Recycling of Packaging Material in the Home to Deliver Cost Competitive Manufacturing Inputs Empowering Householders to Contribute to and Benefit from the Circular Economy

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Abstract

Post-consumer recycling (PCR) packaging must meet strict manufacturing input specifications and remain price-competitive with virgin materials produced through extraction and mining in the linear economy.

This paper demonstrates how close loop recycling (CLR) of plastics, glass, and metals can be achieved in the home or other decentralized locations. It outlines the engineering solution, including equipment design. and the integration of AI, machine vision, machine learning and spectroscopy to identify materials, capture label information, and ensure product purity across the supply chain.

The proposed in-home appliance scans and validates used items, processes them to precise specifications, and stores six distinct material streams. An on-demand collection service then delivers these high-quality recyclates to manufacturers. This system empowers households to contribute to and directly benefit from the circular economy.

CLR generates three revenue streams: (i) sale of recycled materials, (ii) provision of DRS and EPR services, and (iii) first-party data for omnichannel marketing and advertising platforms. Compared to virgin inputs, CLR materials used in remanufacturing can reduce energy consumption by 35–95% and lower CO_2e emissions significantly, depending on the energy mix.

Recent advances enhance CLR system viability, including AI-driven MV/ML models with GPU-CPU-RAM accelerators for rapid material recognition, and at-home parcel delivery services developed through online shopping. Together, these technologies enable accurate substance identification, efficient logistics, and scalable deployment.

While industry stakeholders are setting ambitious recycled content and emissions reduction targets—often backed by legislation such as California Assembly Bill 793—CLR appliances can meet these requirements without new regulatory mandates.
Beyond single-family homes, CLR units can be adapted for multi-family dwellings, educational institutions, and other sites, though additional mechanisms are needed to address operational complexities.

This paper will detail the enabling technologies, processes, and business model underpinning household CLR, showing how they can accelerate packaging circularity and expand consumer participation in the circular economy.

Introduction and Motivation

Inputs to manufacturing process to produce packaging for consumer products are still predominantly delivered by mining and extraction of virgin raw materials. At the end-of-life the packaging produced and consumed predominantly ends up in landfill or as pollution contaminating the natural environment. This system represents a linear economy.

Used materials that are closed loop recycled to become manufacturing inputs or post-consumer recycling (PCR) require a lower amount of energy compared with virgin raw materials[1]. Consequentially closed loop recycled manufacturing inputs to a first order of magnitude should be more competitive, both financially and environmentally, as inputs to manufacturing than those sourced from virgin raw material processes. Mostly to date in the US and around the world, delivering closed loop recycled manufacturing inputs competitively has not been achieved. Closed loop recycling is a key requirement of a circular economy.

The first motivation for this paper is to understand why the existing curb side recycling system, after fifty plus years of development and commercial operation, has not delivered significant closed recycling materials for manufacture and why that situation is unlikely to change in the near, medium or distant future. The second and more important motivation is to offer an alternative recycling system that has a sensible and reasonably likelihood of producing the maximum practically possible closed loop recycled materials. It is centered on a recycling appliance in the home, office or other places and supported by an efficient logistic system to transport the close recycled materials to manufacturers, which focuses on a decentralized system empowering householders, office workers and others to contribute to and benefit from the circular economy. They contribute by producing recycled materials and reducing their carbon footprint. They benefit by knowing they are doing the right thing with the environment and being reimbursed for delivering environmentally valuable and cost competitive manufacturing inputs.

In this paper, specific word meaning and usage is in place. The term "waste" refers to material that has no further use and no further value. This is material that should be delivered straight to landfills. It is at its "end-of-life". This process describes a linear economy. "End-of-use" is used instead of "end-of-life" to describe used materials or products at the end of use, since most materials or products have significant additional life through reuse or recycling into equivalent products. This process describes a circular economy.

The current recycling system including the bin being emptying at the curb side, the contents transported to a materials recovery facility (MRF) for sorting of materials into bales before being transported to recycling or processing or recovery plants or factories is called a "collection for recycling" system. Recycling or processing or recovery plants are called "recycling plants". The bales of used PET or HDPE plastic containers output by MRFs when processed to PET or HDPE flakes respectively is called "recycling". The processes that precede "recycling" are called "collection for recycling".

"Used materials" are the inputs to an alternate recycling system. The outputs are materials to exact technical specifications suitable to be inputs to manufacturing processes as far down the manufacturing process as possible. To clearly differentiate between near zero value inputs to and high value outputs from the alternative recycling system, inputs to are called "used materials" and outputs from are called "products".

