Closed Loop Recycling of Laptops

WHITEPAPER

1 Introduction

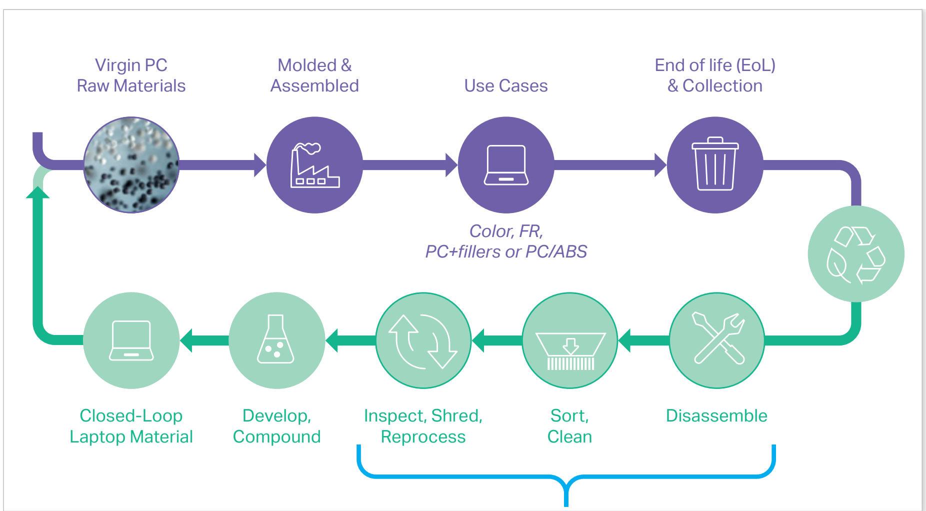
The future is closed-loop. At Covestro, innovative recycling is a priority, plastic waste is a valuable raw material, and the path to circularity is possible. The economy and society at large will benefit from turning linear manufacturing into circular economies. Today's supply chain for recycling engineering polymers is not sufficient for these closed loop economies. Challenges include the difficulty in sorting dissimilar materials, incompatible coatings, varying filler content in plastics, degree of cleaning, and overall inconsistent quality. Because of this, there is a strong need for collaboration between plastics suppliers and the market, to assess feasibility and create ways to capture devices at end of life (EoL). Better education on environmental impact and the use of incentives could significantly decrease the volume of e-waste. A shift towards business models, such as Product-as-Services, or leasing of devices may also decrease the volume of e-waste. The relatively small amount of e-waste that is currently collected is often incinerated after extracting metals, which have a more mature recycling stream and perceived higher value. Covestro sees the residual plastic from these devices as a valuable raw material that should be reclaimed. Recyclers may benefit from an added revenue stream derived from the supply of high-quality thermoplastics back to plastics manufacturers. It is beneficial to start with an industry that has large volumes, few material variations, and where a take-back network is viable to capture parts at end of life (EoL). Therefore, educational notebooks appear to be a wise place to start this journey.

2 Proof that recycling is possible

The main challenge is that there is only a limited supply of transparent, high-purity polycarbonate and polycarbonate blends, which can be ground-up after its first life and re-incorporated into new plastic materials. A possible solution is to segregate plastic used in a specific, high-volume application (e.g., laptops), re-grind it and re-incorporate it into plastic used for the same application. This is termed a closed-loop.

Covestro set out to research whether engineering properties, such as tensile, impact and flame retardance could be retained, when plastic components (both painted and un-painted) from previously used laptops were recovered, ground-up and re-incorporated into plastic used for molding new laptop parts. Covestro worked with Dell Technologies®, a leading notebook manufacturer, to accomplish this study.

Figure 1. E-Waste Closed Loop Recycling



What level of disassembly, sorting, and cleaning is needed?
Painted/unpainted parts? Metals removed? How are coatings treated?

PROPOSED SOLUTION

- Utilize closed-loop PC/blends as a source of recycled content for electronic devices.

