# Development of Generative Recycling System in Rural Eastern Ghana through Co-Design Principles

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## *Introduction*

Since society began using plastic, 7.8 billion tons has been produced globally [1]. This is approximately one ton per person. Today, more than 300 million tons of plastic are produced annually [2]. Plastic production is ubiquitous. It is spread throughout industries such as transportation, packaging, textiles and construction. Plastics do not break down in the environment quickly, it takes from 20-500 years for most plastics to deteriorate. This has led to major global pollution primarily in the oceans and rivers, with more than 8 million tons of plastic ending up in the ocean or major rivers annually [1]. Policy makers in high income countries, like the US and Europe, have also used exporting waste to other lower income countries as a way to mitigate their own countries' waste management [3]. Policy makers in countries like India, Kenya, and Morocco, and institutions such as the European Union have also sought to address the plastic crisis through banning single-use plastic, such as plastic bags and utensils [4]. Despite the leadership of some, the absence of recycling initiatives is still the standard.

Low- and middle-income countries are disproportionately responsible for managing most of the world's plastic waste [1]. Due to the lack of policy or intervention in low- and middle-income countries, approximately 84% of the globe’s population, resorts to littering, dumping, and plastic burning, which all cause significant environmental and health issues [5]. Often, plastic disposal involves burning which contributes to greenhouse gas emissions, global warming, and exacerbates problems associated with public health [1]. In rural communities in the Eastern Region of Ghana, inadequate management of plastic waste has resulted in widespread adoption of the harmful practice of burning of plastic [2]. A growing awareness of these consequences among these communities has fostered a desire to seek alternatives, one of them being recycling. There are numerous hurdles to successfully implement a recycling system in any rural area, including high transportation costs, a lack of infrastructure for plastic preprocessing, and difficulties in collecting plastic waste generated by individual disparate communities.

Here, we present a case study of our effort to develop local waste management and recycling initiatives in Ghana's Eastern rural region. In doing so, we document their challenges and their innovative solutions in the context of plastic waste management. This case study provides actionable business and implementation plans that can help scale this system to other regions of Ghana, and other rural communities in sub-Saharan Africa. In partnership with Akyem Dwenase, a village in Ghana’s Eastern region, our plan will enable Akyem Dwenase and surrounding villages to expand an existing plastic collection process to a regional collaborative recycling system. With our partners in Ghana we have facilitated a design that brings together four already cooperating communities. Led by Chief Osabarima Owusu Baafi Aboagye, III, of Akyem Dwenase, the collaboration of partners and traditional leadership formed a regional plastic waste management partnership in order to manage and maintain the necessary labor and infrastructure. To scale this initiative, we propose a mutual investment partnership with Accra

recycler, in order to increase recycling capacity and guarantee a permanent buyer. In return, necessary plastic preprocessing steps will be established in Akyem Dwenase as the hub. The project, if successful, will provide jobs, educational opportunities, entrepreneurship opportunities and an adequate alternative to burning plastic waste.

This chapter will serve to contextualize the problem of plastic waste management in a global context as well as outline the co-design framework that governed the design process of our proposed generative system. Once these design principles are established, we will document the iterations of our proposed system using co-design to incorporate feedback from local partners and other stakeholders. Ultimately, we will present a co-designed generative recycling plan outlining the necessary stakeholder contributions and infrastructure to establish and ensure the sustainability of this project . This will be followed by a discussion on the lessons learned over the course of the co-design process, so as to better prepare future partnerships for the challenges inherent in successfully co-designing cooperative businesses.

## *Background*

Globally waste production is a multifaceted problem that many countries struggle to develop an adequate all-encompassing response to all forms of waste, including plastic. There is high variability in the types of waste, technologies to handle them as well as the cultural attitudes towards different types of waste around the world. This section will outline the global problems with waste management and some of the shortcomings in Ghana's waste management systems as well as the potential of plastic recycling industries that are being developed in Ghana. This information informed our co-design process and will lead into the description of our case study aiming to address plastic waste management in rural Eastern Ghana.

### *Global Waste Management*

Globally waste management, specifically plastic waste, has been a growing issue for both the environment and health of people around the world [6]. This is due to the increased production and use of plastic as well as improper disposal methods [6]. The majority of this waste can be classified as municipal solid waste (MSW). MSW is a specific stream of waste that is most broadly defined as waste generated from households and commercial or industrial sectors [6]. Within this global issue, there are variations in how different regions view and handle MSW [7]. The main factors that impact how MSW is handled in all of these countries has to do with the waste characteristics, economic factors, and social views [7,8].

#### *Waste Characteristics*

Waste characteristics are determined by the percentages of types of waste that are found within a stream of MSW. Waste characteristics are determined by the cooking habits, eating habits and different lifestyles found within a region. Variations in these factors will produce different amounts of waste and different ratios of the types of waste within the MSW stream [7]. Waste characteristics mainly impact the biodegradable parts of MSW, like food and paper, but can also impact discarded plastic. Biodegradable waste is mainly handled by using landfills or burning [1]. Burning the waste has the potential to reuse this waste to produce energy or new types of fuels but it can result in the additional release of toxins and add to the emission of greenhouse gasses that cause global warming [8,9]. Other easily recyclable materials found in MSW are paper, glass and metal [6,7].

#### *Economic Factors*

Economic factors impact the overall response nations and governments employ in handling MSW. While higher average income can remove some forms of waste from the MSW stream it has also been seen that income will impact the waste characteristics [7]. This is due to the difference in societal views of what is waste. Having a higher average income will impact the view of what is considered waste and the type of technology they have available to deal with that waste. Those with higher incomes are more likely to view durable materials as disposable and

thus add additional waste. The average income of a country will also impact the types of waste that are seen in different communities. For example higher income countries are more likely to have access to technology such as waste grinders in sinks that will remove some of the biowaste seen in MSW. Technology like this as well as others available in higher income countries would also remove some waste from the overall waste stream. Also the willingness of citizens to pay higher taxes so that more or better waste removal can occur is more likely to be accepted in richer countries [7].

*Social Factors Driving Waste Management*

Social and cultural factors can impact people's ability to take part in MSW management at home or within their community. One limitation can be location within or external to a city. Difficult to access parts of cities that are unplanned, like slums, can limit access of vehicles and make it difficult to plan routes to places where recycling or other waste can be collected. It is also a challenge to transport waste away from places with steep hills or uneven roads making waste management difficult in more remote places. Attitudes towards littering and cultural views of recycling and its benefits are major factors in the success of waste management and recycling programs. Places like Singapore and China have heavily enforced littering laws. Also in these places waste management is easier because culturally they believe it is a community responsibility to keep their streets clean. This leads to less waste in the roads and overall better MSW management among these communities. A result of these types of cultural views can lead to financial profits from solid waste which has been seen in Singapore, Australia and Sweden [10]. Lastly environmental awareness can impact how different countries recognize and take action against negative impacts on the environment caused by humans. More developed countries have taken interest earlier, as early as 1960, resulting in more established systems for waste management that were later redeveloped to be less harmful to the environment [1].

The increase of MSW has affected people around the globe. The response by the individual countries is greatly determined by the average economic wealth and cultural views on waste management and recycling. Within waste management plastics have a large environmental and health impact if they are not recycled or disposed of properly.

## *Environment and Health Effects of Improper Waste Disposal*

*Environmental Impacts*

Plastic is first made from polymers that consist of oil, making it difficult to break down. As plastic ultimately degrades over time it turns into microplastics entering the sediment in the ground [13]. Once plastic enters through the soil, the plastic waste is in the ecosystem. This process pollutes the ecosystem where every organism that is a part of the ecosystem is affected. When there are open plastic fires these potential toxic elements enter the atmosphere, soil, and

water. The multiple ways of entrance into the ecosystem is damaging. Once the toxins are introduced in multiple areas of the ecosystem, results in more exposure of the carcinogen. Carcinogens are potentially toxic elements that have the capability to cause cancer in the living tissue of a human [13]. Ecosystems in the environment are connected through pathways, allowing constant interaction. Pathways that form these complex networks are primarily created by bodies of water such as ground water, surface water, rivers, streams that lead to the ocean where multiple ecosystems meet. Other pathways that connect ecosystems include suspension in the atmosphere through particles, gasses, and ash. Through deposition, toxins enter through dust, soil and sediments. Once potential toxic elements enter one of the ecosystem pathways, organisms that live within the area become receptors [13].

All bodies of water lead to the ocean, making the ocean a hub where potential toxic elements collect and disperse. Once the elements disperse the organisms that live in the ocean obtain the toxins, entering the food chain. Other ways toxins can enter the food chain are through entering soil and groundwater, crops are polluted, where humans then ingest the toxins. Harmful substances like Phthalates and dioxins stay in the atmosphere providing exposure of inhalation to organisms in the surrounding ecosystem, shown in figure 1 [12]. Also seen in figure 1 is the population of receptors made up of organisms, children and adults that are around the contaminated ecosystem. Those that are closer to dumpsites where the open fires take place are more at risk than others that are farther away [12].

The risk of being in a contaminated ecosystem has its physical dangers but there are dangers beyond the physical. An environment is not always an area or setting you can physically see. The Earth is our environment as humans however there is another aspect of the environment that is also impacted. Environment is also made up of the people, behaviors, and attitudes an individual surrounds themselves with. When dangerous substances are added to a physical environment, fear and worry are introduced. This fear creates emotional distress especially when there are multiple pathways where contamination can spread as seen in figure 1.

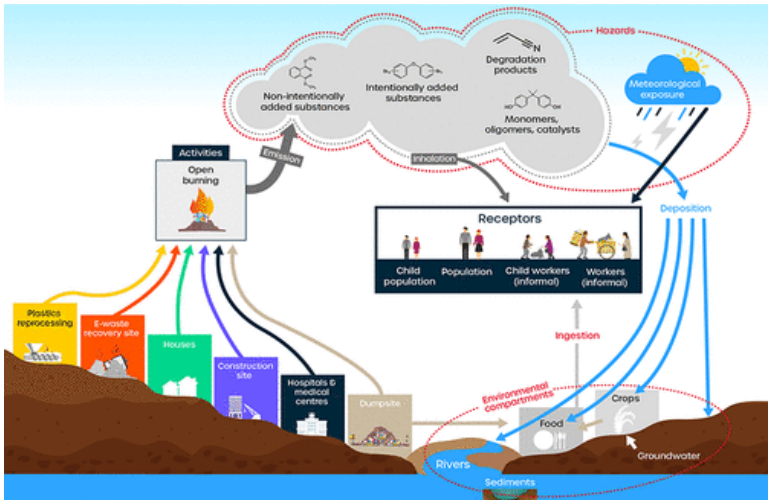


*Figure 1: Environmental Impacts of Open Fire Burning.* Open fire burning from a variety of sources releases several substances into the atmosphere that are known to have harmful health and environmental impacts.[14]

*Health Impacts*

When plastic is burned dangerous chemicals are released into the air. These emissions are known to be dangerous to human health. When the plastic is burned chemical reactions take place. These reactions release compounds in the plastic that can be inhaled by people at the site of burning and beyond [13]. Plastic is manufactured by chemical materials known as monomers, oligomers and catalysts. When burning these materials in the open there is a degradation process where by-products are formed, such as: “brominated flame retardants; phthalates; potentially toxic elements; dioxins and related compounds; bisphenol A; particulate matter; and polycyclic aromatic hydrocarbons”. These emissions are extremely dangerous. Phthalates and plasticizers in PVC readily bond with fats, allowing the phthalates to be absorbed in the bloodstream easily [13]. This process in the human body impacts metabolites affecting the endocrine system, metabolism, and thyroid hormones. Dioxins are harmful to human health as the half-life for dioxins are 7-11, leading to short term conditions in the skin as well as long term conditions such as cancer, reproductive issues, neurological, immunological disruptions in development. The long-term effects of dioxins are more prominent in children as disruptions occur during development. This, and other emissions present aggravate the respiratory system and increase risk of heart disease. The health conditions of open plastic burning products have been as “ data and combined them with a global burden of disease study by Lim et al. to estimate 270 000 premature deaths per year worldwide (5th to 95th percentiles: 213 000 to 328 000) from the open burning of waste” [12]. The health conditions that occur from open burning plastic is dangerous and needs to be addressed.

With the spread of plastic, the result is wildlife consuming microplastics and contamination of our food and water supplies. Waterborne plastics have become a part of our everyday life, where about 23% of aquatic mammals contain traces of microplastics. If plastic

waste continues to grow at current rates around 99% of seabirds will contain microplastics by 2050 [11]. And together human consumption of toxins like Zinc and Mercury will continue to increase. Through the consumption of produce with microplastics and these toxins, irreversible damage is being done to our digestive system and bodies as a whole. While many are consuming plastic, some are also inhaling toxins, such as Phthalates, that come from the burning of plastic. When plastic is not incinerated in a controlled facility properly, for example in the backyards of homes, the emissions lead to health problems, such as premature death, increased heart disease risk, allergies, and asthma [12]. The continuation of plastic production is definite for our future, however through the implantation of plastic disposal projects globally, we can create a sustainable and healthier lifestyle for ourselves and the environment.

## *Waste Management in Developing Countries*

Effective waste management in developing countries has yet to be implemented in significant ways because of several of the limiting social and economic factors [7]. Other more specific issues faced in developing countries include inadequate resource mobilization, over reliance on imported equipment, inequitable service provision, inappropriate methods of finance and inappropriate technology implementation, like recycling [7]. By understanding the current issues with waste management and its techniques we can better develop recycling initiatives that meet the needs of specific communities.

## *Waste Management in Ghana*

Despite spending 30 to 50% of their operational budgets on solid waste management, cities in low- and middle-income countries such as Ghana, only collect between 50 and 80% of the waste generated [15]. The most common disposal methods for MSW, especially plastic, are dumping in landfills or incinerators, waste collection by sanitary workers, dumping in unauthorized places, burning or burying near the household or recycling/composting [16]. There is also the potential for new disposal methods to be introduced to Ghana that utilize MSW for a source of renewable energy. In the following section we will compare our proposed system to these common methods of waste disposal and discuss the different impacts they will have on the environment and local communities health as well as the local and national economy.