The alternative recycling system is an optimized decentralized closed loop recycling system (CLRS). The phrases "closed loop recycled" and "closed loop recycling" are used regularly in the paper. CLR will be the acronym for these two phrases.

Bottle deposit systems or deposit return schemes are one in the same thing and will be called DRSes.

Current State of the Technology Industry Uses

There is little information available indicating the amount of used material that is currently closed loop recycled (CLR) by the existing curb side recycling systems in developed western countries.

In the US there are numerous industry reports [2, 3 & 4] with information about the amount of material collected for recycling. For the US the International Aluminum Institute (IAI) states that approximately 42% of aluminum cans are recycled and a Recycling Partnership Report states 30%[5]. From information in NAPCOR's 2020 PET Recycling Report it is possible to estimate that US PET closed loop recycling rate is below 10%[6]. The Ellen Macarthur Institute's 2020 Plastic Agenda for Business advised that "globally only around 15% of plastic is recycled"[7]. In an EU presentation, the presenter displayed the slide depicted in Figure 1 below indicating that in the EU in 2024 8.7 million tonnes or 15% of used plastics was recycled into new plastics[8].

Circularity of Plastics

Plastics in EU 27+3 in 2022

58.8 MT produced

32.3 MT waste collected & sorted

8.7 MT recycled into new plastics

Plastic recycling 13X higher when collected separately

Scaling up collection, sorting & recycling is needed to reach our recycling & recycled content targets

Source: Plastics Europe, *The Circular Economy for Plastics – A European Analysis* (2024)

Figure 1

These reports don't specifically provide CLR metrics. The International Aluminum Institute (IAI) states that world-wide 33% of aluminum cans, 20% of glass bottles and 7% of PET containers are can-to-can recycled or CLR[5]. These results come after five decades of the western world developing and implementing systems that improve the recycling of plastics, glass, metals, paper and cardboard. Aluminum cans are the most recycled packaging in the US, achieving a 42% can-to-can recycling rate.

Purportedly, improved collection for recycling results are achieved where there are bottle deposit or deposit return schemes (DRS)[9]. And industry representatives claim that extended producer responsibility (EPR) systems also help[10]. Industry reports or peer reviewed literature do not provide the CLR key performance indicators (KPIs) for these regions and systems. For example, the percentage of Californian's CRVs (container return values) collected for recycling PET containers that are closed loop recycled is not provided by CalRecycle's published KPIs.

The solutions proposed by governments and industry to improve the performance of curbside recycling are more DRSes, more EPR systems, more infrastructure spending for material recovery facilities (MRF)[11], and more education of householders and consumers. The solution proposed by the Ellen Macarthur Foundation is for businesses to "collectively shape wider market conditions"[12], in other words influence government policy.

Attempts at implementing DRSes and EPR systems by US State governments in the last twenty years have not been successful. The State of Washington has had four failed attempts. The last DRS system enacted in the US was in 2002, 23 years ago! The first US EPR system enacted was in Maine in 2021. California's SB 54 Plastic Pollution Prevention and Packaging Producer Responsibility Act was passed on June 30, 2022. However, recently the Californian Governor has called for a reassessment of SB 54 and it is not yet clear whether this is a delay or a skuttling of the Californian EPR bill. No material wide EPR system is in operation in a US State. Further, the current US Federal political environment is not receptive to supporting government administered systems.

A recent US EPA report estimates an investment of $36.5 to $43.4 billion is needed to improve US curbside collection, drop-off, and processing infrastructure[11]. However, the EPA Solid Waste Infrastructure for Recycling (SWIFR) funding is concluding. Delivering the funding called for by stakeholders could be years off if not decades.

This current "State of the Technology" relying on the enacting DRS and EPR systems and significant government funding is one recycling solution. The last round of US EPA administered Solid Waste Infrastructure for Recycling (SWIFR) grants ends at the end of 2025. There does not seem to be funding available to educate householders who, from the industry's perspective, are always seemingly in need of more education. Without these industry requests being delivered so their solutions can be implemented, the existing recycling system can be expected to struggle to improve its performance

The low recycling outcomes have many causes. One is the historical and continued industry focus on the collection of recyclables and calling the activity "recycling". Reports on collection, as mentioned previously, are numerous. Reports in the public arena, whether industry or peer-reviewed literature, providing CLR metrics are difficult to find. NAPCOR in the US and PETCORE in the EU[12] produce annual reports that enable CLR metrics to be estimated. However, the recent NAPCOR and PETCORE reports are not publicly available. Collection is an important first step in any recycling chain. Though the focus should be on the required recycling systems outcomes. Also, if there is validity in Peter Drucker's statement **"***What gets measured gets managed***"**, when the focus is on measuring collection, it is understandable that since CLR outcomes are not the focus of measurements and reports, then they don't get managed.

