

PREFACE

On the constant look for a good topic for the thesis, the objective of this master thesis was found in the first part of 2015 during travels through South America. On the way through Bolivia, the problem of an undeveloped system for waste management became apparent. After a bit of research on the situation, we got in contact with a Swiss organization (Swisscontact) working on exactly this topic in one of the bigger cities in Bolivia, La Paz. At the same time, the municipality of the city was looking at bettering the handling of electronic waste. They had already been working on this for a while without much progress. A thesis written on the topic could lift the project to the practical planning phase. After a meeting between the municipality and Swisscontact a topic for our thesis was starting to take shape. That way Swisscontact and the municipality of La Paz gave us the opportunity to write a thesis with a greater purpose. It gave us the chance to dig deeper into the state of the developing world and to take part of a piece of Bolivia's exciting future.

The thesis has taught us all kinds of aspects of waste electronics, and has let us live in Bolivia and get to know the culture, language and people of the country. Almost half of the time of the project was spent in Bolivia, while the other half has been used to study the necessary theory and write the thesis in Norway.

As well as being able to apply what we have learned during the five years of studies to the real world, this thesis has given us life changing experiences. It has shown us a world and a system extremely different from what was known to us before. It is hard to express how grateful we are for getting this opportunity.

There is a long list of people we can thank for making this possible. First we want to thank our supervisor at NTNU, Knut Aasland, for trusting in our project, and for help with the organization. Swisscontact in Bolivia has done a great job, and the project would not have existed without them. They helped us from the beginning to the end, by finding the topic, giving us all the contacts we needed, helping us plan our visits to Bolivia and following the work closely all the way to the final presentation of the project. They have also done a great job implementing the project in the municipality. If the project is to be realized, it will largely be because of their effort. Especially we want to thank Martin Dietschi and Ximena Ayo for this.

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The owner and runner of RAAE Recicla, Jonathan Butrón, and all his workers deserve a big thanks for the close contact throughout the whole project, the help with idea development and prototyping and for letting us use their facilities. From the municipality in La Paz we have gotten a lot of good information, and they have helped with the organization and planning of the project. We hope the project will persevere, and we wish the municipality all the best luck with this. There are a lot of people we can thank in the municipality, but especially we want to thank Fernando Averanga, Farina Flores and Alfredo Clavo for their close following.

Engineers Without Borders Norway (IUG Norge) made it possible to travel to Bolivia by supporting the travel costs, and have been of great help with information about how to get as much as possible out of the field works. They have helped us in extensive debriefing and reflection after the field trips, as well as pointing out important points to focus on in the report.

Thanks to Peru Green Recycling for spending two days showing us their recycling plant and providing us with all the information we asked for and much more. The results in this thesis is strongly influenced by what we learned during the visit. In the preoperational part of the report, professor David Sanders, and the other teachers in the class “Theory and Methods”, and Dr. Syed Mansoor Ali have been of great help with valuable information about preparations and considerations around work in developing countries.

There is also a long list of people that has been helping with the thesis. A lot of people in Bolivia were willing to help with whatever we needed for the project, and could sometimes spend a whole day showing us around or giving us important information. During our visits we also made a lot of good friends who made our stay a great experience and let us deeper into the culture. Especially we want to thank Karina Villca y Yessenia Romero Flores for this. We will also like to thank Petter Hørthe, Carl Christian Sole Semb, Martin Furevik and the rest of the office at NTNU for moral support and good discussions in tough times and hard decisions.

And last but not least: Gracias Pachamama, por toda nuestra buena suerte!

- *Señor Storesund and Señor Vigerust*

ABSTRACT

Waste electrical and electronic equipment (WEEE) is becoming an growing problem in developing countries. WEEE often contains hazardous materials as well as expensive and/or rare metals. Treating the waste electronic in developing countries to avoid contamination and extract valuable material should be established. This thesis presents a study on how a manual dismantling plant can be implemented and designed to increase the WEEE treatment capacity in La Paz, Bolivia. In addition, the design should facilitate for employing workers with disabilities. Research and development has been done during a field trip lasting 4 months. The work in La Paz was accomplished in cooperation with an international NGO, local WEEE dismantling entrepreneur and municipality. A manual dismantling plant should be funded by the municipality and operated in collaboration with local entrepreneur. This will create a capable treatment facility that increases capacity as well as stimulating for smaller private WEEE dismantling companies to establish. Production can be done profitable and without releasing contaminants. With the developed design of workflow and dismantling station, efficient production can be performed. The design is also suitable for employing workers with disabilities. To establish a WEEE recovery system in Bolivia, creating a successful pilot plant is an important first step.

SAMMENDRAG

Elektrisk og elektronisk avfall (EE-avfall) kommer til å bli et økende problem i utviklingsland. EE-avfall inneholder ofte farlige materialer samt dyre og/eller sjeldne metaller. Behandling av det elektroniske avfallet i utviklingsland bør etableres for å unngå forurensning og utvinne verdifullt materiale. Denne avhandlingen presenterer en studie om hvordan et manuelt demonterings anlegg kan iverksettes og utformes for å øke EE-avfalls behandlingsskapasiteten i La Paz, Bolivia. I tillegg bør utformingen tilrettelegges for å ansette arbeidstakere med nedsatt funksjonsevne. Forskning og utvikling har blitt gjort i løpet av en ekskursjon med varighet på 4 måneder. Arbeidet i La Paz ble gjennomført i samarbeid med en internasjonal NGO, lokal demonterings entreprenør av EE-avfall og kommunen. Et manuelt demonterings anlegg skal finansieres av kommunen og drives i samarbeid med den lokale entreprenøren. Dette vil skape en behandlingssanlegg som øker kapasiteten samt stimulere mindre private demonterings selskaper for EE-avfall å etablere seg. Produksjonen kan gjøres lønnsom uten å slippe ut forurensninger. Med utviklet design av arbeidsflyt og demonterings stasjon, kan effektiv produksjon utføres. Designet er også egnet for å ansette arbeidstakere med nedsatt funksjonsevne. Etablering av et EE-avfalls behandlingssystem i Bolivia, og skape et vellykket pilotanlegg, er et viktig første skritt.

RESUMEN

Para evitar la contaminación y extraer los materiales valiosos debería establecer tratamiento de RAEEs en los países en desarrollo. Esta tesis presenta un estudio de como una planta de desmantelamiento manual puede ser implementado y diseñado para aumentar la capacidad de tratamiento de RAEE en La Paz, Bolivia. Además, el diseño debe facilitar para emplear trabajadores con discapacidades. La investigación y el desarrollo estaba hecho durante un excursión con duración por 4 meses. El trabajo en La Paz se llevó a cabo en colaboración con una ONG internacional, empresario RAEE desmantelamiento local y municipio. Una planta de desguace manual debe ser financiada por el municipio y es operado en colaboración con el empresario local. Esto creará una instalación de tratamiento capaz de que aumenta la capacidad, así como para estimular más pequeño RAEE empresas privadas para establecer el desmontaje. La producción puede hacerse rentable y sin liberar contaminantes. Con el diseño desarrollado de flujo de trabajo y el desmontaje de la estación, la producción eficiente se puede realizar. El diseño también es adecuado para el empleo de los trabajadores con discapacidad. Para establecer un sistema de recuperación de RAEE en Bolivia, la creación de una planta piloto con éxito es un primer paso importante.

**MASTER THESIS SPRING 2016
FOR
STUD.TECHN. GEIR BENDIK STORESUND
and EIRIK LERUM VIGERUST**

**SEPARATION PLANT FOR WASTE ELECTRICAL AND ELECTRONIC EQUIPMENT IN
BOLIVIA**

Behandlingsanlegg for elektrisk og elektronisk avfall i Bolivia

In Bolivia, waste disposal has become a large and increasing problem both concerning space and the environment. Therefore, the city authorities of La Paz wants to focus on recycling and reuse instead of landfills. One part of this is handling of electrical and electronic equipment.

The municipality of the Bolivian city, La Paz has started the process of developing a separation plant for waste electrical and electronic equipment. The municipality is working together with an entrepreneur, who already has a private business separating EE waste and the Swiss NGO, Swisscontact. Together they hope to obtain a facility that can process the waste EE generated in La Paz in a environmentally friendly and sustainable way.

The candidates have in their pre-master project investigated the situation and the solution options. Based on this, the master assignment will concentrate on the following:

1. Design of manual workstations for the small, private EE waste collector and for the planned facility.
2. A research on the possibility of implementing a refrigerator treatment facility
3. Design of the layout of the large-scale municipal separation plant

The details of each of these activities will have to be planned as part of the project.

Formal requirements:

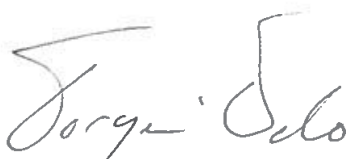
Three weeks after start of the thesis work, an A3 sheet illustrating the work is to be handed in. A template for this presentation is available on the IPM's web site under the menu "Masteroppgave" (<https://www.ntnu.no/web/ipm/masteroppgave-ved-ipm>). This sheet should be updated one week before the master's thesis is submitted.

Risk assessment of experimental activities shall always be performed. Experimental work defined in the problem description shall be planned and risk assessed up-front and within 3 weeks after receiving the problem text. Any specific experimental activities which are not properly covered by the general risk assessment shall be particularly assessed before performing the experimental work. Risk assessments should be signed by the supervisor and copies shall be included in the appendix of the thesis.

The thesis should include the signed problem text, and be written as a research report with summary both in English and Norwegian, conclusion, literature references, table of contents, etc. During preparation of the text, the candidate should make efforts to create a well arranged and well written report. To ease the evaluation of the thesis, it is important to cross-reference text, tables and figures. For evaluation of the work a thorough discussion of results is appreciated.

The thesis shall be submitted electronically via DAIM, NTNU's system for Digital Archiving and Submission of Master's theses.

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og materialer

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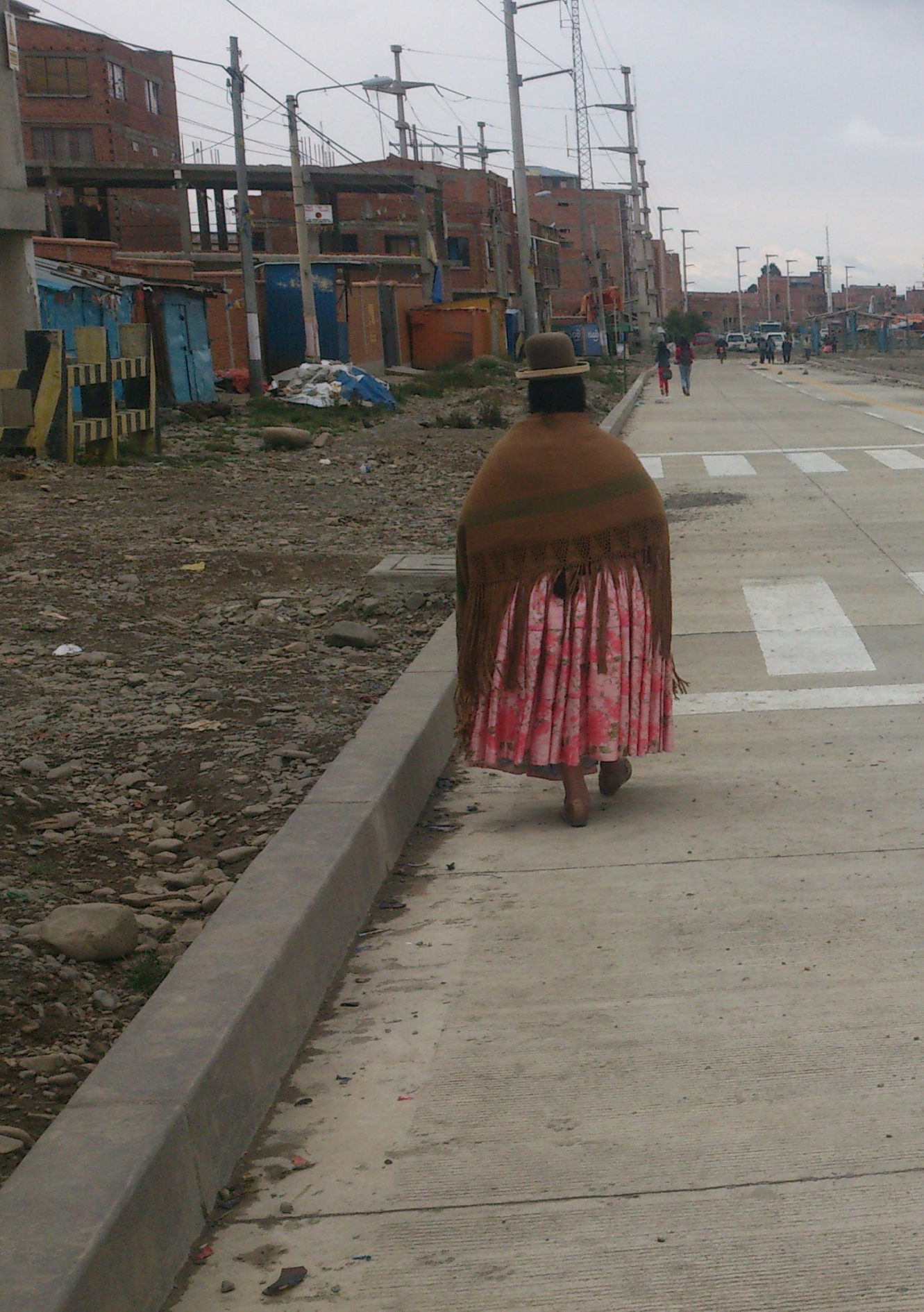
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DICTIONARY

SWM	Solid Waste Management
WEEE	Waste Electrical and Electronic Equipment
RAEE	WEEE in Spanish. Residuos de Aparatos Eléctricos y Electrónicos.
RAEE Recicla	Private WEEE recycling company in La Paz
Depth of dismantling	How much of an article is dismantled
EoL	End of Life (Product). Product at end of its useful lifetime
Producer	Distributor of product
EPR	Extended Producer Responsibility
GAMLP	Gobierno Autónomo Municipal de La Paz Municipal Governmet of La Paz
COGO	Comisión Gubernamental de la Capa de Ozono Governmental department for the ozone layer in Bolivia



A photograph of a city street with a crosswalk and a background of dense urban buildings. The foreground shows a concrete road with white crosswalk stripes and a yellow line. In the background, there are various buildings, including a prominent multi-story building with a blue roof and a yellow facade. The sky is overcast.

INTRODUCTION

1 Objective

Bolivia has for a long time been among the poorest countries in South America. Now it is the south american country with the highest economical growth, and things are changing rapidly. The new generation is growing up with technology connecting them to the outside world, and a general growth in wealth among the popuation has increased the ability to buy more things. It is interesting times, where the systems have to keep up with and try to be ahead of the rapid change.

With higher consumption in the country, folows an increased amount of waste. One of the faastest growing waste types are waste from electrical and eletronic equipment (from here on reffered to as WEEE)

Much of the WEEE contain materials with the potential to harm the environment if not treated correctly. It is also a resource that can give economic profit if treated correctly. Automated systems for treating and separating WEEE are developed in the western world, however they are an expensive investment and therefore not implemented in developing countries. A less expensive treatment method based on manual labor and adapted to local condition is needed.

La Paz is one of the major cities in Bolivia, and has large waste handling problems. The municipality of La Paz decided in 2015 to build a large facility for treatment of the most important types of waste. A part of this facility is planned to treat WEEE. Implementing a manual dismantling plant in La Paz that is supported by municipal regulations and waste collection system would be crucial step toward a more complete waste handling system for La Paz, as well as demonstrating for other cities how WEEE can be handled.

The study includes research on how workers with disabilities can be implemented in this type of treatment facility. People with disabilities in La Paz have a hard time making a living, and social benefits are few. If the plant

could employ people with disabilities as well, it could potentially have a high social value in terms of increased integration, and easier economic situation for these people.

An improved design of a working station for WEEE treatment is one of the larger objectives in the thesis. A design that increase the general efficiency for the normal worker, as well as easy to use for people with disabilities will be presented.

The main objectives of this thesis are:

1. Making proposal of complete layout a dismantling facility. Sub objectives in this proposal will be:
 - What processes should be implemented
 - Material flow analysis
 - Design that is appropriate for workers seated in wheelchairs and diagnosed with autism.
2. Developing a concept for a dismantling station that is to be implemented in the layout. Sub objectives will be:
 - Making the station more efficient than current solution
 - Make it usable for workers seated in wheelchairs and workers diagnosed with autism.
3. Reviewing the possibilities of how refrigerators can be treated.

The limitations we have operated with during this thesis is first of all the lack of accurate data on WEEE generation. This is mainly because of the informal market of electronics. Prototyping has been limited to small scale testing, with 2-4 test subjects over approximately two months. Adaptation for workers with disabilities has been developed in consultation with local handicapped, local psychologist and other specialists in this field from the municipality in La Paz.

We have assumed that WEEE generation in the future will follow estimated pattern of existing reports, even though the estimated quantity is expected to be inaccurate. Regarding the input from the local test subjects, we have assumed that these are representative for feedback and influence to the solutions chosen in layout design and workstation design.

2 Painting the situation picture

2.1 Overview

In La Paz, Bolivia the waste generation has developed into a serious problem. The landfill is receiving waste at a rate that will make it reach its capacity in few years. The waste handling as it is today, is turning out to be an expensive solution. Therefore a lot of focus is put on the management of solid waste, and much resources are used to ensure that the waste is treated appropriately for the improvement of living conditions and environmental aspects. The municipality of La Paz decided in 2015 to build a large facility for treatment of the most important types of waste. A part of this facility will take care of waste electrical and electronic equipment (WEEE). Together with the private waste electronics recycling company, RAEE Recicla, the municipality wants to expand the capacity of treating WEEE.

2.2 The whole project – Master thesis

A few years ago a private dismantling plant was started in La Paz by Jonathan Butrón. Today he is leading the small family business, RAEE Recicla (Spanish; translates to WEEE recycling). Electrical and electronic equipment (EEE) is gathered from companies and offices for proper dismantling. After the dismantling, the separated materials are sold to other facilities for further treatment. The municipality and Butrón has agreed to cooperate on the project, to include the experience from the established company, and the funding and momentum of the municipality.

The Swiss non-governmental organization (NGO), Swisscontact, is also involved in the project. They have been working with economic development, vocational training, tourism and environmental projects in Bolivia since 1988. Swisscontact are working on a big waste management project called Ecovecindarios, where they are in close contact with the municipality and with private companies within different sectors of solid waste management (SWM). Swisscontact have been working with Jonathan and RAEE Recicla

for several years already. Now they act as a consultant for the cooperation of the municipality and Recicla to establish a new recycling plant. This master thesis is written on request from Swisscontact, and is written in collaboration with them.

A project thesis was written about the same topic during the last half of 2015. The main purpose of the study was to serve as preliminary work for the master thesis, and to present a half-way report. A big part of the report was about research on solid waste management, WEEE, information about the Bolivian WEEE situation and detailed research on how Recicla operates. Much of the information has been used in the master thesis, and some parts in this report are taken from the project thesis.

Data gathering and testing was done through two trips to La Paz, Bolivia. The first trip was done over three weeks in October to November 2015. The second trip was done from February to May 2016.

2.3 Purpose of the thesis

There are two purposes of this thesis. Firstly it is the final project to finish a five year masters degree at the Norwegian University for Science and Technology. It is also a report written for the municipality of La Paz and Swisscontact to make a realistic recycling plant that can be implemented in the city. The desired effect is that this study will accelerate the bureaucracy in the municipality which often can be painfully slow. The objective of the thesis is constructed in cooperation with Swisscontact, on the terms of fitting it to the field of study, Mechanical Engineering.

Because of the two purposes of the thesis, there will also two written reports: one for the university and one for Bolivia. The one you are now holding in your hands is the most extensive one, while the part to Bolivia mainly will consist of the “Results and Discussion” chapter found. Both the results and discussion, as well as some background information is therefore gathered in one part in this report.

A day in Bolivia

It is 8.15 in the morning, and the sun is slowly rising over La Paz. We were supposed to meet our contact person from the municipality at 8.00, but as usual we are running a bit late. Everyone does that here. In the beginning this was hard to adapt to, but little by little we have found ways to handle it.



Figure1: A "cholita" in the Rodrigues market

The traffic is really bad this morning, and the minibus is so full of people that it is hard to move. The streets are full of these minibuses. They go everywhere. And they stop everywhere. Even in the middle of the street. You never know how long it will take to get somewhere. Everyone complains about the minibus problem in the city. With some guidelines on where they can drive and stop, the problem could probably be solved pretty easily. But no one does that.

Around us in the bus you find businessmen in old suits, the traditional women: "cholitas", and families with kids that seem very grown up for their age. Mostly they are pretty quiet, but we know that if we started talking to

them, they would be nice and slightly shy people, interested in helping or hearing about our story. Everything would be in Spanish.

We drive by lots of small street markets selling fruits, fresh juice or the traditional "pasteles". Behind the desks the "cholitas" are trying hard to convince the

people passing by to buy their goods.

The reason for today's meeting is that we finally have found a date to go to RAEE Recicla to look at the possibilities to implement people in wheelchairs. The municipal department for people with special needs has shown its interest in the project, and we have been waiting for them to find a time to join us. Originally the session was scheduled to Monday, but it was cancelled by the municipality. They didn't tell anyone about the canceling until we were almost at the plant on Monday morning. Cancelled meetings are also something we are starting to get used to, but this one managed to upset the leader of RAEE Recicla. He had spent a lot of time preparing the plant,

but didn't hear anything about the cancelling either. Today it is Thursday, and so far the meeting seems to be happening.

We finally get to the place we were supposed to meet our contact person. We find him waiting, and together we go to meet the officials in their office. They are running late. We wait for them in their office for about an hour before we get into their car. We thought we were supposed to pick up people in wheelchairs that could try the facilities, but we find out they haven't found these people. Instead we drive around the city for another hour picking up more people from the municipality. When we get to the

plant we are nine people in the car. The clock turns 11 by the time we are there.

At the recycling plant we meet Jonathan Butron, the owner of the plant. He explains how the work in the plant is done and about his visions of implementing people in wheelchairs and people with autism. The six people from the department are very interested. There are no other businesses in the city fitted for the needs of handicapped, and this project has the potential to change this. A lot of resources are put into compensating for what the disabled don't have, but now they have the potential to become a resource.



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THEORY

1 Introduction

In this chapter the necessary information is gathered to give an understanding for the reasons behind the results later in the report. Firstly the situation where the system is to be integrated is explained. The culture and the place the plant will be implemented in is closely connected to the solutions in the result. The more technical theory is then presented to give an understanding of the different aspects in waste electronics recycling, before the projects stakeholders and our role in the project are analysed.

The theory has mostly been gathered from research papers, reports, some books and information gathered while living in Bolivia and the class Theory and Method at the university (NTNU).

Only a selection of the theory is included in this chapter. More in-depth information can be found in the appendices.

CHAPTER CONTENT

- WEEE definition and explanation
- Understanding of situation
 - About Bolivia
 - Waste situation in Bolivia
 - WEEE situation in La Paz
 - WEEE calculations for La Paz
- WEEE Theory
 - Materials in WEEE
 - Treatment method of WEEE
- Stakeholders and our role in the project

2 WEEE and recycling in development countries and as a global issue

The last 25 years we have seen a rapid development in electrical and electronic equipment (EEE). Worldwide PC's, cellphones, tablets, game consoles and TV's have increased massively in the market. In western countries this has early presented itself as a problem in terms of End of Life (EoL) for a product, and how to handle it after it has been disposed. This has led to big investments of facilities and systems to handle waste electronic and electrical equipment (WEEE). In Europe advanced automatic separation facilities have emerged to recycle the materials from WEEE.

The increased globalization and improvement of national economies has led to increased ability to buy EEE in developing countries. An example is that several countries in Latin America have seen dramatic increases in EEE sales. Appropriate systems and facilities to handle the WEEE are few or more often, completely absent. Waste management in development countries are often also simple in terms of treatment of other types of waste. Lack of governmental funding and understanding of benefit of proper waste handling result in that many rely on landfilling as the major treatment for waste. Landfilling electronic waste can have huge environmental impacts in terms of leakage of acids, heavy metals and other chemicals into surface and ground water along with potential toxic emissions.

2.1 Definitions

WEEE is generally defined as any disposed or intended to be disposed electric or electrical equipment. (OECD, 2011). The European Union WEEE directive has defined EEE as any equipment dependent on electric currents or electromagnetic fields in order to work properly (Schafer et al., 2003). The EU has further categorized WEEE into 10 different categories.

Table 1: EU defined WEEE categories. Source: The EU WEEE directive

No:	WEEE category
1.	Large household appliances
2.	Small household appliances
3.	IT and telecommunications equipment
4.	Consumer equipment
5.	Lighting equipment
6.	Electrical and electronic tools (with the exception of large-scale stationary industrial tools)
7.	Toys, leisure and sports equipment
8.	Medical devices (with the exception of all implanted and infected products)
9.	Monitoring and control instruments
10.	Automatic dispensers

2.2 Waste hierarchy

The waste hierarchy shows how treatment of waste should be considered to reach the most cost-effective system. Prevention and reuse are highly regarded as there is little loss in energy. Recycling is next step which demands more energy but does not cause any loss of material. Recovery is not preferred but at least harvest energy at the cost of material loss. An example of waste recovery is an incineration plant that burns household residues and collect the heat generated by means of electricity or heating. Disposal on landfill lead to both loss of material and energy. Additionally leachates and releases of gases from landfill cause contamination of local and global environment.

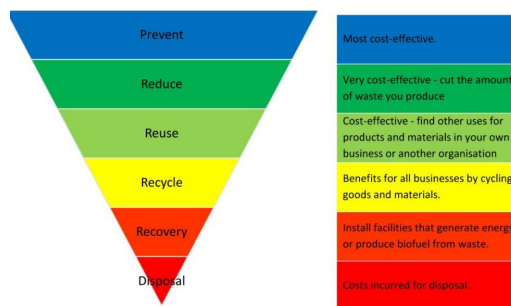


Figure 2 The waste hierarchy (1)

3 Bolivia

3.1 Introduction

Bolivia's official name is the Plurinational State of Bolivia, and it is located close to the center of South America. It has a population just above 11 million people, where almost 64% lives in urban areas. Sucre is the official capital of the country. The government is seated in La Paz, and is often talked about as the capital. La Paz is ranked as the third most populated city, with a population of 757 184 (2012). Geographically La Paz, and El Alto (the second biggest city) are connected, but politically they are two different departments. Bolivia has the largest portion of indigenous people in South America, with 62% indigenous (UNDP, 2006). (3)

3.2 People and culture

The Bolivian culture is strongly influenced by the indigenous traditions and ways of living. For a long time they have been oppressed, and about two thirds of the indigenous are among the poorest 50% of the population (2004) (7). In 2005 President Evo Morales was elected to presidency as the first indigenous president in Bolivia. He is now in his third presidential term. His politics are focused on keeping the indigenous traditions and culture intact. This work both in the way that the overall culture are more influenced by the indigenous, as well the indigenous are more included in the rest of the system, influencing their culture to be more like the culture of the rest of the people.

3.3 Economy and development

Bolivia is in many means of measures the poorest country in South America. It is also the country with the most rapid economic growth in South America the last years. A natural consequence of increased wealth is a higher use of resources, which if not handled carefully can mean exploiting health and environment. An increasing GDP usually lead to increased

waste generation. WEEE is one of the waste types expected to increase the most over the next years. It is therefore essential to establish a good handling system before the problem grows too big. WEEE contain much hazardous materials that, if not handled properly, can be harmful for the environment and the people living in its proximity.

3.4 Governance and corruption

According to the World Bank's Worldwide Governance Indicators (WGI), Bolivia is scoring weaker than regional and global averages in most governance areas. Political corruption is looked upon as a big problem in Bolivia. The last years with the Morales administration leading the country, much effort has been put into anti-corruption work, and new laws have been added to stop the problem. The last years many people have taken the consequences of being corrupt, losing their jobs or going to jail.

For companies corruption has been stated to be one of the primary obstacles for doing business in Bolivia. In a survey done by the World Bank and IFC Enterprise Surveys in 2010, about one fifth of companies said they expected to pay or give gifts to "get things done". This problem seem to have decreased the last years. (4)

3.5 Informal sector in Bolivia

The informal sector can be described as "the activities that are not registered, recorded, protected or regulated by public authorities" (definition by ILO, 1972). In Bolivia nearly 80% of urban and rural employment is informal, making it the South American country with the largest informal sector. Such a large amount of informality is a sign of a big separation between the government and the people, and a sign of little trust in the authorities. This is important to have in mind when working with authorities and the formal sector in Bolivia. Changes are being done to decrease the informal sector, and to improve the trust in the system. The changes seem to have a positive effect, and the last years it seems like more people see the benefit of being formal. (5).

4 Current waste handling systems in La Paz

4.1 Waste economics and regulation

In October 2015 the first national law for solid waste management was adopted in Bolivia. Until then there were no regulations giving responsibility, taxes, specifying conditions or giving technical guidance. It was up to each municipality to choose how much money to spend on handling the waste, and how they wanted to do it. Throughout the country there have been big differences in where the solid waste end up, and what impact it has on the environment. The new law distributes responsibilities, and requires that the waste is handled in an appropriate way following national guidelines and requirements. The law does still not cover regulations for waste electrical and electronic equipment.

As of now La Paz is one of the municipalities in Bolivia with the most developed plan for how to handle waste. They have an own department in the municipality for waste management, and have systems for cleaning the streets, collecting household waste and disposing the waste in a controlled landfill outside of the city. Lately they have started looking more into the possibilities of recycling, and are planning to make a large scale recycling facility. In many of the schools, recycling has also become a part of the education. Information and awareness is an important subject the municipality is working on.

