Waste Management at Rapid Onset Disaster Sites

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Abstract

Humanitarian assistance helps regions struck by hardships. The United States Agency for International Development supplies humanitarian assistance to devastated people after a disaster strikes. When humanitarian assistance is supplied, it is delivered in multi-layered, durable packaging. Excess packaging waste, in the form of plastic, cardboard, and metal, has devastating impacts on the local environment when not properly processed. This project provided USAID with assessment tools necessary for evaluating waste management systems and their application to rapid onset disasters. The generation of such tools required analysis of waste management solutions employed in a variety of fields to optimize them for use during a rapid onset disaster. These assessment tools were provided to the USAID Supply Chain Management Division to provide an outline for implementing effective solid waste management methods in the aftermath of a disaster.

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Management of Solid Waste at Disaster Sites

When disasters happen, people need assistance. Assistance lessens the hardships experienced in disaster areas. This assistance, commonly referred to as humanitarian assistance, consists of material goods and logistical assistance. Organizations around the world such as the Red Cross, Red Crescent, Salvation Army, and the United States Agency for International Development (USAID) supply humanitarian assistance. Organizations contribute to the relief effort through the distribution of resources, such as hygiene kits, shelter kits, and kitchen kits. Each kit arrives on site pre-packaged to be distributed with the goal of improving quality of life post disaster. Many humanitarian groups fail to consider the negative environmental impacts created by the discarded packaging of relief materials delivered to disaster sites, such as plastic bags and cardboard boxes. The USAID wants to reduce these negative impacts by incorporating more environmentally sustainable assistance practices, such as improved disaster area waste management.

While striving to supply rapid assistance in the immediate aftermath of disasters around the globe, many humanitarian organizations leave behind waste created from the packaging of provided assistance. While USAID's projects progress towards sustainability, improvements can be made. Such improvements include more effective handling of waste produced by assistance efforts. Advancements in the areas of waste disposal have become a topic of particular interest. According to Solid Waste Management During Humanitarian Crisis, the disposal of waste within a disaster zone primarily falls upon the infrastructure of affected regions, leading to an unsatisfactory clean-up effort.[1] This project aimed to identify solutions that could remedy this waste problem in an environmentally, culturally, and economically sustainable way.

With a goal to help return waste materials to the global economy, this project investigated the implementation of circular economic structures at disaster sites. Circular economic structures allow for a cyclical flow of materials between goods and waste. Such economies require effective recycling and reuse methods to remain sustainable. This project proposed solid waste management systems to process the waste generated by major disaster recovery efforts. Proposed waste management systems prioritized reuse and recycling of materials. As part of this project, waste collection and waste processing methods were investigated.

Disaster Waste Management Culture

The primary goal of this project is to investigate the implementation of a circular economy at USAID disaster sites. This project will consider new waste management systems to process waste in the emerging circular economy. Proposed systems will allow for sustainable waste management in humanitarian relief efforts around the world. Waste created at humanitarian sites is a byproduct of the consumption of aid materials such as medicine, food, and water. These materials are often packaged and shipped in single use plastics, cardboard boxes, and metal cans. Packaging of items consumed in relief efforts remains long after serving their initial humanitarian relief purposes, compounding the already existing waste problems plaguing many disaster areas.

Proper implementation of waste management systems to handle packaging relies often on decisions made by outside vendors. Vendors will consist of private sector companies and non-governmental organizations that wish to purchase recyclable materials. An economic structure such as a circular economy significantly reduces the necessity to harvest new raw materials. Circular economies are more environmentally friendly than other economic models, but require effective and efficient waste processing to allow for the reuse of materials. The following background sections describe circular economies and sustainable waste management systems. To understand circular economies, it is critical to analyze waste management methods in both circular and linear economic models.

The main deliverable of this project is an investigation of practical ways to implement a circular economy in disaster areas. The results of this investigation were supplied to USAID, detailing the opportunities and obstacles pertaining to the implementation of a circular economy.

Circular Economic Models and Their Effects

Circular economies enable materials to flow in a cyclical manner, thereby reducing or minimizing the extraction of raw materials. The sourcing of materials produces waste as existing resources are consumed in the process. Waste minimization can be completed through recycling and a combination of repairs and reuse methods. Circular economies are much more resource and environmentally conscious whereas a linear economy will continually source raw materials and discard, often in a wasteful method, products that no longer serve a purpose as can be seen in figure 1. Most resources remain in the reform, reduce, reuse, recycle loop until the material quality degrades past a useful point. One significant problem is that circular economies are difficult to implement on a large scale without widespread waste management reforms. Regions that have been devastated by natural disasters often lack critical waste management infrastructure or have existing infrastructure that has been crippled. With waste management in disarray, a larger focus must be placed on the establishment of sustainable waste management systems at disaster sites.

Figure 1:A map of how circular economies function.[2]

There are several large-scale circular economies in development which might serve as models that could be adapted for use in disaster relief situations. The most impressive can be found in the European Union.[3] Many companies in the European Union (EU) are pushing for additional legislation to increase incentives to recycle. One method of encouraging recycling is known as a buy-back program. Buy-back programs exchange money for material waste; encouraging reusable waste disposal. The EU is not the only governing body to implement a buy-back program; similar programs can be found around the world. For instance, Mumbai, India, has a well-established buy-back program, implemented in 2018. Excess flooding turned deadly when canals began to overflow from improper drainage.[4] Canals were plagued with large amounts of plastics and a variety of garbage. This new system helped reduce pollution in the city, referring to figure 1 which visualizes collection purposes. Several states within the United States have implemented buy-back programs. Most buy-back programs in the United States focus on plastic bottles and aluminum cans. States that have active bottle buy-back programs include Connecticut, Massachusetts, New York, California and many more.

Dearth of Circular Economic Models

Conversely, developing countries are unable to implement a circular economy, thus they rely on what they are familiar with, a linear economy. Poor waste management systems exacerbate this issue. Developing countries have variable agricultural output and often can also be characterized by low per capita incomes.[5] Examples of developing countries include Haiti, Indonesia, Thailand, and Brazil. These countries lack the capability to sustainably process large portions of the waste made within their borders. Developing countries face other crises such as poverty, hunger and high levels of illiteracy. This situation gives precedence to more immediate needs faced during disaster situations and disincentivizes consideration of new systems for waste management. Over time, poor waste management systems will deteriorate into an environmental crisis because of open dumping and burning of waste.[6] Humanitarian aid organizations find themselves in a prime position to assist in ameliorating this crisis. Most aid organizations, such as USAID, reside at a home base in wealthier countries that have the existing infrastructure to efficiently process waste. While this technology can be shared, it is only part of the solution. Countries must develop and maintain their own waste management systems.