There are alternative technological approaches, which do not focus on collection, which could sensibly and reasonably be a practical, deliverable and financially viable CLR solution.

Technology Approach

A technological approach would be defined by the required solution. That solution is to produce high-purity high-volume manufacturing inputs as quickly and efficiently as possible. Household appliances provide technological solutions to clean and dry our dirty clothes, wash our used dishes, preserve our food, cool our drinks and assist with other household tasks. The alternate technology hypothesis was that a decentralized CLR home appliance could perform household recycling.

It has been generally accepted by stakeholders that source-separation of used containers and items produces higher quality recyclables. In Figure 1 on the previous page, please note the diagonal text *"Plastic recycling 13X higher when collected separately"*. Despite this seemingly accepted metric, source-separation for the existing recycling system has not been implemented. The current curb side collection-for-recycling system has focused on centralized collection capturing the maximum volume at minimal cost. Because source-separatiin adds to collection costs, it has not found favor with industry stakeholders.

However, a smart household recycling appliance incorporating a sensor chamber which sets out to guarantee mistake-free source-separating decisions by substance and color for used-packaging items is technically viable today. Such a decision-making system removes the need for public education programs for householders. AI models trained by machine vision and learning to provide accurate used container information are a timely and potentially a cost-reducing technological development. Used material size reduction equipment, which processes or size reduces plastic containers to flakes, glass bottles to cullet, and metal cans to shreds, can have their dimensions and manufacturing-cost reduced. Size reduced containers are volume-efficient materials for storage and transport. Label material, glue, tamper ring and any remaining content contamination can be removed by washing, drying and classifying. The product storage container (PSC) includes six small bins, one for each of the six sperate products. They are PET and HDPE plastic flakes, clear, grean and brown glass cullet, and steel and aluminum shreds. The PSC is located at the bottom of the appliance. For product collection from the home, the PSC is disengaged from the appliance and wheeled to the curb. The six products are transferred separately into the correct bins in the collection vehicle. During transfer, the products are separately weighed for supply chain verification and auditing. At-home on-demand logistics systems are now reliable and cost effective primarily due to the Amazon-styled on-line shopping administered from apps on smart phones, pads or notebooks.

Manufacture ready input specifications and product collection at home

The overarching principle of a CLRS is to eliminate the risk of cross contamination between recyclable materials from the point of generation by the consumer through to the final product arriving at a remanufacturer. By analyzing the current process flow for recyclable materials from curbside collection through the MRF, onwards to the processing facility before finally arriving at a remanufactures and following the typical product design process, the CLR appliance development team has taken the processes that work well in the current system, reimagined those that do not and miniaturized them to be suitable for a working TRL 5 domestic appliance prototype of moderate dimensions 47"(H) x 36" (W) x 26" (D) which compares with the dimensions of an average US top-loading washing machine of 44" (H), x 27" (W) x 28" (D).

Before loading a used container into the appliance any closures, caps, neck rings, or foils are removed by the user using simple mechanisms recessed into the front of the appliance. This initial step simplifies the need for separation of dissimilar materials from the core substrate later in the process. The used container is then loaded into the front of the appliance via the loading hatch with the container orientated so that the base, in the case of containers, or unobstructed side in the case of thermoforms, is presented correctly to the sensor array for material analysis. At this stage if closures, caps, neck rings, or foils are not removed, the container will not be accepted and returned to the operator. Once the container has been confirmed as one of the six acceptable material streams it is accepted into the appliance and directed to one of the three processors where it is size reduced. Glass is converted into cullet, plastics into flakes and aluminum cans into shreds. As the containers still retain their labels at this point the processors all operate without screens to mitigate the risk of blockages and post processing residue causing cross contamination. The size reduced materials are fed into agitation chambers to be cleaned with a combination of hot water and surfactants which separate any remaining label and organic material from the core material. The use of selective buffers between the processors and agitation chambers ensures that the appliance can keep accepting containers rather than causing a bottle neck whilst a particular material stream is undergoing the washing process. Once cleaned the material is dried and any remaining label debris driven off in a classifier. Waste water containing organic matter and suspended adhesive from the cleaning process is filtered before being recycled back into the system to limit water usage.

