ANALYSIS OF POST-USE HYPODERMIC NEEDLE MEDICAL WASTE DISPOSAL

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ANALYSIS OF POST-USE HYPODERMIC NEEDLE MEDICAL WASTE DISPOSAL

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"Slowly the poison the whole blood stream fills.
It is not the effort nor the failure tires.
The waste remains, the waste remains and kills."

William Empson
Missing Dates, 1935

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SUMMARY

A cost-estimation model is created in which the disposal flow of used medical injection equipment (hypodermic needles) is analyzed and optimized to find the most desirable cost and time outcomes possible for use in developed and transitional countries. The variables of the model are the volume of waste to be disposed of, the distance from medical facility to disposal facility, the method of transport between the two, and the use of either traditional metal needles with a plastic and rubber syringe or a proposed, all-plastic needle and syringe system.

By varying each of these inputs, a recommendation is made for each combination based on the most cost-effective and time-effective outcomes possible. In nearly every case, the all-plastic needle required less processing time and has a lower cost to reprocess than its traditional metal needle counterpart. The all-plastic needle and syringe unit is recommended due to the simplification of reprocessing stages.

For all practical volumes of needles considered, an animal drawn cart is the most beneficial method of transportation available. This option is most likely to be incorporated in areas where vehicles are not a practical purchase, whereas work animals and carts generally are available. An additional case is also considered in which the disposal or recycling process takes place onsite, resulting in no significant transportation requirement.

CHAPTER 1

INTRODUCTION

The amount of medical waste is increasing constantly throughout the world, raising the issue of its safe and economical disposal. The importance of an improved method for handling this waste is apparent as current landfills and burial pits begin to reach their capacity and the creation of new waste sites is met with strong resistance. An additional concern with this traditional disposal method for used medical equipment, such as hypodermic needles and syringes, is the risk of their illegal recovery and resale. Improper handling of the used syringe/needle combination dramatically increases the risk of infection from contaminated equipment.

By developing a more effective process for the disposal of medical waste, the risk of cross contamination decreases. Also, through current recycling options, a profit actually may be realized as new products are formed from the disinfected waste. This thesis explores various paths suitable for both the disposal and recovery of used syringe/needle equipment, beginning after its use and ending with its final destination, whether properly disinfected and rendered harmless in a landfill or reprocessed into a secondary plastic product. The most ideal process can be determined based upon considerations such as the type of area (rural versus urban, village versus nationwide) and the cost, which will be minimized (economic versus time).

1.1 Problem Description

As the harmful effects of needle reuse become known, namely the spread of Hepatitis and the Human Immunodeficiency Virus (HIV), organizations such as the World Health Organization (WHO) and the Safe Injection Global Network (SIGN)

strongly discourage the use of sterilizable needles and syringes (1). In many instances sterilization procedures are not properly followed, leading to the spread of disease and infection. In an effort to reduce this risk, WHO and SIGN both advocate the use of single-use, auto-disable, disposable syringes and needles. These medical devices are intended to be disposed of after only one use, and are not designed to be sterilized or reused under any conditions. A problem with the increased use of disposable equipment is the resulting increase in the amount of waste produced. The nature of the syringe/needle combination introduces a challenge in terms of currently available options for its disposal, with special concern raised over the sensitive nature of handling blood-infected equipment with such potentially harmful sharp tips.

Efficient, safe disposal methods for needles and syringes are necessary as cost requirements are always an important aspect of any program, whether in developing, transitional, or developed nations. (The main focus here is developed and transitional countries.) The needles need to be blunted or removed so that the risk of an accidental needle stick injury is reduced. This action also serves another valuable purpose in that it prevents the improper reuse of the needle/syringe combination if it were to be recovered at this stage. The entire unit also must be disinfected for the same reason.

The exact method to be employed as a disposal option depends on the area in which the needle and syringe use occurs. When they are located in extremely impoverished countries, special considerations must be taken to choose a disposal or recycling option suited for the area's labor force and energy availability. This does not always match the options available to a developed country where labor and energy requirements may easily be met. Another important aspect of the design of a disposal

method is the selection of an area to be covered. For example, an independent hospital that is responsible for its own waste treatment onsite has very different considerations (transportation, size of machinery, and otherwise) than a 100 km^2 area with multiple clinics that must be serviced jointly.

1.2 Research Goals

The goal of this research is to create a model in which every aspect of syringe/needle disposal is explored from the moment after its use until it is properly disposed of or recycled into a new product. These stages include transportation, containment, disinfection, size reduction, and reprocessing. Based on the nature of inputs to the system, such as the area to be covered and the number of syringe/needle systems recovered from that area, the ideal disposal method can be determined for various levels of rural and urban areas, as well as local and nationwide areas.

An additional goal is to explore the consequences of using all-plastic needles with existing plastic syringes, and eliminating the rubber stopper pictured in Figure 1-1.

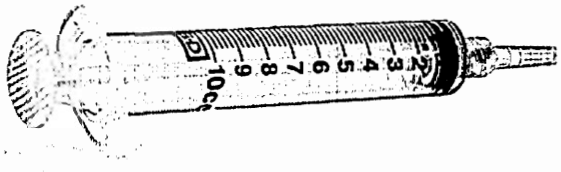

Figure 1-1: Syringe with rubber stopper

Syringes are currently available both with and without the rubber stopper in place. In units without the rubber piece, the same plastic material used in the bulk of the syringe is slightly enlarged to also act as a stopper as seen in Figure 1-2.

Figure 1-2: Syringe without rubber stopper

Disposal and recycling options for a pre-existing, all plastic system are compared to those of the traditional metal/(rubber)/plastic system in which special separation processes must be included, as well as increased capacity machines that are robust enough to process both metal and plastic. With an all-plastic needle and syringe, the entire unit may be treated for disposal together, with no need to separate material.

1.3 Summary

This chapter provided a basic overview of the project and detailed its goals. In Chapter 2, the background and motivation will be discussed and a literature review of both previous and existing work in the area of plastic recycling will be included, as well as current procedures in the handling of needles and syringes.

Chapter 3 will cover the theory portion of the project in which the entire post-use hypodermic needle flow model will be discussed in full and broken down into the techno/economic cost and the burden of disease portions. An explanation of the model,

including urban versus rural settings and traditional versus all plastic systems, will be included.

Data obtained for use in the model will be documented in Chapter 4, where a sensitivity analysis will be employed to call attention to any possible highly influential variables in the model that need to be further explored for increased accuracy. The details of the experimental procedure also will include specifications to define regions as rural or urban.

The results of the model and experimentation will be presented in Chapter 5, which will include an analysis and a discussion of each set of outcomes, comparing the results. Finally, conclusions and recommendations will be presented in Chapter 6.

CHAPTER 2

BACKGROUND AND MOTIVATION

2.1 Previous Cost Models of Injection Equipment

Due to the large impact of medical injection equipment worldwide, from preventative and curative measures to disposal concerns, a significant amount of research has been performed in the area of cost estimation. Many of these models focus on the hidden costs of needle cross-contamination caused by accidental needle sticks or through the improper reuse of needles. Ekwueme et al. (2) conducted a study in which seven different types of injection devices were compared on the basis of bloodborne pathogen transmission and economic costs. The resulting model was formulated by compiling several aspects of cost, beginning with the direct costs of purchase and usage. These direct costs included figures such as needle and syringe purchase, costs of sterilization equipment and other supplies, disposal facility rates, and labor estimates (where applicable). The second main group of cost estimates focused on the burden of disease resulting from the likelihood that the use of each injection method would result in the transmission of disease. Both medical costs and lost productivity costs were considered and included factors such as doctor visits, drug and lab fees, and resulting lost wages when the patient is no longer able to work due to disease progression. The results of the study show that sterilizable and disposable needles and syringes have the highest overall costs, by far, due in part to the lack of proper sterilization or disposal. With significantly low purchase and usage costs, the main cost factor with these systems is the extremely high likelihood of disease transmission, presenting a need for increased sterilization and disposal standards.

Other models provide cost estimates of injection intervention programs based on the method of intervention. Dziekan et al. (3) have formulated a model in which the consequences of having no intervention program are determined in terms of overall injection use and unsafe injection use. These statistics are compared to the results of a variety of programs, the first of which is concerned with the safety of injections where the main goal is to provide disposable syringes to be used for each injection procedure. The second program focuses on the appropriate use of syringes. In this case, patients and providers are involved in group discussions concerning proper injection use. A third program combines safe and appropriate use of injections both by providing disposable syringes and by fostering discussion among patients and their providers. New overall injection use and unsafe injection use statistics are found for each of the three intervention types and compared to the control group in which no program exists. Cost factors used in this model to asses the effects of the programs include staff member salaries and material resources, as well as the price of disposable needles and syringes and the resources necessary for the collection and management of sharps waste. Overall, the effectiveness of each program was assessed on the basis of disability adjusted life years averted in addition to these material costs. The study essentially proves how vital proper injection practices are, including the absolute prohibition of needle and syringe reuse to prevent disease transmission.

Some studies focus on the overall cost benefits of ensuring that needles and syringes are not reused by implementing the auto-disable system. Miller et al. (4) base a case for safer injection technologies primarily on estimates of the mortality and costs of disease attributable to unsafe injections. This model combines the initial cost of

purchasing the syringe and needle system with the healthcare costs resulting from improper use of the equipment, showing that a higher initial cost for equipment that will automatically disable itself after a single use actually reverses itself in the long run as overall costs for disposable equipment are driven up by increased medical costs associated with the reuse of the unsterilized equipment. The main result of this cost model is that the associated medical costs of improperly used injection equipment serve to defeat the goal of medical care in general in that healthcare should do no harm. The authors also call for a more thorough analysis of the cost of medical injections by identifying strategies to reduce the social and financial burden of unsafe injections.

Prior to the widespread rejection of sterilizable needles and syringes due to improper sterilization techniques, cost models were generated to illustrate the benefits of such equipment. In 1999, Battersby et al. (5) conducted a study to assess the costs and benefits associated with disposable (including auto-disable) and sterilizable needles and syringes. The level of effort required to use each system, the costs associated with each, and the disposal requirements were compared to determine the overall best syringe type. It was determined that large amounts of planning and resources are dedicated to the supply and disposal processes involved with single use equipment, whereas sterilizable systems require effort in the areas of sterilization and verification of total disinfection, but staff time was not included in this model. Cost per injection was found based strictly on total needle and syringe cost (divided by the number of times the system could be used when sterilizable needles and syringes are considered), neglecting any future costs associated with improperly sterilized or reused equipment. Finally, disposal requirements were shown to be an issue due to the dramatically increased amount of waste generated

by single use systems. The model clearly shows the benefits of an ideal sterilization process for sterilizable needles compared to a poorly designed procurement and disposal system for the handling of disposable needles. It was recommended that in areas where disposable needles and syringes are to be used, great effort be taken to ensure proper post-use handling.

The above mentioned cost models all point to a need for increased safety of injections as well as for a more appropriate disposal method for the used equipment. Even the Battersby et al. study (5), which clearly represents views concerning sterilizable needles and syringes that currently are not accepted, makes a case for the need for an effective disposal system for disposable equipment.

2.2 Injection Equipment Details

2.2.1 Use of Injection Equipment

Injection equipment, when referred to in this thesis, represents a system comprising a hypodermic needle and complementary syringe used for a preventative or curative purposes in a human healthcare setting. Injections are one of the most frequently performed healthcare procedures, with an estimated 16 billion injections administered annually in developing and transitional countries alone. Three percent of these injections are administered strictly for immunization reasons, totaling approximately 480 million injections each year (6). Globally, 750 million injections are given annually as a part of routine immunization programs (4).

2.2.2 Types of Injection Equipment

2.2.2.1 Sterilizable Needles and Syringes

Sterilizable needle/syringe systems are the oldest of the injection types. Generally, the syringe is composed entirely of glass or plastic and is fitted with a stainless steel needle. Sterilizable equipment is designed to be used only one time between sterilization procedures, which include cleaning in an autoclave or a steam-based sterilizer (7). When using sterilizable components, it is important to consider equipment, spare parts, and accessories required for the sterilization process. These items must be kept in constant supply, but the injection unit has a lifespan significantly longer than other alternatives due to repeated use (5).

2.2.2.2 Disposable Needles and Syringes

As a result of the concerns regarding improper sterilization of the multiuse equipment that are described above, disposable needles and syringes were developed. The disposable injection unit consists of an all plastic syringe and a stainless steel needle. The intent of the disposable needle and syringe is that, after a single use, the entire product will be disposed of. A problem with this assumption is that there is no actual mechanism preventing reuse, so in many cases the disposable injection equipment is used in the same manner as that of the sterilizable equipment (7). An additional concern with both the sterilizable and disposable needles and syringes is that even when used as designed (resulting in the patient being kept from any type of harm), there is no guaranteed protection for the healthcare worker or the community as a whole who may stumble upon the equipment once discarded (5).

2.2.2.3 Auto-Disable Needles and Syringes

In an attempt to improve injection safety by preventing any improper or unintended needle penetration once contaminated, auto-disable syringes were developed in the late 1980's (8). The auto-disable syringe is essentially a disposable syringe with modifications that prevent reuse. There are two popular disabling mechanisms for this type of syringe, the first of which uses a fixed needle that is rendered useless after a single use when the plunger is deactivated, preventing flow through the needle (7). This type of unit is effective against reuse, but with a small amount of tampering it can be overcome. A second design consists of a sheath that is slid manually over the needle after the injection takes place, completely covering its tip. The primary goal of this unit is to prevent accidental needle-stick injuries to the healthcare worker or to the general public who may come into contact with waste that is improperly disposed of (9).

In trials conducted using auto-disable syringes in the immunization program of a developing country, healthcare workers generally preferred them to traditional disposable needles due to the speed and ease of their use. The only complaint was an additional amount of friction when expelling the vaccine, but with practice results were favorable (10). When used in another national immunization campaign, the auto-disable syringe was found to be superior to the ordinary disposable syringe once again. In addition to the previous comments regarding ease of use and speed, the auto-disable equipment was found to be more precise, accurate, and consistent with less vaccine waste than the disposable syringe (11).

As a result of these favorable studies in the past, researchers have proclaimed the auto-disable needle to be valuable in both mass immunization campaigns and routine

immunization procedures, citing the reduced vaccine waste and superior injection safety as reasons to overlook a generally higher equipment purchase price (10, 11). In the year 1999 alone, over 100 million auto-disable syringes were used in immunization programs around the world (8), with a goal of the strict use of only auto-disable syringes in immunization procedures around the world by the end of 2003 set forth by the World Health Organization, the United Nations Children's Fund, and the United Nations Population Fund (12).

2.2.3 Current Flow of Used Injection Equipment

According to the World Health Organization, "a safe injection does no harm to the recipient, does not expose the health worker to any risk, and does not result in waste that is dangerous for the community" (1). Oftentimes even injections given in healthcare situations are not safe. The primary concern with the unsafe use of injection devices is the transmission of blood-borne pathogens. Three main paths in which disease is spread by contaminated needles and syringes are patient to patient, patient to healthcare worker, and patient to community (2).

Patient to patient disease transmission takes place when a needle infected by one patient is reused on another patient. Accidental or intentional, there is a high risk of disease and death when disposable syringes and needles are reused, and in some areas of the world up to 70% of injections given are with unsterilized equipment (12, 6). Blood-borne infections are spread from a patient to a healthcare worker when the healthcare worker is giving an injection and accidentally sticks himself with the needle after using it on the infected patient. There is an increased likelihood of this situation occurring when the worker attempts to recap a used needle. When infected injection equipment is

collected and disposed of in an unsafe manner, the risk of needle-stick injuries increases (6). In this case, patient disease is spread to the community as a whole, as trash collectors and scavengers recover the used equipment and either stick themselves or sell the needles and syringes to someone else who will reuse them.