Assisting developing countries in their journey to efficiently process waste will increase the effectiveness of humanitarian aid. Environmentally friendly humanitarian aid practices improve both the recovery speed and quality of humanitarian relief efforts while improving the health of beneficiaries. A study performed in Thailand found that insufficient linear waste management methods, similar to those employed in other developing nations, results in higher infection rates coupled with long term psychological damage when compared to waste management methods performed in more developed nations. In addition, this study found that current waste disposal methods result in an increased rate of cancer and birth defects.[7] Solving developing countries' waste management problems can create long term improvements in the lives of millions of people for decades to come.

Effective Supply Chain Management

A crucial part of an efficient circular economy are effective supply chains. As the world emerges into a more globalized economy, supply chains will grow more complex. Natural disasters destroy roads, harbors, and airports, thus crippling existing supply chains.[8] The overall strength of a circular economy is determined by the weakest link in the supply chain. It is critical to maintain the effectiveness of supply chains throughout the relief effort. Having interlinked supply line connections will limit the negative effects of any one link failing.

USAID has struggled with the maintenance of supply chains in the past. In 2018 there was a critical delay of malaria bed nets for Nigeria and missing shipments of HIV medicine in Ukraine.[9] As a result, USAID re-evaluated existing partnerships with the goal of keeping supply chains open. This project investigated the use of supply chains to remove processed waste from disaster areas.

Implementation of Buy-Back Programs

A buy-back program is an effective way to stimulate a circular economy. Buy-back programs reward individuals for returning waste to specified locations. Primarily, buy-back programs serve to incentivize proper disposal of waste goods so they can be processed into new materials. Newly processed materials are regularly sold to private vendors in need of resources that can be reprocessed into a wide array of products. Several private companies operate plastic buy-back programs, such as “The Plastic Bank,” that serve as potential models for buy-back programs.[10] Companies that currently flourish within this industry demonstrate that environmental sustainability can be profitable.

Buy-back programs are present in many well-established cities. For example, Mumbai, India, implemented a buy-back program by slightly increasing prices on recyclable materials.[11] Upon returning recyclable waste, the monetary compensation received was the difference between the original price and the increased price. This effectively raised costs on those unwilling to recycle but did not impact those who already recycle.

This program saw great success that helped to clean Mumbai’s streets, beaches, and drainage systems. Before the buy-back program’s implementation, the city overflowed with recyclable waste. Since this change, Mumbai has seen drastic improvements in urban cleanliness.

Figure 2:Before (left) and after (right) clean-up of Mahim beach, Mumbai, in July 2018[12]

Numerous states within the US have bottle deposit laws, whereby consumers who return used bottles receive monetary compensation.[13] This system is a partial buy-back program focusing on one specific type of waste. These cases in Mumbai and the US should serve as examples for effective buy-back programs. However, the lack of waste management awareness and damages to road networks could serve as potential barriers for implementing waste management systems at disaster sites.

Waste Management

There are many forms of waste processing, including landfills, incineration, recycling, and composting. Waste processing methods that utilize repurposing, reuse and recycling systems are optimal. Only after those systems have been exhausted should solutions such as landfills and incineration be considered. Recycling can be performed on a variety of materials. For example, the Hewlett-Packard Company (HP) in 2016 collaborated with Thread International to develop the First Mile Coalition, seeking to turn plastic waste into new products. Nate Hurst, Chief Sustainability and Social Impact Officer of HP indicated, “This initiative supports our overall efforts to reinvent the way we design, manufacture and recover our products as we shift toward a circular and low-carbon economy.”[14] The First Mile Coalition investigates methods of recycling plastic into forms usable in HP products, most notably ink cartridges. Privatized initiatives such as this benefit the company’s public relations to consumers and may spur additional initiatives in competing companies.

Effective waste management is a critical part of developing a circular economy. Many aid organizations leave waste management up to the region's existing infrastructure. However, existing waste management systems are often severely crippled following natural disasters, while these systems are often insufficient before a disaster. Waste management has two main parts, waste collection and waste processing. Multiple years have passed since the humanitarian crisis in Haiti, yet Haitians are still struggling. Haiti, a developing nation, was unable to collect and process much of the waste left by humanitarian organizations. Figures 3 and 4 were taken in Haiti five years after the earthquake of 2010 and illustrate the extent of the crisis faced by Haitians.

On January 21, 2010, the White House released a statement that over a million water bottles had been delivered to Haiti within the first 11 days after the earthquake.[17] This influx of plastic, with no means to recycle on the island, led to a disastrous buildup of plastic waste as shown in the figures above. The waste buildup shown in Figures 3 and 4 demonstrates the need for efficient waste management systems in disaster areas. Without efficient systems, waste will rapidly build up.

Figure 3: A Haitian's house located 5km outside of Port-au-Prince, surrounded by waste. [15]

Figure 4: Large piles of plastic bottles found outside of Port-au-Prince.[16]

Waste Collection

Multiple forms of waste collection exist around the globe. Commonly found collection practices rely on a pickup and a centralized drop off method.[18] Centralized drop off systems offer consolidation of waste to a centralized facility. In this waste collection method, people bring waste to a centralized facility where it is collected and processed. Centralized drop off systems are common around the world, especially in countries that fail to implement proper waste collection for their citizens.[19] In these locations, planned pickup systems display inefficiency since they require workers to travel, collecting waste. Pickup methods vary as mobile compactors can be used to consolidate waste; in developed cities the most common form of this is waste collection vehicles. The removal of waste from a location does not mean that the waste has been effectively and efficiently processed. Waste within the collection vehicles still requires delivery to a waste processing facility. The pickup method depends on scheduled pickup routes with the addition of labor. During a disaster existing infrastructure may be heavily damaged, as such disaster sites may have implemented successful centralized drop off methods which worked prior to the disaster. There has been limited success regarding the implementation of pick up methods during and following the impact of a disaster.

In Haiti, there were attempts to organize a waste collection effort. This collection effort began long after waste was already being produced, leading to a massive buildup. Proposed collection systems typically will start clean-up as soon as goods are consumed, to minimize buildup. Figure 5 shows the clean-up effort in Haiti to give a sense of scale. These workers are looking mainly for recyclables.

Figure 5: A clean-up van attempting to clean-up the areas around Port-au-Prince in 2015.[20]

Figure 5 shows Haitians cleaning up waste left over after the disaster response. As seen in this figure the pickup method is extremely inefficient, requiring many people to cover a small area, especially if waste is left to pile up as it was in Haiti.

Waste Processing Methods

There are several unique ways to process waste. The most common methods include reuse, composting, recycling, and landfill. Landfills are plots of land designated for the burial and consolidation of large waste piles; these plots of land serve as repositories. While possible to dispose of waste in landfills, it is extremely wasteful to place recyclable materials in a landfill, let alone the hazardous chemicals that may be left untreated. Landfills are an inexpensive waste processing method but landfill use ruins the quality of any usable goods and potentially causes irreversible environmental damage. These methods also facilitate linear economic models. Recycling is more ecologically friendly and has an output of a usable product, facilitating a circular economic model, as seen in Figure 6.[21] Figure 6 illustrated the aspects necessary for a circular economy that include: reformation, reduction, reuse, and recycling.