### *Sanitary services and Landfills*

Together more 80% of all MSW is disposed of by sanitary services or makes its way to landfills in Ghana [16]. Sanitary services include businesses that collect MSW and deposit it in nearby landfills. Landfills are a popular option in Ghana because of their low cost and convenience, according to the Environmental Protection Agency [17]. There are currently 15 landfills throughout Ghana in a range of locations from Kumasi in central Ghana with a population of 800,000 to Elmina on the south coast of Ghana with a population of 30,000. The

annual budget for these landfills range from .19 million USD, in Elmina, to 6.28 million USD in Kumasi [18]. Although landfills and incineration are a popular method of disposal the improper implementation and operation of landfills and incineration sites can have devastating environmental and local health impacts. Landfills if not operated correctly can lead to environmental pollution such as surface and groundwater pollution and bad odor, as well as a prevalence of diseases [17]. On a global scale landfill gas represents a major source of greenhouse gas emission up to 5% of total greenhouse gas emission in developing countries [19]. "As a result of anaerobic digestion of organic wastes in landfills releasing gasses such as methane (CH4), NOx, and SO2 coupled with the emission of particulate matter into the air during incineration, the current methods of wastes management (landfilling and incineration) in Ghana become inappropriate" [16]. Along with environmental impacts "Management of solid waste (mainly landfills and incineration) releases a number of toxic substances, most in small quantities and at extremely low levels. Because of the wide range of pollutants, the different pathways of exposure, long-term low-level exposure, and the potential for synergism among the pollutants, concerns remain about potential health effects but there are many uncertainties involved in the assessment" [20]. "The evidence of causal relationship with hazardous waste was defined as limited for: liver, bladder, breast and testis cancers and non-Hodgkin lymphoma. Among non-neoplastic diseases, asthma was found to be related to hazardous waste with limited evidence. We evaluated as limited the evidence of the association between the exposure to hazardous waste and adverse birth outcomes, including low birth weight, preterm birth, congenital anomalies overall and anomalies of the urogenital, connective and musculoskeletal systems. The evidence of a causal relationship was defined as inadequate for most other health outcomes" [20]. Economically, landfills and sanitation service in Ghana are a large sector of business. Some urban centers in Ghana have reported spending US$ 3.45 million annually on the collection and transport of waste for disposal [15]. They have also reported spending US$ 0.28 million per month to pay waste contractors and for landfill maintenance [15]. Along with the cost to transport MSW and upkeep the landfills the Ghanian government spends 1.6% of the country's Gross Domestic Product every year to combat the poor sanitation protocol that results in widespread health and environmental impact [15]. Although landfills and snatiation can be expensive they play a large role in maintaining the current level of waste disposal that is done in Ghana as well as providing thousands of jobs to sanitation workers, landfill workers and waste pickers that are prevalent across Ghana's landfills and dumps [21].

*Disposal in unauthorized places*

Burning, burying and dumping in unauthorized places is the way MSW is disposed of 13% of the time [16]. This is approximately 630,000 tonnes of plastic waste per year that is littered or burned in Ghana. Because of this high volume of plastic that is disposed of in this way there are several serious environmental and health impacts that have occured, mostly in major cities. Burying without burning has very few short term environmental impacts but can become an issue if done in excessive amounts over a long period of time near water sources. The toxins

from the plastics and other material can leak into the ground wate similar to the limited issues reported with landfills. This could be more of an issue when done in unauthorized places that are closer to populations and water sources. Burning MSW and especially plastic contributes to greenhouse gas emissions. Burning plastic has several adverse environmental impacts, most important is the release of toxins into the air such as Dioxins that lead to short term conditions in the skin as well as long term conditions such as cancer, reproductive issues, neurological, immunological disruptions in development [13]. Health impacts of it leaking into water. Unauthorized waste cleanup and management costs the Ghanian government $290 million USD every year to combat the poor sanitation that results in these negative health and environmental impacts [15]. Unlike the other forms of waste disposal this method does not bring any financial value to Ghana.

*Energy generation from MSW*

Using MSW for energy generation is not yet a common practice in Ghana. Burning MSW for energy has potential to be a large-scale solution to the MSW problem that also provides a source of renewable energy. This method of waste disposal can be used for all types of waste. In the future the best implementation would be to add energy generation portions to existing landfill and incineration sites [16]. Environmentally this solution for waste disposal would still release greenhouse gasses from the landfill portion of the operation. There is also the potential to release toxic fumes from the burning operation similar to current burning operations if not done correctly. The health impacts would be similar to those seen in landfills currently but because the waste would have less time to decompose before being burned some of the issues with the toxins leaking into the water and soil would be lessened, although it cannot be known by how much. Economically the adaptation of landfills into energy production facilities would add lots of value to the national ghanaian economy by providing a source of locally produced power from a renewable source. Would have a high initial input cost to augment the existing landfills and incineration sites but would be a valuable resource if maintained for many decades. Augmenting existing landfills to produce energy when compared to our proposed system is better environmentally and health wise (if maintained correctly. Burning waste for energy will also have more economic impact over time and will positively impact a large portion of the Ghanian population.

Landfills and unauthorized dumping make up more that 90% of waste management techniques commonly used in Ghana today. Their popularity is due to their relative ease in comparison to other management options like energy generation. While these options are the most common there has been a recent rise in the interest of recycling plastic in Ghana. This is due to the recognition of the harmful health and environmental impacts plastics can have as well as the desire to develop a plastic recycling industry [22].

## *Plastic Recycling in Sub Saharan Africa*

Most countries in West Africa, including Ghana, are projected to produce at least 1000 - 5000 (10^3) tonnes of municipal solid waste (MSW) per year by 2025 [23]. Annually, sub-Saharan Africa produces 17 million tons of plastic waste per year, forecasted to grow exponentially as urbanization in the region continues to increase. With a population of 1.14 billion, the per capita plastic usage is estimated at 16kg per year, though this figure fails to highlight the differing degree of plastic waste generated between urban and rural areas. Many high-density population centers in Sub-Saharan Africa fail to adequately manage plastic waste, leading to rates as high as 0.8kg of plastic waste entering the environment per person per day [24,25].

Plastic is a very common waste product in developing countries like Ghana and other countries within Africa [23]. It is used in several industries, primarily packaging as well as textiles, construction and in the production of consumer goods [1]. Plastic comes in a few different types that must be sorted before they can be recycled because of the varying material properties. Most common plastics used in consumer products that end up in MSW are Polyethylene Terephthalate (PET), High Density Polyethylene (HDPE), Polyvinyl Chloride (PVC), Polypropylene (PP) and Polystyrene (PS) [26]. “PET is used to make water and beverage bottles HDPE is used for shampoo bottles, milk bottles, and freezer bags; LDPE is used to make the ubiquitous plastic bags and food packaging film; PP is used to make bottle caps and plastic bags; PS is used for plastic cups and cutlery; and expanded PS for hot drinks cups and protective packaging. Mixed plastic packaging (trays, tubs, pots) Plastic collected for recycling is first sorted for polymer type, then shredded, washed, melted, and pelletized before being made into new products' ' [26]. The different types of plastic have to be sorted because of their composition which would impact the melting point of the plastic. Paper and glass waste are recycled in similar processes and can often have an unlimited lifetime in terms of ability to be recycled again, unlike plastic [27].

## *Recycling in Ghana*

The issues around plastic are now becoming a major problem in many developing countries like Ghana. In Ghana approximately 5 million tonnes of solid waste is produced annually with 1 million tonnes of it being plastic waste. Throughout Ghana plastic is used in many industries in order to package products to sell, making up as much as 26% of the total volume of plastic used [15]. This high demand results in 10,000 metric tonnes of plastic imported annually in order to make plastic containers, shopping bags and very common water sachets [28]. Ghana's municipal waste has yet to be seen as a source of revenue so the waste management and recycling programs are still in their infancy [9]. On average, 13% of MSW generated in Africa is plastic and 57% is organic waste. An estimated 70–80% of the MSW generated in Africa is recyclable, yet only 4% of that recyclable waste is currently recycled [23].

Two major cities in Ghana, Accra and Kumasi, are estimated to generate 4000 tonnes of waste daily this includes all of the plastic that is used in almost every consumer product [29,30]. The rate of waste generation in urban centers in Ghana is estimated to .47 kg/person/day [31]. A large portion of the plastic waste that is produced comes from single use plastics, like the water sachets and other product packaging. Water sachets are 500mL polyethylene (PE) plastic bags that are used to package and sell water to individuals [32]. These water sachets are popular because it is commonly believed that the water sachets provide cleaner water than the available tap water, although this is not always the case. Water sachet production is under the authority of Ghana's Food and Drugs Board. But water sachet production is not centralized and it is often done by a small group of people with the means to acquire, clean and produce the water sachets . This can lead to a wide variety in the quality of water [32]. Some PE can contain toxic chemicals and can be environmentally damaging if left discarded like they often are in storm drains and along the roads in urban and rural areas of Ghana. Water schaets ease of use leads to difficulties in dissuading public use of these disposable items. As a consequence, the widespread improper disposal of PE is very environmentally damaging. When discarded into waterways, blockage leads to flooding during storms. Stagnant water blocked by the plastic is a breeding ground for disease carrying mosquitoes and other illnesses [12]. If left long enough, the plastics begin to leach harmful chemicals into the water supply. Thus, efforts have been made to clean up improperly disposed plastic, but most of this waste ends up in landfills where it can just as easily leach toxins into the same waterways. To better handle plastic waste the focus has shifted towards developing recycling programs in order to recirculate the material out of the environment.

*Recycling and Composting*

Recycling and composting make up 3.5% of MSW disposal in Ghana. Recycling programs currently range from community based to governmental programs [16]. There are few government sponsored programs, like the World Economic Forum's Global Plastic Action Partnership (GPAP), but gahan is looking to change this [33]. There are approximately 25 well established non-profit organizations and private plastic recycling or reuse businesses [34]. These organizations are smaller and have a limited range in which they operate, which is usually within urban city centers like Accra. Of the plastic, 13% of plastic waste that is generated in Ghana annually only 4-5% of the recyclable plastic is actually recovered from the MSW [23]. Environmentally and economically recycling and composting have a very positive impact. The collection of littered plastics, especially in high traffic areas in urban cities helps to mitigate some of the negative environmental effects seen in the unauthorized disposal of plastics. Also by collecting littered plastics this lessens the negative health impacts seen in urban areas such as The collection of plastic directly from homes helps to lessen the impacts of issues seen when plastic is disposed of in landfills and incorrectly managed. In urban settings recycling allows for the generation of income for those involved in processes that reuse the plastic to make new

products. The collection, sorting and cleaning of the plastic to be recycled also has a positive impact on residents in urban areas.

*Recycling Industry in Ghana*

Almost all initiatives around recycling or waste management are focused in urban areas with large centers of waste. Focus in urban areas is because that is where the most profit from recycling at these larger volumes can be done easier. Examples of these programs can be seen at many different levels and range from community based to governmental programs. A government initiative example is joining the World Economic Forum's Global Plastic Action Partnership (GPAP) in 2019 [33]. Nonprofit community lead organizations are mostly based in urban centers and whose aim is to help reduce the burden of plastic waste on the community by providing collection programs. Some examples of nonprofit organizations include the University of Ghana Plastic Recycling Project (UGPRP), Zero Waste Accra initiative and Green Africa Youth Organization (GAYO) [35]. There are also private recycling businesses like Nelplast and MckingTorch Africa that use technological innovation to create multipurpose processes and material that are sold for profit [36]. All of these businesses and programs have similar goals to collect and dispose of plastic waste from MSW or to collect and repurpose the plastic.

While plastic pollution continues to rise in Ghana, so too have creative solutions emerged to tackle this problem. Historically, the majority of plastic waste recycling in sub-Saharan Africa has been facilitated by informal waste-pickers [37]. In the absence of formal programs and government oversight of solid waste management, these workers act as key intermediaries in the recycling process, collecting, sorting, and transporting salvageable waste to buyers. Beyond plastic, this informal economy of recovering value from waste extends into every available niche, from upcycling discarded e-waste to the processing of discarded coconut fiber into usable products led by independent entrepreneurs.

*Recycling Programs*

In order to scale, these businesses transition to the formal economy, as to take advantage of loans and grants in order to expand. For example, Ghana-based company Nelplast, founded with the goal of converting plastic waste into building material for houses and roads, was able to receive funding from a partnership between the national government and the Danish International Development Agency, successfully developed a cost-competitive process for brickmaking which serves as a viable alternative to imported materials. While these businesses often drive innovation and maintain demand for waste, ensuring less results in landfill, as downstream recyclers, they still rely on the waste-picking model in order to fulfill demand.

Waste-picking is fraught with risks; Dangers from toxins and sharp objects, violence among other waste-pickers, and precarious employment due to shifts in waste prices all necessitate away from a reliance on the informal waste-picking economy [37]. Some entrepreneurs seek to solve this issue by focusing upstream, by developing collection initiatives

and sorting programs to curb the buildup of domestic waste before it reaches landfill. Enterprises like Makingtorch Africa, which began as a downstream plastic recycling and creative project, have adapted to the prohibitive costs of recycling by setting up collection centers at point-of-disposal, as well as shifting public policy through advocacy and social media to redouble efforts to segregate waste at point-of-collection [38]. While these efforts have demonstrably increased the level of plastic recycled in urban areas, waste-picking continues to attract a large workforce, especially from rural areas, searching for economic opportunity. Therefore, a sustainable recycling initiative should not ignore the necessity of waste-picking, but should seek to address the viability of waste-picking as a supplement to the income of rural workers especially as plastic consumption in rural areas continues to rise.

*Geographic Impacts on Recycling Initiatives*

In rural villages the cost of participating in recycling programs has deterred villagers from managing their waste. These recycling programs are so expensive because without charging high prices or receiving substantial outside grants there is not enough money in the recycling of plastics to sustain a profitable business. Although many villagers do not participate in recycling incentives they are well aware of the negative health effects of discarding their waste [39]. Addressing the viability of rural recycling programs in sub-Saharan Africa requires an assessment of existing programs, their shortcomings, as well as their potential for innovation. The challenges of rural recycling in this region are well documented, owing to a lack of infrastructure, poor financing options, and a lack of governance [39]. Without an at-cost, taxpayer-funded waste management system, local municipalities are often unable to implement a sustainable recycling initiative. Figure 2 summarizes the types of initiatives and shows the correlation between the locations they service, the types of plastic collected as well as the scale of the collection.

