Advancing the Circular Economy of Plastics through eCommerce

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ABSTRACT

The production growth and short life cycle of plastics has created concerns around its waste management process. Despite efforts to increase recycling over the years, the rate of recycling does not come close to the rate of plastics production. This capstone project develops an innovative and convenient business model that leverages the existing eCommerce logistics network to facilitate a closed-loop supply chain for recycling plastic packaging. We design the model based on the Extended Producer Responsibility (EPR) framework, to identify the key stakeholders and define their roles and responsibilities throughout the process. Stakeholder interviews were conducted for validation and feedback, and are incorporated to further refine the model. We develop a universal, adaptable, and scalable financial analysis tool to evaluate the economics of the model. Finally, we provide recommendations on a pilot test to launch, validate, and improve the developed plastics closed-loop supply chain model. Our results highlight that a multi-stakeholder coalition, with a high level of integration and engagement among all the stakeholders, is necessary to make this model a success. Through a collaborative approach, stakeholders can significantly increase the amount of plastics recycled, divert millions of metric tons of plastics from landfills and ocean waste, reduce the need for production of new plastics, and thus, promote sustainability.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

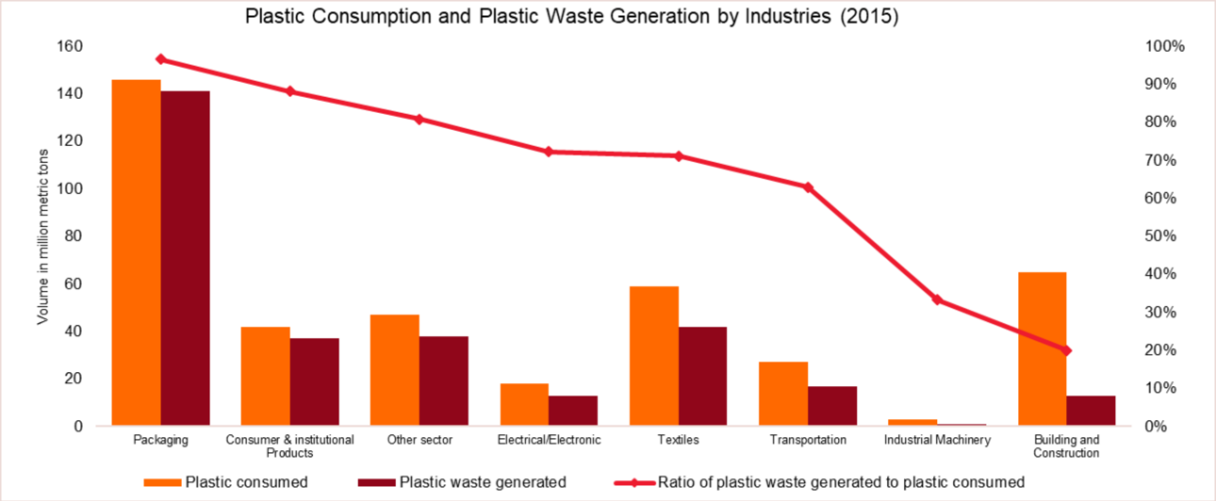
1 INTRODUCTION

Plastic is one of the most common materials in the world due to its functional properties, low processing cost, and versatility. The use of plastics has exponentially grown over the last 70 years. Bakelite was the first form of plastic, produced in 1907; however, the large-scale production of plastics did not commence until 1950. In 1950, the total production of plastics was 2 million metric tons a year. This production growth has increased 200-fold to 380 million metric tons per year in 2015. The cumulative amount of plastic produced from 1950 to 2015 was 7.82 billion metric tons (Geyer et al., 2017).

Each type of plastic has a different life span depending on its intrinsic material properties and its functional application. Figure 1 shows a comparison between plastics used by different industries in 2015 and plastic waste generated by those industries in the same time period. In 2015, the largest utilizer of plastics was the packaging industry, with an allocation of 146 million metric tons per year, equivalent to 42% of the annual production. The packaging industry includes packaging used in consumer-packaged goods (CPG), food and beverage sector, grocery chain, retail, and so on. The second largest user was the building and construction industry, with a usage of 65 million metric tons in 2015, equivalent to 19% of annual production. The packaging industry generated waste at a rate of 97% of consumption, producing 141 million metric tons in 2015. The building industry generated waste at a rate of 20% of consumption, producing 13 million metric tons. The difference in waste generation is driven primarily by the life span of the plastic used in the different industries. The average life span of plastic in the packaging industry is around 6 months or less; however, in the building and construction industry, the life span is around 35 years (Geyer et al., 2017). The lower life span of plastics in the packaging industry, coupled with the exponential rate of usage and waste generation, has raised concerns over the waste management process.

Figure 1

Comparison of Plastic Consumed and Plastic Waste Generated by Different Industries in 2015



Note. The red line describes the ratio of plastic waste generated to plastic consumed in a year, which is negatively correlated with the life span of plastics across industries. Adapted from Geyer, R., Jambeck, J. R., & Law, K. L. (2017). Production, use, and fate of all plastics ever made. Science Advances, 3(7), e1700782. https://doi.org/10.1126/sciadv.1700782

Plastics are known to have a harmful impact on the environment. More than 99% of plastics are produced from chemicals derived from fossil fuels such as oil, coal, and natural gas (Friends of the Earth, 2019). Most plastics are not biodegradable, meaning they will not break down naturally over a short amount of time and will continue to exist in their current form. For example, it is estimated that a plastic cup will take 450 years to decompose (World Wildlife Fund, 2019). Since most plastics are produced from petrochemicals, demand for plastics increases the demand for fossil fuel production. This increased demand for fossil fuels leads to an increase in greenhouse gases and contributes to global warming and the climate crisis. It is estimated that 5% of all greenhouse gas emissions are due to plastic through production, consumption, and disposal (Friends of the Earth, 2019).

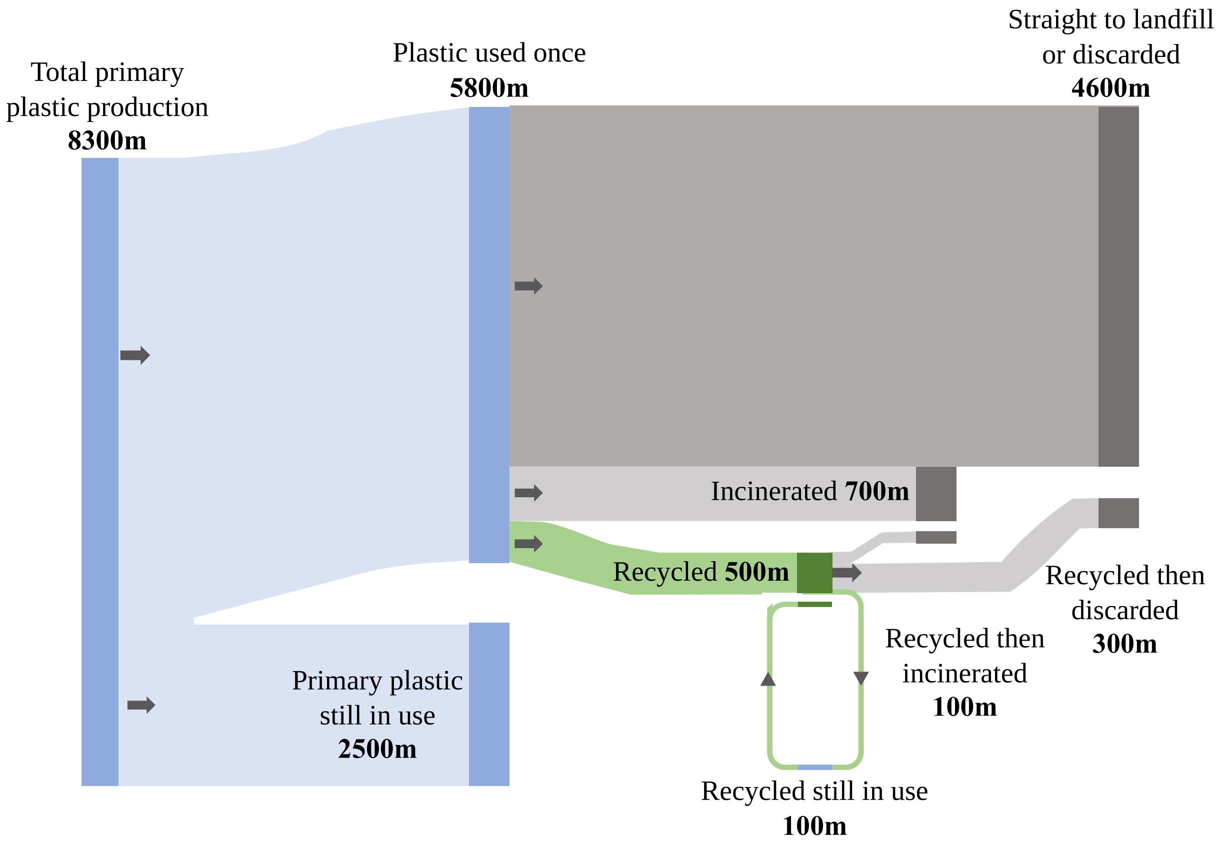
Plastic leakage is when plastic enters the environment due to mismanagement at the end of its life cycle. It is estimated that 8 million metric tons of plastic enter the ocean each year and 150 million tons are currently circulating in the ocean (Stanford News, 2018). To put this figure into perspective, a typical garbage truck has a payload of 9 metric tons, meaning that the equivalent of just short of 900,000 garbage trucks of plastic are leaked into the ocean each year (Waste360, 2011). Once plastic enters an environment, wildlife can become trapped in it or mistake it for food, which can lead to the death of the animal. Micro plastics measuring less than 5mm have entered the food chain; however, their effects on humans and wildlife are still unknown (NOAA, 2020).

In 2019, the European Parliament passed transformative legislation regarding the use and disposal of plastics within the European Union. The legislation had three key initiatives that banned production of single-use plastics by 2021, required 90% collection of plastic bottles by 2029, and increased pressure on the manufacturer for its role in pollution (Leung, 2019). On October 7, 2020, the Canadian government released a plan to achieve zero plastic waste by 2030. The plan includes a ban on single-use plastics and a commitment to environmental sustainability. The plan is expected to become a law in 2021 (Government of Canada, 2020). The United States has no national laws requiring the recycling of plastics or limiting the use of plastics; instead, it is up to individual states, cities, and local communities to pass their own legislation and run their own recycling programs. While 25 states have passed laws regarding the recycling of electronics, only six states have laws to regulate the use or recycling of plastics (APR, 2020 ; ERCC, 2019).

While the efforts to recycle, re-use, or incinerate plastic have increased over the years, the rate is not nearly as close to the rate of the increase in plastic production. Figure 2 shows the lifecycle of the polymers, resins, synthetic fibers, and additives produced from 1950 to 2015 (Ritchie & Roser, 2018). According to Ritchie and Roser, the total amount of primary plastics that was still in use totals 2,500 million metric tons (30%). Out of the remaining 5,800 million metric tons of primary plastic no longer in use, 4,600 million metric tons (79% of plastics not in use) went straight to a landfill or were discarded, 700 million metric tons (12%) were incinerated and 500 million metric tons (9%) were recycled. Out of the 500 million metric tons recycled, 100 million metric tons were incinerated after recycling, 300 million metric tons were discarded and only 100 million metric tons were recycled and still in use, forming a closed-loop supply chain. The amount of plastic that formed a closed-loop is equivalent to 1.7% of the total single-use plastics produced from 1950 to 2015 (Ritchie & Roser, 2018).

Figure 2

Representation of the Total Amount of Plastics in the World at Different Stages of the Life Cycle as of 2015



Note. The figure depicts the amount of plastics for each waste management technique. Adapted from Roser, M., & Ritchie, H. (2018, September). *Plastic Pollution*. Our World in Data. https://ourworldindata.org/plastic-pollution

CPG companies, being one of the primary users and waste generators of plastics, are under increasing pressure to lessen their environmental impact. The extremely low rate of plastics that form a closed-loop presents a huge opportunity for the packaging industry and the relevant stakeholders to transition from a linear model to a circular economy. A linear model is a traditional supply chain model where products are manufactured, used and disposed at the end of their life cycle (Farooque et al., 2019). A circular economy is defined as a closed-loop process with constant flow of materials through the same system, rather than waste generation (Farooque et al., 2019). Aside from the environmental benefits, the value of the materials can be preserved since the product is not discarded.

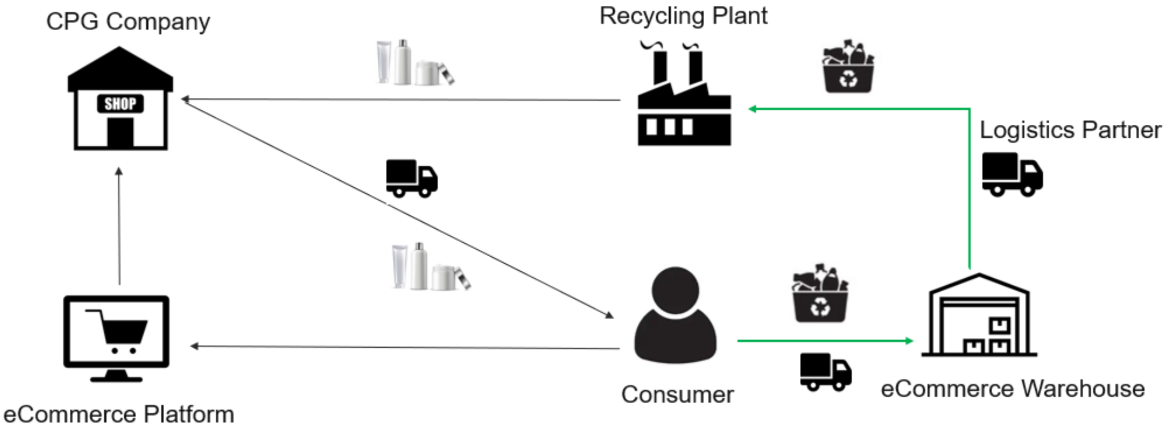
1.1 Problem Statement and Objectives

The purpose of this capstone project is to model the economic and operational feasibility of an innovative and a convenient business model that enables the circular economy of plastics. The research focuses on leveraging the existing eCommerce logistics network to create an economically feasible, closed-loop supply chain for plastics.

Each day, millions of packages are delivered around the world to both homes and businesses. In 2019, UPS alone delivered an average of 21.9 million packages and documents every day (UPS, 2019). Traditionally, the delivery personnel delivers the package and leaves empty-handed. The business model for this research leverages the vast delivery system that is already in place by requiring the delivery personnel to retrieve plastics from the consumers after they have made the delivery (Banerjee, 2020). Once the plastic is back in the system, it can be recycled to form a closed-loop supply chain, as shown in Figure 3.

Figure 3

Simplified Closed-loop Supply Chain Model for Plastic Recycling Through eCommerce Network



Note. The products packaged in plastics are shipped to the consumer from a CPG company through an eCommerce platform. The disposed plastics are picked up from the consumer and transported to the recycling plant forming a reverse supply chain, depicted by green arrow. The plastics are recycled and recycled raw material is shipped to CPG companies for packaging.

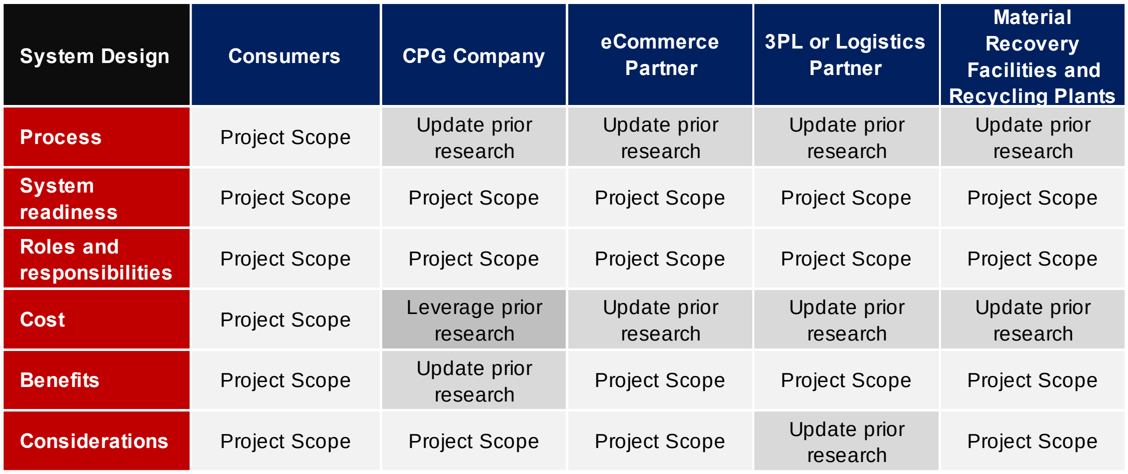
This capstone project will build upon previous research done on a closed-loop supply chain cost equation for CPG companies (Banerjee, 2020). A partnering CPG company will be used for data collection and model validation, but the model will be generic and applicable to any CPG or similar company looking to increase the circularity of their supply chain. The project will be approached in three phases:

1. <u>Design of the Closed-loop Supply Chain</u>: In this phase, the relevant stakeholders in the closed-loop supply chain model are mapped. In-depth analysis on different categories like process, system readiness, capabilities, cost, and so on are performed for each of the stakeholders, as

depicted in Table 1. The existing research on understanding the feasibility and evaluating the cost equation for the CPG company is considered and updated to build a practical closed-loop supply chain model. Stakeholder and industry expert interviews are considered in the design of the system. The deliverable of this phase is a detailed system design that defines the flow of plastic, expected costs, and the roles and responsibilities of each stakeholder in the closed-loop design.