The burden of disease brought upon by unsafe injection practices is a serious concern. When new hepatitis and HIV cases are tracked according to their original source, it is possible to quantify the magnitude of infection caused by the improper use of needles. Table 2-1 shows the effects of this practice.

Table 2-1 The burden of disease associated with unsafe injection practices (6)

Disease	% New Infections Caused by Unsafe Injections	Number of New Cases Caused by Unsafe Injections Each Year
Hepatitis B Virus	33%	21,700,000
Hepatitis C Virus	42%	2,000,000
Human Immunodeficiency Virus	2-9%	96,000

The management of used injection equipment currently is handled in a variety of ways. Where a disposal method is in place in developed or transitional countries, used syringes and needles are generally collected and stored in either open containers or sharps boxes, where they are finally disposed of through open pit burning or incineration followed by disposal in community garbage facilities, or through burial. In other areas, such as developing countries, it is common practice for the used equipment to be discarded right outside the facility. In these cases, the needles and syringes generally are collected by scavengers and sold on the black market to be reused or to plastic recyclers

as scrap (6, 13). Workers in the plastic-ware industry accept the plastic syringes and reprocess them into household items after crushing into small granules (14).

2.2.4 Recommended Flow of Used Injection Equipment

Because infectious waste management systems frequently are lacking from the health planning systems of most transitional and developing countries, unsafe waste management is common (6). When this occurs, healthcare workers, sanitation workers, and the general community are prone to infection, injuries, and overall toxic effects of the contaminated waste. In order to eliminate these problems, a comprehensive system of healthcare waste management must be developed that includes appropriate measures for disposal, destruction, and final containment of the waste similar to those currently in place in countries with well developed waste management systems (5, 15). This lack of disposal and destruction systems for the magnitude of disposable syringes generated leads to the development of new methods of eliminating contaminated injection equipment from the community. Sharps boxes are needed at each point of use of the syringes and needles, generally a specially designed five-liter cardboard disposal box to be incinerated or burned in an open pit for 30 minutes to one hour to ensure complete destruction (13, 16). General recommendations call for the burnt remains to be disposed of in municipal waste areas or to be buried underground until a more acceptable method is in place, as there has been much resistance to incineration in some areas (5, 12). There is a growing concern regarding the harmful effects of incinerators due to the emissions, such as trace metals and dioxins, that may lead to cancers and other undesirable outcomes (17). Incinerators are not considered in some situations where a waste collection infrastructure is lacking or where fuels are needed to achieve the required temperatures

due to pollution considerations, generally due to cost constraints (13). Alternatives to incineration for effective syringe and needle disposal are low-heat thermal technologies such as autoclave, microwave, and dry heat systems. These methods ensure that waste remains under 300°C and does not burn (17). When the metal needles and polypropylene plastic syringes are kept between the temperatures of 150°C and 230°C, the syringes will melt into a plastic block, encapsulating the metal needles. Within these temperatures, the components of the injection device do not burn and the equipment is effectively sterilized (13).

While the above methods may be used to disinfect and dispose of used needles and syringes, there is a significant cost involved in the acquisition and maintenance of the equipment required with no additional funds generated. By recycling the plastic syringes instead of disposing of them, new items may be created, offsetting the disposal cost of the remainder of the system. By taking this approach, the plastic recycling industry is supported, as are workers with low skill levels who are available to work in the industry (14). Additional benefits to the plastic recycling process are the applications for reused materials such as polypropylene, which has properties superior to many other widely available plastics as well as an abundance of uses. By recycling plastic syringes into items such as food containers, packaging materials, textiles, films, and automotive parts, the return benefit to the community may be significant (18).

An important consideration in determining a method of waste treatment is that each system needs to be customized. No current disposal technology fits every situation, and factors such as available funds, space, and labor, as well as the volume of waste to be included play a significant role in the decision (15). For example, in an urban area where

many needles and syringes will be collected, it might be beneficial cost-wise to take the extra effort required to disable and decontaminate the components using a melting system or shredders and steam sterilization, where the material may then be recycled or sent to municipal waste treatment facilities where it will be harmless. In a rural area where the amount of needles and syringes collected is very small, and not many funds are available for disposal methods, open pit burning, incineration, or encapsulation and burial may be the most cost effective (13).

The most important consideration in determining a waste treatment system is that all stages are supervised so that proper operation is assured. Any lapse in the flow of the devices can lead to needle-stick injuries, resale, and reuse, all of which pose serious threats to the community (5).

An alternative to current injection equipment is an all-plastic needle and syringe unit. By replacing the metal needle with a plastic one, and by completely eliminating the rubber stopper (as in some currently available devices), the device becomes significantly easier to disable (melting of the needle tip at much lower temperatures is possible) and to reprocess (complicated and expensive separation procedures are eliminated). By reducing the number of material and components in the system, the hypodermic needle and syringe have a simplified disposal path with the number of required steps reduced.

2.3 Summary

This chapter provided a history of several types of injection devices and their uses and went on to cover current practices in medical waste disposal and their consequences. Finally, details of currently recommended treatment options were described in detail.

The next chapter will offer options for the safe disposal of injection devices from technological, economic, and burden of disease perspectives. Methods of choosing an appropriate system of treatment options based on specific circumstances will be provided.

CHAPTER 3

THEORY

3.1 Cost Model

3.1.1 Overall Model

In order to understand every outcome possible after the first use of a needle and syringe, a model is created to analyze each step involved in the potential flow schemes. The complete model will help to determine the most cost effective flow for used medical equipment by taking all options into account. In tracing each possible path of travel of the equipment from its original use to its final destination, both current and ideal situations will be included. The model begins with used disposable injection needles and syringes and traces all options from reusing the infected equipment to recycling the individual components into beneficial products.

In situations where the equipment is not properly disposed of (as in some current locations), the needles and syringes would likely be used and go on to either cause an accidental needle-stick injury or be purposely reused. Both situations could occur either in a hospital setting or in the community, and will result in medical costs incurred if they lead to the spread of disease through an infected needle.

In a situation following a safe and proper disposal method, all contaminated equipment would be contained immediately before further action is taken. The needles and syringes would go on to be properly disinfected and disposed of or separated and reprocessed into further items. In this situation costs incurred consist mainly of the time required in each stage of the flow and actual monetary cost of purchasing, maintaining, and operating the equipment involved.

3.1.2 Technological and Economic Costs

This thesis explores the technological and economic costs involved with the various available options for needle and syringe flow after their original use. In considering only paths that are safe for the community, no disease spread is included. The injection needles are immediately contained and may be blunted or otherwise rendered useless. Upon containment, the equipment is reduced in size and disinfected, both of which include multiple methods of achieving the desired action. The clean materials are either disposed of or separated in a stage where many options exist to sort metal and rubber pieces from the plastic. After the separation process, individual material components may be sold to be recycled. Plastic may also be kept in-house for onsite reprocessing. An overall view of these flow options may be seen in Figure 3-1, which illustrates the energy, material, and information flow for the recycling of injection needles.

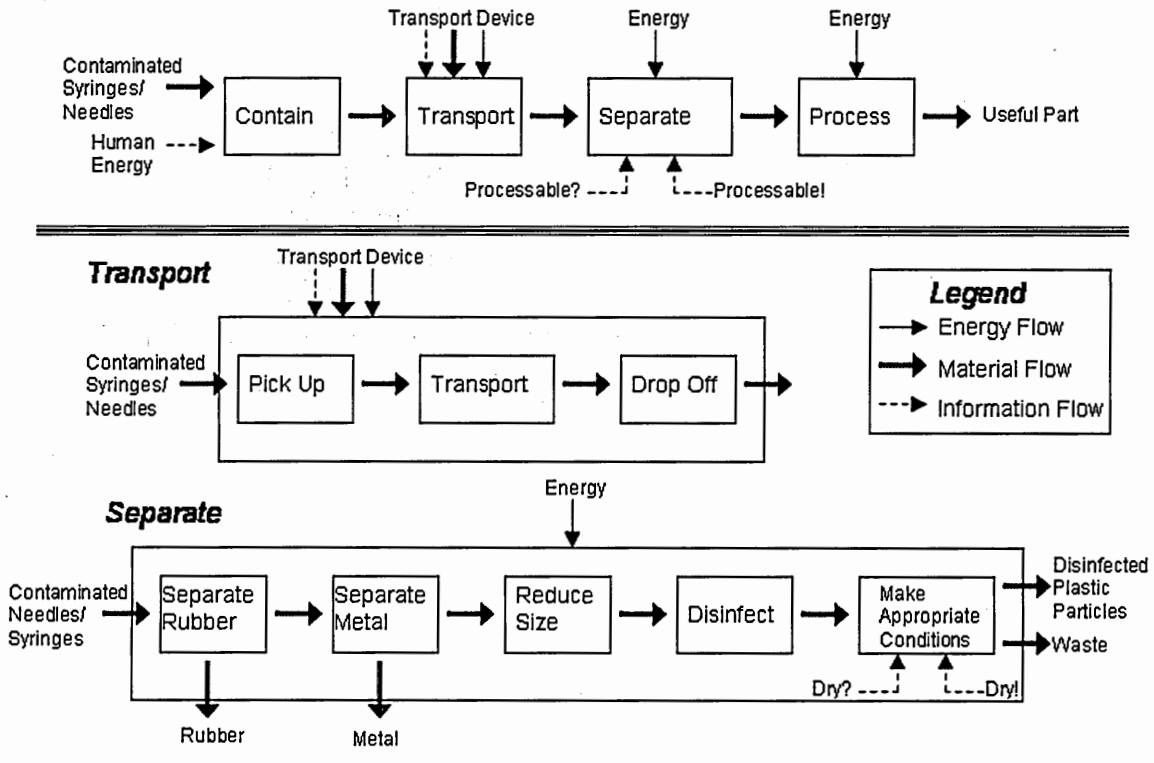

Figure 3-1: Energy, material, and information flow for recycling injection needles

The specific processes involved in each step of the flow of the recycled needles and syringes are detailed in Figure 3-2 (traditional metal needles with plastic and rubber syringes) and Figure 3-3 (all-plastic unit).

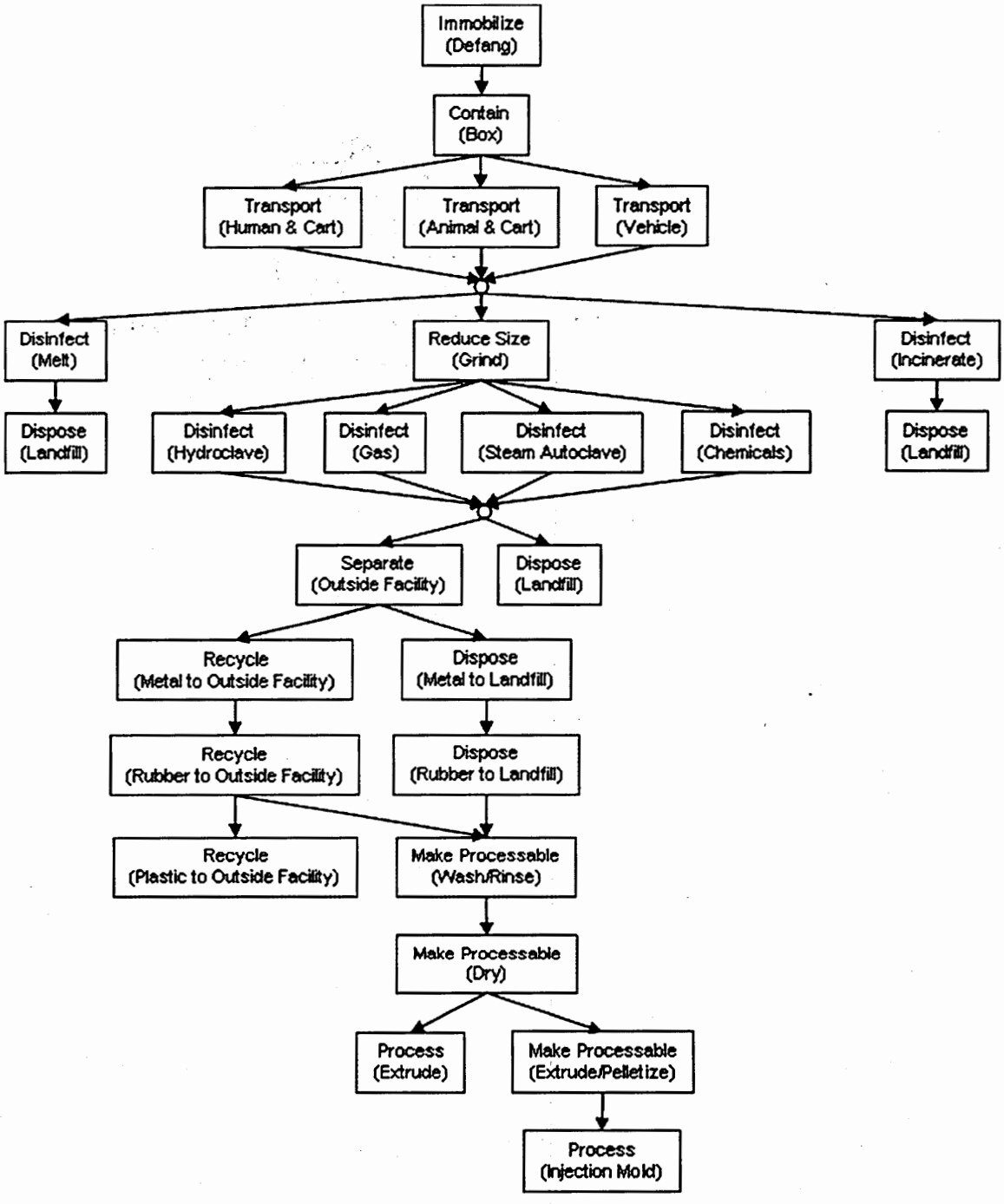

Figure 3-2: Flow of used injection equipment for traditional needles and syringes.