Unlike in urban areas, which benefit from the centralization of the necessary capital to facilitate the collection, sorting, cleaning, and recycling of discarded products, rural areas must contend with higher costs to transport waste while simultaneously lacking the volume of waste generated to achieve an economy of scale. In high-income countries like the United States, decentralized alternatives to the conventional recycling model have been proposed, utilizing at-home recycling kits that convert plastic waste into polymer filament compatible with 3-D printers [40]. This distributed approach enables the growth of cottage industries capable of producing consumer-grade plastic products, but relies on some existing infrastructure and access to expensive technology. However, this case does demonstrate the viability of local maker-spaces to reshape the nature of plastic waste recycling in rural communities in sub-Saharan Africa.

Urban and rural settings in Ghana, like many other places internationally, can impact the quality of waste management and recycling. The wealth of the people locally and regionally can impact the level of waste management that a community has access to. This is even more evident

in Ghana. Although there are many programs like these starting in Ghana they all focus in one area, Urban city centers. This leaves a large gap in providing recycling solutions for rural communities that still have plastic waste that needs to be taken care of. This unintentional neglect to expand the growing recycling economies of Ghana to rural areas leaves a large amount of the population in these rural communities without adequate ways to recycle their plastic. This resorts to harmful methods in order to get rid of their plastic waste.

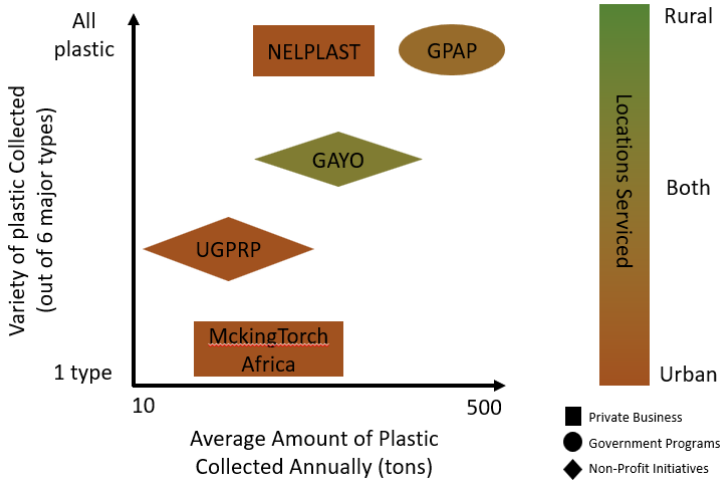


Figure 2: *Comparison of Recycling programs in Ghana.* This graph demonstrates the high variability of the types of recycling programs currently in Ghana and their wide range in abilities.

## *Case Study - Existing Recycling Initiative*

In one such community, Akyem Dwenase, a small farming village in Ghana's Eastern Region in the Kingdom of Akyem Abuakwa, our team, working in partnership with Chief Osabarima Owusu Baafi Aboagye, III, sought to design a recycling system that capitalized on an existing collection initiative. The town had placed designated bins to curb the discarding and burning of single-use plastics, which posed health and safety risks to the population. However, these bins eventually began to overflow, lacking a means of adequately recycling the waste. To close the gap in ways to continually recycle the collected plastic, this project will bring together partners from Akyem Dwenase, residents, traditional leadership, as well as entrepreneurs and representatives from surrounding chieftaincies, in order to address the recycling capacity of the area and provide a long term generative solution.

### *Waste Management: A Generative Justice Approach*

Traditional methods of waste disposal, such as discarding and burning, were satisfactory when the majority of solid waste produced in a rural context was organic. In contrast, these methods fail to capitalize on the material value of plastic waste. However, the process of recycling plastic seeks to close the loop, connecting end of stream waste back to the producers.

We intended for our proposed model to be self-propagating, but this posed a question of independence versus interdependence. In an independent model, each hub village is responsible for servicing the communities in its radius, as well as developing production and buyer arrangements, effectively one of many "single-celled" operations throughout the Eastern Region. The model grows in number, but the size and logistical complexity of each individual recycling system remain similar. In contrast, an interdependent model incorporates each new village into the partnership, and seeks to create a larger hub collecting from smaller hubs. This self-similar quality is well understood to be more conducive to growth, referred to as a nested loop, "in which networks of generative cycles are linking social, technical and ecological value circulation at multiple scales, such that they increase the propagation of these sustainable technosocial structures" [41]. Thus, our primary design consideration was to ensure that the model could be easily built upon, and that the model was functionally similar at all levels of scale.

As we planned out the local recycling initiative for Akyem Dwenase and our partner villages, our aim was to take advantage of a closed-loop model to foster a generative cycle of value circulation from plastic waste. This first required an understanding of the value generators accessible in a local context, shown in figure 3. We identified three categories of sources of value that would make up a recycling system: the plastic waste stream, organizational capacity, and our recycling partners. Independently, these elements do not form a self-sustaining and self-directed system of value circulation, as evidenced by the logistical shortcomings of the previous collection initiative. The feasibility of the initiative is limited unless a sufficient scale can be achieved, wherein the costs associated with the collection, preprocessing, and transportation of plastic must be balanced by volume of plastic collected. In Basins of Attraction for Generative Justice, Eglash and Garvey demonstrate that interdependence within a system tends to produce better outcomes for those involved and that these systems are stable and self-forming [42]. This supports that an inter-village partnership organized to collectively recycle their plastic will be self-sustaining and mutually profitable.

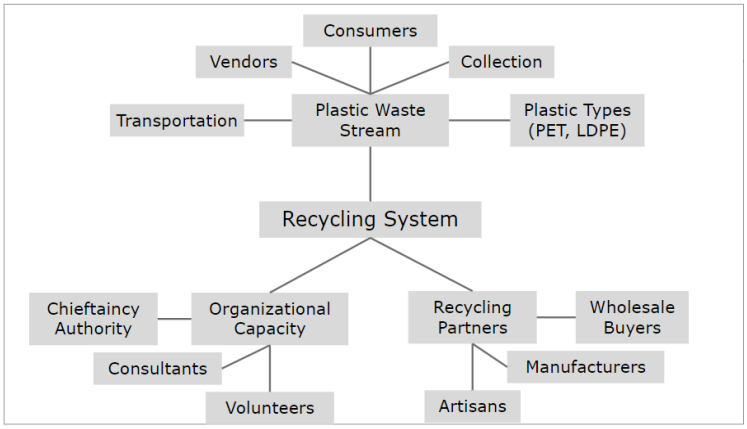


Figure 3: *Components of a Recycling System in Rural Ghana*. A network of value sources that make up the components of a recycling initiative in rural Ghana, categorized by organizational capacity, plastic waste stream, and recycling partners.

The profits of the recycling system will be returned to the community as an investment into increasing the communities recycling capacity, as well as ensuring that the recycling business established with our proposed system can expand their recycling capacity to meet further demand. This community investment has the added benefit of increasing the future value of plastic sold through preprocessing and improved collection. By meeting buyer needs, investing the partnership will be able to maximize the efficiency of exchange, ensuring the lowest possible amount of value loss between villages and recyclers. We diagram this exchange in figure 4. While investing in production capacity and collection efficiency are important to maintaining the profitability of this initiative, there are other sources of value that have yet to be mentioned, and have remained alienated from this approach. A key aspect of community investment is in education. Local Ghanaina entrepreneurs in the recycling industry indicated they would not have grown if not for their focus on experimentation with recycled materials, but this expertise came from exposure, which is lacking in rural areas. Education is not only a means of conveying information, but also a method of inducing generative cycles of social and political expression. In addition to encouraging students to transform plastic waste into purposeful items of value to them and their communities, students must also be empowered to challenge the behaviors and systemic pressures that initiated the plastic problem in the first place. Through the incorporation of generative techniques for design our plan will be able to circulate previously alienated value back into the community providing many sources of value to enrich the local economy and local residents.

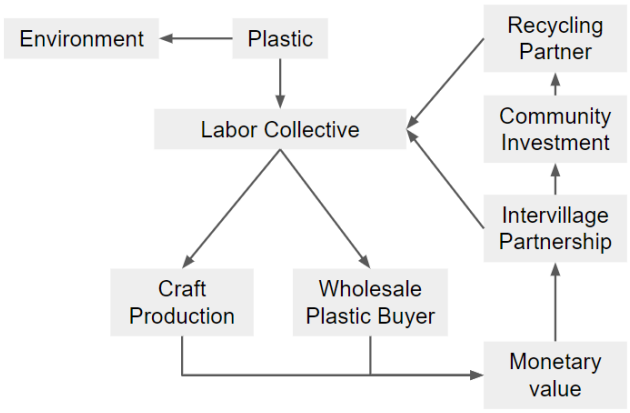


Figure 4: *Value Circulation within an Inter-Village Recycling Partnership*. Diagram of value flow, diverting plastic material value from environmental sink to community investment through the sale of plastic crafts and wholesale recycling.

Our analysis of the existing recycling initiative reveals that the foundation of a sustainable recycling initiative is present, but that key aspects such as developing partnerships and securing buyers must be implemented in order to secure the feasibility of this project.

# *Methodology*

## *Our Partners*

This project is the result of a collaborative effort between numerous partners, stakeholders, and generous consultants. Firstly, as liaison, translator, and organizer, we were assisted greatly by Chief Osabarima Owusu Baafi Aboagye, III of Akyem Dwenase. In addition to his expertise, we were also reliant on the expertise of his deputies who answered our questions and collected necessary data on site. Through the chief, we were also able to connect with the chiefs of the villages of Abombpe, Batabi, and Tumfa in order to form the inter-village recycling partnership. We were also greatly assisted by the expertise of numerous recycling entrepreneurs whose experiences in starting and scaling a recycling initiative were invaluable.

## *Description of Design Process*

Development of this plan did not occur in a vacuum. While separated from our partners on the ground, we were still able to plan, communicate objectives, and examine proposals collaboratively. Working around the limitations of distance and language is a critical aspect of co-design in the modern era. In this section, we describe our goals for the design process, and how we achieved those goals.

### *Goals of Design*

Before exploring the problem of plastic waste in rural Ghana, we first needed to establish our goals of design to serve as the foundation behind any future proposal. Topics around designing for sustainability, such as bottom-up principles of value circulation, co-design, and the use of culturally situated design tools were direct considerations in generating our goals. We entered the design process with three goals: ensure the design is generatively just, ensure the design is culturally centered, and ensure the design is scalable. Generatively just, so as to achieve meaningful and non-exploitative value exchange between human and ecological sources. Culturally centered, so as to respect and incorporate existing social relationships, customs, and values. Finally, scalable, so as to ensure that the design can achieve wider adoption while maintaining the two previous goals.

### *Design Framework*

With goals established, we required a framework for the design process. We centered on the Elizabeth Long Lingo, *Empathetic, User-Centered Design Process for Sustainable Outcomes*. We sought to follow this design philosophy, shown above in Figure 5 in order to achieve a sustainable outcome.  The diagram outlines an iterative process, beginning with an exploration phase where the problem space is better understood through the lens of the local culture. Then

we engaged in empathetic inquiry with our stakeholders by consistently iterating on our design proposals and redesigning based on their feedback. This feedback allows us to better define the end-user needs whereby we can then co-ideate with our end-users to better address those needs. Finally, we discuss implementation of a pilot initiative that we believe best meets the needs of our partners.

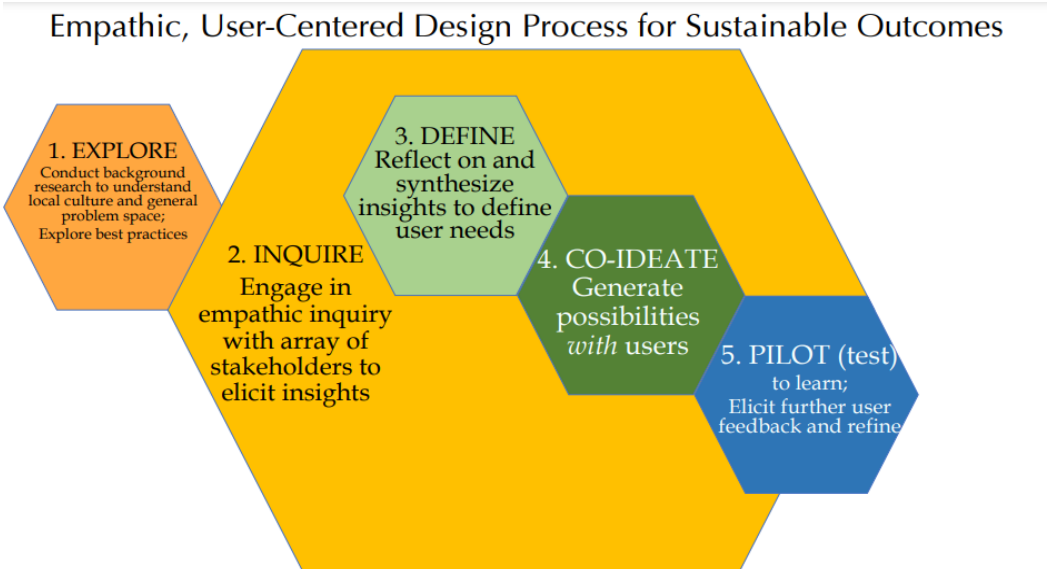


Figure 5: *Empathetic, User-Centered Design Process for Sustainable Outcomes.* This diagram outlines the design process to achieve sustainability through empathetic, user-centered design; Once explored, design for a problem necessitates an iterative inquiry stage of redefining and co-ideation before finally piloting the program.

## *Background research for local culture and problem space*

The plan for this case study was fully devised by the process of co-design. In order to create a smart village that has a sustainable generative justice system, co-design is required. Throughout this process partnerships were created to design a recycling system in Akyem Dwenase, Ghana. First, the connection was created with a WhatsApp phone call with our project advisor, introducing us as a team. Our advisor previously built relationships with chiefs and citizens that want to work together to improve their community. With community initiatives in Ghana, the chiefs of the villages have the ability to engage their community by asking them to participate.