4.2 Collection system in La Paz

The collection system in La Paz is mostly based on curbside collection. Garbage trucks are of similar configuration as in most European countries (one compartment with compactor). The trucks drive around the city in routes and ring a bell to signal people to put the waste at the curb. Often people put their trash bags out on the curb at night, where it is picked up in the morning. This makes a problem because of all of the dogs that like to dig through the bags searching for food. When the truck comes the trash is

spread out in the street, and they have to use a dustpan to clean it.

The frequency of the collection vary. In the city center trucks might have collection as often as two times a day on the same location. Less frequent in the outer regions. The household collection is for all household waste, without any source segregation or separation into waste type. The collection routes are often hindered by the notorious traffic in La Paz. Traffic flow is often very slow which makes the collecting during day difficult.

With this collection system, the landfill estimates that more than 90% of the household waste is collected and ends up in a proper landfill. Some is also dumped into nearby rivers and unregistered landfills, but this is unconfirmed data.

There is now also an option for households to separate their paper and plastics in public collection points set up around the city every Sunday. 23 Green Point stations (Puntos Verdes) are set up around the city to gather recyclables. Every station has staff to do some extra sorting of the waste and prepare it for further actions. As of now, people can deliver bags of paper and plastics that they sort out at home. In the future the plan is to expand the possibilities and accept other kinds of waste types as well, such as glass and WEEE/RAEEs (Residuos de aparatos eléctricos y electrónicos). The Green-Point project is still under development, but has so far turned out as a success, with a growing number of users.

Recently there have been incentives to include recycling in the primary school education. The students learn to separate plastics and papers from other waste, and the purpose is for them to spread the knowledge to their home and families.

4.3 Landfill (Relleno Sanitario)

The landfill, Relleno Sanitario Nuevo Jardin Alpacoma, is owned and run by the municipality. It is placed in the outskirts of La Paz. It is a high capacity landfill, with an initial estimated lifetime until at least 2026. Between 2004 and 2015, the landfill has received about 1.900.000 tons of solid waste. Every day around 100 trucks come in with waste weighing about 540 tons (wet weight). There is estimated that the price of landfilling one ton of waste cost about 15 \$US. Every day about 8000 dollar, or almost 3 000 000 dollar

a year is used to get rid of the waste in La Paz.

The daily amount of incoming waste is increasing rapidly. The increase has been faster than what was projected. To keep the lifespan of the landfill as planned, they want to reduce the amount of waste coming in. Finding a place for a new landfill has proven to be both hard and expensive, making it more beneficial to prolong the life of the landfill. This is an important reason for why the municipality want to start a larger recycling facility: to make the waste a resource and not high cost problem.



Figure 3 The landfill of La Paz: Relleno Sanitario

Other Instances

Recycling is a catching trend that is growing in La Paz. A municipal classification plant is separating plastics, aluminum and paper/cardboard collected for the green points. A project about extracting biogas from organic waste is being worked on by Swisscontact. In addition there is a newly started private factory started to produce plates of pressed polypropylene with equivalent properties as chipboard. The picture below shows the classification plant.



Figure 4 Clasification plant at Alpacoma outside of La Paz. Workers separate the fractions manually

4.4 Future plans in La Paz and current waste generation

The municipality of La Paz has plans to be involved in starting up treatment plants for many of the most common types of waste. We will not go in detail on these in this report. The initial wish was to gather as many recycling facilities as possible in one location, as a complete waste treatment plant. Because of limited available space, this does not seem to be an alternative at the moment. The different plants will therefore be spread around in the city.

4.5 WEEE in La Paz

In La Paz there exist a few formal and informal actors collecting electronics, dismantling and selling the materials. RAEE Recicla is formalized, and is the largest actor in La Paz. Because of the informal sector, it is hard to know how many plants exist. Some of the plants are doing their business for pure economic reasons without taking the environmental factor into account. Good regulations and sanctions can help make a more healthy recycling industry. In the national law introduced in 2015, there were no specifications for WEEE. A draft is being made and is planned to be implemented in the first revision of the law in October 2016. La Paz does already have a set of guidelines, but these are not followed up strictly.

In many surrounding countries, as well as recommended in the EU, the electronics producers have a large responsibility to make sure the WEEE is dismantled in a qualified facility. In Bolivia the largest part of the electronics are imported informally (not going through the producers). This makes it hard to put so much responsibility on the producers in Bolivia. It is therefore exciting to see where the responsibility will be put in the new regulations.

4.6 Tendencies of WEEE handling in La Paz households.

Disposal of electronic/electric articles has been researched in La Paz. The intension is to get an idea of what happens when the user decide to discard an electronic article. As shown in the graph below, a significant percentage of the electronics are kept as storage in the households. Nearly nothing is recycled as result of lacking the option of handing it to treatment. The sta-

tistic representing La Paz reflect that a considerable amount of EEE is either repaired, stored or sold as second use.

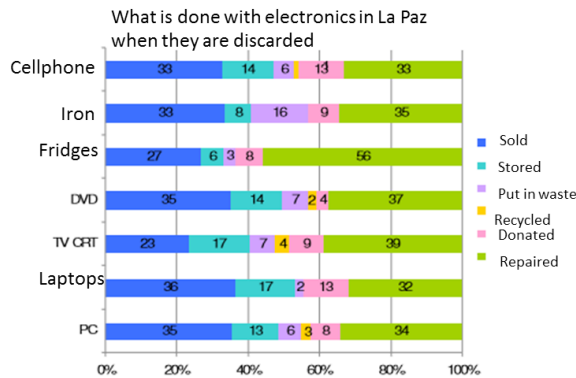


Figure 5 What is done with electronics in La Paz when they are discarded (7)

This means that the electronics are kept longer in use. When starting a system to accept handling inn of WEEE for treatment, the amount of WEEE stored in households will be expected to go down. As the economy of the citizens is expected to rise, less of the electronics will be worth repairing because of growing cost.

5 RAEE Recicla

Jonathan Butrón has for a couple of years been running a successful WEEE separation company in La Paz. From the start it was a completely private initiative, where he identified the potential of EEE when its lifetime expired. His business is named RAEE Recicla and has its location in his private backyard in the south of the city.

5.1 Business model of RAEE Recicla

RAEE Recicla has specialized itself to handle WEEE mainly from companies. Dealers of electronic brands such as Sony, Samsung and similar, contact him with a request to handle broken, returned or outdated models of electronics. Other clients, such as office departments, are also a part of the customer selection. A typical order request from a client will usually be a list of electronics which the client wants to be discarded in an appropriate way instead of dumping it on the landfill.

5.2 Facility layout and processing

RAEE Recicla is initiated as a private company that handles WEEE in relatively small scale. Therefore initial investments are small, and the production relies on manual labor. The facility is shown in the pictures below



Figure 6 Backyard facility at our arrival



Figure 7 Figure 8 Backyard facility after roof and workstations were set up



Figure 8 The four workstations at the dismantling floor



Figure 9 Us with Jonathan and the rest of the workers at RAEE Recicla

5.2.1 PROCESSES AND MATERIAL FLOW

The processing of WEEE in RAEE Recicla is fairly simple. Articles entering the business are sent to storage before they are weighed and dismantled. Steel, plastic and aluminum fractions are compressed into cubes and then weighed. Materials are then put on storage until sufficient volume for shipping is obtained. The material flow is shown in the figure below.

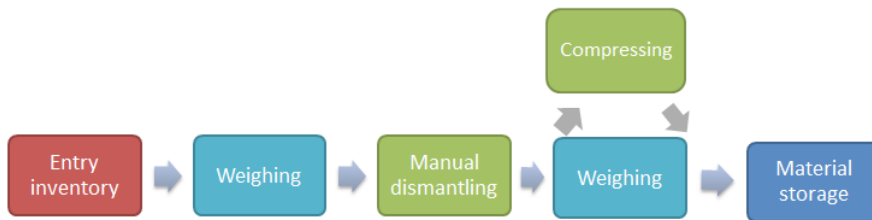


Figure 10 Material flow through the facility

At the plant the equipment is received and stored in individual orders. Each order is strictly separated, and the dismantling processes of the orders does not mix. The components are then dismantled, and the different materials are separated in different containers. Each fraction of material is weighed, documented and photographed.

The different materials are put in the material inventory until they reach a sufficient quantity, and transportation cost is justified. Most of the material is shipped out of La Paz. The metals are mostly sold to remolding in Bolivia or Peru. Plastics are sent to Mexico for treatment, but the process here is unknown. Circuit boards are sent to Belgium at special separation plant for circuit boards. Here the circuit boards are chemically treated and elements are extracted. Therefore the quantity of each material has to be compared to the shipping cost per kilo and selling price per kilo.

5.2.2 LAYOUT

The layout of the facility has a functional setup, where the WEEE is moved to different processes for different treatment. The machines and stations are able to treat all varieties of WEEE. A setup like this is flexible and easy to fit to the big variety of incoming products.

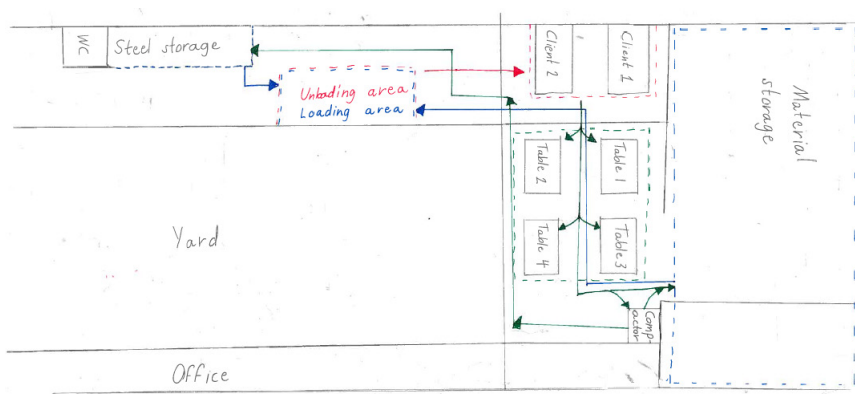


Figure 11 Layout of RAEE Recicla's facility

6 Generated WEEE in La Paz

6.1 Introduction

Exact information and research on WEEE quantities in Bolivia is limited. In this section, two sources have been used to analyze the situation and make an assumption of total E-waste generated in Bolivia and La Paz.

6.2 Comparing data: EEE and WEEE

In 2009, Swisscontact and Delin Consultora published a prediction of expected development of WEEE in Bolivia and expected increase of EEE in the market Composition of WEEE (7). The graph below shows the amount of electronics entering the market, and compare it to the produced amounts of waste electronics.

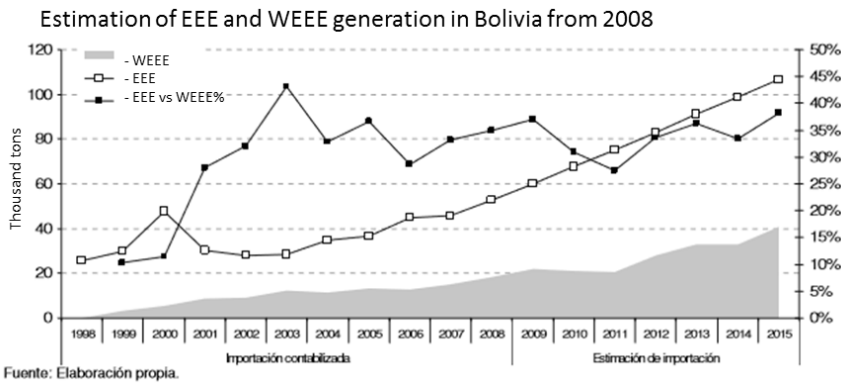


Figure 12 Estimation of EEE and WEEE generation in Bolivia (7)

The report is from 2009 and development of WEEE and EEE until 2015 is based on predictions. As shown in the graph, there is a gap between EEE

entering the market and WEEE generated. This gap is caused by the life time of the electronics. If there is a sudden increase in EEE at the market, the responding increase in generated WEEE will not be visible until several years after, because of the lifetime of the products. The increasing gap between generated EEE and WEEE is a result of no treatment method for the WEEE.

6.3 Estimate of WEEE generation in La Paz

The United Nations University (UNU) has done a more recent study of generation of WEEE in Bolivia. The study shows amount of EEE put on the market (2012) and WEEE generated (2014). The results are presented in the table below.

Table 2 WEEE and EEE generated in Bolivia (8)

	Year	Total in kilo tons	Kg/capita year
EEE put into market	2012	82	7.6
WEEE generated	2014	45	4.0

The two analyses fit fairly well together. The estimated amount of EEE introduced is very close to each other in the two reports, while the generated WEEE is a bit higher in the UN report. It seems like the WEEE generation prognosis is about 1.5 years behind what is found in the UN report. This is not very far off. The data from the UN report will be used for further calculations.

In 2014, La Paz had 785 605 citizens (6). With a generation of 4 kg/capita (8), this gives an estimated generation in La Paz of:

$$4.0 \text{ kg/capita} \times 785\,605 \text{ capita} = 3142 \text{ tons/year} = 262 \text{ tons/month.}$$

Another report was done by the United Nation University was done in 2015 (9), based on the data from their previous report. In the report the WEEE generation in all the countries in Latin America is predicted for the year 2018. It predicts a WEEE generation of 5.1 kg/capita in Bolivia in 2018. The Bolivian central for statistics predicts a population of 804 000 people (6). A calculation shows that:

$$5.1 \text{ kg/capita} \times 804\,000 \text{ capita} = 4100 \text{ tons/year} = 342 \text{ tons/month.}$$

La Paz can be assumed to be on equal level of development with other major cities in the country. An immediate source of uncertainty is that 64% of the population in Bolivia lives in urban areas. The generation of WEEE is bigger in urban areas than in rural areas. The number can therefore be expected to be a bit higher than the calculations.

7 Materials in WEEE recycling

7.1 WEEE Components

Large-sized EEE, like washing machines, refrigerators, and monitors, are considered the main source for the base metals, like iron, aluminum, copper, lead and zinc. These usually consist of bigger parts that easily can be separated and reused or recycled. Smaller devices, such as laptops, mobile phones and printed circuit boards (PCBs) are important for precious metals, like silver, gold and palladium. These precious metals are often more integrated in the parts, and harder to separate than the large pieces in the bigger equipment, but at the same time they mostly give good value for the resources put into it. For less common materials like Ba, Bi, Co, Ga, Sr and Ta, mid-sized equipment as printers and fax machines are a good source. A lot of these metals are used in small quantities in important technology. Many of them exist only in small quantities on the earth, or are mined in controversial areas. Therefore, recycling of these metals are very important for the environment.

7.2 Expected Materials

The diagram below is taken from a study by Swisscontact, showing the amount of different materials fragments found in some of the most common waste electronics. The most commonly found materials are plastics and metal. In some articles glass make out a large part. The tendency is that newer equipment use more plastics, and the technological components are smaller in size, but with high value.

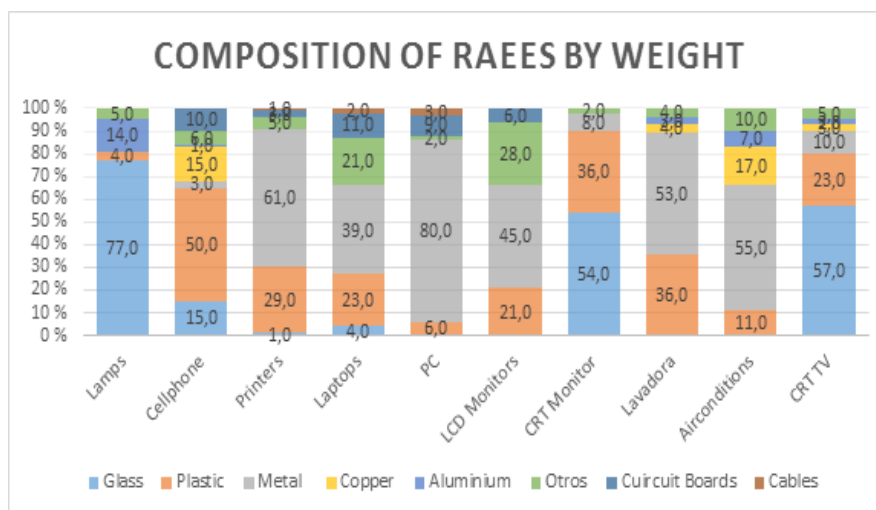


Figure 13 Composition of RAEs. Data from (7)

7.3 Metals in WEEE

Metals are the most attractive materials to separate out of the recycling process of electronic waste. Ferrous metals are the most used metal in electronics, and it is also the easiest to sort out. Often big steel pieces can be easily sorted out manually, and the magnetic properties makes it easy to separate from the other materials. Aluminum, copper and nickel are also relatively easy to separate, and are after iron the most used metals. The most environmentally and economically favorable metals are the once with lower concentration, like gold, silver and palladium, because these are much more rare and hard to mine. They are also harder to separate from the other materials, and require more advanced operations. In a developed country recycling plant, they manage to separate 12-25% of the total content of these metals. In a low cost plant this can be expected to be considerably lower. (10)

7.4 Plastics in WEEE

Due to its good properties as a durable, light, low cost and easily formed material, polymers, or plastics, are used a lot in EEE. In Europe (Norway and Switzerland) about 6%, or 3.150.000 tons, of the total plastic consump-

tion is used in EEE. Often it is found in bigger parts as casings and such, but also for structure and support for parts inside the equipment. The most used plastics in EEE are Polypropylene (PP), High Impact Polystyrene (HIPS), Acrylonitrile-Butadiene-Styrene (ABS) and Polyphenylene Oxide/HIPS (PPO/HIPS). Also the use of mixtures with Polycarbonate (PC) and PC/ABS has been growing lately. Often other materials are added to the polymers as well, some categorized as hazardous materials, and then often as flame retardants. Therefore it is important that plastics are handled with care by people with knowledge on the topic. On much of the plastic pieces produced properly, an ISO recycling mark can be found somewhere on the piece, telling what material it's made from. To find other materials a number of techniques are used in the industry. Much of it is highly automated, with the use of infrared spectroscopy to decide on the material. (11)

In many cases, the plastics does not end up being a profitable part of the WEEE recycling. A system with rules and regulations is therefore important to ensure proper handling. Separation of plastics into different kinds can make plastics be more valuable, but this require much knowledge or advanced systems.

7.5 Hazardous materials

A good plan for hazardous waste is very important. In many places where they do low cost EE-recycling, hazardous materials are not properly taken care of. Close to these places, content of heavy metals and other unhealthy materials are found in the soil, animals, food and drinking water, and consequences have already started to show among the people living there (like higher rate of stillbirth, lower birth weight, decreased height of the children, skin damage, headaches and gastro-intestinal disorders among grown-ups). Hazardous materials are found in various components in WEEE. These components can contain Cadmium, polychlorinated biphenyl (PCB), lead, mercury, phosphor, radioactive substances and different acids.

The most common components to contain hazardous materials that we have found are:

- Batteries
- Fluorescent tubes
- CRT monitor element
- Toner cartridges
- Capacitors containing PCB
- Printed circuit boards
- Refrigeration systems
- Ionization smoke detector
- Medical equipment

Most of these components need to be treated in specialized chemical separation processes. However CRT monitor element and fluorescent tubes can be dismantled with fairly simple techniques and simple equipment. They are described further under the results and discussions chapter.

8 Separation of WEEE

In this section we have looked at how different methods of separation are set up and function. The two main subjects are automated separation and manual separation of WEEE.

8.1 Manual Separation

Manual separation in terms of dismantling WEEE, is a process relying on manual labor from a human operator. Although tools can be mechanized, it requires a human identification of components and materials.

Manual separation is about reversing the assembly process which the electronic article was constructed. This includes releasing the mechanisms which the components were assembled with during production. That means you will have to unscrew, or unclip any fixing mechanisms which connect the materials to each other. Each part is dismantled step by step until all components are of one material.

In a paper on WEEE separation (12), Wang states the need of finding the appropriate depth of manual dismantling. As an example he brings up a DVD player. The dismantling steps are shown in the figure below.

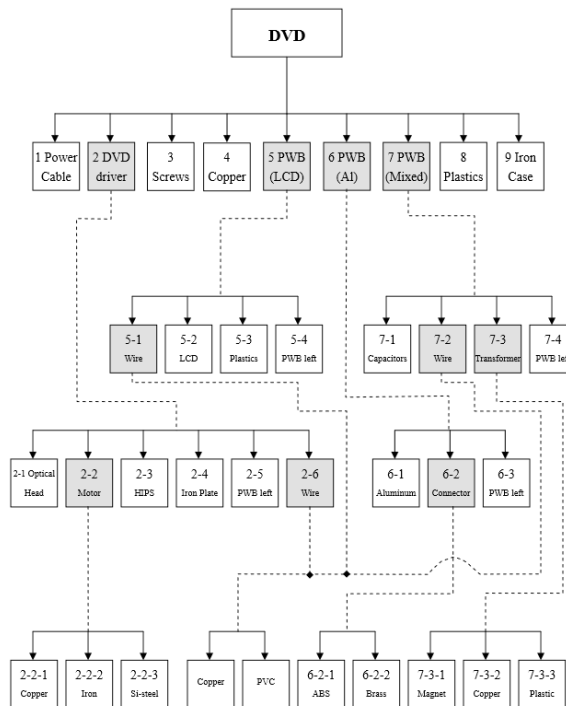


Figure 14 Depth of dismantling (12)

The depth of dismantling is illustrated by the different rows in the figure. In manual dismantling, this should be limited by the factors of physical difficulties and time. To what level is it economically beneficial to stop dismantling and sell to another treatment plant with higher depth of dismantling? Hazardous processes for the dismantler should also be factor to decide the depth of the dismantling. (12)

8.2 Automated separation

Automated separation systems for WEEE are broadly used in Europe and North-America. These are high investment recycling plants with high efficiency. Although they are mainly automated, they also rely on some degree of human interaction. There are certain steps of the separation that needs human disassembly or separation. This can for instance be in initial separation where hazardous components, such as batteries are removed. After the initial separation the WEEE is shredded and sent through a series of auto-

mated separation processes that collect the different materials (appendix III)

8.3 Comparing automatic and manual separation

Separation systems in Europe which are highly automated can handle high quantities and volumes quickly. Although at the cost of high energy consumption and inefficient separation quality compared to manual separation. Amount of recycled material gathered from the WEEE in an automated separation plant is around 70%. Trained labor in a manual separation facility can reach around 84% of the material being recycled. Important to remember that manual dismantling has its limitations:

- **Time consumption** manual dismantling will be limited to the time required for dismantling the parts. If a part takes too long to dismantle it is no longer profitable to dismantle
- **Hazardous materials** in a component poses a health risk if dismantled
- **Size of component** is a limiting factor. Small components will make it very difficult to separate the materials.

Both Gmünder and Wang conclude that in a manual separation, it is important to find the appropriate dismantling depth for the WEEE to obtain an efficient dismantling process. (13), (12).

9 The stakeholders and our participation in the project

When going into an unknown country to work on a project, the most important factors for the outcome is not just the result itself, but how it is implemented into society. Many projects fail because they are done in a way that would work in their home country, but doesn't work in the country you try to implement it into. This shows that is important to let the people with knowledge on the culture be strongly involved in the process. It is important to know your own role in the context, and not try to change social and political aspects. Some parts are better to leave to the other participants of the project.

As a person coming from a western culture, the strong culture make it extra important to step carefully and prepare well before trying to change things for the "better". With a very different set of values and view on what is good, what is commonly accepted as good in the western world may not be right in countries like Bolivia.

In this project there are two main participants: the municipality and RAEE Recicla. These are two actors with a lot of knowledge about the local society, each with their own expectations and interests in the new separation plant. Jonathan Butrón in RAEE Recicla is sitting on much competence in WEEE recycling, and is a key person for the project to be efficient and sustainable. As a private sector actor, it is important for him to make a profitable business. The municipality's interests in the plant is rather to make a large scale sustainable treatment plant for environmental and social reasons, and to reduce the load on the landfill. This saves them money and time before they have to open a new landfill. A private and a public participant are involved. There are many examples of successful private-public partnerships, and it is often essential for a good result of public beneficial projects. The partnership can also be a source of trouble. Sometimes contradicting expectations will appear, and they will have to compromise. It requires them to system-

atically work together. Good cooperation and communication is essential. External partners who can facilitate with the partnership has had positive effects in other cases. (14)

Swisscontact is another part in the project. The company has a lot of competence organizing projects, and is well established in the Bolivian system. They have worked with both private and public partners, and can be a positive effect in the partnership. They also have some meanings about how to make the plant work, but have a more objective view on the situation. Swisscontact role in the project is mostly as a consulting part and communication hub.

Our role in the project should therefore be as “experts” on process and layout design; and product development. That way we will let the people with better knowledge of the culture and the systems take care of the big picture, while we provide them with the technical part they want from us. It is still important to understand the systems as good as possible to understand the choices that are taken, to be able to implement the thoughts in our design.

Swisscontact should be our main point of contact. There are a few reasons for this. Primarily it means that we will be seen as a part of a serious organization, which can make us more influential. It can be easier to respect and accept the work we deliver if it comes through a known organization. The thesis may be used in an official proposition for a realization of the project, whereas it may be important that the information comes from a respected source. More information and reflections around this can be found in appendix IV.

The analysis of the stakeholders is presented in the figure below.

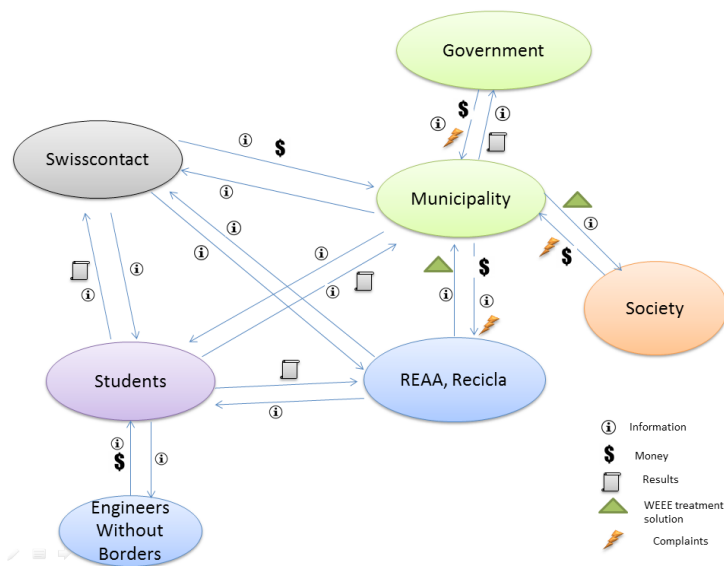


Figure 15 Stakeholders in the project

10 People with disabilities

In the thesis we have looked at two different handicaps, autism and wheel-chair users respectively, and how to implement them for operations in the dismantling plant.

10.1 Autism

People with autism is a challenging group to implement in this work environment. The condition is very wide and can differ a lot between individuals. For guidance in this area we got help from a psychologist who have specialized in autism and has 20 years of experience and practicing in La Paz, Tania Llanos. In dialog with her, people with autism are considered as potential workers because of their ability to systematize with high accuracy and interest. However there are some concerns to this group in relation to working at a dismantling facility. The main points that can be challenging for this group are:

- Distracting elements such as noisy environment and stress.
- Their judge of dangerous activities is not always present.
- The fact that they will have to dismantle and break objects, instead of constructing them

Llanos expresses that implementing a person with autism will have to be done gradually through training, preferably in early age around 16 years old. Also it is a matter of judging if each person with autism is fitting for this kind of work since degree of autism is very different between persons. Implementing workers with autism is a process that has to be planed carefully and done step by step.

The goals of implementing people with autism is:

- Integrate them socially so they grow accustomed to working and cooperating with other people
- Give them sense of independence and give them sense of achievement
- Integrate them to an ordinary job.

- Lessen load on family
- Further work on how to implement people with autism in general

This is not a implementation that can be rushed. We are therefore recommending an approach that readies and make them accustomed in the start, and then fully include them in the work flow.

10.2 Wheelchair users

Wheelchair users are people seated in wheelchairs because of lacking functionality in the legs. This can be because of lameness, amputation, injury or sickness. In Bolivia this condition is a challenge. Moving around can be challenging, especially in La Paz. Streets and sidewalks are of poor quality and often very steep. A government organ has been established to improve accessibility for handicapped in La Paz, but much work is still needed. Because of movement difficulties obtaining a job is not easy. Work will have to be done from a seated position, transporting larger object from one place to another can be a challenge. When implementing persons with this handicap to the plant, accessibility should be planed, and independent working ability should be supported. As a minimum requirement for workers with this type of handicap, full functionality in the hands should be required. Benefits with implementing wheelchair user both individually and socially is:

- Integrate them socially
- Give them economic independence
- Heighten the social status, and remove the impression of uselessness
- Open new thinking and solutions that can implement this handicap in other industries

To allow for this implementation a design without challenges of movement will be important to the working space.