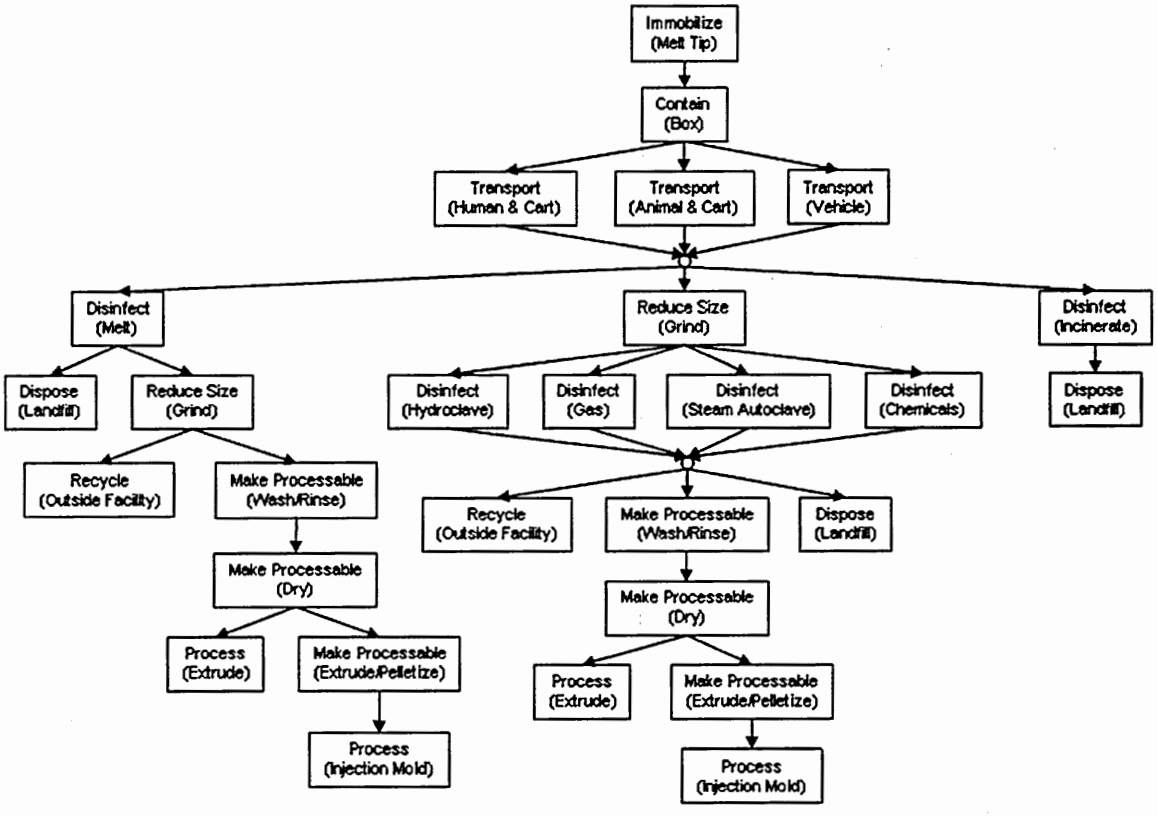

Figure 3-3: Flow of used injection equipment for all-plastic needles and syringes.

3.1.3 Burden of Disease

An additional aspect of the cost model concerns situations in which a needle and syringe become contaminated with hepatitis or HIV after their original use and result in the infection of additional people. In these cases, the equipment is not handled according to previously mentioned guidelines and either leads to an accidental needle-stick or it is reused.

In circumstances where a needle-stick injury occurs, this may be due to a healthcare worker attempting to recap a needle, or it may be the result of equipment that

is disposed of while still infected. If contaminated needles and syringes are improperly disposed of, trash pickers who earn a living from gathering and reselling needles may be stuck by an infected needle. It is also possible that contaminated equipment end up in an open landfill where children may be stuck by a contaminated needle while playing.

When needles and syringes are not rendered useless in any way after their original use, it is very possible for them to be recovered and reused. Trash pickers or even hospital staff may collect the used equipment to resell to medical facilities where it is reused without disinfection measures.

In either situation, whether disease transmission occurs through a needle-stick injury or through reuse of a contaminated needle and syringe, when a person is infected with disease by means of a used needle, there are many costs associated with the outcome. Burden of disease calculations include doctor visits, hospital stays, and medication associated with the infection for the duration of the person's life. This cost also includes lost productivity as a result of infected people who lose their ability to perform useful work for the remainder of their lives, or people whose lives end early due to progression of the disease. In this manner, costs are associated with each possible outcome of not properly disposing of used injection equipment. Burden of disease costs are not included in this thesis, but can be added to the model in the future.

3.1.4 Urban versus Rural

Any cost model tracing the path of used needles and syringes must take into account the environmental setting. One way of classifying the type of setting is by labeling it as either urban or rural. In the countries under consideration, an urban location is defined as one in which electricity and automobiles are available. In this situation, all

options are viable concerning the use of any machinery without energy constraints. Transportation to and from a disposal, recycling, or reprocessing facility is also not limited in any way. A rural setting, on the other hand, is defined as one in which electricity is limited and therefore not all processing technologies are available. Similarly, transportation could be restricted to the use of animals and carts for the transport of materials at any stage in the disposal process.

When a rural setting is considered in which electricity is limited or unavailable, alternative fuel sources should be considered. When energy is in forms other than electricity, not all machinery may be altered to accommodate this change, but some basic equipment (such as ovens) can still be used. Depending on the specific location in which the disposal process is to take place, a variety of fuels may be available. Alternative fuels that would be suitable for simple equipment operation and the heat content of each are given in Table 3-1.

Table 3-1: Fuel sources and their heat content (19)

Fuel Type	Heat Content (MJ/kg)
Wood (0% moisture)	20.4
Gasoline	43.8
Kerosene	43.5
Propane	50.4
Paraffin	42.4
Oil (light fuel)	42.3
Cattle manure	17.2
Coal (anthracite)	30.0

The area over which the disposal method is to take place also plays a significant role in cost estimation. In situations where one very large hospital generates a great deal

of used needles and syringes and has abundant resources, an onsite recycling plant may be an available option. Alternatively, if multiple small clinics join together to handle their disposal needs, a transportation system must be in place to collect and deliver used equipment from each facility to a central processing area.

3.1.5 Needle Composition

Another consideration in the determination of the most cost-effective system of disposal is the composition of the equipment. Traditionally, the injection unit is composed of a metal needle attached to a polypropylene syringe with a butyl rubber stopper inside. In this case, separation is a necessary step in any recycling or reprocessing plan intended to make use of the individual components. An additional type of syringe is currently available in which there is no rubber present, and the entire unit is polypropylene. While this device eliminates the need to separate rubber from the plastic, the problem of removing the metal needle is still present. As a result, separation procedures are still required. If the entire needle and syringe unit were composed of the same material, namely polypropylene as is considered, compatible material separation precautions would not be required. The entire unit could be processed in the same manner without concern for cross-contamination of materials.

3.2 Summary

This chapter presented an overall view of the options for needle flow after initial use. Technological and economic costs were detailed as they are included in the present model, and burden of health considerations were defined as they will be added to the model in the future. Additional aspects of the model consist of the size and setting of the medical facilities to be included in the disposal system, as well as the needle composition

of the chosen injection needles to be used, whether traditional (metal, polypropylene, and butyl rubber) or an all-plastic design (strictly polypropylene or compatible materials).

The next chapter details the experimental procedure used to estimate each cost. Data sources for various machines and other considerations will be revealed, as well as actual values used as inputs to the model and sensitivity analyses created to determine what aspects of the estimation should be better defined. Finally, numerical differences between rural and urban settings, and traditional metal and proposed plastic needles will be stated as used in the model.

CHAPTER 4

EXPERIMENTAL PROCEDURE

In this chapter, the data input to the cost estimation model are described. Assumptions and actual machine specifications are given for each possible step in the flow of injection equipment after its initial use, as well as a basic differentiation between rural and urban definitions as used in the model. Differences in disposal procedures between traditional and all-plastic needles and syringes are explored, and sensitivity analyses are performed to determine the significance of variables within the model. For simplicity, all costs are from the United States.

4.1 Experimental Data

The injection units currently considered in the cost model consist of a 5 mL syringe with a 23 gage needle. The overall length of the unit is 10.8 cm with a minimum diameter of 1.27 cm and a maximum diameter of 2.54 cm as the contour of the syringe changes near the end of the barrel. The total mass of the unit is 4.348 g when a metal needle is used and is estimated to be 4.313 g when a plastic needle is used. The entire unit has a volume of 5.47×10^{-5} m^3.

The most basic numerical values needed to perform any type of cost analysis involving the operation of machinery are energy and labor rates. For the purpose of this model, a power rate of \$0.0683 per kW is used based on general values given by the United States Department of Energy Office of Energy Efficiency and Renewable Energy (20). A labor rate of \$5.15 per hour is used as the minimum wage in the United States, as reported by the Employment Standards Administration within the United States Department of Labor.

The first step in the flow of a used syringe and needle is the immobilization of the entire unit. For cases where a metal needle is considered, the Disintegrator Pro (Disintegrator Products, Broadview Heights, Ohio) is used to remove the needle from the syringe, where it is then contained for further disposal. This unit is shown in Figure 4-1.

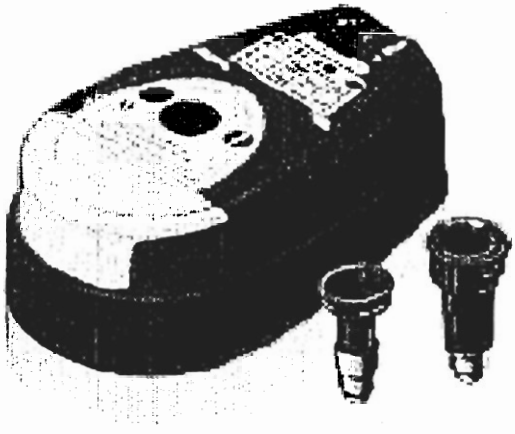

Figure 4-1: Disintegrator Pro metal needle disabling device

With an all-plastic unit, a Thermolyne hotplate, model HPA1915B, is kept on during injection procedures so that after a single use of the plastic needle, the healthcare worker can simply touch the tip of the needle to the hotplate to render it useless and harmless. This procedure has not been perfected, however, as decontamination and cleaning issues are presented when the surface of the hotplate has residue from the melted needle tips on it, but is used here only for illustrative purposes. A ventilation unit may also be considered, as smoke is generated by the burning fluids contained within the needles. (In developing countries, a simple candle would suffice to disable the needle.) The hotplate is shown in Figure 4-2, while specifications for both immobilization units are provided in Table 4-1.

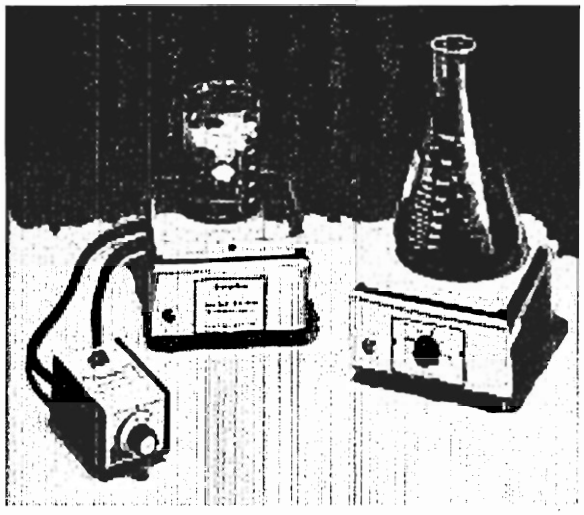

Figure 4-2: Thermolyne hotplate for plastic needle disabling

Table 4-1: Immobilization equipment specifications

Immobilization Unit:	Disintegrator Pro	Thermolyne Hotplate
Cost of equipment ($):	399	217
Power required (kW/hr):	0.248	0.756
Time required (sec./needle):	1.0	5.0

In the analysis of the above immobilization equipment, as well as all of the following machinery, the power required was found as shown in Equation 4.1. Total time required is given in Equation 4.2, where the time required per unit is a function of the needle and syringe mass and the throughput value given as a specification of each machine. The total cost of the specific procedure (here immobilization of the needle) is shown in Equation 4.3 where the cost of labor is neglected in this case because the immobilization step is performed immediately following an injection and adds no significant labor on the behalf of the healthcare worker. The cost of supplies is included

for equipment requiring additional chemicals, filters, or other components that are used on a regular basis.

$$\text{Power Required (kW)} = \frac{\text{Voltage} * \text{Amps}}{1{,}000} \tag{4.1}$$

$$\text{Total Time} = \text{Operation Time Required per Unit} * \text{Number of Units} \tag{4.2}$$

$$\begin{aligned} \frac{\text{Total Cost of Procedure}}{\text{Year}} = {} & \frac{\text{Cost of Equipment}}{\text{Life of Equipment (years)}} \\ & + \text{Power Required} * \text{Operation Time} * \text{Power Rate} \\ & + \text{Operation Time} * \text{Labor Rate} \\ & + \text{Cost of Supplies} \end{aligned} \tag{4.3}$$

The next step in the disposal process is containment within a sharps collector. The standard box chosen is a Becton Dickinson 8 qt polypropylene unit (B-D model EW-07940-76, Franklin Lakes, New Jersey) that can hold 178 needle and syringe units with a close-packed configuration. Each container costs approximately $5 (21). This box was chosen because it is compatible with the plastic of the injection equipment so that the entire box of needles and syringes may be processed together. It is shown in Figure 4-3. A cardboard box could also be used to collect the equipment, such as the solid fiber-board sharps container available from Bacto Laboratories. The cardboard box is not included in this model because it requires a different method of disposal than that of the polypropylene box and injection units.

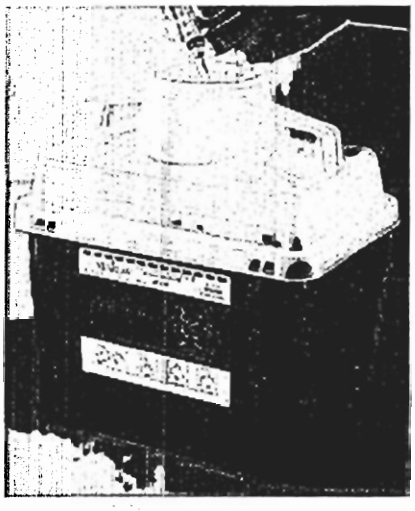

Figure 4-3: Becton Dickenson 2 gallon polypropylene sharps collector

With syringes and needles contained in sharps collectors, they must now be transported to the disposal facility. Depending on the distance to be covered and whether the setting is rural or urban, transportation means vary dramatically. In each case, the shipment of needles and syringes takes place when the transportation source has reached its maximum capacity. When traveling distances under 0.25 km, a human is able to move the equipment using a Rubbermaid Tilt Truck cart (Rubbermaid model 1304, Wooster, Ohio) shown in Figure 4-4. The heavy duty utility cart is available for about $450 and has a capacity of 0.4 m^3, or approximately 5750 close packed injection units (78.54% packing density), each with a volume of 5.47×10^{-5} m^3 (22). The Rubbermaid cart is quite expensive, so alternate methods and equipment could be used, such as a wooden cart or wagon. As reliable costs of these cannot be determined, this thesis will only consider the Rubbermaid Tilt Truck cart. The human is expected to push the cart at an average of 4.5 km/hr (23).

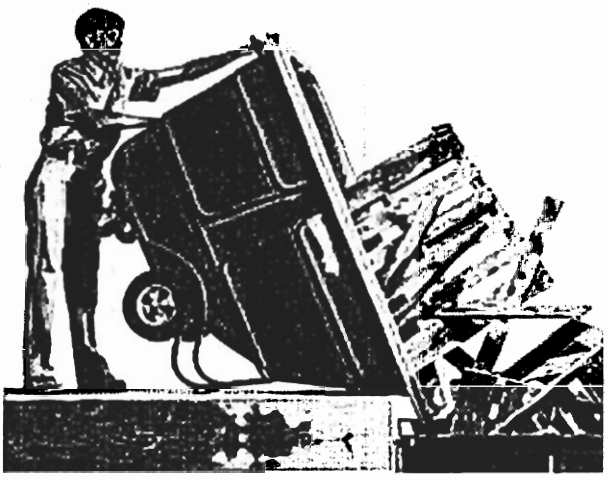

Figure 4-4: Rubbermaid Tilt Truck for needle transportation

For distances over 0.25 km, two transportation options are assumed: either an animal drawn cart or a pickup truck. The decision regarding which is more suitable depends on the availability of work animals or vehicles and practicality of the situation. In extremely poor areas, where no fuel is available and owning automobiles is not feasible, an animal and cart is an ideal choice. When extreme distances or unfavorable environments are present, a vehicle is the best option for the transport of equipment. Costs involved with the use of a donkey and a cart in the Amhara region of Ethiopia are shown in Table 4-2.