Community engagement is critical in the co-design process because if collaboration with the local community does not exist then the co-design process will not occur. The connection with the Chief Osabarima was built first when our academic advisor introduced our group to him over the phone and exclaimed our excitement for support. After our advisor introduced us, we

opened the floor and invited the idea of working together to develop a recycling system in Akyem Dwenase. After obtaining input and establishing a connection from Chief Osabarima, we were introduced to two other important officers of Akyem Dwenase, Ghana. In another call, Chief Osabarima introduced us to the Deputy Chief of Education, and Deputy Chief of Agriculture. The idea of co-designing a recycling system was introduced and a connection was built. A WhatsApp group chat was made as we obtained Chief Osabarima's phone number who connected us with the Deputy Chief of Education and Deputy Chief of Agriculture. The Deputy Chief of Education is an important part of the co-design process to create proper education on the dangers of burning plastic with open fires and the benefits of recycling to engage the community. This provides a likelihood where more villagers will take part of the community initiative if the dangers are known. The Deputy Chief of Agriculture is necessary in the co-design process as location is an important part of the recycling system. With the Deputy Chief of Agriculture it was determined where in the village the majority of open plastic fires occur in the village. With his knowledge we determined where the location of the recycling bins will be as places where many people in the village congregate. With his help we can figure out where plastic will be stored, sanitized and sorted.

### *Engage in empathetic inquiry with array of stakeholders*

With all of the partnerships created, more connections can be made to have representatives for the village of Akyem Dwenase. A representative for the village would be someone well known that would be able to be notified when certain recycling bins are full and can move to the next part of the system. The system will be designed off the villages needs as the representative gave input on how to better implement it. A meeting was made with Chief Osabarima and the Deputy Chief of Agriculture to speak about the representative system and it was determined the Deputy Chief of Agriculture would be the representative for Akyem Dwenase. Upon request from the chief, the Deputy Chief of Agriculture did not hesitate to take up this role as they were the overseer of the previous recycling system in the village. They were able to provide insight about how the previous system operated by employing children on their weekends to collect the plastic from their bin system, place it into large bags, and place it in an area in the school to be stored to be sold for profit in the future.

Our group had a conversation with the Deputy Chief of Education for Akyem Dwenase who is currently in retirement but helps the village undertake new projects requested by the chief. To use the co-design strategy we worked with them to create educational infographics to notify the villagers of the importance of recycling. They would host a recycling workshop to educate the village on how to use the recycling system that would be implemented. The educational resources would include informing the village of Akyem Dwenase about the dangers of open fire of plastic. This would include the negative health and environmental impacts of the

burning plastic and how it would affect everyone in their daily life. In addition to dangers of open fires of burning plastic, the town would be educated on what the recycling would be used for and the profit that would arise from the community initiative. This gives incentive to the villagers to recycle as they will be able to see that their community will benefit long term and short term by selling plastic and receiving profit as well as creating a centralized makerspace operation in their village. The educational workshop would include how to use the recycling system. The recycling system that has been proposed has been a bin system on 10 bins located in higher populated areas of the village that the deputy of agriculture will determine. The community will put their plastic in a bin and if the bin is full of plastic up until a line that will be marked to display the top of the bin, then that community member should notify the Deputy Chief of Agriculture. There will be a flag that can be put up or down that will help notify other villagers if the bin is full of plastic or not. If the flag is up on the bin then the bin is at its maximum capacity of holding plastic, and if the flag is down then the bin has not reached its maximum capacity of containing plastic. The flag system will be used to help notify the Deputy Chief of Agriculture of the packaging step of the recycling system for the plastic in the bin to be put in a package to be stored and sold in the future.

When speaking to Chief Osabarima the question was asked if other villages would be interested in being a part of a community initiative recycling program. It was determined that Akyem Dwenase would be a centralized hub of plastic collection with a makerspace to create a product of community needs. We reached out to Chief Osabarima for the WhatsApp contact information of the surrounding villages. The villages that are going to be a part of this system are Abompe, Batabi, and Tumfa.

With the help of Chief Osabarima, a meeting was coordinated including the village chiefs willing to participate in this recycling system. In the meeting the recycling initiative plan was generally proposed to give all of the chiefs more insight. The bin system was discussed further for the chiefs of Abompe, Batabi, and Tumfa to determine if that would be a possibility in their village. In this discussion we asked each chief what their current process is to collect plastic waste. We were able to gather that each village has a communal dump site to put all waste or the waste is littered in the environment. All village chiefs agreed that educational workshops for the village would be beneficial in order to support the community initiative. It was agreed that a representative would be needed for each village to coordinate the plastic collection process and deliver the plastic to the centralized hub.

Our business consultant for plastic recycling has a portfolio that focuses on innovation, sustainability, and community participation. Conversations with the consultant occurred through WhatsApp and Zoom regarding initiating and maintaining a recycling program, with a focus on the process of collection to purchase of plastic. The process starts from citizens picking plastic and cleaning it, where the most valuable plastic is water sachets and the common plastic black

bags are not commonly utilized. In the case of our recycling system, the plastic would be collected from Abompe, Batabi, Tumfa, and Akyem Dwenase, where Akyem Dwenase would serve as the recycling programs hub. The facilitation that would occur in Akyem Dwenase includes collection, sorting, cleaning, and redistribution of plastic processed. We then developed connections with our business partner, who has a business that will be expanded into Akyem Dwenase. Where we held conversations over WhatsApp discussing the feasibility and the struggles of implementation of a recycling system in the Eastern region of Ghana. As well as our business partners' interest in the operation system into Akyem Dwenase due to the need for a larger operation to fulfill the business's needs. Concerns of our business partner surrounded the start-up and maintaining costs of a recycling system. Where the highest cost of facilitating the system is the purchasing of machines, electricity, and transportation. Our business partners and chief's of the villages have agreed to provide some of the financial costs, where the leftover costs will be fulfilled through NGOs and grants.

The expansion of our business partner's business into Akyem Dwenase and the surrounding villages is able to provide affordable housing and job opportunities for the villagers, specifically with women and young adults. The plastic collected additionally allows for the recycling program to be transformed to cater to the needs of the village through outlets for innovation. Makerspaces are an option that was agreed upon by village leaders to allow local businesses to develop and innovate with raw plastic and from plastic products. The connections made with businesses can provide plastic products to the community for the villagers to develop new infrastructures such as buildings, bags, and apparel within these makerspaces.

Our partners identified that the expansion would still face the challenge of establishing relationships with buyers. To address these concerns we identified a marketplace where a representative would be sent to assess prices and meet buyers. The marketplace, known locally as Cable and Wireless, is a shopping center located in outer Accra which doubles as a meetup for buyers and sellers of scrap. Some buyers purchase plastic wholesale from waste pickers with demands for cleanliness and specific material type. Surveys of buyers done by our recycling consultant indicated that plastic waste is generally sold at a rate of 50-70 pesewa (0.07 - 0.1 USD) per kilo, with higher value plastics like the LDPE-Vinyl mix found in water sachets being worth around 70 - 100 pesewas (0.1 - 0.15 USD). Our contact also indicated the transportation costs can exceed eight times the value per kilo in small quantities. We determined that buyers were much more likely to buy segregated, high value waste, such as water sachets, and that it would generally be more profitable to hire a truck to transport directly to the buyers, rather than paying the additional pickup fees charged by buyers.

*Reflect on and synthesize insight to define user needs*

Stage two, inquiry, focused on identifying pain points and desires of our partners, centering on ideals of clean and safe environments, economic empowerment, and concerns over the program as a vector for spreading the Covid-19 virus. As indicated by the diagram, this stage is all-encompassing of the following definition, co-ideation, and piloting stages. Therefore, we ensured that our proposals were not only designed in consideration with the insights gained from our initial inquiry, but also that discussions surrounding the proposal always circled back to an assessment of satisfaction and concern with each aspect of the proposal. For example, one proposal iteration advocated for the independent operation of each village in collecting and selling their plastic waste in Accra. This proposal, while intended to ensure less conflict between partners over equitable contribution and compensation, was met with concern from partners that the proposal would not help to develop a strong link between villages. We had failed to identify an equally important objective of our partners, to use the recycling initiative to better strengthen ties between each village, which necessitated a redefinition of our design objective.

After numerous revisions, we were able to satisfactorily define our user needs at increasing scales of involvement. Though many of our discussions were held with village leadership, we still aimed to define the user needs from the bottom up. At minimum, the daily operations of this initiative require labor, capital, and connections. Initial appointed collectors need safe and efficient collection systems and fair compensation for their labor. Thus, they need permanent collection sites that permit sorting and safe, dry storage of plastic waste. In addition, they need transportation, so as to efficiently deliver waste to a centralized collection site and potentially expand their operations outside of the village proper. Finally, and most crucially, they need buyers. This has been the largest challenge of this project, however, access to buyers and bargaining power are better facilitated by organized collectives. Thus, we then defined the needs of the organizational structure behind the recycling initiative. In order to implement a community wide arraignment, the initiative requires the authority of the chiefs. Luckily, this arrangement is mutually beneficial as many problems facing the chiefs, such as pollution and low employment, are addressed by this recycling initiative. The organizational structure also needs equitable exchange, therefore, there is a need for standardized methods of weighing and compensating for plastic brought to Akyem Dwenase. Moreover, there is a need for regulation and management to ensure that the continued operation of the initiative is accountable to both the laws and customs of the area. At the core of this initiative is the need for the recirculation of value in these rural communities. Each of these components: the need for a clean environment, the need for employment, the need for a fair exchange of value, and the need for a management structure are all symptomatic of a need to reverse the drain of value due to the waste of plastic.

After more scrutiny, we determine that the needs of our users differed by region. While Akyem Dwenase had already implemented a village-wide collection initiative with bins,

collectors, and designated storage, the other villages did not have this infrastructure, relying instead on landfill. As each village had differing sizes, the need for regular collection and transport was inconsistent. Additionally, the location of each village, distance from Akyem Dwenase, and type of route influenced their needs. Batabi, with a permanent population of over one-thousand, may only be able to justify transport of plastic waste after a few months as compared with Abompe with nearly four times the population which may fill a plastic quota within two weeks. These differences necessitate alternative strategies to ensure that needs are met, not only for the sake of each village, but of the enterprise as a whole. While each village needs transportation, we questioned the implication of access to permanently available transportation as opposed to a shared model, wherein villages have shared usage of a single *Aboboye (*motorized tricycle) which alternates possession. While this approach would save money on capital expenditure, it does conflict with another stated need of these villages to expand their collection initiative to other villages. We sought to discuss both options with our partners to determine the best approach.

## *Generate possibilities with user*

With these needs in mind, we focused on generating possibilities with our partners for how to address those needs through a coherent and consistent plan. Through a set of meetings with the chiefs from each partner village, we established a baseline for conditions of a successful enterprise in the eyes of our partners, that being to maximize collection, maximize plastic value, maximize efficiency, and maximize opportunity for employment.

### *Maximizing Collection*

To address the first concern, maximizing collection, we highlighted the success of the bin system in Akyem Dwenase and provided cost figures for the price of bins and bags to facilitate collection. Plastic consumption data was limited, however, it was noted that plastic usage is often sporadic, correlating with funeral services and other gatherings that occured at the end of each month. These gathering places, churches, marketplaces, and schools, are the prime locations for collection bins.

### *Maximizing Value*

To address the second point, maximizing value, we needed to address the concern of contamination at point of collection. Discussions with the chiefs determine the best approach would be a combination of informative graphics on the bins indicating proper use in tandem with a town-meeting hosted by a chief appointed educator to convey the necessity of recycling, the requirement of sorting, as well as the community benefits from a successful recycling initiative. It was also pointed out that specific buyer relationships needed to be established, thus a survey

team from the Academic City University College would be sent to plastic buyer marketplaces in Accra to gather contact information, wholesale quotes, and plastic demands.

*Maximizing Efficiency*

To address the third point, maximizing efficiency, idea generation centered around how best to transport the largest amount of value with the least amount of cost while ensuring coordination of various operations. One possible approach focused on establishing independent collection, sorting, processing, and selling operations out of each village. While independent collection and sorting were deemed feasible independently, it was agreed that a portion of profits generated should go towards investments in processing technology centralized in Akyem Dwenase as well as the purchase of one larger transport truck as opposed to a fleet of smaller trucks.

*Maximizing Employment*

Finally, addressing the fourth point, maximizing employment, the discussion focused on where jobs would emerge at each stage of the recycling process. In the initial stage, local collection might be facilitated by a chief appointed collector who would ensure that recycling standards are met and that collection and transportation run smoothly. As the business grows and capital investments into baling machines are made, additional operators and managers will gain employment as processing increases. As the operation expands, the chiefs acknowledged the role that independent waste collectors would play by collecting from other local towns, and granted that a portion of the profits would be invested into helping establish these entrepreneurs. Besides direct employment, as profits are collected from the recycling initiative, local projects in need of attention, like building a maternity ward, could be funded, providing additional income to local masons and carpenters.

## *Data and Results*

### *Community Recycling System in Rural Ghana*

The core of our recycling system began with the collection and sorting of plastics. Akyem Dwenase and the local villages of Tumfa, Abompe, and Batabi will all be fitted with bin-based recycling systems. We organized a collection and transportation plan using local community representatives for each village. The proposed plan was made up of two major parts: the collection and the profit making. Within each village the recycling representative will organize the bin collection, plastic storage, and transportation to Akyem Dwenase. The relative location and distance of the primary villages are shown in Figure 6. Within Akyem Dwenase the representative will also have to manage the cleaning, final sorting of all plastics, and sale in Accra. We formulated several plans that cover different options for making profit over time. The financial costs of the different proposed plans will be discussed in the following section.


Figure 6 : *Scope of proposed plan.* This map shows the relative distance of all the locations we are linking in our proposed collection system.