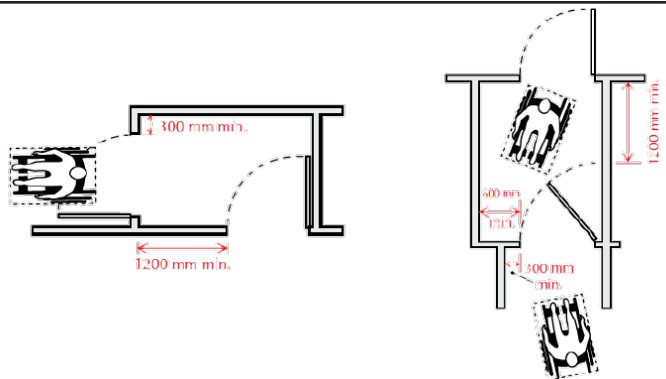
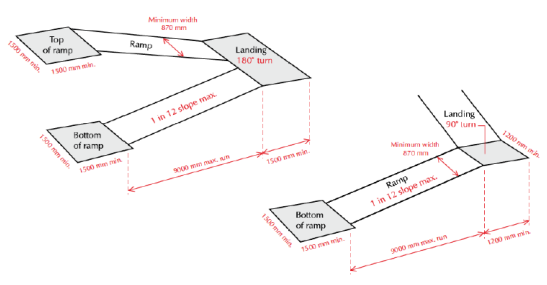
10.3 Barrier-free Design for people with disabilities

A barrier free design is the design of a place that suited for easy movement and access for all kinds of people. This includes not only the design of the work place itself, but does also include the outside area, entrance and bathrooms and offices. The most important factors in the design is to ensure enough space and easy access to all relevant areas, easy visibility and availability to navigate, clear marking and smooth surfaces with few obstacles. The considerations needed to be followed to achieve this are:

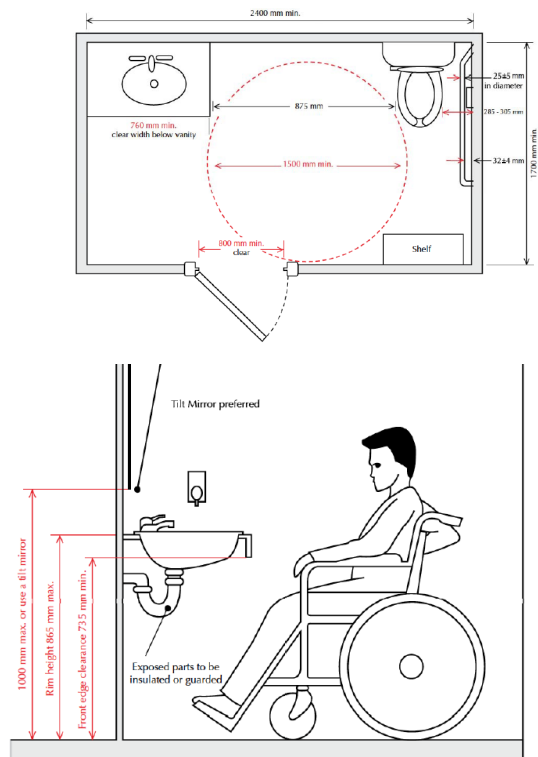
- Work environment preferably in one plane
 - Any elevated section is accompanied with a ramp
 - If there are more than one floor, an elevator should be installed
 - Floor surface needs to be smooth not to hinder wheel movement
- Door solutions needs to be practical
 - Wide enough for wheelchairs
 - Easy to open in both directions (automatic for example)
- Reduce noise as far as practically possible
 - Chose machinery with low noise levels
- Bathrooms and dressing rooms are placed conveniently and designed with usability in mind
 - Toilet is handicap adapted
 - Sink is placed in correct height

In 2008 a guide for barrier free design in Canada was published (15). The designs described are in compliance with the Canadian normative, and can give a good idea of what works and what is important to think about in the design. Below follows a summary of the most relevant parts for this thesis. All the figures are taken from the report (15).

Hallways	Minimum 920 cm for a wheelchair to pass Wider recommended for others to pass as well: - Wheelchair + person: 1200 cm - 2 wheelchairs: 1500 cm
Doorways	Free clearance of min 800 mm Easy to open: automatic or easy to push open

	
Ramps	<p>Slope no more than 1:12</p> <p>Minimum 870 mm wide</p> <p>Handrails (915±50 mm high)</p>
	

Bathroom





A photograph of three men in a workshop or garage. In the foreground, a man with a beard and red hair, wearing a plaid shirt, stands with his hand on his chin, looking thoughtful. Behind him, two other men stand near a workbench. The man on the left wears a black jacket over a white shirt, and the man on the right wears a black sweater and sunglasses. The workshop is filled with various electronic components, including a large black plastic casing on the floor, a white cabinet with open drawers, and a workbench with a power drill and other tools. The scene is brightly lit by natural light from an open bay door.

METHODOLOGY

11 Introduction

A systematic process has been essential for the way towards the result of the thesis. The goal of the master thesis is to set up a good layout of a separation plant. This could have been done early in the process, but because of additional aspects, like knowledge on the culture, politics and the systems in Bolivia, it has been very important to gather local information before making the solution. Field work in Bolivia has helped to get a more accurate impression of how the project could be realized, and has given a sufficient understanding of the surrounding aspects.

The timeline of the thesis work can be divided into four parts. The first part is represented by the first semester and the project thesis. The last three parts are divided into the three objectives of the master thesis: the working table, refrigerator treatment option and the design of the layout of the new recycling plant. They will here be represented chronologically.

12 Project Thesis

Knowing that both the project thesis and the master thesis was going to be written about the same topic made it possible to distribute the time from the beginning. It made it possible to spend most of the first four months to do in-depth theoretical studies. In addition we wanted to finish a layout proposition for RAEE Recicla, to be used as a test facility for the plant that should be designed in the master thesis. Concept generation of a new working station should also be started, so testing could be started at RAEE Recicla in the beginning of 2016.

12.1 Theoretical studies

In the first part of the project thesis, it was important to gather as much relevant information about the situation as possible. There were two important aspects of the project; the technical: WEEE recycling, and the social: local culture. At the start of the project, boundaries were not clear. To get an objective and unbiased approach to the project, it was important to do basic research before getting too involved with the people whom was already working with it. Much work was spent on research of existing solutions for WEEE recycling in both developing and developed countries. A similar amount of time was spent to gather information about Bolivia, how people live and what the current waste management situation is in the country. To understand how to approach the problem, much time was spent looking at important factors and methods for work in developing countries.

To gather the information a few methods were used. Literature study was done to gather general information and go in depth of selected topics. Most of the study of Bolivia was with the use of research made by non-governmental organizations (NGO) and statistics from Bolivian government. Through lectures in the subject Theory and Methods at NTNU, and conversations with the professors, knowledge was achieved about working methods, and important factors to take into account when working in

developing countries. In appendix IV a study can be found about how to approach the cultural side of the project.

12.2 Fieldwork

To thoroughly understand what we were working with and to test how well the learned theory fitted with reality, a three week long field work was done in La Paz. The goal of the visit was to meet the partners in the project, determine the final project boundaries and understand as much of the waste system in La Paz as possible. Together with Swisscontact a schedule full of meetings and visits was made for the first two weeks, while the last week was left for independent work. Within the first few days we met the municipality, RAEE Recicla and Swisscontact, and learned their expectations of the project. After some meetings and long discussions to express our and theirs concerns, the scope of the project was decided.

Much time was spent on understanding the general waste situation in Bolivia. Visits were made to many of the waste facilities in La Paz, as well as participating an international solid waste conference in Cochabamba, Bolivia.

With the schedule in Bolivia, a good base knowledge of the Bolivian system was achieved. During the last week of the stay, much of the time was spent at RAEE Recicla to understand how they dismantle WEEE. This was done to find difficulties and to identify potential improvements in the plant.

12.3 Project Thesis Report

The project thesis was finished in December 2015 in Norway, presenting the data and experiences from Bolivia. A proposal for improvements in RAEE Recicla was included, and sent to Bolivia to be implemented. A primary concept for the work station was included as well.

13 Master Thesis

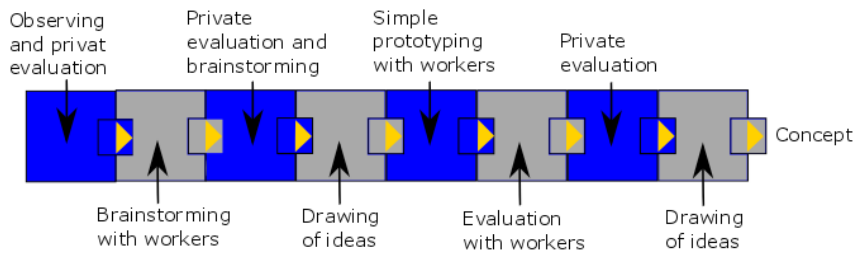
The master was written from January to June 2016. Contact on a personal level with the involved stakeholders in the project was considered as one of the most essential factors to understand the needs and to be able to implement solutions. For this reason we prioritized to spend as much time as possible in Bolivia. The Bolivian tourist visa limited the stay in the country to 90 days. The field trip was therefor started in the beginning of February and ended in the beginning of May. That way there were some time to prepare for the travel before going, as well as some time to finish the thesis after the visit.

13.1 Working Station

While visiting RAEE Recicla during the first field travel, we observed that the tables where the dismantling was done were full of parts and materials with no separation. This proved to be the bottleneck of the production. A better design of the table was reviewed to be the part of the plant with highest potential for improvement of efficiency, and was for this reason included as its own part of the thesis.

13.1.1 FIRST CONCEPT FOR DISMANTLING TABLE

At RAEE Recicla we made good use workers experience in dismantling WEEE. We decided to include them as much as possible in the development of a new concept for the table. With the willingness to change at RAEE Recicla, it gave a golden opportunity to develop a concept as far as possible with the workers, before fitting the design to the new recycling plant when an optimized result was ready. The design process was therefore started with the workers at RAEE Recicla during the first visit to Bolivia. This was done by needfinding, making concepts, reviewing the concepts and improving until a plausible solution was ready. The process is illustrated in the diagram below.



Figur 6.16: Concept development process

13.1.2 PROTOTYPING

In the beginning of the second field trip a concept was ready. We prioritized to start testing the concept as fast as possible. Prototyping is a fast and efficient way of testing and improving an idea. We aimed for simple prototyping to be able to make a rough version of the workstation concept. After the prototype was finished, testing was done with the workers. This showed us which solutions were practical, and scrap the ones that were not. The manual dismantling table is the primary process station in the dismantling plant. We considered testing with the workers at RAEE Recicla as the best way to get important feedback for changes and improvements. Also including them in the idea-generation was important.

A very simple prototype was made at first to be tested at the plant. Chip-board was used for easy forming and duct tape to attach it to one of the table frames at the plant. Card board boxes were used for material storage. Later an overhead rack with magnets was mounted in order to hang containers and tools on it. Continuous revision and feedback of the prototype led to a more final design. The wood-top prototype was used for a couple of weeks in the plant before it broke down.

What was learned from the first prototype was implemented into a second prototype that was made soon after the first broke down. This was made by modifying one of the original dismantling tables at RAEE Recicla. A steel rack was mounted to the table, and was filled with magnets from recycled hard drives to construct the tool holder.

The concepts were made with a theoretical background in the needs of people with disabilities in mind, but they had only been tested by people with full body functionality. To optimize the table for people in wheelchair

and people with autism, plans were made to invite disabled people to test the prototype. The municipal department for handicapped and volunteers in wheelchairs came to review the layout and test the prototype. This was done in order for us to test what kind of practical difficulties the table would present for persons seated in wheelchairs.

Jonathan is a person full of enthusiasm and "can do" attitude. Implementing the prototype table in his daily production was met with positive response. The workers was very eager to test the revised concept on the second prototype.

Testing with people diagnosed with autism accompanied with the local specialist on autism, Tania Llanos was also intended, although we were unable to accomplish this.

After the testing was done we revised the second prototype and what difficulties it presented to the volunteers in wheelchairs and made changes accordingly. Finally a solution proposal was put together.

13.2 Refrigerator treatment

10% of work in the thesis was decided to be spent on an in-depth study of how refrigerators should be treated as waste. A literature study was done on refrigerator technology and end-of-life treatment. Through communication with the governmental department for Ozone in Bolivia, COGO, and during one day of field work with a refrigerator technician, an understanding of the Bolivian situation was also gained. On this basis a report was written on the topic. The report can be found as its own chapter later in this thesis.

13.3 Plant layout

Most of the time of the master thesis was spent on designing the layout of a plant. This included making a technical design where everything is properly worked through, as well as tailoring it to be as likely as possible to be realized

13.3.1 IMPLEMENTATION OF PROJECT

One of the main obstacles in the project was early determined to be the actual execution of the project. The thesis is a part of the planning phase, but does not ensure the plans to be carried out. After the thesis the contact between us and the project partners in Bolivia will stop, and we wanted

to make sure that the partners could keep working from where we left. To include the partners in the development of the project, and to make them believe in it, was for this reason highly prioritized. Weekly meetings and open communication with the municipality and close involvement with Jonathan Butrón and Swisscontact was planned and followed through. In the last part of the stay in Bolivia, much effort was put into convincing the decision makers in the municipality and facilitate further planning without our involvement.


The close contact with the partners also had the benefit of continuously update us on their expectations of the project, and made it possible to fit the design to their expectations.

13.3.2 TECHNICAL ASPECT

Proper understanding of every aspect of the layout was important to make the plant design as realistic as possible. Much time was spent on theoretical research and on studying existing WEEE recycling plants. Accurate calculations were made for many parts of the system, and the systems were planned to a sufficient level of details. The detail level was set to be where all the most important requirements were given, but not enough to make it possible to follow a recipe. The reason for this is to make sure the people making the final design of the plant have to understand every part of the system and the reason for why it is chosen. This can be achieved by forcing them to decide on the details of the final solution on their own.

To understand how other WEEE recycling companies work in practice, we chose to benchmark with two different types of companies. Before going on the second field trip to Bolivia, a visit was made to the more advanced separation plant, Stena Recycling (appendix XI) outside of Oslo in Norway. During the field trip, a visit was made to Peru Green Recycling (appendix XII) in Lima, Peru to see a large scale manual WEEE plant. The experiences from the business visits has affected the design of the layout largely.





RESULTS AND DISCUSSION

14 Introduction

In this chapter the final solutions in the project will be explained. The layout and the workstation development are closely connected, and will both be presented in this chapter. The refrigerator treatment study can be found in the next chapter.

The complete layout of the plant will be explained, including the base decisions on how the plant will work, an explanation of the layout and the material flow, implementation of people with special needs, as well as an administrative and economic part.

One of the mayor priorities has been to make the system as realistic as possible to implement. To make this happen, it was important to analyze who would be the gatekeepers who can make the project go through, and what they wanted from it. The analysis showed that they wanted a system that would be easy to start up with low risk, and an economically good alternative to place the electronic articles in the landfill. As well it was important to make a pilot project that include people with special needs. The presented result is therefore made as a low threshold recycling plant with relatively small investments, and the ability to grow. It is fitted into the society in a way filling needs that are not filled today, and is designed to be partly handled by people in wheelchair and with autism. The environmental aspects did not seem to be as highly prioritized by the municipality as expected. It is however prioritized in the design of the plant, and can hopefully be an important part of making them realize the benefits and needs of this aspect.

It has been focused on making a simple design where all the parts have been thoroughly thought through to make it as realistic as possible. The solution is presented at a level of details that state the necessary requirements, but does not explain enough details to be followed as a recipe. The reason for this is to make sure the people executing the project have to make the final decisions and understand all the details and reasons for the solutions.

This chapter will be the main part of the report sent to Bolivia, and is written to be possible to read as a standalone report (with some modifications). Some of the sections does therefore include theory, and some of the statements made earlier in the report are repeated in this chapter.

15 Business model

The new recycling plant will be implemented in a city where waste electronics recyclers already exist. The other facilities are small business, mainly dismantling WEEE from electronics producers that pay for the dismantling service. At the moment there are no system to treat the waste electronics from the households and institutions. With the municipality's ability to make communal systems (such as waste collection and normative) involved, it is a good opportunity to enter this market.

As it is today, the small recycling plants are not large enough to be economically sustainable only from the dismantling (given that they sell materials of value to be recycled, and pay to have material without value recycled). With a larger capacity, higher efficiency and higher depth of dismantling, it should be possible to have a profitable dismantling plant with no income from outside sources. With this business model, the new plant will enter another part of the waste market that yet not is taken. This way it can function in addition to the existing facilities. With a deeper depth of dismantling, components that needs to be dismantled further, can be bought from the small businesses. Cables is an example of such components. They consists of plastic and copper that is difficult to separate efficiently without proper equipment. This does also go for materials that come in small quantities and are expensive to export. These can accumulate at the new plant and can be sent in large quantities more frequently.

15.1 Source of WEEE

In the figure below is a proposition of how the new plant can be implemented in the society. the red text indicate approximate frequency of delivery. Each source is explained below.

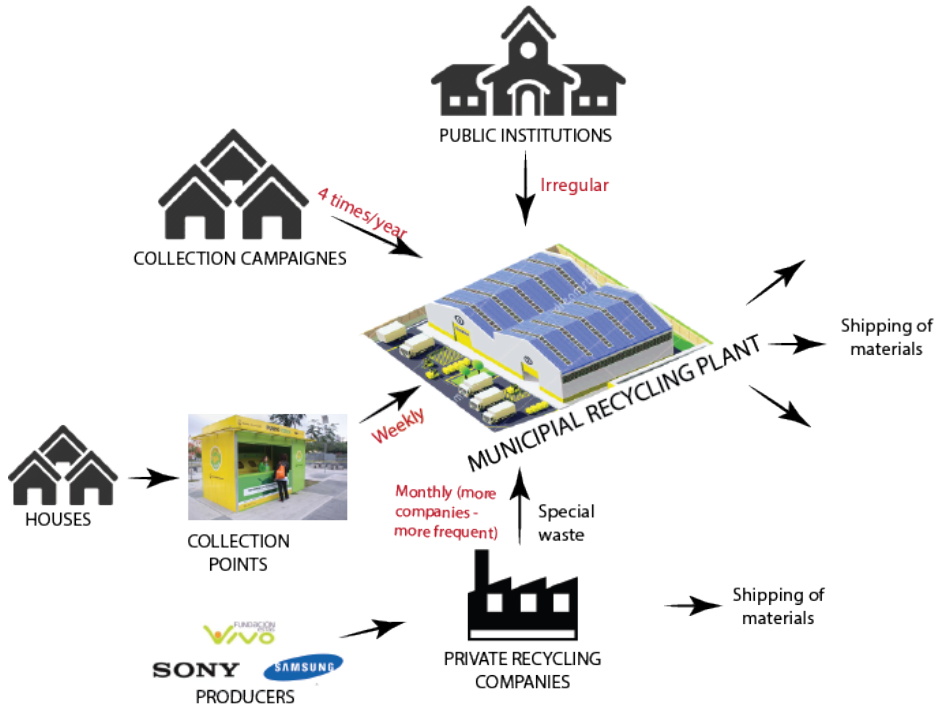


Figure 17 Sources of WEEE collection

Green Points: There are already an existing system of collection point (green points) for recyclables in La Paz. These does not yet accept electronics, but this is planned to be implemented in the close future. Every Sunday, the collection points are open for anyone to deliver their household recyclables. The collected waste is taken from the green points and gathered in one common storage point. The storage point can have weekly deliveries of the gathered WEEE to the new recycling plant. This will be one of the main sources of WEEE to the plant. This is expected to be a consistent and fairly predictable delivery.

Public institutions (governmental institutions, schools and such) and larger companies sometimes throw away large batches of equipment. They should be able to deliver their equipment to the plant. A notice should be given to the plant ahead of the delivery, so the dismantling can be planned. This will be a less predictable and less frequent source of WEEE.

Collection campaigns are campaigns where WEEE is gathered directly from the private homes. In Bolivia it is very common to store equipment

in the house for a long time after its end-of-life, and a lot is not delivered to the collection points. Campaigns should be organized a few times a year to collect equipment from the households. Quantities of collection may be hard to predict, but the campaigns may be placed at convenient times for the plant.

Other WEEE recyclers: The new plant will dismantle to a deeper level than the other recyclers. The equipment with potential of further dismantling can be sold to the larger plant. This requires the plant to have competitive prices with the alternatives, which should be possible because of low transportation cost due to close location. Materials that accumulate slowly and need to be sent in large quantum can also be sent to the larger plant. Quantities and frequency of deliveries depend on the size of the company, but should be possible to predict after some time with experience.

To make sure as much as possible of the WEEE end up in approved treatment plants, a directive that distribute responsibilities, and good information system should be implemented. Bolivia's first WEEE directive is in the drafting phase, and is supposed to be implemented in October 2016.

15.2 Role of stakeholders

The project is initiated as a cooperation between the public and a private actor. The inclusion of the municipality allows for an initial investment, and it gives the municipality opportunities to affect the directions of how the plant work. This makes it possible to ensure safe treatment of hazardous materials, as well as implementation of people with special needs. The drive to be economically profitable is secured by the private actor. A functional cooperation needs to be established, and should be thoroughly discussed with a facilitating partner. This will not be addressed further in this thesis.

16 Capacity Calculations

The statistics documenting the amounts of electronic equipment and WEEE in Bolivia are few and probably not very precise. With a large share of informal import of electronics there are no certain data on the size of the electronics market or products existing in Bolivia. There is an existing informal market buying waste electronics, and it is hard to estimate how big part of the electronics will end up here. A report by The University of United Nations from 2015 (9) estimates the amount of electronic waste generated per person per year and project the amount for 2018. The data are presented in the diagram below.

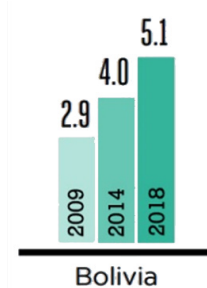


Figure 18 Calculated kg WEEE/person generation in Bolivia in different years (9)

These numbers are based on import and export of electronics and their life expectancy. The numbers can be considered conservative because of the large part of unregistered import. However because of lacking other data, these estimates have been used to calculate the capacity of the plant. Because of the expected delay before the plant is operational, the numbers for 2018 are used in the capacity calculations.

- Projected population in La Paz 2018 (6): 804.000 people
- UN Projected generation of WEEE per person in Bolivia 2018: 5.1 kg/person
 - Can be expected to be higher in La Paz (more electronics in urban areas).
 - The amount is expected to grow rapidly in the coming years.
- **Calculated generation of WEEE in La Paz: 4.100 ton/year or 342 ton/month**

According to an article in the WEEE news collection, *Economía Circular y Minería Urbana* (20), about 25% of the total WEEE in the world is treated properly. In the beginning phase of WEEE collection in La Paz, the number must be expected to be lower than this worldwide average.

The plant should not have a higher considerably than the expected incoming amount of articles, and it should aim to always work at full capacity. At the same time, it should aim to treat as much WEEE as realistically possible to collect to have a high capacity. This will make sure as much as possible of the electronic waste in La Paz is treated. In an economical perspective, larger amounts treated equipment means larger revenue. The reasons for this are: the possibility to organize the plant more efficiently; higher value of materials because of deeper dismantling; better prices for the materials (large quantities get better prices); and more WEEE treated per person working at the plant (including administrative employees).

With these baseline assumptions, a plant with a capacity of 15%-20% of the total WEEE generated in La Paz is analyzed to be a good solution. With little effort, more capacity can be added to the plant by adding more people and tables to the dismantling sector and expand some of the storage area.

Assuming a dismantling capacity per operator of 5 tons each month, which is the same as the comparable operators at Peru Green Recycling, a total of 12 dismantling operators give a capacity of about 60 tons, or 17.6% of the total WEEE in La Paz.

To find an appropriate size of the plant is very important for the economics of the plant. The statistics used in this calculations have high uncertainties. More work to gather good statistics is recommended to ensure an appropriate capacity. All the numbers used in the calculations are stated and explained in appendix XIII.

17 What should be treated in the facility?

The waste delivered to the facility has to be well defined. It is important that electronic waste is not confused with other house articles such as kitchen articles or furniture. Therefore the plant is advised to follow the European union's definition of WEEE. Information about what articles are accepted should be given at the points of collection and through information campaigns .

17.1 Accepted WEEE

We advise the plant to accept WEEE from all of the 10 categories defined in the European union's definition, except the articles containing refrigerants, and lightbulbs not containing mercury. Refrigerator treatment will be briefly explained in this section, and explained in detail in the next chapter. The other types of WEEE should be accepted and treated at the dismantling facility.

Most of the WEEE is unproblematic to dismantle manually. However some of the articles need more specialized treatment methods. In this study three categories have been identified for special treatment. The reasons for treating the equipment in these categories are: to sufficiently contain harmful materials, and/or because of economical benefits. The categories recommended for special treatment are CRT monitors, fluorescent tubes and cables.

17.2 CRT monitors

17.2.1 WHY

CRT monitors are computer and TV screens that use cathode ray technology, shown in the picture below. These screens are big and bulky, and are based on a technology that commercially is decreasing rapidly. Yet these monitors are still used in a lot of households in Bolivia. Large amounts of waste CRT monitors are expected to be generated as a result of end-of-life time expiring in the years to come. Also as the economy improves, more households and offices will be able to change computer and TV CRT monitors with the lighter and smaller LCD or plasma screens.



Figure 19 CRT monitor (35)

Because of the high lead and phosphor content, disposal of these articles should be done appropriately rather than disposal at the landfill. Special equipment is needed to get a proper separation of the materials in CRT monitor. Some of the materials can be sold, while some need more advanced treatment outside of the country. With a deeper level of dismantling, a less of the monitors materials need to be included in the expensive container shipment out of the country. Because of the monitors bulky design, it is a large difference in how fast a container fill depending on the level of dismantling.

17.2.2 HOW

The first part of the dismantling of a CRT element does not require special tools. Circuit board, plastic and cables are relatively easy to extract. The funnel glass is the part that contains lead and phosphor. In the back part of the monitor is a transparent glass cylinder (electron gun). The inside of the monitor has of low pressure, so improper dismantling pose the risk of imploding the element and pose a risk to personnel damage. The dismantling

of a CRT monitor is done in two stages:

Stage 1: Initial dismantling is done by removing plastic casing, cables and circuit boards from the CRT. Then the reflector attached to the CRT is removed. Most small companies stop the dismantling at this level. The CRT element with its components is shown in the pictures below.



Figure 20 CRT element after stage 1 dismantling

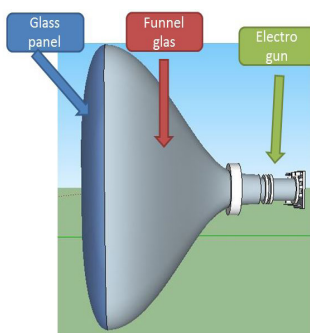


Figure 21 CRT element and its components

Stage 2: Secondary dismantling should involve:

- Releasing the vacuum in the tube to avoid implosion risk
- Removing metal band around the CRT element and the electron gun
- Separating panel glass from funnel glass. The funnel consists of a glass containing lead oxide, and usually has a black color. At the bottom the panel glass that is non-lead glass. The funnel and panel glass needs to be separated to get non-lead glass apart from the lead-glass.
- Removing the phosphor coatings from the panel glass

17.2.3 RECOMMENDATION

Our recommendation is that the plant should have the ability to recycle CRT monitors. This is a procedure that smaller WEEE-recycling businesses

are unlikely to invest in because of the incoming quantity needed to justify the purchase for needed equipment. A municipal plant should be able to gather large enough quantities to justify investment in this process. There is also an environmental responsibility to avoid that the CRT monitors enter the landfill because of the large amounts of lead they contain.

For dismantling stage 2 we recommend a method called **electric wire separator**. This is a method where a wire of NiChrome is wound around the interface between the funnel and the panel glass. With electricity the wire is heated for a designated time, then cooled with cold air. The thermal shock will break the glass at the interface, and the leaded glass can be lifted from the non-leaded glass. This method is suitable for small to medium quantities of CRT monitors. Electric wire separation is a low cost alternative that offer a good separation of leaded glass. Producers of this equipment estimate a capacity of one station fitted with electric wire and an experienced worker, can treat 40-60 sets/hour. For a plant in the initiating phase we assume this will be sufficient. The panel glass can be recycled as regular glass. Possible uses for the leaded glass is fluxing agent for lead smelters (17) Also there are smelters located in Europe that are dedicated to extracting lead from CRT funnel glass. When shipped, the funnel glass should be sent as a whole component. We don't recommend breaking it to make it more compact, without being sure this can be done without the release of dust containing lead.

Separating the funnel glass from the panel glass makes a huge difference in volume of materials. As of now, the CRT screen elements are sent from Bolivia as a whole component to Europe for treatment. This is because of the funnel glass containing lead. If only the funnel glass is shipped, it can be stacked much more efficiently. It is estimated that 3-4 times as many units of funnel glass can be sent with each container. Calculations can be seen in **appendix**. With each container shipped to Europe having a price of approximately 5000 dollars. Saving this volume makes a very good economical motivation for machine investment.

17.3 Fluorescent tubes

17.3.1 WHY

Fluorescent tubes are light emitting tubes used in light armatures. They are widely used for lighting in offices and administrative buildings, but also in households. They are often preferred as a source of lighting because of the long life span. Fluorescent tubes contain small amounts of mercury and a layer of phosphor inside the tube. These materials should be contained instead of dumped for landfilling and cause contamination of groundwater.

Fluorescent tubes are fragile and take up much volume. This makes them hard to store or transport to other cities with treatment facilities.

17.3.2 HOW

Florescent tubes contain a phosphorus layer on the inside of the tube, and vaporized mercury. The rest of the components consist of aluminum, brass, copper-nickel wire and others as shown in the figure below (18).

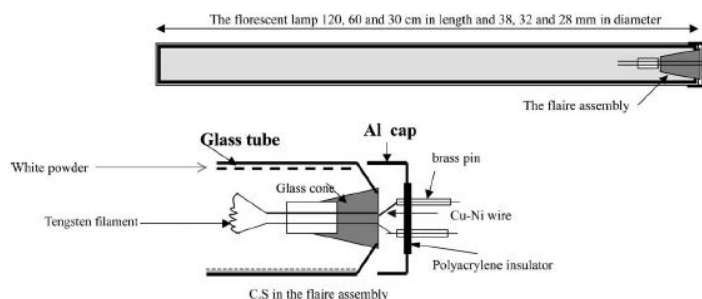


Figure 23 Components in a florecent tube (18)

The most important part of recycling the florescent tube, is containing the mercury and phosphorus. The vaporized mercury and the phosphor powder-coating has to be extracted. Later the glass tube and metal caps can be separated and recycled.