Figure 6:A map of how circular economies function.[22]

Recycling utilizes expensive processing facilities that can only process certain forms of waste. Composting has many of the same benefits of recycling with two major differences. Composting is an inexpensive option, though it can only be performed on organic waste.[23] Reuse is another waste processing method that facilitates a circular economic model through maximizing the utilization of existing products. Reuse of material goods for new purposes is critical for minimizing the environmental impacts of consumption. Through minimal processing, many forms of waste, from plastic packaging to metal cans, can be used in many creative ways once their main purpose is served. Plastic bottles, for example, can be made into many things from small organizational tools to building materials.[24]

Project Description

This project investigated the feasibility of an effective solid waste management system for disaster areas. Several systems were proposed to USAID for implementation at disaster sites. These systems contain methods for both collection and processing of waste produced locally during the humanitarian relief efforts. Proposed systems sought to encourage the reuse of goods that can serve a new purpose in their current form. This project accomplished this goal by proposing ways to optimize waste management in disaster areas, especially those in regions that lack infrastructure to efficiently process waste. Proposed systems sought to minimize the reliance of aid programs on the current ineffective waste management systems like landfills. Lastly, the project must follow guidance provided by USAID.

Investigating Waste Management Systems

An effective waste management system is critical for developing a circular economy. This project analyzed previous disasters to look at waste management methods used in various disaster sites. The team focused on the processing of non-hazardous wastes, thus limiting the variation of designs needed. Information gathered was used to investigate the feasibility of new solid waste management systems in disaster areas.

This project proposed new solid waste management systems for disaster areas with guidance from humanitarian assistance workers. Our project focused on employees at USAID and partnered organizations. These employees provided vital firsthand experience from workers familiar with the limitations and successes of current waste management systems. Humanitarian assistance workers provided a firsthand account of past disasters and recovery efforts. This project required information about six main topics:

1. Methods of solid waste collection and processing that are currently being used at disaster sites;
2. The limitations of current solid waste management methods;
3. Types and quantities of typical humanitarian waste;
4. Tested ways to reform waste management systems;

5. Feedback that assistance workers have on current waste management systems;

6. Effectivity measurements for disaster area waste management.

This information was collected and analyzed in four main ways. First, information about past waste processing methods was gathered through literature reviews and semi-structured interviews. Second, the information gathered was analyzed to determine the expectations for modern disaster area waste management systems. Third, information from literature reviews was used to identify methods for implementing circular economies, particularly those in disaster areas. Finally, analysis of this information was used to determine the characteristics of new solid waste management systems that facilitate circular economies. The flowchart in figure 7 maps the methods used to collect data, and the information gathered from these methods.

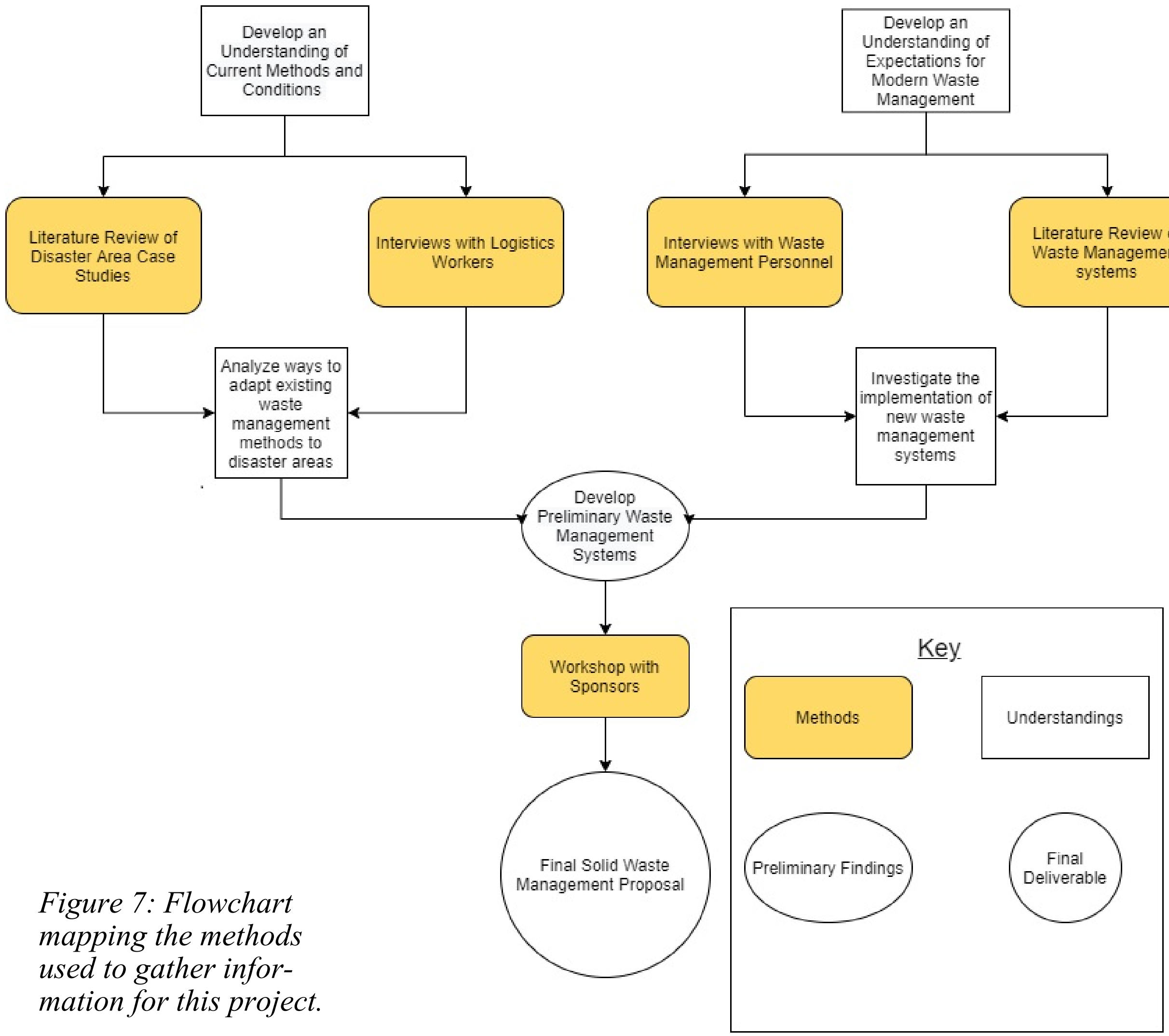

Figure 7: Flowchart mapping the methods used to gather information for this project.

Current Waste Collection and Processing Methods

Solid waste management has three main parts, waste collection, waste processing, and waste reduction. A true circular economy requires each part of waste management to be carried out efficiently. As such, it was critical to analyze the strengths and limitations of current waste collection and processing systems. The team studied current waste processing and collection methods employed in disaster areas to determine their characteristics. The team studied non-disaster area waste management systems to find new technologies that could be viable in a disaster setting. This study was conducted using two main methods: semi-structured interviews and a literature review.