Table 4-2: Animal transport specifications (24)

Cost of animal ($):	38
Useful life of animal (yrs.):	5
Cost of animal care ($/yr.):	116
Cost of cart ($):	180
Life of cart (yrs.):	5
Needles per cart:	26787
Velocity of travel (km/hr.):	3.2

In situations where a vehicle is to be used, a 2004 Ford F-450 pickup truck is chosen at an average cost of $27,630. The truck will hold about 31,500 needles and syringes per trip based on a bed capacity of 77.7 ft^3, and will achieve about 15 miles per gallon efficiency at an average of 30 miles per hour on rough terrain. Annual maintenance costs are determined as a function of distance traveled, with an approximate figure of $0.10 per mile (25). Only new vehicles were considered, as it would be difficult to accurately determine actual costs of used vehicles in other countries.

Once the injection units reach the processing location, the next step is to reduce them in size. Two main options exist for this: granulating and melting. If the needles and syringes are to be granulated, they can either be thrown into a relatively small-scale granulator without the sharps box shown in Figure 4-5, or the box and its contents can be granulated together in a larger-scale machine seen in Figure 4-6. If the box is not included with the sharps, it must be disposed of using a separate procedure.

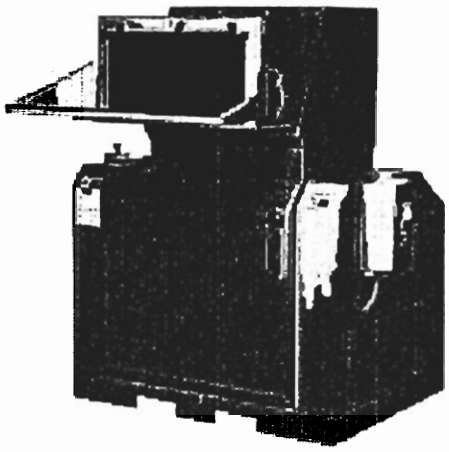

Figure 4-5: Conair CB-1012 granulator for small-scale size reduction

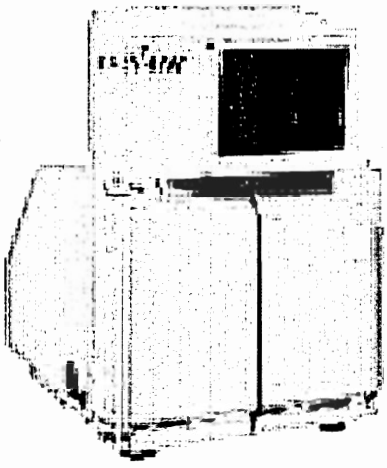

Figure 4-6: Conair CK-1824 granulator for large-scale size reduction

The other size reduction method, melting the entire unit, serves to encapsulate the needles within the plastic syringe mass into the size and shape of a standard brick using the hot press shown in Figure 4-7.

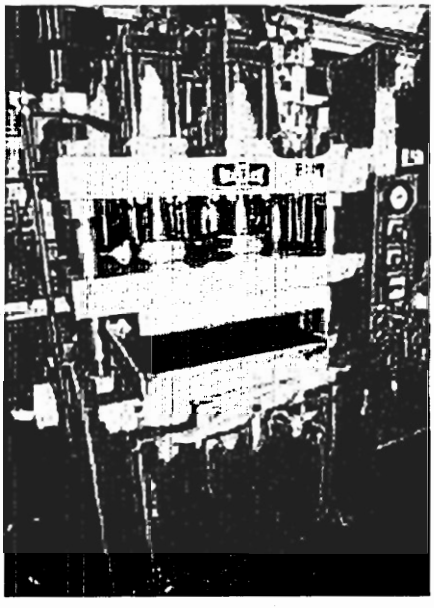

Figure 4-7: Wabash hot press for needle encapsulation

When this option is considered, the time and temperatures required to melt the polypropylene are sufficient to kill any pathogens remaining within the equipment, as a temperature of 160°C held for one hour is accepted in medical practices as a dry autoclave sterilization standard (26). Also, the units are rendered harmless as the metal needles are fully contained within the plastic and do not protrude from the brick (19). Once a brick is formed, it is disposed of directly in a municipal landfill and the disposal process is complete. Details of each size reduction method are given in Table 4-3.

Table 4-3: Reduction equipment specifications

Reduction method:	Granulation	Granulation	Encapsulation
Equipment:	Conair CB-1012	Conair CK-1824	Wabash Hot Press
Cost of equipment($):	11 188	26 000	75 000
Power required (kW/hr):	3.64	15.64	N/A
Time required (sec./needle):	0.0356	0.04572	38.7

The next stage in the disposal of the injection units is to disinfect the components. Once the needles and syringes are granulated, they are ready to begin this stage as all crevices and air pockets are broken open and may be reached directly by the chosen sterilization process. Several options exist for this step, including the use of a hydroclave, steam autoclave, gas disinfection, chemical disinfection, or incineration. The hydroclave uses very high temperature water to kill all pathogens that may remain on the medical equipment, whereas the steam autoclave is similar to a pressure cooker, using high pressure and temperature saturated steam to achieve the same results (seen in Figure 4-8).

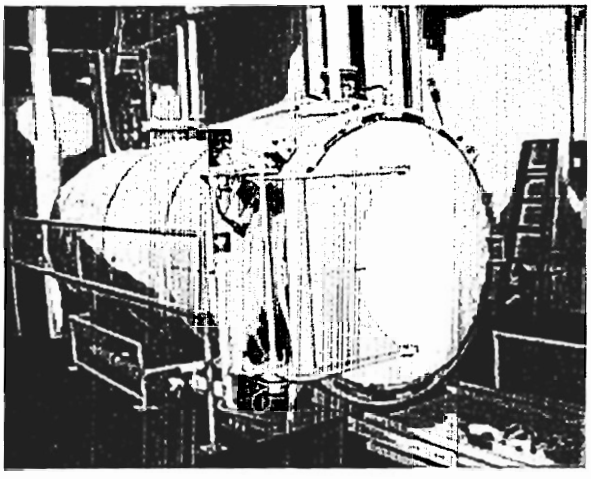

Figure 4-8: Bondtech steam autoclave

The gas disinfection unit utilizes ethylene oxide to sterilize medical equipment and is most often used with sensitive pieces that cannot withstand the high temperature and humidity environments fundamental to the previously mentioned systems. This machine is shown in Figure 4-9.

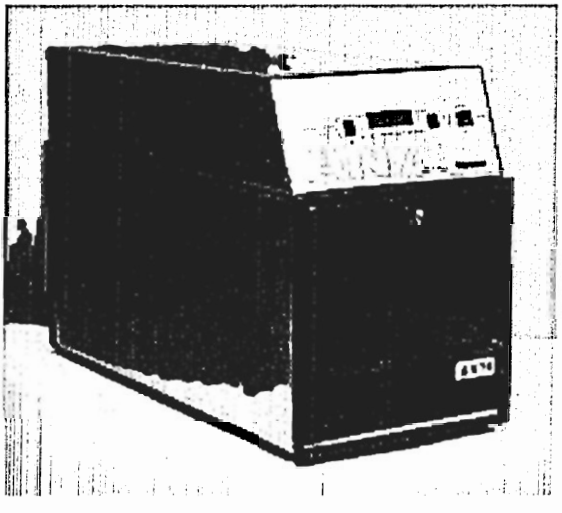

Figure 4-9: Anprolene gas sterilization unit

With any of the above sterilization methods, when a final wash and dry procedure is required, the Polycycler 2000 (Amplasco, Mechanicsville, Virginia) is used. This complete wash line processes 2000 lbs/hr and is available for $70,000. A chemical disinfection unit is also considered, in which a concentrated chemical (proprietary information to the company) is combined with water to sterilize equipment, after which the parts are rinsed clean and are free of contaminants. As energy requirements are low, this option may be ideal in rural environments where low volume and limited energy are constraints to a disinfection system, provided water resources are not limited.

Another option for completing the disinfection process is to recover the bricks formed by melting the syringes and needles together. After undergoing the temperatures of the melting process, all harmful pathogens remaining on the equipment are destroyed so that these bricks can be considered sterilized.

The final method of disinfection considered is the incinerator shown in Figure 4-10, in which the medical equipment is burned at a very high temperature so that no harmful waste remains after the process.

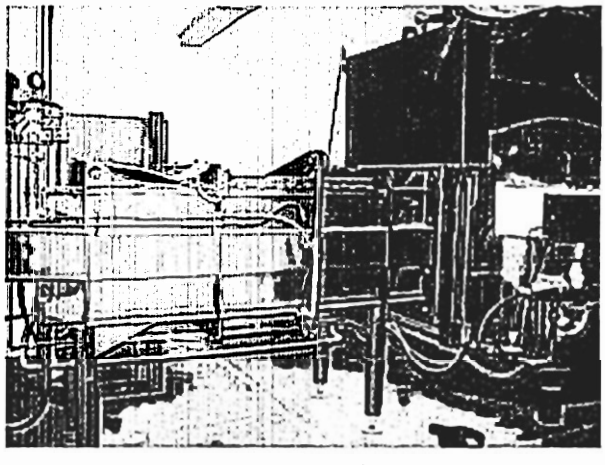

Figure 4-10: Consumat waste incinerator

No size reduction is necessary before considering this method. As previously mentioned, this method of disinfection has met strong resistance in some areas due to perceived health and environmental hazards, so it is not as widely used as in the past. Also, when incineration is chosen as the preferred method of disinfection, there is no way to recover materials for separation or recycling. Basic specifications of the disinfection equipment are shown in Table 4-4.

Table 4-4: Disinfection method specifications

Disinfection method/ model:	Manufacturer/ Location:	Cost: ($)	Power: (kW/hr)	Time: (sec/needle)
Hydroclave H-25	Hydroclave Systems Kingston, Ontario	106300	1.65	0.172
Steam autoclave BTT100	Bondtech Corporation Somerset, KY	89500	1.1	0.256
Gas disinfection Anprolene AN74i	Anderson Products Haw River, NC	2750	0.15	33.527
Chemical disinfection System 1	Steris Corporation Mentor, OH	18000	1.8	7.5
Incineration C75PKD	Consumat Richmond, VA	61500	6.9	0.197

Once the material is reduced in size and disinfected, it can either go to a municipal landfill, where the tipping fee is $29.50 for each ton of waste, or it can be separated for recycling (27). Current separation technology includes density separation (in which materials are sorted by floatation in a tank of liquid where materials of higher density sink and those of lower density float), air separation (where terminal velocity differences between materials are used to drop out each individual material from air), and optical separation (where differences in color are the method of differentiation between

materials). For the case of traditional injection units, in which metal, polypropylene, and butyl rubber are to be separated, air separation is not a viable option because the terminal velocities of each material are too similar. The same case exists for injection units comprised of a metal needle and an all-plastic syringe. This method would be more appropriate in a case where a film, such as the equipment packaging, was to be sorted from the bulk material. With regard to the remaining sorting methods, Butler-MacDonald, Inc. of Indianapolis, Indiana, is currently the only company offering material separation solutions applicable to the requirements of this application. Because their methods and equipment are proprietary, the specific steps of the sorting process in which the material would go are not available, and for the same reason, machinery cannot be purchased for individual separation needs. Separation methods, therefore, are modeled as an off-site step in which the materials would be sent out to the company and returned in three individual component batches for an approximate cost of $0.14 per pound (28). At this rate, about 750 needle and syringe units would be sorted for $1.

If the sorted material were to be recycled by an outside company, profits would be realized and are shown in Table 4-5.

Table 4-5: Recycling value for traditional needle and syringe components

Material:	Recycling Value:
Stainless steel	$0.029/kg (29)
Butyl Rubber	$0.637/kg (30)
Polypropylene	$0.400/kg (31)

To recycle the polypropylene in-house, a Conair Model 304 (Conair, Pittsburgh, Pennsylvania) strand pelletizer is used to extrude and pelletize the plastic flakes

recovered from the separation process. This machine, shown in Figure 4-11, is available for $14,800 with a 5.52 kW/hr power requirement and 272 kg/hr throughput.

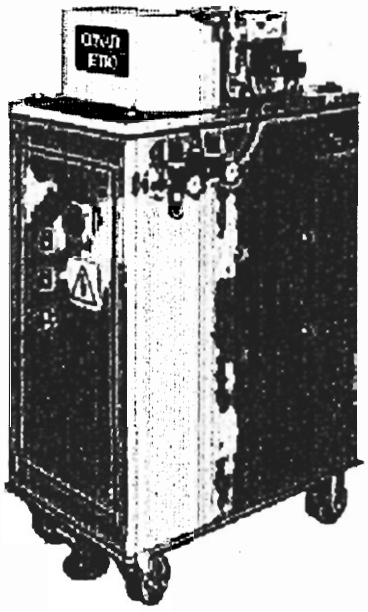

Figure 4-11: Conair Model 304 strand pelletizer

Upon pelletizing, the material may be sent to an injection molding machine where a variety of useful household items are made. Other options for the injection molding process are to create automotive parts such as fenders or the cases of car batteries. An appropriate machine to create such products is the Vandorn Caliber Model 730 shown in Figure 4-12 (Van Dorn Demag Corporation, Strongsville, Ohio). This unit costs approximately $310,000 and has a 220 kW/hr power requirement (32). When this method of reprocessing is chosen, there is a cost benefit associated with the resale of molded parts. This profit is not included in the analysis because of the uncertainty of actual product costs to the manufacturer.

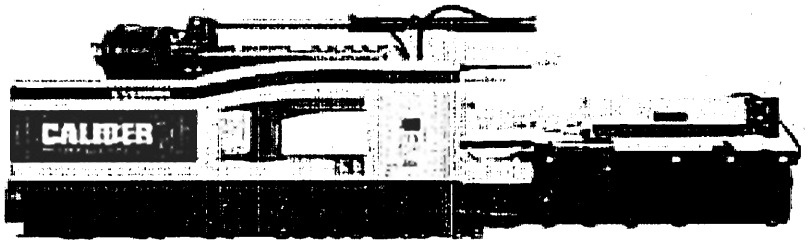

Figure 4-12: Van Dorn Caliber Model 730 injection molding machine

A final option for recycling the plastic is to incorporate it into plastic lumber. When creating plastic lumber, only 30% of the final product is actually plastic. This process also requires about 60% real wood and 10% additives. It is because of this reason that unless the processing plant is located near an abundant source of wood, this option is not feasible due to the dangers of transporting wood flour because of its high explosiveness. The total cost for a plastic lumber processing line is about $1,760,000 including blending, extrusion, and embossing (32). The equipment comes from a variety of sources available from Conair (Pittsburgh, Pennsylvania).

The depreciation schedule of each piece of equipment is provided by the Internal Revenue Service (33). An assumption is made that the equipment cost is spread over the span of the useful life and has no monetary value at the end of this period.

4.2 Rural versus Urban

A source of variation between ideal disposal methods for used injection equipment centers around the type of region served. When considering a rural area, clinics and small-scale vaccination campaigns are the main contributors to immunization injection needle and syringe waste. In this case, the number of people served is quite low compared to the area traversed to collect the waste. For experimental purposes, a figure of less than 1,000 persons per square mile constitutes a rural area (34).

In urban areas, hospitals are the primary source of hypodermic needle and syringe waste. Medical care is readily available in this centralized location, where the general population is significantly high within a small area. Urban areas are defined as having over 1,000 persons per square mile (34).