17.3.3 RECOMMENDATIONS

For recycling florescent tubes we recommend the drum shredding option. This is a cheap investment that contains the hazardous material in a very easy and efficient way.

Barrel Shredding is a common way to recycle fluorescent tubes. The tubes are fed into the shredder that shred them and captures the vaporized mercury and phosphor inside the tube. The phosphor powder is contained in filters while the mercury that consist of smaller particles is captured in a carbon activated filter inside the barrel. The remaining waste will mostly be glass and metal caps. These can be separated and recycled accordingly. The captured mercury and phosphorus need an additional process to be properly separated, and can be separated in a different treatment plant. A facility for this treatment is under construction in another Bolivian city. After separating the phosphor and mercury, the mercury can be distilled and soled as liquid mercury for reuse in production. Although this treatment method only treats the tubes half way through the complete recycling process, it ensures a much more compact and secure way of storing the material. It also makes it easier have the treatment facility further away, without high transportation costs related to volume.



Figure 22 Flurocent tube shredder (37)

With a drum shredding system in La Paz, florescent tubes can be collected and shredded, then shipped safely to the Bolivian city constructing a plant for further treatment. Until the distilling plant is operational, exporting the shredded material for treatment abroad is recommended.

17.4 Cable Separation

17.4.1 WHY

Cables mainly consist of copper and plastics. The copper has a high value, and can be sold for a higher price if separated from the plastics. The type of plastics used varies, but does not have a value. Some of the plastic contain harmful flame retardant substances, and need to be treated as hazardous waste.

The cables at RAEE Recicla is today sold to a company in Bolivia without further treatment. In a smaller plant, the investment in a cable separating machine does not make sense. In a larger plant enough cables will accumulate to make a profit from the investment. The larger plant can also buy cables from the smaller plants.

Assuming that about 1% of the weight in the WEEE is cables (with use of data from (7)) and a capacity of 60 tone/month, 600 kg cables each month, or 20 kg per day can be treated.

17.4.2 HOW

There exist different types of machines that separate the metal from the plastic in cables. The large variety of sizes and types of cables in WEEE require for a machine that can treat all these types quickly and efficiently. The best option for this is to use a cable separation machine where the cables are put into a grinder that cuts the cables to very small lengths. The plastic will then easily be separated from the metal. The separation process is often done on a shaking table that shake the small cable pieces and separate them with the use of the difference in density. Other well working methods are also used. After the separation, the product should have a purity of about 98% clean copper. The products are as shown in the picture below.



Figure 24 Cable separation process(20)

A typical machine like this has a capacity much higher than what will be generated in a day on the plant. The cables can therefore quickly be treated at the end of the day or at the end of the week. A typical machine has a capacity of minimum 50-100 kg/hour.

Estimated price for machine: 10 000 \$US

17.4.3 RECOMMENDATION

With up to date numbers of cable and copper prices at RAEE Recicla it is found that the value of the cables can be increased by 37.5% by separating the plastic and the copper. This results in an added income of 4600 \$US/year. This again mean the investment of the machine will be paid down in a little over two years with the used plant capacity. This investment is recommended.

The machine will have a capacity much larger than what is produced at the recycling plant. Increased plant capacity or additional sources of cables can therefore be treated without problems, and will increase the benefits of the machine more. With the current capacity, about 120 kg of cables will be generated each week. A good model can therefore be to have one person operate the machine for 1-3 hours at the end of each week.

17.5 Refrigerator Treatment

A study was done to find a good solution for refrigerator treatment in La Paz. A short summary of the conclusion will here be given. The full report can be found later in the report, and gives an in depth explanation of the background and the conclusion. Refrigerators does here include refrigerators and freezers.

The problem with refrigerators is the content of environmentally harmful gases. The most important articles to handle, are the refrigerators containing CFC-gases, which have a large effect on the ozone layer and a large global warming potential. Bolivia has slowly reduced the use of CFC-gases from early 2000's, leading up to a complete phase-out in 2010. With the long life span of refrigerators and the Bolivian storage culture of old electronics, CFC-refrigerators are the most common refrigerators thrown away today, and will be thrown away in large amounts the coming years. Newer refrigerators contain other gases that also are harmful for the ozone layer and has high greenhouse effect. These also require the same special treatment.

Refrigerators are hard to dismantle properly. There exist advanced plants with automatic systems and high technology. The plants are relatively expensive, but very efficient. Manual treatment is slow and complicated. It is also shown that about 23% the insulating gases, CFC-11, is released during manual dismantling. This alone can have a large environmental impact.

Manual treatment of refrigerator in the municipal recycling plant is not recommended because of the large amount of released gases. The generation of refrigerators is not large enough in La Paz to justify the investment of a more advanced facility. On a national level enough refrigerators are thrown away to justify a state-of-the art facility. Our recommendation is therefore to not treat waste refrigerators locally in every city, but build a large plant that can recycle refrigerators from all parts of Bolivia. Importation of waste refrigerators from surrounding countries can also be considered to improve revenue. A plant like this will not be implemented by the municipality, but must be taken to a national level.

18 Layout proposal for the dismantling plant

In this section the solution proposal for the plants layout is presented. The plant is in many ways similar to RAEE Reciclas basic principle of receiving WEEE which is dismantled manually and separated into different materials. Materials are stored separately until they are shipped. The layout include all processes we have decided to implement in the plant. Setup of the processes and how material flow is supposed to run between them is also demonstrated. The plant has been modeled in a 3D modeling software to illustrate the layout.

Material flow analysis has been done in order to dimension storage capacity. How a dismantling schedule can be made is suggested. In this way the production of materials, storage capacity and export of materials can become predictable.

The layout has been designed with streamlined material flow in mind. This means that materials are entering the dismantling facility and following one direction through the facility without backtracking. This has been done to have the dismantling done as efficiently as possible, and make the material flow simple.

Each process that we have included in the layout is illustrated and explained with specific function and what type of equipment it requires. Between the processes color indicators are used to show where it is safe to move, and where movement with carefullness is required.

18.1 Production control

18.1.1 DISMANTLING ARTICLES

The dismantling process can be predicted if dismantling times are logged and the inventory in the entry storage is well mapped. By logging how long it takes to dismantle the different categories of WEEE, average times of how long a pallet of computers, printers, monitors or small electronics takes to dismantle can be learned. A mapped entry storage where each pallet is listed with content and location in the racks should also be maintained.

By implementing these two registrations it opens up for a more predictable production. With this system a timetable for the production can be established. By setting up a schedule for each table, instructing what pallet to dismantle and how long it should take, predictions on future storage space for both entry and material storage can be made. This can be helpful if the storage is operating at its limits. Also this can help predict how much of a specific material will be generated. For example if more pallets with CRT monitors are sent for dismantling, higher quantities of plastic and glass will be generated. By this kind of production planning, you will be able to have rough predictions on when a material fraction will be ready for oversea container shipping. That will enable the logistic process for shipping arrangements to start sooner, and the material will spend less time in storage. It will also make it possible to determine main storage capacity based on rate of dismantling time for different categories awaiting dismantling.

18.1.2 WEEE STORAGE

The WEEE storage, will store all the WEEE coming into the plant. It will be separated by type of equipment and stored on well-marked pallets in four level racks.

To calculate the acquired storage capacity, it has been assumed a capacity of 60 tons per month, given it contains 4 weeks per month and 6 work days a week. We have further assumed a distribution of incoming equipment as follows:

- Puntos verdes (PV)(Collection points): 12 tons every Monday
- Separation companies (SC): 1 ton every Wednesday
- Public institutions (PI): 0,5 tons every Friday
- Collection campaigns (CC): 18 tons every three months

The needed storage capacity with this distribution is shown in the graph

below:

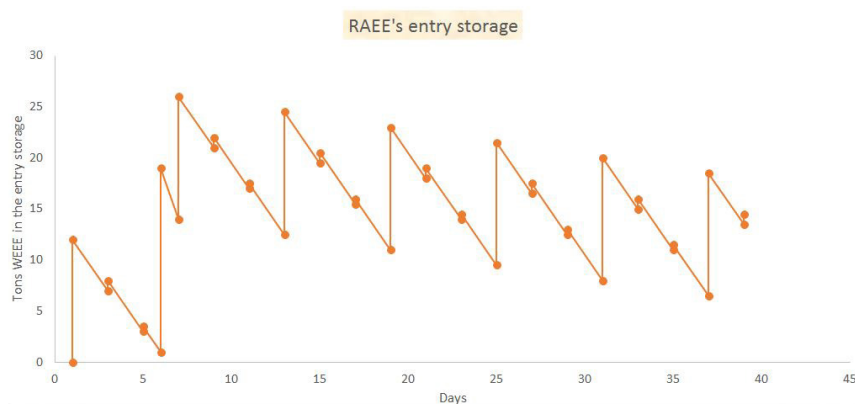


Figure 25 Estimated tons of WEEE in WEEE storage over a periode of 40 days

The graph shows the predicted amounts stored for seven weeks. Following the model, the graph will sink to zero after three months, before repeating the same pattern. The collection campaigns can be planned in accordance with the state of the inventory.

Less storage capacity means less space occupied by the storage area and less possibility to accumulate equipment for longer time. It will increase the need to have a high material flow. In the figure above, the necessary storage capacity with the assumed dismantling capacity is 26 tons. Because of high uncertainty on the inflow to the plant and an additional buffer, a capacity of at least 30 tons will be recommended.

- Assumption: Average weight of fully packed pallet: 300 kg
- Storage size: 30 tons/300 kg/pallet = 100 pallets
- Size of rack: 4 pallets wide x 4 pallets high x 2 sides = 32 pallets
- Amount of racks to fulfill capacity: 4
- Storage capacity: 128 pallets or 38,4 tons

Rack Specifications

- Width: 2 pallets (min 225 cm free space)
- Height: 4 pallets (min 135 cm free space per level)
- Depth: 1 pallet (min 105 cm)
- Weight capacity: min 1000 kg/pallet
 - Pallet of compacted steel = 800 kg.
 - Pallet of copper assumed heaviest load – unsure of weight. If too heavy less should be packed on each pallet or it should be stored on the floor.

18.1.3 MATERIAL STORAGE

There are 4 material types that are subject for container shipping. A standard 10 feet container has area for 10 pallets measuring 120x100cm. We also assume that it is possible to stack two levels in the container. This means that each container can take 20 pallets. The amount of storage space needed for these material fractions will then be:

- Plastics: 20 pallets
- Parts for shredding: 20 pallets
- Printed circuit boards: 20
- Leaded glass: 20

All of these materials will not be sent at the same time, so we estimate a needed storage for these to be 80 pallets. We estimate a need for additional 48 pallets for the remaining materials which are sent much more frequent. This makes the proposed material storage capacity has a to be 128 pallets.

18.2 Flow chart and layout

The flow chart below illustrates the material movement through the plant. Green arrows indicates the regular WEEE that does not require special treatment. The thinner arrows in orange and purple indicates the flow of the articles requiring special treatment. Each process is explained in detail in the following section.

The different areas are marked with color boundaries if restriction and carefulness is necessary. Areas with free movement is indicated within the blue zones. The storage areas with pallets placed at floor level is indicated with green zones. Storage space with racks and movement of forklift and machine operating zones, are indicated by orange. In the orange zones personnel movement should be kept to a minimum to avoid accidents. Areas processing or containing hazardous material are marked with red. Entering these areas should only be done by authorized personnel with appropriate protection.

18.3 Layout, processes and material flow

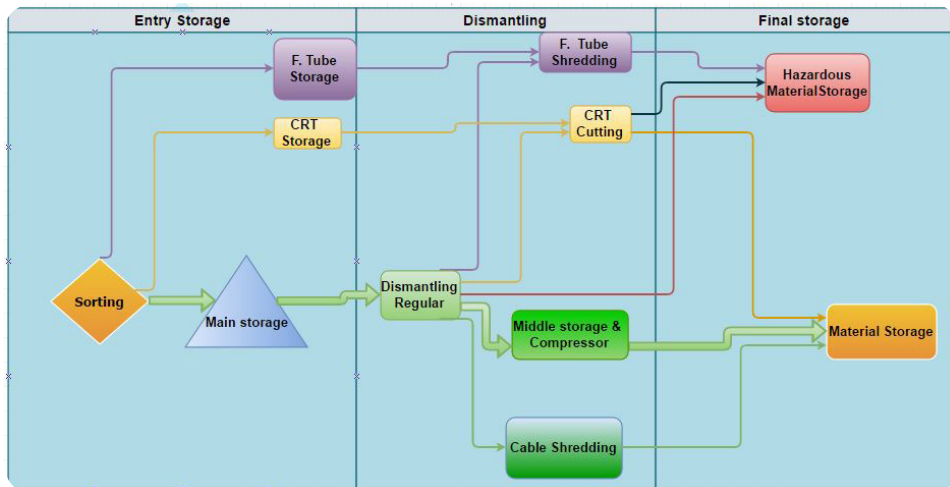


Figure 26 Material flow chart for the plant

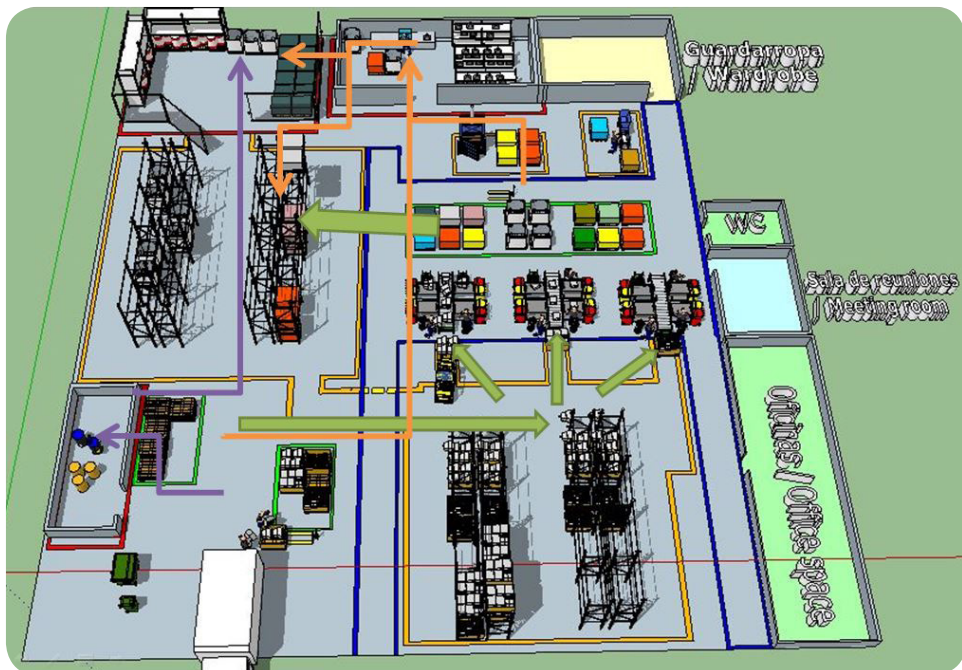


Figure 27 Flow chart indicated in the layout model

18.3.1 SORTING

At arrival, all of the electric articles are sorted into categories. Computers in one pallet, CRT monitors in one and printers in another. We recommend sorting the electronics categorically in this fashion within limits of practicality. Small electronics such as cellphones, remotes controls and computer mice take up small volume and is therefore more practical to mix in a pallet for small electronics. Also any packaging (cardboard or plastic) covering the electronics is removed here, so it won't delay the processes later in the material flow.

The sorting is done to make material control easier during dismantling and to create repetitiveness at the dismantling stations. Sorting electronics by category also makes it easier to separate types of plastic after dismantling, for example: plastics from monitors in a pallet, plastics for printers in another. The sorting is also meant to divide the material flows so that they are sent directly to their appropriate storage: WEEE storage, CRT storage or fluorescent tube storage.

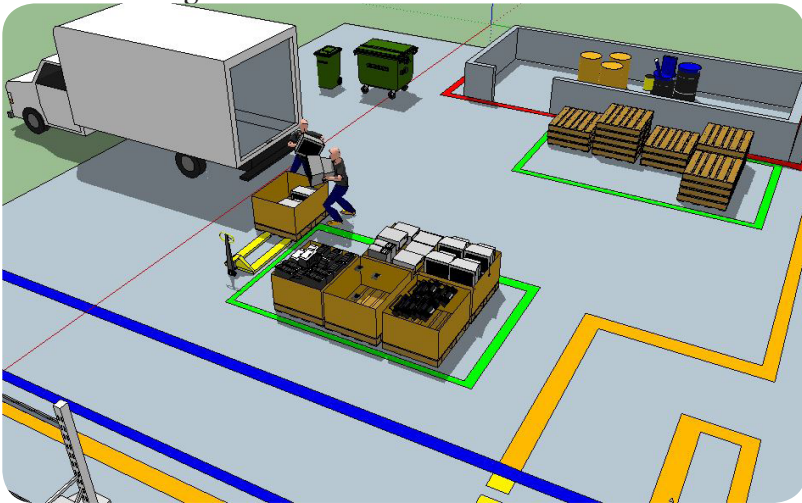


Figure 28 Entry sorting

Function

- Unpack electronic articles
- Sort the electronic articles categorically
- Ready pallets with electronics and secure them for safe storage

Equipment

- Pallet truck
- Empty pallets for loading

18.3.2 WEEE STORAGE

The WEEE storage is shown in the picture below. This is where the pallets with different articles are stored until dismantling. A good idea for maintaining easy storage is to have similar articles stored together so they are fast to find. Everything is placed on pallets to ensure easy collecting and transportation. The pallets are stored in two double-pallet racks of 4 levels.

The pallets will fill up with equipment as it comes in. If pallets are not filled up by one delivery, more should be added in later deliveries. The pallets that are not full, should therefore be marked with what type of equipment it contain and be placed close to the entry area. The full pallets should be prioritized for treatment.

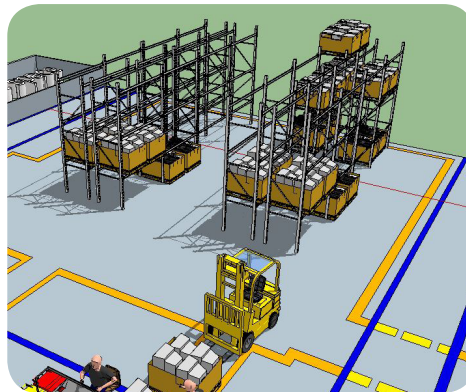


Figure 29 Main storage

Function

- Categorically store different electronic articles.
- Easy access to materials awaiting dismantling
- Space efficient storage

Equipment

- Regular counterweight forklift around 1.5 tons. Minimum elevation of 4.3 meters.
- Pallet racks with 4 levels and 1-1.3 m between each level.

18.3.3 CRT STORAGE AND DISMANTLING

The CRT storage and dismantling is an individual cell within the plant for treatment of CRT monitors. This cell is included with storage for the CRT monitor elements. This is to avoid the fragile monitor elements posing a risk after the protective plastic is removed in dismantling. It is also separated from the rest of the processes with walls. This is because the CRT elements contain hazardous substances. The whole processing cell for CRT is therefore placed in an area marked by red. Storing is done by simple shelves with appropriate height between shelves to store CRT elements in each level as shown in figure above.

The separation process of CRT elements is done by electric wire separation. The CRT element is collected from the storage and brought to the separation station. Separation is done inside a protective glass, depending on the workstation setup. The phosphor powder is vacuumed and the different material fractions are thrown in individual containers. The material fractions will be steel, glass and leaded glass (hazardous material).

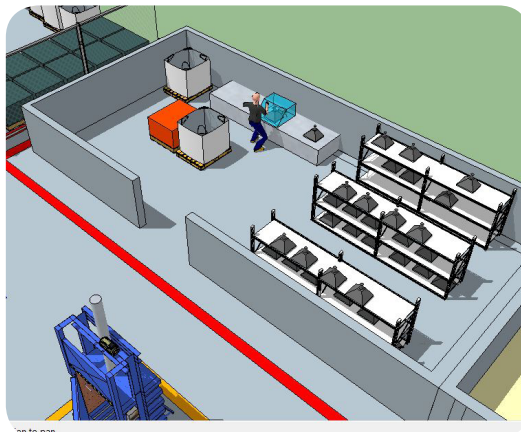


Figure 30 CRT storage and dismantling

Function

- Safely store CRT elements
- Separate glass panel from the funnel glass by means of electric wire
- Contain the hazardous materials

Equipment

- Storage shelves with appropriate space for CRT elements
- Separation station equipped with electric wire separator
- Vacuum hose that can remove any phosphor powder in the screen element, and contain it
- Pallets with material fractions: glass, steel and leaded glass.

18.3.4 FLORESCENT TUBE SHREDDING

Florescent tubes that arrive in the plant are sent directly for storage in the area for florescent tube shredding. The tubes are to fed into the shredder where gases and materials are contained. When a barrel is full, it is sent to the hazardous material storage, and later shipped for appropriate treatment.

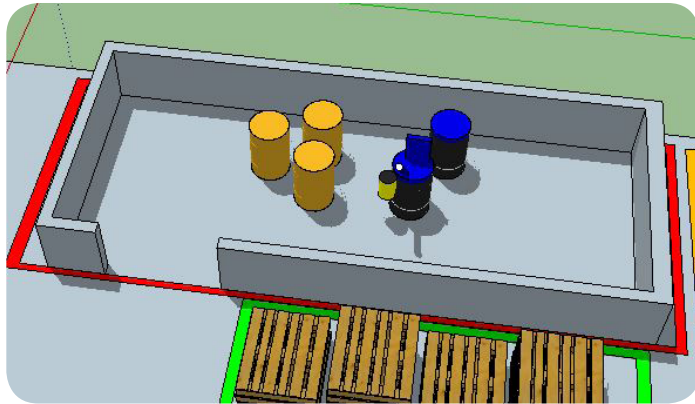


Figure 31 Florescent tube shredding

Function

- Store florescent tubes for treatment
- Shred the tubes and contain the hazardous materials

Equipment

- One mercury containing lamp shredder with filters
- Barrels for storing florescent tubes

18.3.5 DISMANTLING STATIONS, CABLE SHREDDER AND COMPACTOR

The dismantling stations is where most of the electronic articles are dismantled. Electric articles arrive in categorized pallets at each dismantling group. The articles are loaded on to the roller conveyor and dismantled. During the dismantling the different materials are separated into different boxes at each table. When the material boxes are full, they are emptied into the pallets containing the respective material (pallets in the green zone). These pallets are located in the middle storage behind the workstations. When a material pallet in the middle storage is full, it is brought to material storage. Materials fractions that are suitable for the compactor are brought here. The materials suitable for compression are steel, plastic and aluminum indicated as pallets in red, yellow and green. Compacted blocks of the respective materials are repacked and secured to pallets before they are sent to material storage. Cable separator is also part of the dismantling cluster. Here the gathered cables can be brought once a week, or when the pallet is full. Pictures showing the compactor and cable separator are below.

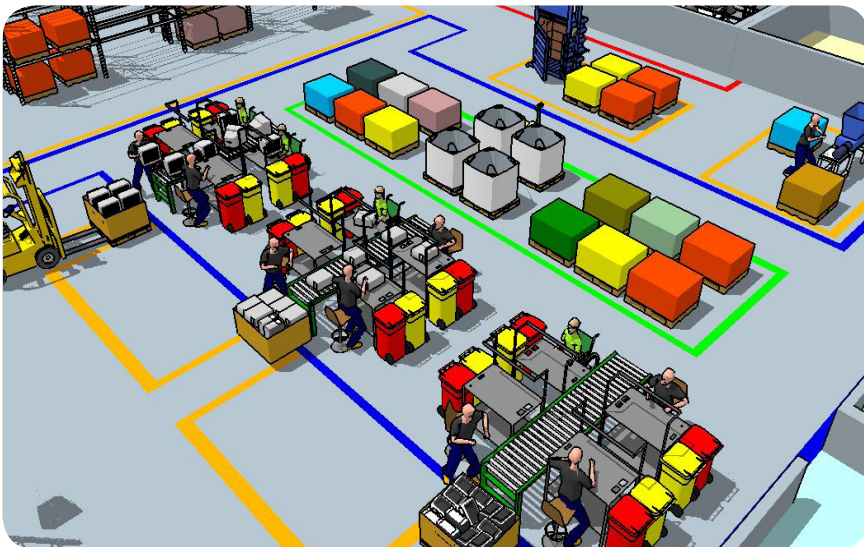


Figure 32 Dismantling stations

Equipment

- 3 groups of dismantling tables equipped with roller conveyor
- Pallets for storing material
- 1x Compressor

18.4 Dismantling station

18.4.1 THE SETUP

The workstation setup has different criteria that we have taken into account:

- Support efficient production
- Allow workers in wheelchairs and with autism to work efficiently on the workstation
- Low investment costs

The working tables will be set up in groups, where four tables work together in each group. The group is organized in two tables placed on each side of a roller conveyor. The roller conveyor is used to transport electronic articles to the tables inside the group. The tables are facing each other to allow easy communication. The setup is illustrated below, where material flow follows the blue arrows.

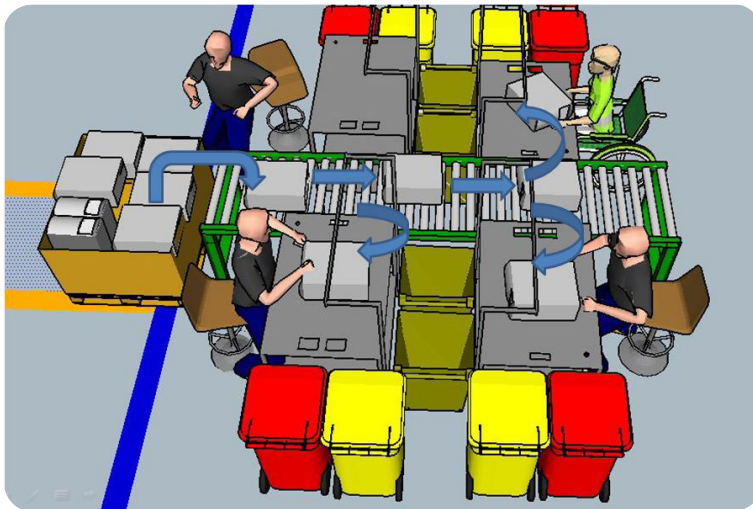


Figure 36 Dismantling group setup

Electronic articles arrive at each group in pallets containing one category of articles. One of the workers load the articles on to the roller conveyor. This minimizes time for collection of materials and makes the dismantling of a pallet into a team effort. Each table should be fitted with a simple rake

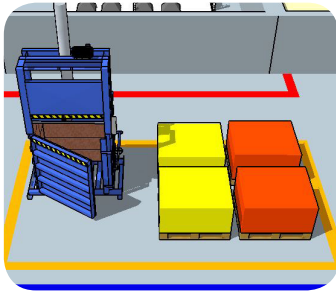


Figure 33 Compactor

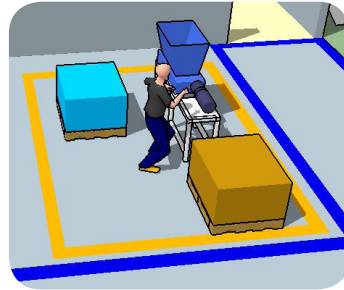


Figure 34 Cable separator

Dismantling table

The solution of the manual dismantling table is presented in the picture below. It is explained in detail later in this chapter.

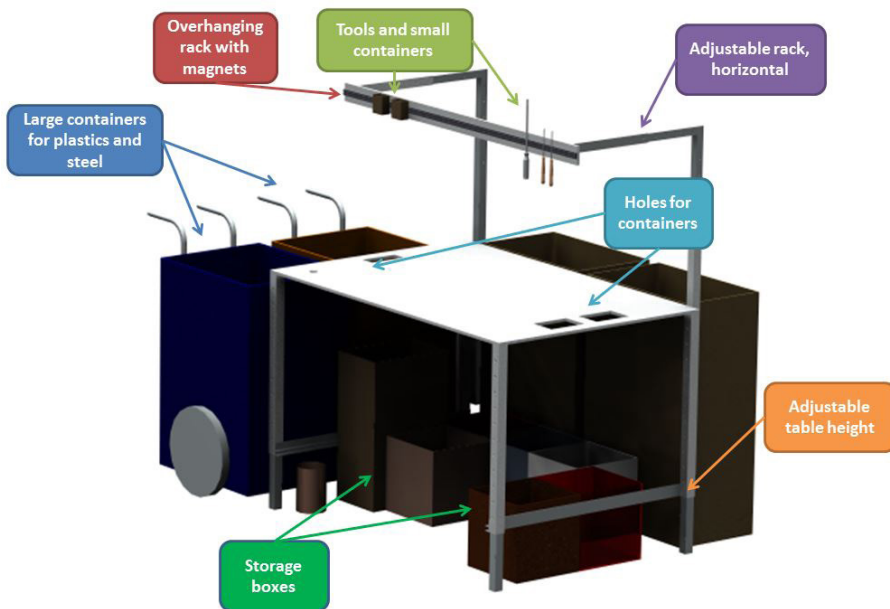


Figure 35 Dismantling table

Function

- Dismantle the main part of the electronic articles
- Separate the materials into pure fractions
- Store material pallets until they are full
- Compact the materials suitable for compression

in case a article is out of reach on the conveyor. With this setup, workers in wheelchairs will have no problem collecting the next article to dismantle.

Workers with disabilities should be mixed with workers without disabilities, but not more than two persons in wheelchairs at each group. Transportation of WEEE from pallet to the table should not be done by people in wheelchairs. When the containers at the table are full of materials, they need to be emptied at the pallets behind the dismantling groups. For the people in wheel chairs this can solve in two ways. Boxes can be with a small cart, or full boxes can be emptied by the other workers in the group. The processes in the work group is explained below.