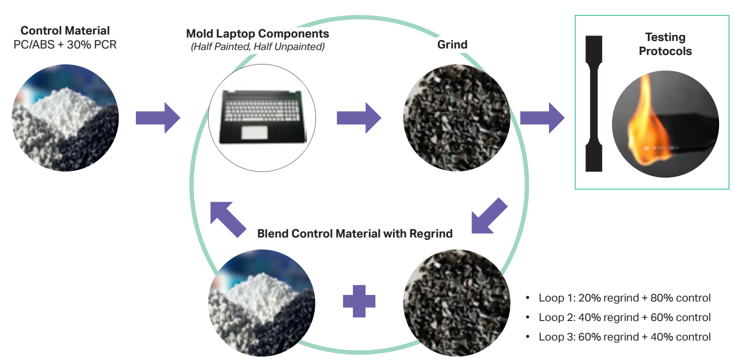
CHALLENGES TO ADDRESS

- ☐ E-waste recycling is complex with many plastic types: **PC+fillers or PC-blends**, containing **FR additives** and **colorants**.
- ☐ Additional recycling steps in **disassembly, sorting, reprocessing**, and consideration of **properties** to adopt in end products.
- ☐ E-waste collection **volumes** are not yet at sufficient scale.

The study used our Bayblend® PC/ABS plastic, which has a mineral filler, is flame-retarded (FR) and contains 30% post-consumer recyclate (PCR). The molded parts were ground-up, following which, 20% more re-grind was added in each loop, thus increasing the recycled content in the plastic after each loop:

- Starting material: 30% recycled content
- Plastic after 1st loop: 44% recycled content
- Plastic after the 2nd loop: 58% recycled content
- Plastic after the 3rd loop: 72% recycled content

Figure 2. Simulated Closed-Loop Recycling

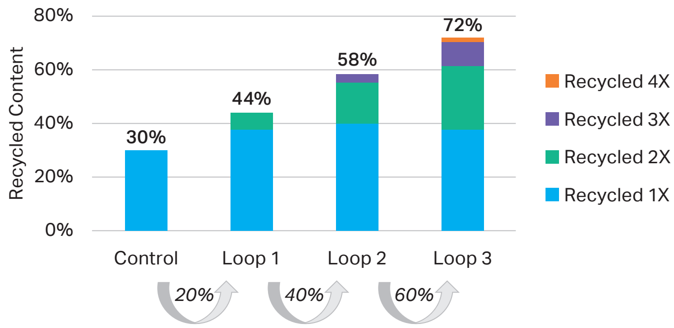


Covestro discovered, that when a well-defined source was used to generate the re-grind, the engineering properties of the new plastic material which was created did not deteriorate markedly and were similar to the starting plastic, even after three recycling loops. Interestingly, there was also little effect observed when the recycled parts which were ground-up had previously been painted.

Since the average lifetime of a laptop is 3 to 8 years, going through three of these closed loops would keep plastic laptop components in circulation for up to 32 years, while producing plastic which retains the engineering properties which Dell specifies.

Covestro presented this closed loop recycling study, jointly with Dell Technologies®, at ANTEC® 2023, on Mar. 29, 2023.

Figure 3. Simulated Closed-Loop Content



3 How to Improve Design to get even more PCR

The above study on mechanical property retention is a great start when discussing circularity concepts. There is additional opportunity for improving the economics of a closed loop system, when Circular Design principles, such as Design for Disassembly, are employed at the beginning of a loop.

Before recycling of plastics can begin, metal parts, including metal-threaded inserts, must be removed from the part into which they are embedded. Removal of metal connectors, like these, is a major drawback to the streamlined recycling of such assemblies, because longer time is required for disassembly, which translates into increased recycling costs. To reduce or eliminate problems, therefore, a need exists in the art for laptop parts to contain a greater amount of homogenous plastic and fewer metal connectors, so they may be more quickly removed, recycled and repaired, than those made according to the state of the art.

Covestro worked with an industrial design consultancy to develop a series of design concepts for notebooks, in order to maximize the amount of easily recyclable PC/ABS. Common threads in these new designs are using fewer glues and adhesives, replacing metal components with plastics, where possible, and replacing screws, in favor of plastic-to-plastic joining methods, like heat staking. Other, more complex re-designs, calling for a major overhaul of displays, electronic boards, and EMI shielding are deployed as well.

By adopting concepts like these, OEMs can create a notebook that is easier to repair or upgrade and easier to recycle, such that the yield of recyclable plastic is higher when the device is disassembled. Some examples of such designs are shown below. Covestro estimates that up to 400 grams of plastic can be recovered per notebook, with some redesign, compared to roughly 50 grams which are recoverable from today's traditional designs.