The team conducted semi-structured interviews with humanitarian assistance workers, at USAID and Samaritan's Purse. The interviews conducted with Samaritan's Purse employees served the initial goal of learning about current solid waste management systems and potential obstacles to new systems. An interview was conducted with David Bock, the International Disaster Response Manager at Samaritan's Purse. (See Supplemental Materials Appendix D.4) The analysis of this interview allowed the group to predict the effects of solid waste management in disaster areas and learn about how proposed systems could apply to waste generated by USAID and other humanitarian organizations.

Interviews were also conducted with Mr. John Lamm, as well as Ms. Tracy Wise and Mr. Frank Broadhurst. (See Supplemental Materials Appendix D.1 & Appendix D.2) These USAID employees provided firsthand accounts of different disaster areas and a recollection of solid waste conditions during recovery efforts. The purpose of these interviews was to investigate criteria for a successful solid waste management system. These criteria will be discussed in future sections.

The second method implemented to collect information was a literature review. This literature review examined case studies to gather supporting information about current waste management processes in disaster areas. The team analyzed multiple case studies about disasters in Haiti and studies documenting waste management systems used in other sectors, for example, the cruise ship industry. These case studies were analyzed to investigate the performance of different solid waste management systems. This literature review also provided analysis of waste management systems used in other sectors. This allowed the group to determine their feasibility in disaster situations prevalent in humanitarian assistance efforts.

Developed Waste Management Solutions

To address the problem of excessive waste at rapid onset disaster sites, the research team investigated the implementation of circular economic structures at these sites. This economic model will allow a cyclical flow of materials between goods and waste. This project proposed solid waste management solutions to process the waste created as a result of humanitarian assistance during disaster recovery efforts. Proposed waste management practices were those that prioritized reduction, reuse, and recycling of materials. To support the circular economic structure, the research team investigated waste collection and processing methods that might be applicable to rapid onset disasters. While analyzing these disasters, the team chose to focus research in Haiti, as one of the poorest nations in the Western Hemisphere, and a nation battered by natural disaster, many waste management solutions applicable here will work in other places around the globe. From this research, limitations for implementing waste management solutions were determined. These limitations are outlined in following sections.

Important Limitations

Accomplishing a goal of proposing solid waste management solutions for rapid onset disaster sites requires a focus on the limitations present in disaster settings. The main limitations on which this project has focused include: a lack of workers or electricity; a lack of water; weak supply chain connections to the outside world; and a lack of widespread concern for environmental sustainability. These limitations were discovered through the research conducted on case studies of past natural disasters and the subsequent global humanitarian response. Each limitation is defined in the following sections to outline what should be considered before developing new disaster waste management systems. Each disaster is somewhat unique, involving different forms and quantities of waste. No single solution can be suitable for every disaster setting, but it is imperative to understand the limitations in effect when deciding on new disaster area solid waste management solutions.

Human-power and Electricity

A lack of human-power and electricity may become a major concern for waste processing on site. Many waste management solutions that were discovered were deemed not feasible due to these limitations. In the immediate aftermath of a disaster, the focus is on saving lives and assisting with victim recovery, hence the lack of concern for waste particularly during the rapid onset portion of disaster response. When asked about the importance of waste management during a Rapid Response, David Bock, the International Disaster Response Manager at Samaritan's Purse Canada, noted, "The priority, particularly in the immediate aftermath of a disaster, is to save lives." Research sources confirmed this priority, but with one important note: processing waste as it is generated is critical for improving the quality of life and even saving lives in the long term. While most personnel are, and should be, devoted to saving lives immediately, designating a few workers to operate waste management systems is crucial for long term disaster recovery. Proposed waste management solutions should utilize, but minimize, the necessity of human-power dedicated in the short term to waste solutions. It is common for local infrastructure to be incapacitated in a disaster situation; therefore, a constant and reliable supply of electricity cannot be guaranteed. A lack of electricity places focus upon machinery that can be powered using hand cranks and levers. Simple machinery decreases the necessity for skilled workers. Simple machinery provides the opportunity to change the processing rate of material to match waste production rates without consuming vital resources such as electricity.

Water

The most vital resource of all, and the most lacking at a rapid onset disaster site is potable water. Water plays critical roles in cooking, cleaning, and hygiene. Water is typically provided using purification machines like the one shown in figure 8.[25] With water resources often stretched thin during a rapid onset disaster response, it is critical that any water present is used for more pressing issues such as food preparation or hygiene. Hence, waste management solutions should drastically limit, if not avoid, the usage of water during processing. For this project, the usage of water was completely avoided with the goal of making waste management systems as unobtrusive as possible to other aspects of disaster response. This is a common theme to which this project gave priority.

Figure 8: WASH Water Purification Station- This station was found at a Disaster site in Haiti; stations like this are used to purify water after a disaster[26]

Reliance on Ground Transportation Networks

During a disaster, links to the global market such as ports, airports, roads, and railroads may be destroyed. This lack of connection to the rest of the world serves as a limitation on many aspects of a humanitarian response, particularly solid waste management. With a lack of transportation infrastructure, it is critical that any machinery is easily deployable and will fit with other materials already being transported to a disaster site. Figure 9, shows a road after the earthquake in Haiti in 2010. Even in a best case scenario many roads and other land networks are impassable after a major disaster.[27] The waste management solutions that our project is proposing seeks to limit reliance on the outside world, particularly for shipping resources in and out.

Figure 9: Destroyed Infrastructure in Haiti after the 2010 Earthquake[28]

Environmental Sustainability

Environmental sustainability is critical for waste management systems that follow circular economic principles. In terms of waste processing, environmental sustainability requires minimizing the impact of processed waste. As such, waste should be processed into a form where it will not have a negative impact on the environment. For example, landfills often leach chemicals and waste particles into the nearby soil and water sources, posing a health risk to people and wildlife in the area. Some burning processes spew material into the air. If done properly this outflow of materials can be limited with air filtering technology. Waste management solutions proposed by this project seek to be as environmentally sustainable as possible by focusing on reuse and recycling methods that require minimal processing. Minimizing processing encourages solutions that can be performed in a disaster context with few imported machines.

Solid Waste Management Criteria

From analysis of the limitations that might be imposed on a solid waste management system in disaster sites, there remains the necessity for it to be evaluated with criteria to determine how successful a system might be. A list of these criteria include: 1) Processing rate; 2) Processing diversity; 3) Reliance on ground networks; 4) Resource Consumption; 5) Operating Cost; 6) Environmental Sustainability; 7) Deploy-ability. A discussion of each of these criteria follows.

Processing Rate

The processing rate refers to how much waste is being processed in a given period of time. Due to the rapid onset nature of disaster response it was important that the solutions proposed allowed waste to be processed quickly. Failing to account for this could lead to a solution being suggested that cannot handle the volume of waste produced. This would cause waste to pile up and remove the concern of addressing the waste problem.