- The forklift collects a pallet from the main storage and arrives at the dismantling group. The pallet placed at the end of the roller conveyor.
- Articles are then put on a roller conveyor by a worker with functional legs. Articles are added to the roller conveyor until it's full. When the conveyor gets empty, the workers fill on more from the pallet.
- The workers grabs the articles from the roller conveyor and dismantles it. The materials are put in their separate boxes at each table.
- When a box is full, it has to be weighed before placed in the correct material pallet.

18.4.2 MATERIAL STORAGE

The material storage is meant to store the material fractions after they have been separated, until they are collected for transportation. Some of the materials are collected regularly, while others need to reach a certain volume before they can be shipped in containers. Plastics, circuit boards, and parts containing copper, are subject for shipping with containers. The material storage, will therefore at least have to store pallets to fill 4 containers. Additionally comes pallet space for the rest of the materials sent more frequently like steel, copper and aluminium. A pallet truck should transport full material pallets to the material storage. Then the forklift will pick it up and place it in the racks. The layout is shown in the figure below.

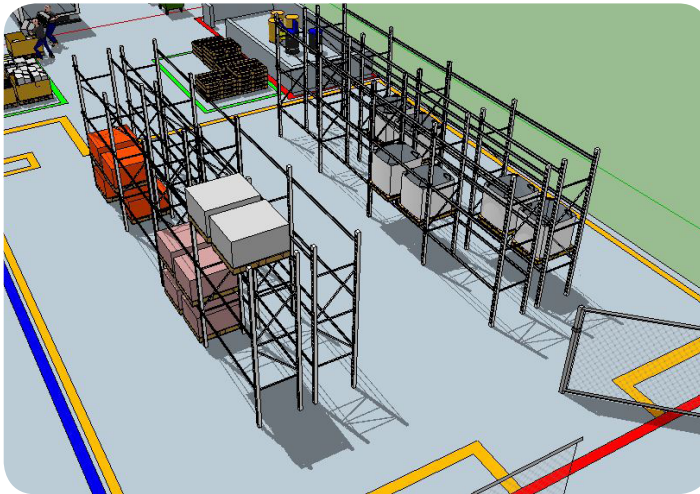


Figure 37 Material storage

Function

- Store pure material fractions until shipping
- Space efficient storing
- Systematic storing

Equipment

- 2x Pallet racks with 4 levels and 1-1.3 m between each level.

18.4.3 HAZARDOUS MATERIAL STORAGE

All of the separated hazardous component fractions are meant to be stored in this section. For safety reasons this area restricts access with a fence and marked with red lines to indicate hazardous area. This area is closed off because of the consequences of a accidental breaking and leaking of the containers. Here materials such as toners, lead glass, batteries, containers with shredded florescent tubes and others. All hazardous materials should be stored in sealed containers to avoid leakages. All containers in this area should be placed on pallets. This is to give the containers some clearance over the floor in case of flooding, and eliminate the risk of hazardous chemicals solving into the water.

The storage capacity in the hazardous material storage is lower than the in the material storage. This is because the material fractions here is smaller, but also to avoid long term storing. The largest space occupier in this storage will be the leaded glass from CRT monitors. The storage will have to be able to store at least 20 pallets of leaded glass before it can be sent with container. Other hazardous components that will be stored here are: CRT electron guns, treated fluorescent tubes, batteries, fuses and capacitors.

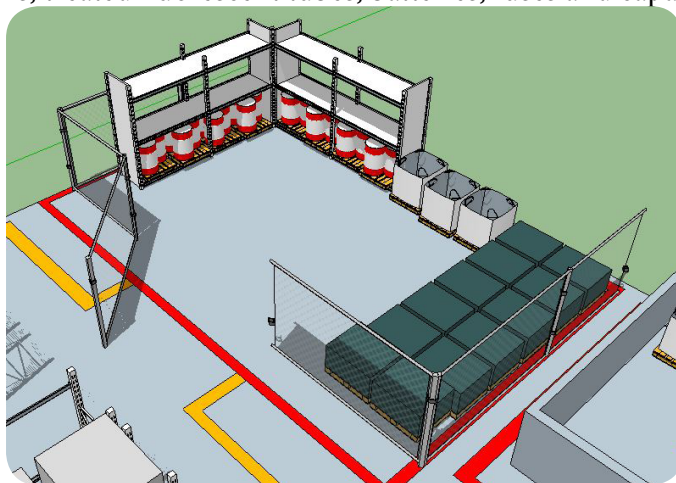


Figure 38 Hazardous material storage

Function

- Contain hazardous material from contaminate people and environment.
- Store the hazardous material until shipping

Equipment

- Fence with gate
- Shelves to store pallets, preferably with floor plates in each level to avoid pallets falling in between (see figure above)

19 Implementation of workers with disabilities

As a pilot project in implementation of people with special needs, it is important that much resources are spent to facilitate and truly understand how to optimize the use of the disabled workers. With a design that implements aiding factors to the disabled, we believe that they will prove valuable resources to the production. Experience and help from experts on the area are factors that can be important to make this work

19.4.1 WORKERS WITH AUTISM

To implement workers with autism we sought guidance from a local expert on autism, Tania Llanos. Together with her we have made some facilitating solutions to the dismantling table, and revised which working activities are suitable.

The workstation has a layout that supports tidiness and systematic disposal of materials and parts. This will make the table more inviting to the systematic way of thinking for workers with autism. There are different ways of facilitating a working station for a person with autism. The measures that can be implemented to the table are made to make the work easier and more inviting for a worker diagnosed with autism.

Measures implemented in the table:

- Colors to mark different material holes and boxes. Text and pictures can also be added to make it clearer what material is designated to which box or hole. Each material destination is marked with a specific color, to make it easier to relay each material to their destination as shown in pictures below.
- Easily accessible containers also makes disposal easy, and keeps the working space clean.



Figure 39 Dismantling table with colors marking each material hole

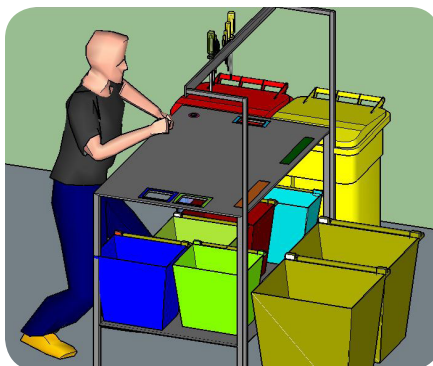


Figure 40 Dismantling table with containers under in colors indicating the different materials

Work activities should first of all be limited to operations that are considered safe for a person with autism. These activities should be identified by technicians in the plant together with a psychologist experienced in work with autism after the construction of the dismantling plant.

During our work, we have together with the psychologist in La Paz identified the following work activities as suitable for a person with autism:

- Normal dismantling of electronics
- Sorting of electronic articles at the entry sorting

In terms of dismantling this means leaving articles with components that present a health risk, to be dismantled by other workers. These are for example articles like CRT monitors that potentially pose a risk of imploding if they are fractured.

The plant floor is also marked with a colored borders between different work areas. Red and orange, represents areas that should not be entered by others than authorized personnel, while green and blue represent area with free, and safe movement. This should aid the employees with autism to identify where it is safe to move.

19.4.2 WORKERS SEATED IN WHEELCHAIRS

Workers that have legs with limited or no function is also a group that is desired to be implemented. They should have normal functionality in their upper body. In the dismantling plant the best option for wheelchair users is on the dismantling stations or in the administrative work. Heavy articles

that involves heavy lifting should be avoided for these workers.

The working table: Important factors for the wheelchair user for work on a table are:

- Easy accessibility that all the work can be done from one place
- All equipment is within reach
- Correct working height on the table.

A good working height is when the work can be done a little bit under the natural position of the elbows. To enter the table with a wheelchair, a free ground clearance off around 750 mm is recommended. The table height should therefore be slightly higher than this. There should be enough space to easily get to the table and maneuver around in the plant. When seated in working position, all equipment and tasks should be within reach. For this reason the toolrack at the table needs to be not far from the worker. The picture below demonstrates how the working situation for a person in wheelchair is intended at the table.

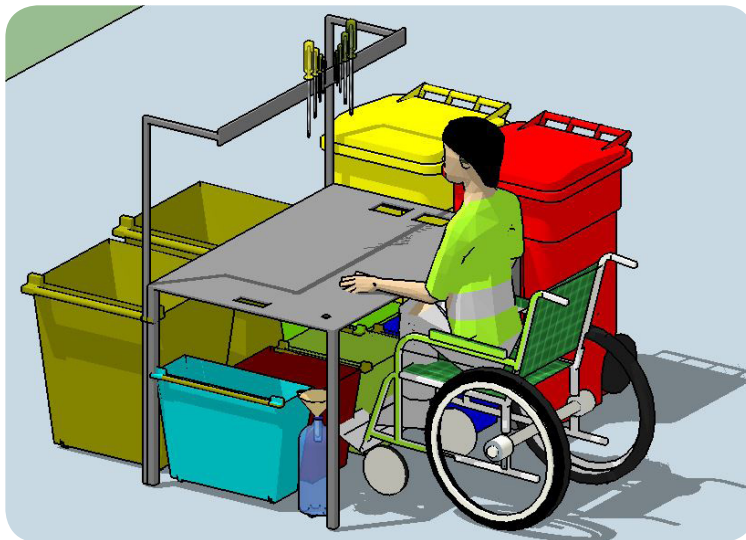


Figure 41 Dismantling table with worker in wheelchair

Work activities for workers in wheelchairs at the plant, should mainly be dismantling. They should be limited to articles fit for seated dismantling. Heavy or large objects such as flat screen monitors or other articles that present big strain or difficulty for a seated worker should be avoided.

20 Devolping the dismantling table

20.1 Concept development

The development of the dismantling table was started during the project thesis in 2015. Workers from RAEE Recicla were involved to find the needs they had as users, and what requirements the dismantling table should have. From the observations and data gathered, A list of requirements was made for the user and for the product. The requirements are listed in the tables following.

USER DEMANDS

<i>Demand</i>	<i>"Must"</i>	<i>"Should"</i>
<i>Functional requirements</i>		
Easy to maintain tidiness on the table	x	
Ergonomic working space		x
Have multiple storing boxes for different materials	x	
Easy and fast access to material containers		x
Work space large enough to treat all types of electronics	x	
Design suitable for worker seated in wheelchair and worker that is able to stand.	x	
Store tools for dismantling	x	
Design that is cheap and simple to manufacture		x
Able to implement visual assistance (colors, pictures or text) for operator with autism.	x	
Clear and logical setup of material containers (Easier adaptation for operator with autism)	x	

Tabell 2: User demands

PRODUCT DEMANDS

<i>Function</i>	<i>Unit</i>	<i>Value</i>
Store number of material containers	Units	10
Store number of different tools	Units	12
Minimum load capability	kg	100
Table height for operator with functioning legs	mm	1000
Table height for operator seated in wheelchair	mm	750
Minimum working area	mm	1000x800
Maximum manufacturing cost	USD	300

Tabell 3: Product demands

20.1.1 CONCEPTS SKETCHING

The following concept sketches were made after brainstorming with the workers at RAEE Recicla.

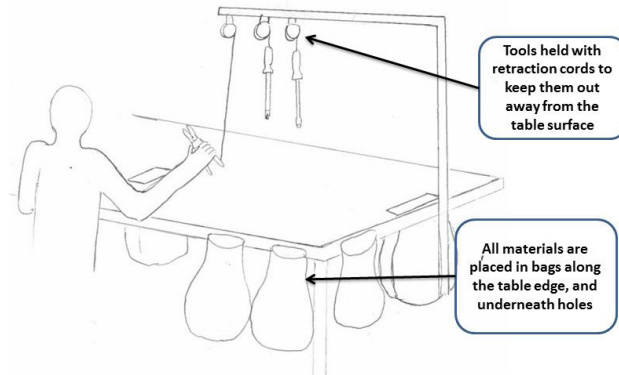


Figure 42 Concept scetch 1

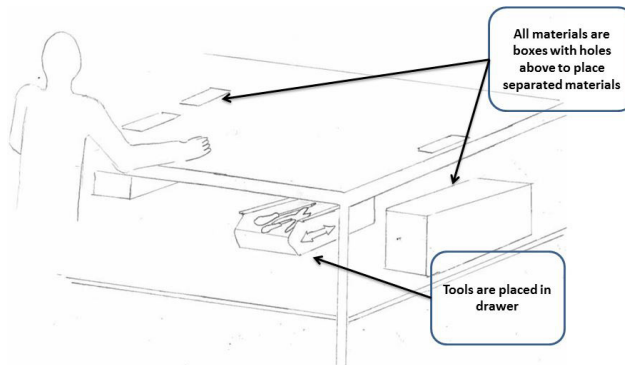


Figure 43 Concept scetch 2

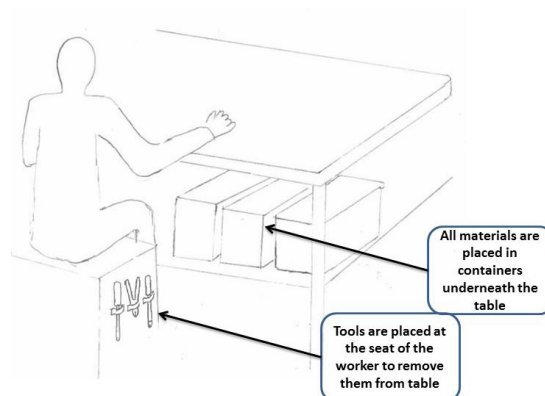


Figure 44 Concept scetch 3

20.1.2 CONCEPT PROPOSAL

After a revising process of the different concepts, the concept illustrated below was the most fitting for our mission and fulfilled the demands we had set in the best way.

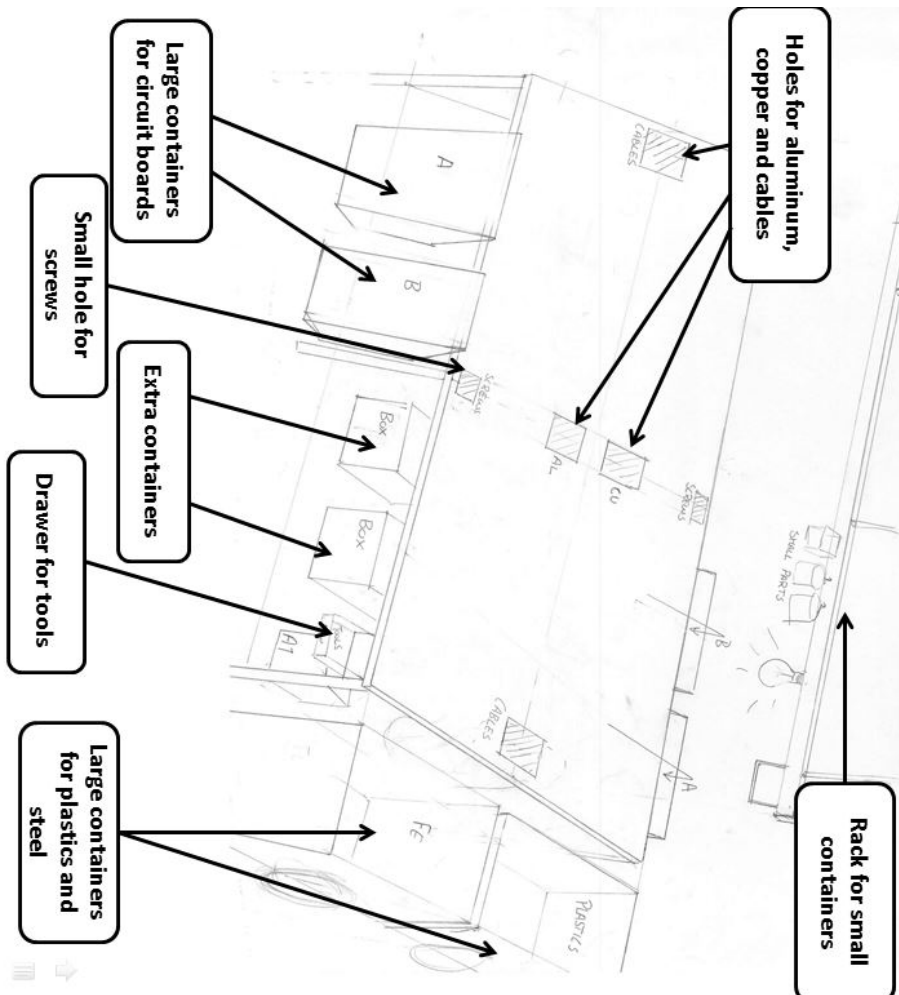


Figure 45 Sketch of chosen concept

20.1.3 PROTOTYPING

Testing of the prototypes was done with the workers at RAEE Recicla. A chipboard table was used as the first prototype. After the first prototype was thoroughly tested and further developed, a second prototype was built in steel. The second prototype was also tested by the volunteers in wheelchairs. The construction and testing of prototypes is showed in the pictures below.



Figure 46 Initial testing of prototype



Figure 47 Added rack to first prototype



Figure 48 Prototype of tool holder made with magnets and duct tape



Figure 49 Construction of second prototype



Figure 50 Tool rack with magnets on second prototype



Figure 51 Finished second prototype



Figure 52 Testing with volunteers in wheelchairs



Figure 53 2nd volunteer in wheelchair testing the table

20.1.4 RESULTS OF THE TESTING

During the testing, observations were done and new ideas of how to improve the prototype of the table were made. The concerns and ideas from the workers was prioritized to shape the final solutions.

Holes for containers seemed practical for effective removal of separated material. Size of the holes seemed to allow easy access without occupying too much of the surface area. During testing miss dropped objects into the holes did not seem to be an big issue. Especially the effectiveness and ease of removing screws was appreciated. During dismantling the table had considerably fewer things on the surface than during regular dismantling which made working easier. The holes were used for the materials: aluminum, copper containing parts and cables since these come in large quantities. Screws and bolts come in large quantities as well, and easily make a mess. A circular hole to scoop them into worked very well to gather these.

Storage boxes worked as intended placed underneath the holes. Steel and plastics are the most common materials in electronic articles. These come in large quantities, and should have large containers. The rate of which the containers were filled, were mostly appropriate to their size, except the one for cables, which was filled a lot quicker than the others. Type A and B circuit boards take up much space and needed large storage compartments. Big containers for circuit boards A and B filled fairly slowly.

Overhead rack served for the purpose of carrying container to dispose small lithium batteries and fuses. A magnet placed on it proved to be practical when tools needed to be removed from the table to give room to large electronics such as the flat screen TV. The preferred solution for this rack, was a solid frame from the table. This frame would also allow for future setup of cabled power tools.

Magnets on rack for tools was a solution the workers appreciated highly. This solution allow quick easy removal and collection of the tools. This kind of system is flexible and allow for each worker to set up their tools in the way they prefer. A drawer for the tools, was also tested but turned out to be less practical than the rack.

An automatic screwdriver can be cabled from above the table to give easy access without the cable being in the way of the work. On the end of the table a slot can be added to fit the power tool. The automatic screwdriver should be located on the right side of the worker at the same height as the table.

Working position

During testing with the people in the wheelchairs, it became clear that table with non-adjustable height would not serve the need. Wheelchairs come in many different heights, and also upper body height can vary quite a lot. This would also benefit other workers with height differences. Also horizontal adjustment for tool rack was observed to be beneficial.

What also came up was that the setup where the workers are facing each other, made it easy to socialize, and therefore was preferred by the workers rather than working side by side.

Seated work is desirable for dismantling of small equipment that do not require strength to handle. A chair that offer the possibility to alternate between sitting and standing without difficulty is important.

20.1.5 ADAPTION TO THE NEW PLANT

The tables used for testing were fitted to the needs of the workers at RAEE Recicla. By optimizing the layout for them made it easier to get good feedback during the testing, as well as the company could benefit directly from the improvements. After the construction and testing of the prototype there were some adjustments necessary to adapt the design to the new plant. The new concept was quickly prototyped and tested by the workers at RAEE Recicla and people in wheelchair with a positive result.

Table layout was changed from two workers sharing one table, to one table for each individual worker. This to make it easier to for height adjustments to be correct for each worker instead of making a compromise for the two of them.

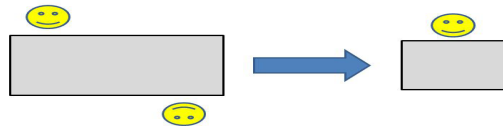


Figure 54 Change of table layout from two workers on each table to one

Tool rack design was changed from being fixed on the side of the table to the back. This allowed for more free space on the sides of the table and the possibility for horizontal and vertical adjustment of the rack.

Table height was initially intended to be divided in two sizes: tables suitable for people in wheelchair or workers able to stand. During testing this proved to lack important possibilities for optimization. Adjustable height was implemented in the design.

20.2 Final solution design

The table design is shown below, followed by the explanation of the different features. The table consist of a working surface, a solid plate level underneath an elevated rack.

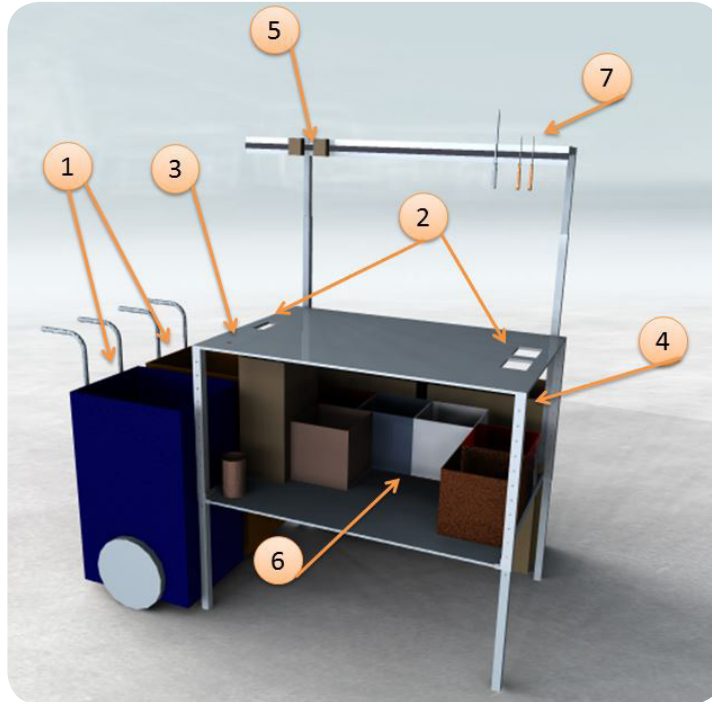


Figure 55 Dismantling table concept solution

1. Larger containers with wheels placed on the side of the table for steel and plastic storage.
2. Holes in the table placed in the level 3 access area allows for quick and easy disposal to boxes under the table.
3. A small hole in the level 2/3 access area allows to slide the screws directly to a small container underneath the table
4. Boxes placed on the far side of the table. The large circuit boards can be pushed of the far edge and right into the box.
5. Small containers on the rack for batteries and fuses
6. Boxes under the table are fairly easily accessible, and can be used for the necessary materials.
7. The tools can be hung on the rack with the use of magnets. This way they are easily accessible, not in the way of the work and gives a good overview.

20.2.1 EFFICIENCY

The main features of the table is its ergonomics and its ability to easily clean the most important parts of the table. To avoid accumulation of parts and materials on the table, the materials should immediately be separated and taken away from the working surface during the dismantling. To do this it is important to have easily accessible compartments to put the most common and the most important materials. The closest area to the worker should at all times be as clean as possible. This is indicated as level 1 in the figure below, and is where most of the work will take place. Level 2 is an easy access area. This should be clean, but can also be used for some short time storage. As much as possible of the work should be within level 1 and 2. Level 3 requires larger body movements, and the use of this area is more tiresome and put more strain on the body.

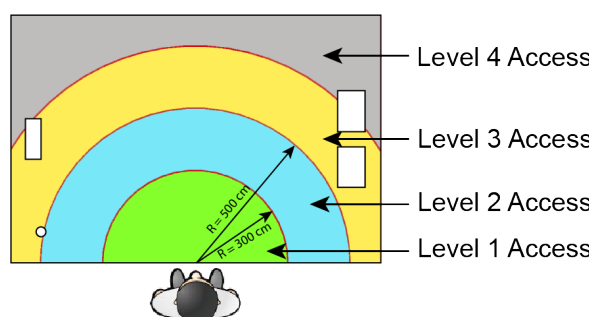


Figure 56 Ergonomics of working station

The holes are placed in the level 3 access to not be in the way of the work, but be within close enough reach for quick and easy disposal. The holes come with the possibility of wrong types of materials accidentally falling into the hole. Smaller sized holes is therefore preferred. During the test period of the tables at RAEE Recicla, materials falling into the wrong hole did not seem to be a problem.

The boxes are placed on the plate underneath the working surface. The height difference between the two levels make it possible to use boxes of a good size and still have a good overview and easy accessibility.

20.2.2 FLEXIBILITY

Adjustable height: To optimize the ergonomics for each user the table is

designed to be adjustable in three levels. The adjustments are especially important for users in wheelchair. They are more bound to keep the same working position all the time, and optimization of working position will have a larger impact on them. Wheelchairs come in different sizes, and it is not possible to find a good height for all. The table height is therefore adjustable with 5 cm intervals from table height of 60 cm to 100 cm. This is done by separate legs that are slid into the legs fixed to the table, and adjusted by fitting holes in the parts together.

Removable bottom plate: To enter a good working position with a wheelchair, the bottom plate is a hinder. The plate is therefore removable. It can be slid out on rails at the bottom legs connected to the table. This also makes it possible to slide the material boxes out along the floor, and not having to lift them down from the bottom plate. This makes material removal easier for the people seated in wheelchair.

Adjustable rack: The reach of different people vary. This is especially true for people with reduced movement in their upper body. The material holes are within reach for most people, but the rack can be hard to reach. Adjustment in altitude and horizontal distance is added to the rack. With increments of 5 cm the height of the rack can be placed between 40-75 cm and the horizontal distance to the worker 30-50 cm.

20.2.3 TABLE PARTS LIST

The table consist of six parts and connection parts:

- Table top with legs
- Leg extensions
- Bottom plate
- 3 x rack parts
- Connections between bottom plate and table and between rack and table
- 20 x M8 bolts, nuts and pairs of washers

The table design and the exploded view of the table is shown in the figures below.



Figure 57 Describing assembly of the dismantling table

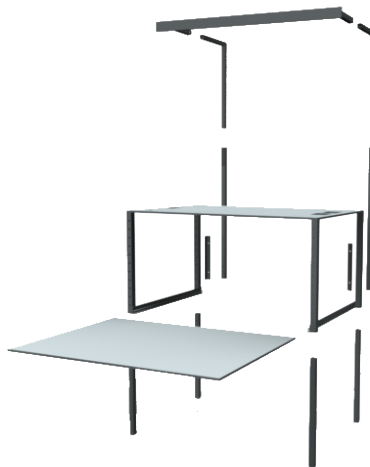


Figure 58 Describing parts of dismantling table

The technical drawings of each part can be found in appendix VIII.

Materials are chosen by the manufacturer as they see fit. However we recommend the legs and rack are of steel for strength concerns.

20.2.4 ERGONOMICS

The height of the table should be adjusted to an upright and comfortable working position when standing. It should be low enough to use the force from the weight of the body, but high enough so the operator doesn't have to bend to work. The standing position is the preferred working position for large and heavy parts. This gives more force and let the worker use the weight of the body. To deposit materials in the holes or reach for tools, the operator does not have to move more than their arms can reach. A working height of about 1 meter is suitable for most people.

When working with small and light articles, it can be preferred to work in a sitting position to relax the legs and the back. The seated person should have the table a little bit underneath natural elbow height for optimal working position. While seated, the legs can be rested on the bottom plate. The position of the worker will change often, but the height of the table should not be adjusted very often. The height of the table should therefore be adjusted to the standing position height, while the chair should be of a height that makes a comfortable seated position with the standing position height of the table.

For people working in wheelchairs it is hard to get close enough to the table with the bottom plate mounted. This should therefore be removed in the stations fitted to them. The height of the table may vary depending on the person and the size of the wheelchair, but working height of around 735 mm is recommended other places in the world.

21 Administration

The main objective of the dismantling plant is the dismantling of WEEE and proper storage and commercialization. The rest of the people working on the plant are there to make this operation as efficient and good as possible. A suggestion to how the company can be organized will be given in this section. The structure is made with consultation from Jonathan Butrón, who has experience with company structure in Bolivia. The suggestion include 24 positions, and is shown in the organizational chart below.

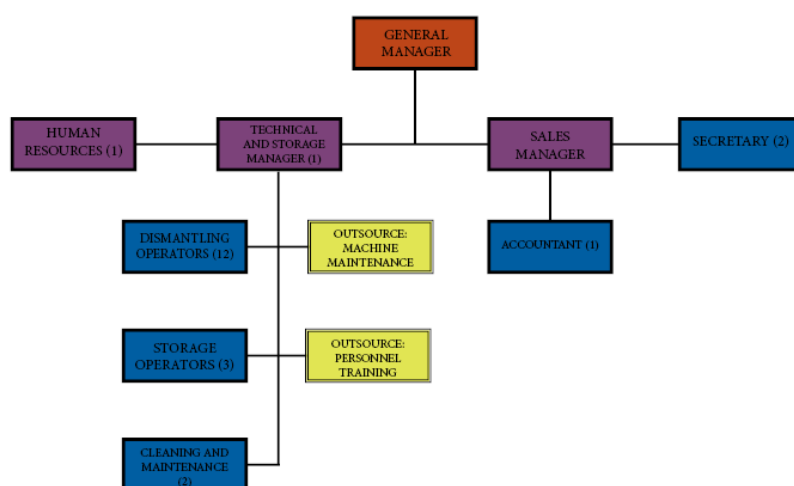


Figure 59 Organizational chart

The diagram shows how the different positions are connected with lines. This set-up should cover all the tasks needed in the company. Due to the size of the plant, positions like technical manager and storage manager are suggested to be covered by one person. The economical part can be covered by the marketing manager and the accountant and the general manager.