#### *Collection and Transportation System*

The collection and transportation was designed to be modular so that all the villages can operate independently. This allows the community collection system to work best for all the villages and allows for other interested villages to be added to the recycling initiative in the future easily, with low initial investment. The proposed collection system was based on the existing bins that Akyem Dwenase had access to, seen in Figure 6. Our proposed system builds on the initial implementation by adding sorting and a full bin notification system. The sorting

will be implemented by labeling the bins with images of the types of plastic that can be put in there. The bins will be arranged in pairs where one bin is only for the collection of water sachets and the other bin collects all other types of plastic. The bin pairs, seen in Figure 7, will be arranged in several locations throughout each village in places that have the most foot traffic and are easy to access. To implement a full bin notification, we proposed that each bin be augmented with a flag system that can indicate how full the bin is. This flag system would be implemented on the side of the lids of the bins shown in Figure 7. This is useful for the community recycling rep to know what bins are close to full so that they can be monitored for collection. We also proposed a sliding latch on top of the lid to provide security of the bins. This lid would be made of wood connected with rollers on a track that would be attached to the top of the bins lids shown in Figure 7. This lid can be closed and locked when the bin is full or at night if needed. When a bin is full the community recycling representative can collect the plastic and then reopen the bin. The community recycling representative has other duties such as monitoring the plastic collection and transporting the plastic. The complete process of their roles is shown in Figure 8.


Figure 7: *Existing Recycling Bins.* The existing recycling bins that were initially provided to Akyem Dwenase.

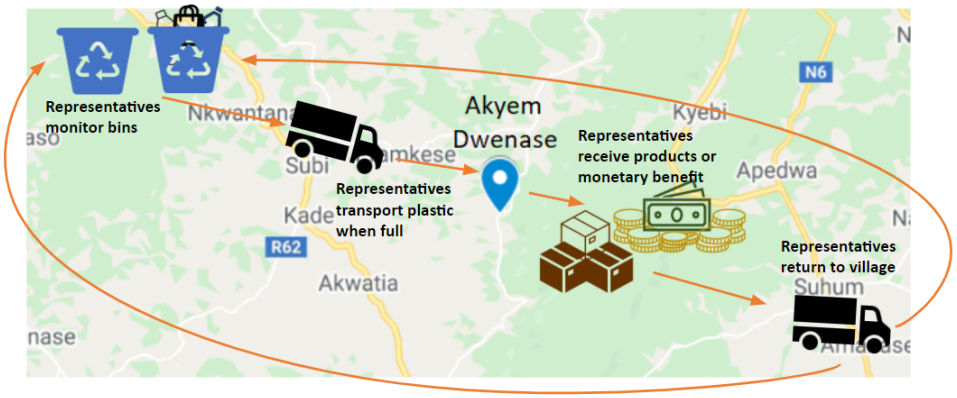


Figure 8: *Role of Community Recycling Representative.* This diagram outlines the major responsibilities the community recycling representative will have. The monitoring of bins is a daily requirement. The transportation of the plastic will start off being a bi- weekly obligation of the community recycling representative.

Twice a month the collection of the plastic will be transported from the other communities to Akyem Dwenase. The route that will be taken is shown in Figure 9. Akyem Dwenase will serve as the hub for this recycling system. Each local community recycling representative will be responsible for organizing times with the representative in Akyem Dwenase to drop off their plastic. A cross village panel of management, ABDT (Abompe, Batabi, Akyem Dwenase, Tumfa) recycling, was developed to oversee all intervillage operations and the distribution of revenue. This panel can organize different collection times and days based on what works best for each of the communities. In Akyem Dwenase there will initially be a dedicated shed to store the collected plastic from all the villages. Once the plastic is collected and transported to Akyem Dwenase there are several operation plans that can be implemented all with different initial investments and profit options.

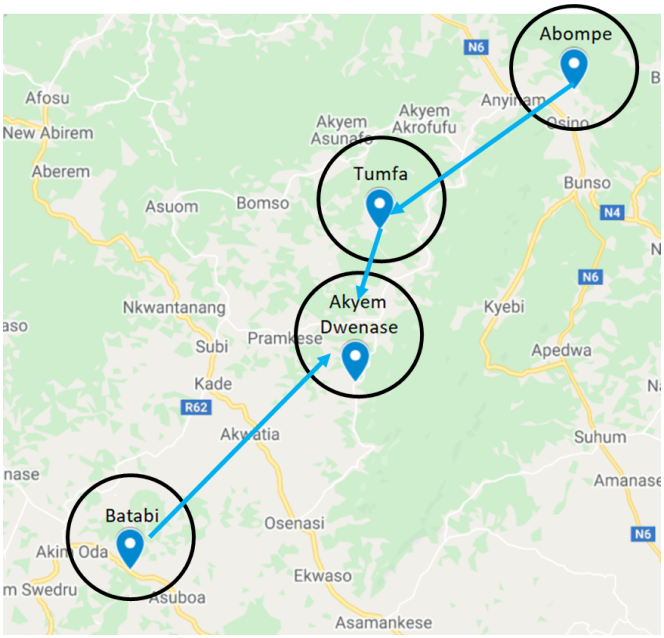


Figure 9: *Transportation Plan.* This diagram outlines the travel routes for the surrounding villages to transport their plastic to Akyem Dwenase. The black circles are the proposed outer areas of the towns that can be included in the recycling initiative in the future. The proposed organization has a combined route to Akyem Dwenase from Abompe through Tumfa to lessen the overall transportation costs. This route is 43 km long.

*Operation plans*

In developing the recycling system we were able to provide several different operation plans, each with its own purpose. The main difference in each operation plan is where the profit is generated. The main three plans that are proposed to be used are the starting operation, the short term operation plan, and the local long term operation. The ABDT recycling panel would be responsible for setting the markers and goals for when or if each next operational plan should be implemented and to what extent. Each of these plans also has financial variations that are presented in the next section.

The starting operation plan is designed to be the initial operation plan when the proposed recycling system is first implemented. This operation plan requires the least amount of initial investment. The value flow for the profit generation for the initial operation plan is shown in Figure 10. This system requires a two thousand USD investment for bins and bags to set up the collection system in the other three villages, Abompe, Batabi and Tumfa. This plan would require the renting of a vehicle to transport the plastic to Accra once a month. The plastic would then be sold to our business partner and other plastic recyclers in Accra. The water sachets would be prioritized to be sold to other buyers because our business partner can use the other mixed plastic in their business. The recycling management panel, ABDT recycling, will be responsible for using the profits to pay for the expenses, such as the truck for transportation and fuel cost for inter village transportation.

The variations on this plan would be to increase the initial funding to seven thousand USD in order to purchase a small vehicle for each village and a larger truck. The smaller vehicles, likely Tro-Tros or motorcycles, would be used to facilitate collection from other locals outside of the main villages as well as transportation to Akyem Dwenase. Shown in figure 9, each village would be able to service a small area around them for additional plastic collection by the village representative. The larger vehicle would be used to transport all of the collected plastic to Accra, helping to lower overall expenses over time.

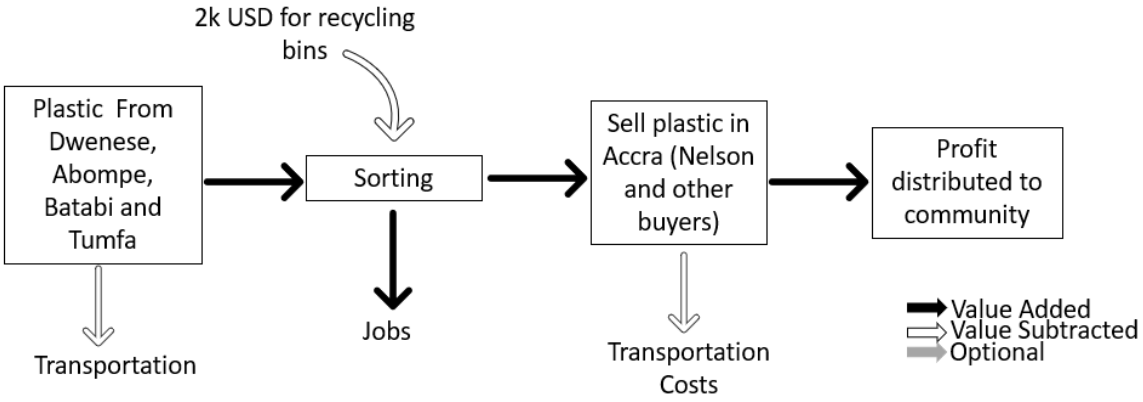


Figure 10: *Initial Operation Plan.* This diagram outlines the flow of value for the plastic collected in our proposed recycling system when it is first implemented. The main investment is the bins that would be used to collect the plastic before it is transported to Accra to be sold.

After the goals of the initial plan that are set by the ABDT recycling panel are met the next operational plan, short term, would begin. The short term operation plan is very similar to the initial operational plan in terms of the profit generation. Where they differ is that the short term plan requires a larger investment for equipment. The value flow for the profit generation for

the short term operation plan is shown in figure 11. The investment in the short term plan would be to purchase a cleaning and baling system for Akyem Dwenase. The price of this system was quoted by our business partner based on the systems implemented in larger scale plastic making businesses in Accra. The cleaning system is used to wash any food or other waste that is left on the plastic. The bailing system is made up of a hydraulic press and wrapping system that can be used to compact more plastic into a smaller volume. Both of these systems together will add more value to the plastic being sold in Accra. This will bring in more profit per trip as well as provide jobs in Akyem Dwenase for the operation and maintenance of these systems.

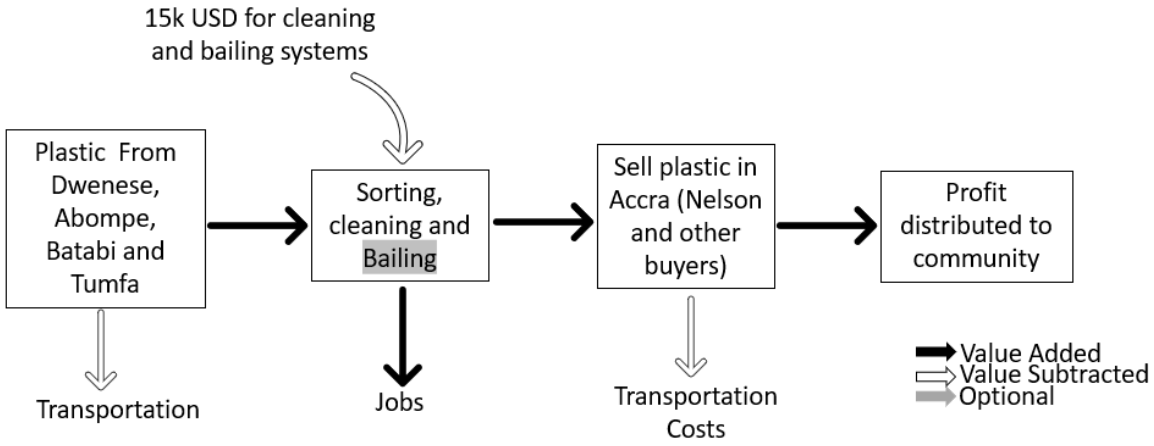


Figure 11: *Short Term Operation Plan.* This diagram outlines the flow of value for the plastic collected in our proposed recycling system. The main investment is the bailing and cleaning system that would be used to add more value to the plastic before it is transported to Accra to be sold.

Lastly the local long term operation plan would be to set up the operation of a plastic brick making business in Akyem Dwenase. This requires an initial investment of three hundred thousand USD in order to purchase the machines and build the building in Akyem Dwenase. The value flow for the profit generation for the local long term operation plan is shown in figure 12. The purchase of land is not necessary as Chief Osabarima Owusu Baafi Aboagye III can provide space for this business to be set up. The cost of the machines is estimated by the larger scale plastic brick making business of our business partner in Accra. Once this business is operational the bailing system would no longer be needed and the larger truck used to transport plastic to Accra can be repurposed to transport the plastic brick produced by this business to the customers in the region. This plan requires a lot of investment but brings lots of value to the community. There will be several jobs available as well as scientific, entrepreneurial and educational opportunities that can help in the creation of other businesses in the future. This operational plan is the final goal for the proposed recycling system. The bricks made by the business would be used to provide building materials to all of the local villages as well as provide more profits to be shared among the villages. The ABDT recycling panel would be able to determine how the profits would be shared as well as decide what next steps this initiative could take in the future.

The machines purchased for the plastic brick making operation have many uses so in the future there is the option to create additional smaller businesses that can use any leftover plastics.

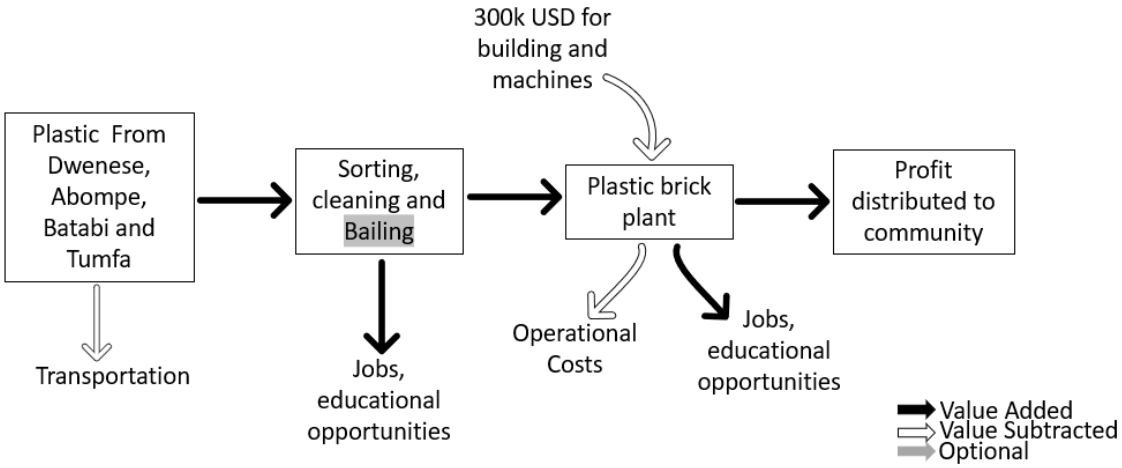


Figure 12: *Local Long Term Operation Plan.* This diagram outlines the flow of value for the plastic collected in our proposed recycling system. The main investment is in setting up a plastic brick making company based on the model from our business stakeholder.