Processing Diversity

Secondly, the processing diversity of the solution was taken into consideration. Processing diversity indicates how many different types of waste can be processed using a specific solution. Waste management solutions that can process a variety of waste are optimal because they allow a wider range of products to be shipped in. Conversely, solutions that only process a specific type of waste become ineffective when there is little of that specific type of waste. These waste management solutions, if implemented, will limit the type of materials that can be sent into a disaster area. If waste that cannot be processed is collected, it will only exacerbate any existing waste management problem.

Reliance on Ground Networks

The degradation of roads and transportation routes during extreme circumstances make the challenge of delivering aid to those located in remote regions stressful. As the group primarily focused on rapid onset disaster response, it is probable that roads might be inaccessible. It is important to understand the quality and quantity of suitable methods of transportation that exist within a disaster area. This concept follows two main principles: redundancy of duplicated assets and flexibility to discover alternate routes or transportation methods.[29] Redundancy offers the need for additional transportation routes; should a route prove inaccessible backups will be needed. As humanitarian organizations combat this impasse, the ability to receive solid waste from inaccessible regions alludes to a larger dilemma. If there is a certain lack of transportation routes to settlements, supplies may not be trucked overland at all. Through airdrops, areas that had proven inaccessible for trucks now represent a viable solution. Airdrops should only be considered when all existing transportation methods have been exhausted. The solid waste management system under consideration must have several tracts for possible deployment to such regions. Should roads that are integral to the shipping of supplies remain effective, the solid waste management system (SWMS) can be strategically deployed at a distribution center. If large scale operations are not feasible, smaller, compact systems should be deployed to more local regions. The delivery of humanitarian supplies should continue but the viability of transporting the solid waste might prove impractical. As the relief effort continues into the 2nd and 3rd month, the improvement of road conditions might determine a shift from the localized approach to a more centralized operation at a distribution facility.

Resource Consumption & Operating Costs

There is an expectation that rapid onset disaster relief teams are unable to utilize pre-existing sources of power. For integral parts of the relief effort, such as maintaining communication for those on the ground with people around the world, generators may be brought in to satisfy these requirements. Proposed solid waste management systems must limit the need for electricity as much as possible. A system that relies heavily on electricity will not be viable within the first few days of the relief effort. A proposed system might not even receive electricity until many months later should there prove to be substantial damage to the existing power grid. Additionally, if there is no existing power grid where a disaster takes place, the operation of this system will sap vital resources if implemented.

Labor Limitations

SWMS will face labor limitations; this can be resolved through designation. Designating assistance organizations to work with the solid waste management system will minimize supervision required. It is assumed that they will receive proper training and instruction on how to operate the system, if not there should be a certified individual capable of training designated workers. A question remains, who is in charge of managing waste? Outsourced laborers will require supervision is to safely operate some waste management systems. Operating costs of systems that are dependent on external manpower will vary with wages and transportation fees. Costs should be relatively low as aid workers from humanitarian organizations or outsourced labor to those affected would be designated to work on the SWMS. The cost of a 3rd party to operate this system will be the largest factor, more so if a team is required compared to a single individual. Contracted workers may either operate the machinery themselves or be trained to serve in a supervisory role. Contracted workers need not be skilled, however they should undergo basic training on the systems they are operating. This is dependent on the system itself and what conditions are required for safe operation.

Environmental Sustainability

The lack of sustainable waste management in current humanitarian relief efforts gives rise to the problem humanitarian organizations are currently faced with, the inability to control and handle solid waste as it arrives onsite. It is difficult to extrapolate estimated amounts of waste within the first seven to ten days and the first month overall. It is only after the first month that assistance relief administrators truly understand what additional supplies are required to meet the needs of those on the ground and those receiving assistance. Plastic packaging accounts for most of the humanitarian waste. Plastic far outweighs the cardboard and metals shipped in conjunction with aid suppliers around the world. The inclusion of large-scale plastic packaging increases the severity of this issue. Many of these plastics cannot be reused and need to be recycled. Attempts to mitigate plastic packaging in all forms will reduce possible pollution of these materials in the environment. The collection and sorting of plastic packaging, hypothetically, should be relatively feasible. As supplies arrive, they are unloaded and distributed should this occur at a centralized distribution facility. A centralized distribution facility is an area where humanitarian organizations will gather forming a forward operating base. The plastic packaging should be collected and deposited at a designated location. An alternative to depositing waste at a centralized facility is a decentralized approach where waste is processed onsite where it is generated.

Deployability

Due to the nature of rapid onset deployment, solid waste management systems (SWMS) must be ready to be shipped at a moment's notice. The setting of the disaster will dictate the structure of the resulting solid waste management system. This refers to the idea of having multiple systems that can be both complex for large scale recycling and simplified versions for smaller scale disasters. Large scale systems can take considerable time to set up but, if they arrive in a timely fashion following the initial response, these systems can have an effective impact. Simplified versions of SWMS can be deployed in a wide array of settlements and villages throughout the disaster. The deployment of smaller systems would hypothetically counteract their limited effectiveness compared to a larger scale system. For each disaster that occurs there needs to be an analysis of waste streams to determine the exact size, scope, and scale of SWMS that is needed. The larger system in question would see faster deployment to the forward operating base as it can begin processing plastic packaging as the supplies are distributed. In terms of a smaller system that operates with a decentralized approach it will depend on the speed of arriving at villages/ settlements to distribute supplies.

Proposed Waste Management Solutions

As discussed, this project has developed criteria for analyzing waste management solutions. This project also investigated solid waste processing systems for plastic, cardboard, and metal packaging. Respectively, these materials make up 80%, 10%, and 10% of the packaging waste generated by humanitarian organizations as noted by Greg Rulifson during a meeting on the packaging of humanitarian goods. This clearly denotes plastic as the major contributor to humanitarian packaging waste. As such, this is where research was focused. Proposed waste management solutions and waste streams are analyzed in the following sections with respect to the criteria and limitations discussed throughout this paper. Methods for shipping out waste are also evaluated using these criteria and limitations as these methods have been used in some disaster areas. The flow chart shown in figure 10 should be used as an overview of waste processing methods and to determine which of the proposed methods for processing plastic is more applicable in different situations.