More people should be added with expansion of the plant.

The organizational structure depend of the chosen level of documentation. With a high level of documentation, more people should be hired for this work. More about level of documentation in the next section.

21.1 Position descriptions

Each administrative position will not be explained in detail this thesis. Some of the most important positions will however be briefly explained in the following.

The dismantling operators will be the core working force of the company. The technical manager, human resources and storage operators should make sure they are able to work as consistently and efficient with the dismantling work as possible.

As earlier described, one working group consist of four workers. Two of the tables within the group should be served by people with full functionality, whereas the two others can be handled by people with disabilities. People in wheelchair are suitable for this work, and people with autism are likely to be able to learn. One of the three working groups should be served solely by people with full body functionality. The recommendation is that four of the 12 dismantling operators can have disabilities. This number is likely to be possible to change with more experience at the plant.

The storage operators will do the practical work to make sure the dismantling operators have organized equipment to dismantle, and organized places to put the materials from the dismantling. They are also responsible to make the physical structure of the plant works as smoothly as possible. They will be responsible to receive products, operate and maintain the storage areas, transportation and to send the separated materials away. With the business model explained in this project there will not be enough deliveries to employ people to each of these individual station. If they have spare time they are also relevant candidates to help the dismantling operators to handle the machines for special waste. They should therefore be included in the training of this.

Three people should be enough to fulfill the storage operator position. This

should include two people with full functionality and one person with special needs. The work will include a lot of sorting of articles and boxes, and has the potential to be fitting for a person with autism.

Outsourcing includes hiring people from outside of the company to do work that does not fill a full work position. Maintenance of machinery and other equipment should be done regularly in accordance with recommendations from the supplier. People should also be hired to train the employees and to check the safety and status of the plant.

The Human Resources (HR) position has the responsibility for the personal aspect of the workers in the company. In this company it has an especially important role because it will be one of the pioneer industries in La Paz using employees with special needs. The HR should be closely involved in the training of the workers, and find suitable people to do proper training of the employees. Close follow-up for the workers with special needs should be ensured by the HR. The experience from working with people with special needs can be valuable resource for other companies that want to do the same. Having a person responsible for this can improve the chances of spreading the employment of disabled people in the industry.

In a plant with manual work like this, the human resources position will also be responsible for a safe working environment, and to ensure training and updating of all the workers. The person hired in the Human Resources position can with benefits have special qualifications in adaption of people with disabilities.

21.2 Resource Flow

In the figure below a proposition of the flow of materials and information within the operating part of the company is illustrated.

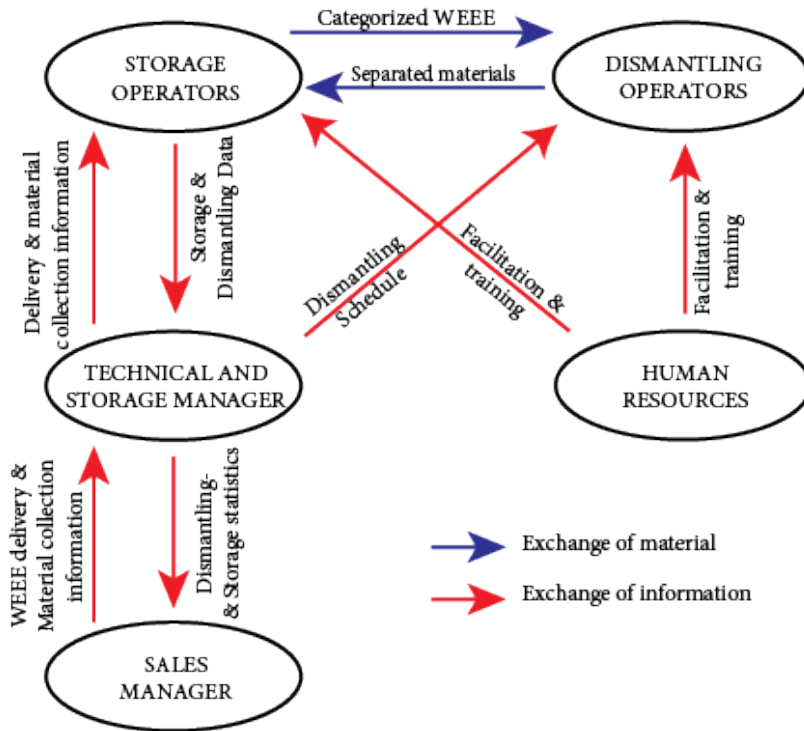


Figure 60 Flowchart within the plant

21.3 Training and facilitating

To make the work as efficient and safe as possible, sufficient resources should be spent on proper training of the workers. Regular training and updates on new methods and processes within the work field should also be done. Proper work on these areas will benefit the company largely.

22 Economics

22.1 Introduction

A brief study of the economics of the recycling plant has been accomplished to get an overview of a probable economic prediction. It does however depend on several factors. The first section look at the economics of the startup phase. It contains a close to complete list of the needed equipment investments with an estimated price quotation. The day-to-day economics of running the plant is then investigated, and takes as much of the realistic costs and income as possible into account.

The data in this section is done by engineer students with little experience in economics, and should be read thereafter. The purpose is to give a rough estimate and is not an exact study. Costs are based mostly on number obtained from RAEE Recicla. More work should be done on this part.

22.2 Initial Investments

The table below shows the close to complete list of equipment needed in the plant. Price quotations are not exact, but are based on comparable products found on the Internet. The prices may differ significantly from the estimates.

Tabell 4: Initial investments

Item	Quantity	Unit Price (USD)	Total Price (USD)	Comments
<i>Storage Racks</i>	14	500	7000	<i>For all storage areas</i>
<i>Working tables inc. tools and boxes</i>	12	400	4800	<i>Table constructed in Bolivia</i>
<i>Air Compressor inc. installation</i>	1	3000	3000	<i>NA if electrical drill.</i>
<i>Roller conveyors</i>	3	500	1500	
<i>Forklift (used)</i>	1	3000	3000	<i>Buy used in Bolivia</i>
<i>Pallet truck</i>	2	150	300	<i>Minimum capacity 1,5 tones</i>
<i>Scale</i>	1	200	200	
<i>Compactor</i>	1	5000	5000	<i>Bolivian producers exist</i>
<i>Cable separator</i>	1	10000	10000	
<i>Fluorescent tube recycler</i>	1	9000	9000	<i>Consider buying from Cochabamba company</i>
<i>CRT Recycler</i>	1	10000	10000	
<i>Truck*</i>	1	30000	30000	<i>See * below</i>
<i>Pallets</i>	200	5	1000	
<i>Other</i>	1	2000	2000	<i>Office materials, extra boxes, trashcans etc.</i>
Total			86800	

*One company owned truck for local transportation is included in the budget. This option gives more freedom, but the investment can be postponed to a later moment. This option depends a lot on the transportation model of how the WEEE is collected and shipped, and the decision should be taken in accordance with that.

The budget include all the equipment needed in the plant, but does not take building costs or infrastructure into account. This may contribute to a large part of the plant cost. The infrastructure will be discussed in the next section.

22.3 Infrastructure

The cost of infrastructure is not looked at in this project. There are different options on where to place the plant. The most permanent and flexible option is to find a large enough area and construct the plant from the bottom. This is also the most expensive option. It does however give the freedom to design the plant optimally for its purpose. If this option is chosen, the plant should be built large enough to be expanded at a later point.

Another option is to buy or rent an existing facility. It may be hard to find a building that is optimal for the production, but the design can then be refitted to the available space. This option makes the threshold to start smaller, and it is easier to change to another location if necessary.

In the cost analysis a monthly rent is added to take the infrastructure into account. It is therefore added as a regular cost instead of an initial investment. This solution is chosen because it is the easiest to get as close to realistic as possible and fits the infrastructure cost nicely into the analysis.

22.4 Operating cost

The running costs of the plant is summarized in the table below. The numbers are based on numbers from comparable Bolivian companies and systems, and fitted to the recycling plant. They are to be taken as an approximation, and should not be fully relied upon.

Tabell 5: Operational costs

Operational cost		
Expenses	\$US/month	\$US/year
<i>Salaries (inc. taxes and extra costs)</i>	12274	147289
<i>Outsourcing</i>	144	1724
<i>Plant costs</i>	3200	38400
<i>Rent</i>	1500	18000
Total	17118	205413

The largest cost is to pay the workers in the plant and the taxes related to them. The cost breakdown of this can be found in appendix IX. Changes in the working staff can therefore have large implications on the economics of the company.

The plant costs include the predictable costs of running the plant. Among other things, this includes safety equipment, monthly services, local transportation costs.

22.5 Income

To calculate the income of the company, updated values of the most common articles dismantled at RAEE Recicla are used (30% CPU, 10% cell-phones, 40% monitors and 20% printers). The values have been found from looking at the price of the most relevant materials found in the equipment. The numbers have been adjusted to the capacity of the plant. The prices of cables and CRT monitors have been changed in accordance with the new implementations done in the plant.

Tabell 6: Operational income

Operational Income		
Income	\$US/month	\$US/year
<i>Dismantling</i>	41 113	493 352

The table used for the calculations can be found in appendix X.

The income does include a compensation price for treating CRT-monitors. This is an existing compensation paid to the RAEE Recicla per CRT monitor dismantled at the plant today. This price is set to the same level as it is today.

The income calculated is from the dismantling process only. No other income than for the CRT monitors is collected at the plant for delivery of WEEE from external sources.

The used method of calculating the income is simplified, and should not be expected to be correct. The prices used for the materials are close to the true value received at RAEE Recicla today. The amounts of each material in the articles are based on experiences from RAEE Recicla, and will be off by a small amount. The amounts of each type of articles coming into the plant are not exact, but a simplified version of the truth at RAEE Recicla. The model ignore the less common articles, which together make up an essential part of the work. This would however be hard to model and might end up making the model less predictable.

22.6 Economic result

The table below shows the calculated result of the operation:

Tabell 7: Operational Result

Operational Result		
	<i>\$US/month</i>	<i>\$US/year</i>
<i>Income</i>	41 113	493 352
<i>Cost</i>	17 118	205 413
<i>Result</i>	23 995	287 939

A positive result of close to 290.000 US dollars is obtained through the calculations. This means that the company should be profitable only from the operation itself. In most countries an additional income is received due to regulations and such. This will come on top of the result.

The initial investment for the equipment in the plant is 86.800 \$US (see list above). With the operational cost found above, this investment will be

gained in about two months. This shows that the initial investments can quickly be regained, and investing more money in high efficiency equipment may easily be justified.

The result make it possible to do larger investments for further upgrades and higher capacity. One implication can be prices to invest in building infrastructure.



REFRIGERATOR TREATMENT



23 Introduction

Refrigerators and freezers are some of the articles that require special treatment after end-of-life. In this part of the report possibilities to recycle refrigerators in La Paz will be studied. The study will be a research study to look at ways to implement such a system, and will not contain complete solutions or complete recommendations.

Refrigerators and freezers are large electrical articles, mostly containing ferrous metals and plastics. They are both treated in the same way, and will hereby be described as refrigerators. The treatment is mainly to avoid the release of hazardous gases, but also to recover the materials. There has been a shift in use of hazardous gases, and in newer equipment gases with less environmental impact are used. Still a lot of the refrigerators reaching end of life these days contain CFC (chlorofluorocarbon) gas. The dismantling process is complicated because of how the refrigerators are built, and therefore high end treatment plants are required for a good dismantling.

A refrigerator works with the use of a compressor driving a cooling gas or liquid in a circuit to cool the inside of the refrigerator. The cooled room is covered by well insulated walls, mostly made of ferrous metals, plastics and insulating foam. For better insulating properties, the foam contain gases that should not be released to the environment. The foam is glued to the walls, making it hard to separate from each other. Other parts used in fridges are cables, non-ferrous metals and other electrical parts, whereas in some cases can contain hazardous materials. (23)

The most important reason to treat the refrigerators and freezers properly is to make sure the CFC gases aren't let into the atmosphere. In earlier refrigerators these gases was the most used for refrigerant (CFC-12/R-12) and containment in the foam (CFC-11/R-11). These gases react with the ozone in the atmosphere, and has globally been one of the most important reasons for breakdown of the ozone layer. When the impact was discov-

ered, a worldwide shift in the use of gases was done. First it was changed to hydrochlorofluorocarbons (HCFCs) and hydrofluorocarbons (HFCs) with a lower environmental impact, but still a considerable impact. These days hydrocarbons (isobutane and cyclopentane) with a much lower environmental impact is used.

Still a lot of the refrigerators used today contain CFC-gases. The steady-state lifetime (the time before the same amount of gas is removed from the atmosphere as is being added) of CFC-11 and CFC-12 can respectively be up to 64 and 132 years (31). By landfilling end-of-life refrigerators, the gas will slowly leak out and impact the ozone layer and contribute to global warming. Within 300 years, all the gas can eventually be expected to leak out if the articles are stored without treatment (24). Removal and proper treatment of the gases should therefore be done.

24 Refrigerator Treatment

24.1 Important factors when treating refrigerators

The handling of refrigerators has a couple of critical factors that needs to be handled. We have listed them up as gas leakage, leachates and storage/transportation:

Gas leakage is the most important contamination hazard to avoid when dismantling the refrigerators. In a dismantling facility there are two dismantling processes that risk releasing gases. Emptying the coolant circuit for cooling gas is a very critical process. A well tested and approved gas extraction tool should be used for this.

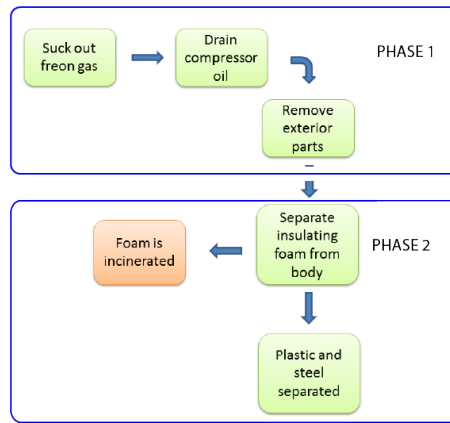
The other gas leakage is potentially from dismantling the insulating foam in the fridge. The foam contain CFC-11, cyclopentane or other gases to improve insulating capabilities. The foam is attached to the walls of the refrigerator, making it hard to separate without releasing gases. Well tested and approved methods that keep the gases contained and under control is important for this part of the treatment.

Leachates is another possible contaminant from dismantling refrigerators and freezers. Each unit contain oil which have to be drained without spilling. Also CFC-12 has a boiling point at 29.8 C and CFC-11 boils at 23.7 C (39). Therefore leachates of liquid CFC-11 and 12 is also a possible contaminant. A treatment facility for refrigerators and freezers should have a sealed drainage system to avoid leachate into the groundwater.

Storage and transportation is important to take into account to avoid contamination. Transportation needs to be done as carefully as possible to avoid puncturing or damage to the fridges and freezers. Storage should be under roof to avoid rain transporting leachates, and to avoid corrosion which can lead to leaking units.

24.2 Process

The basic terms of dismantling refrigerators and freezers are mostly the same. The cooling units needs to be drained for coolant gases and oil. Insulating foam needs to be removed and separated from the rest of the refrigerator body. There are different methods of doing this but in basic terms the dismantling is divided into two phases.



Figur 8.61: Refrigerator treatment process

Phase 1

Refrigerator cooling circuit is punctured and the gas is sucked with a special tool and stored in tanks. This procedure is the same for all types of refrigerators containing the coolant gases CFC-12 (R-12), HCFC and isobutan. This process has to be with zero leakage.

Compressor containing oil has to be drained. Oil is stored in containers. After gas and oil is removed, loose and exterior parts such as compressor, shelves and capacitors are removed.

Phase 2

The body of the refrigerator contain insulating foam that has to be extracted. This is either done mechanically by shredding, or manually. This process releases gases from the foam, and it is therefore important to make sure that none of this is released to the atmosphere. This is not easily contained with manual dismantling.

The separated foam can be incinerated and reduced so no harmful by-product is produced. However there is also other methods for treating the foam. The remaining material of the body (mostly plastic and steel) is separated.

24.3 Treatment plants

State-of-the-art facilities today are fully encapsulated treatment plants built in accordance with the RAL quality assurance specifications (RAL GZ-728 Quality Assurance and Test Specifications). In these plants, more than 90% of the CFCs are separated and safely handled. The best results are gained in joint treatment plants, treating all types of refrigerators and freezers in the same machines (26). In a study done by Öko-Institut e.V. in Germany in 2007 showed that most of the CFC in a fridge was found in the insulating foam. About 75% of the total weight of CFC gases were CFC-11 found in the foam, while the remaining 25% were CFC-12 found in the refrigerant. At that point about 80% of the articles were containing CFCs. Each with about 0.45 kg CFC. It can be assumed that the amount of gases used in the foam is more or less the same as in this test around the world. (28).

24.4 Example of treatment facility

Ecofrigo has invested in a facility in Mexico that recycles refrigerators and freezers on a national level. The facility has near to no release of any of the refrigerant gases. The facility is divided into two phases of recycling as described earlier. Phase 1 is assisted with machine that tilt the refrigerators to an angle which helps for complete draining of gas and oil. Equipment that punctures the cooling circuit without any loss of the containing gas is used. Exterior parts are removed before next phase.

Phase 2 is done by closed shredding. This process shreds the fridges and freezers to small parts. Any gas released during shredding is contained inside the closed shredder, and sucked into an active carbon filter. The active carbon filter captures the gasses of CFC-11 for safe storage and further treatment. Separation of plastics and steel is done by magnets and eddy current. The remaining foam is incinerated.

24.5 Manual Treatment

In another report by Öko-Institut e.V (28) manual separation of the foam from the refrigerators were tested. Special tools were used for the removal of the foam, and the CFC emissions were measured. It was found that an average of about 23%, or 99 g of the total CFC-11 in a fridge were released in this process. This is about 100 times more than with a state of the art facility.

24.6 Environmental Impact

The most important environmental impact of CFC is its potential to deplete the ozone layer long term. In the Montreal Protocol in 1987, it was agreed upon that the use of CFC gases and some other gases should be phased out worldwide. As the use of the gases has decreased, the situation of the ozone degradation has shown to be improved. CFC gases also has a high global warming potential (GWP). CFC-11 has a GWP of 4680, meaning that 1 kg of CFC-11 has the same impact on global warming as 4680 kg of CO₂. By this means of measure, the 99 g CFC-11 released on average from a fridge in the manual dismantling test, equals a GWP of 460 kg CO₂. For comparison with an average sized car, releasing about 180 g CO₂ per kilometer, the manual dismantling of one refrigerator will have the same GWP as driving the car for about 2550 km. In a state-of-the-art facility, about 0.45 g of CFC gas would be released, letting the car drive about 12 km. If all the CFC-11 from the refrigerator were to be released (average of 432 g per fridge), it equals a GWP of driving the car for 11200 km.

The big difference in emissions from a manual plant and a state of the art facility shows that the benefits from investing in a proper plant are big. The by far most environmentally beneficial solution is therefore to invest in a well-tested state-of-the-art facility.

24.7 Ozone layer

The ozone layer is a layer of ozone in the stratosphere that stops much of the UV light from entering the earth. Ozone is very reactive, and is easily broken down to oxygen in contact with ozone depleting gases. More UV light will then enter the surface of the earth, which can be harmful for the environment and for humans. Too much UV light can cause cancer, skin diseases and eye diseases.

In Bolivia, especially in the altiplano, some of the strongest UV light in the world are found. A hole in the ozone layer has been apparent in the northern region of Bolivia. The protection of the ozone layer does therefore have a direct effect on the people living in Bolivia. In a health perspective, Bolivia should therefore be one of the most important countries in the world to prevent further ozone depletion.

25 Refrigerators in Bolivia

25.1 Expected articles in Bolivia

Bolivia has in last 10 years experienced an increase in general wealth among the population. This has increased amount of electric articles among the population. Refrigerators is no exception of this. According to Swisscontacts survey, 90% of households and business in Bolivia is in possession of a refrigerator. From 2000 to 2008, importing of refrigerators has increased from less than 40 000 units per year, to more than 60 000 units per year (7). The amount of refrigerators and freezers has increased over the last years, and according to Bolivia's development since 2008 there is no obvious reason to believe the amount of imported fridges and freezers has stagnated. We were unable to find any data on specific amount of discarded refrigerators. However we were able to obtain indications of what type of refrigerators that exists in households today.

According to the book PU Latin America (2001), 80% of the refrigerators entering the market in western part of South America in 2001, was CFC-12 based refrigerators. 20 % was HCFC based refrigerators. (38)

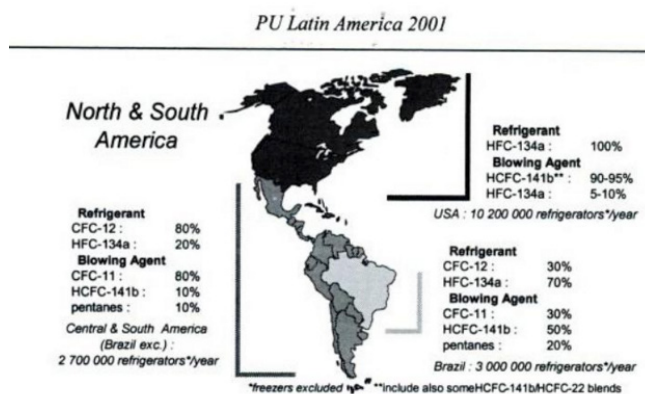


Figure 2
Status of CFC substitutes in the appliance industry for North and South America

Figur 8.62: CFC consumption in the world 2001

An analysis done by Swisscontact for tendencies on the disposal of refrigerators, shows that a very low percentage are thrown or recycled (7). We assume the life expectancy of a refrigerator is 15 years (27). Hence most of the refrigerators entering the market in 2001 was CFC-12 based, and refrigerators and freezers have a high percentage of repair and redistribution to further extend its functioning time. Our conclusion is therefore that it is reasonable to assume that a significant share of refrigerators existing in households in Bolivia today (2016), are CFC-12 based.

25.2 CFC phase out

In the Montreal Protocol Bolivia agreed upon a plan to phase out CFC consumption by 2010. To reach the goal they have received funding and training. A number of gas suction equipment has been distributed throughout the country, and CFC gases from old refrigerators and from vehicles are collected. An own governmental department, COGO (Comisión Gubernamental de la Capa de Ozono), has been established to reach the goals. The plans has been followed and the goals have been met, and there are no more formal CFC consumption in Bolivia. The country is now working to phase out other ozone depleting gases. (25) (22). All refrigerators formally entering the country are checked and certified before reaching the market. The majority of the imported refrigerators are however most likely imported through the informal sector. Of this part there are no control, and therefore hard to fully understand the whole situation.

25.3 Scale of a recycling plant

From the survey done by Swisscontact, it was shown that some more than 60.000 refrigerators were imported to Bolivia in 2008. It is reasonable to assume that the numbers added to the Bolivian household and industry has kept increasing since then. With the life expectancy of a refrigerator, there will be a delay of about 15 years or more between the product is first used until it reach end-of-life and need to be recycled. The use of CFC gases in refrigerators was decreasing from year 2002 until it was phased out in 2010. The need for recycling of the fridges will still be important for the fridges made after the phase out, but in a lesser degree than the ones with CFC. With a large amount of the fridges stored today, it can be assumed that many older products soon will need treatment as well.

With a population of less than 10% of Bolivia, it can be assumed that not much more than 10% of the refrigerators in the country can be found in the city.

In 2008 a project was started in Brazil to recycle refrigerators. They built a recycling plant with the capacity of recycling 350.000-400.000 refrigerators each year. The project was funded by German institutions, and the total project had a budget of 5.000.000 euros. (21)

A treatment plant like the one installed in Brazil are able to recycle more than the needs of all of Bolivia. There also exist smaller and customized plants. Anyways it will be a relatively big investment to build a state-of-the-art facility. To build one that only cover the needs of La Paz can therefore not be recommended.

26 Conclusion

A large part of the refrigerators in Bolivia are expected to contain environmentally harmful gases. The use of CFC gases in refrigerators has stopped, but waste refrigerators will be likely to contain these gases for many years in the future.

The gases make a huge contribution as greenhouse gases, but the most important impact is on the ozone layer. The Altiplano region in Bolivia is especially affected by this, with one of the weakest ozone layers in the world. Reduction of ozone depleting gases should therefore have extra high priority in Bolivia.

As manual dismantling of refrigerators is shown to release a significant share of the insulating gases in the equipment, it will contribute significantly to the ozone depletion and greenhouse gases. Preferred is therefore to invest in a larger scale treatment plant. La Paz does not produce a large enough amount of waste refrigerators to justify an investment like this, and a plant should therefore include all of the country. Treating refrigerators from areas outside of the country can also be considered. The size of the plant should depend on this. The placement of the plant and the transport infrastructure are important factors that are not considered further in this report.



REFLECTIONS



27 Introduction

This section contain reflections on the state of the project and where it should go from here. The master thesis has been very different from most other master projects, and a very important part of it has been the non-technical aspects. The culture and the experiences from Bolivia has influenced many of the decisions made along the way. The experience from being in Bolivia has formed the process of the thesis greatly. It has been one of the most educational experiences in our lives. The last part of this section will reflect on what it has been like working in Bolivia, what has been difficult, what has been learned and what can be taken away and used in similar projects.

To take the time to sit down to reflect on situations and problems has been one of the keys to success in this project. With a lot of new impressions and chaotic experiences the importance of cleaning up your mind, identifying problems and figure out how to improve the situation has been valuable.

28 State of the Project

28.1 Current state of project

The municipality had been talking with Jonathan Butrón about starting the recycling plant for about four years now. Butrón is very enthusiastic about the future of WEEE in Bolivia, and has plans to drive the country in the right direction. He is very interested in a cooperation with the municipality. Jonathan is however starting to lose his patience waiting for the municipality to get started. He has therefore started to look at how to expand his own plant, RAEE Recicla. When we left he had just landed a deal with a cell phone company willing to finance expansions of his business. He is also the driving force of starting the first circuit board recycling company in Latin-America in cooperation with the national government. If the partnership with the municipality can work, he is still interested.

Hopefully our work with the thesis can be the triggering factor to take the project to the next step. They will now have a study telling them how a recycling plant can be established, and specific suggestions on how it can be operated. Before we left Bolivia, the main participants met and concrete plans were made about where to go on from here.

28.2 Future of project

After the delivery of this report, our participation of the project will mostly be over. The municipality and Jonathan have expressed that they want to stay in contact, but contact on the same personal level is difficult to maintain because of the distance. The report will most likely be used as guidelines, and not be read thoroughly by the workers at the plant. It can however be used to show a project solution to convince municipal waste administration to apply for financing. One of the most important parts of the thesis was to make sure the people that will keep working on it would receive extensive knowledge about everything we learned and concluded before we left the country.

The most important person for this is probably Jonathan Butrón, as he will be one of the main drivers to get the plant going. He will most likely be highly involved with operation at the plant. He does also have the technical insight in the systems to understand the reason for the solutions. We worked together as often as possible when finishing results, and discussed the conclusions thoroughly with him. The technicians in the municipality will be the ones to convince for municipal support. They got frequent updates on what we worked on and the conclusions, as well as getting a few more detailed presentations.

The management in the municipal administration are higher in the hierarchy than the technicians. They don't have to know all the details of how the plant should work, but need to know about administration and economics, and to know that the project is properly thought through and is likely to succeed. The final presentation of the project was shaped after their needs, and was presented to convince the decision makers that it would be a good decision to use a part of the budget on a new recycling plant for electronic waste.

At the final presentation all the three main participants, Butrón, the municipality and Swisscontact, were presented, and discussions were initiated to plan the next steps. This was a great opportunity to make all the involved parties to talk and express what was needed. Swisscontact took lead of the discussions and distributed responsibilities with deadlines to the people from the municipality and showed their abilities as a great facilitator. They know their position as facilitator, and will hopefully be a strong driving force in making the partners cooperate and make the right steps towards a viable solution.

28.3 Politics

One of the most important things we have learned from the work is how much politics influence a project like this. The political situation in Bolivia does in fact present some issues. La Paz municipality is at this point opposition party, while the government is controlled by the Mas party. The people with leader positions in the municipality are highly politically influenced. For this reason projects has to apply to their political party's policy, and any cooperation or communication across political parties is avoided. This makes it hard to implement new systems in the society. Especially hard

to start projects involving the outside of the municipal borders.

Within the municipality it seems to be a clear hierarchy. The technicians are working on the technical aspects of projects, but they are not supposed to take much initiative themselves. Even for smaller tasks, they often have to ask permission from a senior person up in the system. The authorities higher in the system have to respond to a variety of projects, and are not able to have control of everything. The communication with the technicians did for that reason not give as much influence on the project as we hoped for.

The national governments and the local governments are elected every five years. All the people working in the municipality are employed to the political party, and a change of power mean that all of the current staff will be replaced. This is a major reason for why cooperation with Jonathan has advanced so slowly. The project should therefore be started as fast as possible, and be up and running before the next election in 2020. If not, it is possible that the project will disappear with the change of power.

Another impediment is that there is a large conflict going on between the municipality and the national government. They are both seated in La Paz, but are of opposition parties. The two are not cooperating on projects and are not communicating well. This makes it hard to implement new systems in the society. Especially hard to start projects involving the outside of the municipal borders.

“When the time for the final presentation of the project was getting closer, a list of who we wanted to participate was made. The environmental department and ozone depletion department was invited as well. Our intention was to inform the national government (Mas pary) as well. The municipality (opposition party) took the responsibility to invite everyone listed.

Two days before the presentation, the municipality confirmed who they had invited. The national government was removed from the invitation list. The municipality decided that attending the same presentation as the opposition party was not acceptable. We therefore ended up having two separate presentations, one for the municipality and later for the persons representing the gouvernement.