Table 1

Matrix Highlighting the Gaps in the Existing Research that are Addressed in this Project



System Design	Consumers	CPG Company	eCommerce Partner	3PL or Logistics Partner	Material Recovery Facilities and Recycling Plants
Process	Project Scope	Update prior research	Update prior research	Update prior research	Update prior research
System readiness	Project Scope	Project Scope	Project Scope	Project Scope	Project Scope
Roles and responsibilities	Project Scope	Project Scope	Project Scope	Project Scope	Project Scope
Cost	Project Scope	Leverage prior research	Update prior research	Update prior research	Update prior research
Benefits	Project Scope	Update prior research	Project Scope	Project Scope	Project Scope
Considerations	Project Scope	Project Scope	Project Scope	Update prior research	Project Scope

2. Development of the Closed-loop Supply Chain Model: In this phase, the detailed system design and updated cost equation from Phase 1 are used to develop a model that performs a robust, financial analysis. The model requires input data from the stakeholders and uses optimization to return the anticipated cost of the closed-loop system. Assumptions and standards used in the model are well defined and adjustable by the user of the model. The model includes sensitivity analyses across different parameters. The model is designed to be simple, repeatable, scalable, and relevant for all the stakeholders.

3. Pilot Design and Recommendation: In this phase, design considerations and test parameters are recommended for a pilot test of the model. The location determination parameters and well-defined evaluation metrics are included to validate the model developed in Phase 1 and Phase 2. The pilot test implementation is out of the scope of this project; however, the pilot test readiness is within the scope of the project.

2 LITERATURE REVIEW

This chapter covers the existing research and literature pertaining to this project. This review includes:

(1) An overview of reverse logistics system: The eCommerce reverse logistics system, and e-waste reverse logistics system are studied to draft the responsibilities of the reverse logistics stakeholders in the suggested closed-loop supply chain model.

(2) Relevance of eCommerce industry: The role and growth of eCommerce industry is examined to validate the feasibility to scale the closed-loop supply chain system. We also explore eCommerce companies' commitment to sustainability, as they are a key stakeholder in the proposed solution.

(3) Review of existing laws, legislation, and commitment of different levels of government in driving recycling initiatives: This section describes the relevant policies in place for plastics recycling in different regions and the role of government and legislatures in impacting the effectiveness of the system.

(4) Consumer attitude and incentives required to ensure participation in a plastic take-back system: We study the different incentive programs and initiatives that can increase consumer participation and improve collection rates for plastics recycling.

(5) CPG companies and their involvement as a key stakeholder in the circularity of plastics: We explore current commitments made by large manufactures in both Europe and the United States and the challenges they face in achieving their goals. This information is useful in assessing process ownership and actions required from CPG companies or other stakeholders to achieve their goals.

(6) Material recovery facilities (MRFs) and the technology infrastructure: The impact of operational complexity of MRFs is studied to gather insights on recycling challenges and limitations and to build a closed-loop supply chain model that can overcome the key challenges.

2.1 An Overview of Reverse Logistics Systems

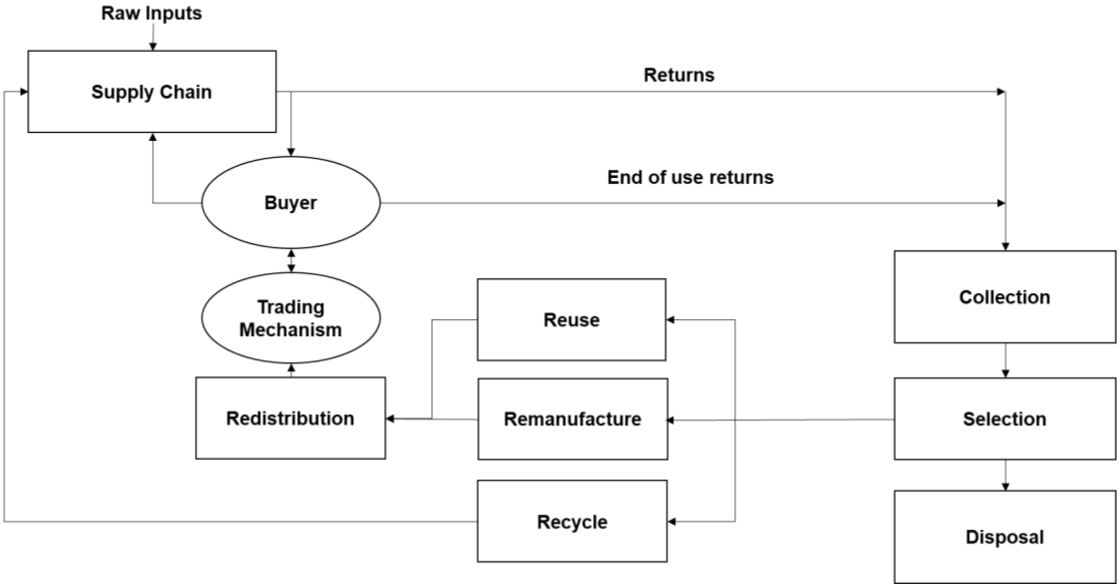
The reverse logistics process is useful in determining the responsibilities of the reverse logistics stakeholders, specifically the logistics providers and third-party logistics providers (3PLs), as well as mapping the process-flow of goods in the suggested closed-loop supply chain model.

2.1.1. eCommerce Supply Chain Reverse Logistics Process

The reverse logistics process is initiated when the consumer decides to return the product that was delivered to them. The product is usually dropped off at a location specified by the eCommerce company. The product is then shipped to a warehouse, where the returned products are collected and sorted. After sorting, depending on the state of the product, they are sent for reuse, recycling, or remanufacture. Damaged products, which are unable to go through any of the abovementioned streams, are disposed-off appropriately. This reverse logistics process enables movement of products away from the consumer, to the manufacturer, forming the reverse logistics network shown in Figure 4 (Kokkinaki et al., 2002).

Figure 4

Simplified Reverse Logistics Network



Note. The Figure describes a generic reverse logistics process for products and different avenue for returned products such as reuse, remanufacture, recycle or disposal. Adapted from Kokkinaki, A. I., Dekker, R., De Koster, M. B. M., Pappis, C., & Verbeke, W. (2002). *E-business models for reverse logistics: Contributions and challenges.* Proceedings - International Conference on. Information Technology: Coding and Computing, ITCC 2002. *https://doi.org/10.1109/ITCC.2002.1000434*

2.1.2. Existing Reverse Logistics Processes Used in E-waste Management

The Waste of Electrical and Electronic Equipment (or e-waste) Directives of 2003 provided guidelines to manufacturers and recyclers in Europe to collect and dispose of electronic products without causing any harm to the environment (Information Resources Management Association, 2020). In order to ensure effective implementation of the process, the responsibilities of the different stakeholders were specified as depicted in Table 2. In this process, the producers are held accountable for the physical design of products as well as the overall cost of the process, defined as Extended Producer Responsibility (EPR). The municipalities control the process of collection from the consumers, with the support of the electronic product distributors. The recyclers ensure products are recycled as per the required standard before selling it back to the producers. The system is monitored by the ministries or the government that implemented the waste management regulation. Parallels can be drawn from the study of e-waste management in Europe to assign stakeholder ownership and accountability for the plastics closed-loop supply chain model.

Table 2

Responsibilities of the Stakeholders of the E-waste Management Process in the European Union

Stakeholder	Responsibilities
Ministries	Check and control collection and recycling activities across the different players
Municipalities	Collection of e-waste and ensuring seggregation of domestic waste and e-waste Control activities of collection and recycling centres
Producers	Ensure product design is fit for recycling applications Ensure recycled compenents can be used in product manufacturing Finance the e-waste management process Extended Producer Responsibility
Recycling companies	Ensure compliance through developed technology and quality controls in place
Electronic Product distributors	Support collection of old and used electrical and electronic components from consumers and direct waste to recycling centres
Consumers	Appropriate disposal of e-waste at the right locations

Note. Adapted from Information Resources Management Association (Ed.). (2020). *Waste management: Concepts, methodologies, tools, and applications.* Engineering Science Reference, an imprint of IGI Global.

2.2 Relevance of eCommerce Industry

The growth of the eCommerce industry as well consumers' know-how of the technology of eCommerce operations are leveraged to build the plastics closed-loop supply chain model. eCommerce companies are held accountable to sustainability standards due to growing pressures from the industry and consumer awareness.

2.2.1 eCommerce Industry Growth

eCommerce is a growing sector, which increased at an annualized rate of 12.7% over the past five years in the United States. In addition, the revenue and the number of players in the eCommerce industry is expected to grow at an annualized rate of 5.7% and 8.9%, respectively, from 2020 to 2025 (Spitzer, 2020). The growth is driven by consumers' preference of eCommerce over traditional brick-and-mortar stores due to the ease of execution and convenience offered.

In 2020, the world was changed in many ways due to the COVID-19 global pandemic, including how consumers purchase goods. Due to health concerns, governments imposed strict lockdowns that drove consumers to purchase through eCommerce platforms instead of traditional brick-and-mortar stores. In the second quarter of 2020, eCommerce sales increased by 44% year over year, with online sales accounting for 20% of all purchases (Digital Commerce 360, 2020). According to Eric Roth, a managing director at the investment firm MidOcean Partners, "eCommerce penetration was pulled forward 2–3 years, and trends that already were here are being magnified" (Digital Commerce 360, 2020).

2.2.2 Relevance of eCommerce System and Sustainability Commitments

According to Amazon's Climate Pledge, the eCommerce giant has pledged to be carbon-neutral by 2040, has committed to power its operations with 100% renewable energy by 2025, and is expanding their electric delivery fleet with a purchase of 100,000 vehicles. Amazon has many circular economy initiatives, such as increasing recycling infrastructure, using recyclable mailers for packaging and creating recycling partnerships. Amazon has invested $10 million in closed-loop infrastructure aimed at increasing the number of products and packaging that are taken back for recycling (Amazon, 2020).

Like other leading companies, Dell is committing to increasing the circular economy and reducing their environmental impact. Dell is providing consumers free, convenient recycling options by partnering with FedEx to provide prepaid mailing or drop-off locations for PCs, laptops, ink and toner cartridges, and computer accessories (Dell, 2020). Dell has also partnered with Call2Recycle for free battery recycling (Dell, 2020). Similar to Dell, a number of electronics companies in the US like Asus, Epson, HP, Lenovo and Lexmark have employed a mail-back system using 3PL providers to enable recycling of electronics, by providing customers free shipping for take-backs (Electronics Take-back Coalition, 2016).

2.3 Recycling Mandates by Governments

As stated in Chapter 1, plastic recycling laws vary by city, state, and country around the world. In early 2019, the EU passed a law requiring all plastic bottles to be made of a minimum of 25% post-consumer, recycled material by 2025 and 30% PCR material by 2030 (Resource Recycling, 2019). Europe and Canada have some of the most restrictive plastic recycling mandates, while the United States has no national mandates. On June 18, 2020, “The Plastic Waste Reduction and Recycling Act,” a bill to improve US recycling technologies and reduce plastic waste, was introduced in the U.S. House of Representatives, but it has yet to be passed into law (Bioplastics News, 2020).

Although there are no national mandates in the US, there are state-level mandates such as container-deposit legislation in over 10 states, including California, New York, and Michigan, where consumers receive a refund varying from 2 cents to 15 cents per bottle for returning the empty bottle at supermarkets or collection centers for recycling (National Conference of State Legislatures, 2020). In addition, there are municipality-level initiatives such as pay-as-you-throw programs, where residents are charged for the garbage disposal but not for recyclables disposal, to promote segregation of waste and recyclables at the consumer level (Hundertmark et al., 2019). Cities which have the pay-as-you-throw programs, like Austin, Phoenix, and Seattle, have recycling rates 10 to 20 times higher than cities without the program, such as Charlotte, Houston and Chicago (Hundertmark et al., 2019).

The studies signify the role of government and municipalities in determining the efficiency of the recycling system. Municipalities or countries with recycling laws are more likely to collect and recycle better than the ones without. The role and the importance of government laws and regulatory policies will be considered when designing the multi-stakeholder closed-loop supply chain model.

2.4 Drivers to Increase Consumer Participation

Consumer education and awareness has been a challenge in different recycling programs; however, some initiatives have proved to provide positive results and drive increased participation. The City of Kingston (Ontario, Canada) Solid Waste Division released a strategy to increase the efficiency and effectiveness of the recycling program and divert materials from landfills. The top three findings that increased consumer participation based on their study were: (i) dedicated promotion and education campaigns; (ii) reward and recognition programs; and (iii) providing free additional recycling boxes (Waste Recycling Strategy, 2010). Instead of offering incentives to all residents for recycling, it was found to be more economic and effective to incorporate a reward program to recognize residents for their quantity and quality of recycling. Residents were able to enter a draw, out of which two residents a year were selected at random for a two-week audit of their recycling practices. If the residents' practices matched the city's standards, the residents were awarded a small prize. The small prizes served as a motivation not just for the individuals but also for increasing the competitive spirt of the communities, which helped improve the recycling rates (Waste Recycling Strategy, 2010).

We can also draw parallels to the incentives that are effective in other take-back recycling systems such as electronic waste and common household waste. For example, Shevchenko et al. (2019) found that the dominant determinant for consumer participation for e-waste collection varied by continent and was dependent on factors such as time, money and convenience. For Europe, the determining factor was consumer knowledge and awareness while in the United States convenience was a dominant factor for participation. In Asian and some African countries financial incentives were the most effective measure to increase participation in recycling initiatives (Shevchenko et al., 2019).

Based on these studies, it is evident that in highly developed countries like the US, European nations and Canada, consumer participation can be increased through (i) convenient collection systems, (ii) awareness initiatives and (iii) reward programs. The study of the initiatives relevant to the US show that no financial incentives are required to promote recycling, which is the assumption used in the proposed closed-loop supply chain model.

2.5 Sustainability Goals and Challenges of CPG Companies

In this section we review CPG companies' existing sustainability commitments and level of involvement in driving recycling commitments as well as any challenges they may face in reaching these commitments.

In April 2018, Procter & Gamble (P&G) announced some of their first sustainability goals, including the pledge of 100% recyclable or reusable packaging by 2030 (P&G, 2019). In April 2019, they announced an even bigger goal, to reduce the use of virgin plastics in packaging by 50% by 2030 (P&G, 2019). In the announcement, 9 of the 11 bottles containing at least 25% PCR material are distributed in Europe, while only 2 of the 11 are in the United States (P&G, 2019). While P&G is moving forward with sustainability initiatives in both the United States and Europe, it is clear that Europe is leading the change due to the laws passed by the EU, which adds pressure on companies to enforce and enact on their sustainability goals.

In 2019, Colgate developed a recyclable toothpaste tube that will be rolled out across all their products by 2025. The product design was modified to ensure the toothpaste tubes are recyclable at local MRFs to achieve circularity. Colgate has announced that it will make the technology available to other interested companies to enable increased recycling rates (Colgate, n.d.). In addition, labels are modified to communicate the product recyclability to the consumers. The consumers will be able to recycle the toothpaste tubes that contain the "recycle tube" label (Colgate, n.d.).