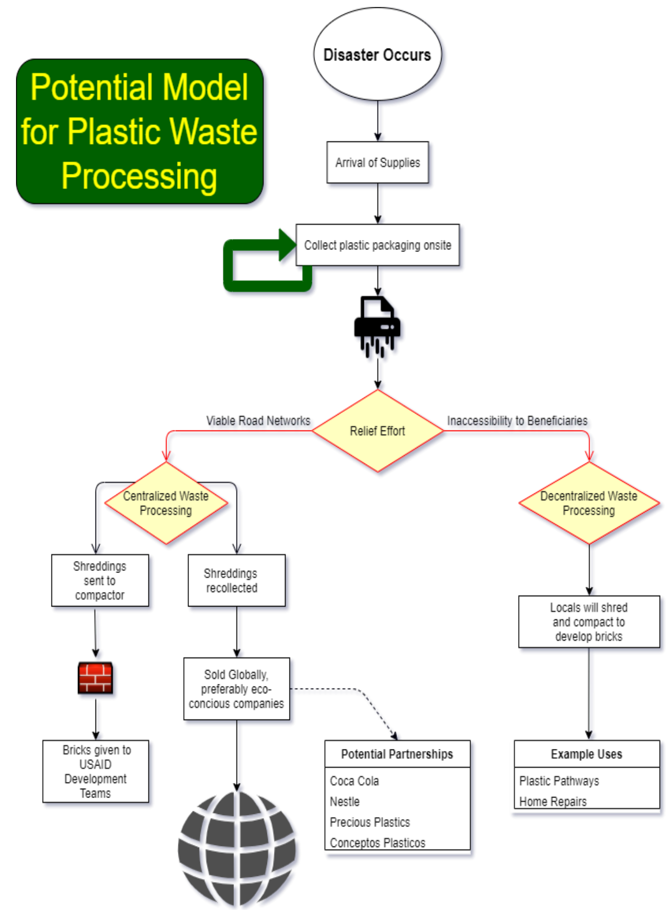

Figure 10:A flowchart of plastic processing methods

Plastic Packaging

Plastic packaging is the primary contributor to waste in humanitarian aid relief efforts, plastic accounts for 80% of waste by weight. It is critical to analyze why this waste is so prevalent. Before supplies are shipped, typically on pallets, there needs to be appropriate plastic packaging to protect the goods while in transit. After the supplies are placed on the pallet, they need to be secured using a band, or in most cases, shrink wrap. USAID has switched to a water purification system rather than relying on plastic bottles in an effort to reduce waste. USAID contributes, depending on what circumstances dictate, ample water purification systems for the affected people.

Figure 11:A UNICEF WASH Water Station-Stations like this provide water to remote areas after a disaster[30]

Had USAID not shifted towards this technology, the plastic waste at disaster sites could have exponentially increased, not solely from USAID but also from other contributing humanitarian organizations supplying water bottles. By transitioning to this alternative in 2008, USAID demonstrated that it is possible to reduce plastic waste at humanitarian assistance sites.[31] USAID's transition to this technology is a monumental step forward. Two years later, in 2010, Haiti would experience a 5.9 magnitude earthquake. The United States was one of the first responders; USAID was joined by the United States Air Force to procure and distribute supplies. CNN reported: " A C-17 cargo plane left Pope Air Force Base in North Carolina shortly after noon, and three hours later dropped 40 pallets -- or 'bundles' as the Air Force refers to them -- holding bottled water and Meals, Ready-to-Eat, or MREs, on a field just north of the Port-au-Prince airport in Haiti."[32] The amount of plastic packaging may seem minute within a single pallet, but cumulatively organizations are sending thousands of pallets full of plastic, to the island. Haiti had long been faced with a failing SWMS. The exponential amount of plastic waste that remained after recovery effort ceased gave rise to an environmental disaster. To this day (2020) plastic waste from the 2010 relief effort can be found, littered throughout the environment. Noticing the disasters that were caused by plastic waste, USAID began using water purification rather than water bottles in an effort to reduce plastic waste production. Initiatives like this are key to minimizing plastic waste in the future.

Humanitarian organizations realize the importance of developing new and innovative ways to mitigate the widespread use of plastic packaging. While critical to reduce waste creation, it is also critical to process generated waste. Conceptos Plasticos is a Columbian company that produces plastic bricks from plastic waste collected from disaster sites and recycling initiatives. This technology produces bricks that, when used together, create a sturdy structure. The background in Figure 12, depicts the plastic bricks developed by Conceptos Plasticos, in partnership with UNICEF.

Figure 12:Plastic Brick-Bricks made from plastics can be used globally as a way to minimize waste[33]

This design makes the structures simplistic and easy to piece together. Plastics manufactured into an assortment of goods have a long-life expectancy, sometimes upward of 500 years, and these bricks have a similar life span. Plastic bricks are eco-friendly, and are non-toxic to those who reside within structures produced from them. An image of such a structure follows. Additionally, these structures are typically resilient to earthquakes, are typically cooler than the outside temperature and are fire retardant.

The construction of these structures may not be possible in a rapid onset disaster effort; however the shredding of plastic and brick production can be implemented. Bricks should then be provided to development teams for use as building materials. Plastic brick making technology could revolutionize plastic waste processing in the immediate aftermath of a disaster. Including supplies that are distributed to those in need, the packaging used to protect those goods will also serve the purpose of supplying assistance. If not wanting to process plastic themselves, USAID should consider a partnership with Conceptos Plasticos to help treat plastic waste sustainably and efficiently. If a partnership with Conceptos Plasticos is not available, there are many other private companies that are willing to purchase the shredded plastic packaging.

Figure 13: Plastic Brick Building- A building built through a partnership between UNICEF and Conceptos Plasticos[34]

Conceptos Plasticos utilizes larger machines, deployable to distribution centers accommodating large percentages of plastic packaging and shrink wrap. Alternatively, smaller machines, like the one shown in figure 14, can be deployed to disaster sites to get a jump start on plastic processing. These smaller systems do not require electricity but produce a lower quality brick. Smaller scale shredders and compactors should be implemented particularly where road and land networks are not sufficient to allow larger scale waste collection and processing.

Figure 14: Plastic Brick Factory- The machinery needed for industrial quality brick production can be seen here. [35]

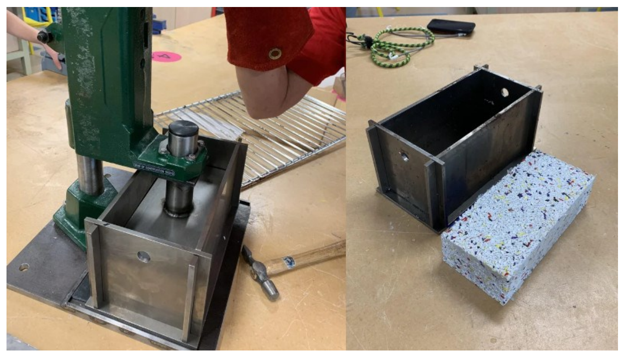

Figure 15: Compact Plastic Brick Production - The machine above can be used in remote areas to create plastic bricks with little manpower or electricity[36]

Another potential waste management solution is a partnership with an organization such as Precious Plastics. This organization is based in the Netherlands with a goal of reducing plastic waste. This is accomplished by boosting recycling and repurposing plastic waste, through the Precious Plastic Universe. The Precious Plastic Universe is a global network with the purpose of providing plastic recycling methods to sites around the globe. Precious Plastic members gather plastic waste and deliver it to a collection point. The collected plastics are then sent to a recycling workspace where they are transformed into new products, such as tiles, flower pots or cups.[37] The image shown in figure 15 is of a Precious Plastic workshop where plastic waste is shredded and used to create products like the plastic chair. A partnership with Precious Plastic will allow USAID to process plastic in Precious Plastic's global network, into goods that could either be sold for a profit or given to development teams and used as part of a recovery effort. If a partnership is not feasible, USAID should incorporate machines like the ones shown in figure 16 into distribution centers. These machines will help transform plastic waste into a variety of usable products. With either approach it is critical to sort plastics on site as mixed plastics result in a weaker final product. Sorting on site will facilitate a larger demand for shredded plastic waste and repurposed plastic products. Products processed, even in part, at disaster sites may be viewed as collectable.