The clean, dry, size reduced material, now called a product, is then released from the agitation chamber to the product storage container (PSC). The individual bays of the PSC, one for each material type accepted, are sized to allow uniform filling to maximize the storage capacity of the PSC and therefore maximize the time between collections.

Through modification of specific geometries within the crusher, granulator and shredder the output cullet, flake and shred dimensions respectively can be tuned to reliably meet industry standards whilst the preparation and treatment of the materials pre- and post-processing ensure that the contamination levels of the final product also fall within allowable industry standards. A comparison of the Industry and CLRS standards for recycled PET (rPET) is given in Table 1 below.

Table 1

rPET	**Industry Standard**		**Closed Loop Recycling (CLR) Standard**
Source	Post consumer PET containers		Post consumer PET containers
Colour	Transparent		Transparent

Property	High Value	Target Value	Unit		High Value	Target Value	Unit
Density	300 - 450	300 - 450	g/l		300 - 450	300 - 450	g/l
Fines content <0.5mm	< 0.1	< 0.1	% < 10mm		< 0.1	< 0.1	% < 10mm
Oversize flakes content	< 0.5	< 0.5	% > 12mm		< 0.5	< 0.5	% > 12mm
Content of light blue flakes	< 2	< 1	%		< 2	< 1	%
Content of colored flakes	< 500	< 100	ppm		< 50	< 25	ppm
Moisture	< 1	< 1	%		< 1	< 1	%
Intrinsic viscosity IV	TBD	TBD			TBD	TBD	

When the PSC is full using an app a user schedules an at-home collection. Recycling figures per household per annum from the Recycling Partnership's national report[2] and bulk density of processed material allows the PSC to be appropriately sized, to fill evenly, and be collected approximately 8 times per year. When the user ejects the PSC from the appliance for collection the PSC bays close and lock to prevent environmental and user interference with the stored products. The user hinges out the PSC handle and moves the wheeled PSC to the curbside, orientating it correctly, the same as is required for the current curbside bins. The Lasso trailer arrives for the collection and deploys a hydraulic arm to interface and capture the PSC. The geometry of the mating parts indexes the PSC to the collection arm so that when it is raised the six material bays align with the corresponding manifold inputs on the collection trailer. An electronic handshake is performed between the PSC and trailer to confirm its correct association with a registered appliance before the bays are unlocked, and products are allowed to flow into individual hoppers. The products are weighed and recorded before being released to the bulk storage bins within the trailer. The PSC bays are closed and locked and the PSC returned to the curbside for the user to collect and return to the bottom of the appliance.

When the collection trailer is full it returns to a product onforwarding depot (POD) where the products are removed from the trailer, cross checked by weight, aggregated and stored ready for sale and bulk transport direct to remanufacturers.

The Sensor Chamber

A CLR appliance sensor chamber is the key technology which sets this CLR system apart from the current and traditional curbside recycling system. It has the capability to accurately identify a used container's or item's substance, its color, whether it is DRS qualifying or not, linking the container's consumer with the brand owner to enable delivery of EPR, and the reading of label image and text information for omnichannel marketing and advertising platform use.

The chamber is the first and critical function to guarantee each of the recycled products produced are to the CLR specification. The householder's "which bin does this item go in" common dilemma is resolved removing the need for householder recycling education. The label image information and sensor chamber software deliver the maximum realizable value of each container. A container's CLR material value represents only one sixth of each used container's potential realizable value.

NIR spectroscopy in the sensor chamber

Near-infrared (NIR) spectroscopy is an analytical technique that uses light in the near-infrared range to identify the chemical composition of materials. For plastics, this is particularly valuable because different polymers—such as PET, PE, PP, PVC, and PS—have unique spectral "fingerprints." When NIR light interacts with a plastic material, specific wavelengths are absorbed depending on the molecular bonds present. By analyzing the reflected or transmitted light, it becomes possible to determine quickly and reliably which type of plastic is being processed.

A Hamamatsu compact FT-NIR spectrometer based on Fourier-transform infrared analysis uses near-infrared light to measure characteristic absorption patterns of materials. The device is capable of reliably distinguishing different types of plastics based on their unique spectral signatures. The spectrometer is small with low energy consumption and is suitable for integration into a CLR appliance.

Distinguishing between different plastics is crucial for efficient sorting in CLR appliances. Traditional methods, such as manual sorting or density separation are slow and error prone. Moreover, these classical techniques are difficult or even entirely unfeasible in a space and cost-constrained context, such as an appliance in a home. Also, they require large equipment, significant amounts of water or chemicals, or manual labor. Such processes simply do not fit into a domestic environment, where space, time, safety and cost constraints are given. On the other hand, NIR spectroscopy systems offer compact, rapid, non-contact cost-effective and automated identification, making them suitable for small-scale, home-based or similar recycling applications.