Figure 4. Assembly Details

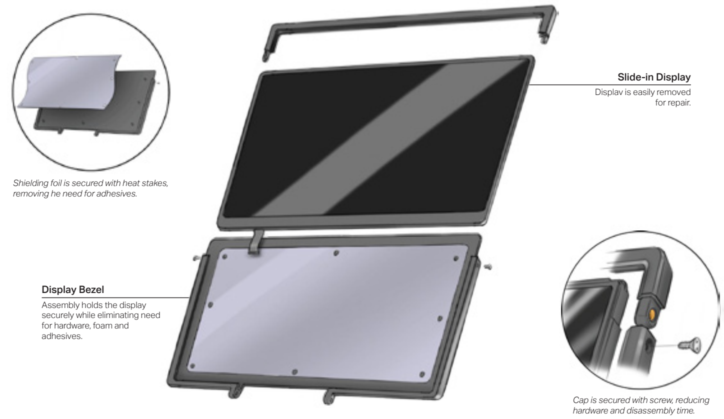


Figure 5. Conventional Design vs Covestro's two concepts (Design for Disassembly), highlighting the PC/ABS parts that are easily recycled.

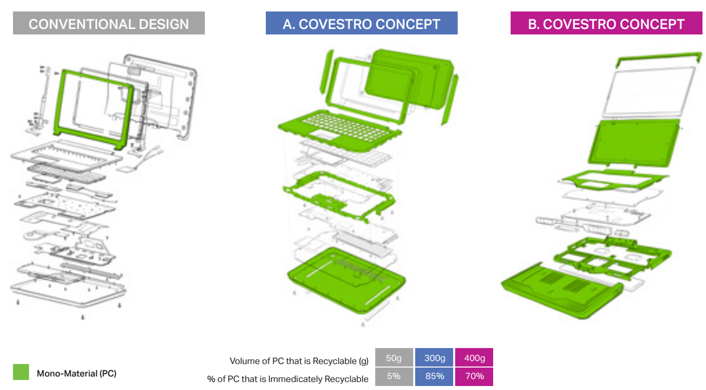


Figure 6a. Details for Sustainability

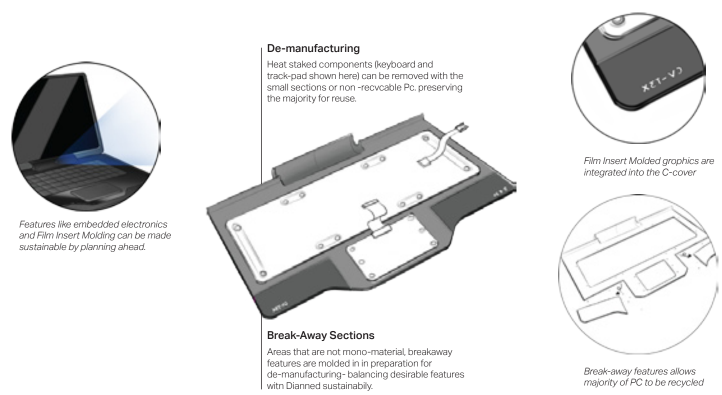


Figure 6b. Threaded inserts designed with 'break-away' feature- for homogeneous disasseembly.

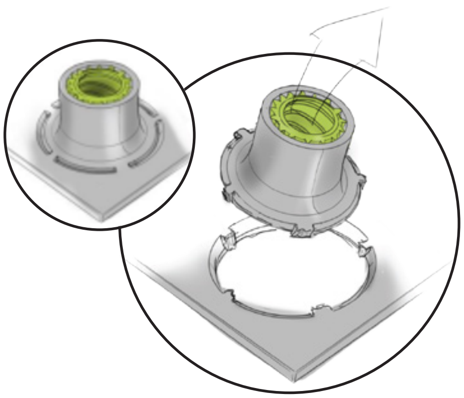


Figure 6c. Molded-in wire harness to eliminate tape

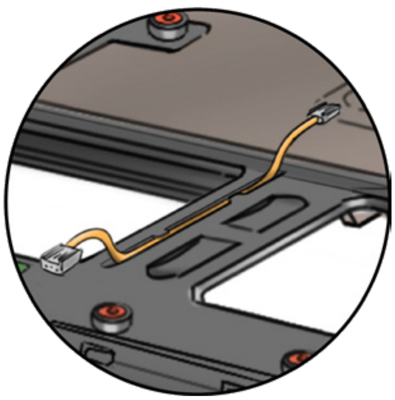


Figure 6d. Ultrasonic welding of C+D covers to eliminate inserts and screws.