4.3 Traditional versus Plastic Needles

The experimental cost model consists of two main branches. One branch is applicable when dealing with traditional metal needles and plastic/rubber syringes, and the other considers only the all-plastic equipment. Experimental mass and volume measurements were recorded to gain an overall idea of the amount of material involved in each unit as well as the size it occupies. The hypothetical plastic needle and syringe unit has the same volumetric dimensions as the traditional system, but weight considerations are different due to the difference in densities between metal, rubber, and plastic.

4.4 Sensitivity Analysis

To assess the impact of hypothetical data input to the cost model, parameter values are varied to be both two times greater than and one half of their assumed values. When the results of the model vary dramatically with a variation in a specific input, this indicates that more research should be done on the topic to confirm the practicality of the information. Figures that have little impact on the model are not of as great importance and may be considered acceptable.

Input data, such as the assumed power and labor rates, are varied to test the sensitivity of the model , and hence to what extent the results are affected. Other hypothetical data include the choice of an animal and cart or a vehicle to travel between the medical facilities and the processing plant. If the outcome of the model is

dramatically different when using an animal and cart to travel 1 km, 10 km, or 100 km as compared to the use of a vehicle, the practicality of such a situation needs to be investigated further. Also, definitions of urban and rural are altered to assure that slight population variations within a region do not have a dramatic effect on the most appropriate disposal method. This is achieved by obtaining results for the cases of one thousand, ten thousand, one hundred thousand, and one million used needles and syringes per year.

4.5 Summary

This chapter defined the basic experimental procedures of the cost model, and went on to provide details such as individual machine specifications and in which cases each would be considered. The distinction between rural and urban locations was made, and fundamental differences between traditional metal needles with plastic and rubber syringes, and an all-plastic design were described as they relate to the disposal process. Finally, sensitivity analyses were described in detail regarding their use as a tool to assess the impact of individual data included in the model. An important factor concerning the use of this model is the hypothetical nature of all input values. The overall frame of the model holds true in any situation, where input values may be changed by each user to reflect local costs and conditions.

The next chapter will reveal the results of the model after the above described data were included. Inputs to the model will be varied, and individual results for each outcome will be presented and discussed in relation to each other.

CHAPTER 5

RESULTS AND DISCUSSION

5.1 Model Description

The general frame for the cost estimation model was created using Microsoft Excel software on a Microsoft Windows XP operating system. The model consists of three basic spreadsheets: input data, coded data, and output data. In general, the input data page is the only portion of the model intended to be altered with each cost estimation procedure. Figures such as the number of needles and syringes to be disposed of, the distance between the medical facility and the processing facility, and the period of time over which the model pertains are inputs to the model, defined by the user for each situation. The main portion of the model consists of the coded data. This section contains all data and calculations pertaining to the equipment to be considered and its specifications. General data such as the labor rate and the energy rate are also included in this area. (Labor cost contributions are calculated on a fractional basis so that labor is needed only for the period of time that each machine is in operation.) Calculations made to determine cost and time requirements for each possible combination of disposal processes are presented in the output data page, where full capital costs are included for each selected piece of equipment. This portion of the model clearly shows how each method ranks with the others by including overall time and cost values. A set of hypothetical input data is shown along with the coded equipment specification data and the resulting output data in the Appendix.

Although the model contains a "coded data" section, this information may be easily adapted to include other data relating to alternative equipment, fuel sources, etc.

This modification may be made when considering technologies appropriate for developing nations.

5.2 Assumptions and Justifications

The model is currently set up to perform cost estimations based on the constant flow of 5 mL syringes with 23 gage needles, but these specific units were chosen based only on their availability. In this case, the overall length is 10.8 cm with a minimum diameter of 1.27 cm and a maximum diameter of 2.54 cm as the contour of the syringe changes near the end of the barrel. The two main groups of injection systems are traditional and all-plastic, where traditional systems generally refer to a metal needle with a plastic and rubber syringe. By also considering a syringe composed entirely of plastic, but with the same metal needle, the resulting analysis is virtually identical to that of the plastic and rubber syringe because the mass and weight differences are insignificant. Processing considerations are the same for both "traditional" types of syringes, even considering the separation process, since metal will still need to be removed from the plastic. The mass of traditional and all-plastic injection systems are shown in Table 5-1.

Table 5-1: Component mass values for two types of injection systems

Injection unit type:	Traditional	All-Plastic
Mass of metal (g):	0.039	0
Mass of rubber (g):	0.191	0
Mass of plastic (g):	4.118	4.313
Total mass (g):	4.348	4.313

In each given time and cost analysis, the defanging or disabling process is always included as the first step. Because this thesis describes the most cost and time effective

method of safely disposing of injection equipment, it is a necessary first step to ensure that every precaution is taken to prevent accidental needle-stick injuries. Worldwide, defanging is seldom used, and does pose an added risk of accidental needle-stick injury due to increased handling. When considering an all-plastic needle and syringe, the tip of the needle is briefly touched to a hotplate to melt it closed. For a traditional metal needle, a defanger is used that removes the needle and stores it in a separate container for disposal. Currently, a single disabling station is considered for use in each medical facility or clinic. This number can be changed within the model.

From the disabling step, the equipment is always thrown directly into a polypropylene sharps box. Each sharps box used is disposed of with the needles and syringes. The boxes will never be dumped out once filled in order to prevent any disease spread caused by opening sealed medical waste. By choosing to include the entire sharps container in the process, if grinding is considered as a size reduction method, a grinder of a large enough capacity to accept the entire box of needles and syringes is considered. Information regarding a smaller size grinder is made available for use when this concept of recycling the sharps box is not in use, such as when a cardboard sharps box is used. The incinerator is not considered in this model due to the previously mentioned lack of public support and acceptance. The incineration data is included, however, for further use in a situation where there is little resistance.

Once the injection equipment is contained, even if the disposal facility is onsite, basic transportation costs are included in the form of purchasing and loading/unloading a cart. Travel time is considered insignificant, however, and is not included. Machines will not be placed near the injection site (in which case the used equipment could be

thrown directly in) due to sterility issues that arise when large machinery is run in close proximity to healthcare procedures. In situations where the disposal facility is not at the same location as the hospital or clinic, cost and time calculations include a single trip from the healthcare facility to the disposal facility. All processes are assumed to take place at one of the two.

Finally, in the cost and time approximations given, data are provided for each of three situations. The first situation (melting) makes use of total needle and syringe encapsulation. In this case, the temperature would be high enough to kill any pathogens on or inside the equipment since the material is kept at a temperature well above 160°C for one hour as prescribed in the previously mentioned dry autoclave standards. By using the encapsulation method, the metal needles of traditional injection units become harmless, and plastic needles blend in with the rest of the bulk material. This is the only situation in which the sharps box is not included in the disposal process.

In the second case (recycling), the equipment is reduced in size, disinfected, separated, and recycled. This situation provides a time and cost analysis for a situation where the material is prepared for recycling but the sterilized and separated material is sold for reprocessing rather than incorporating any further steps into this model. For any case that does not consider the recycling process directly, it is still necessary to ensure that the material is recycled rather than disposed of. This is due in part to the original issue of creating additional waste and filling landfills with materials that could be remanufactured.

The third option (reprocessing) for needle and syringe disposal is to reduce, disinfect, and separate each component material for recycling directly into new products.

This process involves the production of household and automotive products made using injection molding. The other option for final reprocessing is extrusion into plastic composite lumber, but this step is not considered due to the amount of additional material necessary and the required setting near a forest or large wood supply. The circumstances in which this situation applies are so few that this study only considers the use of injection molding as a reprocessing method.

5.3 Results of Analysis

In the first case, a human pushing a cart is the selected mode of transportation. Cases are analyzed in which the recycling facility is onsite and 0.25 km away. Table 5-2 shows the time requirements for each of the three previously described disposal methods: encapsulation by melting, sale for recycling through an outside source, and injection molding. It is seen that with 1,000,000 needles to be processed within the selected timeframe of one year, encapsulation would require multiple hot presses to accommodate all needles and syringes. The total costs for the above situations are provided in Table 5-3, in addition to costs per unit and per unit mass.

Table 5-2: Time requirements of a disposal process using a human and cart as a transportation method

		Human & Cart	
# Needles	Method:	0 km	0.25 km
10 000	Melting	110.74 hrs	110.84 hrs
	Recycling	15.10 hrs	15.20 hrs
	Reprocessing	16.24 hrs	16.34 hrs
1 000 000	Melting	11074.00 hrs	11083.67 hrs
	Recycling	1510.15 hrs	1519.82 hrs
	Reprocessing	1623.95 hrs	1633.63 hrs

Table 5-3: Cost requirements of a disposal process using a human and cart as a transportation method

# Needles	Method:	Human & Cart		
		0 km		
10 000	Melting	$8,809.23	$0.88/unit	$0.20/g
	Recycling	$4,316.82	$0.43/unit	$0.10/g
	Reprocessing	$41,364.93	$4.14/unit	$0.96/g
1 000 000	Melting	$131,158.63	$0.13/unit	$0.03/g
	Recycling	$40,384.06	$0.04/unit	$0.01/g
	Reprocessing	$78,313.69	$0.08/unit	$0.02/g
		0.25 km		
10 000	Melting	$8,809.73	$0.88/unit	$0.20/g
	Recycling	$4,317.31	$0.43/unit	$0.10/g
	Reprocessing	$41,365.43	$4.14/unit	$0.96/g
1 000 000	Melting	$131,208.45	$0.13/unit	$0.03/g
	Recycling	$40,433.87	$0.04/unit	$0.01/g
	Reprocessing	$78,363.51	$0.08/unit	$0.02/g

For the situation of transportation through narrow, unpaved paths that are inaccessible to vehicles or when vehicles are not available, an animal drawn cart is an acceptable alternative in many areas of the world. In the case of melting 1,000,000 needles and syringes within a year, multiple hot presses are required regardless of distance. Table 5-4 and Table 5-5 show the time and cost requirements associated with the use of an animal drawn cart as a method of transportation.

Table 5-4: Time requirements of a disposal process using an animal drawn cart as a transportation method

# Needles	Method:	Animal & Cart	
		1 km	100 km
10 000	Melting	110.89 hrs	122.44 hrs
	Recycling	15.25 hrs	26.80 hrs
	Reprocessing	16.39 hrs	27.94 hrs
1 000 000	Melting	11088.80 hrs	12243.74 hrs
	Recycling	1524.95 hrs	2679.89 hrs
	Reprocessing	1638.75 hrs	2793.70 hrs

Table 5-5: Cost requirements of a disposal process using an animal drawn cart as a transportation method

# Needles	Method:	Animal & Cart		
		1 km		
10 000	Melting	$8,913.93	$0.89/unit	$0.21/g
	Recycling	$4,421.51	$0.44/unit	$0.10/g
	Reprocessing	$41,469.63	$4.15/unit	$0.96/g
1 000 000	Melting	$131,338.78	$0.13/unit	$0.03/g
	Recycling	$40,564.21	$0.04/unit	$0.01/g
	Reprocessing	$78,493.84	$0.08/unit	$0.02/g
		100 km		
10 000	Melting	$8,973.41	$0.90/unit	$0.21/g
	Recycling	$4,480.99	$0.45/unit	$0.10/g
	Reprocessing	$41,529.11	$4.15/unit	$0.96/g
1 000 000	Melting	$137,286.74	$0.14/unit	$0.03/g
	Recycling	$46,512.17	$0.05/unit	$0.01/g
	Reprocessing	$84,441.81	$0.08/unit	$0.02/g

In areas where vehicle use is practical and may be afforded, a pickup truck provides much faster transportation services. For the cases of transporting 10,000 and 1,000,000 injection units either 1 km or 100 km in the given time frame of one year, one truck was sufficient. Table 5-6 and Table 5-7 give the results of time and cost

estimations using a truck as a transport method. Once again, the melting/encapsulation process requires much more time than one year. Therefore, multiple hot presses are needed.

Table 5-6: Time requirements of a disposal process using a pickup truck as a transportation method

# Needles	Method:	Pickup Truck	
		1 km	100 km
10 000	Melting	111.84 hrs	115.14 hrs
	Recycling	16.20 hrs	19.50 hrs
	Reprocessing	17.34 hrs	20.64 hrs
1 000 000	Melting	11079.53 hrs	11185.13 hrs
	Recycling	1515.68 hrs	1621.28 hrs
	Reprocessing	1629.49 hrs	1735.09 hrs

Table 5-7: Cost requirements of a disposal process using a pickup truck as a transportation method

# Needles	Method:	Pickup Truck		
		1 km		
10 000	Melting	$15,666.84	$1.57/unit	$0.36/g
	Recycling	$11,174.43	$1.12/unit	$0.26/g
	Reprocessing	$48,222.55	$4.82/unit	$1.12/g
1 000 000	Melting	$138,042.94	$0.14/unit	$0.03/g
	Recycling	$47,268.37	$0.05/unit	$0.01/g
	Reprocessing	$85,198.01	$0.09/unit	$0.02/g
		100 km		
10 000	Melting	$15,696.14	$1.57/unit	$0.36/g
	Recycling	$11,203.73	$1.12/unit	$0.26/g
	Reprocessing	$48,251.84	$4.83/unit	$1.12/g
1 000 000	Melting	$138,980.41	$0.14/unit	$0.03/g
	Recycling	$48,205.84	$0.05/unit	$0.01/g
	Reprocessing	$86,135.48	$0.09/unit	$0.02/g

5.4 Discussion of Results

The above results illustrate the various relationships between the number of injection units to be disposed of, the disposal method, the transportation method, and the distance to the nearest processing facility. The distance of travel has an insignificant impact on both time and cost estimates with the exception of the case in which an animal drawn cart travels 100 km. This is not a practical use of a work animal due to the extreme distance of travel required and the fact that it would take several days for the animal to arrive at the disposal facility, as the animal averages 3.2 km/hr. Overall, the most significant time contribution to the transportation process is loading and unloading time, so the actual travel time does not have a very big impact on the overall time required of each proposed method. Cost requirements of the transportation stage depend heavily on the choice of a transportation method, but are relatively unaffected by the distance traveled. This is evident in the per unit costs. For each transportation method, the disposal cost per unit was unaffected by a change in the distance traveled. The cost of labor for the operator responsible for transportation is affected by the time required for each distance considered, but this is a very small figure in relation to the other cost components, such as the original purchase price of the equipment. The significant contribution of capital investment to overall cost of the disposal method chosen reinforces the practicality of applying the model to developed or transitional countries, as developing countries would not be able to provide the initial investment required.

The choice of a transportation method plays a significant role in the time and cost required to dispose of the waste material. Differences between an animal drawn cart and

a cart pushed by a human are very small, but the use of a vehicle adds a considerable amount to the cost due to the high purchase price of the truck. This is most evident in the case where 10,000 injection units are to be processed in a year. Concerning time estimates, the animal drawn cart and the truck are very similar where recycling and reprocessing activities are concerned. For 1,000,000 units, the truck becomes more time effective because it doesn't take so long to gather enough full sharps boxes for a full load. Time differences when encapsulation is the chosen disposal method are not as significant as recycling and reprocessing time differences due to the longer melting and cooling times required of this method when compared to the long loading time of the others.

