Part II: Performance Measures for Electronics Recycling Programs

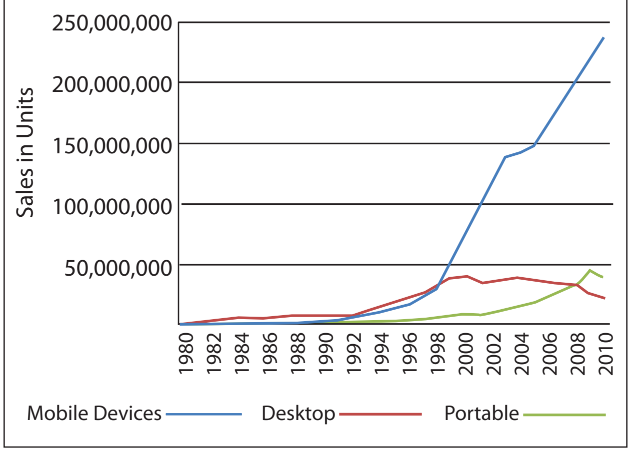
The Challenge of Measuring Success

Traditionally, measuring the performance of provincial electronics recycling programs has been limited to indices of program results, such as tonnes collected for recycling per capita and, in some cases, the capture rate, which is a percentage of the material assumed to be collected relative to what is available for collection. Although such measurements are useful, the information they provide is void of any real meaning in terms of program performance.

To start with, weight measurements offer no information about the composition and toxicity of WEEE, nor do they take into consideration that weights of products are constantly changing. Recent trends toward producing multi-function electrical and electronic equipment, as well as toward light-weighting products and miniaturization, suggest that, over time, overall WEEE tonnage will decrease.

However, while some EEE products have decreased in size and weight, others have increased or remained the same. The weight of an average cathode ray tube (CRT) TV over 19 inches has remained static at 70–75 pounds since 1980, for example. Similarly, the average weight of a desktop CPU (22 pounds) has not changed since 1980. Flat screen TVs, on the other hand, entered the market place in 1989 with an average weight of 29 pounds. Due to consumer demand for larger screens, the average weight of a flat panel display (FPD) TV had increased to 61.1 pounds in 2005, and to 85.3 pounds in 2010. These are the FPD TVs that are being collected today. Unlike televisions, which have increased in weight over the years, laptops are becoming lighter. When they were introduced in 1992, they weighed 9 pounds. Today, in 2013, the average weight of a laptop is only 6.4 pounds. At the same time, the desktop is losing market share and is expected to make up only 18% of all PCs sold by 2015, while the mobile phone, which weighs only a fraction of a pound and has many of the same consumer-friendly applications as the desktop, is gaining market share. It is expected that billions of hand-held mobile devices will be sold worldwide throughout this decade alone.

Figure 1: US sales of desktop PCs, laptop PCs, and mobile devices, 1980–2010



Understanding the effects of sales on the weight collected now and in the longer term is a critical question when planning for end-of-life management in the future. It can also provide some indication of program success. But further difficulties arise with the addition of the variable that accounts for the lifespan of an electronic device. This, too, is a moving target.

In some cases, the technology is improving at rapid rates, so a product becomes obsolete quickly. Smart phones, for example, have an estimated replacement time of only 18 months.[1] Printers are designed with built-in obsolescence and usually die after only three years.[2]

In addition is the factor of reuse. For some WEEE, refurbishment and reuse take place in the economy, but this fact is not recognized in collection data. This would have a deflation effect on the capture rate. Export of WEEE (legal or illegal) is yet another variable affecting our ability to project how much e-waste is produced, and export data cannot be determined accurately.

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[1] US Environmental Protection Agency, *The Life Cycle of a Cell Phone*, accessed July 23, 2013, http://www.epa.gov/osw/education/pdfs/life-cell.pdf.
[2] Steve Pociask, president of the American Consumer Institute, in interview with the author on printer life and printer ink, July 2013, estimated 3 years as the "life of the printer." See also Jeff Bertolucci, "How Much Ink Is Left in That Dead Cartridge?" *PC World*, November 2, 2008, http://www.pcworld.com/article/152953/printer_ink_costs.html.

There are several e-waste projection models that have been designed to consider weights, lifespans, and hoarding patterns. These offer the best estimates of WEEE availability for future planning and can provide some performance information in terms of year-over-year tracking.

EPRA Key Performance Indicators

The Electronic Products Recycling Association (EPRA) uses a suite of core performance indicators to measure the performance of each provincial program (Table 1). Using the same set of indicators for each province is part of EPRA's mandate of harmonizing the programs for better comparison.