Unilever has made similar commitments as P&G on the circularity of plastics but with accelerated timelines. They have committed to reduce their use of virgin plastics by 50% by 2025 and that all their plastic packaging will be 100% reusable, recyclable, or compostable by 2025. Unilever will also increase the use of PCR material in all their packaging to be at least 25% by 2025, while P&G has not pledged to such an initiative. Another, remarkable commitment by Unilever is that they are contributing to the circular economy of plastics by helping collect and process more plastic than they sell (Unilever, 2020). When discussing circular goals, Unilever states that "We cannot succeed alone. There are many elements which are outside our control, such as selective collection of packaging waste, little or no infrastructure and limited investment in the waste industry … A technological breakthrough and a multi-stakeholder effort to increase recycling is the kind of combined approach that will make the circular economy a reality" (Unilever, 2020).

We see that government policy has an influence on CPG companies' commitment to reducing plastic waste. Although CPG companies have made commitments towards the circularity of plastics in their products, there are still many challenges they face with implementation to reach these goals due to the lack of infrastructure for collection. By leveraging the vast eCommerce network instead of relying on the limited take-back recycling infrastructure, the amount of plastics re-entering the system can be increased and help CPG companies achieve their sustainability goals.

2.6 Role of Material Recovery Facilities (MRFs)

Figure 2 in Chapter 1 highlights that only 1.7% of the total plastics form a closed-loop supply chain through recycling initiatives. Despite numerous recycling programs and the presence of recovery facilities, the plastic recovery rate has been low due to two major drivers: (i) operational complexity of sorting and recycling plastics, and (ii) managing supply through collection process and demand through packaging industries (Bureau of International Recycling, 2020).

2.6.1. Operational Complexity Challenges in Sorting and Recycling

Generally, the MRFs sort the recyclables collected through curb-side recycling processes and create unique bales of sorted material. The bales are sold to the respective recycling facilities, who use chemical or mechanical processing techniques to recycle and create recycled material. The recycled material is sold to manufacturers such as the CPG companies to be used in packaging products. The setup of a recycling plant is a medium-level capital investment project, as it requires technology investment in addition to setup and operation costs to process multiple varieties of recyclables (Roth, 2020). The unique material properties of different types of plastics demand different sorting and recycling techniques, driving up operation costs (Bureau of International Recycling, 2020).

In the United States, around 30% of the plastics entering the MRFs are not sold to recyclers due to the lack of sorting technology (Hundertmark et al., 2019). An MRF in Berks County, Pennsylvania, is working on a pilot project to sort flat and flexible packaging like films, wraps and bags, which are currently not recycled through standard technology (Hundertmark et al., 2019). Similarly, Unilever worked with their pigment supplier and recyclers in the UK on a technology to improve the detectability of black bottles, which are normally not detected at MRFs (Unilever, n.d.). Unilever has announced that it will make this technology public to the industry as well as other markets globally (Unilever, n.d.).

2.6.2. Managing Supply and Demand in the Collection and Recycling Process

Currently, in the US, the location and concentration of MRFs relate to regional population and the economic state of the region as well as the level of government support in driving recycling initiatives (Roth, 2020). California represents the highest concentration of MRFs, with around 10.1% of US MRF establishments due to continuous supply of recyclables driven by regional population and government regulations (Roth, 2020). Based on Figure 4 in Chapter 2.1.1, in a reverse logistics process of disposed plastics, supply is determined by the amount of recyclables returned by the consumers to the MRFs. Even with curb-side recycling programs, consumers in the US end up returning only 40% of the total recyclable waste, and the remaining 60% of recyclables is disposed of along with other domestic waste (Hundertmark et al., 2019).

The demand for recycled plastics is created through companies in textiles, packaging, automotive and electrical and electronics industries that require post-consumer plastics for their applications (Recycled Plastics Market, 2018). Due to the competition and limited supply, CPG companies are unable to fulfil their requirements through recycled plastics supply from MRFs. Unilever was unable to meet their goal of using 100% recycled content in their Dove and liquid hand wash bottles due to a lack of supply of recycled plastics (Unilever, n.d.).

2.7 Conclusion of Literature Review

In this literature review, we studied the reverse logistics system and key stakeholders in the process to explore the feasibility of using eCommerce network to enable the circular economy of plastics. We reviewed the role of the government, eCommerce companies, consumers, CPGs, and MRFs to understand the commitment, challenges, and opportunities for each stakeholder. CPG companies have increased their circularity goals; however, they have faced challenges in achieving these efforts due to the lack of plastics and the lack of collection infrastructure in the take-back process. Improved infrastructure and increased consumer participation are key factors in increasing the amount of plastics that enter the closed-loop supply chain. For consumer participation, the key factors that determine the rate of recycling are awareness and convenience. In terms of infrastructure, we learned that the electronics sector has been successful in partnerships that use reverse logistics systems for the recycling of e-waste.

The accelerated growth of the eCommerce industry across the world coupled with consumers' preference for convenience, makes eCommerce-based closed-loop supply chain suitable and a relevant model that can be scaled across different regions, markets and countries. There is very limited literature and research on developing a business model using the eCommerce plastics take-back system. Therefore, this project aims to develop a convenient, sustainable and practical plastics closed-loop supply chain model for CPG companies using the eCommerce network.

3 DATA AND METHODOLOGY

Based on the literature review, we have identified that the existing research related to plastics closed-loop supply chain using an eCommerce network is limited. Moreover, day by day there is a growing need to build an effective and efficient take-back model due to the exponential production and use of plastics globally. CPG companies have commitments in place to achieve plastics circularity; however, the progress has been slow due to the lack of existing infrastructure or a viable business model. Previous research has shown that a plastics closed-loop supply chain model using eCommerce would theoretically be economically feasible in terms of transportation (Banerjee, 2020); however, there is a need for a practical, real-world business model that companies can adopt in order to achieve circularity.

We approach this project of building a practical, real-world plastics take-back model through three objectives. Each objective, and its associated methodology, is detailed below.

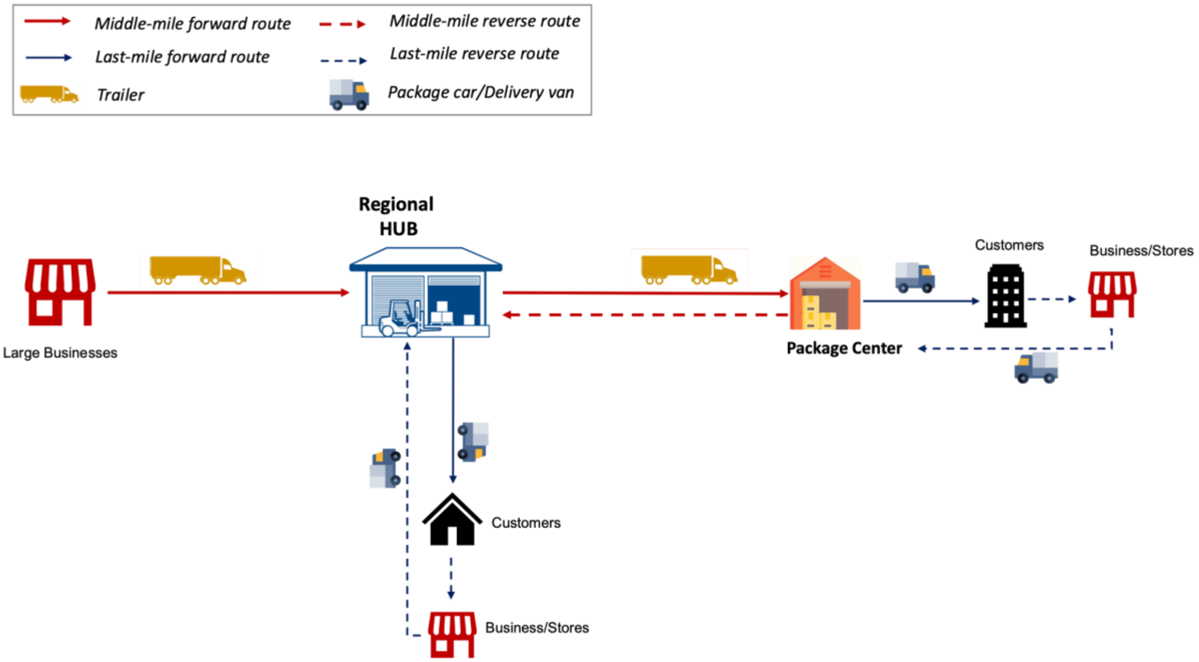
3.1 Design and Definition of the Plastics Closed-Loop Supply Chain Model

The plastics closed-loop supply chain model was designed through identification of stakeholders, process mapping, ownership assignment for each process, analysis of cost drivers for each activity, and an assessment of readiness of each stakeholder to successfully implement the circular model. The design of the process was conducted based on information gathered from literature reviews and through understanding the different practices in the relevant industries. Interviews were conducted with a CPG company, eCommerce companies, 3PL providers, and MRFs to better understand their processes and limitations.

Large eCommerce and 3PL providers use a hub-and-spoke network model as depicted in Figure 5, consisting of large regional hubs (or Distribution Centers, DCs) across the US, each supporting multiple last-mile centers. The last-mile centers are small, high-frequency centers located closer to the cities. The hubs receive the packages from multiple businesses. The middle-mile logistics involves the distribution of packages from hubs to their respective last-mile centers on a daily basis. This is serviced by larger trucks, typically a standard 18-wheeler trailer. Each last-mile center uses multiple smaller vans to distribute the packages to the customers. Each van is responsible for one pre-determined route a day, with multiple stops. The route is determined based on distance optimization, the size and weight of the packages, and the capacity of the vans. The forward logistics system is similar for most eCommerce and 3PL providers. However, based on the interview, a large 3PL package delivery company, after deliveries to customers, picks up packages from businesses to fill their vans during the reverse route. The new packages are consolidated at the last-mile centers and shipped to the hubs through the middle-mile reverse route. However, for other large eCommerce providers, the vans are empty when they return to the last-mile centers, as they do not pick up products in their reverse route (Senior Employee from Supply chain and Sustainability Department of a Large 3PL company, personal communication, 17 March, 2021)

Figure 5

Simplified 2-Echelon Distribution Network of a Partner 3PL Company



Note. This model is a simplification based on an interview with a partner 3PL and is not meant to represent the actual 3PL logistics network. Adapted from personal communication, 2021.

To design the closed-loop supply chain model, parallels were drawn from Extended Producer Responsibility (EPR) enforced by the European government for e-waste management. Similar to Section 2.1.2, the stakeholder responsibilities for the closed-loop system are as follows:

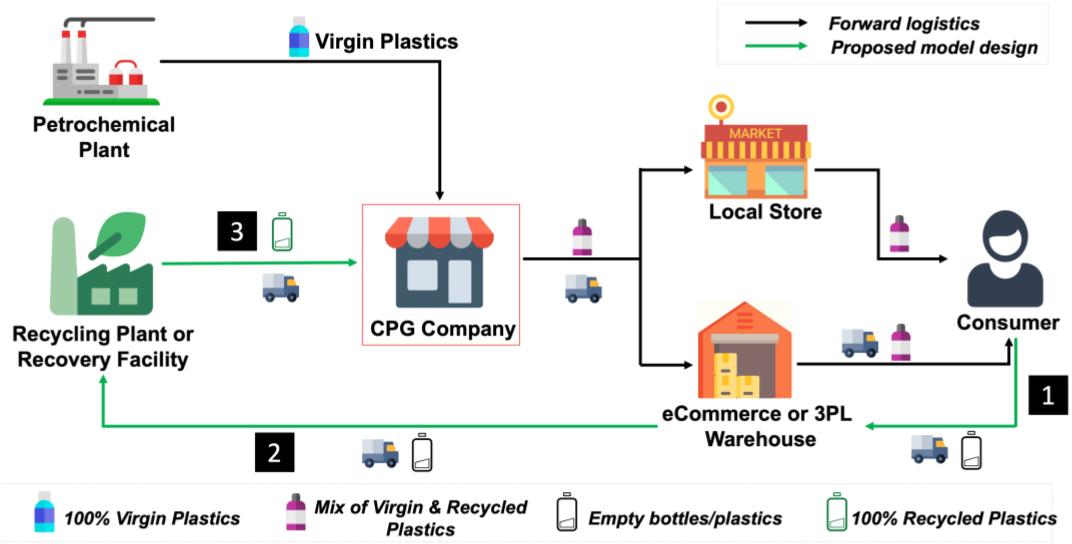
- The overall responsibility of the plastics closed-loop supply chain model is held by the CPG company. The CPG company is ultimately responsible for initiating, running and financing the closed-loop model, in addition to ensuring design compliance and recyclability of the plastics packaging. The CPG company will establish partnerships with the different stakeholders to assign process owners and drive the plastics circular economy.

- Consumers hold the responsibility of ensuring the appropriate disposal of the specified plastics packaging at the right locations.
- The collection, storage, and transportation process are managed by the eCommerce or 3PL company. Each step of the process incurs cost as the products move through the reverse logistics system. Therefore, a strong partnership between the CPG and eCommerce or 3PL company are required, along with financial compensation for the reverse logistics partner.
- MRFs are responsible for sorting and segregating the disposed plastics into different material types. They are also responsible for selling the disposed plastics to the plastics recyclers that will convert the collected, sorted, and baled plastics to recycled plastics.
- Governments or municipalities are responsible for monitoring and controlling the activities across the different stakeholders to ensure system stability.

Based on the stakeholder responsibilities and the existing forward logistics network, the plastics closed-loop model was designed: The proposed process begins at the point of disposal of the plastic product by the consumer after use and ends with the recycled plastic material being used for re-manufacturing by the CPG manufacturer. Green arrows in Figure 6 highlight the reverse logistics network designed in this project.

Figure 6

Proposed Plastics Closed-Loop Supply Chain Model Leveraging eCommerce or 3PL Logistics Network



Note. The green arrows signify the reverse logistics system developed as part of this project. The black arrow depicts the existing forward logistics system used to deliver CPG products to consumers.

Figure 6 – Process Step 1

a) The consumer is responsible for cleaning and storage of the plastic products until pickup. The scope of the project is limited to product pickup, following the home delivery only. Pickup at a drop-off location or an intermediary were not considered in this project.

   i. From the literature review, we assumed that the consumer is a willing participant; therefore, no cost is incurred in the form of incentives.

   ii. Costs incurred with educating the consumers, awareness campaigns through advertisements and digital promotions are considered negligible. Cost of re-labelling for better communication to consumers is assumed to be equal to the current cost of labelling, and therefore, no impact on the cost equation.

b) When the consumer receives their next delivery from an eCommerce or 3PL provider, the logistics provider is responsible for collecting the plastics and transporting them to the warehouse.

    i. In a multi-echelon network design, each delivery van brings the collected plastics to the last-mile center, leveraging the last-mile reverse route. The collected plastics are consolidated at the last-mile centers and are shipped back to the hubs through the middle-mile reverse routes.
    ii. In a single-echelon network design, the delivery vans transport the collected plastics directly to the DCs. To simplify the supply chain complexity, the research will assume a single-echelon network design.
    iii. By leveraging the existing forward logistics network and its reverse routes, there are no logistics costs for the transportation of the plastic from customers to DCs.
    iv. The driver has a productivity loss, due to new processes such as pickup and storage of the material on the truck. This is considered as a cost per pickup at each customer.
    v. The model assumes that there is available capacity in the trucks after delivery, which enables drivers to pick up the plastics from consumers. As the trucks make more and more deliveries, there is increased available capacity.
    vi. The system incurs unloading costs at the DCs; this is considered as an unloading cost per truck
    vii. The truck is equipped with collapsible storage containers for the collected plastics, which is a one-time cost per vehicle but is excluded in the model.

Figure 6 – Process Step 2

a) A collection area is established at the DC to store the collected plastics.
    i. There are costs associated with storing the products at the DC. The storage cost will vary depending on the duration of storage, size of the storage area, and if it is an indoor or outdoor space.
    ii. Most large DCs have compactors to bale the recyclables. The compactor can be used to condense the plastics to minimize the storage space required and prepare the plastic for optimal shipments to the MRF.
    iii. The storage function can be outsourced to MRFs that offer capabilities to drop off storage containers of different sizes and different functionalities (regular, compactor container) at the DCs. In this scenario, the MRFs pick up the filled containers from the DC and replace them with empty containers. These activities are conducted for a monthly rental cost, which will be used in the model as a storage rental cost.

b) Once a full truckload worth of plastic is available, the DCs load a truck and transport the material to the nearest MRF for recycling.
    i. The cost of loading the plastics into the truck is defined as cost per pickup.
    ii. The transportation cost from the DC to the MRF is defined as a cost per mile driven.
    iii. The handing and transportation can be outsourced to MRFs that charge based on an hourly rate.