With the three disposal options for each transportation method and amount of injection equipment to dispose of, selling the disinfected separated material to be recycled is always the most cost effective option. The most expensive option for the case where 10,000 units are considered per year is reprocessing using injection molding, where the amount of material to be processed is not enough to offset the high initial cost of the equipment. When 1,000,000 units are processed each year, encapsulation by melting becomes significantly more expensive than recycling and reprocessing due to the requirement of multiple machines. This is because the hot press requires more time to operate (per unit mass) than the other machines because the bulky bricks have a long cooling time in the mold of the hot press. In addition, without operating several hot presses at once, the process could not be completed within the comparison time of one year. In this case, encapsulation by melting has an average annual cost of $135,000, recycling costs approximately $45,000, and reprocessing by injection molding has a price of about $80,000. Injection molding is consistently high in price, regardless of the

number of needles and syringes processed per year, due to the high cost of the machinery. In this model no resale value is considered for the profits of the reprocessed goods. If sales profits were included, injection molding would not have such a high cost, but in this study they are neglected due to the inability to accurately quantify actual conditions (marketing and packaging costs, sales price, increased workforce, etc.). This skews the results of the current model too much to be useful without further analysis. It also reinforces the application of injection molding as the chosen disposal process for use in developed or transitional countries because of the intricate nature of developing such a process (from production to sales).

When analyzing disposal methods as a function of time, encapsulation consistently takes significantly longer than reprocessing or recycling. This process takes so much more time than injection molding because of the bulk of the material to be melted and cooled with each run. The high costs resulting from the purchase of expensive processing equipment illustrates the need for a significant amount of capital before implementing such a course of action.

In every time estimate for encapsulation of needles by melting, traditional needle and syringe systems are more efficient. This is due to the impact of the first step in the process, defanging. The machine used to defang the metal needles operates more quickly than melting plastic needle tips using a hotplate. In every other case, plastic needles are either faster to process or cost less to process. With regard to the disposal flow involving injection molding, the disinfection process yielding lowest cost varied as a function of the number of needles and syringes to be processed, but in every time estimation case, the hydroclave proved the most time efficient. Concerning cost estimation, gas disinfection

proved the least expensive for the case of 10,000 units, but when 1,000,000 units were available for processing, the hydroclave becomes the most cost effective. The reason why different machines become more cost effective as volume increases is related to the throughput and initial cost of each one. For example, a machine with a very high throughput and a very high price may not be suitable for a small number of needles and syringes because of the high cost per unit and the low time that it would be in use each year. When considering a large number of needles and syringes, the same machine is more useful than one that costs much less but has a very low throughput. Because of this, the amount of waste to be processed is important to determine before specifying an ideal disposal process.

5.5 Sensitivity Analysis

The results of the sensitivity analysis performed to test the significance of values such as volume of waste generated per year, transportation methods, and distance traveled between medical facilities and disposal facilities are presented and discussed above as variables changed to obtain various cost and time estimates. Power and labor rates were also tested for sensitivity. Results are given in Table 5-8 and Table 5-9.

Table 5-8: Sensitivity analysis of power rate

		Human & Cart: 0 km	
		Power Rate: $0.0683/kW	Power Rate*2
# Needles	Method:	Cost:	Cost:
10 000	Melting	$8 809.23	$8 809.95
	Recycling	$4 316.82	$4 318.81
	Reprocessing	$41 364.93	$41 369.97
		Pickup Truck: 100 km	
		Power Rate: $0.0683/kW	Power Rate*2
# Needles	Method:	Cost:	Cost:
1 000 000	Melting	$138 980.41	$139 052.16
	Recycling	$48 205.84	$48 315.36
	Reprocessing	$86 135.48	$86 549.32

Table 5-9: Sensitivity analysis of labor rate

		Human & Cart: 0 km	
		Labor Rate: $5.15/hr	Labor Rate: $20/hr
# Needles	Method:	Cost:	Cost:
10 000	Melting	$8 809.23	$10 412.47
	Recycling	$4 316.82	$5 472.66
	Reprocessing	$41 364.93	$42 537.68
		Pickup Truck: 100 km	
		Labor Rate: $5.15/hr	Labor Rate: $20/hr
# Needles	Method:	Cost:	Cost:
1 000 000	Melting	$138 980.41	$300 954.63
	Recycling	$48 205.84	$52 009.87
	Reprocessing	$86 135.48	$91 629.54

Time requirements are not presented in this sensitivity analysis because the power and labor rates have no impact on time. (This means that the time requirements for each

situation are equivalent even with differing rates.) The cost differences for the case of varying the power rate are very slight and do not indicate a significant dependence on the assumed values. In varying the labor rate from minimum wage ($5.15 per hour) to a more generous amount of $20 per hour, the resulting cost requirements change dramatically. When processing 10,000 needles and syringes each year, the difference in cost is not very extreme, illustrating the heavy impact of equipment cost. This is also the case when recycling and reprocessing are considered as methods of disposal for processing 1,000,000 units annually. However, when 1,000,000 needles and syringes will be encapsulated by melting, the increase in cost with the increased labor rate is extreme, and increases by over 150% per year. This shows the impact of the processing time in this case, as labor costs are derived directly from the time required to process each brick.

In order to assess the sensitivity of the cost model to the value of the tipping fee, only encapsulation by melting is analyzed, as this is the only method presented in these results that includes disposal to a landfill. Table 5-10 shows the results of varying the tipping fee from $29.50 to $56.00 per ton to illustrate how a higher tipping fee charged in other areas would affect cost requirements (35).

Table 5-10: Sensitivity analysis of tipping fee

		Human & Cart: 0 km	
		Tipping Fee: $29.50/ton	Tipping Fee: $56.00/ton
# Needles	Method:	Cost:	Cost:
10 000	Melting	$8 809.23	$8 811.21
		Pickup Truck: 100 km	
		Tipping Fee: $29.50/ton	Tipping Fee: $56.00/ton
# Needles	Method:	Cost:	Cost:
1 000 000	Melting	$138 980.41	$139 106.43

The cost model is not very sensitive to the value of the tipping fee, as shown above. This is due to the relatively low mass of the needles and syringes collected as compared to the tipping fee given as a cost per ton, where difference in costs above is approximately $0.02 for every 100 needles processed.

5.6 Fractional Cost Estimates

In all of the above analyses, full capital cost of all equipment was considered for each cost estimate. In a situation where resources are shared between various entities, equipment purchase costs may be shared. In this case, machine cost contributions are calculated based on the fraction of time they are needed out of a full 2,000 hour work year. Tables 5-11, 5-12, and 5-13 provide the results of fractional costs calculated using each of the three transportation methods.

Table 5-11: Fractional cost requirements of a disposal process using a human and cart as a transportation method

# Needles	Method:	Human & Cart		
		0 km		
10 000	Melting	$1,261.74	$0.13/unit	$0.03/g
	Recycling	$289.42	$0.03/unit	$0.01/g
	Reprocessing	$302.79	$0.03/unit	$0.01/g
1 000 000	Melting	$126,173.94	$0.13/unit	$0.03/g
	Recycling	$28,941.90	$0.03/unit	$0.01/g
	Reprocessing	$30,279.14	$0.03/unit	$0.01/g
		0.25 km		
10 000	Melting	$1,262.24	$0.13/unit	$0.03/g
	Recycling	$289.92	$0.03/unit	$0.01/g
	Reprocessing	$303.29	$0.03/unit	$0.01/g
1 000 000	Melting	$126,224.03	$0.13/unit	$0.03/g
	Recycling	$28,991.98	$0.03/unit	$0.01/g
	Reprocessing	$30,329.23	$0.03/unit	$0.01/g

Table 5-12: Fractional cost requirements of a disposal process using an animal and cart as a transportation method

# Needles	Method:	Animal & Cart		
		1 km		
10 000	Melting	$1,378.50	$0.14/unit	$0.03/g
	Recycling	$406.18	$0.04/unit	$0.01/g
	Reprocessing	$419.55	$0.04/unit	$0.01/g
1 000 000	Melting	$126,366.22	$0.13/unit	$0.03/g
	Recycling	$29,134.17	$0.03/unit	$0.01/g
	Reprocessing	$30,471.41	$0.03/unit	$0.01/g
		100 km		
10 000	Melting	$1,438.23	$0.14/unit	$0.03/g
	Recycling	$465.91	$0.05/unit	$0.01/g
	Reprocessing	$479.29	$0.05/unit	$0.01/g
1 000 000	Melting	$132,339.36	$0.13/unit	$0.03/g
	Recycling	$35,107.31	$0.04/unit	$0.01/g
	Reprocessing	$36,444.56	$0.04/unit	$0.01/g

Table 5-13: Fractional cost requirements of a disposal process using a pickup truck as a transportation method

# Needles	Method:	Pickup Truck		
		1 km		
10 000	Melting	$1,272.80	$0.13/unit	$0.03/g
	Recycling	$300.48	$0.03/unit	$0.01/g
	Reprocessing	$313.85	$0.03/unit	$0.01/g
1 000 000	Melting	$126,374.68	$0.13/unit	$0.03/g
	Recycling	$29,142.63	$0.03/unit	$0.01/g
	Reprocessing	$30,479.87	$0.03/unit	$0.01/g
		100 km		
10 000	Melting	$1,313.50	$0.13/unit	$0.03/g
	Recycling	$341.17	$0.03/unit	$0.01/g
	Reprocessing	$354.55	$0.04/unit	$0.01/g
1 000 000	Melting	$127,676.86	$0.13/unit	$0.03/g
	Recycling	$30,444.82	$0.03/unit	$0.01/g
	Reprocessing	$31,782.06	$0.03/unit	$0.01/g

These values illustrate the effect of normalizing the cost requirements so that only the fraction of resources in use is considered. Fractional cost values and corresponding costs per unit and per unit mass illustrate that recycling and reprocessing consistently cost approximately $0.03 per injection unit. Encapsulation by melting is about four times as costly, with an average of $0.13 for the processing of each unit. These costs vary significantly from the non-fractional costs, specifically in cases where 10,000 injection units are processed annually. With such a low throughput, the machines are not utilized to their full capacity. This provides an opportunity to use the equipment to make other products. This is especially evident when reprocessing by injection molding is the chosen method. The non-fractional cost of reprocessing (i.e., charging the entire capital cost to the products) the needles and syringes is over one-hundred times greater than the

fractional cost (i.e., charging only the fraction of the capital cost associated with making the products) in some cases. As throughput increases, the differences between non-fractional and fractional costs begin to decrease. This is due to a higher usage of each machine.

5.7 Summary

This chapter provided the results of the cost estimation model, as well as assumptions that were used to guide the determination of acceptable disposal paths. Sensitivity analyses were provided, illustrating the insignificance of assumed power and labor rates and demonstrating the effects of transportation method, distance traveled, and volume of waste to be disposed. Fractional costs also were given, demonstrating the reduction in cost associated with sharing resources (and capital costs) with others who have use for the same equipment.

The next chapter will state conclusions drawn from these results and present recommendations for future work in cost and time estimation for the disposal of used injection equipment.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

This chapter draws conclusions regarding the most cost effective disposal methods for a variety of situations. When deciding upon an ideal disposal process, it is important to first define all of the conditions of the model. The choice of a transportation method, the volume of waste to dispose of, and the distance to cover in travel is necessary to find the most appropriate system.

6.1 Conclusions

Due to a variety of outcomes dependant upon inputs to the cost-estimation model, the most cost-effective option depends on the specific situation in which the disposal process takes place. For example, for distances 1 km and greater between medical and recycling facilities, an animal drawn cart is always the most economical choice. This may not be practical, however, for several reasons. The animal may only be able to work for one-third the amount of time in which a vehicle could run within a single day, making transportation time requirements for this option unreasonably high. Also, the use of animal drawn carts is better suited for developing countries, so that in developed or transitional countries, vehicles or simple carts pushed by humans are more likely to be accepted.

The purpose for considering disposal or recycling options is also important in determining the best situation. In an area where there is no market for recycling, and adequate facilities are lacking to begin a new recycling plant, needle encapsulation is the best situation. No new useful products are being created in this situation, but there are still many benefits to choosing this method over traditional disposal in a municipal

garbage facility. The bulk volume of used syringes is reduced by about 75% after encapsulation, so the amount of space occupied in a landfill is much smaller after melting. Also, the high temperature the materials undergo in the process kills any pathogens remaining on the equipment so that no disease can be spread through contact with the block. Finally, encapsulated needles are harmless compared to exposed needles currently being dumped into municipal landfills.

If the primary goal of beginning a new disposal process is to make new products from what would otherwise become trash, injection molding is suitable for these purposes. Profits from molded goods are not included in this model, but in a case where reprocessing the material is the most important step, injection molding is the most cost-effective and useful process to make items that are beneficial to the community. In this type of situation, the main decision required is a choice of disinfection equipment.

It is also very important to assess the number of needles and syringes to be processed in a given amount of time because as this number increases, the most efficient process often changes. By properly determining this amount, machinery purchased may be of an adequate size that it will neither be under-utilized nor over-filled so that there might be a backup in material waiting for processing, or so that multiple machines are necessary.

The cost of capital is significant when considering the purchase of such expensive equipment. This analysis assumes the existence of such capital, but when it is not available, a further examination is needed to determine alternate methods to obtain the machinery. In the case where fractional costs are assumed, capital machine costs can be shared with other products which can utilize the remaining time available on each

machine. By considering fractional costs of all equipment based on actual usage time, capital costs can be significantly lowered, depending on the number of needles and syringes to be processed and the method by which this is done.

6.2 Recommendations

In order to make the greatest positive impact on the community through needle and syringe recycling, several factors should be considered. The first idea is to incorporate an all-plastic needle and syringe into the system. By eliminating all materials outside of plastic, such as metal and rubber, that are very difficult to get rid of, the entire system may go directly from being granulated and disinfected to reprocessing without a separation stage required. This may be an important consideration due to the proprietary nature of separation companies and the necessity of sending out assorted materials to be sorted by an independent company rather than performing this onsite within the reprocessing facility. Both money and time will be saved in this situation, and more material will be available for future recycling.

Another consideration is to include as many medical facilities as possible into the recycling process, so that there is a significantly large amount of plastic available for recycling. With a constant, high volume supply of material (over 1,000,000 needles and syringes per year), a reprocessing plant will always have the ability to create new products to be sold for a profit. There is also a lower reprocessing cost per unit because the machine may be used to its full capacity, in which case there are no unnecessary idle times or situations in which the machine is not running through the day.

Finally, for the most accurate output data from the model, the benefits of reprocessing should be included in the analysis. This includes the economic profits that

would be realized from the sale of newly created products, where currently only the cost of production is included. An analysis that includes benefits as well as costs may show reprocessing as a more realistic option for used injection equipment.