Reuse & Composting

Cardboard packaging forms one of the major sources of waste this project sought to help process. To develop solutions for cardboard waste, research was conducted to gain a better understanding of the sources of cardboard present at disaster sites. The majority of cardboard comes from cardboard boxes used to package goods as they are shipped into the disaster site. Cardboard makes up around 10% of the packaging waste generated by weight as noted by Greg Rulifson. While cardboard does not make up much of the

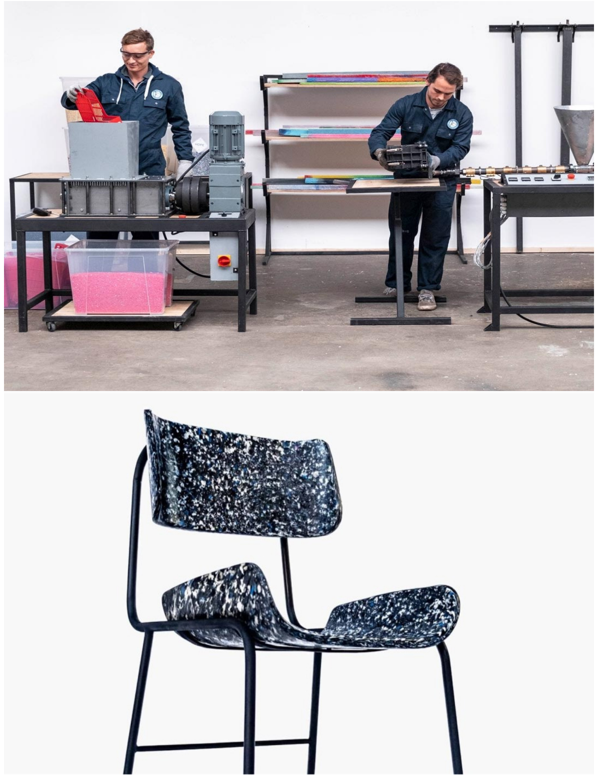

Figure 16: Plastic Chair - Plastic waste being shredded and a chair made from shredded plastic waste[38]

packaging waste by weight, it is critical to remember cardboard is primarily used for its light weight and durability. This study proposes two methods for dealing with cardboard waste. First, develop simple instructions that can be printed onto cardboard packaging with instructions for how to reuse it. Secondly, composting cardboard and other paper products can be used as a long term solution for sustainably dealing with waste. This is accomplished by creating composting piles where organic materials can break down over time into a nutrient rich compost pile. Each of these solutions is analyzed in the following paragraphs using the criteria outlined in the previous sections with full descriptions found in Supplemental Materials: Appendix A.

One solution for eliminating cardboard waste is through reuse. To reuse cardboard boxes, this project suggests printing instructions for how to fold and cut different shaped and sized boxes into useful containers. Reshaped boxes can be turned into goods like makeshift backpacks or carrying cases. Some sample instructions can be found in the Supplemental Materials: Appendix C section of this paper. The following image is a sample backpack that could be created by people impacted by the disaster. The backpack shown is created by MDPI, can be made using only a cutting tool, a few small pieces of tape, and the plastic ties used to hold the boxes together during shipping.[39]

Figure 17: Cardboard Backpacks developed from Assistance Packaging[40]

While some may not have the time or need for products like the ones outlined here, even a few people reusing cardboard packaging may go a long way towards reducing waste. The processing rate of this method is semi-rapid for what is being created, the backpack above was created over the span of 15 minutes. Tests from MDPI determined backpacks made in this style are capable of carrying 20kg for sustained periods of time with loads up to 30kg for short periods of time.[41] This processing method should work for any cardboard box that is still in good condition. Unique instructions may be needed for different sized boxes, however each box can be made into different products from carrying cases to sandals. This waste management solution also requires no access to external supply networks and minimal resources. A few small pieces of tape that are needed should be added into the pack so that construction is as convenient as possible, this is the only deployment required for this method. The methods used to generate these boxes require very minimal operating costs, just the cost to print instructions and the minimal cost for extra tape. This method is very environmentally sustainable, expanding the life of cardboard long after its initial purpose is served.

Another method that was investigated for cardboard processing is composting. A compost pile creates fertile soil valuable for agriculture. This processing method is extremely slow as it requires decomposition of waste materials however this process accelerates the longer processing sites are set up. A compost pile can also easily be expanded to contain large volumes of material. As such this method was determined to have an acceptable processing rate. Many cities around the globe have large compost piles that can handle much of the area's waste in a short period of time. While a rapid onset disaster site operation will not reach this scale, any organics left will break down over time and eventually have a benefit. The wide processing diversity provides an important benefit of this method; any form of organic waste will eventually be broken down. The main cost of this processing method comes from the loss of land needed to house the compost pile. An ideal site would be relatively dark, wet, and far away from major settlements. This cost is offset by the payoff of compost for agricultural uses. The sites this can be accomplished at are semi-deployable. Either one large compost pile can be used for a disaster site, or many smaller, spread out, sites can be used. This method requires minimal manpower, mainly for "turning" the pile with a minimal reliance on outside resources.

Compacting Metal

Humanitarian relief efforts also rely on the use of metal containers. Metal packaging is not as widely used as plastic or cardboard packaging, but is present nonetheless. The team's investigation found that metal cans, mainly aluminum cans, are used for food items such as chicken, mixed vegetables, tomato paste and corned beef. Aluminum cans are 100% recyclable and can be recycled indefinitely. [42] USAID relies on a mix of steel, aluminum, and tin in efforts to deliver goods to disaster sites.

Proposed solution for managing metal packaging waste is compacting and shipping. This method involves collection of metal waste, compacting it and shipping it to an aluminum processing facility. Compacting aluminum is accomplished through use of a baler machine. This machine crushes the aluminum cans into easily transportable, dense 3D structures. Figure 18, shows aluminum cans after going through a baler. Alternately, aluminum cans could be crushed manually and packed for shipping.

Compacting and shipping of waste is not sustainable for other packaging materials due to the lack of demand for their recycled products. Aluminum, on the other hand, is one of the most expensive metals because it is difficult to extract from its ore, requiring large amounts of electricity to properly extract. This waste management solution negates the need to extract aluminum from ore, making it inexpensive and attractive to outside buyers. Removing the extraction phase makes the production of aluminum more environmentally sustainable.[44] Compacting and shipping waste has a processing rate only limited by the quantity of ships that can get into port. Large quantities of aluminum cans can be compacted and shipped to large facilities for recycling. However, this method relies on the ground networks to bring the compacted waste to the ports. Shipping is also a heavy pollutant, reducing the environmental sustainability of this processing method.