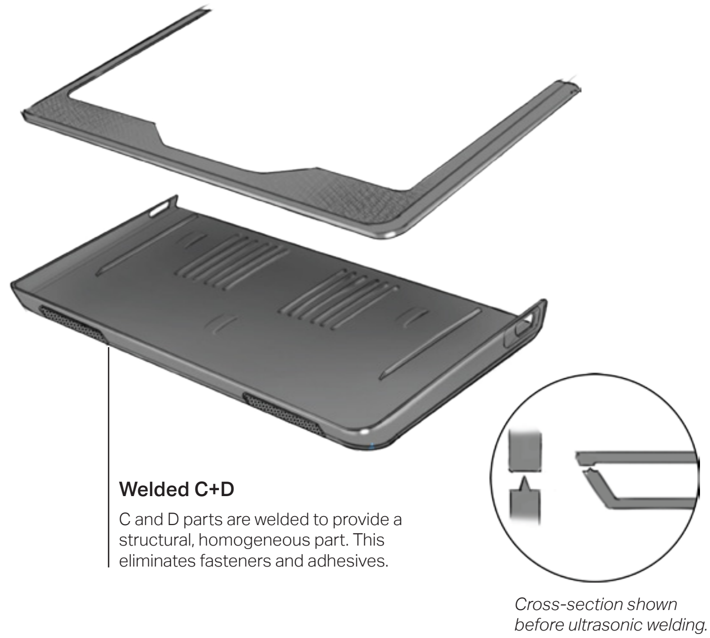
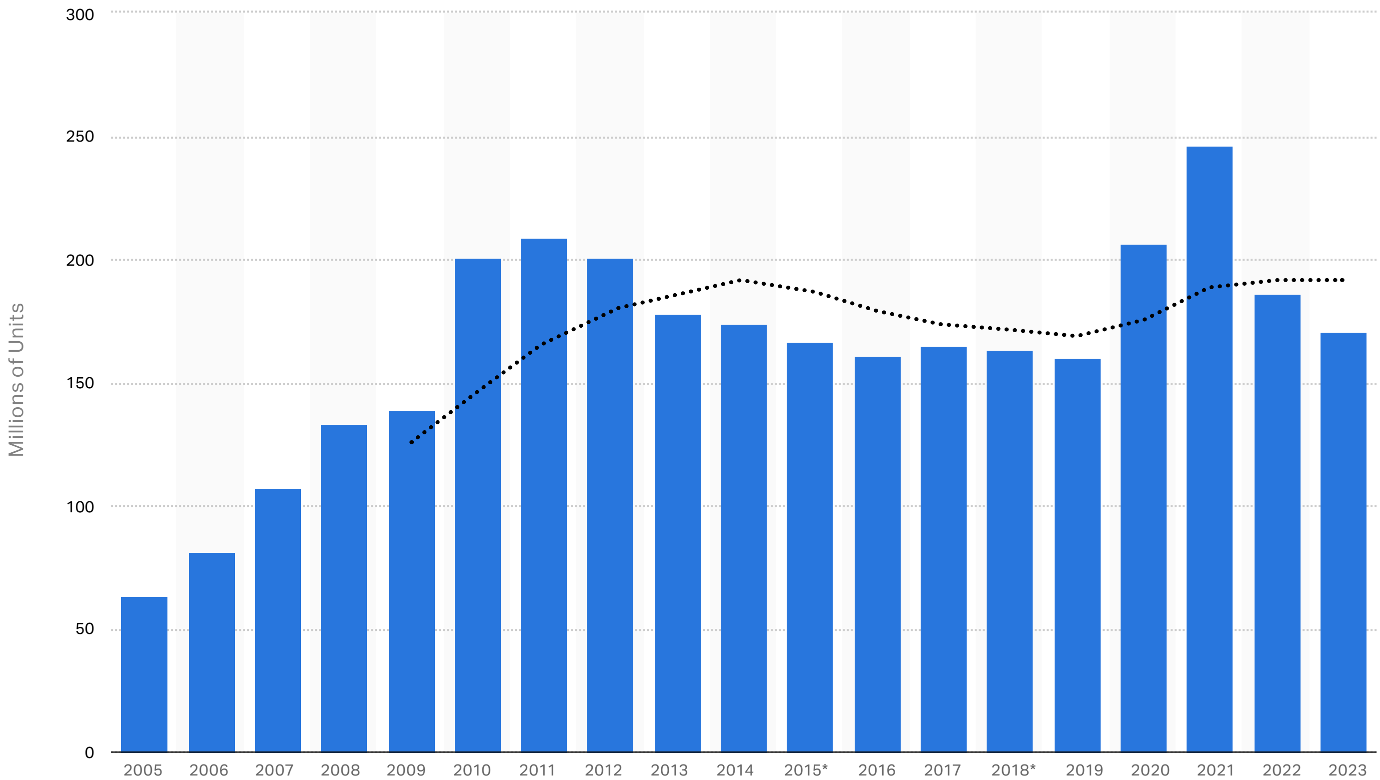


Figure 6e. EMI shielding foil held in place by formed metal standoffs around the grommet, requiring no adhesives.