Table 1: EPRA performance indicators

COLLECTION	Total tonnes collected
	Tonnes collected per capita
ACCESS	Percentage of population within a specific driving distance of a collection depot
	Number of collection sites
AWARENESS	Percentage of population aware of the program
	Number of participating stewards
COST	Operational costs per tonne
	Overhead costs per tonne
	Total program costs per tonne

None of the indicators, by itself, can paint an accurate picture of the performance of a program. For example, one province might collect significantly more tonnage than the others, but this larger amount could be reflective of the province's size and the scope of materials accepted rather than an indicator of superior performance.

The summaries in this report will provide data for six of these performance indicators. Note that, in the provinces where EPRA is the program operator, collection events are no longer used as an indicator.

Table 2: Performance indicators used in this report

Total tonnes collected
Tonnes collected per capita
Number of collection events
Number of collection sites
Percentage of population aware of the program
Total program costs per tonne

New Measurements: Performance Rates

In terms of measuring performance, EPRA's key performance indicators certainly represent a step in the right direction. However, other measurements, specifically, those that relate to the efficiency of the actual recycling process and to the end destination of material, provide further clarity on program performance.

To understanding the benefits that come from recycling WEEE, research must rely on science-based life cycle analysis (LCA). LCA examines the environmental implications of a product throughout its entire life cycle, from raw material extraction, production, and use of the product, through to final disposition. LCA compiles an inventory of relevant energy and material inputs and environmental releases and identifies the potential environmental impacts associated with identified inputs and releases.

LCA consistently shows[3] that the greatest environmental benefits in material management are derived from those systems that keep the material in use longer, thereby replacing virgin material extraction and production for as long as possible.

Each time virgin metals and elements are replaced with recycled raw material, there is a significant reduction in pollution, greenhouse gas emissions, and energy consumption. Metal recycling derives the greatest environmental benefits compared to recycling plastic and glass products.

These benefits suggest that the output of the recycling process—what WEEE is recycled into—offers important information and can determine the environmental merit of the collection program.

The United Nations Environment Programme (UNEP) published *Recycling Rates of Metals: A Status Report in 2011*.[4] It was compiled by UNEP's International Resource Panel, a group of experts from industry, academia, and government, and it evaluates recycling rate information for sixty different metals.

[3] US Environmental Protection Agency's waste reduction model (WARM) provides up-to-date net energy and pollution factors for source reduction, recycling, EFW, and landfilling with and without energy recovery.
[4] UNEP International Resource Panel, *Recycling Rate of Metals: A Status Report* (Nairobi, Kenya: United Nations Environment Programme, May 2011).

The report defines recycling rates and explains that the benefits of recycling are found in a **closed-loop system** where metalp can be continually recovered and used as substitutes for virgin metals. Pl j b j etal ob`Isboba _rq used in a manner in which the crk`qfIk^ifqv Ic qeb j bq^i is lost j ^v _b fk qeb cIo j Ic cfk^i t ^pqbp) pi^d) bccirbkqp ^ka arpq+ Qefp fp `^iiba kIk*crk`qfIk^i ob`v`ifkd ^ka fq fp bu`iraba coI j qeb obv`ifkd o^qb+

If this definition is extended to other materials found in WEEE, then knowing the fate of the recyclate from WEEE processors (or the flow of materials) will further inform program performance.

Figure 2 illustrates a basic model for the flow of most products and material destined for recycling, energy recovery, and disposal. The flow of materials and products in the recycling chain passes through a series of stages, from virgin extraction to the manufacturer (a) and then to the user (b) and on to the various EOL and reuse destinations.

These are all of the stages in the recycling chain in which material may be lost as waste (w), recovered as energy (x), diverted as non-functional recycling (y), and recycled into a secondary raw material (e & f). Each material's flow path is identified by a letter, which can be used in performance rate calculations.

Each rate is important because it offers different types of information to evaluate how well the EOL programs are working relative to the overall program objectives. These rates also offer insight into the individual links in the chain, which may be deficient (or weak) and require a modification or improvement in management.

Rate Calculations

Isolating the different flows of materials relative to their final disposition provides a framework on which to develop a series of performance rates and indicators. This section identifies the formula for calculating these rates and offers some insight as to how these indicators (rates) are useful.