Figure 18: Aluminum cans compacted with a baler machine.[43]

Shipping Waste

One solution being considered to deal with humanitarian waste during the rapid onset response is compacting and shipping waste. This solution has several benefits as well as several negative aspects. A compacting and shipping system is notable for having a broad processing diversity. Such a system would rely on reverse logistics to remove waste from disaster sites as new assistance is being supplied. All three of the main waste forms this project investigated can be processed through compacting and shipping to other nearby ports to have the waste more fully processed. Once waste is sorted into different groups including metals, cardboards, and different groups for each plastic, the materials must then be cleaned, compacted, and prepared for shipping. As part of the shipping process it will be critical to find a nearby port willing to accept the waste. In order for this method to be economically sustainable, processing plants near ports must be willing to pay for the waste, which is not feasible for some waste streams. Cardboard, for example, does not typically have a large amount of value, with as little as $5 per ton for used cardboard.[45] Metals and some plastics, however, may sell for enough to be profitable in some markets as previously discussed.

One major issue with shipping waste is the extreme reliance on external markets and supply chains which are frequently impaired by a disaster. This method of waste processing also has a slow processing rate due to the necessity of ships to transport waste. Ships are often slowed due to potential damage to ports. Other methods for exporting waste include by road or by plane. Air travel is far too expensive for this method to be viable under any feasible circumstance. Road travel on the other hand is feasible for small quantities of waste but cannot keep pace with larger waste loads. This is due to the quantity of trucks needed to transport large volumes of waste and a lack of suitable roads after a disaster. This method has high operating costs due to the necessity for vacant space on cargo ships, and machines comparable to the other methods mentioned previously. A benefit of this waste processing method is it does not rely on consumption of resources like water, designs are being proposed to minimize electricity usage, replacing it with human power.

Shipping waste is not the most environmentally sustainable solution. Transporting goods by boat currently makes up 18% of some key pollutants contributing to climate change including carbon monoxide, and sulfur dioxide.[46] Cargo shipping was also responsible for 2.2% of global carbon dioxide emissions in 2012 according to a study done by the International Maritime Organization.[47] In order to make this method more environmentally friendly it is critical to minimize cruising time which can make up as much as 99% of engine emissions from cargo ships.[48] This can be done by moving between ports that are close together. It is critical to choose ports that will accept waste and are close to the disaster in order to remain somewhat environmentally sustainable. The environmental benefit gained from recycling in established processing plants, however, will likely be outweighed by the negative impacts of shipping, using any standard shipping methods. While it is easy to view shipment as a full waste management solution it is critical to remember that all shipping does is move waste around, waste that must still be handled properly after reaching its destination.

Once waste has left the disaster site a new issue arises: where should it be shipped to? A study of Mediterranean ports found that 82% of ports in the region offer waste management in the form of landfills. Only 71% were found to offer basic recycling for plastics and metals.[49] Other sustainable processing methods were almost nonexistent at most ports. Further investigation is needed into ports globally that will accept waste; no compiled list of ports that accept waste is readily available but is critical for determining where to ship waste post disaster. Having a list of ports that will accept disaster waste will expedite the processes of determining where it is possible to ship waste post-disaster.

Proposed Waste Management Solutions

This project has investigated a combination of waste processing methods with emphasis on reusing, recycling, and composting in an effort to minimize the amount of waste that goes into landfills. Proposed waste management systems have incorporated the reuse of goods that can serve other purposes in their current form. Recycling systems were proposed to process other inorganic waste such as plastics and metal. Composting will be used to process the organic waste, such as compostable packaging.

The new proposed systems strive to be environmentally and economically sustainable. In recent years, the need for such systems has grown. As the frequency and severity of natural disasters continues to rise, it is imperative to find sustainable waste management solutions for disaster areas. It is extremely important that the humanitarian assistance community accept the underlying issues that possible assistance results in continued harm.

One limitation of implementing the technologies that have been proposed is public concern. Concern about the environment is a recent change among humanitarian actors, it is critical to foster this change and supply means to make it easier to help. As noted in many interviews conducted for this project, the emphasis is and must, remain on saving lives. That being said, it is critical that humanitarian actors come to the realization that being environmentally sustainable will save countless lives throughout recovery efforts and long into the future.

To address this issue, the team focused their approach on literature reviews and interviews to gather information to develop potential waste management systems. This approach allowed for the group to rapidly gather large quantities of information from humanitarian actors and other global organizations.

This project has provided a flow chart to assist with the choice between which waste management solution to implement. Solutions will be selected by USAID Logistics Personnel based on the types of waste present and condition on sites discussed in the previous sections. The requirements of each design have been specified throughout the previous sections and in the Supplemental Materials: Appendix A. It is important to note that there is no one size fits all solution that will work. Each disaster brings with it a unique set of challenges that will require analysis. The limitations and strengths of each solution work to complement one another, with one solution's strengths being the others' weaknesses.

A set of limitations critical for determining the feasibility of different waste management solutions were developed. This set included: a lack of ground networks; a lack of human-power and electricity; a lack of water; as well as environmental and economic sustainability. These limitations were used to determine a set of criteria necessary for a successful waste management solution, mainly: a rapid processing rate; a wide range of processable materials; minimal reliance on ground networks; minimizing resource consumption and operating costs; maximizing environmental sustainability and deploy-ability. Newly developed solutions will need to balance these criteria in order to be effective during a disaster response. Deploy-ability is a major concern when looking at rapid onset disasters and should be prioritized as such.

Recommendations for Moving Forward

The Nexus Environmental Assessment Tool (NEAT+) was developed by 33 partners within the humanitarian sector to identify issues of environmental concern.[50] The tool is used to gauge the situational status on the ground before developing a plan for disaster relief. The assessment tool developed by this project should in conjunction with a NEAT+ tool to assist with analyzing new waste management solutions and their application at disaster sites. This tool walks through the recovery processes to determine how solutions to waste can be deployed in future disaster settings. This tool should be used by USAID or affiliated organizations as an outline for looking at waste management solutions in a simple form.

This project recommends that USAID develop the machinery that is needed for the solutions previously mentioned; many of these machines already exist but must be optimized for disaster sites. After solutions are selected humanitarian aid personnel must prepare to implement the collection methods mentioned in earlier sections and in the analysis of each solution. Each solution should be developed into its own prepared kit so that machines are ready to be deployed as soon as a disaster strikes; this will be easier for the smaller machines that will fit multiple on one pallet. Larger machines will need to be optimized by USAID to fit into pallet methods, this is mainly a concern for the Centralized Brick Production Method.

The project developed unique ways to sustainably handle waste. The decision making tools produced serve to help humanitarian actors address the issue of packing waste in disaster areas. This will allow humanitarian organizations to save lives while fostering environmental and economic recovery.

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Supplemental Materials for this project can be found at https://www.wpi.edu/library

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