Figure 7. Global Notebook Unit Volume, 2005-2023 (via Statista)



The chart above shows the global shipment volumes of notebooks, along with a 5-year moving average. There are two primary variables researchers will examine in order to estimate how much potential PC/ABS plastic is recoverable. The first variable is through the use of Circular Design, i.e., how much mass of PC/ABS can be easily recovered without a de-coating step, or metal removal, etc. This is represented in the baseline case of 50 grams, and also in the Covestro re-design concepts denoted as Path A (next generation) and Path B (2-3 generations away).

Table 1. Increase in recoverable plastic through re-design

Expected recoverable mass, PC/ABS (g)			
	Baseline	Path A	Path B
Current	50	300	400

The other variable to examine would be recovery rate. This increases with incentives to collect more of the laptops that already exist, both at recyclers and at the consumer level. The current status, based on available industry information, is estimated at 5% recovery with upside targets increasing to 10% and 15%.

Table 2. Improvements in reverse supply chain

Expected recoverable notebooks. %		
Base Case	Consumer Interest	Consumer Interest + TakeBack
0.05	0.1	0.15

Using an expected lifetime of 5 years +/- 1 year from Figure 7, tables 3a, 3b and 3c were derived to understand how many kilotons of plastic might be collected now (baseline), by year, vs. what *could be* collected under design paths A and B, and what *could be* collected in the future, with implementation of a more robust Take Back system and consumer motivation.

Covestro estimates 0.2-0.5 kT (kiloton) per year to be the minimum viable starting feedstock level for a closed loop operation like this to be commercially viable.

Table 3a. Design Options, No reverse supply (5%) chain help (kT)

	Baseline	Path A	Path B
2024	0.4	2.7	3.5
2025	0.5	3.0	4.1
2026	0.5	3.2	4.3
2027	0.5	3.0	4.0
2028	0.4	2.7	3.6

Table 3b. Design Options, Some reverse supply (10%) chain help (kT)

	Baseline	Path A	Path B
2024	0.9	5.3	7.1
2025	1.0	6.1	8.2
2026	1.1	6.4	8.5
2027	1.0	6.0	8.0
2028	0.9	5.3	7.1

Table 3c. Design Options, Good reverse (15%) supply chain help (kT)

	Baseline	Path A	Path B
2024	1.3	8.0	10.6
2025	1.5	9.2	12.3
2026	1.6	9.6	12.8
2027	1.5	9.0	12.1
2028	1.3	8.0	10.7

From an environmental perspective, for every kT of plastic recovered, we expect a reduced CO2 footprint and less adiabatic depletion.

Note that the above calculation is for the total notebook market, whereas educational notebooks likely represent 20-25% of these values.

5 Why Bayblend? Why the Educational segment?

OEMs have demanding requirements for the external housings of a notebook. The reason Bayblend® FR3021 PC/ABS works well in this application are the material's physical properties, such as flame retardance (FR), durability, stiffness, impact resistance, etc. Commercial and education laptops appear to be the ideal first category to look at. Scale and material uniformity are worthwhile, and the ability to re-capture fleet notebooks at trade-in time is higher. These notebooks have better known use histories and environmental aging conditions, so the tolerances on PCR quality should be tighter. All of the above factors make a closed loop more realistic. The end users (e.g., school districts and companies) may also be more receptive to initiatives aimed at reducing carbon usage, higher waste recovery, etc. than convincing each individual consumer in the market.

6 Current offramps of refurbished and end of life computers

Some current recovery mechanisms can lead to reduced recovery rates (downcycling /refurbishing) with supply chain logistics becoming more difficult to execute. This emphasizes the need for creation of a closed-loop ecosystem.

The results of the closed loop recycling study on notebooks, may potentially be replicated in other consumer and business segments, where high volumes of parts are made, by using well-defined plastic materials. Examples include network devices, servers, home automation devices, smart speakers, gaming and other mobile devices.

7 Conclusions / Discussion

Covestro believes the future is closed-loop. The research outlined here demonstrates that the process can be successful and that the polymers derived retain their engineering properties. The next steps are for OEMs to utilize more efficient designs and for recyclers to achieve higher "Take Back" rates. Working together, Covestro, recyclers and OEMs can create an ecosystem that significantly reduces the amount of e-waste.

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