29 Working in Bolivia

During the work in Bolivia we attended a lot of meetings with different people. In South America, aspect on time is a bit different from what we were used to in Norway. To be delayed for a appointment was more normal than not. Meetings were very often delayed and sometimes canceled on short notice or no notice at all. Deadlines were often not followed, which made it hard to rely on having problems solved in time. To cope with this, meetings were often scheduled half an hour before expecting it to start, and we learned to closely follow up on everything we needed to have ready in time.

Close contact with the ones we were working with also showed to be very important to keep them up to date and interested in the project. If we lost contact for a while we experienced that people lost connection to the project and to us. To solve this, we made different arrangements for weekly meetings with the municipality and more frequent consultations with Jonathan and relevant people in Swisscontact.

29.1 Defining project boundaries

Until our first field trip to Bolivia, the topic for the thesis was not very specific. Within the first two days we met the three main partners of the project. They all had different expectations. As a newcomer in the country, it was very easy to just say yes to everyone. At one point we thought we would end up making very general solution for three different waste systems. After some time we understood the importance of setting very definite borders and limitations of the project. To be very clear on this with the partners was important. By then we had a sufficient understanding of the different partners interests, and could sit down and make a specific list of what would be included in the thesis. It ended up being some fairly long discussions with some of the partners. When we were done, everyone knew what they could expect. In their view this showed that we were serious about the project and

knew what we were going to deliver. Instead of making them less satisfied, it ended up giving us more respect. Spending enough time on this part in the beginning of the project has been very helpful for the rest of the project.

29.2 The Bolivia Experience

An important factor to fully experience Bolivia is to speak Spanish. Close to no one speaks English. During our first field trip we did not speak Spanish as fluently as we should have. This made it challenging to understand what people wanted to tell us, and to express what we wanted to say. To not understand people was much more tiring than expected, and it was good to be more than one person speaking the same language. If we knew less Spanish than we did at this point, the stay would have been far from as successful as it was. By time our Spanish got more fluent, and communication and everyday life got much easier. Not having to think a lot about how to speak makes it easier to focus on the task and get where you want.

What you learn from living in another country depend heavily on how you choose to live. To properly understand the culture we wanted to experience the life of people from all parts of the society. To a certain degree this goal was met by working with Bolivians in different fields, living with Bolivians, dancing local dances and finding local friends. With their hospitality they took us in and learned us about their ways and thoughts. The social life outside work ended up teaching us a lot more about the day to day life for a Bolivian. This has influenced the thesis, but more than anything it has given another perspective on life which will be very valuable for the rest of our lives.



A group of four people are posed in a warehouse or storage area. In the foreground, a woman sits in a blue wheelchair, wearing a patterned black and white top and light grey pants. Behind her stand three men. The man on the left wears a dark jacket with orange and blue stripes over a blue and white striped shirt. The man in the center wears a dark blue jumpsuit with 'PCE' and a power button logo, and a baseball cap. The man on the right wears a grey and brown striped sweater. The background is filled with stacks of cardboard boxes and wooden pallets. A large, white, serif text 'CONCLUSION' is superimposed over the center of the image, enclosed in a thin black rectangular border. The scene is lit by natural light from a high window.

CONCLUSION

During the studies we have reached the goals set for the research. A solution proposal of a dismantling plant has been presented. This solution proposal has been made that was dependent on results from the following factors:

Business model has been proposed in order for the plant to cooperate with upcoming WEEE recycling companies.

Sustainable economy is a factor that is important in regards of motivation for investment in this plant. Results show that the plant should be able to operate with positive income from dismantling WEEE, given that the WEEE are of quantitie and composition as estimated.

Layout proposal of a dismantling plant has been made, that has a streamlined material flow. The layout includes processes needed to treat all the WEEE that the plant is to accept. The layout demonstrate that it should be possible to facilitate for workers with autism and that are seated in wheelchairs. The material flow has been analyzed and made efficiently. Storage and dismantling stations have been dimensioned to handle the intended capacity of the plant.

Dismantling table was prototyped and tested for both regular workers and volunteers in wheelchairs. A design of this table was reached, that is expected to improve efficiency and allow workers with autism and that are seated in wheelchairs to use it. The prototyping process proved to be practical, and including the workers and volunteers in wheelchairs gave solutions that met the user's needs.

We experienced high culture difference during this study, and a lot of work went to building relationships and understanding the stakeholders. This proved to be a very time demanding, however it also proved to be a very important part of the project. Creating understanding of our limits and establishing clear project boundaries was crucial. Also important was, maintaining close contact with stakeholders to keep them included and interested in the project.

The study shows that WEEE generation in La Paz is going to rise significantly in the years to come. If the complete quantity of electronics entering informally is added to the calculations as well, WEEE will be a pressing issue in waste handling. This study shows that it should be possible to increase the WEEE treating capacity in La Paz with a plant that is reasonably

cheap to implement. Implementing workers with handicaps is realistic, and is believed gain social benefits.

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Appendices

- I. Capacity Calculations
- II. Expected WEEE Distribution in Bolivia
- III. WEEE Automatic Separation
- IV. To Enter a Developing Country
- V. CRT and Fluorescent Tube Calculations
- VI. Cable Calculations
- VII. Automatic Screwdriver
- VIII. Working Table Drawings
- IX. Operational Costs
- X. Operational Income
- XI. Stena Recycling
- XII. Peru Green Recycling
- XIII. Documentation and Certification
- XIV. Risk Assessment

Appendix I

Capacity Calculations

Table 1 Population in La Paz and Bolivia

<i>Place</i>	<i>Population</i>
<i>Population La Paz 2015</i>	789541
<i>Population Bolivia 2018</i>	11307314
<i>Population La Paz 2018</i>	804268
<i>Percentage La Paz</i>	7,1 %

Table 2: Capacity calculations

<i>Description</i>	<i>Value</i>
<i>Kg/Pers WEEE Bolivia 2018 UN</i>	5,1
<i>Population La Paz 2018</i>	804268
<i>Kg WEEE/year La Paz 2018</i>	4101767
<i>Ton WEEE/year La Paz 2018</i>	4101,767
<i>Ton WEEE/month La Paz 2018</i>	341,8139
<i>25% Capacity</i>	85,45348
<i>20% Capacity</i>	68,36278
<i>15% Capacity</i>	51,27209
<i>Capacity per person tons/month</i>	5
<i>% capacity: 60 ton/month</i>	17,55 %
<i>Amount of workers: 60 ton/month</i>	12

Appendix II

Expected RAEE distribution in Bolivia

Current WEEE situation in Bolivia

A lot of electronic articles are accumulated in household and in offices. With a good collection system and a good information stream, making people conscious of the benefits of recycling their equipment, it can be expected that a big variety of accumulated articles will be sent for dismantling in the beginning. After a while it will be expected that the most common articles will be the products sold in large quantities with short lifetime.

In a campaign done in January 2016, RAEE Recicla and the municipality gathered four tons of domestic electronical waste. The distribution of articles reflects the distribution that can be expected of received RAEEs in La Paz in the close future. The most common articles were:

White goods	VHS players
Computers (CPU, monitor, keyboard, cables ++)	Cellphones
Laptops	Chargers
TVs	Printers
Radios	Cameras

Table 1 Most common RAEEs received in La Paz campaign

In a survey done by Swisscontact in Bolivia, a comparison was done between lifetime and average household inventory of different types of electronics. The result is shown in the diagram below.

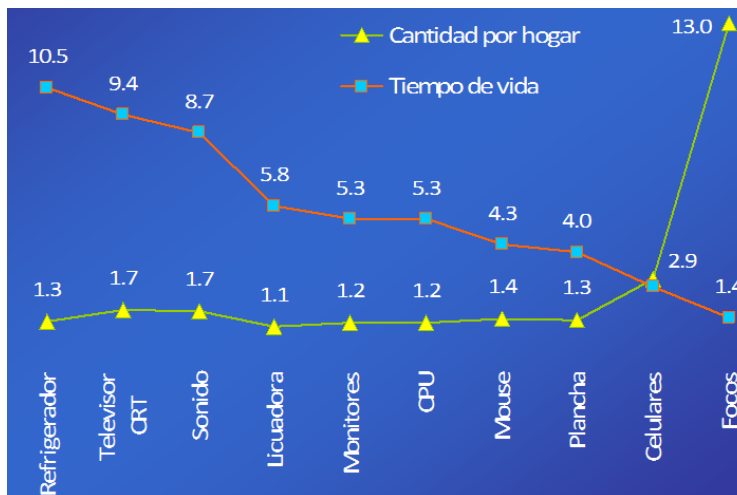


Figure 1 (Swisscontact, 2009)

Judging from this survey we can see that cellphones and lighting equipment is expected to have relatively short life and are in big quantities in the population. Large unit numbers of these kind of products can therefore be expected. Lightning equipment seems to be the article that most often will come for treatment. It is not mentioned in the table above because it does not have treatment options in La Paz, and was therefore not collected in the campaign. The need for treatment equipment does however become apparent in the graph.

Future WEEE predictions

In a report done by The United Nations University in 2014 (Baldé, 2014) the distribution of WEEE worldwide was analyzed. The report also show the amount of WEEE generated in the different countries in the world. In South America, Bolivia has the lowest yearly generation per inhabitant with 4.0 kg per person. Peru, which in many ways was in a similar situation as Bolivia a few years ago has a generation of 4.7 kg/person. In Chile each person generated 9.9 kg in 2014, while the most developed countries, in Northern and Western Europe, North America and Australia generated more than 20 kg/person (up to 28.3 kg/person (Norway)). The technological growth is spreading quickly to the developing world as it gets cheaper and more accessible. It can therefore be assumed that the amount of EE-articles in Bolivia quickly will grow towards higher numbers with more or less the distribution showed in Figure 2 Global E-Waste distribution Figure 2.

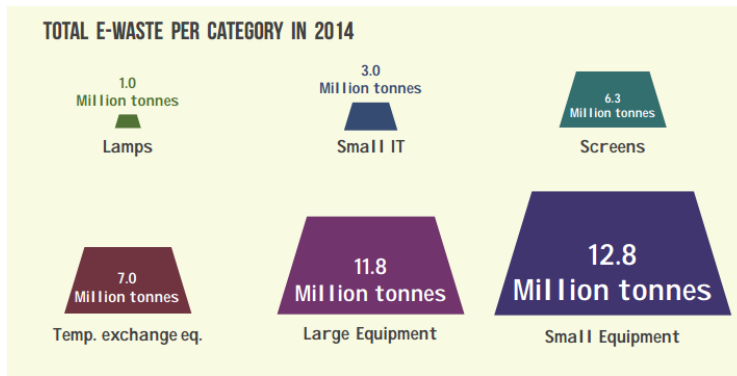


Figure 2 Global E-Waste distribution (Baldé, 2014)

The figure shows that the biggest part of the waste electronics are from small equipment. The tendency in technology is that the equipment gets smaller with more technology inside. This means that a lot of the equipment that can be expected is small devices with high technology. It can be more work to get less materials, but also the technology inside the devices can be of higher value. A large part of the RAEs can be expected to be cellphones. A shift from a majority of CPU computers towards laptops and tablets can be expected. The newer LED, LCD and Plasma screens has taken over the market from CRT-screens, and the CRT RAEs will slowly go towards zero. In a report from Peru in 2012 (Zellweger and Martínez, 2012), the consumption of the different TV types until 2012 was graphed, and an estimation was made until 2016. They predict reaching a consumption of CRT close to zero in 2015. As the neighboring country of Peru with an in many ways similar situation, these predictions may not be much off for Bolivia.

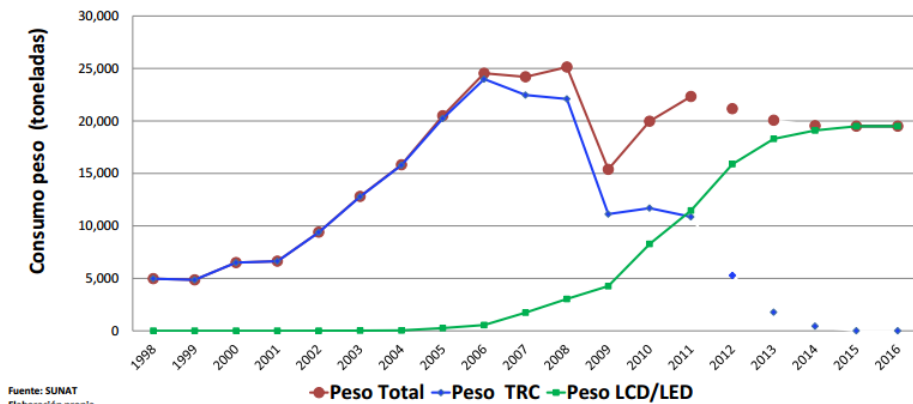


Gráfico N° 15.- Consumo de Televisores en el Perú, peso y unidades

Figure 3 Weight of CRT monitors compared to LCD/LED screens in Peru with future predictions (Oscar Espinoza and (IPES), 2010)

Expected Materials

With a shift toward smaller equipment, it can be expected that for many of the articles there will be more work for less materials. As well many of the articles that does not depend on high technology and small size will stay the same. It has been a tendency to use more plastics in EE-articles, often replacing metals and other coverage and fixing materials. The material composition of some of the most common EE-articles are shown in Figure 4 below.

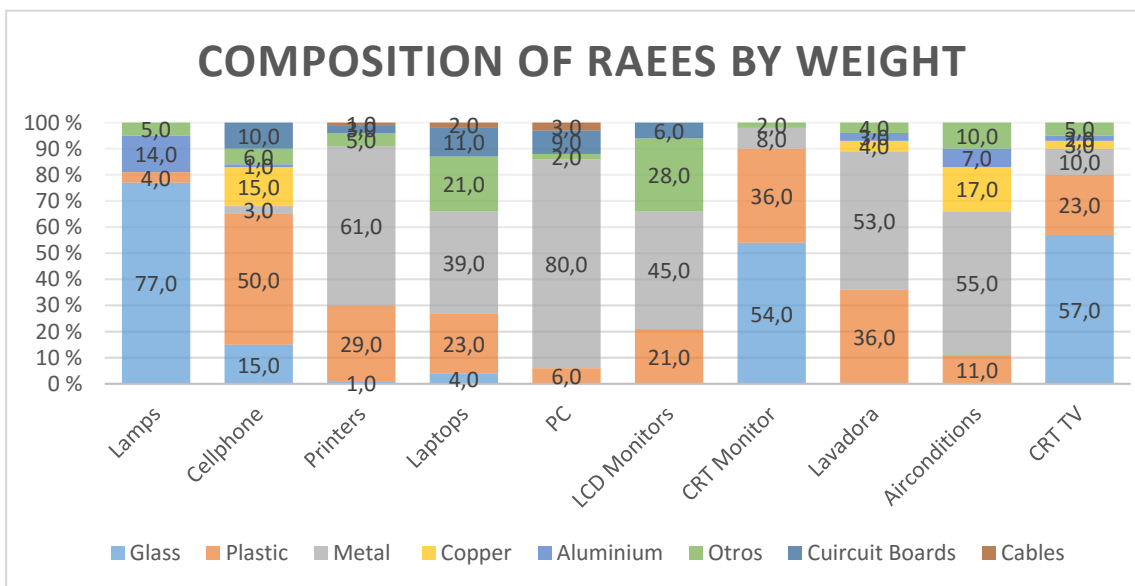


Figure 4 Composition of RAEEs. Data from (Swisscontact, 2009)

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Appendix III

Automated separation systems

Comminuting process

The point with the comminuting process is to crush the WEEE into so small particles that they can effectively be separated due to differences in material properties. Material properties can be different metals with magnetic and non-magnetic properties, material density (1). Comminuting can be done by means of shredding, hammer mill or cutting mill. Through these processes the WEEE will be comminuted into small enough parts to be separated. Usual particle sizes are between 20mm-5mm.

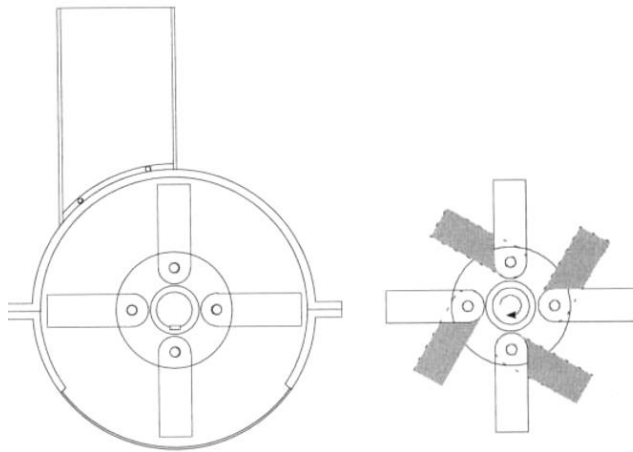


Figure 1

Source: http://www.rewin-china.net/tools/TtT-WEEE%20dismantling%20recycling%20and%20recovery_BOKU.pdf

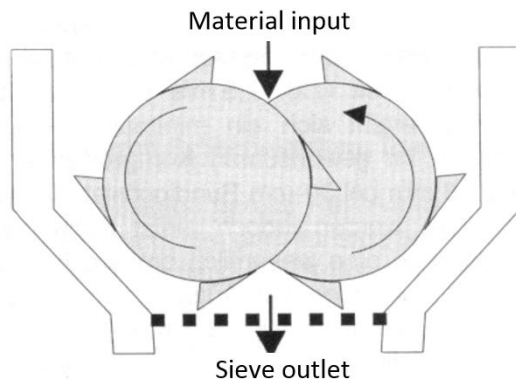


Figure 2

Source: http://www.rewin-china.net/tools/TtT-WEEE%20dismantling%20recycling%20and%20recovery_BOKU.pdf

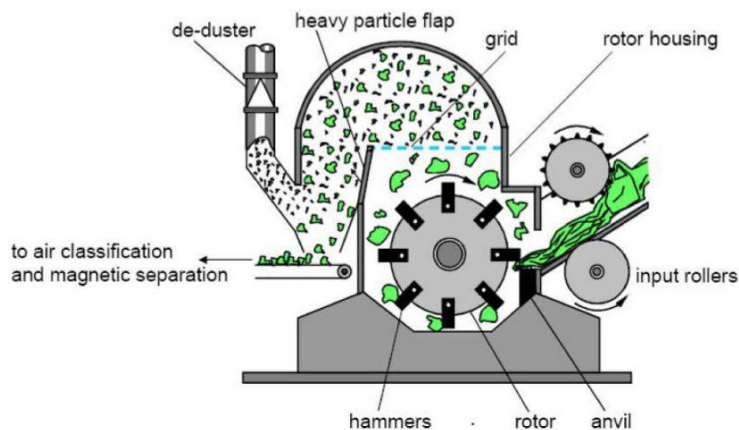


Figure 3

Source: http://www.rewin-china.net/tools/TtT-WEEE%20dismantling%20recycling%20and%20recovery_BOKU.pdf

Separation methods

- Magnetic separation is used to separate the ferrous metals from the waste mixture. Powerful magnets lift the ferrous metal parts of moving

stream of fragments. Later technology of high intensity magnets can also separate copper alloys from the mix. (1)

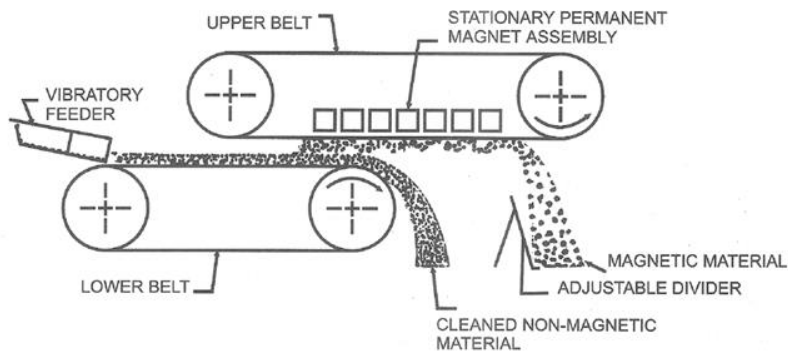


Figure 4

Source: http://www.jupitermagnetics.com/permanent_magnetic_seperator.htm

Separation with electric conductivity is used to separate materials with different conductivity or resistivity. There are various methods to solve this.

- Eddy current separation is a way of removing non-ferrous metals from a waste mixture. It is typically used to remove aluminum and copper from car scrap, or metal from glass. The principle is that material flow will pass over a drum with alternating magnetic field. Material with conductivity will be thrown further than material without. (2)

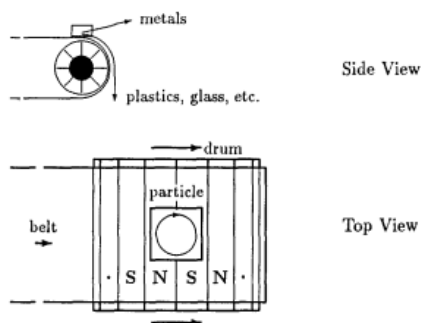


Figure 5 (2)

- Corona electrostatic separation works in similar to the eddy current. The difference is that the material is ionized which make them stick to the drum longer than the non-conductive material. (3)

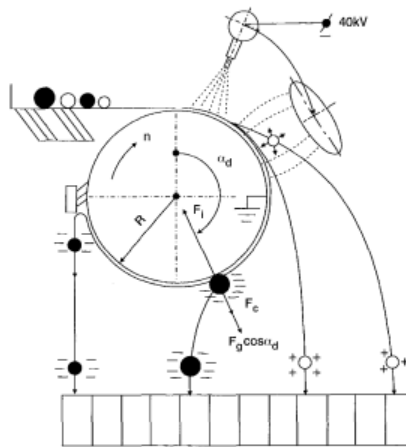


Figure 6 (3)

- Density separation is also a way to part the different materials. This can be done by means of wet jigging. The purpose is to have the light product float in the media, while heavier product will sink to the bottom of the jig. A plunger creates a pulsating current that keep material moving towards the end of the separation chamber (4).

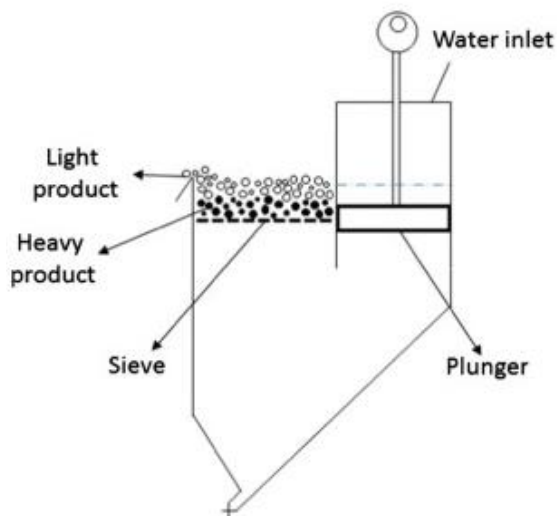


Figure 7 (4)

Setup and flow chart

The different separation methods are set up in stages so that you separate desired material as you move through the processes. First shredding is performed, which gives a material output of about 20 mm. Then fine commuting is done to reduce particle size down to 5-20 mm depending on the facility. (5). From there, different separation faces are initiated. The order of how materials are separated can vary, but an example can be as figure 8 demonstrates below. After commuting, screening can be done to separate very light material from the mix. This is to avoid the difficulties of too small particles that can cause clogging related problems in the later stages. Pieces that are significantly smaller than the rest can cause wrong separation in the later processes which also will affect the quality of the end product. For example a particle being too light to throw the correct distance in an eddy current.

After screening material flow can be guided through magnet separation. This is an effective way of taking only ferrous metals from the metal flow. Eddy current is good way of treating the material afterwards. The eddy current will ionize the non-ferrous metals and throw them in a separate shaft than the rest of the material stream. The circuit boards are often separated with use of optical tracking technology and removed from the material stream with pneumatic bursts. The non-ferrous metals and plastics can be separated by use of gravity separation. Variety density will make sure different metals will sink in a media with different speed and therefore separate in layers. In this way you should have a reasonable pure fractions of ferrous metals, non-ferrous metals, plastics, circuit boards and residual waste.

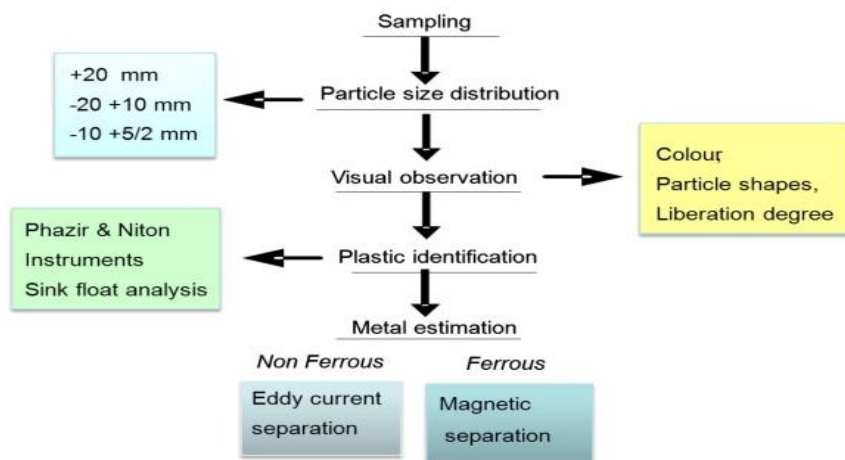


Figure 8 (5)

Sources:

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Appendix IV

To Enter a Developing Country: Waste Management Project in Bolivia

Eirik Lerum Vigerust, October 2, 2015

1 Abstract

In relation to the startup of a plant for waste management in Bolivia, this article look at important factors in foreign involvement in developing countries. The importance of a thoroughly understanding of the culture and the views of the involvement by the public sector, private sector, NGOs and people in communities, and the impact from these parts on a project is discussed. By looking into experience form related projects, an understanding of how important it is to secure a good relationship between the parts and to let all their voices be heard in the process is given. Different reasons for failures is looked into, indicating factors on how to get a successful long term result.

2 Introduction

When going into a new country as a foreigner to start a project that is not a common practice, the most important factors for the outcome is not necessarily the project itself, but how it is implemented into the society. Many projects fail because they are done in a way that would work in the home country and culture. Chances are it will not work outside of the borders you know. As a consequence of this, it is important to make sure to spend enough time and resources to understand the system, before starting the actual work. This essay is written as a preparation for work with the planning and startup of a separation plant in Bolivia. Questions on what to think about entering a society as a foreigner, and how to make a sustainable project with long term positive effects without negative impacts on the culture will be thoroughly discussed. The focus of the paper will be to understand the importance and views of the different parts involved in the project.

3 Project idea

Before discussing the impediments of going into a developing country, a description of the background of the project will be given. The project will be the master thesis of two students at the Norwegian University of Science and Technology, at the study Mechanical Engineering.

While traveling around in Bolivia in the beginning of 2015, a professor at Universidad San Francisco Xavier in Sucre suggested writing a master thesis about the problem of overflowing landfills and handling of the trash problems in Bolivia. We got in contact with the Swiss NGO (Non-Governmental Organization), Swisscontact, who are involved in the startup of a solid waste management (SWM) plant in the city of La Paz. Our job in this project will be focused on planning the layout of a separation plant of waste electrical and electronic equipment (WEEE) that will be a part of the bigger recycling plant. The separation plant shall employ disabled people, so workstations have to be fitted to their needs. To make the plant as efficient as possible is important, but it is also very important to keep as much people employed as possible. Machinery and automatic systems will have to be considered thereafter.

For us the project is mainly supposed to be focused on technological and structural planning. In addition to this technical part of the work, making it work in La Paz need some special considerations. This article will be a study of the Bolivian situation, and look into the non-technical needs and views for the thesis. A private Bolivian company will do the actual startup of the plant together with the municipality of La Paz. This means that both the public and the private sector, along with the NGO are involved in the project, and have the possibility to add their meanings to the process. An optimal result of the project is to not only build a separation plant, but raise awareness and enthusiasm about the trash problems in the country, and make the system work in a long term perspective. The bigger goal is to help the city and the country with the increasing trash problem, and getting as many positive effects out of it as possible.

4 Bolivia

4.1 People and culture

Bolivia has a strong culture, difficult to understand from an outside perspective. The large portion of indigenous people, and the economy of the country are big contributions to the life in Bolivia. With a percentage of 62% indigenous (UNDP, 2006), the culture is very influenced by their traditions and ways of living. For a long time they have been oppressed, and about two thirds of the indigenous are among the poorest 50% of the population (2004) (1). In 2005 President Evo Morales was elected to presidency as the first indigenous president in Bolivia. He shone the light more on the indigenous, with a focus on keeping their traditions and culture intact. This work both in the way that the overall culture are more influenced by the indigenous, as well the indigenous are more included in the rest of the system, influencing their culture to be more like the culture of the rest of the people. This may be a reason for a rapid drop in the percentage of indigenous the last years. As a person coming from a western culture, the strong indigenous culture make it extra important to step carefully and prepare well before trying to change things for the “better”. With a possibly very different set of values and view on what is good, what is commonly accepted as good in the western world may not be right in countries like Bolivia.

4.2 Economy and development

Bolivia is in many means of measures the poorest country in South America. It is also the country with the most rapid economic growth in South America the last years. They have big reservoirs of natural resources, and much of the reason for the growth the last years is better plans for how to use the resources more beneficial, and improved public institutions. The growth is very positive in many ways, but does also present a lot of new challenges. People have a tendency to hold on to the familiar, but must now be quick to deal with the problems coming with increased wealth and quick change. Often rapid growth is related to bigger difference between rich and poor. In Bolivia on the other hand, the Morales administration have had a big focus on the poor, and therefore the overall difference has

decreased the last years. A natural consequence of increased wealth is a higher use of resources, which if not handled carefully can mean exploiting health and environment. More money imply more trash is produced. Today WEEE make out a small portion of the total waste, but it is one of the types that is expected to increase the most the next years. A good system of capturing the waste and handle it is therefore essential to establish before the problem grows too big. WEEE contain much hazardous materials that, if not handled properly, can be bad for the environment and the people living around.