## *Financial Planning*

Planning the finances of the recycling initiative led to the creation of three financial models, which were each evaluated to find: time to ROI, profit after 10 years, rate of return after 10 years, and the ratio of profit to initial investment. To help display calculations we will walk through the work done to find the outputs for the proposed initial low investment operation plan.

Finding these values began by calculating transportation costs. To do so we took a vehicle's fuel efficiency and divided it by the fuel cost to give the vehicles fuel price per kilometer. Next the distances on the primary roads between each village and Akyem Dwenase were found via Google Maps. The estimated distances may be different in practice due to the many unpaved shortcuts that locals may be able to use when transporting between villages. Multiplying the distance between villages and the fuel price per kilometer gave an approximate gas price for each trip. This is reflected in the table below, note that the gas price to Accra is noted as 150 GHc (USD 21.82). This cost is quoted from local representatives for hiring a large truck to take two tonnes of plastic between Akyem Dwenase and Accra.

Table 1: *Gas Cost Calculations*

| Location | Distance to Akyem Dwenase (km) | Gas price (GHc) |
|---|---|---|
| Batabi | 50 | 35 |
| Tumfa + Abompe | 62 | 43.4 |

| | | |
|---|---|---|
| Accra | 120 | 150 |

Next the estimated weekly net profit of each route was calculated. Multiplying the approximate amount of recycling produced by each village against the current price per kilo of plastic gave the weekly income of each village. Subtracted from this value was the gas price and estimated weekly expenses. Combining the value of each route gave the overall weekly net profit.

Table 2: *Weekly Net Profit Calculations*

| Location/Route | Recycled Plastic Per Week (kg) | Price Per Kilo of Plastic (GHc) | Gas price per week (GHc) | Estimated Weekly Expenses (GHc) | Estimate Weekly Profits (GHc) |
|---|---|---|---|---|---|
| Batabi | 306 | 0.65 | 35 | 22.92 | 140.98 |
| Tumfa + Abompe | 994.5 | 0.65 | 43.4 | 22.92 | 580.105 |
| Dwenase/Accra | 765 | 0.65 | 150 | 22.92 | 324.33 |

Combining the estimated weekly profits for all the villages and subtracting weekly expenses gives a net profit of 1045.42 GHc/Week. To find time until return on investment the total initial investment of 12,870 GHc (Table 10) was divided by the weekly next profit. Giving a ROI time of 0.24 years, approximately 3 months.

It must be acknowledged that due to the virtual nature of this project not all of the necessary information was able to be obtained. This lack of material resulted in incomplete calculations and estimated formulas. The data shown below are values that were estimated with the data that was available from our local representatives.

To find the cost of transportation between villages and Accra an estimation of vehicle fuel efficiency was made. After looking at the fuel efficiency of popular tro tros models an assumption of 10 km/L was taken.

Table 3: *Fuel assumptions*

| | |
|---|---|
| fuel efficiency (km/L) | 10 |
| Fuel cost (GHc/L) | 7 |
| Price per (km) | 0.7 |

Village population and kg of recycled plastic per person per day were needed to estimate how much plastic the villages would produce per week. Village population was estimated through the co-design meetings with the village representatives. Kilograms of plastic recycled per person per week was calculated from data published in [44]. We are operating under the assumption that at peak efficiency we can collect 90% of the village's discarded plastic. After

analyzing the local population within fifteen kilometers of each village we estimated how many more people we could service by implementing motorbikes.

Table 4: *Village & Recycling assumptions*

| Village | **Total** | Dwenase | Abompe | Tumfa | Batabi |
|---|---|---|---|---|---|
| Village pop | **13500** | 5000 | 5000 | 1500 | 2000 |
| kg recycle per person per week | **0.170** | 0.170 | 0.170 | 0.170 | 0.170 |
| recycle efficiency goal | **90.00%** | 90.00% | 90.00% | 90.00% | 90.00% |
| Recycle per week initial | **344.25** | 127.5 | 127.5 | 38.25 | 51 |
| Additional population serviced from bikes' | | 15% | 15% | 10% | 10% |
| Updated plastic amount | **2348.55** | 879.75 | 879.75 | 252.45 | 336.6 |

To calculate profits one must deduct recurring costs. In this situation it was unknown how much electricity or building upkeep would cost per week. Instead estimates of $10, $25, and $40 per week were used. Increasing with the use of bikes, cleaning systems, and bailers.

Table 5: *Weekly expenses assumptions*

| | Price (USD) |
|---|---|
| pay | Unknown |
| upkeep | Unknown |
| electricity | Unknown |

In our financial models small scale versions of the full quoted products are used. Without being in Ghana finding a quote for large machinery is impossible, These prices were taken as reductions of the originals and their outputs were adjusted accordingly.

Table 6: *Initial machinery assumptions*

| | |
|---|---|
| Four Motorbikes (USD) | $5000 |
| Small bailer (USD) | $5000 |
| Small wash (USD) | $5000 |

As value is added to the recycled plastic its price per kilo is increased. These are based on values given by our Ghanian Entrepreneur partners. Though they are heavy estimates and don't factor point of sale price negotiations.

Table 7: *Plastic Price Per Kilo*

| Value Added | Plastic Price per Kilo (GHc) |
|---|---|
| Sorted | 0.65 |
| Cleaned + Sorted | 0.8 |
| Bailed + Cleaned + Sorted | 0.9 |

To estimate the price of Implementing bins and bags a quote from jiji.com was taken.

Table 8: *Bin system prices*

| | cost (USD) | cost (GHc) |
|---|---|---|
| Bin | $60 | 390 |
| Bags (100 pack) | $30 | 195 |

After conversing with the owner of Nelplast Ghana the team received quotes for the heavy machinery needed to run his makerspace operation.

Table 9: *Makerspace Machinery Quotes*

| | cost (USD) | cost (GHc) |
|---|---|---|
| Hydraulic Press (100 ton force) | $17,000 | 110500 |
| Sand Poly Extruder | $28,000 | 182000 |
| Mold (at least the 2 set) | $16,000 | 104000 |
| Cooling System | $4,000 | 26000 |
| Plastics Crusher | $12,000 | 78000 |
| Washing System | $12,000 | 78000 |
| Training and Consultation | $20,000 | 130000 |
| Bailer | $15,000 | 97500 |

At the moment these ROI calculations serve as a good preliminary estimation of rate of return, final profit, time until reimbursing the initial investment, and the ratio of profit to initial investment. However, as noted previously the virtual nature of this project required a significant amount of assumptions to be made. Lacking information about the size and weight of full bags, the volume of transportation trucks, and others resulted in imperfect equations.

Looking forward we suggest incorporating the volume reduction from the bailer as its own separate value. At the moment, all value added innovations are factored in by increasing the plastic price per kilo value. For example, gaining the small bailer increased plastic price per kilo from .8c/kg to9c/kg. It's estimated that this is reflective of the value gained by adding a bailer, however it is an indirect means of calculation.

Three financial methods were proposed to the chiefs. The first was: low investment, fast return. This method involved only a $660 initial investment in bins for each village, assuming Dwenase already had bins, and would begin seeing profit after only 0.24 years. After ten years this method would earn $81,920 at a rate of $161.35/Week with a profit to initial investment ratio of 4137.42% . The second method was characterized as the High Initial Investment model. This began with the purchase of bins in each village but also featured the purchase of motorbikes, a bailing system, and a cleaning system in Akyem Dwenase. The initial investment of $33,980 would be paid back in full after 3.1 years, earning $75,615.54 at a rate of $210.76/Week with a profit to initial investment ratio of 222.53%. The final method is a continuous reinvestment model nicknamed "Hybrid". This system starts by following the low investment model for the first year until enough money has been earned to pay back the initial investment and purchase four motorbikes for $5000. This process is continued with a $5000 cleaning system and a $5000 small bailer, immediately reinvesting profits back into the business until the maximum rate of return is achieved. The Hybrid system returns its initial investment back after 0.24 years, earning a total of $80,750.81 after 10 years at a final rate of $210.76/Week with a profit to initial investment ratio of 4078.32%.

Table 10: *Outputs of each Method*

| Method | ROI | Initial investment USD | Profit 10 years USD | Weekly Rate of return 10 years USD | Ratio of profit to Initial investment |
|---|---|---|---|---|---|
| Low | 0.24 | $1,980.00 | $81,920.89 | 161.3478591 | 4137.42% |
| High | 3.10 | $33,980.00 | $75,615.54 | 210.760654 | 222.53% |
| Hybrid | 0.24 | $1,980.00 | $80,750.81 | 210.760654 | 4078.32% |

| Method | ROI | Initial investment Ghc | Profit 10 years Ghc | Weekly Rate of return after 10 years Ghc | Ratio of profit to Initial investment |
|---|---|---|---|---|---|
| Low | 0.24 | 12,870.00 | 532,485.76 | 1048.761084 | 4137.42% |
| High | 3.10 | 220,870.00 | 491,501.01 | 1369.944251 | 222.53% |
| Hybrid | 0.24 | 12,870.00 | 524,880.27 | 1369.944251 | 4078.32% |

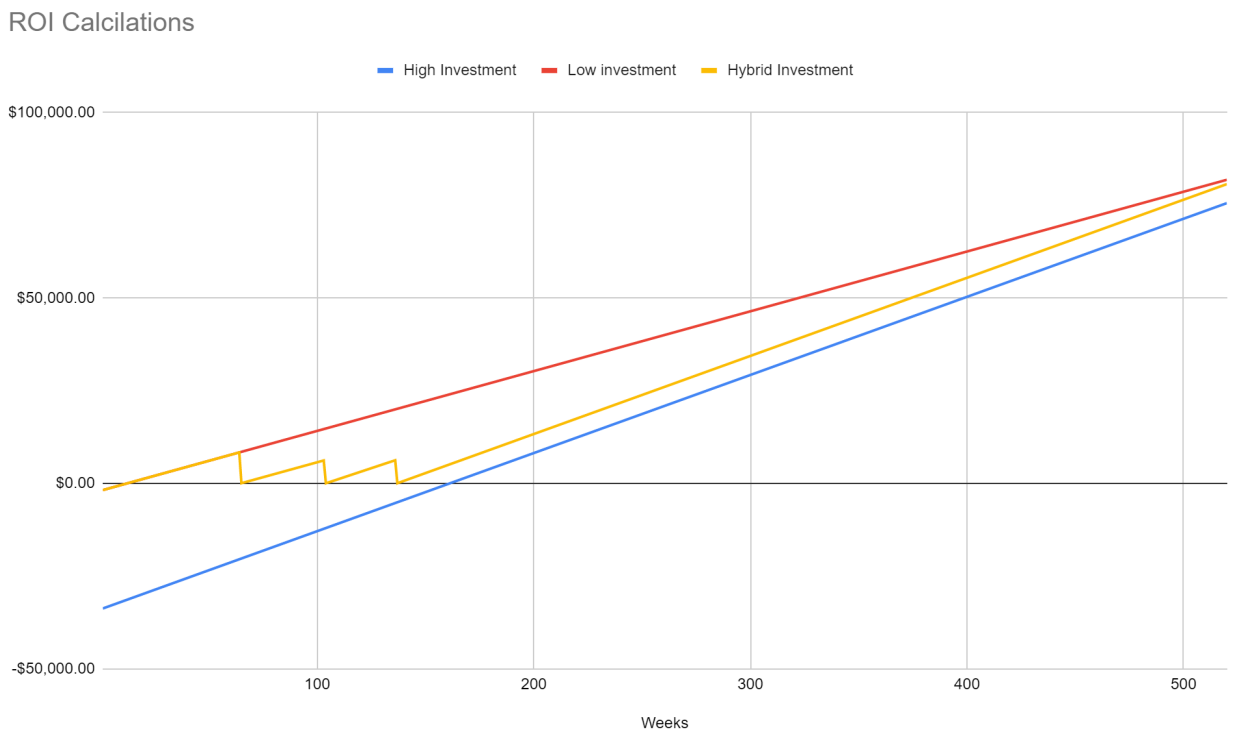


Figure 13: *ROI Comparisons.* To better visualize the value of each method we have displayed their returns over a 10 year period.

After presenting these three methods to the village chiefs they noted a preference in the Hybrid model. As such this is the system that we will implement. By Figure 13 the Hybrid investment model appears to be inferior to the low investment model. However, what the data shown here omits is the opportunity to scale and collect more plastic. If larger amounts of plastic were to be collected the added value per kg of recycled plastic that the cleaning system and binning machine provide would have a greater effect. This is what the chiefs are betting on. They believe that over the course of the recycling initiative the program will expand and recover more plastic. It must be noted that scaling the business may not always be the best course of action. If a village is unable to expand their collection investing in a greater value per kg of recycled plastic may not be worth it. Lastly, the effect of our required assumptions cannot be overstated. The values presented were calculated off of the information available to us but we believe more accurate values could be found.

## *Justification of Proposed System through Co-design*

### *Akyem Dwenase Stakeholders*

Chief Osabarima Owusu Baafi Aboagye III was our first contact in the Eastern region of Ghana. He was able to express his concerns about the air quality around his village due to the amount of plastic burning that had been occurring. This issue was of concern to him because his community already had an established recycling system, but because of COVID-19, they had to stop the collection of plastics. This led to a rise in the burning of plastic again negatively affecting the air quality. When having conversations with him he expressed interest in developing an alternative way to prevent the burning of plastic, since COVID-19, was still a concern to him.

Our team looked into developing sensors to determine if plastic was being burned but through more research and conversations with Chief Osabarima it was determined that starting the plastic collection again would be the best way to prevent plastic burning. Chief Osabarima expressed that he would like to see a business developed to possibly employ some of the youth in Akyem Dwenase. Our team started to look into small scale, single recycling businesses in Ghana with which to partner. We looked at several businesses, each with unique business plans, in search of models that interested Chief Osabarima. He looked to mainly focus on apparel manufacturing (i.e. flip flops) and long term plastic products (i.e. building materials). Chief Osabarima was also interested in business that could produce electrical energy from the plastic through creating and maintaining generators. However interest in this method was dropped after learning that the main method of energy creation requires burning or melting the plastic. Which if done incorrectly could recreate the same air-quality problem that he is trying to stop.