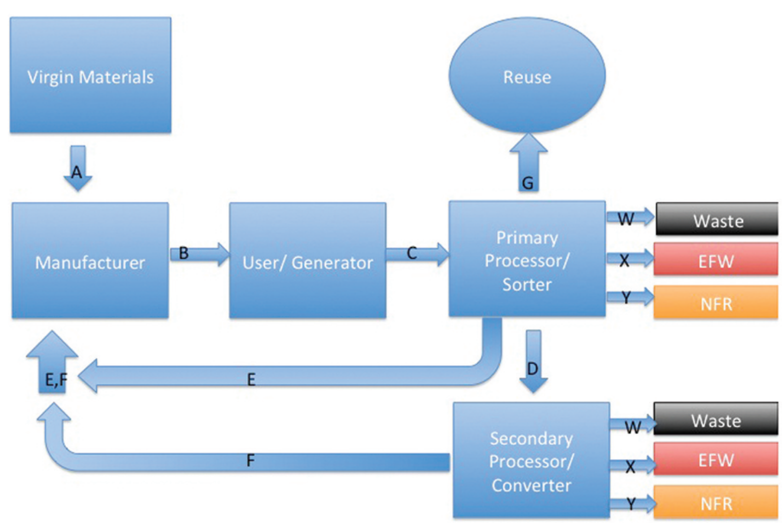
Each rate is calculated using the definitions in the legend of Figure 2. Datasets used for calculation (total product units or total material weight in tonnes) are identified with letters in the flow chart.

Collection rate (CR)

This measures the amount of category-specific material (by weight) or products (by count) collected for recycling compared to the amount available for end-of-life management.

The CR is a good indicator of program success in relation to consumer awareness and collection optimization.

Figure 2: Recycling Flow of Materials Schematic



Legend:

a: Virgin material extracted and shipped to the manufacturer
b: Products or material sold to users which are available for recycling
c: EOL materials collected for diversion
d: Sorted material shipped to secondary processors or converters
e & f: Secondary materials shipped to manufacturers as substitutes for virgin materials
g: Products shipped for reuse and refurbishment
h: Reused and refurbished goods re-sold to users
w: Waste for disposal
x: Waste for energy
y: Materials shipped for non-functional recycling

The CR is measured as the amount of material collected for diversion divided by the amount of material available for diversion:

$$\frac{c}{b}$$

(Note that all equations in this section are as per flow chart in Figure 2.)

Diversion rate (DR)
This measures the amount of category-specific material (by weight) or products (by count) collected for recycling minus any material sent for disposal compared to the amount available for end-of-life management.

The difference between the collection rate and the diversion rate is the amount of "other" waste that was collected along with targeted material. The DR, then, is a good indicator of how well generators and users are source-separating WEEE.

The DR is measured as the amount of material shipped for diversion divided by the amount of material available for diversion:

$$\frac{c-w}{b}$$

(Note that w is the sum of all waste shipped from primary and secondary processors combined.)

Recovery rate (RVR)
This is a measure of the amount of material that is recovered for reuse, functional recycling and energy recovery (EfW) compared to the amount of material available for end-of-life management. This rate excludes any non-functional recycling. The difference between the diversion rate and the recovery rate identifies how much non-functional recycling is occurring for a particular flow of materials.

The RVR is measured as the amount of material shipped for reuse, functional recycling and energy recovery divided by the amount of material collected for diversion:

$$\frac{e+f+g+x}{c}$$

(Note that x is the sum of all material shipped for EfW.)

Recycling efficiency rate (RER)
Recycling efficiency is the percentage of original production nutrient inputs that are recirculated into industrial and natural material cycles rather than lost to wastes that cannot be metabolized by industrial systems as technical nutrients or by natural production systems as biological nutrients.

The RER measures the efficiency of a recycling process. It is the amount of material (by weight) or by product (by count) as an output of a processing process (primary and secondary combined) divided by the material weight (net of water) or the product count that was originally processed. Outputs exclude discarded residual, material used as fuel (i.e., EfW), and any non-functional recycling that occurs further in the recycling chain.

The RER provides a clear picture of an existing recycler's or converter's level of high-value recycling or "functional recycling."

The RER is measured as the amount of material shipped for functional recycling (from both primary and secondary processors) divided by the amount of material received by the primary processor:

$$\frac{e+f}{c-g}$$

(Note that, if metal is recovered from an EfW facility for functional recycling purposes, the weight of this metal should also be included in the numerator. Likewise, if a manufacturer ships a portion of its secondary feed stock out to EfW, disposal or non-functional recycling, this flow should also be accounted for.)

Recycling rate (RR):
The RR measures the net effect of both the collection and recycling efficiency rates. The RR is the most informative performance indicator because it measures the entire recycling process, from collection to final disposition. It is represented this way:

$$\frac{e+f}{b-g}$$

Verified mass balance data to calculate these rates can offer a consistent approach to measuring recycling of WEEE versus measuring only the amount collected. These more detailed measurements would help level the playing field between different processors and encourage improved recycling.