Figure 6 – Process Step 3

a) The MRF sorts and separates the collected plastic based on the different material types.

    i. The MRFs charge a total sorting costs per pound of collected plastics which includes costs such as receiving costs, unloading costs, storage costs at the MRFs, sorting costs as well as baling costs.
    ii. The sorted plastic bales are sold to the recycling facilities for a scrap value, agreed between the MRFs and the recycling facilities. The recycling costs vary depending on the MRF's equipment and the type of the plastics, as reviewed in Section 2.6.1. The recycling facilities convert the baled plastics to recycled plastics.

b) The CPG Company purchases the recycled plastic from the recycling facilities. Value is generated during the recycling process as the material is transformed into a desired product for both CPG companies and other industries.

The goal of the project is to develop a practical plastics closed-loop supply chain model. Therefore, the concept design was shared with stakeholders such as partner CPG company, partner 3PL company, partner eCommerce company and two MRF facilities. Based on the interviews, no major concerns were identified with the design of the model. The feedback from the different stakeholders were gathered to refine the model and take into account key considerations for the model. The feedback was combined with research on existing practices to draft the system considerations, benefits and challenges for each stakeholder which are addressed below:

CPG Company: The set-up allows the CPG company to have a steady flow of recycled material for new packaging and helps achieve their sustainability goals. The CPG companies hold the responsibility of designing and producing packaging that is not only recyclable, but also incorporates recycled content. Based on the interview with the partner CPG company, only rigid packaging like polyethylene terephthalate (PET) bottles, polypropylene (PP) caps and High-Density Polyethylene (HPDE), and Low-Density Polyethylene (LDPE) bottles are recyclable. Further product development is required to address recycling of flexible packaging like pouches, bags, and films. A coalition among multiple CPG companies is essential, to innovate together and standardize the material type to facilitate increased recycling among customers. In addition, CPG companies need to communicate and educate the consumers on the type of plastics that can be recycled through their local MRFs. The communication could be in the form of advertisements, labelling, published information on their websites, and so on.

Consumers: Consumers are the source of supply of recycled plastics, therefore, strong buy-in from consumers is essential to build and sustain the closed-loop supply chain model. As indicated in Figure 2 in Chapter 1, only approximately 9% of the plastics are recycled through existing recycling programs. The lack of consumer education and awareness, coupled with the lack of collection infrastructure results in a reduced plastic recycling rate.

The closed-loop model, which leverages the eCommerce network, provides increased recycling access to consumers who do not have access to curb-side recycling and to consumers who are unable to afford the current curb-side recycling as there are recycling fees charged by certain municipalities in the US. Consumers also need to ensure the product is clean before disposal at the collection box. Heavily contaminated plastics lead to loads being rejected at MRFs, resulting in decreased supply and increased logistics and processing costs. Disposal instructions should also be established by the CPG companies through product labelling. Consumer participation can be increased by education in school or communities, and campaigns that can promote awareness.

eCommerce and 3PL Provider: The most impacted stakeholders are the eCommerce or 3PL providers, as they incur the highest cost in the system. A strong partnership between the logistics provider and CPG company is required to facilitate the plastics closed-loop model. Based on the interview with the partner 3PL company, it was identified that for a van or a truck to pick up used or disposed items and transport them along with clean items, specific certifications might be required as per the US regulations. This may, however, be resolved, if the collected plastics are stored in an enclosed box or in storage containers. The CPG company and the eCommerce or 3PL provider will have to review the regulations on transport of plastics prior to launch of the closed-loop supply chain model. The box or storage containers collected from customers should be in compliance with the standard size and weight specifications established by the logistics provider (Senior Employee from Supply chain and Sustainability Department of a Large 3PL company, personal communication, 17 March, 2021). As discussed in Section 2.2.2, eCommerce and 3PL providers have sustainability commitments in place, with a goal to achieve net neutral carbon emissions. Supporting carbon offset projects like plastics closed-loop model helps companies contribute towards its goal.

Materials Recovery Facility: Based on the two meetings with MRFs, there is a strong interest in the plastics closed-loop model. There is open capacity and existing capability to sort the collected plastics. The MRFs gain increased volume processed through their facilities, providing economies of scale for their existing production lines. The MRFs also benefit from increased revenue generated through additional plastics collected through the eCommerce network.

The summary of the stakeholder map based on the design and development of the closed-loop system is depicted in Table 3.

Table 3

Stakeholder Map Required to Successfully Implement the Plastics Closed-loop Supply Chain

System Design	Customer	eCommercer/3PL Provider	Material Recovery Facility	CPG Company	Government
Roles and responsibilities	Supply generator	Process facilitator	Value generator	Extended Producer Responsibility (EPR) Demand creater	Process enforcer
Process	Appropriate disposal of plastics at the right locations	Collection of plastics from customers and transportation to DCs for storage and consolidation	Sortation and formation of plastic bales Recylers to convert plastics to valuable material	Purchase of recycled material from recycling facilities	Control and monitor the quality of the process Enforce regulations to promote recycling
System readiness	Consumer awareness Cleaning and disposal instructions	Collapsible storage containers Determine package size and weight specifications	*(No action required)*	Design recyclable products with clear labelling and instructions to recycle Initiate awareness programs	*(No action required)*
Cost	*(Not relevant for the model)*	Pick up costs Loading/Unloading costs Storage costs Transportation costs	Sorting costs Selling Price of sorted bales	*(Not relevant for the model)*	*(Not relevant for the model)*
Benefits	Convenience No recycling fees	Sustainability commitments - Offset activities Fewer empty miles, increased profit	Increased business portfolio through multiple customers Production economies of scale	Sustainability commitments Reduced carbon footprint	Sustainability commitments Local community infrastructure development
Challenges	Expectation of financial incentives	Reduced delivery efficiency	Variation of processing costs across MRFs	Standardized packaging across CPG companies Product development pending for flexible packaging	Similar laws and regulations across all US states

3.2 Data Analysis and Development of the Plastics Closed-Loop Supply Chain Model

In this section, we define the methodology deployed in the development of the plastics closed-loop supply chain model. The data analysis was conducted through: (i) data collection; (ii) data preparation; (iii) exploratory data analysis; (iv) model assumptions; (v) problem formulation; (vi) data analysis; and (vii) sensitivity analysis.

3.2.1 Data Collection

The different types of data collected to conduct the analysis are summarized below:

a) CPG Product Sales Information – The information of the different products sold, the total volume sold in 2019, and the weight per packaging product was gathered from a partner CPG company.

b) CPG Market Share Information – The market share for each product sold by the partner CPG company was used to calculate an estimation of the overall plastic waste generated for certain CPG product categories across the US.

c) Number of Households in the US – The total number of households in the US was calculated to estimate the amount of plastics disposed by a household in a time period [Data source: Census.gov].

d) Amazon Fulfillment Centers in the US – The location and size of Amazon fulfillment centers were collected to estimate the total amount of plastics collected by each fulfillment center. Amazon was used as a reference in this project, due to the ease of information availability from public sources [Data source: MWVPL International, n.d.]. The full list of Amazon fulfillment centers used in the model can be found in Appendix B.

e) MRF Locations Across the US – The location of the top 68 MRFs across the US, based on volume of recyclables processed, was gathered to map the distance between the MRFs and the Amazon fulfillment centers [Data source: "Waste Today", 2019.]. The full list of MRF locations used in the model can be found in Appendix A.

f) MRF Operations Costs – The MRF operating costs were gathered as quotations from multiple MRF operators through interviews. The costs collected were (i) Sorting costs (US$/MT), (ii) Transportation services cost from the fulfillment center to MRF location (US$/hour), and (iii) Rental cost of storage container and storage container with compactor of different sizes (US$/month).

g) MRF Operational Parameters – The MRF operating parameters were gathered from multiple MRF interviews. The parameters collected included (i) Capacity (lbs.) and volume (cubic feet) of a storage container, (ii) Capacity and volume of a storage container with compactor (cubic feet), (iii) Volume of a plastic bale (cubic feet), (iv) Weight of a plastic bale (lbs.), and (v) Sale price of a sorted plastic bale to recycling facilities (US$/lb.).

h) Forward Logistics Network Information – The network design information was gathered through online research of a large eCommerce company. The parameters collected included (i) Range of total number of packages delivered per month in the US and (ii) Total number of routes serviced per week in the US.

i) Vehicle Information – The capacity of the vehicle is gathered from public sources to gauge potential volume constraints in the closed-loop supply chain model.

3.2.2 Data Cleaning and Preparation

After data collection, the data was cleaned and prepared for data analysis as per below:

a) Data Cleaning – Redundant data, missing data, and erroneous data was removed from the data set to ensure model integrity.

b) CPG Product Sales Information (2020) – The CPG product sales information was updated for the year 2020 using the partner company’s growth rate year over year.

c) Total Addressable US CPG Plastic Waste Generation – The total sales of the partner CPG company for each product category were divided by the respective market share to estimate the total US sales for each product category. The amount of addressable plastic waste generated (lbs./year) was calculated using the weight of each packaging product and the total US sales for each product category.

d) Addressable CPG Plastic Waste Disposal per Household – The total addressable CPG waste disposed per household per year (lbs./household/year) was calculated using the total addressable CPG plastics waste generated divided by the total number of households in the US.

e) Amazon Fulfillment Center to MRF Mapping – The location of each Amazon fulfillment center and MRF were geocoded to obtain their latitude and longitude using the Llamasoft Software.

f) Average Number of Customers per Year – Each customer was assumed to receive one package per online order, resulting in the average number of customers per day being equivalent to the average number of packages per day.

j) Average Number of Customers per Route – The average number of customers serviced per route was calculated by the average number of customers delivered in a day divided by the average number of routes serviced in a day. The average number of customers per route is also equivalent to the average number of stops per route.

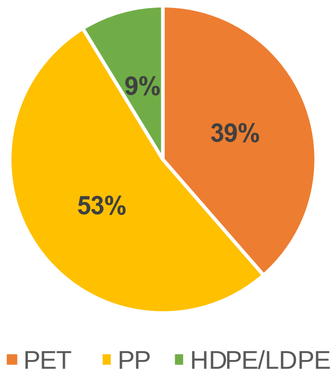
k) Unit Normalization – All the units across the different data sets, including distance, weights and so on, was normalized to ensure consistency across the datasets.

3.2.3 Exploratory Data Analysis

The total amount of CPG plastic waste generated in the US in 2020 was approximately 628 thousand metric tons for the addressable product categories. Based on Figure 7, polyethylene terephthalate (PET) and polypropylene (PP) represented around 91% of the plastics volume, equivalent to 242 and 330 thousand metric tons, respectively. PET and PP are commonly used as packaging materials for shampoo bottles, soap bottles, dish soap bottles, and so on. PET is commonly used in bottles, whereas PP is commonly used as bottle caps (Senior employee from partner CPG Company's Sustainability Department, personal communication, 8 January 2021). High-density polyethylene (HDPE) and low-density polyethylene (LDPE) represented less than 10% of the total plastics used in 2020.

Figure 7

Volume of Plastics Used in CPG Companies for Addressable Product Categories Across the US



Note. This distribution is limited to the product categories produced by the partner CPG company and not a representation of the entire CPG market. Adapted from a partner CPG Company, 2021.

Each plastic type has a different value; for example, based on the interviews with the MRFs, it was estimated that the average selling price of sorted PET, PP, HDPE clear, and HDPE color bale by MRFs to recyclers was US$0.65/lb., US$0.70/lb., US$0.630/lb., and US$ 0.170/lb. respectively. The volume split across the different type of plastics was used to identify the total value generated after the recycling process due to varying value of plastics based on the different types.

The Amazon fulfilment centers were categorized based on their size, as described in Section 3.2.2. Table 4 depicts the classification of the fulfillment centers based on their area, and Figure 8 depicts the total number of fulfillment centers for each category.

Table 4

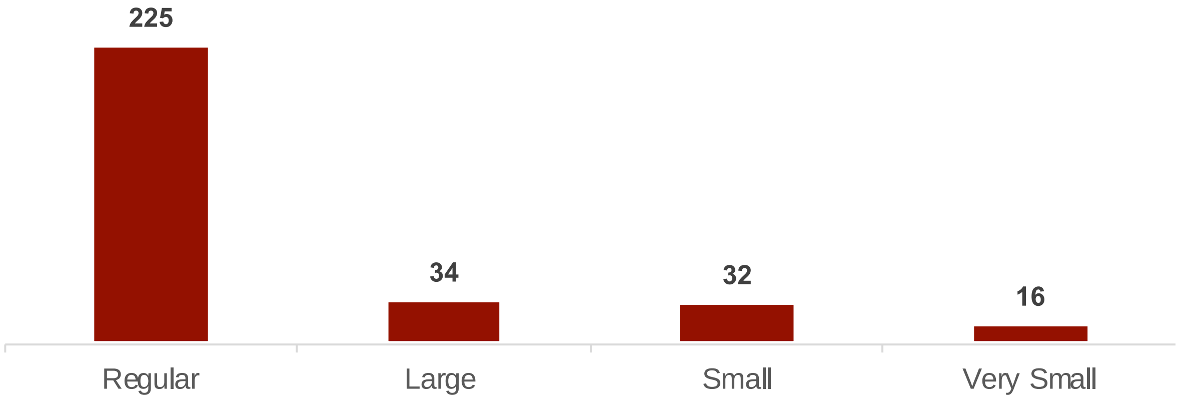
DC Size-Type Categorized Based on the Area of the Fulfillment Center (sq. ft.)

DC Size-type	Size (from) sq.ft.	Size (to) sq.ft.
Regular	439,615	1,052,118
Large	1,052,119	1,358,370
Small	133,363	439,614
Very Small	12,500	133,362

Note. The area range for each fulfillment center size-type was determined based on the mean and standard deviation of the dataset comprising all Amazon US fulfilment centers.

Figure 8

Total Number of Fulfillment Centers Across the US, Categorized by Size



3.2.4 Model Assumptions

Model-level assumptions which were defined to appropriately scope the problem and draw preliminary results. The key assumptions are as follows:

- The model was developed only for a single-echelon network to simplify the problem and analyze the financials prior to scaling the model to address more complex supply chains.
- The model was developed only for eCommerce home-delivery network; it doesn't account for any drop-off points.
- The model assumed that consumers returned only the addressable CPG plastics products.
- The model assumed that the eCommerce provider would pick up the plastics from customers and transport the plastic back to their respective DC at no additional cost; the model assumed that this was an existing route taken by the eCommerce delivery van and thus, no incremental transportation cost was incurred.
- The model assumed that the eCommerce van returned to the same DC where the route originated; i.e., the origin point of the delivery van was the same as the destination point.

3.2.5 Problem Formulation

The problem formulation section describes the methodology used to arrive at the system cost equation, value equation, and subsequently the profit/loss equation.

The network was designed to connect the Amazon fulfilment centers to the relevant MRFs. The collected plastics are transported from the fulfilment center i, to the nearest MRFs j. Network optimization was conducted using Python to map each of the Amazon fulfilment center to the nearest MRF location based on the shortest route. Since the number of MRFs was limited to only the largest 68 MRFs by volume in the US, there were some abnormalities in the network mapping, resulting in some extremely long transport distances between Amazon fulfilment centers and MRFs. However, MRFs are present in most municipalities in the US, though they are small in size. All abnormal distance mappings between Amazon fulfilment centers and MRFs were replaced with the median distance value to reflect the reality.

The distance for each link, d_{ij}, is calculated based on the network optimization model, and the time taken to cover the distance d_{ij} is calculated based on the average speed of the trucks and depicted by t_{ij}. For urban transportation, the average speed is assumed to the 25 miles/hour, and for sub-urban transportation, the average speed is assumed to be 40 miles/hour for trucks. Since most Amazon fulfilment centers and MRFs are located outside the cities, the sub-urban speed is used in the model.