NIR spectroscopy plays an important role in CLR appliances when plastic items are first inputted. By identifying plastics quickly and accurately at source, material streams are kept separate from the start, reducing cross-contamination and increasing purity, the key requirement to deliver competitive manufacturing inputs.

AI Decision Models from Machine Vision + Machine Leaning

In addition to identifying container characteristics, image data is used to read barcodes, labels and print on containers using optical character recognition (OCR) technology which extracts text from images. The extracted text helps to identify the container and is specifically used to determine DRS qualification.

Multiple sensor fusion algorithms (SFA) create consensus about container identification and recyclability. Each SFA has its own container characteristics to identify, make decisions, or leverage specific AI models for the task. Some SFAs run in parallel while others use previous SFA outputs as their inputs to form a consensus over all available sensor, image and SFA data. SFA's are designed for strictness, certainty and accuracy, rejecting a container rather than risking product contamination. The SFA algorithms decision is made, and a container will be accepted or rejected.

All relevant sensor chamber data, such as sensor and image data and SFA consensus data, is stored and will be used for quality control, container traceability and accountability for DRS and EPR systems. The data is also used extensively for testing, improving and re-training the Lasso AI models by extending and enhancing the Lasso datasets by performing quality control and annotation and inference verification. This ensures proper working of the sensor chamber and its algorithms and continual improvement of the container characteristics identification. Figure 2 displays a sensor fusion algorithm for a sensor chamber for a CLR appliance.

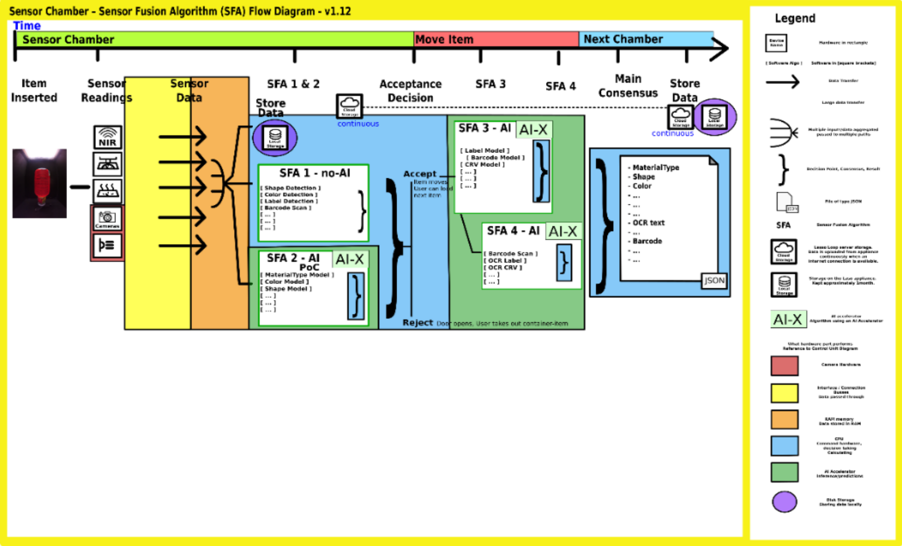


Figure 2

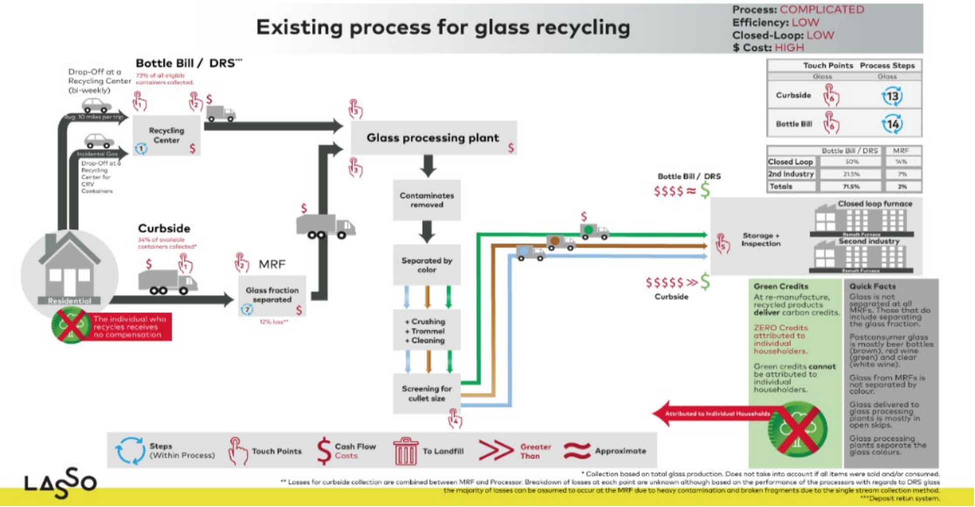
Recent advancements in computation and artificial intelligence technology have enhanced the accuracy and speed of algorithms. AI accelerators, such as GPUs and other specialized chips, are engineered to perform complex computations at a faster rate, improving the overall throughput of the sensor chamber while significantly lowering its energy footprint and cost. Advancements in AI models have led to lightweight architectures, such as EfficientNet a convolutional neural network. These lightweight AI models facilitate faster inference speeds, decrease energy and computational requirements at lower costs.

