblies and subassemblies. For example, Teehan and Kandlikar\textsuperscript{12} manually disassembled fourteen different products following a methodology similar to that used in this work. Complete BOM were reported, including information on model number and year. In cases like this, the literature data could be directly aligned to the primary BOM data sets with no or minimal adjustments (e.g., aggregating material compositions at a product level).

Scenario 2: Literature provided a transparent product disassembly methodology, but the reported BOM are only partially detailed or reported in a different format, and thus required processing for consistency with the primary disassembly data. For example, a study by the California Department of Toxic Substances\textsuperscript{25} also used direct disassembly of 19 products to find composition of major component assemblies. Based on the goals of that study, only the mass of major components (PCBs, LCD panels, and fluorescent bulbs within LCD lighting) were detailed, and no distinctions were made between types of metals present in the products. To align these data with the BOM dataset, some minor processing was required, such as disaggregating the “total metal” category into specific metal categories (aluminum, copper, steel and other metals) according to the percentages observed for similar products in the primary disassembly data. This assumption was based on empirical observation of consistent relative contributions of specific metals within most product categories.

Scenario 3: In studies where reporting a BOM is not the primary goal of the research, material data may be presented without a full explanation of methods or compositional breakdown. For example, Oguchi \textit{et al.}\textsuperscript{19} provided a comprehensive study on the characteristics of end-of-life electronics as a potential source for metals recovery. Because the study goal was quantifying the metal content present in electronic products, there was less focus on other materials, such as plastics or glass. As a result, the published material data do not sum to 100% of the product mass. In these cases, the partial data are listed in the BOM datasets with the missing mass percentage composition assigned to the “other” category. Because these data have a fundamentally different structure, they cannot be compared directly to the primary disassembly results and are not included in final average mass compositions reported.

Subsequent to these determinations, literature values that reflected scenarios one and two above were included in determining average material compositions for each product category as follows.

| Reference | Traceability | Level of detail | Category consistency |
|-----------|--------------|-----------------|----------------------|
| AEHA reported in Oguchi \textit{et al.}\textsuperscript{19} | low | low | low |
| California Department of Toxic Substances control report\textsuperscript{25} | medium | medium | medium |
| Chancerel and Rotter\textsuperscript{19} | medium | medium | medium |
| Hikwama\textsuperscript{19} | high | high | high |
| Huismann\textsuperscript{14} via Huismann \textit{et al.}\textsuperscript{15} | medium | medium | high |
| Huismann \textit{et al.}\textsuperscript{16} | medium | medium | high |
| IEA reported in Oguchi \textit{et al.}\textsuperscript{19} | low | low | low |
| JOGMEC reported Oguchi \textit{et al.}\textsuperscript{19} | low | low | low |
| Kozak and Keoleian\textsuperscript{15} | high | high | high |
| Lee and Hsi\textsuperscript{10} | medium | medium | high |
| MoE reported in Oguchi \textit{et al.}\textsuperscript{19} | low | low | low |
| Oguchi \textit{et al.}\textsuperscript{19} | low | low | low |
| Peeters \textit{et al.}\textsuperscript{18} | low | low | medium |
| Socolof \textit{et al.}\textsuperscript{17} | medium | medium | high |
| Streicher Porte \textit{et al.}\textsuperscript{11} | medium | medium | medium |
| Stobbe\textsuperscript{18} | high | high | high |
| Teehan and Kandlikar\textsuperscript{12} | high | high | high |
| Tohoku Bureau of ETI via Oguchi \textit{et al.}\textsuperscript{19} | low | low | low |
| Townsend \textit{et al.}\textsuperscript{22} | low | low | medium |

Table 2. Assessment of literature BOM data sources.

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Table 3. Example of assembly-level BOM data for a tablet (Samsung Galaxy Tab 4 SM-T530, 2014), illustrating how data are presented in the “Disassembly Detail” workbook. Mass data are in grams.

| Material          | Casing | Display | Battery | Interior parts | Motherboard | Total material mass |
|-------------------|--------|---------|---------|----------------|-------------|---------------------|
| Aluminum          |        |         |         |                |             |                     |
| Copper            |        |         |         |                |             |                     |
| Steel             | 20     | 0.3     | 6.1     | 125            |             | 26.4                |
| Plastic           | 65     | 43.5    | 41.3    | 149.8          |             |                     |
| Li-ion battery    |        |         |         |                |             |                     |
| PCB               | 7.3    | 2.4     | 26.2    | 35.9           |             |                     |
| Flat panel glass  | 60     |         |         | 26.2           |             |                     |
| CRT glass         |        |         |         | 90             |             | 90                  |
| Other glass       | 90     |         |         |                |             |                     |
| Other metals      |        |         |         | 1              |             | 2.6                 |
| Others            | 1      | 1.4     | 0.2     | 2.6            |             |                     |
| Total component mass | 66    | 222.2   | 125.3   | 52.2           | 26.2        | 491.9               |

\[
\text{Average material composition} = \frac{\sum_{i=1}^{n} PD_i + \sum_{j=1}^{N} LD_j}{n + N}
\]

where \( PD_i \) is the material composition for each product “\( i \)” disassembled in the lab, and \( n \) is the number of products disassembled in that product category. \( LD_j \) is the material composition for each product “\( j \)” taken from literature, and \( N \) is the number of products taken from literature for the product category. The final calculated averages are shown in the data record described below and the summary BOM (Online-only Table 1).