The supply of plastics is generated by customers, when they return the plastics to the eCommerce drivers after their home-delivery. The number of customers serviced by each fulfillment center, X_i, was calculated by proportionally adjusting the total number of customers delivered in a day based on the size of the fulfilment center. The number of delivery vans serviced per fulfilment center, N_i, was determined by the total number of customers serviced by the fulfilment center, X_i , divided by the average number of customers per route. A delivery route is defined as the trip taken by the delivery driver from the fulfilment center to the different customers and back to the fulfilment center. Based on the interview with the 3PL company, each delivery van is responsible for one delivery route per day. Thus, in this case, the number of routes per fulfilment center is equal to the number of delivery vans (N_i) serviced per fulfilment center. Given the amount of plastic waste generated by one household (or customer) p, the total amount of plastics collected per day per fulfilment center (V_i) in lbs. is calculated using the formulation in Equation 1.

$$V_i = X_i * p \tag{1}$$

Three (3) variables were defined in the data model: (i) Time taken to pick up the plastics from one customer (t_{pick}) during the delivery route; (ii) Time taken per delivery van to unload all the collected plastics at the end of the day, or the end of the shift at the fulfilment center, t_{unload}; (iii) Operating cost per hour of delivery vans, O_{cost} including driver hourly wages, fuel consumption, fuel efficiency, and other fixed costs and variable costs pertaining to delivery operations. The total time taken to pick up plastics at all the serviced customers per fulfillment center T_{i_pick} is calculated using Equation 2. The total time taken to drop off the collected plastics per fulfilment center T_{i_unload} is calculated using Equation 3. The total cost associated per fulfilment center per day from the additional pickup and unloading activities is defined as the productivity loss, L_i , and is calculated using Equation 4.

$$T_{i\_pick} = t_{pick} * X_i \tag{2}$$

$$T_{i\_unload} = t_{unload} * N_i \tag{3}$$

$$L_i = (T_{i\_pick} + T_{i\_unload}) * O_{cost} \tag{4}$$

The plastics collected at the Amazon fulfilment centers are now transferred to the MRFs. Amazon fulfilment centers rent the storage containers with compactor from the MRFs for a monthly fee, B_i. The MRFs are responsible for picking up the filled storage containers and replacing the filled storage container with an empty storage container; the time taken for this activity is described as t_{handle}. The transportation and handling cost per hour, quoted by the MRF, is depicted by w. The frequency of the collection of plastics from each Amazon fulfilment center,

f_i, is determined based on the capacity of the storage container and the volume of incoming plastics material per fulfillment center V_i. The total cost charged by each MRF to the respective fulfilment center for the handling and transportation services, H_i, is calculated using Equation 5.

$$H_i = (2 * t_{ij} + t_{handle}) * w * f_i \tag{5}$$

The plastics collected by the MRFs are subject to sorting costs per lbs., s, charged by the MRFs. The total sorting cost associated per fulfilment center is calculated using Equation 6.

$$S_i = V_i * s \tag{6}$$

The total costs incurred for each fulfilment center, C_i, in a time period and the total costs incurred by the system, C_{system}, is calculated using Equation 7 and Equation 8, respectively.

$$C_i = S_i + H_i + L_i + B_i \tag{7}$$

$$C_{system} = \sum_i C_i = \sum_i S_i + \sum_i H_i + \sum_i L_i + \sum_i B_i \tag{8}$$

The sorted plastics is sold by the MRFs to the recyclers at a selling price, z, per pound, depending on the type of plastics as discussed in Section 3.2.3. The total revenue generated from the volume of collected plastics, R_{system}, is calculated using Equation 9.

$$R_{system} = \sum_i V_i * z \tag{9}$$

3.2.6 Data Analysis

Based on the formulations described in Section 3.2.5, the financial model was built to conduct the analysis. Although the model is scoped based on the partner CPG company and Amazon fulfillment centers, the model is scalable and replicable for any CPG companies and any eCommerce or 3PL Companies. The model can be run for any system by adjusting the inputs based on the stakeholder partnerships, geography, or product types. The model is designed to be simple for the user and can be used to simulate multiple scenarios of closed-loop systems. To ensure model robustness, some variables are evaluated using both top-down and bottom-up approach. After evaluations of all defined Equations from (1) to (9), the final profit or loss result equation, P_{system}, is calculated using Equation 10.

$$P_{system} = R_{system} - C_{system} \quad (10)$$

Finally, life cycle assessment (LCA) was conducted for virgin plastic bottles and recycled plastic bottles to estimate the total reduction in carbon footprint driven by the project. Additional details and analysis from model development and evaluation are explained in Section 4.4.1.

3.2.7 Sensitivity Analysis

After the completion of the data analysis, sensitivity analysis was conducted to evaluate the performance of the model under different scenarios. The variables used in the model are subject to their reasonable minimum, maximum and average value to gauge the performance of the model. Different execution scenarios are evaluated to understand the economics of the different variations of the closed-loop supply chain model. Break-even analysis was conducted to estimate the critical break-even parameters to successfully run the closed-loop supply chain model. Finally, the pilot design of the project is defined based on the results obtained from the sensitivity analysis of the different scenarios.

4 RESULTS AND DISCUSSION

The results in this section were obtained using the outlined methodology, data preparation, and problem formulation described in detail throughout Chapter 3. This section beings with the evaluation and discussion of results of the Base Case Scenario, which is the current state representation of the current closed-loop design. After the Base Case, sensitivity analyses are conducted to explore the various cost drivers and improve the economic feasibility of the model. Break-even analysis was conducted to understand the practical feasibility of the model at the break-even point. The input variables that were changed during the different analyses are shown in each table; the other variables were kept constant. The section is followed by a discussion on the different analyses, including the Extended Producer Responsibility and Life-Cycle Assessment analyses of the different plastic types reviewed in this report. The section concludes with recommendations for a pilot test that can be implemented to validate the proposed model.

4.1 Scenario 1 – Base Case

The Base Case is the current state implementation of the closed-loop model using the data, and assumptions defined throughout Chapter 3. The Base Case represents the network of Amazon fulfillment centers that are used in a single-echelon model across the US. Consumers only return plastics for specific CPG product categories. In the closed-loop supply chain model, consumers return the product to the Amazon delivery drivers, who transport the product to the fulfilment centers on a daily basis. The collected plastics are stored at the fulfilment centers in the storage containers, which are picked up by the MRFs as they get filled. The MRFs sort, bale and sell the plastics to the recyclers for further processing. The Base Case does not include any efficiencies in the process, and reflects the potential impact to the current state of the system.

The input variables used in the model are depicted in Table 5, and the results of the closed-loop supply chain model for the Base Case Scenario is depicted in Table 6.

Table 5

Scenario 1 Inputs – Base Case of Developed Plastics Closed-Loop Supply Chain Model

Scenario 1 Inputs – Base Case	
Plastics per Customer (p) – 11.3 lbs./ year	Container/ Compactor Cost (B_i) – \$400/ month
Pickup Time per Customer (t_{pick}) – 5 sec.	Transportation and Handling Cost (w) – \$125/ hour
Unload Time per Van (t_{unload}) – 2 min.	Sorting Cost (s) – \$80/ MT
Van Operating Cost (O_{cost}) – \$25/ hour	Value of Plastics (z) – \$0.1/ lb.

Table 6

Scenario 1 Results – Base Case of Developed Plastics Closed-Loop Supply Chain Model

Scenario 1 Results (Monthly) – Base Case			
Total Plastics Collected (lbs.)		10,812,806	
Total System Revenue	**$**	**1,081,281**	
Total System Cost	**$**	**14,144,899**	% of Cost
Total Container/Compact Cost	$	121,200	0.9%
Total Sorting Cost	$	392,369	2.8%
Total Productivity-Loss Cost	$	13,525,000	95.6%
Total Transportation and Handling Cost	$	106,330	0.8%
Total System Profit	**$**	**(13,063,618)**	

Though the Base Case collects over 10 million pounds of plastics in a month, the estimated incremental cost impact of the system is \$13 million per month. The total cost of the Base Case scenario exceeded \$14 million per month, while the total revenue, from the sale of the baled plastics, only generated approximately \$1 million for the month. The primary cost driver for the Base Case system was the productivity-loss cost, accounting for almost 96% of the cost of the closed-loop model. The productivity-loss cost is driven by three key inputs: pickup time per customer (t_{pick}), unload time per van t_{unload}, and van operating cost (O_{cost}). In the Base Case, the three key inputs were set to reasonable estimates but are varied during sensitivity analysis to account for increased eCommerce network efficiency. There is an uneven distribution of costs and benefits across the closed-loop supply chain model, where most of the costs are incurred by the eCommerce company, no costs are incurred by the CPG company and both costs and benefits are realized by the MRFs. The Base Case Scenario does not prove to be economical in the absence of eCommerce pickup efficiencies, collaboration among the stakeholders, and limited scope of plastics.

4.2 Sensitivity Analysis

After the completion of the Base Case in Section 4.1, sensitivity analysis was conducted to evaluate the performance of the model under different scenarios. Considering the significant impact of the closed-loop supply chain model, two models were explored to reflect two key scenarios: (i) High-efficiency process with minimum productivity-loss; and (ii) Break-even analysis through multi-stakeholder business model and increased coalition.

4.2.1 Scenario 2 – Minimum Productivity Loss

The Base Case showed that productivity-loss cost was the most significant cost driver of the closed-loop system and resulted in the system incurring a loss. Scenario 2 lowers the productivity-loss cost drivers to the absolute minimum values that are still within reason. The input variables that are changed include: pickup time per customer (t_{pick}), unload time per van (t_{unload}), and van operating cost (O_{cost}). The pickup time per customer and unload time per van are reduced to account for efficiencies that can be realized by the eCommerce companies over time. The van operating cost is modified to include only the variable cost, pertaining to the operations such as driver wages, fuel cost and van maintenance. All other inputs are the same as the Base Case scenario. The input parameters used in Scenario 2 are depicted in Table 7, and the output of the closed-loop supply chain model using the input parameters from Table 7 are depicted in Table 8.

Table 7

Scenario 2 Inputs – Minimum Productivity Loss of the Plastics Closed-loop Supply Chain Model

Scenario 2 Inputs – Minimum Productivity Loss	
Plastics per Customer (p) – 11.3 lbs./ year	Container/ Compactor Cost (B_i) – \$400/ month
Pickup Time per Customer (t_{pick}) – 2 sec.	Transportation and Handling Cost (w) – \$125/ hour
Unload Time per Van (t_{unload}) – 1 min.	Sorting Cost (s) – \$80/ MT
Van Operating Cost (O_{cost}) – \$18/ hour	Value of Plastics (z) – \$0.1/ lb.

Note. The blue boxes highlight the variables that were changed in Scenario 2.

Table 8

Scenario 2 Results – Minimum Productivity Loss of the Plastics Closed-loop Supply Chain Model

Scenario 2 Results (Monthly) – Minimum Productivity Loss			
Total Plastics Collected (lbs.)		10,812,806	
Total System Revenue	**$**	**1,081,281**	
Total System Cost	**$**	**4,613,899**	% of Cost
Total Container/Compact Cost	$	121,200	2.6%
Total Sorting Cost	$	392,369	8.5%
Total Productivity-Loss Cost	$	3,994,000	86.6%
Total Transportation and Handling Cost	$	106,330	2.3%
Total System Profit	**$**	**(3,532,618)**	

Increasing the efficiency of the eCommerce processes of plastics collection and unloading at the fulfilment centers has a significant impact on the financial performance of the model. The system impact was reduced by 73% from \$13 million per month to \$3.5 million per month for collection of 10 million pounds of plastics across the US. The total cost of Scenario 2 decreased compared to the Base Case but still exceeded \$4.5 million per month. The total revenue, from the sale of the plastics, stayed constant to the Base Case at approximately \$1 million for the month. The primary cost driver for the Base Case system remained the productivity-loss cost, accounting for almost 87% of the cost of the closed-loop model. The pickup time per customer (t_{pick}), unload time per van $\underline{t_{unload}}$, and van operating cost (O_{cost}) were lowered to the absolute, realistic minimums; however, maintaining these values on a consistent basis may not be feasible in practice. It is evident from the two scenarios that despite an efficient eCommerce process, the costs incurred by the system to perform the closed-loop supply chain model are still significant. There is a need for a coordinated effort across the different stakeholders to ensure the closed-loop supply chain model is successful.

4.2.2 Scenario 3 – Stakeholder Coalition, Break-Even Analysis

Scenario 3 models a stakeholder coalition, where all the stakeholders are working towards creating a more sustainable world. The coalition includes the CPG company, eCommerce company or a 3PL provider, and the MRFs working together to reduce cost to make the system more economical for all parties involved. In Scenario 3, members of the coalition are assumed to reduce their respective costs by 25%. For the eCommerce company, this would mean maintaining the van operating cost at \$18/hour to include only the variable costs. For the MRFs, this would mean reducing their container rental cost (B_i), transportation and handling cost (w), and sorting cost (s) by 25%. The reduced cost results in a reduction of the input variables that drive the cost.

The scope of the Base Case and Scenario 2 was limited to collection of specific CPG product categories defined based on the data collected from the sponsor CPG company. Scenario 3 assumes other CPG plastics such as beverage bottles, detergent bottles, makeup containers, and so on to be collected in addition to the Base Case products, resulting in an increased plastic supply. The flow of additional plastics in the closed-loop model is reflected by an increase in the input variable plastics collected per customer pickup (*p*).

The value of recycled plastics is volatile. The value of recycled plastics may increase with the rise in demand for the material by CPG companies as described in Section 2.5. Scenario 3 increases the value of plastics (*z*) by 25% compared to the Base Case to explore the financial impact on the closed-loop model.

Scenario 3 keeps the productivity-loss cost drivers at an absolute minimum, that are still within reason, from Scenario 2. All other inputs are the same as the Base Case and Scenario 2. The input parameters that are used in the Scenario 3 are depicted in Table 9, and the output of the closed-loop supply chain model using the input parameters from Table 9 is depicted in Table 10.

Table 9

Scenario 3 Inputs – Stakeholder Coalition, Break-Even Analysis for Plastics Closed-Loop Supply Chain

Scenario 3 Inputs – Stakeholder Coalition, Break-Even Analysis	
Plastics per Customer (p) – 47.1 lbs./ year	Container/ Compactor Cost (B_i) – $300/ month
Pickup Time per Customer (t_{pick}) – 2 sec.	Transportation and Handling Cost (w) – $94/ hour
Unload Time per Van (t_{unload}) – 1 min.	Sorting Cost (s) – $60/ MT
Van Operating Cost (O_{cost}) – $18/ hour	Value of Plastics (z) – $0.125/ lb.

Note. The blue boxes highlight the variables that were changed in Scenario 2. The purple boxes highlight the variables that were updated in Scenario 3.

Table 10

Scenario 3 Results – Stakeholder Coalition, Break-Even Analysis for Plastics Closed-Loop Supply Chain

Scenario 3 Results (Monthly) – Stakeholder Coalition, Break-Even Analysis		
Total Plastics Collected (lbs.)	45,182,392	
Total System Revenue	**$ 5,647,799**	
Total System Cost	**$ 5,647,799**	% of Cost
Total Container/Compact Cost	$ 90,900	1.6%
Total Sorting Cost	$ 1,229,665	21.8%
Total Productivity-Loss Cost	$ 3,994,000	70.7%
Total Transportation and Handling Cost	$ 333,234	5.9%
Total System Profit	**$ -**	

In Scenario 3, the volume of plastics per customer (*p)* was increased to determine the minimum volume of plastics required per customer to achieve the break-even point. The break-even analysis resulted in a plastics per customer (p) value of 47.1 lbs. per year. The increase is more than four times the volume collected in the Base Case, but is reasonable considering the expansion of plastics products collected and the overall plastic consumption per customer.

The total revenue, from the sale of the plastics, increased by 423% compared to the Base Case due to both the increase in plastics per customer (p) and the increase in the value of plastics (z). The primary cost driver for Scenario 3 remained the productivity-loss cost, accounting for 70% of the cost of the closed-loop model. This scenario shows that a consolidated effort of the different stakeholders of the supply chain can effectively divert 45 million pounds of plastics per month from landfills and ocean waste and generate value without having a significant financial impact to the business.

While Scenario 3 represents a break-even point of the practical, closed-loop system, there are risks regarding the operational feasibility of implementing the model. Although the plastics per customer *(p*) is reasonable for the customer to produce, it may not be feasible for the pickup per van. Scenario 3 results in each van picking up a total of 27.4 lbs. per route. While the weight of the plastic is not an issue, the volume, and thus the space required to store the plastics, may exceed the available capacity of the delivery van. A small collapsible container may be used to collect and organize the plastics and limit the space required, but this area of implementation will need to be further explored. The operational considerations should be evaluated as part of the pilot test recommendation in Section 4.4

4.3 Discussion

The model development and the financial analyses highlight that it is practically feasible to leverage an eCommerce network to facilitate the closed-loop supply chain of plastics. Based on the Base Case and Scenario 3, we can conclude that the break-even point of the model can be achieved by increasing the volume of plastics collected, making the eCommerce pickup process efficient, and by forming a multi-stakeholder coalition to decrease cost.