### *Business Stakeholders*

While developing our plan we contacted two Ghanian entrepreneurs. They helped us to understand what the plastic recycling market is like in Ghana. They also provided helpful feedback on best practices for how to start, maintain, and grow our proposed business. The first entrepreneur we contacted develops manufacturing techniques that use specific types of plastic to create versatile materials. From one material, artisans are able to make sleeping mats, bags, and shoes. The business model focused around community engagement and education to get more plastic for his business. Another key part of his business was the development and patterning of the manufacturing technique to make his unique materials. The second entrepreneur we contacted used mixed plastics of all types as well as sand to create paving blocks and bricks. These products have been used to build houses and pave roads in Ghana. This business model focused on buying plastic from waste pickers and then using that along with two hundred thousand USD worth of machines to make his two products.

From our business stakeholders we developed a better understanding of how to design a business based on recycling plastic that would operate well in Ghana. The first entrepreneur helped us to realize how important educational resources would be when implementing this plan. If people understand how recycling will impact their daily life and their health/environment they will be more willing to join recycling initiatives. It was also emphasized that other forms of value, such as educational and entrepreneurial opportunities, can be built into the system and have a positive impact on the whole community. The creation of a unique manufacturing technique is something that the first entrepreneur warned us against. Development required significant time and monetary investments, during this time the business received no money and was sustained by other ventures. This influenced us to design the implementation of our process around an already established plastic recycling technology. The second entrepreneur helped us to understand how to make a plastic business profitable. Reflecting on his operation of paying waste pickers we were able to develop our system to include the other three villages: Abompe, Batabi and Tumfa. This implementation allowed us to use the plastic collected by each village as a separate source, increasing the overall plastic collected. From the second entrepreneur we were also able to understand the overhead costs for setting up an established plastic recycling business like his. After a few conversations with this entrepreneur we were able to develop a relationship between his business and the chiefs of the four villages in our recycling system. The second entrepreneur, who developed a plastic brick making business in Accra, had mutual interest in the establishment of our recycling system led to the second entrepreneur becoming a business partner in all stages of our operational plan: initial, short term, and long term. In the initial and short term plans he will be the main buyer of our mixed plastics. In the local long term plan he will be responsible for helping to set up and train the local communities on how to operate the machines as well as best business practices for selling the bricks to make a profit. Further involvement by this entrepreneur will be negotiated by the ABDT recycling panel.

*Local Community Stakeholders*

After having meetings with Chief Osabarima and the business stakeholders we were able to develop the short term and local long term operational plans. Our team then started meeting with local community representatives, including the chiefs from the other three villages. We met with the deputy chief of education and the deputy chief of agriculture of Akyem Dwenase to discuss plastic generation and ways to add value to recycled plastic that would be impactful to the community. We also had a meeting proposing the short and long term operational plans as well as the return on investment (ROI) data with them. In this meeting we received fantastic feedback on what management structure would work as well as more updated numbers for more accurate ROI data. Our team then held a meeting with a national stakeholder who had interest in our system's very long term implementation across multiple regions in Ghana. This national stakeholder along with our plastic brick business partner, and Chief Osabarima had a discussion with us to validate the financial, logistical, and social aspects of our plan.

From these meetings our team was able to develop the final versions of all plans presented as well as determining how ideas fit as short or long term goals. From the meetings with the Chairs in Dwenase our team used this information along with students from Academic City College University (ACUC) , in Accra, to make educational resources that can be used to explain the health and environmental impacts of burning or dumping plastic. The ACUC students were also able to help us develop resources to best explain how the community would benefit from participating in our proposed recycling system. The meetings with the deputy chiefs of Akyem Dwenase also solidified our choice in partnering with the plastic brick making entrepreneur in Ghana. We feel this is the correct decision as the community would see more long term value from the plastic brick business than from other options we presented(ie clothing options). The meeting with the national stakeholder, Chief Osabarima, and the plastic brick business partner allowed us to understand how funding from outside sources and the logistical operation of our initial system design were faulty. From this conversation we developed better goals for educational resources, a better understanding of how to best present ROI calculations, and a more well rounded understanding of how this system can be implemented on a national scale in the future. The meeting with the village chiefs from Abompe, Batabi, Akyem Dwenase and Tumfa allowed us to make the final changes to the collection and transportation systems. We received feedback suggesting the purchase and implementation of four vehicles. These motorbikes would increase the area we could service and would be the first upgrade of the Hybrid system. This option was very promising and the chiefs indicated this would be the best way to service a wider area of collection with a small budget. The meeting with the village Chiefs also facialted the idea of a local board of representatives, the ABDT recycling panel, that would manage the overall system in the long term. This was suggested so that the system would have defined leadership in each community as well as a panel of representatives, that can include future WPI students, who would locally be responsible for implementing, maintaining, and expanding our proposed recycling system.

The process of Co-design as outlined above was used to design our proposed system to meet the needs of all stakeholders involved. Every stakeholder added valuable insight into the development and final implementations of all parts of our system. Besides our system meeting all of the local community needs we evaluated the potential future impacts on the local community that our proposed system would have.

### *Comparison of Proposed System to Existing Options*

The proposed recycling plan in rural Eastern Ghana has many benefits as compared to the current recycling program in Akyem Dwenase. The proposed plan, when compared to other common waste disposal methods, has better environmental and health outcomes. This section will outline the benefits that the proposed recycling system has over the major waste

management methods that Ghana currently uses as well as possible future waste management methods to be adopted in Ghana.

*Sanitary services and Landfills*

Our proposed recycling system operates on a smaller scale but similar range in locations as landfills in Ghana, both urban and rural locations. Landfills in Ghana service all regions but focus on the urban populations for collection. The proposed recycling system, when implemented nationally, would mostly service the rural areas in all regions of Ghana. Our system produces less overall value than landfills but the value that is produced is direct to the local community that the waste comes from more directly. Landfills can often service a wide area and the value produced in the form of jobs is not seen by communities that are not near the landfill site. Landfills provide value in terms of general waste removal and a source of income for more people in urban areas. Our recycling system would not be able to provide an alternative source for other forms of waste in MSW in rural regions, besides plastic. The proposed system would be more impactful in rural communities by providing added value in terms of business opportunities, education and monetary gain for the community as a whole. Environmental impact wise landfill that are often not managed well in Ghana would have a much more negative impact on the environment. Negative environmental impacts will lead to negative health impacts for the surrounding communities. The proposed system, because it is implemented in conjunction with other waste disposal methods for other types of waste, will have a more positive impact on the local communities environment and health.

*Disposal in unauthorized places*

Disposal in unauthorized places includes littering, burying waste near the home, and burning waste near the home. All of these waste disposal methods have a negative impact on the environment and health of the local people. Littering has had several harmful impacts on the environment in urban areas. In some cases the plastic pollution in the streets will get into the sewer system and cause issues with drainage. The dragniage issues then lead to stagnant water and diseases. Unauthorized burying of large amounts of waste can lead to pollution issues with the local water. Unauthorized burning of waste will have high environmental and health impacts due to harmful toxins being released. Our proposed recycling system would have positive impacts on the environment and local health as it provides a healthy alternative to discarding waste. It also provides value directly back to the community where the waste was generated. Lastly, our proposed recycling system is overall more beneficial than unauthorized waste disposal because of its current and future business opportunity.

*Recycling*

Our proposed system would have a similar scope to the current non-profit and private recycling businesses that are established in Ghana and as such would have similar environmental, health and economic impacts. Our proposed plan would have a much smaller

impact than the governmental initiatives that are currently in place and those that the Ghaninian government hopes to encat. However our system would serve a different community and help to recycle more plastic that is taken outside of the scope of these existing programs and initiatives, specifically outside of urban settings.

*Energy generation from MSW*

Our systems' impact will be more direct for rural populations who will not likely see the benefits of the power production from MSW systems as quickly as urban citizens. It will also see less harmful environmental impacts than MSW systems which rely on landfills. Although some of the environmental issues like contamination of local waterways is likely to be mitigated through energy generation, there is no way to quantify by how much. The largest environmental impact will be the release of greenhouse gasses through the burning of the MSW. There is also a chance of continued health impacts as burning without the right infrastructure can lead to the release of harmful fumes including doxins which have been linked to health issues. Our proposed recycling system would not be able to be a replacement for power production from MSW, however it would provide value other than the energy that would go directly to the villages. Energy generation from MSW would be a very long term solution, potentially longer than our proposed recycling system.

## *Conclusion*

The dislike for burning plastic and local dumps has been acknowledged by our local partners as a characteristic of many of the villages in the rural Eastern Ghana. Using the process of co-design through a series of several meetings with local partner villages, business stakeholders, educational stakeholders, and governmental stakeholders we were able to develop the proposed recycling system. The system involves establishing a sorted bin collection system in each partner village. The sorted plastics are transported to the local hub in Akyem Dwenase. Depending on the time frame the plastic is then either transported to Accra and sold or in the future the plastic would be sold to a local brick making operation, set up with a Ghanain entrepreneur based in Accra.The proposed recycling plan was developed to address the air quality concern due to burning plastic as well as provide a self contained generative recycling initiative. As seen in figure 14, the proposed recycling system has many advantages to the existing and future waste management options in Ghana. The difference with our plan is that it was designed to directly service rural areas in Ghana, places that are often left out of governmental and other recycling plans due to their small population. Figure 14 correlates the types of waste management and our plan on the scales of environmental impact, longevity and value added directly back to the community. These were determined to be the important factors when co-designing our proposed system with the local representatives. Our plan is designed to bring the value obtained from the plastic directly to the villages who participate in its collection.

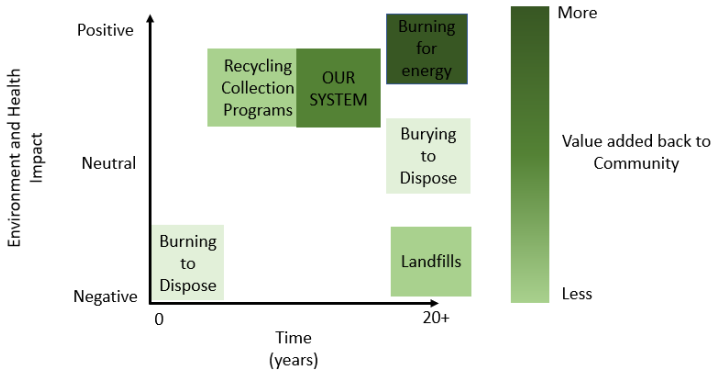


Figure 14: *Overview of Municipal Solid Waste Disposal Methods and their Impacts.* The general comparison is shown for the major ways in which waste is disposed of in Ghana and how they impact the environment, health, and economy of the local residents over time.

# *Discussion*

## *Reconceptualized Smart Villages*

Although smart villages are being looked at as community based initiatives it must be noted the effects of big technology conglomerates that strive to make money from these next generation smart city and village projects. We were especially careful to limit the involvement of outside businesses. We feared involving technological enterprises, like IBM and SAP SE, who looked to contribute a lot to recycling efforts in developing countries like Ghana, but only to the benefit of their business and profits [33]. When planning our business model one of the first topics we focused on was ensuring all value generated by our system remained internal. Making sure those who created value saw the benefits of the work they did. The introduction of a cross-village management board gave village leaders authority over profits generated by the recycling system. We have outlined suggestions for financial plans but in the end our partners have full control over all parts of the recycling initiative. Handing over full responsibility means it will be their job to use information we provided along with their local expertise to address all issues that may arise and to control the speed of development of this system over time. This is by design, we have outlined our plans and solutions with expected issues, however the long term feasibility of the recycling system hinges on our partners' ability to maintain all aspects of the supply chain we have identified. It's our belief that going completely hands off and ensuring all generated value remains internal to the village will see the best long term success. Naturally with the focus of this project being on recycling we concentrated on the sustainability of this initiative. Beyond the direct environmental sustainability our system will create, we also plan to bring jobs, educational opportunities as well as future entrepreneurial opportunities to the people of Akyem Dwenase. Employing younger generations and educating them about the importance of recycling opens doors for future initiatives, fosters a love for the environment and helps to develop a greater sense of identity in regard to future Ghanian entrepreneurs and scientists.

## *Different Forms of Solutions*

We initially spoke with village leaders to discuss their opinions on the plastic in the area and actions towards recycling that occurred in the past. Our team learned about a recycling program that was created in 2018 where bins were placed across Akyem Dwenase collecting plastic and being stored in local buildings. We met with the chief of Akyem Dwenase to co-ideate a recycling plan that is sustainable and an improved adaptation of the original with additions to combat coronavirus. Conversations with the chief of Akyem Dwenase illustrated the needs and wants of the villagers, where we began to design a plan that incorporates an opportunity for entrepreneurs to arise through the return of created plastic products or monetary benefit in the village from the collected plastic. This plan incorporates the entire community and expansion into surrounding villages, specifically Abompe, Batabi, Tumfa. The recycling program was then optimized with a focus to maximize monetary benefits through the guidance of entrepreneurial experts in plastic recycling from Ghana. Where their insight provided details on the selling of plastic, purchase of equipment, transportation expectations, and possible external funding options. The information provided by these experts allowed us to develop a scale of how our recycling plan would affect those involved financially. Our experts expressed their concerns with the high start-up cost that the original plan would require. From our research on funding opportunities, pricing of machines, and return on investments we were able to create a more appropriate financial plan and redesign the recycling system to be more sustainable and become community funded. Where we then spoke with the chiefs of each of the villages and received their support in the expansion to their villages. The conversations with these leaders allowed us to develop sustainable information for chiefs to use as the years go on.