Discussion

Implications resulting from research and developing a working close loop recycling appliance and supporting logistics system to TRL 5 prototypes are discussed below. The next step is to produce an engineering prototype (EP) from which, in a pilot project, 100 appliances will be manufactured to be trialed in homes. The discussion recognizes that empirical pilot project data is not yet available and is based on a digital model which produces simulation data rather than empirical data.

Labor and Infrastructure Costs

Up until the CLR collection vehicle at the curb empties the product storage container (PSC), householders have provided labor at zero cost. By comparison, the touch points or labor requirements to produce manufacturing ready inputs in the existing recycling system are multiples of those required in a CLR appliance system. Please refer to Figure 3 which shows the flow of glass cullet in the existing curb-side system. Note the touch points and the process steps in the window at the top right of the figure.



	Touch Points	Process Steps
	Glass	Glass
Curbside	6	13
Bottle Bill	6	14

	Bottle Bill / DRS	MRF
Closed Loop	50%	14%
2nd Industry	21.5%	7%
Totals	71.5%	2%

Green Credits

At re-manufacture, recycled products **deliver** carbon credits.

ZERO Credits attributed to individual householders.

Green credits **cannot** be attributed to individual householders.

Quick Facts

Glass is not separated at all MRFs. Those that do include separating the glass fraction.

Postconsumer glass is mostly beer bottles (brown), red wine (green) and clear (white wine).

Glass from MRFs is not separated by colour.

Glass delivered to glass processing plants is mostly in open skips.

Glass processing plants separate the glass colours.

* Collection based on total glass production. Does not take into account if all items were sold and/or consumed.

** Losses for curbside collection are combined between MRF and Processor. Breakdown of losses at each point are unknown although based on the performance of the processors with regards to DRS glass the majority of losses can be assumed to occur at the MRF due to heavy contamination and broken fragments due to the single stream collection method.

***Deposit retun system.

Figure 3

Figure 4 below is a flow chart for a glass CLR system based on an appliance in the home. The three separate clear, green and brown streams of glass cullet are produced by the appliance in the home. Note the reduction in touch points, a proxy for labor costs, by a factor of two (2X) and the reduction in process steps, a proxy for infrastructure costs, by a factor of thirteen (13X).

	Touch Points	Process Steps
	Glass	Glass
Lasso	3	1

	Lasso
Closed Loop	100%
Totals	100%

- Neck ring & cork removal
- Label removal
- Separated by color
- Washing
- Processing
- Storage by color

Green Credits

At re-manufacturing recycled products deliver carbon credits...

Lasso substantially increases green credits and can **attribute them to individual householders.**

Quick Facts

The Lasso appliance accepts Flint, Green and Brown soda lime glass in-house, producing industry acceptable cullet for each colour fraction which is stored in separate compartments.

Contamination = 0%

The Lasso Appliance washes and removes labels from the used soda lime glass as part of the conversion process which eliminates the need for further washing.

The Lasso Product Onforwarding Depot (POD) receives Flint, Green and Brown cullet from Lasso's collection and logistics process. Each cullet fraction is stored separately to maintain the cullet purity.

Figure 4

Process flow diagrams for plastics and aluminum similarly also deliver multiple times reductions in labor touch points and infrastructure process steps.

Product Quality, Energy, and Carbon Footprint

In Figures 3 & 4 above, the three streams of brown, green and clear glass cullet produced by the appliance are depicted as the same as those produced at the end of the traditional recycling system. This is not the case. The cullet color quality is lower in the current recycling system than that proposed for the CLR system. This lower product quality also applies to plastic and metals.