From the Base Case and Scenario 2, it is evident that plastics collected using the closed-loop supply chain model are less than the total addressable plastics of the CPG company. This difference is driven by the limited penetration of customers and households in the US, as the model accounts only for 303 Amazon fulfilment centers across the US. If additional fulfilment centers and additional logistics providers are added to the closed-loop supply chain model, higher customer penetration can be achieved, resulting in increased volume of collected plastics.

The critical cost driver of the closed-loop model is the pickup time loss per customer incurred by the delivery driver. This time loss can be reduced, especially in urban locations, by using one drop-off box at each apartment or condominium. This will result in increased volume of plastics collected per pickup from multiple customers. Though consolidated drop-off points were out of the scope for this project, this scenario is highly relevant and can be explored as part of the pilot test recommendation to improve the model efficiency.

Costs are incurred mainly by eCommerce or 3PL logistics providers and MRFs in the closed-loop supply chain model; however, the primary benefits are experienced by the CPG companies. Therefore, the overall responsibility of forming and running a multi-stakeholder business model should fall on the CPG companies, similar to the Extended Producer Responsibility Framework (EPR). The proposed closed-loop supply chain model, using the multi-stakeholder approach, will create an economic and a convenient system to promote the plastics recycling process, which is currently a cost-intensive process.

4.3.1 Extended Producer Responsibility (EPR)

Based on the model developed in Chapter 3 and analysis conducted in Section 4.1 and Section 4.2, it is evident that there is an uneven distribution of effort and cost between the eCommerce company or the 3PL company compared to the CPG company. The CPG company is not involved in the execution of the project and thus, incurs no cost in the model. This also means that there are no incentives for the eCommerce company or 3PL company to consistently execute the model. With the EPR framework established as described in Section 2.1.2, the CPG company would be responsible for covering; all the costs throughout in the model, managing the supply chain, ensuring products sold are recyclable, and promoting customer participation through campaigns and awareness programs. A CPG coalition is required to onboard multiple CPG companies to the closed-loop supply chain model to increase the amount of plastics that can be collected from the households and achieve the break-even point of the model. As discussed in Section 2.2.2, some electronics companies, in the US, have embraced the concept of EPR by paying for the shipment of electronic products from customers back to the producers through FedEx. Similarly, the CPG companies participating in the closed-loop supply chain model should work on increasing the amount of plastics collected and covering any additional costs, if applicable, to ensure success of the program.

Governments can play a role as a process enforcer by enforcing laws pertaining to plastics recycling and mandating the use of recycled plastics. Governments or municipalities need to ensure development of the required infrastructure as EPR is mandated. Establishing regulations for appropriate plastics disposal, labelling requirements for producers, performance monitoring system for MRFs, recycled plastics end-of-life quality standard monitoring for recyclers, and financial support of local MRFs are some ways the government can strengthen the plastics closed-loop supply chain system.

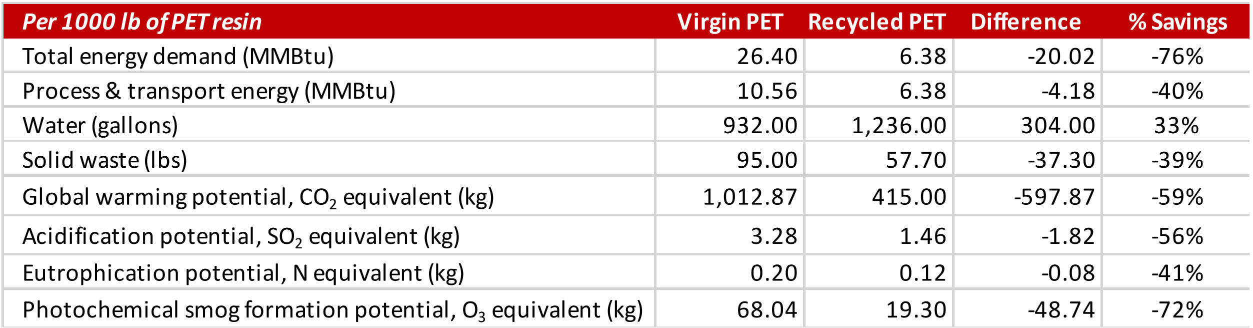
4.3.2 Life-Cycle Assessment (LCA) Analysis

The developed plastics closed-loop supply chain model will be able to divert millions of metric tons of plastics away from landfills and ocean waste. Though the business model is only cost-neutral in an efficient scenario, it is evident that there are significant non-financial benefits to the model. In addition to appropriate disposal of plastics, the model minimizes the need for production of new plastics, as the disposed plastics are now recycled and converted into usable recycled plastics. We reviewed in the literature review in Sections 2.2 and 2.5, the existing sustainability commitments of large CPG companies and eCommerce companies, respectively. eCommerce companies like Amazon have ambitious carbon net-neutral goals, which make decarbonization projects and carbon offset projects highly attractive.

A study conducted by National Association for PET Container Resources (NAPCOR) analyzes the savings generated from production of virgin PET plastics compared to production of recycled PET plastics, as shown in Table 11. The LCA analysis confirms that there are indirect cost savings and benefits associated with the use of recycled plastics over virgin plastics (NAPCOR, 2020). Based on the data provided by the partner CPG company, the addressable PET volume is 242 thousand metric tons on an annual basis. Based on Table 11, this is equivalent to an annual reduction of 319 million kgs of CO_2. In addition, there are other savings with respect to energy consumption, reduction in acidification, eutrophication potential, and so on. Similarly, a study conducted by Franklin Associates in December 2018 measures metrics for PET, PP and HDPE plastics.

Table 11

Life-Cycle Assessment Results Based on Key Environmental Metrics for Virgin PET, Recycled PET



Per 1000 lb of PET resin	Virgin PET	Recycled PET	Difference	% Savings
Total energy demand (MMBtu)	26.40	6.38	-20.02	-76%
Process & transport energy (MMBtu)	10.56	6.38	-4.18	-40%
Water (gallons)	932.00	1,236.00	304.00	33%
Solid waste (lbs)	95.00	57.70	-37.30	-39%
Global warming potential, CO_2 equivalent (kg)	1,012.87	415.00	-597.87	-59%
Acidification potential, SO_2 equivalent (kg)	3.28	1.46	-1.82	-56%
Eutrophication potential, N equivalent (kg)	0.20	0.12	-0.08	-41%
Photochemical smog formation potential, O_3 equivalent (kg)	68.04	19.30	-48.74	-72%

Note. The table highlights the savings from transitioning from virgin PET to recycled PET across different categories such as energy, waste, waste, greenhouse gases, and so on. Retrieved from National Association for PET Container Resources. (2020). *Life Cycle Analysis: Evaluating Environmental Impacts of Virgin and Recycled PET Resins*. *https://napcor.com/sustainability/life-cycle-analysis/*

Table 12

Calculation of the Greenhouse Gases Emission Savings Generated for each Plastic Type

Global Warming Potential Reduction, CO2 equivalent (kg)	Virgin Plastics	Recycled Plastics	Difference	% Savings
PET	541,025,996	221,672,421	(319,353,575)	-59%
PP	608,638,600	174,209,132	(434,429,468)	-71%
HDPE	103,956,379	30,568,270	(73,388,109)	-71%
TOTAL	**1,253,620,975**	**426,449,823**	**(827,171,152)**	**-66%**

Note. The data on global warming potential reduction for each plastic type is gathered from sources and applied to the plastics volume of the capstone project to obtain the total impact. Information for PET is retrieved from National Association for PET Container Resources. (2020). *Life Cycle Analysis: Evaluating Environmental Impacts of Virgin and Recycled PET Resins. https://napcor.com/sustainability/life-cycle-analysis/* and data for PP and HDPE was retrieved from Franklin Associates on behalf of the Association of Plastic Recyclers. (2018). *Life Cycle Impacts for Postconsumer Recycled Resins: PET, HDPE, and PP. https://napcor.com/wp-content/uploads/2020/05/LCA-2018-APR-Recycled-Resin-Report.pdf*

Using the research data and applying it to the addressable plastic volume in this model, as shown in Table 12, results in a reduction in carbon footprint of 827 million kilograms of CO_2 equivalent in one year, which is around 66% reduction in greenhouse gas emissions. To put the number into perspective, this is equivalent to removal of 178,000 passenger cars from the road in a year. If the CPG company were to buy carbon offset credits ranging from $5/MT - $20/MT for the calculated annual emissions for the plastics in use, the transition from virgin to recycled plastics is equivalent to a cost avoidance of USD 4 million to USD 16 million annually. Given that this is the benefit for the CPG company, this puts further emphasis on establishing a EPR framework such that all the stakeholders will be able to equally benefit from the closed-loop supply chain model.

4.4 Pilot Recommendations

The developed model took into account existing literature review on reverse logistics and waste management, market insights, and added practical considerations to the closed-loop supply chain model. The financial analyses included the practical costs incurred by the different stakeholders and estimated the amount of plastics collected from the customers. In order to validate the proposed model, the recommendation is to launch a pilot test to mimic the scenarios discussed in Section 4.1 and Section 4.2 to evaluate any potential operational challenges in the execution phase.

The developed model will be tested through a pilot launch organized by the CPG company, in collaboration with other stakeholders such as the 3PL or eCommerce company, and MRFs. The pilot test execution is out of the scope of this project; however, this section will ensure model readiness for the pilot test. This section outlines the methodology for location selection, parameters for pilot design, and evaluation metrics for performance analysis.

The identification of the pilot location will be based on the different characteristics of the model: (i) location and capabilities of the partner MRFs, (ii) consumer education and awareness on recycling, (iii) availability of eCommerce or 3PL transportation network, and (iv) level of government involvement in plastics recycling initiatives.

As discussed in Section 4.2, the cost equation or profitability of the model varies significantly based on the scenario-based sensitivity analysis. To address different situations and develop a universal model, the recommendation is to perform multiple pilot tests under different test conditions. For example, the government of Kitchener, Ontario, in Canada ran multiple pilot tests to identify the most practical model for a plastics curb-side recycling program. Four different pilot tests were conducted, and the test conditions that produced the best results were selected to move forward for the regional launch (The Blue Box Story, 2013).

The purpose of the proposed pilot is to validate the financial analysis of the model and identify operational challenges that arise during implementation. The key design parameters that need to be established include: short-listed locations, number of test locations, duration of the pilot test, plastic products in scope, frequency of collection, and the container used for collection. Each pilot location test needs to collect data for evaluation metrics. Key evaluation criteria for the pilot test include: (i) the collection rate, determined by the amount of plastics collected through the system, (ii) throughput, determined by the total amount of plastic bales sold divided by the total amount of plastics collected, (iii) quality of recycled plastics determined by the CPG Company, (iv) productivity loss incurred by the driver in each test location based on the number of pickups and, (v) van capacity in terms of amount of plastics that can be collected in a route. The actual metrics from the pilot tests can be compared against the model to determine the validity of the proposed model. The proposed model can be updated based on the results from the pilot tests. The pilot locations can be compared against each other and the learnings can be used to plan a larger multi-stakeholder launch across different regions in the US.

5 CONCLUSION

This capstone builds upon previous research that leverages the existing eCommerce logistics network by requiring the delivery personnel to retrieve plastics from the consumers after they have made a delivery (Banerjee, 2020). We have developed a practical, multi-stakeholder business model based on the Extended Producer Responsibility (EPR) Framework, to facilitate a closed-loop supply chain for plastics that could increase recycling rates across the US. The relevant stakeholders for the proposed model include the consumer, CPG company, eCommerce company or a 3PL provider, MRF, and the government. The model outlines the flow of plastics and process ownership, and estimates costs throughout each step.

We developed a universal, adaptable, and scalable financial analysis tool to evaluate the economics of the model. Though the Base Case scenario collected around 11 million pounds of recyclable plastics a month, it did not prove to be economical due to high productivity loss, lack of existing collaboration among different stakeholders, and limited scope of plastic types collected from the customers. Sensitivity analysis was performed based on different scenario assumptions to explore the various cost drivers and to create a break-even scenario for the closed-loop system. Due to the efficiency loss during the cost-intensive last-mile delivery, a larger volume of plastics per pickup was required to render the proposed model economically feasible. The volume of plastics required for the break-even was 47 lbs. per household per year, which is significantly lower than the actual plastic waste generated per household per year. The target volume could be achieved by onboarding multiple CPG companies and other companies in the packaging sector to promote recycling through the closed-loop program. In addition, the break-even scenario requires the CPG company, eCommerce company or a 3PL provider, and the MRF to work together to increase efficiencies and thus, reduce the costs to the closed-loop system. A combined effort to reduce system costs by 25% and increase the selling price of collected and sorted plastics by 25% contributes to break-even of the model. The financial analysis strongly emphasizes the need for a coalition among the different players in the industry to successfully advance the circular economy of plastics economically and at scale.

The coalition would have to be formed and led by the CPG Company, as they have the responsibility as the producer to ensure the circularity of plastics. There are significant, non-financial benefits to the CPG Company as well as to the coalition members in terms of improved reputation, corporate social responsibility commitments, carbon-offset credits, and overall reduction in carbon emissions. Based on the Life-Cycle Assessment conducted for the addressable plastics, the CPG companies could lessen their total carbon footprint by 827 million kilograms of CO_2 equivalent in one year, which is around a 66% reduction in greenhouse gas emissions.

Based on the initial model design and data analysis, we recommend for a pilot test to validate the model and gather real-time data. In this project, we worked with each stakeholder independently to build and confirm the model. In the future, collaboration and communication among all the different stakeholders will be necessary to implement the pilot test and improve the closed-loop model.

To reduce complexities and conduct the initial financial analysis, our model assumed a single-echelon network. Future research should explore the impact of a multi-echelon network, which better represents the operations of large eCommerce and 3PL companies in the US. Our model did not consider the van volume capacity, cost of collapsible storage containers, regulatory compliance on the transportation of used plastics, and other operational challenges. In the pilot test, it will be critical to further explore all operational challenges that arise during the implementation of the model.

Through the innovative and collaborative approach defined in this research, stakeholders can significantly increase the amount of plastics recycled, divert millions of metric tons of plastic waste from landfills and the ocean, and reduce the need for production of new plastics, and thus, promote sustainability.

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APPENDIX A – MRF Locations

Name	Address	City	State	Postal Code
MRF_1	Sims Municipal Recycling 472 2nd Ave.	Brooklyn	NY	11232
MRF_2	Resource Management Cos. 9999 Andersen Ave.	Chicago Ridge	IL	60415
MRF_3	Casella Waste Systems Inc. 24 Bunker Hill Industrial Pk.	Charlestown	MA	2129
MRF_4	Waste Management Inc. 1800 Broadway St. N.E.	Minneapolis	MN	55413
MRF_5	Waste Management Inc. 7175 Kit Kat Rd.	Elkridge	MD	21075
MRF_6	Waste Management Inc. W132 N10487 Grant Dr.	Germantown	WI	53022
MRF_7	Rumpke Recycling 5535 Vine St.	Cincinnati	OH	45217
MRF_8	Penn Waste Inc. 85 Brick Yard Rd.	Manchester	PA	17345
MRF_9	Recology 1000 Amador St.	San Francisco	CA	94124
MRF_10	Solid Waste Authority of Palm Beach County 5860 45th St.	West Palm Beach	FL	33412
MRF_11	Alpine Waste & Recycling (a subsidiary of GFL 645 W. 53rd Pl.	Denver	CO	80216
MRF_12	Republic Services Inc. 1601 Dixon Landing Rd.	Milpitas	CA	95035
MRF_13	Republic Services Inc. 2733 3rd Ave. S.	Seattle	WA	98134
MRF_14	J.P. Mascaro & Sons 1270 Lincoln Rd.	Birdsboro	PA	19508
MRF_15	Balcones Resources 9301 Johnny Morris Rd.	Austin	TX	78724
MRF_16	Potential Industries Inc. 922 E. E St.	Wilmington	CA	90744
MRF_17	California Waste Solutions 1005 Timothy Dr.	San Jose	CA	95133
MRF_18	Groot Industries Inc. (a subsidiary of Waste Connections) 1759 Elmhurst Rd.	Elk Grove Villiage	IL	60007
MRF_19	County Waste & Recycling (a subsidiary of Waste 865 S. Pearl St.	Albany	NY	12202
MRF_20	Western Placer Waste Management Authority 3195 Athens Ave.	Lincoln	CA	95648
MRF_21	Waste Management Inc. 20701 Pembroke Rd.	Pembroke Pines	FL	33029
MRF_22	Republic Services Inc. 4619 West Ox Rd.	Fairfax	VA	22030
MRF_23	Waste Management Inc. 150 St. Charles St.	Newark	NJ	7105
MRF_24	Waste Management Inc. 14020 N.E. 190th St.	Woodinville	WA	98072
MRF_25	Sims Municipal Recycling 1 Linden Ave. E.	Jersey City	NJ	07305
MRF_26	Waste Management Inc. 30869 N. Route 83	Grayslake	IL	60030
MRF_27	Waste Connections 1190 20th St. N.	St. Petersburg	FL	33713
MRF_28	Waste Management Inc. 5201 Bleigh Ave.	Philadelphia	PA	19136
MRF_29	FCC Environmental Services 5200 Simpson Stuart Rd.	Dallas	TX	75241
MRF_30	Cougle's Recycling Inc. 1000 S. 4th St.	Hamburg	PA	19526
MRF_31	Willimantic Waste Paper Co. Inc. 1590 W. Main St.	Willimantic	CT	6226
MRF_32	Waste Management Inc. 1501 W. Gladstone Ave.	Azusa	CA	91702
MRF_33	Rumpke Recycling 1191 Fields Ave.	Columbus	OH	43201
MRF_34	Republic Services Inc. 6200 Elliott Reeder Rd.	Fort Worth	TX	76117
MRF_35	Waste Management Inc. 40 Ledin Dr.	Avon	MA	2322
MRF_36	WestRock 1775 County Services Pkwy.	Marietta	GA	30008