## *Reflect the Ideals of Co-Design*

Designing the proposed recycling system required co-design in order to improve on the existing system and provide more value to the village partners. Throughout the research and design process we aimed to incorporate local partners in Ghana at every step to confirm the result of our research as well as provide more nuance on certain topics, like the fluctuating costs for recycled plastic. Communication between interested parties when designing is one of the most important processes in co-design. We struggled to start this process after the initial meetings due to the lack of understanding of how they prefer to communicate. It is much more common to use text messages, through WhatsApp, or phone calls rather than sending more formal emails. Once our group figured this out the next hurdle was in getting the local partners we identified to respond to our messages. After a few failed attempts to reach out we asked the project site advisor to reach out again to reintroduce us. After this the communication was much

easier and we were able to have very informative conversations with our local business partners and other invested parties, like the village chiefs. Although not being in Ghana presented many difficulties, mainly in quick feedback and communication, we were still able to propose many variations of our solution and work towards a system that meets the short and long term goals of both the local village partners and the wholesale plastic buyer. Some issues with our process of co-design is that due to the limited meeting times we often would not present all ideas we had towards the solutions but the onesie through were the most promising. This impacted the possibility of creating a system that met more of the communities needs and in the future this can be minimized if this project work were done in person. Another concern we had in our implementation of co-design was that we were only able to meet with those in positions of power within the villages. They were able to provide us with much of the information that we needed to design a more concrete plan but the input from other villagers was severely lacking in the development of our proposal. To combat this the deputy chief of education in Akyem Dwenase, offered to hold a community workshop to help get more community feedback as well as provide the community with information on the negative impacts of burning plastic. This was a very helpful solution that we were not aware could be organized and helped to get some form of community feedback. Although this was not ideal it still provided us with an opportunity to get feedback from people of all interests within the village. In the future the issue of community involvement can be better addressed with in person development. Overall we were able to effectively implement the principles of co-design and although being remote we were still able to iterate through many versions of the proposed recycling systems to find the best set-up to meet the needs of our partners in Ghana.

### *Reflect on Generative Justice*

Our primary aim throughout the development of this plan was to ensure that implementation would result in a system that achieved a generativity just model. Much of the focus of our discussions with our partners focused on the generativity of the proposed plan. We could easily envision the structure of reinvestment and growth as initially profits were funneled back into the capital necessary for expansion. Our partners were all keenly interested in how this model would not only sustain itself in its current, localized form, but also expand to incorporate new sources of value, such as establishing maker-spaces for additional revenue generation. We fixated on the self-similar scalability of the project, incorporating first our partner villages of Batabi, Tumfa, and Abombe, followed by the surrounding areas, in order to achieve the largest possible value circulation with the largest possible margins so as to feasibly support as many community initiatives, like building clinics and paving roads, as possible.

Where we lost ourselves was in gradually adopting a utilitarian framework when it came to the ethical implications of certain design choices. Generative justice advocates for bottom-up and peer to peer networks, and ensures that value generators receive unalienated value in kind.

However, limited by distance and means of communication, we tailored our designs to the feedback of a small number of individuals who already held some kind of economic or social power. Ideally, this recycling initiative could have been organized through directly coordinating with individual entrepreneurial-minded individuals and collectives in each village, establishing a mutual, peer-to-peer network un-mediated by an authority or oversight committee. However, this would have required us to bypass the chieftaincy of each village and rely on an authority that we did not possess. To address this issue the ABDT recycling panel was added to the proposed system implementation inorder to have a local panel that would be responsible for facilitating this peer-to-peer communication without circumnavigating the authority of the chieftaincies. Once the sale of plastic begins, there are further questions regarding the distribution of that value. In existing waste-picker economies, individuals receive monetary compensation by weight and quality of plastic. While their collection fee is a pittance swamped by middlemen and profiteers, it is still a direct contribution that compensates equitably. Contrast to this our proposed system is a centralized collection model where profits from the venture are first allocated to the ABDT panel to be distributed and invested. In this model, there is a conflict of interest between whether all profits should be redistributed evenly by community, or whether direct investment should be made into increasing the productive capacity of the collection facility in Akyem Dwenase, with the goal of increasing profitability in the future. Which of these models more closely adheres to the ideal of value generators directly participating in the benefits of their generation; of value producers creating their own conditions of production, and for communities of value generators to nurture their own path towards self-sufficiency?

While some compromises needed to be made in the implementation of generative justice, we can be sure of our intentions by examining the answers to the following questions:

Who are the value generators in this system?
Are individual contributions to the system distributed equally?
What are the tangible and intangible benefits that value generators wish to receive?

In the case of plastic recycling, the consumer of plastic products is superficially extracting ecological value when improperly disposed. However, as we have discussed, plastic is, by design, incompatible with the natural recycling process of biodegradable waste, requiring large waste management systems in order to deal with the problem. Since an individual, especially a low-income, rural resident with limited access to clean water, can not meaningfully address the plastic waste crisis alone, their capacity for value generation is also limited. Instead, the value generator must necessarily be the entire community, as only by collective action can an economy of scale be achieved that enables sustainable plastic collection and recycling. The value they generate is the small but meaningful effort to recycle their waste and unlock the value within their plastic.

With that in mind, an equitable system can only persist if there is a sense that each individual makes a contribution proportionate to the labor, culture, and social value they receive. Within the community, certain individuals may serve with additional responsibility, though there must be a distinction between service born from an entrepreneurial spirit and the expectation of service entailed by authority. In our understanding of the necessary forces behind a plastic recycling initiative, we know that a single entrepreneur can tackle the issue, take on personal risk in order to finance the collection and transportation of plastic waste, and reap the individual reward. However, this evidence is anecdotal, stemming from an instance of a pastor in Akyem Dwenase who operated a local collection initiative without support. Alternatively, the chiefs and their appointed authorities serve as coercive forces to ensure that the practice of collection, sorting, transportation, and selling are facilitated with the justification of serving the public interest. This approach, while stemming from a top-down authority, does come with the added responsibility towards supporting the community beyond the act of cleaning up plastic. This approach enables coordination with other authorities, allowing the formation of a broader community by which each individual contributor receives a larger share, and providing a greater legitimacy to seek assistance from partners domestically and abroad. The mitigation of addressing these primary questions of developing a generative system were not totally addressed here in order to maintain a culturally centered design that respects and utilizes the established structures of power while still providing a method, the ABDT recycling panel, to address community involvement within the recycling system.

The concept of unalienated value implies that value generators are in control of the form their value is returned to them, both in tangible forms such as food and shelter, but also in intangible forms such as satisfaction or interpersonal bonds. Admittedly, this plan does not immediately enable the generation of unalienated value shared by all. It relies on the continued profitability of the venture in order to more efficiently circulate value in the long term, but necessitates that the community place a level of trust in the organizer at the stead. Meanwhile, any community direction of the initiative also relies on the unhindered cooperation and communication between each chief and his people, to ensure that the mutual needs of the people and the partnership are respected. We know there are other models that could be implemented that more evidently empower the value generators, like maker-spaces for producing locally recycled goods instead of relying on wholesale waste buyers. However, transition to a generative system from an exploitative system cannot exist in vacuum and engagement with alienated value streams is unavoidable. Thus we aim to be pragmatic, and to utilize the existing systems as effectively as possible while minimizing exploitation of the environment and of the labor of the people by investing in the infrastructure that enables us to most efficiently recirculate the value within plastic waste.

### *Shortcomings of our Process and Future Advancements*

When this plan was created there were many shortcomings that we could not expand upon due to time frame or lack of access to information. As we created this plan, we wish we could have implemented it as well. However, due to our timeframe of seven weeks to work on this project, implementation was not possible. We look forward to the group that continues this project to implement it. Funding for the plan was a part of the plan we knew would be necessary but was difficult to obtain when not actively implementing the plan. The plan was constructed January 10th 2022 to March 3rd 2022. Since this plan was constructed at the beginning of 2022, grants for the current fiscal year were no longer available. This made it difficult to acquire grant funding for implementation on such a short timeline.

The system we created during our time frame to work on this project we thought of improvements to be added in the future plans of implementing this recycling plan. To expand upon this plan and continue the ideals of co-design it should be expected to continue collaboration with future advancement implementation within the recycling system. It is ideal that the plastic can provide profit for the community through money. However it is equally as profitable to reuse plastic to create a good that villagers in the community would be in need of and be able to use. The advancement of implementing makerspaces allows artisan value to be implemented in the system. This brings opportunities among the villagers to create these items that are needed for the community. Allowing the village to create more employment options for each other. An idea that to be a part of this expansion is to have a makerspace in each village. Therefore each village can address different needs their community needs met. Each village could focus on having a makerspace of a specific good to be created. This allows advancements in generative justice within the recycling system. Goods that the village would normally extract would be able to be created within the village. This limits extracted value within the village creating a more sustainable environment. Goods that would not be a need for the villagers but would be able to sell for profit would be beneficial as this would provide employment to many. This would open up the opportunity to have more business in the village. The plastic would be able to be shredded and made into items such as flip flops, reusable bags, etc. in order to make profit.

With our proposed plan for implementing this recycling system in Akyem Dwenase, Ghana funding is a large factor in making it a reality. There are multiple ways to be able to fund this system. Since there are different goals based on timelines the short term plan will require less funding then the medium and long term plan. A form of funding that is possible for a long term system in the future is a Susu system. A Susu model is a funding plan with involvement of multiple parties. Each party invests into a large sum that will return a profit where everyone that participates reeps the benefits [44]. This financial collaboration benefits those that contribute their value. It is a possibility in the future to use a susu funding model in the long term recycling

plan. The community in Akyem Akyem Dwenase can contribute their value in the form of their plastic waste and in return the profits can be redistributed to financially fund larger projects, or to keep a sustainable recycling system.Another form of funding to be able to implement the short term plan would be grant funding. Grant funding is a large sum of money usually supplied through Non-governmental Organizations (NGO's). This funding system is more possible to finance the long term goal to supply the machinery needed for the Nelplast production in the centralized hub, Akyem Dwenase.

Once the short and medium term plans reach the goals desired, focus can be steered towards advancements for long term goals. Long term goals will include creating more connections, and education initiatives, and future innovation. A national scale recycling program would be an initiative to combat the world's plastic waste issue. To create a national scale recycling program, involvement of smaller villages in the region would be a positive starting point. Building connections with surrounding villages of Abompe, Batabi, Akyem Dwenase, and Tumfa would result in more concrete initiatives as more representatives would co-create. In the future this would allow the opportunity of a regional representative in efforts to expand to have multiple regions in the plastic waste recycling program. In expansion of the size of the program, there would need to be connections with more independent contractors. The Nelplast operation would need to expand to more regions or partner with other independent contractors in order to create a sustainable recycling system. Including independent contractors there could be assistance in collection and transportation of the plastic. More people collecting and transporting plastic can supply a large demand to reduce the plastic waste and produce a profitable business.

Developing a national scale recycling system would contribute knowledge and educational value to all the villages. Students would be able to learn the importance of recycling and have the ability to have hands-on experience. Students would be able to then educate their families on the value of the recycling initiative to display more contribution. The students would be able to be a part of the co-design process by collecting plastic or creating a product that could be constructed from the recycled plastic. This would be part of a shorter term goal as on a national level students have their main job of school to attend. The students co-creation of products would result in longer term benefits as this would be able to help creativity in makerspaces. Additional educational initiatives that can be taken in the recycling system longer term would be to use sustainable options of plastic. This would include reusable bags when purchasing goods that would be placed in single use bags that cannot be recycled.
To plan future innovation implementation in the long term plan there are many engineering additions that could be made when more funding is available. In the bin system we proposed there would be a line painted on the inside of the bin to signify that the bin is at its maximum capacity of plastic. To improve the bin system there could be sensors put inside the bin where the line would normally be. The sensors can detect if the bin has reached its maximum capacity and then notify the chosen representative that the specific bin is full and can be emptied.

Another advancement that would be helpful to a centralized hub of a recycling system would be a macreator. A macerator is an important tool that can break down plastic quickly. Adding a macerator to the Nelplast production would speed up the ability of breaking down plastics. In addition to the plastic crusher that is currently a part of the Nelplast system to break down the plastic, this would allow for faster production eliminating the time waiting to break down the plastic. This would allow more products to be created making a more efficient business system. Currently the plastic crusher that is a part of the Nelplast process can only break down certain plastics such as water sachets. The addition of a macerator would expand the opportunities of types of plastics that would be able to be used in this production. The more options of plastic able to be used allows for a larger supply to be created.

## *Conclusion*

This case study displays the use of the co-design process to develop a recycling system that aims to establish a generativity just recycling system in rural Eastern Ghana. As a team, we were able to look at the impact of the global plastic waste issue in Akyem Dwenase, Ghana. It was brought to our attention that one of the main strategies to eliminate this plastic is to burn the waste. However, this form of waste management is dangerous to the community and environment. Moreover, this practice represents an exploitative relationship between value generators (environment) and the beneficiaries of this value (plastic consumers). To help restore a generative cycle, co-design principles were implemented to find ways to instead recirculate plastic value to the community. Meeting with various partners in village leadership, local recycling entrepreneurs, and local residents, we identified the need to co-create a recycling system that would both address the problems of plastic burning, plastic collection, sourcing buyers for plastic from Akyem Dwenase as well as assist other villages in the Eastern Region in tackling plastic recycling. Collaboration is important for the sustainability and success of the implementation of a recycling system as it allows rural areas to overcome many of the challenges that hinder an economy of scale. Our plan includes various stages of expansion as the project matures that will empower local entrepreneurs, strengthen the ties between rural communities, and demonstrate the priority of coevolution in creating a system with generative justice in mind. With village leaders we reviewed their current recycling and waste management systems in place to see where the plastic waste could be separated and turned into value. We also identified gaps where investment, either community based or outside funding, needed to be made in order to ensure the long term viability of the recycling initiative. With these needs and opportunities established, we were able to facilitate the foundation of a recycling partnership between four villages in the Eastern region which would commit to the installation of collection bins, the building of sanitary storage areas, and the transportation of waste to a centralized hub in Akyem Dwenase. Most importantly, they agreed to hold the profits from the venture in a common fund, to distribute as needed in order to help expand the initiative. This system, whereby the community ensures that the value stored in their plastic is properly retained, is fundamentally a bottom-up system, but without our partners, this project would not have had the impetus to begin.To address this the village chiefs agreed upon a local inter-village panel to monitor the initial installment of the system as well as its long term development. This panel would also be responsible for monitoring the profits and distributing them as they see fit. This panel provides a local authority that is able to interact with the community to adjust the development of the system in the future to meet the current and future community needs. Beyond the business initiative, this project has served as an example of the transformative potential of designing for generative justice. Far from heavily industrialized visions of a smart village, this work is a revelation that the existing social networks in rural communities, cultural institutions, and daily practices are ultimately smart.

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