APPENDIX

Table A-1: Cost model input data

A	Number of Needles	1 000 000
B	Type of Needle:	metal
C	Shot Volume (mL):	5
D	Packaging Included:	none
E	Time Length (months):	12
F	Distance to Closest Facility (km):	100

Table A-2: Cost model coded data

		Metal	Plastic
Constants:	Power rate ($/kW):	6.833E-02	6.833E-02
	Labor rate ($/hr):	5.150E+00	5.150E+00
	Mass of metal (kg):	3.900E-05	0.000E+00
	Mass of rubber (kg):	1.910E-04	0.000E+00
	Mass of plastic (kg):	4.118E-03	4.313E-03
		4.348E-03	
A1	Immobilize: (Defang)		
	Cost of equipment ($):	3.990E+02	
	Life of equipment (yrs.):	2.000E+00	
	Power required (kW/hr):	2.475E-01	
	Time required (hrs./needle):	2.778E-04	
	Total time (hrs.):	2.778E+02	
	Total cost ($):	2.042E+02	0.000E+00
A2	Immobilize: (Melt Tip)		
	Cost of equipment($):		2.170E+02
	Life of equipment (yrs.):		1.000E+01
	Power required (kW/hr):		7.560E-01
	Time required (hrs./needle):		1.389E-03
	Total time (hrs.):		1.389E+03

Table A-2 (cont'd)

	Total cost ($):	0.000E+00	9.345E+01
B1	Contain: (throw in box)		
	Volume of box (needles/box):	1.780E+02	1.780E+02
	Cost of each box ($/box):	4.966E+00	4.966E+00
	Time required (hrs./needle):	0.000E+00	0.000E+00
	Total time (hrs.):	0.000E+00	0.000E+00
	Total cost ($):	2.790E+04	2.790E+04
B2	Contain: (throw in machine)		
	Total time (hrs.):	0.000E+00	0.000E+00
	Total cost ($):	0.000E+00	0.000E+00
C1	Pick Up: (human with cart)		
	Cost of cart ($):	4.453E+02	4.453E+02
	Life of cart (yrs.):	8.000E+00	8.000E+00
	Needles per cart:	5.743E+03	5.743E+03
	Velocity of travel (km/hr):	4.500E+00	4.500E+00
	Trips required:	1.741E+02	1.741E+02
	Loading time per trip (hrs.):	2.500E-01	2.500E-01
	Travel time per trip (hrs.):	2.222E+01	2.222E+01
	Cost per trip ($):	1.157E+02	1.157E+02
	Total time to load (hrs.):	4.353E+01	4.353E+01
	Carts required:	2.000E+00	2.000E+00
	Total cost ($):	2.026E+04	2.026E+04
	Total time (hrs.):	3.913E+03	3.913E+03
C2	Pick Up: (animal and driver with cart)		
	Cost of animal ($):	3.800E+01	3.800E+01
	Useful life of animal (yrs.):	5.000E+00	5.000E+00
	Cost of animal care ($/yr.):	1.160E+02	1.160E+02
	Cost of cart ($):	1.800E+02	1.800E+02
	Life of cart (yrs.):	5.000E+00	5.000E+00
	Needles per cart:	2.679E+04	2.679E+04
	Velocity of travel (km/hr.):	3.200E+00	3.200E+00
	Trips required:	3.733E+01	3.733E+01
	Loading time per trip (hrs.):	1.250E+00	1.250E+00
	Travel time per trip (hrs.):	3.125E+01	3.125E+01
	Cost per trip ($):	1.674E+02	1.674E+02
	Total time to load (hrs.):	4.666E+01	4.666E+01
	Carts required:	1.000E+00	1.000E+00
	Total cost ($):	6.408E+03	6.408E+03

Table A-2 (cont'd)

	Total time (hrs.):	1.213E+03	1.213E+03
C3	Pick Up: (vehicle)		
	Cost of vehicle ($):	2.763E+04	2.763E+04
	Useful life of vehicle (yrs.):	4.000E+00	4.000E+00
	Cost of maintenance ($/yr.):	1.988E+02	1.988E+02
	Cost of fuel ($/gal):	1.500E+00	1.500E+00
	Vehicle efficiency (mi/gal):	1.500E+01	1.500E+01
	Vehicle velocity (mi/hr):	3.000E+01	3.000E+01
	Needles per vehicle:	3.157E+04	3.157E+04
	Trips required:	3.200E+01	3.200E+01
	Loading time per trip (hrs.):	1.500E+00	1.500E+00
	Travel time per trip (hrs.):	3.333E+00	3.333E+00
	Cost per trip ($):	2.489E+01	2.489E+01
	Total time to load (hrs.):	4.800E+01	4.800E+01
	Vehicles required:	1.000E+00	1.000E+00
	Total cost ($):	8.102E+03	8.102E+03
	Total time (hrs.):	1.547E+02	1.547E+02
D1	Disinfect: (hydroclave)		
	Cost of equipment ($):	1.063E+05	1.063E+05
	Life of equipment (yrs.):	1.000E+01	1.000E+01
	Cost of supplies ($/month):	0.000E+00	0.000E+00
	Power required (kW/hr):	1.650E+00	1.650E+00
	Time required (hrs./needle):	4.778E-05	4.740E-05
	Total time (hrs.):	4.778E+01	4.740E+01
	Total cost ($):	1.088E+04	1.088E+04
D2	Disinfect: (gas)		
	Cost of equipment ($):	2.750E+03	2.750E+03
	Life of equipment (yrs.):	1.000E+01	1.000E+01
	Cost of supplies ($/month):	5.000E+03	5.000E+03
	Power required (kW/hr):	1.500E-01	1.500E-01
	Time required (hrs./needle):	9.313E-03	9.313E-03
	Total time (hrs.):	9.313E+03	9.313E+03
	Total cost ($):	1.083E+05	1.083E+05
D3	Disinfect: (steam autoclave)		
	Cost of equipment ($):	8.950E+04	8.950E+04
	Life of equipment (yrs.):	1.000E+01	1.000E+01
	Cost of supplies ($/month):	0.000E+00	0.000E+00
	Power required (kW/hr):	1.100E+00	1.100E+00

Table A-2 (cont'd)

	Time required (hrs./needle):	7.174E-05	7.116E-05
	Total time (hrs.):	7.174E+01	7.116E+01
	Total cost ($):	9.325E+03	9.322E+03
D4	Disinfect: (chemicals)		
	Cost of equipment ($):	1.800E+04	1.800E+04
	Life of equipment (yrs.):	1.000E+01	1.000E+01
	Cost of supplies ($/month):	2.344E+03	2.344E+03
	Power required (kW/hr):	1.800E+00	1.800E+00
	Time required (hrs./needle):	2.083E-03	2.083E-03
	Total time (hrs.):	2.083E+03	2.083E+03
	Total cost ($):	4.091E+04	4.091E+04
D5	Disinfect: (incineration)		
	Cost of equipment($):	6.150E+04	6.150E+04
	Life of equipment (yrs.):	1.000E+01	1.000E+01
	Cost of supplies ($):	0.000E+00	0.000E+00
	Power required (kW/hr):	6.900E+00	6.900E+00
	Time required (hrs./needle):	5.466E-05	5.422E-05
	Total time (hrs.):	5.466E+01	5.422E+01
	Total cost ($):	6.457E+03	6.455E+03
E1	Reduce Size: (Grind - SMALL)		
	Cost of equipment($):	1.119E+04	1.119E+04
	Life of equipment (yrs.):	1.000E+01	1.000E+01
	Power required (kW/hr):	3.640E+00	3.640E+00
	Time required (hrs./needle):	9.882E-06	9.802E-06
	Total time (hrs.):	9.882E+00	9.802E+00
	Total cost ($):	1.172E+03	1.172E+03
E2	Reduce Size: (Grind - BIG)		
	Cost of equipment($):	2.600E+04	2.600E+04
	Life of equipment (yrs.):	1.000E+01	1.000E+01
	Power required (kW/hr):	1.564E+01	1.564E+01
	Time required (hrs./needle):	3.044E-05	3.033E-05
	Total time (hrs.):	3.044E+01	3.033E+01
	Total cost ($):	2.789E+03	2.789E+03
E3	Reduce Size: (Melt Whole - Hot Press)		
	Cost of equipment($):	7.500E+04	7.500E+04
	Life of equipment (yrs.):	9.500E+00	9.500E+00
	Power required (kW/hr):	0.000E+00	0.000E+00

Table A-2 (cont'd)

	Time required (hrs./needle):	1.075E-02	1.075E-02
	Total time (hrs.):	1.075E+04	1.075E+04
	Total cost ($):	6.327E+04	6.327E+04
F1	Separate: (Air Classification)		
	Total time (hrs.):	8.064E+03	0.000E+00
	Total cost ($):	1.339E+03	0.000E+00
G1	Dispose: (Metal to landfill)		
	Disposal fee ($/kg):	3.252E-02	0.000E+00
	Total time (hrs.):	0.000E+00	0.000E+00
	Total cost ($):	1.268E+00	0.000E+00
G2	Dispose: (Rubber to landfill)		
	Disposal fee ($/kg):	3.252E-02	0.000E+00
	Total time (hrs.):	0.000E+00	0.000E+00
	Total cost ($):	6.212E+00	0.000E+00
G3	Dispose: (Plastic to landfill)		
	Disposal fee ($/kg):	3.252E-02	3.252E-02
	Total time (hrs.):	0.000E+00	0.000E+00
	Total cost ($):	1.339E+02	1.403E+02
G4	Dispose: (Recycle metal)		
	Payment ($/kg):	-2.900E-02	-2.900E-02
	Total time (hrs.):	0.000E+00	0.000E+00
	Total cost ($):	-1.131E-06	0.000E+00
G5	Dispose: (Recycle rubber)		
	Payment ($/kg):	-6.370E-01	-6.370E-01
	Total time (hrs.):	0.000E+00	0.000E+00
	Total cost ($):	-1.217E-04	0.000E+00
G6	Dispose: (Recycle plastic)		
	Payment ($/kg):	-4.000E-01	-4.000E-01
	Total time (hrs.):	0.000E+00	0.000E+00
	Total cost ($):	-1.647E-03	-1.725E-03
H1	Make Processable: (Wash/Rinse)		
	Cost of equipment($):	7.000E+04	7.000E+04
	Life of equipment (yrs.):	1.000E+01	1.000E+01
	Power required (kW/hr):	0.000E+00	0.000E+00

Table A-2 (cont'd)

	Time required (hrs./needle):	4.540E-05	4.755E-05
	Total time (hrs.):	4.540E+01	4.755E+01
	Total cost ($):	7.234E+03	7.245E+03
H2	Make Processable: (Hopper Dryer)		
	Cost of equipment($):	2.995E+03	2.995E+03
	Life of equipment (yrs.):	1.000E+01	1.000E+01
	Power required (kW/hr):	8.050E+00	8.050E+00
	Time required (hrs./needle):	3.028E-05	3.171E-05
	Total time (hrs.):	3.028E+01	3.171E+01
	Total cost ($):	4.721E+02	4.803E+02
H3	Make Processable: (Extrude/Pelletize/Blend)		
	Cost of equipment($):	1.480E+04	1.480E+04
	Life of equipment (yrs.):	9.500E+00	9.500E+00
	Power required (kW/hr):	5.520E+00	5.520E+00
	Time required (hrs./needle):	1.514E-05	1.586E-05
	Total time (hrs.):	1.514E+01	1.586E+01
	Total cost ($):	1.642E+03	1.646E+03
I1	Process: (Extrude)		
	Cost of equipment($):	1.760E+06	1.760E+06
	Life of equipment (yrs.):	1.100E+01	1.100E+01
	Power required (kW/hr):	0.000E+00	0.000E+00
	Time required (hrs./needle):	6.040E-06	6.326E-06
	Total time (hrs.):	6.040E+00	6.326E+00
	Total cost ($):	1.600E+05	1.600E+05
I2	Process: (Injection Mold)		
	Cost of equipment($):	3.100E+05	3.100E+05
	Life of equipment (yrs.):	1.100E+01	1.100E+01
	Power required (kW/hr):	2.200E+02	2.200E+02
	Time required (hrs./needle):	1.784E-05	1.868E-05
	Total time (hrs.):	1.784E+01	1.868E+01
	Total cost ($):	2.854E+04	2.856E+04

Table A-3: Cost model output data (traditional metal needle time requirements)

Step 1	B1	B1	B1	B1	B1	B1	B1	B1	B1
Step 2	G1	C3	D5	C3	C1,C2,C3	C3	E2	E1,E2	E2
Step 3	G2	E3		E2	E1,2	E2	D1,2,3,4	D1,2,3,4	D1,2,3,4
Step 4	G3	G1		D1,2,3,4	D1,2,3,4	D1,2,3,4	F1	F1	F1
Step 5		G2		F1	F1	F1	G4	G1	G4
Step 6		G3		G4	G1	G4	G5	G2	G5
Step 7				G5	G2	G5	G6	H1	H1
Step 8				G6	H1	H1		H2	H2
Step 9					H2	H2		H3	H3
Step 10					H3	H3		I1,2	I1,2
Step 11					I1,I2	I2			
Total Time (hrs)									
w/ defanging:									
	2.778E+02	1.119E+04	3.324E+02	8.575E+03	8.651E+03	8.683E+03	8.420E+03	8.496E+03	8.517E+03
w/o defanging:									
	0.000E+00	1.091E+04	5.466E+01	8.297E+03	8.373E+03	8.406E+03	8.142E+03	8.219E+03	8.239E+03

*NOTE: Step codes are provided in Table A-2

Table A-4: Cost model output data (all-plastic needle time requirements)

Step 1	B1	B1	B1	B1	B1	B1	B1
Step 2	G3	C3	D5	C3	E2	C3	E2
Step 3		E3		E2	D1,D2,D3,D4	E2	D1,D2,D3,D4
Step 4		G3		D1,D2,D3,D4	G6	D1,D2,D3,D4	H1
Step 5				G6		H1	H2
Step 6						H2	H3
Step 7						H3	I2
Step 8						I2	
Total Time (hrs)							
w/ melting:							
	1.389E+03	1.230E+04	1.443E+03	1.621E+03	1.467E+03	1.735E+03	1.580E+03
w/o melting:							
	0.000E+00	1.091E+04	5.422E+01	2.324E+02	7.773E+01	3.462E+02	1.915E+02

*NOTE: Step codes are provided in Table A-2

Table A-5: Cost model output data (traditional metal needle cost requirements)

Step 1	B1	B1	B1	B1	B1	B1	B1	B1	B1
Step 2	G1	C3	D5	C3	C1,C2,C3	C3	E2	E1,E2	E2
Step 3	G2	E3		E2	E1,2	E2	D1,2,3,4	D1,2,3,4	D1,2,3,4
Step 4	G3	G1		D1,2,3,4	D1,2,3,4	D1,2,3,4	F1	F1	F1
Step 5		G2		F1	F1	F1	G4	G1	G4
Step 6		G3		G4	G1	G4	G5	G2	G5
Step 7				G5	G2	G5	G6	H1	H1
Step 8				G6	H1	H1		H2	H2
Step 9					H2	H2		H3	H3
Step 10					H3	H3		I1,2	I1,2
Step 11					I1,I2	I2			
Total Cost ($)									
w/ defanging:									
	2.810E+04	2.616E+05	3.456E+04	4.966E+04	8.586E+04	8.755E+04	4.156E+04	7.783E+04	7.945E+04
w/o defanging:									
	2.790E+04	2.614E+05	3.436E+04	4.946E+04	8.565E+04	8.734E+04	4.135E+04	7.763E+04	7.924E+04

*NOTE: Step codes are provided in Table A-2

Table A-6: Cost model output data (all-plastic needle cost requirements)

Step 1	B1	B1	B1	B1	B1	B1	B1
Step 2	G3	C3	D5	C3	E2	C3	E2
Step 3		E3		E2	D1,D2,D3,D4	E2	D1,D2,D3,D4
Step 4		G3		D1,D2,D3,D4	G6	D1,D2,D3,D4	H1
Step 5				G6		H1	H2
Step 6						H2	H3
Step 7						H3	I2
Step 8						I2	
Total Cost ($)							
w/ melting:							
	2.799E+04	2.615E+05	3.445E+04	4.821E+04	4.010E+04	8.614E+04	7.803E+04
w/o melting:							
	2.790E+04	2.614E+05	3.436E+04	4.811E+04	4.001E+04	8.604E+04	7.794E+04