MRF_37	Waste Management Inc. 8491 Fruitridge Rd.	Sacramento	CA	95826
MRF_38	Republic Services Inc. 1131 N. Blue Gum St.	Anaheim	CA	92806
MRF_39	Friedman Recycling Cos. 3640 W. Lincoln St.	Phoenix	AZ	85009
MRF_40	Republic Services Inc. 770 E. Sahara Ave.	Las Vegas	NV	89104
MRF_41	Republic Services Inc. 4076 Bayless Ave. (Bella Villa)	St. Louis	MO	63125
MRF_42	Republic Services Inc. 6025 Byassee Dr.	Hazelwood	MO	63042
MRF_43	Lakeshore Recycling Systems 6201 W. Canal Bank Rd.	Forest View	IL	60402
MRF_44	Casella Waste Systems Inc. 15 Hardscrabble Rd.	Auburn	MA	1501
MRF_45	Waste Management Inc. 2404 S. 88th Ave.	Kansas City	KS	66111
MRF_46	Waste Management Inc. 72 Salem Rd.	North Billerica	MA	1862
MRF_47	Rhode Island Resource Recovery Corp. 65 Shun Pike	Johnston	RI	2919
MRF_48	Waste Connections 6601 N.W. Old Lower River Rd.	Vancouver	WA	98660
MRF_49	Waste Connections 3840 N.W. 37th Court	Miami	FL	33142
MRF_50	E.L. Harvey & Sons Inc. 68 Hopkinton Rd.	Westborough	MA	1545
MRF_51	Recology 7 S. Idaho St.	Seattle	WA	98134
MRF_52	Waste Management Inc. 4550 Steelway Blvd. S.	Liverpool	NY	13090
MRF_53	Atlantic Coast Recycling 611 New Hampshire Ave.	Lakewood	NJ	8701
MRF_54	Waste Management Inc. 2050 N. Glassell St.	Orange	CA	92865
MRF_55	Midwest Fiber 422 White Oak Rd.	Normal	IL	61761
MRF_56	Advanced Disposal Services Inc. 10370 Central Park Dr.	Manassas	VA	20110
MRF_57	Rocky Mountain Recycling 3110 S. 900 W.	Salt Lake City	UT	84119
MRF_58	TFC Recycling 1958 Diamond Hill Rd.	Chesapeake	VA	23324
MRF_59	Waste Management Inc. 3600 E. 48th Ave.	Denver	CO	80216
MRF_60	Waste Management Inc. 5395 Franklin St.	Denver	CO	80216
MRF_61	Outagamie County 1419 Holland Rd.	Appleton	WI	54911
MRF_62	Waste Management Inc. 2902 S. Geiger Blvd.	Spokane	WA	97230
MRF_63	Republic Services Inc. 725 44th Ave. N.	Minneapolis	MN	55412
MRF_64	Republic Services Inc. 1949 Hormel Dr.	San Antonio	TX	78219
MRF_65	Waste Management Inc. 1200 Brittmoore Rd.	Houston	TX	77043
MRF_66	Waste Management Inc. 4100 Grand Ave.	Pittsburgh	PA	15225
MRF_67	Waste Management Inc. 5610 FM 1346	San Antonio	TX	78220
MRF_68	Resource Management Cos. 10244 Clow Creek Rd.	Plainfield	IL	60585

APPENDIX B – Amazon Fulfillment Center Locations

Name	Address
PPX1	3809 E Watkins St, Phoenix, Arizona, USA. 85034
LGB1	2417 E. Carson SL, Long Beach, California, USA, 90810
GEG1	10010 W. Geiger Blvd., West Plains. Spokane, Washington. USA, 99224
ONT9	2125 W. San Bernardino Ave, Redlands, California, USA, 92374-5005
Amazon_1	1115 Wesel Boulevard, Hagerstown. Maryland, USA, 21740
GYR3	8181 W Roosevelt St, Phoenix, Arizona, USA, 85043
IVSE	2951 Marion Drive, Unit 101, North Las Vegas, Nevada, USA, 89115
SLC4	770 South Gladiola, Suite 500, Salt Lake City, Utah, USA, 84104
IVSF	2921 Marion Drive, Unit 109, North Las Vegas, Nevada, USA, 89115
WIN1	14831 Foundation Ave., Evansville, Indiana, USA, 47725
BW11	45121 Global Plaza, Sterling, Virginia, USA, 20166
BHM1	975 Powder Plant Road, Bessemer, Alabama, USA, 35022
STN1/ HBN1/ VTN1	10 Dell Parkway. Nashville, Tennessee, USA, 37217
IVSA	4620 Olympic Blvd, Erlanger, Kentucky, USA, 41018
SDC1/ HDC1	6885 Commercial Dr, Springfield, Virginia, USA, 22151
ABE5	2455 Boulevard of the Generals, Norristown, Pennsylvania, USA, 19403
ITX1	9851 Fallbrook Pines Dr, #100, Houston, Texas, USA, 77064
SDF6	271 Omega Pkwy, Shepherdsville. Kentucky. USA, 40165
CAE3	222 Old Wire Rd, West, Columbia. South Carolina, USA, 29172-2862
SIL1	2379 Davey Road, Woodbridge, Illinois, USA, 50517
SMD1	7200 Dorsey Run Road, Elkridge, Maryland, USA, 21075
LEX5	4600 Olympic Blvd, Erlanger, Kentucky. USA. 41018
SIL2	7555 Under Ave, Skokie, Illinois, USA, 60077
SCA4	16915 Via Del Campo, San Diego, California. USA, 92127
FW D 5	4121 International Pkwy, Carrollton, Texas, USA, 75007
SAD/ VAZ1/ HPX1	3333 S. 7th St., Phoenix, Arizona, USA, 85040
SMI1	Hazel Park. Michigan, USA. 48030
ORD4	25810 S. Ridgeland Ave., Monee, Illinois, USA, 60449
MSN5	4718 Helgesen Dr, Madison, Wisconsin, USA, 53718
STX3	4445 Rock Quarry Road, Dallas, Texas, USA, 75211-1409
XUSF	901 W Landstreet Rd, Suite C, Orlando, Florida, USA, 32824- 8028
Amazon_2	Building 3, Chisholm Trade Road Round Rock, Texas, USA, 78681
Amazon_3	Park Frisco, Texas, USA, 75035
PHL1	1 CenterPoint Blvd, New Castle, Delaware, USA, 19720-4172
SWA1/ VWA1/ HBF3	607 Riverside Rd, Everett, Washington, USA, 98201
MSN4	1301 E Washington Ave, Madison, Wisconsin, USA, 53703

STX2	1625 Hutton Drive, Carrollton, Texas, USA, 75006
GYRO	10205 W Roosevelt St, Avondale, Arizona, USA, 85323
Amazon_4	vvanrman 1-td & bit-Joy Kd, Pinnacle Park, Building B, Michigan, USA, 48174
Amazon_5	Gateway Drive, Star Business
ITX2/ HHO2	6911 Fairbanks N, Houston, Texas, USA, 77040
ACY8	8 Campus Drive. Budington. New Jersey, USA, 08016
PIN2	3620 Plainfield Rd, Building 4, Hendricks, Indianapolis, Indiana, USA. 46231
IVSB/ HCN1	3521 Point Pleasant Road, Unit 2 Hebron. Kentucky. USA, 41048
LAS2	3837 Bay Lake Trail, Suite 111, North Las Vegas, Nevada, USA, 89030
LASB/LAS9	5801 N Nicco Way, North Las Vegas, Nevada, USA, 89115
IVSC	1225 Forest Pkwy, West Deptford, New Jersey, USA, 08066
LEX2	172 Trade St., Lexington, Kentucky, USA, 40511
AVPB	250 Enterprise Way, Pittston, Pennsylvania, USA. 18640-5000
BOLE	120 County Line Drive, Cromwell, Connecticut, USA, 06416-1186
ISM1	2314 Waverly Barn Rd, Davenport, Florida, USA, 33897
XUSG	9645 West Hills CI, Kutztown, Pennsylvania. USA. 19530-8644
XUSC	40 Logistics Drive, Carlisle, Pennsylvania, USA, 17013
PFL2	8060 State Road 33 N, Lakeland, Florida, USA. 33809
HOUT	16225 Tomball Parkway, Building 1, Houston, Texas, USA, T7064
RIC3/ HRC1	4949 Commerce Road , Richmond, Virginia, USA. 232.34
BFI8/ HWA2	20529 24th Ave S. Seatac. Washington, USA, 98198
Amazon_6	4701 Commerce Road , Richmond, Virginia, USA, 23234
AFWI	1511 NE Loop 820 Fort Worth, Texas, USA, 76131
IVSD	800 Arlington Blvd, Swedesboro. New Jersey, USA, 08085
TUS1	5333 West Lower Buckeye Rd, Phoenix, Arizona, USA, 85043
ABE3	650 Boulder Drive , Breinigsville, Pennsylvania, USA, 18031-1536
CVG1	1155 Worldwide Blvd.. Hebron, Kentucky, USA, 41048-8648
BFI1	1800 140th Avenue E., Sumner, Washington, USA, 98390-9624
XUSB	14900 Frye Road, Fort Worth, Texas, USA, 76155
Amazon_7	1310 Beulah Rd, Pittsburgh, Pennsylvania, USA, 15235
SLC3/ HSL1	355 N. John Glenn Road, Salt Lake City, Utah, USA. 84116
Amazon_8	2710 West Winton Ave, Hayward, California, USA, 94545
XUSU	845 Paragon Way, Rock Hill, South Carolina, USA, 29730
XUSQ	152 Route 206, Hillsborough. New Jersey, USA, 08844
CMH6/ HCM1	3538 TradePort Court, Building 2. Lockbourne, Ohio, USA, 43137
RAD1	3810 Logistics Way, Antioch, Tennessee. USA. 37013
Amazon_9	E_ Airfield Drive & Valley View Lane Irving, Dallas, Texas, USA, 75261
MQJ2/ HIN2	19 Bob Glidden Blvd., Whiteland, Indiana, USA, 46184
CVG2	1600 Worldwide Blvd., Hebron, Kentucky, USA, 41048

Sy	7037 West Van Buren Street , Phoenix, Arizona, USA, 85043
TEN2	1590 Tamarind Ave, Rialto, California, USA, 92376-3008
AZA4/ HPX2	3333 S 59th Ave, Phoenix, Arizona, USA, 85043
MEM2	191 Norfolk Southern Way,Mississippi, USA, 38611-2306
PHL4	21 Roadway Drive, Carlisle. Pennsylvania, USA, 17015
MTN9	5300 Nottingham Dr, White Marsh, Maryland, USA, 21236
Amazon_10	700 Innovation Parkway, Appling, Georgia, USA. 30802
Amazon_11	Majestic Airport Center IV, Buiding A, South Fulton Rd, Georgia, USA, 30349
SDF9	100 W. Thomas P. Echols Lane, St. 3, Shepherdsville, Kentucky, USA, 40165-7594
Amazon_12	12945 Comfort Way NW, Albuquerque, New Mexico. USA, 87121
XUSV	2255 W Lugonia Ave, Redlands, California, USA, 92374
FTW7/ FTVV9	944 W. Sandy Lake Road, Coppell, Texas, USA, 75019
TEN1	1002 Patriot Pkwy, Muhlenberg Township. Reading, Pennsylvania. USA. 19605-2874
LUK7	649 Omega Prkwy, Shepherdsville. Kentucky, USA, 40165-8501
ABE1/ ABE2	705 Boulder Drive, Breinigsville,Pennsylvania, USA, 18031
EWR8	698 Route 46 West, Teterboro, New Jersey, USA, 07608
XUSE	5460 Industrial Court Suite 300, Whitestown, Indiana, USA. 46075
MDWB	1750 Bridge Drive, Waukegan, Illinois, USA, 60085
Amazon_13	Harney Road West of US 301, Temple Terrace, Florida, USA, 30087
RNO4	8000 North Virginia Street , Reno, Nevada, USA, 89506
Amazon_14	4101 S Singleton Station Rd, Rockford, Alcoa, Tennessee, USA, 37853
Amazon_15	16900 51st Ave NE, Arlington, Washington, USA, 98223
PSP1	1010 West Fourth Street, Beaumont, California, USA, 92223
Amazon_16	6948 Otay Mesa Road, San Diego, California, USA, 92154
Amazon_17	4222 Integration Loop, Colorado Springs, Colorado, USA, 80916
Amazon_18	1201 Kennedy Road, Windsor, Connecticut, USA, 06095
ATL2	2255 W Park Blvd, Stone Mountain. Gwinnett County, Georgia. USA, 30087
Amazon_19	NW corner of Morgan Road and the Liverpool Bypass, Liverpool (Clay), New York, USA, 13090
Amazon_20	2600 Manitou Road, Gates (Rochester), New York, USA. 14624
ROU1 -	4851 Jones Sausage Road, Garner, North Carolina. USA, 27529
MC1	2450 Romig Road, Akron, Ohio, USA, 44320
TUL2	4040 N. 125th East Ave., Tulsa, Oklahoma. USA, 74116
OKC1	9201 S Portland Ave., Oklahoma City, Oklahoma, USA, 73159
Amazon_21	Foundation Court, Sioux Falls, South Dakota, USA, 57107
MOY1	Corner of Golden Bear Gateway and East Division Street, Mt Juliet, Tennessee, USA. 37122
Amazon_22	12101 Emerald Pass Drive El Paso, Texas, USA, 79928
Amazon_23	2000 Exchange Parkway Waco, Texas, USA, 76712
Amazon_24	5900 Richmond Hennco Turnpike. Richmond, Virginia. USA 23227