Data Records

The BOM datasets are available at figshare\(^a\). These data records are compiled in two Excel workbooks containing BOM data collected and organized at different levels of aggregation, corresponding to the ways in which researchers might need to access this information. First, the “Disassembly Detail” workbook provides resolved material and component data at the level of each major assembly and subassembly. Each worksheet represents a single product category, and most categories contain detailed data for multiple product samples (Table 1). An example of these results is provided here (Table 3) for the tablet pictured in Fig. 1, demonstrating how the disassembly and material identification processes were translated into an assembly-level BOM.

Second, the “Product Bill of Materials” workbook provides total mass and mass percent of each separable material and component for all products studied and a mean, maximum, and minimum mass (g) and mass percent (%) for each product category calculated using the lab data points. The workbook also contains literature values, which were collected, evaluated, and processed according to the methods section reported above. If available, assembly-level literature BOM data are included, however, it was more common to find published data presented as mass percentages for the product as a whole. The qualitative analysis of data from published literature is indicated next to each data point. An example of these results is provided here (Table 4) for the tablet category, which included two disassembly-based data points and one high-quality literature data point, all of which were reflected in the product category average BOM. A summary table containing the product-level average BOM values is also provided as Online-only Table 1.

In Table 4, Online-only Table 1, and in the Product Bill of Materials workbook, ‘zero’ values for specific materials could result for different reasons, which were conveyed by different cell formatting. Cells left blank indicate that a material is ‘zero’ because it is not applicable to the product. For example, CRT glass is found in CRT TVs and monitors, and lithium-ion batteries are found in mobile products, but these components are not expected to be present in other product categories. Cells containing “—” indicate that a material was not detected by the stated disassembly and material identification process, but we cannot rule out the potential that it is present in the product within a composite component or in a form or concentration not detected by these methods (e.g., as an additive, alloying element, tramp element, or contaminant, etc.). For example, the total reported mass of a PCB (component) would likely include individual materials present in that component (including, for example, aluminium and copper) that are not detectable or separable by physical disassembly alone. However, stated values for each material reflect only the mass of that material when it is separable and quantifiable by physical disassembly, and do not include additional quantities potentially contained in non-separable components (i.e., materials are not double counted).

Technical Validation

Data were validated using quality controls within the study (internal validation) and by best available benchmarks to product market information and literature values (external validation).

One aspect of validation was evaluating if the disassembly and material identification methods were implemented without errors or variations that may introduce uncertainty to the results. In part, such uncertainty was mitigated by using a standard procedure and instruments (balances, XRF) with sufficient resolution and...
For the Kindle, total product mass reported in both BOMs differed by only 1.7 g (0.8%) while mass reported for most similar options available to provide BOM validation.

2008, based on the date stamped on the case; the literature only reported it as ‘circa 2009’. However, these are the

and model, but were potentially manufactured in different years. The lab study identified the iPod to be from

close but not exact matches, as the Kindle described in the literature was a third generation model of the original
description by the literature study. The discrepancy is likely due to small design or manufacturing differ-
ences between the two models. For the iPod, total product mass reported in both BOMs differed by only 1.6 g
(1.4%) while mass reported for assemblies was +/− 1 g or less. The mass contribution by specific materials was
extremely close between the two BOMs, with the biggest variability (3.8 g) stemming from this study assigning
the plastic frame surrounding the flat panel screen to the “plastics” category, while the literature study included it
in the LCD display category.

Table 4. Example of product-level BOM data for the tablet category, illustrating how data are presented in
the Product Bill of Materials workbook. Cells left blank indicate that the specified material is not applicable to
this product. Cells with “−” indicate that the specified material was not detected by physical separation of
the product.

| Material categories | This study | Literature | Average |
|---------------------|------------|------------|---------|
|                     | Samsung (2011) | Samsung (2014) | Apple iPad (2009) | |
| Aluminum            | 45.0        | 8.0        | —        | 137 | 20.0 | 9.3 |
| Copper              | 3.9         | 0.7        | 2.2      | 0.45 | 1.1  | 0.16 | 0.4 |
| Steel               | 28.1        | 5.0        | 26.4     | 5.4  | 12.5 | 1.8  | 4.1 |
| Plastic             | 127         | 22.7       | 150      | 30.5 | 36.4 | 5.3  | 19.5 |
| Li-ion battery      | 135         | 24.1       | 125      | 25.4 | 129  | 18.8 | 22.8 |
| PCB                 | 54.4        | 9.7        | 35.9     | 7.3  | 20.1 | 2.9  | 6.6  |
| Flat panel glass    | 55.0        | 9.8        | 60.0     | 12.2 | 154  | 22.5 | 14.8 |
| CRT glass           | —           | —          | —        | —    | —    | —    | —    |
| Other glass         | 110         | 19.6       | 90.0     | 18.3 | 188  | 27.4 | 21.8 |
| Other metals        | —           | —          | —        | —    | —    | —    | —    |
| Others              | 1.5         | 0.27       | 2.6      | 0.53 | 7.5  | 1.1  | 0.6  |
| Total mass (g)      | 560         | 492        | 686      |       |       |       |