*NOTE: Step codes are provided in Table A-2

Table A-7: Fractional equipment requirements for each possible disposal combination

Human & Cart; 0 km; 10,000 units; Melting

Equipment Type:	Number of Machines Required:
Hot Plate	0.006944444
Sharps Box	56
Cart	0.000217656
Hot Press	0.053763441

Human & Cart; 0 km; 10,000 units; Recycling

Equipment Type:	Number of Machines Required:
Hot Plate	0.006944444
Sharps Box	56
Cart	0.000217656
Grinder	0.000151662
Gas Disinfection	0.04656632

Human & Cart; 0 km; 10,000 units; Reprocessing

Equipment Type:	Number of Machines Required:
Hot Plate	0.006944444
Sharps Box	56
Cart	0.000217656
Grinder	0.000151662
Gas Disinfection	0.04656632
Washer	0.000237762
Dryer	0.000158566
Pelletizer	7.92831E-05

Human & Cart; 0 km; 1,000,000 units; Melting

Equipment Type:	Number of Machines Required:
Hot Plate	0.694444444
Sharps Box	5618
Cart	0.021765628
Hot Press	5.376344086

Table A-7 (cont'd)

Human & Cart; 0 km; 1,000,000 units; Recycling

Equipment Type:	Number of Machines Required:
Hot Plate	0.694444444
Sharps Box	5618
Cart	0.021765628
Grinder	0.015166176
Gas Disinfection	4.656631953

Human & Cart; 0 km; 1,000,000 units; Reprocessing

Equipment Type:	Number of Machines Required:
Hot Plate	0.694444444
Sharps Box	5618
Cart	0.021765628
Grinder	0.015166176
Gas Disinfection	4.656631953
Washer	0.023776185
Dryer	0.015856618
Pelletizer	0.007928309

Human & Cart; 0.25 km; 10,000 units; Melting

Equipment Type:	Number of Machines Required:
Hot Plate	0.006944444
Sharps Box	56
Cart	0.000266024
Hot Press	0.053763441

Human & Cart; 0.25 km; 10,000 units; Recycling

Equipment Type:	Number of Machines Required:
Hot Plate	0.006944444
Sharps Box	56
Cart	0.000266024
Grinder	0.000151662
Gas Disinfection	0.04656632

Table A-7 (cont'd)

Human & Cart; 0.25 km; 10,000 units; Reprocessing

Equipment Type:	Number of Machines Required:
Hot Plate	0.006944444
Sharps Box	56
Cart	0.000266024
Grinder	0.000151662
Gas Disinfection	0.04656632
Washer	0.000237762
Dryer	0.000158566
Pelletizer	7.92831E-05

Human & Cart; 0.25 km; 1,000,000 units; Melting

Equipment Type:	Number of Machines Required:
Hot Plate	0.694444444
Sharps Box	5618
Cart	0.026602434
Hot Press	5.376344086

Human & Cart; 0.25 km; 1,000,000 units; Recycling

Equipment Type:	Number of Machines Required:
Hot Plate	0.694444444
Sharps Box	5618
Cart	0.026602434
Grinder	0.015166176
Gas Disinfection	4.656631953

Human & Cart; 0.25 km; 1,000,000 units; Reprocessing

Equipment Type:	Number of Machines Required:
Hot Plate	0.694444444
Sharps Box	5618
Cart	0.026602434
Grinder	0.015166176
Gas Disinfection	4.656631953
Washer	0.023776185
Dryer	0.015856618
Pelletizer	0.007928309

Table A-7 (cont'd)

Animal & Cart; 1 km; 10,000 units; Melting

Equipment Type:	Number of Machines Required:
Hot Plate	0.006944444
Sharps Box	56
Animal & Cart	0.000291653
Hot Press	0.053763441

Animal & Cart; 1 km; 10,000 units; Recycling

Equipment Type:	Number of Machines Required:
Hot Plate	0.006944444
Sharps Box	56
Animal & Cart	0.000291653
Grinder	0.000151662
Gas Disinfection	0.04656632

Animal & Cart; 1 km; 10,000 units; Reprocessing

Equipment Type:	Number of Machines Required:
Hot Plate	0.006944444
Sharps Box	56
Animal & Cart	0.000291653
Grinder	0.000151662
Gas Disinfection	0.04656632
Washer	0.000237762
Dryer	0.000158566
Pelletizer	7.92831E-05

Table A-7 (cont'd)

Animal & Cart; 1 km; 1,000,000 units; Melting

Equipment Type:	Number of Machines Required:
Hot Plate	0.694444444
Sharps Box	5618
Animal & Cart	0.029165267
Hot Press	5.376344086

Animal & Cart; 1 km; 1,000,000 units; Recycling

Equipment Type:	Number of Machines Required:
Hot Plate	0.694444444
Sharps Box	5618
Animal & Cart	0.029165267
Grinder	0.015166176
Gas Disinfection	4.656631953

Animal & Cart; 1 km; 1,000,000 units; Reprocessing

Equipment Type:	Number of Machines Required:
Hot Plate	0.694444444
Sharps Box	5618
Animal & Cart	0.029165267
Grinder	0.015166176
Gas Disinfection	4.656631953
Washer	0.023776185
Dryer	0.015856618
Pelletizer	0.007928309

Table A-7 (cont'd)

Animal & Cart; 100 km; 10,000 units; Melting

Equipment Type:	Number of Machines Required:
Hot Plate	0.006944444
Sharps Box	56
Animal & Cart	0.006066375
Hot Press	0.053763441

Animal & Cart; 100 km; 10,000 units; Recycling

Equipment Type:	Number of Machines Required:
Hot Plate	0.006944444
Sharps Box	56
Animal & Cart	0.006066375
Grinder	0.000151662
Gas Disinfection	0.04656632

Animal & Cart; 100 km; 10,000 units; Reprocessing

Equipment Type:	Number of Machines Required:
Hot Plate	0.006944444
Sharps Box	56
Animal & Cart	0.006066375
Grinder	0.000151662
Gas Disinfection	0.04656632
Washer	0.000237762
Dryer	0.000158566
Pelletizer	7.92831E-05

Table A-7 (cont'd)

Animal & Cart; 100 km; 1,000,000 units; Melting

Equipment Type:	Number of Machines Required:
Hot Plate	0.694444444
Sharps Box	5618
Animal & Cart	0.606637548
Hot Press	5.376344086

Animal & Cart; 100 km; 1,000,000 units; Recycling

Equipment Type:	Number of Machines Required:
Hot Plate	0.694444444
Sharps Box	5618
Animal & Cart	0.606637548
Grinder	0.015166176
Gas Disinfection	4.656631953

Animal & Cart; 100 km; 1,000,000 units; Reprocessing

Equipment Type:	Number of Machines Required:
Hot Plate	0.694444444
Sharps Box	5618
Animal & Cart	0.606637548
Grinder	0.015166176
Gas Disinfection	4.656631953
Washer	0.023776185
Dryer	0.015856618
Pelletizer	0.007928309

Table A-7 (cont'd)

Pickup Truck; 1 km; 10,000 units; Melting

Equipment Type:	Number of Machines Required:
Hot Plate	0.006944444
Sharps Box	56
Animal & Cart	0.000291653
Hot Press	0.053763441

Pickup Truck; 1 km; 10,000 units; Recycling

Equipment Type:	Number of Machines Required:
Hot Plate	0.006944444
Sharps Box	56
Animal & Cart	0.000291653
Grinder	0.000151662
Gas Disinfection	0.04656632

Pickup Truck; 1 km; 10,000 units; Reprocessing

Equipment Type:	Number of Machines Required:
Hot Plate	0.006944444
Sharps Box	56
Animal & Cart	0.000291653
Grinder	0.000151662
Gas Disinfection	0.04656632
Washer	0.000237762
Dryer	0.000158566
Pelletizer	7.92831E-05

Pickup Truck; 1 km; 1,000,000 units; Melting

Equipment Type:	Number of Machines Required:
Hot Plate	0.694444444
Sharps Box	5618
Animal & Cart	0.029165267
Hot Press	5.376344086

Table A-7 (cont'd)

Pickup Truck; 1 km; 1,000,000 units; Recycling

Equipment Type:	Number of Machines Required:
Hot Plate	0.694444444
Sharps Box	5618
Animal & Cart	0.029165267
Grinder	0.015166176
Gas Disinfection	4.656631953

Pickup Truck; 1 km; 1,000,000 units; Reprocessing

Equipment Type:	Number of Machines Required:
Hot Plate	0.694444444
Sharps Box	5618
Animal & Cart	0.029165267
Grinder	0.015166176
Gas Disinfection	4.656631953
Washer	0.023776185
Dryer	0.015856618
Pelletizer	0.007928309

Pickup Truck; 100 km; 10,000 units; Melting

Equipment Type:	Number of Machines Required:
Hot Plate	0.006944444
Sharps Box	56
Animal & Cart	0.006066375
Hot Press	0.053763441

Pickup Truck; 100 km; 10,000 units; Recycling

Equipment Type:	Number of Machines Required:
Hot Plate	0.006944444
Sharps Box	56
Animal & Cart	0.006066375
Grinder	0.000151662
Gas Disinfection	0.04656632

Table A-7 (cont'd)

Pickup Truck; 100 km; 10,000 units; Reprocessing

Equipment Type:	Number of Machines Required:
Hot Plate	0.006944444
Sharps Box	56
Animal & Cart	0.006066375
Grinder	0.000151662
Gas Disinfection	0.04656632
Washer	0.000237762
Dryer	0.000158566
Pelletizer	7.92831E-05

Pickup Truck; 100 km; 1,000,000 units; Melting

Equipment Type:	Number of Machines Required:
Hot Plate	0.694444444
Sharps Box	5618
Animal & Cart	0.606637548
Hot Press	5.376344086

Pickup Truck; 100 km; 1,000,000 units; Recycling

Equipment Type:	Number of Machines Required:
Hot Plate	0.694444444
Sharps Box	5618
Animal & Cart	0.606637548
Grinder	0.015166176
Gas Disinfection	4.656631953

Pickup Truck; 100 km; 1,000,000 units; Reprocessing

Equipment Type:	Number of Machines Required:
Hot Plate	0.694444444
Sharps Box	5618
Animal & Cart	0.606637548
Grinder	0.015166176
Gas Disinfection	4.656631953
Washer	0.023776185
Dryer	0.015856618
Pelletizer	0.007928309

REFERENCES

1. Fact Sheet Number 234, World Health Organization, Geneva, October 1999.

2. D. U. Ekwueme, B. G. Weniger, R. T. Chen, "Model-based estimates of risks of disease transmission and economic costs of seven injection devices in Sub-Saharan Africa," Bulletin of the World Health Organization 2002, 80 (11), 859-870 (2002).

3. G. Dziekan, D. Chisholm, B. Johns, J. Rovira, Y. J. F. Hutin, "The Cost-Effectiveness of Policies for the Safe and Appropriate Use of Injection in Health Care Settings," 20 December 2002.

4. M. A. Miller, E. Pisani, "The cost of unsafe injections," Bulletin of the World Health Organization, 77 (10), 808-811 (1999).

5. A. Battersby, R. Feilden, C. Nelson, "Sterilizable syringes: excessive risk or cost-effective option?," Bulletin of the World Health Organization, 77 (10), 812-819 (1999).

6. Fact Sheet Number 231, World Health Organization, Geneva, April 2002.

7. Fact Sheet Number 233, World Health Organization, Geneva, October 1999.

8. "Choosing Auto-Disable Syringes or Prefilled Auto-Disable Devices For Delivering Liquid Vaccines: Factors For Consideration," UNICEF Supply Division.

9. "Univec Sliding Sheath Syringe" Product Page, Univec. www.univec.com/page5

10. R. Steinglass, D. Boyd, M. Grabowsky, A. G. Laghari, M. A. Khan, A. Qavi, P. Evans, "Safety, effectiveness and ease of use of a non-reusable syringe in a developing country immunization programme," Bulletin of the World Health Organization, 73 (1), 57-63 (1995).

11. C. M. Nelson, A. Sutanto, I. G. P. Suradana, "Use of SoloShot autodestruct syringes compared with disposable syringes, in a national immunization campaign in Indonesia," Bulletin of the World Health Organization, 77 (1), 29-33 (1999).

12. B. Melgaard, V. Li-Frankenstein, S. Rasheed, M. Nizamuddin, I. Osman, "The use of auto-disable syringes in immunization services," WHO-UNICEF-UNFPA joint statement, WHO/V&B/99.25

13. "Technologies to Manage Infectious Sharps Waste," PATH, October 2001.

14. S. A. Mujeeb, M. M. Adil, A. Altaf, Y. Hutin, S. Luby, "Recycling of Injection Equipment in Pakistan," Infection Control and Hospital Epidemiology, 24: 2, 146-146 (February 2003).

15. R. Carr, "Introducing technologies within a larger framework of health-care waste management," Safe Injection Global Network Annual Meeting Report, 9, 30-31 August 2001.

16. Fact Sheet Number 253, World Health Organization, Geneva, October 2000.

17. J. Emmanuel, "Overview of health-care waste management technologies," Safe Injection Global Network Annual Meeting Report, 11, 30-31 August 2001.

18. D. Allen, D. Bauer, B. Bras, T. Gutowski, C. Murphy, T. Piwonka, P. Sheng, J. Sutherland, D. Thurston, E. Wolff, "Environmentally Benign Manufacturing:Trends in Europe, Japan, and the USA," ASME, Vol. 124, 908-920, November 2002.

19. T. Fortner, H. Heffner, J. Colton, "Oven Melting Encapsulization of Hypodermic Needles by Syringes," Safe Injecition Global Network SIGNPost 00199, October 2003.

20. United States Department of Energy Office of Energy Efficiency and Renewable Energy: www.eere.energy.gov

21. Cole-Parmer Product Catalog, B-D Polypropylene Sharps Collectors – EW-07940-76

22. Fisher Scientific Catalog, Rubbermaid Tilt Trucks – Utility Duty 1304

23. "Study Compares Older and Younger Pedestrian Walking Speeds," Road Engineering Journal, TranSafety, Inc. October 1 1997.

24. G. Kidanmariam, "The use of donkeys for transport in Amhara Region, Ethiopia," Donkeys, people, and development. Technical Centre for Agricultural and Rural Cooperation, The Netherlands. 53-56.

25. Ford Vehicles: 2004 Ford F-450 Chassis, 4x2 SD Regular Cab 141" WB DRW HD XL, www.ford.com

26. Jamani, F. et al. "Testing of Several Methods of Sterilization in Dental Practice." Eastern Mediterranean Health Journal, 1995, 1(1) 80-86 (1995).

27. Wake Country Government Tipping Fees: www.wakegov.com/county/recycling/commercial/tippingfees.htm

28. Discussion with Ray Pomerleau, Butler-MacDonald, 317-872-5115

29. R. Hess, D. Rushworth, M. Hynes, J. Peters, "Disposal Options for Ships," RAND, 2001.

30. Outdoor Fun Store Recycled Rubber Surfacing: www.outdoorfunstore.com/rubber.pg

31. Plastics Technology Recycled Resin Prices: www.plasticstechnology.com/pricing/recyc.html

32. Discussion with Donald Walmsley, Plastic Systems Incorporated, 770-955-1191

33. "How to Depreciate Property," Department of the Treasury, Internal Revenue Service, Publication 946.

34. "Urban and Rural Definitions," US Census Bureau. October 1995.

35. Centre County Solid Waste Authority, "Tipping Fees": www.centrecountyrecycles.com/RefuseTippingFees/RefuseTippingFees.htm