The main justification for recycling is that manufacturing inputs produced from recycled material should have the same quality though lower energy input and consequentially lower environmental footprint than inputs sourced from virgin raw materials. The current recycling system energy use and carbon footprint will be lower than inputs sourced from virgin raw materials. A preliminary LCA-styled study on rPET production by the Mississippi Polymer Institute compares the existing centralized system from collection to flake with the Lasso system from appliance to flake (using the Lasso digital model). The Lasso decentralized system is forecast to produce lower CO2e GHG emissions per unit weight of rPET produced compared to the traditional recycling system.

Transport Costs and Product Sale Prices

An aggregated bulk product delivery system to manufacturers is viable, especially with the CLR system, since it only transports size-reduced valuable products. The per weight sale value of the products produced by the appliance are factors higher than the contents of bales produced by MRFs. Clean washed plastics PET and HDPE flakes ready to be pelletized have a five to ten times higher sale value than baled containers output by an MRF. Over a five-year period, MRFs paid $22 per ton on average to have their collected mixed-colored glass transported from MRFs[13]. Three separate streams of color-pure brown, green and clear glass cullet as produced by a CLR appliance will be each sold for hundreds of dollars per ton. Consequently, long-distant transport of cullet to remelt furnaces will become much less of a disincentive to recycle glass. The physical properties of recycling metal cans make for ease of producing recycled products, hence the premium for closed loop recycled metal shreds compared with compacted MRF bales is lower than plastics and glass. Closed loop recycled shredded aluminum cans, which are 100% free of contaminating plastic containers or bags, will receive a sale price premium.

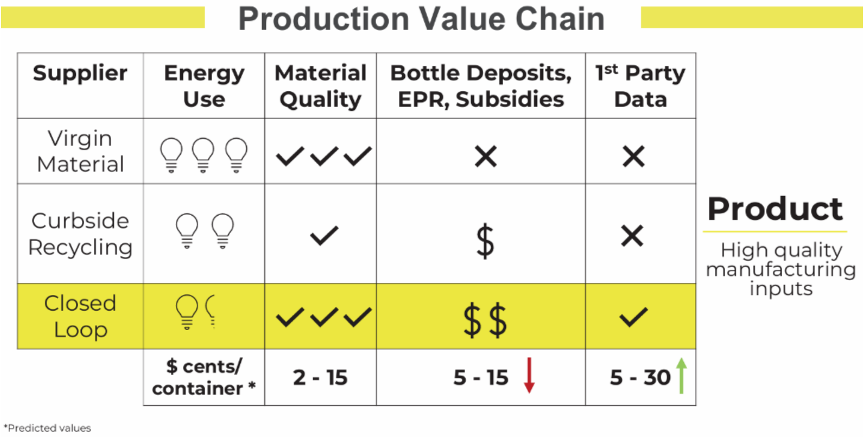
Additional Revenue Streams

Appliance-centric CLR technology delivers high quality and cost competitive manufacturing inputs equal to that sourced from virgin raw materials. Today's recycled product sales prices provide a financial margin. Though further and significant profitable revenue is preferrable. And the recycling appliance's sensor chamber provides the key to delivering that additional revenue. By taking an image of each container, its label and bar code, the sensor chamber gains valuable information. The DRS identification characters can be read qualifying the container for a deposit to be returned. In addition, because each container is size reduced, the appliance "cancels" each container, guaranteeing that that container never fraudulently re-enters the DRS system to receive more than one deposit. When allowed by regulations in those US States that have DRSes, the appliance owner will have the bottle deposit returned to them as easily and simply as when they purchased the product, that is without the need to leave home. In this situation, the deposit will be returned to the right person, that is the person who paid for the deposit in the first place and not to companies nor governments. For the low percentage of households that make time-consuming trips to the recycling centers or reverse vending machines to recover their deposits, a recycling appliance at home will provide them with a convenient time-saving alternative. The sensor chamber links the consumer, who is closed loop recycling the used container in their recycling appliance, to the brand owner. The appliance delivers EPR for each container on behalf of the brand owner, a small additional C2B revenue stream for the householder. Potentially the most valuable revenue stream will result from omnichannel marketing and advertising platforms.

Production Value Chain Comparison

Table 2 below provides a graphical Production Value Chain comparison of the three sources of manufacturing inputs, those sourced from virgin raw materials, those sourced from the current curb side recycling system and those projected to be sourced from the proposed CLR system. Energy use, material quality and revenue streams for the three supply chains are compared. The bottom row provides a forecasted average per container revenue stream comparison.