DSM5	500 SW 32nd St, Bondurant, Des Moines, Iowa, USA, 50035
Amazon_25	5295 East Franklin Road. Nampa, Idaho, USA, 83687-5548
LEX1/ LEX3	1850 Mercer Drive, Lexington, Kentucky, USA, 40511
CLE3	1155 Babbitt Road, Euclid (Cuyahoga), Ohio, USA, 44132
ACY1	240 Mantua Grove Road, West Deptford, New Jersey, USA, 08066-1731
XUSP/ HBA1	1100 Woodley Rd, Aberdeen, Maryland, USA, 21001-4042
MKE2	9700 South 13th Street, Oak Creek, Wisconsin, USA, 53154
MSP2	Hwy 169 & Hwy 610 NE Quadrant, Brooklyn Park, Minnesota, USA, 55445
IND7	9101 Orly Drive, Indianapolis. Indiana, USA, 46241-9605
MDW4	201 Emerald Drive, Joliet, Illinois, USA, 60433-3281
Amazon_26	Route 22 & Nissan ParkwayCanton, Mississippi, USA. 39046
OMA1	NE of intersection of Nebraska Highways 370 and 50Papillion, Omaha, Nebraska, USA, 68138
Amazon_27	Beech Road S of State 161 Interchange, New Albany, Ohio, USA, 43054
MDT1	2 Ames Drive, Building #2, Carlisle, Pennsylvania, USA, 17015
PCW1	27400 Crossroads Parkway, Rossford. Ohio, USA, 43460
PHL5	500 McCarthy Dr., Lewisberry, Pennsylvania. Pennsylvania, USA, 17339-8725
STL4/ DLI4	3077 Gateway Commerce Center Drive South. Edwardsville. Illinois, USA, 62025-2815
ATL8	2201 Thornton Road, Lithia Springs, Georgia, USA, 30122- 3895
SCK3	3565 N Airport Way, Manteca, California, USA 95336-8696
Amazon_28	765 Hamburg Road, New Castle. Delaware, USA, 19720
Amazon_29	Dodd Road & County Road 70, Lakeville, Minnesota, USA, 55044
Amazon_30	6806 Cal Turner Drive San Antonio, Texas. USA, 78220
MDW6	1125 W Remington Blvd, Romeoville, Illinois, USA, 60446- 6529
STL6/ STL7/ HLU1	3931 Lakeview Corporate Dr, Edwardsville, Illinois, USA, 62025-2801
SDF1	1050 South Columbia Avenue , Campbellsville, Kentucky, USA, 42718-2454
LGB4	27517 Pioneer Ave. Redlands, California, USA, 92374-1501
LGA7/ LGA8/ DNJ1/ HEW 11CDW5	380 Middlesex Ave, Carteret, New Jersey, USA, 07008-3446
HMW1	30260 Graaskamp Blvd, Wilmington. Illinois, USA, 60481
LASE	4550 Nexus Way, North Las Vegas, Nevada. USA. 89081
Amazon_31	5000 Lanier Islands Parkway, Building 1, Buford, Georgia. USA, 30518
Amazon_32	1025 & 1035 Boxwood Road, Newport, Wilmington, Delaware, USA, 19804
Amazon_33	Hartford Avenue, Johnston, Rhode Island, USA, 57107
PHX5	16980 W. Commerce Dr., Goodyear, Arizona. USA, 85338- 3620
MKC4	19535 Waverly Rd, Gardner (Edgerton), Kansas, USA, 66030
MGE3	808 Hog Mountain Road, Building F, Jefferson. Georgia. USA, 30549
Amazon_34	2020 Northgate Commerce Parkway, Suffolk, Virginia, USA, 23435
SDF4	376 Amazon.com Blvd. Shepherdsville, Kentucky, USA, 40165
Amazon_35	1200 Featherstone Road, Pontiac, Michigan, USA, 48342- 1938
Amazon_36	Michigan. USA, 48203

Amazon_37	2000 E. Pecan Street Pfiugerville, Austin, Texas, USA, 78660
Amazon_38	West side of Hiatus Road, Between NW 44th Street and
Amazon_39	NW 44th Street, Sunrise, Florida, USA, 33351
Amazon_40	Zeuber Road, Big Rock Township, Little Rock, Arkansas, USA. 72206
PHL6	675 Allen Rd. . Carlisle, Pennsylvania, USA. 17015-7788
LGB7	1660 N. Linden Ave, Rialto, California, USA, 92376
GYR1	580 South 143rd Avenue . Goodyear, Arizona, USA 85338
SMF1	4900 W Elkhorn Blvd, Sacramento. California, USA, 95835-9505
FAT1	3575 S Orange Ave. Fresno, California, USA, 93725-9366
DENS	14601 Grant Street, Thornton, Colorado, USA, 80023
BDL3	Building 3, 415 Washington Ave, North Haven, Connecticut, USA, 06473
MIA1	14000 NW 37th Ave., OpaLocks, Florida, USA, 33054
MC01	12340 Boggy Creek Rd, Lake Nona, Orlando, Florida, USA, 32824-6902
OROS	7001 Vollmer Road, Frankfort, Matteson, Illinois, USA, 60423
IGQ1	15924 Western Ave.Markham, Illinois. USA, 60428
Amazon_41	9401 Cortana PI, Baton Rouge, Louisiana. USA, 70815
DCA1	1700 Sparrows Point Blvd, Sparrows Point, Dundalk, Maryland, USA, 21219
Amazon_42	1600 Osgood St., North Andover, Massachusetts, USA, 01845
DTW1	32801 Ecorse Road, Romulus, Michigan, USA, 48174
GRR1	4500 68th St. SE, Caledonia (Gaines Township), Michigan, USA, 49316
STL8	4000 Premier Parkway, St. Charles, Missouri, USA, 63301
LAST	6001 E. Tropical Parkway, North Las Vegas, Nevada, USA. 89115
Amazon_43	1200. North Las Vegas, Nevada, USA, 89115
JFK8/ DYY6	566 Gulf Ave, Staten Island, New York, USA, 10314-7120
CLT4	8000 Tuckaseegee Road, Charlotte, North Carolina, USA, 28214
CLE2	21500 Emery Road, North Randall. Ohio, USA, 44128-4546
CMH1	11903 National Rd SW, Etna, Ohio. USA, 43062-7793
CMH4	1550 W Main St., West Jefferson, Ohio, USA. 43162
PDX9	1250 NW Swigert Way, Troutdale, Oregon, USA, 97060
MEMO	4055 New Allen Road, Raleigh (North Memphis), Tennessee, USA, 3812B-271B
DAL3	1301 Chalk Hill Road Dallas, Texas. USA, 75211
SAT2	1401 East McCarty Lane, San Marcos, Texas, USA. 78666- 8969
HOU2	10550 Ella Boulevard, Houston, Texas, USA, 77038-2324
HOU8	10507 Harlem Road, Richmond, Texas, USA, 77407
SLC1	777 N. 5600 West, Salt Lake City, Utah, USA, 84116
MKC6	6925 Riverview Ave., Kansas City, Kansas, USA, 66102-3047
MDW7	6605 W. Monee Manhattan Road, Monee, Illinois, USA, 60449-9668
Amazon_44	Sakioka Farms Business Park between Rice Avenue and Del Norte Boulevard, Oxnard. California, USA, 93030
TUS2	6701 S. Kolb Road, Tucson. Arizona, USA, 85756

MSP1	2601 4th Ave E, Shakopee, Minnesota, USA, 55379-1726
PIL1	Building SHorn Lake, Mississippi, USA. 38637-2313
XUSO	657 Nance street, Perris, California, USA. 92571
JAX2	12900 Pecan Park Road, Jacksonville, Florida. USA, 32218-2432
SNA4	2496 West Walnut Ave., Rialto, California, USA, 92376-3009
LGB3	4950 Goodman Way, Building 1, Eastvale, California, USA, 91752- 5087
BFI4	21005 64th Ave. S. Kent, Washington, USA, 98032-2423
Amazon_45	North of Hector International Airport. Fargo, North Dakota, USA. 58102
IND4/ IND8/ UIN1	710 South Girls School Road, Indianapolis, Indiana, USA, 46231-1132
PDX6/ DPDS/ HPD1	15000 N. Lombard Street, Multnomah, Portland, Oregon, USA. 97203-6814
FTW8	3351 Balmorhea Dr, Dallas, Texas, USA, 75241
LGA9	Gateway 10, 2170 Lincoln Highway (NJ-27). Edison, New
IND5	800 South Perry Road, Plainfield, Hendricks County, Indiana, USA, 46168-7937
TEB6	22 Hightstown-Cranbury Station Road. Cranbury Township, New Jersey, USA, 08512
IND2/ IND3	715 & 717 Artech Parkway, Plainfield, Hendricks County, Indiana, USA, 46169
ONT2/ ONT3/ ONT4/ ONT7	1910 & 2020 E. Central Ave.. Building 3, San Bernardino, California, USA, 92408-0123
TTN2	343 Cranbury Half Acre Rd, Cranbury, New Jersey. USA, 08512-3253
CMH3	700 Gateway Blvd., Monroe, Ohio, USA, 45050-1848
LGB6	20901 Krameria Avenue, Riverside, California, USA, 92508
OAK3	255 Park Center Drive, Patterson, California, USA, 95363-8876
Amazon_46	N Plaza Drive at W Riggin Ave, Visalia, California, USA, 93201
DEN2	22205 E.19th Avenue, Aurora, Colorado, USA. 80019
TPA2/ LAL1	1760 County Line Rd., Lakeland, Florida, USA, 33811-1808
MCO2	2600 N Normandy Blvd, Deltona, Florida, USA, 32725
Amazon_47	4490 Corporate Rd North, Jupiter, Florida, USA, 33478
Amazon_48	SW Kanner Highway 76 & SW 96th Street. Stuart, Florida, USA, 34997
MDW9	2865 Duke Parkway, Aurora, Illinois, USA, 60563
SDFB	900 Patrol Road, Jeffersonville, Clark County, Indiana, USA. 47130-7761
Amazon_49	7130 North Broadway Avenue, Park City,VVichita, Kansas, USA, 67219
Amazon_50	3620 NE Evangeline Thruway. Carencro, Lafayette, Louisiana, USA, 70520
DCA6	6001 Bethlehem Blvd. Sparrow's Point, Edgemere, Maryland, USA, 21219
DET2	50500 Mound Road, Shelby Township, Michigan, USA. 48317 1318
MEM6	11505 Progress WayOlive Branch, Mississippi, USA, 38654
CLT3	6500 Davidson Hwy, Concord, North Carolina, USA, 28027-7995
Amazon_51	12220 Carolina Logistics Drive, Charlotte, North Carolina, USA, 28134
CMH2	6050 Gateway Court, Groveport (Obetz). Ohio. USA, 43125
PDX7	4775 Depot Court SE, Salem, Oregon. USA, 97317-8983
PIT2	1200 Westport Road. Findlay Township, Pennsylvania, USA, 15126
BNA3	2020 Joe B Jackson Pkwy, Murfreesboro, Tennessee, USA, 37127-7792

DAL2	2601 S. Airfield Drive Irving, Texas, USA, 75038
Amazon_52	15201 Heritage Parkway, Fort Worth, Texas, USA, 76177-2517
Amazon_53	Missouri City, Houston, Texas, USA, 77489
Amazon_54	Junction of 24th and N Lakeside Drive Amarillo, Texas, USA, 79108
SLC2	7148 Old Bingham Highway, West Jordan, Utah, USA, 84081
BFI3	2700 Center Drive, DuPont, Washington, USA. 98327-9607
MKE1	3501 120th Ave, Kenosha, Wisconsin, USA, 5314,4-7502
JVL1	1255 Gateway Boulevard , Rockford (Beloit), Wisconsin, USA, 53511
SJC7	188 S Mountain House Parkway, Tracy. California, USA, 95377- 8906
CSG1	280 Bridgeport Boulevard, Moreland, Newnan. Georgia, USA, 30263
MA/6	2601 W. Bethel Road, Grapevine (Coppell), Texas, USA, 75261- 4034
IAH1	9155 Southlink Drive Dallas, Texas, USA, 75241-7510
SATE	Fortuna Rd and Yarrington Road. San Marcos, Texas, USA. 78666
Amazon_55	10360 US-90 San Antonio, Texas, USA, 78245
GS01	1656 Old Greensboro Road, Kernersville, North Carolina, USA, 27284
Amazon_56	5705 Campbellton-Fairburn Road, Building A, Union City (Atlanta), Georgia, USA, 30213
Amazon_57	9700 Leavenworth Road, Building A, Kansas City, Kansas, USA, 66109
LGB9	4375 N Perris Blvd. Perris, California, USA, 92571
RDG1	3563 Mountain Rd, Shartlesville, Hamburg, Upper Bern, Pennsylvania, USA, 19526-7947
DET1	39000 Amrhein Rd., Livonia. Michisan, USA, 48150
SWF1	Highway 171gRoute 747 at International Blvd, Montgomery, New York, USA, 12575
ORD2	23714 west, Amoco Rd, Channahon, Illinois, USA. 60410
BOS7	1190 Innovation Way, Fall River, Massachusetts, USA, 02722- 4766
ACY2	1101 E Pearl St, Burlington, New Jersey, USA, 08016-1934
ALB1	1835 U.S_ 9, Rensselaer, Castleton, Schodack, New York, USA, 12033
JAX3	13333 103rd St., Jacksonville, Florida, USA, 32210-8686
SAV3	7001 Skipper Road, Macon, Georgia, USA. 31216-6427
HOU3	31555 US 90. Katy (Brookshire), Texas, USA, 77423-2769
GSP1 .	402 John Dodd Rd. Spartanburg, South Carolina, USA, 29303- 6312
CHA2	225 Infinity Dr NW. Charleston, Tennessee, USA, 37310-1400
TPA1	3350 Laurel Ridge Ave, Ruskin, Florida, USA, 33570-5526
BWI2	2010 Bruning Highway, Baltimore, Maryland, USA. 21224-6027
CHAl	7200 Discovery Drive, Chattanooga, Tennessee, USA, 37416-1749
SNA6/ SLA5/ SNA9/ DCA2	5250 Goodman Way, 5040 Goodman Way, Building B, Eastvale, California, USA, 91752- 5088
PHL7/ PHL9	560 Merrimac Ave, Middletown, Delaware, USA, 19709-4652
FTW2	2701 W Bethel Road, Coppell, Texas, USA, 75261-4015
PGA1/ AGS2	429 Toy Wright Road, Pendergrass. Georgia, USA, 30567
DFW6	940 W Bethel Road . Coppell, W. Texas, USA, 75019-4424
Amazon_58	13001 Highway 70. North Little Rock, Arkansas, USA, 72117

BDL2	200 Old Iron Ore Road, Windsor, Connecticut, USA, 06095
BWI4	165 Business Blvd, Frederick, Clear Brook, Virginia, USA. 22624
JAX7	10501 Cold Storage Road, Unit 500, Building E, Imeson Park , Jacksonville, Florida. USA, 32725
LGA6/ EWR9	8003 Industrial Ave, Building A, Carteret, New Jersey, USA, 07008 -3529
XIX3	1400 Southport Parkway, Building #1, Wilmer. Texas, USA, 75172
Amazon_59	Gateway Development, U.S. Highway 80 and Gateway Boulevard. Forney, Texas, USA,
TPA3	576 C Fred Jones Blvd, Auburndale, Florida, USA, 33823
Amazon_60	13200 Southwest 272nd Street, Homestead, Miami, Florida, USA, 33032
IND1	4255 Anson Blvd , Whitestown, Indiana. USA. 46075-4412
OKC2	8991 S Portland Ave., Oklahoma City, Oklahoma, USA, 73159
RIC1	5000 Commerce Way, Petersburg, Virginia, USA, 23803 6917
SNA7/ SNA8/ LGB5/ KRB1	555 East Orange Show Rd, San Bernardino, California, USA, 92408-2453
ABE4	1610 Van Buren Road, Easton (Palmer Township), Pennsylvania, USA, 18045-7807
Amazon_61	7055 Campbellton Road, Atlanta. Georgia. USA. 30331
MDT2	600 Principio Parkway West, Cecil, North East, Maryland, USA, 21901
TEB3	2651 Oldmans Creek Rd. Swedesboro, Logan Township, New Jersey. USA. 08085
OAK4	1555 N. Chrisman Rd., Tracy, California, USA, 95304-9370
IG02	23257 S Central Ave, University Park, Illinois, USA, 60484
EWR1/ EWR4	50 New Canton Way, Robbinsville, New Jersey, USA, 08691-2350
BNA2	500 Duke Dr, Lebanon, Tennessee, USA, 37087-8123
DFWT	700 Westport Parkway. (Haslet) Fort Worth, Texas, USA, 76177- 4513
RIC2	1901 Meadowville Technology Parkway, Chester, Virginia, USA, 23836-2841
PHX6/ TFC1	4750 & 5050 West Mohave Street, Phoenix, Arizona, USA. 85043-4428
Amazon_62	742 Courses Landing PointCarney's Point, New Jersey. USA, 08069
AVP2/ AVP3	298 1st Avenue, Gouldsboro (Covington Township), Pennsylvania, USA, 18424-9464
CAE1	4400 12th Street Extension, West Columbia (Cayce), South Carolina, USA, 29172-3300
ONT6/ HLA3	24208 San Michele Rd, Moreno Valley, California, USA, 92551- 9561
SAT1	6000 Schertz Parkway. Schertz, Texas, USA, 78154-1461
PHX7/ PHX8	800 N. 75th Ave, Phoenix, Arizona, USA, 85043.3101
Amazon_63	3200 East Sawyer Road. Republic, Missouri, USA, 55044
GEG2	18007 E_ Garland Ave., Spokane. Washington, USA, oolia
SDF2	4360 Robards Lane, Louisville, Kentucky, USA, 40218
Amazon_64	4500 Express AveShafter, California, USA, 93263
PHX3	Phoenix, Arizona, USA, 85043- 4428
SBD2	1494 S Waterman Ave, San Bernardino, California, USA, 92408-2805
SCK1	4532 Newcastle Road, Stockton, California. USA 95215-9446
MGE1/ MGE7	650 Broadway Ave., Braselton.Georgia, USA, 30517-3002
BFL1	1601 Petrol Road. Bakersfield, California, USA, 93308