accuracy for the size and type of measurements made (see instrumental specifications in the Methods section).
This uncertainty was also assessed by identifying data points that could be re-evaluated using multiple estima-
tions. Specifically, the total product mass was determined prior to disassembly (for most products) and then
re-estimated by summing the masses of individual materials and components after disassembly. Variability
between these two estimates would point to small parts or materials lost to disassembly or inaccuracies in instru-
mentation. Data in the “Uncertainty Analysis” workbook, also posted to the figshare repository, demonstrates
that the percent difference between these two mass measurements was about 0.5% on average, with a maximum
of 2.5% for a single product.

To validate these measurements against external references, product mass estimated as the post-disassembly
sum of material and components was also compared to reported weights from manufacturers, where such infor-
mation could be obtained for the same make, model, and year product as studied in the lab. These comparisons
showed about 1% difference on average, with a maximum of about 10% difference between values. It appeared
that the few products with greater differences may be due to exclusion of the power cord in the BOM mass.
Because many of the products disassembled were obtained from the e-waste stream, peripheral items like cords
were not consistently available, and so they were excluded unless they were affixed to the product. Thus, final mass
values may underestimate total mass in cases where a detachable power cord is sold with a product but not cap-
tured in the BOM. Other small discrepancies may represent uncertainty associated with disassembling products
that may have been customized or upgraded after purchase, which would influence the final weight. However,
these cases were few, and the majority of mass estimates were very close to available product specifications, pro-
viding additional confidence that products disassembled in the lab represent realistic models of the product, as
described by the brand or third party verified websites.

The above approaches to validation are limited to total product mass, as no comparable internal measurement
was available for repeating estimates on individual material identification or mass. However, disassembly and
material identification data could be validated against literature sources if a comparable product were available.
From the dataset, two products were identified as being very similar to both our lab data and a high quality liter-
ature study12: an Amazon Kindle from 2010 and an Apple iPod Touch 8 Gb from 2008/2009. The products were
close but not exact matches, as the Kindle described in the literature was a third generation model of the original
design and the one disassembled was a first iteration of a slightly altered design. The iPods were identical in make
and model, but were potentially manufactured in different years. The lab study identified the iPod to be from
2008, based on the date stamped on the case; the literature only reported it as ‘circa 2009’. However, these are the
most similar options available to provide BOM validation.

Side-by-side comparisons of the BOMs for both products are included in the Uncertainty Analysis workbook.
For the Kindle, total product mass reported in both BOMs differed by only 1.7 g (0.8%) while mass reported for
specific assemblies varied by +/− 5 g or less, typically due to small differences in how parts were assigned (e.g.,
assigning screws to ‘interior parts’ vs. ‘casing’ assemblies). The mass contribution by specific materials and com-
ponents were also highly consistent, barring one exception, where this study found an approximately 20 g internal
backplate to be steel (verified by magnetic properties and XRF) and the literature study assigned it as aluminum
based on the lack of magnetic properties. The discrepancy is likely due to small design or manufacturing differ-
ences between the two models. For the iPod, total product mass reported in both BOMs differed by only 1.6 g
(1.4%) while mass reported for assemblies was +/− 1 g or less. The mass contribution by specific materials was
extremely close between the two BOMs, with the biggest variability (3.8 g) stemming from this study assigning
the plastic frame surrounding the flat panel screen to the “plastics” category, while the literature study included it
in the LCD display category.
While this detailed level of comparison was not possible for all products, as no other model and year overlap was found, the two examples provided show high agreement, indicating that the methods of disassembly and material identification were robust. However, it should be noted that the applicability of reported BOM findings to studies involving current electronic products will depend on the similarity of product designs and the extent to which technology has evolved over time. Many of the products included in this data set are older models, currently being discarded. As such, they are good representations of materials and components now found in the e-waste stream, but not necessarily generalizable to new technologies being manufactured and sold currently. For relatively well-established technologies, the overall material composition has been shown to remain relatively constant over time, particularly once a specific design and form factor is established in the market. For emerging technologies, materials are not yet well understood and will require additional study and BOM characterization. However, the framework for disassembly, material identification, and measurement presented here can be adapted to collect additional data for new products as they become available.

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Author contributions
C.B. conceived and designed the analysis, collected data, and wrote the manuscript. H.M. collected and organized the majority of the laboratory and literature data and wrote the manuscript. S.A. collected data, assisted in organizing and presenting results, and contributed to the manuscript. B.K. and E.R. both collected data, obtained literature sources for validation, managed long-term data records, and contributed to the manuscript.

Competing interests
The authors declare no competing interests.

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