Table 2



Production Value Chain

Supplier	Energy Use	Material Quality	Bottle Deposits, EPR, Subsidies	1st Party Data
Virgin Material	💡💡💡	✓✓✓	✕	✕
Curbside Recycling	💡💡	✓	$	✕
Closed Loop	💡◖	✓✓✓	$$	✓
	$ cents/ container *	2 - 15	5 - 15 ↓	5 - 30 ↑

*Predicted values

Taking into account a close recycling systems multi-factor (2X – 13X) decrease in labor and infrastructure costs (see Section Labor and Infrastructure Costs above), add in the multi-factor increase in the sale price of CLR products (see Section Transport Costs and Product Sale Prices above), include the additional revenue from DRS, EPR and omnichannel marketing and advertising platforms (see Section Additional Revenue Streams above) the over-all value-add is forecast to more than compensate for the small-scale amount of product delivered from each appliance in a home or office compared to high traffic locations.

Industry and Stakeholder Solutions

Industry and stakeholder organizations continually call for US States to enact DRSes along with EPR schemes. However, in the last twenty plus years responses from US State governments to the calls to enact DRSes do not give encouragement. Despite numerous attempts, the most recent in Texas last year, the last DRS system enacted in the US was in 2002. EPR systems are seen as positive contributors. However, these take years to implement. Organizing regulations and setting up Producer Responsibility Organizations (PRO) is time consuming. As previously mentioned, the Californian Bull SB 54 is being re-assessed causing delays.

Industry and Government organizations keep calling for increased infrastructure spending[11] in the tens to hundreds of billions of dollars. Over decades there have been consistent calls for more community outreach or communication or education of householders. It is questionable if this money is sensibly spent. The Ellen MacArthur Foundation's recent report "2030 Plastics Agenda for Business" indicates that "Policy and/or collaborative action are required"[14] through influencing governments. The outlook is that DRSes and EPR systems will not get enacted by State Governments, infrastructure funding from the US Federal Government is unlikely, and calls for businesses to collectively influence government policies could continue to fall on deaf ears. In summary, the viability of industry stakeholder calls to improve the performance of the current recycling system is questioned.

A Closed Loop Recycling Solution with privately administered DRSes and EPR Systems

A smart CLR appliance at home supported by an efficient at-home on-demand product collection, aggregation and transport logistics system can deliver high-quality cost competitive manufacturing inputs. In addition, in the appliance's sensor chamber, an image of each container and its label is taken. Assuming the container is accepted by the appliance, that container cannot be accessed by humans again, unless humans willfully damage the appliance. The image ensures the characters can be read that qualify a container for a deposit to be returned. After the image is taken and container is accepted it is size reduced, ensuring the container is cancelled. It's a simple process to return the bottle deposit associated with the cancelled container to the bank account of the appliance owner. This process will occur without the householder leaving home. With this process the appliance keeps an information trail of each container for DRS auditing and guaranteeing the quality of the products delivered by the supply chain.

These features and the data collected exist as a matter of course when operating a CLR system based on a smart appliance enabling the possibility for privately administered DRSes and EPR systems. It is a simple matter of data transfer between participants. And privately administered systems don't need US State regulations. Such DRSes and EPR systems can also be implemented by plastic, glass, and metal packaging industries and private companies collectively or separately at a national, state, county, city, town, postcode or street level.

A Pilot Project for a Closed Loop Recycling Solution

A CLR pilot project based on an appliance in the home, office or other places can be sited in a city or town. It requires approximately 100 willing homeowners to trial an appliance in their home. An estimation of the cost of a pilot project is US$ 4 million.

The following full-scale CLR appliance and logistic system rollout will be funded by the CLR system commercial business case. There will be no need to call on US taxpayers. Extending ZEV or EnergyStar styled programs to CLR appliances will increase the rate of CLR impact if desired.

Conclusions & Recommendations

A CLR system based on an appliance in the home, office or other places supported by an efficient at-home on-demand collection system sets two goals:

- to deliver high-quality high-volume cost competitive manufacturing inputs, and
- to empower householders and users of the appliance to contribute to and benefit from the circular economy. They will contribute via delivering recycled material to the supply chain while reducing their carbon footprint. They will benefit by receiving financial reimbursement for their recycling performance.

This paper has technically described an appliance based CLR system and concludes that technically the two goals are sensible, reasonable and deliverable.

The paper recommends that an appliance based CLR system be considered for pilot projects in several US cities or towns to test the business model and commercial viability. Testing the business model includes delivering KPIs for closed loop recycling, carbon footprint reduction and the contribution to the circular economy.

Acknowledgements

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