4.3 Governance and corruption

According to the World Bank's Worldwide Governance Indicators (WGI), Bolivia is scoring weaker than regional and global averages in most governance areas. After President Evo Morales was elected for his position in 2005, much of the civil unrest in the country started to get better. This has strengthened the position of the poor, but still the government does not have an effective system in many areas. A bureaucracy that is hard and slow to work with, makes it hard for people to go through the work of dealing with official regulations and systems. Also the governmental institutions lack resources and capacity to be of much help for the people who need them.

Much because of this, political corruption is a big problem in Bolivia. Instead of waiting for the governmental system to handle applications or cases, a faster and better result can be achieved from paying corruption. The last years with the Morales administration leading the country, much effort is put into anti-corruption work, and new laws have been added to stop the problem. In 2009 ministries were established to enforce the laws, and the last years many people have taken the consequences of being corrupt, losing their jobs or going to jail. This has been noticed by the people, seeing that the government work is effective. For companies corruption has been stated to be one of the primary obstacles for doing business in Bolivia. In a survey done by the World Bank and IFC Enterprise Surveys in 2010, about one fifth of companies said they expected to pay or give gifts to "get things done". This problem seem to have decreased the last years. (2)

4.4 Informal sector in Bolivia

The informal sector can be described as “the activities that are not registered, recorded, protected or regulated by public authorities” (ILO, 1972). In Bolivia nearly 80% of the activities in the urban and rural areas fall under the informal sector, making it the South American country with the largest informal sector. Among the reasons why such a big group of people don’t register their work and activity, are that they don’t think they will benefit from it. A study done by the World Bank in 2009 shows that this is true for some types of businesses. Such a large amount of informality is a sign of a big separation between the public and the people, and a good sign of little trust in the authorities. From the beginning of the 20s, and especially after the Morales administration, changes has been done to decrease the informal sector, and to improve the trust in the system. The changes seem to have a positive effect, and the last years it seems like more people see the benefit of being formal. (3).

4.5 Private-public-people partnership

In a study done in 2006 solid waste management in four Bangladesh cities was studied. It showed how important it is that the public and the private sector can work together to make a sustainable system of trash handling. A cooperation like this will give the views from both sides and bring the public and the private sector closer. The public sector will incorporate their regulations and have their saying in how the system should be in a bigger perspective. A big problem for the public is its lack of capacity to conceptualize and to implement new innovations, and don’t have the opportunity or funding to be experimental. Things are done in the traditional way. Involvement of the private sector will increase the incentive to be economically sustainable, and can be able to experiment more, and be more innovative. The chance of survival for a public-private partnership (PPP) company is therefore higher. There will also be obstacles in cooperation like this. Due to an increased need for bureaucracy and regulations, the private sector will be more constrained in its work than if it was on its own. On the other hand, the public sector will have to let go of control and be more accepting. As a solution for this, the study shows that these obstacles can be overcome easier with help from external facilitating agencies.

In the case of the separation plant in Bolivia, a public-private partnership is already established. This is a good sign in a country known to have problems with weak governmental institutions. Another problem mentioned in the study is that the public tend to not see the need of involvement of NGOs or the communities. NGOs often try to look at the bigger picture as well, but often in a different way than the national government, and they may have experience from similar situations. They also stay much freer to try new methods and experiment with related projects, and can work as a positive effect for the partnership. As the NGO Swisscontact is involved in the separation plant, some impediments have already been overcome.

With such a big part of the population working in the informal sector in Bolivia, the existing connection between the public and the communities is most likely not very good. In some of the Bangladesh cities in the study, they had managed to make a system where the public and private sector worked closely with the people. On demand from the PPP, streets were cleaned and waste delivered by the people, resulting in a cleaner environment, and more waste to handle. The people in the communities saw the improvement of the environment, and accepted a small fee for the service of gathering trash. That way they made more jobs and at the same time strengthened the relationship between the people and the public and private. To understand the needs and wishes of the people in Bolivia can therefore be a key to success for the separation plant. It may be a potential for gathering of WEEE, but most visible is the need to get the people involved in how the system around the separation plant will work. The plant will employ people with disabilities and strong needs, which may not have much experience with structured work. To make an efficient and sustainable system, their voice has to be a big part of the planning. For example, looking at Bolivia's history, it has come apparent that people choose to leave the formal sector to get the flexibility they can get working in the informal sector. A more flexible working environment can for example be a way to appeal more to the workers of the plant.

The overall trust in the government among the people has been weak, seeing that the regulations they implement are ineffective. This means it can be hard to make people willing to cooperate. A solution for this can be to involve facilitating agencies to make the partnership as favorable for everyone as possible. If the

choice to involve such agencies are taken, it is shown that an agency with good experience in the field makes a big difference in the outcome.(4)

4.6 Swisscontact in Bolivia

The Swiss NGO, Swisscontact, has a broad specter of projects around the world. They have been in Bolivia since 1985, therefore are one of the most experienced organizations on work in Bolivia. At the moment they are working on a variety of projects to improve air quality, help rural markets and waste management work among others (5). They have been working with solid waste management for more than ten years, which make them the organization with most experience on the topic in Bolivia. The WEEE separation plant project will not be a project directly organized by Swisscontact, but they will be closely connected and follow the project through the startup. A close connection with them and the resource it is to have their experience, will be very important when going into Bolivia. In their experience, the Bolivian culture is less different than in many Asian and African countries, and foreigners usually don't stand out as much. Therefore Bolivia can be easier to approach. Even though we still have to think through the methods of integration, the competence Swisscontact hold will make it much easier and safer to focus more on the technical part of the plant. (6).

Another important factor in aid work is to look at the long term as well as the short term consequences. A problem raised about most aid work today is the fact that it is project based, and therefore gives less room to follow the situation for a time after the project is over. Often projects die out when NGOs leave, or the short term effects have after effects that can have negative impact in other areas. All the years Swisscontact has been in Bolivia has given them the chance to see how different projects have worked and what impact they have had on the societies. After earlier solid waste management projects they have observed a change of people's habits and how they separate waste and litter less. It seems like the work they have done has succeeded in raising a sustainable awareness of the trash problem among the population. Analyzing what methods have worked and not in the past and what will fit with the WEEE plant can therefore be very helpful to gain a long term positive change. This is an important area for further research.

5 Lessons from similar projects

Through conversations with Dr. Mansoor Ali, who has a lot of experience in working with solid waste management in developing countries, some important observations and thoughts on what needs to be thought about was discussed. From his impression, Latin American countries has been good at implementing waste management and make it work. Many of the surrounding countries have been through some of the same processes recently, and can be very helpful to explore. They have more similar systems and cultures than countries in Africa and Asia, and can give a more realistic view on what works and not. Especially important can it be to look at project that has failed, and find the reasons why they failed.

For example one typical situation for technical solutions to fail has been connected to technical equipment. Good machinery can be installed. Everything is set up nicely, and the workers and managers has been thought what they need to know. But if something goes wrong with the machine after the project is over, or when the machine needs maintenance, no one knows how to, or they don't have the money to fix it. That way a project can die out. This example shows how important it is to properly think through all the small things that can become a big problem. Maybe it is better to buy tools and machinery from local vendors even though they can sell worse equipment to a higher price than to buy from a big reliable vendor far away. That way they increase the possibility of having people with the competence to fix it and extra parts available without having to put too much effort into it.

Another reason for many failures of technical projects and waste management projects is that they have too high costs after the project is up and running. Keeping the plant less technological and fancy on the cost of worse efficiency may therefore be a way to better the chance of long term survival. To support and follow up projects economically also after it is up and running again shows its importance.

6 Views of the different sectors

Another topic touched upon by Dr. Mansoor Ali was the different involved parts in a project. In this section I will therefore try to analyze and speculate around what the public, the private sector

and the NGO want to gain from involvement in this project. A project with a good balance of wishes from the different sectors is important for a healthy and sustainable relationship.

The reason for looking into this is that there may be many reasons for why the public sector want to be involved in projects. The purpose of the municipality is to provide good government, to provide services, facilities and such for the people and to develop and maintain safe and viable communities in their region of responsibility. With limited financial and practical resources, hard prioritizations have to be done to fulfill these duties as good as possible. According to the purposes above, waste management should be a goal in itself, and should be within their responsibility. Most likely they also see that the growing economy implies growing waste production, which can potentially turn into a big problem in a short amount of time. It seems like the present government is working with the lower classes in society in hope of more trust and a closer connection. Involvement in waste management can be a good way for them to let the people see that the government is helping them to get a cleaner and healthier environment. The WEEE plant will be designed for, and is supposed to employ mostly disabled people. This can also be a way to show the people that they care.

By being a part of the waste management plant, they will also have better control of the regulations that has to be followed, to make the impact on the environment and health as little as possible. These arguments seems beneficial for the government, and can be a big part of why they are getting involved in the plant in Bolivia. There may also be more and stronger arguments, but a better understanding of the system will be necessary to get good answers. Dr. Mansoor Ali mentioned examples of governments going into projects as “test projects” just to see how they work, without future plans. In this case a bigger plant is supposed to be built, and because of the stated arguments, this seems unlikely. More research need to be done on the topic.

With the resources found in the public sector, it can be expensive and difficult to start the plant as a pure public project. Partnering up with the private sector gives room for more innovations and expertise, which can be very essential for a more economically sustainable system. They also share the expenses,

taking less money from the municipal budget. On the negative side, the partnership means they have to let go of a lot of the control.

From the private sectors perspective, the project most likely has an economical motivation. To make an efficient system with as much income and little expenses as possible will probably be their goal. With the partnership with the government they don't need all the capital themselves, and they get the benefits from good institutional resources, which can make it easier to survive in hard times. Disadvantages with the partnership is decreased flexibility and more bureaucracy.

The goal of the NGO is in this case not personally economical, but to ensure more sustainable and healthy conditions for as many parts as possible. They depend on being able to show good results for further funding, so measurable results may be important for them. Too much focus on the measurability can be negative for the overall project. (7).

7 Our approach

From the time the developed countries started to give aid to developing countries, the methods has gone through reforms that it is important to learn from. From a mentality of going into a country as we are to change it towards the developed values, the trend is now leaning towards integration into and understanding of the system. Helping with self-help has become the new focus. As it first was a focus on approaching the higher part of the hierarchy and make the change there (top-down approach) it changed into focusing on the lower levels, with the communities and the people that was the target of the change (bottom-up). Lately it has gone to focus more on both approaches (bottom-top), seeing that it is hard to get things done with a strict focus on the communities. (8)

When we go into Bolivia to work, we will have to deal with many instances and different views on how things should be done, and what our role will be in the setting. We will spend much time on finding the needs of the public and private participants, but most of the focus should be on the needs of the kind of people that will work in the separation plant. This means that we will be using a Bottom-Top approach, where we will work both from the community level and up in the system, as well as from the higher levels of the system and down.

To get the sufficient contact with the partners, planning from a different part of the world can be a problem. As much time close to the work site and in contact with the involved people is important to understand the situation, and to avoid misunderstandings. The plan here is to first visit for a shorter period of time during the planning process, and then go back and stay for as much of the time the actual work is done as possible.

Our closest partners should be the NGO. They are the actor with most experience on similar situations, and already have a good connection with the other sectors. The needs we find in the sectors should therefore be discussed with the NGO, where they are in a better position to make decisions from it.

Our task will be to plan the design to make the workers satisfied with their working conditions, as well as making it efficient and as economically sustainable as possible, while striving to keep a reasonable amount of workers in work. In the bigger picture we have to make sure the people higher up in the system are able to manage the plant in the long term after our help is finished. A big part of their training may be our responsibility. This requires high competence on the field.

The reason why we are wanted in the project is to help with the practical planning to make the plant as good as possible. An important factor is therefore to not put much more social perspectives into the planning, but to be “experts” on the practical level. Most of the research should be done on the technical and practical part, and looking into successes and failures in similar cases. In the view of the public and private participants in the project, we will most likely have a consulting role. Therefore the most important part will be to have a good overview of the technical part.

8 Conclusion

Literature and conversation with people with experience on aid work in developing countries has shown many important factors and methods to use when going into a different culture to work. The importance of the relationship between the parts involved in projects is very essential for a good long term result with satisfied sectors. In a country like Bolivia it is important to close the gap between the people in the communities and the public sector. An involvement of

the communities is therefore important. To ensure healthy relationships between the involved parts, the use of external facilitating agencies with much experience has in earlier projects shown to be a well worth investment.

Going into a country like Bolivia requires a well thought trough view on your own position in the system, and it is important to let the goals of the different parts be heard, and maybe put them above your own. A bottom-top approach should be used to understand the different parts. In our example the largest focus should be to be as good as possible on the technical part of the project.

Involvement of the public sector can give a very positive effect on the system, and it is a good way to decrease risk of a project. It also means that processes will be slower, and strict regulations has to be followed closer – making it harder to start and run a company. Corruption is also a possible problem, and may be necessary to deal with in the startup and running of a company.

11.8 Sources of appendices

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Appendix V

CRT and Fluorescent Tube Calculations

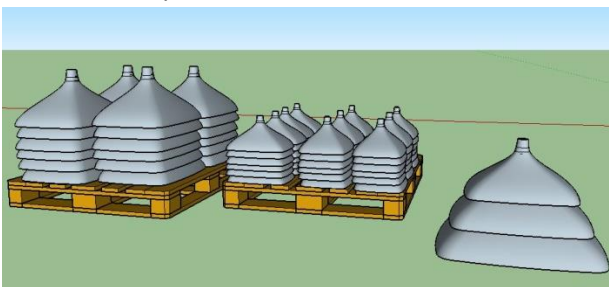
Budget justification

Estimated price for machine: 10 000 USD

Price of treatment at RAEE Recicla per unit CRT monitor at is in 2016 : 5 Bolivianos

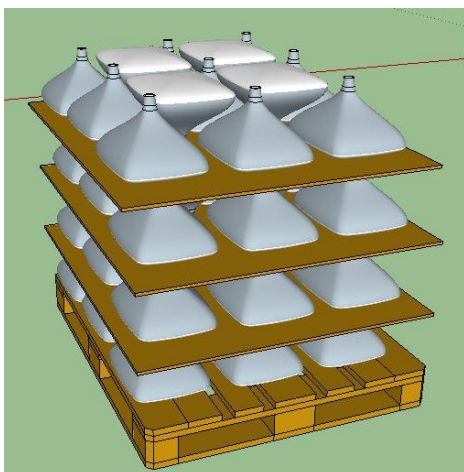
Transporting only the funnel element instead of the whole CRT screen element makes a big difference in volume.

The big difference is that the funnel glass allows you to stack each unit on top of each other. To compare the amount of separated funnels you can stack on a pallet to the amount of CRT monitor elements, we have done the calculations with the 17 inch screen. This is the most frequent screen that Raecicla treats. If they are packed like showed on the picture we estimate a pallet of height 110 cm can room 240 funnels from 17 inch screens. If the funnels are of different sizes, the can still be stacked on top of each other, but less space efficient. The picture below demonstrates different sizes of CRT monitors stacked on top of each other.



Picture 1
Funnel glass stacked into eachother

The CRT screen elements has to be carefully packed and take up a lot of volume. If they are packed showed in the picture, we estimate a content of 90 monitors in a pallet of a height 150 cm. However if they are of different sizes it will be a lot harder to stack them together efficiently.



Picture 2
CRT elements stacked on a pallet

The transportation costs should be less than a third of the price. Also the treatment will be cheaper since the leaded glass come ready for smelting, while steel and pure glass from the glass display can be sold for profit.

With an estimate of 1200 monitors per container shipping stacked in the way illustrated above, and a cost of each container shipping along. Estimated amounts of CRT monitors per year is set to 40% of the weight of WEEE. This is based on estimations of CRT composition in WEEE from Recicla, 40 % and from the paper of direction of processing CRT monitors (Mueller et al., 2012), 35%. The annual amount of dismantled CRT monitors in the plant will then be 288 tons. The average 17 inch CRT monitor weighs about 10 kg. Each container will then fill 12 tons of CRT elements. Cost per kg monitor is then $5000 \text{ USD} / 12000 \text{ kg} = 0.417 \text{ USD} / \text{kg}$.

When the container is filled with funnel glass stacked on top of each other, in pallets of height 112 cm each, they contain 230 funnels. The container can fit

20 of these pallets in two levels.

Quantity of funnels in container: $240 \times 20 = 4800$ funnels /container.

Each takes up about 40% of the weight of a CRT element, which will equal 4 kg.

The container will then room $4800 \times 4 \text{ kg} = 19200 \text{ kg}$

However if we will calculate the oversea shipping costs per kilo CRT element.

Oversea shipping costs for each CRT element will then be: $4800 \times 10 \text{ kg} = 48000 \text{ kg}$

$$5000 \text{ USD} / 48000 \text{ kg} = 0.104 \text{ USD/kg}$$

Also it should be considered to implement a way to break the lead glass without risking exposure of dust containing lead to the workers. This will compact the glass significantly and save more on transportation cost.

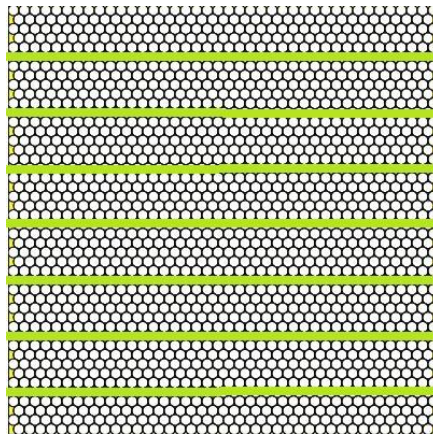
Economics

Volume of transportation:

Average length: 1m

Average diameter 25 mm.

Estimated amount of tubes per m³ including padding in packaging is 1537 tubes/m³. The picture shows the cross-section of a cubic meter of tubes with padding.



Picture 3 Cross-section of 1m³ cube with florescent tubes

With fluorescent tube shredder.

Barrel of florescent shredder is set to be same size as an oil drum with measurements \varnothing 0.61 and height 0.88m. When stacked together these cylinders, each occupies a space equal to :

$$0.61\text{m} \times 0.61\text{m} \times 0.88 = 0.327 \text{ m}^3$$

1 m³ can store $1\text{m}^3 / 0.327 \text{ m}^3 = 3.058$ cylinder drums.

Each drum can carry 2050 tubes of the type T8 \varnothing 25 mm.

Capacity in per m³ is then $3.058 \times 2050 = \underline{6269 \text{ tubes / m}^3}$

The volume of the tubes transported and stored is greatly reduced. In addition the environmental risk of breaking the tubes and causing contamination is a lot smaller.

Transportation and storing costs should be reduced by 100% - (100% / (6269/1537)) = 100% - (100% / 3.98) = 75.5 %

Price of shredder: 5300 USD

Appendix VI

Cable Calculations

Table 1: Cable calculations

<i>Description</i>	<i>Value</i>
<i>Capacity/month kg</i>	60000
<i>Share cables of total weight</i>	1 %
<i>Cables/month Kg</i>	600
<i>Cables/day Kg</i>	20
<i>Value cable/kg (cable average)*</i>	1,71
<i>Value cable/month</i>	1028,571
<i>Value No.1 Copper/kg**</i>	4,71
<i>Weight% copper in cable</i>	50 %
<i>Amount copper in 600 kg cable</i>	300
<i>Value No.1 Copper USD</i>	1414,286
<i>Value difference USD</i>	385,7143
<i>Difference percentage</i>	37,5
<i>Value added USD/year</i>	4628,571
<i>Value of machine</i>	10000
<i>Months to pay machine</i>	25,92593

Table 2: Cable and copper prices

<i>Product</i>	<i>Price \$US/kg</i>	<i>Comment</i>
<i>#1 Insulated Wire</i>	2,14	<i>Actual numbers from RAEE Recicla</i>
<i>#2 Insulated Wire</i>	0,71	<i>Actual numbers from RAEE Recicla</i>
<i>*Cable average</i>	1,71	<i>Calculated based on prices and amounts of different types of cables at RAEE Recicla</i>
<i>**No.1 Copper (96-98%)</i>	4,71	<i>True potential price at RAEE Recicla</i>

Appendix VII

Automatic Screwdriver

Ergonomics of screwdriver

- Working direction: Vertical
 - Wrist should not be bent
 - High table
 - Straight handle preferred
- Twisting movement increase chance of fatigue over time
 - Power drill preferred over manual screw drivers
- Heavy tools hard to handle
 - Higher tension on arms
 - Harder to handle precisely
- Trigger: middle off finger should push
 - Tip off finger increase possibility of tendon damage
 - Low pressure activated triggers decrease chance of tendon fatigue
 - Longer trigger allow use of more fingers – less impact on tendon
 - Push start (activation by pressure on drill bit) is an existing option for straight screw drivers – stable grip

Electric or Pneumatic (air driven) Automatic Screwdriver		
	Electric	Pneumatic
Weight	Heavier	Lighter – easier to maneuver
Effect	Higher torque	Lower torque – sufficient for the work
Noise	Lower noise levels	Higher noise levels
Connection	Easier to handle with thin and flexible cable	Thicker hose – harder maneuvering
Flexibility	Need power output – more flexible	Need compressed air output – restricted to be close to output
Energy efficiency	Less energy use	Higher energy use
Price	Higher unit price	Require compressor installation, cheaper equipment, lower long term cost



Figure 1 Straight handle with push trigger (Copco)

Sound

Automatic tools are related to high noise levels. The ear has protection mechanisms, but it takes 0.04 s to activate. This makes the impact noise of tools a problem. The largest problem however is the over-time noise. In the European directive for noise, 2003/10/EC, the maximum limits for sound levels an operator can be exposed to are stated. The values are shown in the table below.

Value	8 hour dose value dB(A)	Peak value dB(C)
Lower action value	80	135
Upper action value	85	137
Limit value	87	140

Figure 2 Directive 2003/10/EC of the European parliament and of the council (2003)

- Ear protection should be available if noise level exceed lower action value.
- Ear protection shall be used if noise levels reach upper action value.
- Under no circumstances should the noise level exceed the limit value.

The noise level from the different automatic screwdrivers vary largely. The electrically driven tools tend to make less noise than the pneumatic, and are often below the lower action value in the table above. Pneumatic drills are usually noisier, and can be above the lower and even the upper action level in the table. By using an exhaust hose and placing the compressor where the noise does not reach the workers, the noise can be reduced. The noise level should be tested properly to find the noise levels and define the need for hearing protection. (Copco)

Recommendation

Because of the working position with a high table and screw dismantling mainly in vertical direction, a screwing device with a straight handle is recommended. Manual screwdriver require much rotating movement in the wrists and is related to fatigue problems and slow operation. Automatic screwdrivers are recommended.

A pneumatic screwdriver is lighter and easier to handle, which is a big advantage in this type of work. This makes the work faster and easier for the dismantler, and result in less wear on the workers. Pneumatic is also connected to less maintenance than an electric drill. The biggest disadvantage with the use of pneumatic drill in the WEEE recycling plant is that it is noisier than electric drills. In relation with workers with special needs, such as autism, this can especially be a problem. The tool does however not have to be of the most powerful, and it is possible to find both electrical and pneumatic screwdrivers within the lower action limit in the EU directive (DEPRAG). If this is sufficient, the recommendation is therefore to invest in and install an air compressor with outlets above the working stations.

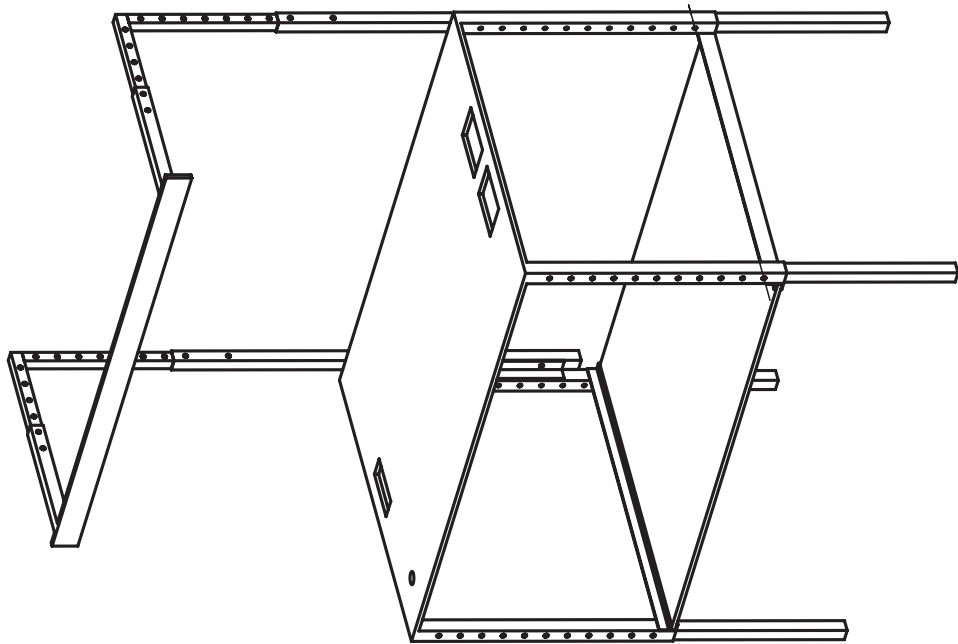
The screwdriver can either be activated by a push trigger or by pressure added to the bit in the working direction. If activated by push trigger, the trigger should require a low push and be possible to use without having to use the tip of the finger or with more than one finger. If activated by down pressure, highly repeated finger movements are avoided, and can therefore be recommended. There exist screwdrivers with more than one speed depending on the push. This can be recommended for better control of the screw dismantling.

References

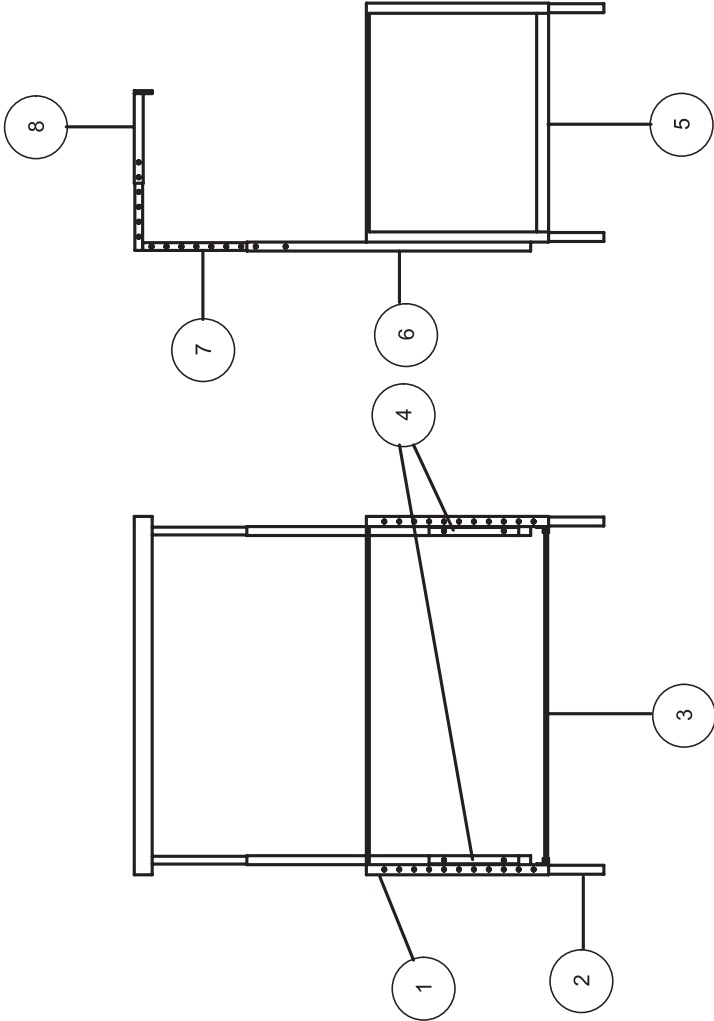
COPCO, A. The Art of Ergonomics.
DEPRAG Recycling Drivers Datasheet.

Appendix VIII


Working Station Drawings

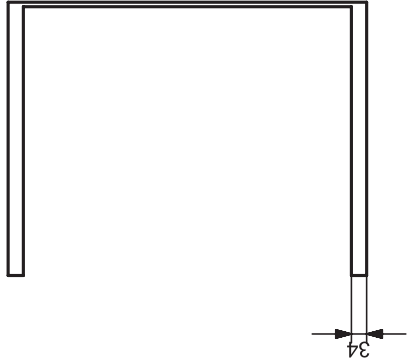
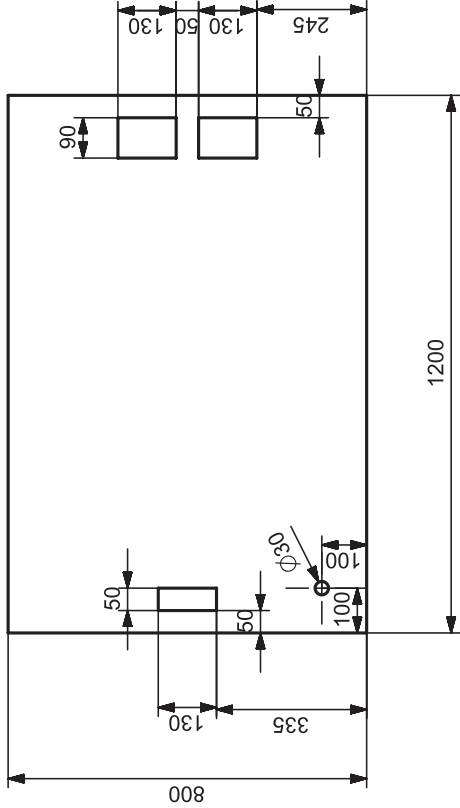
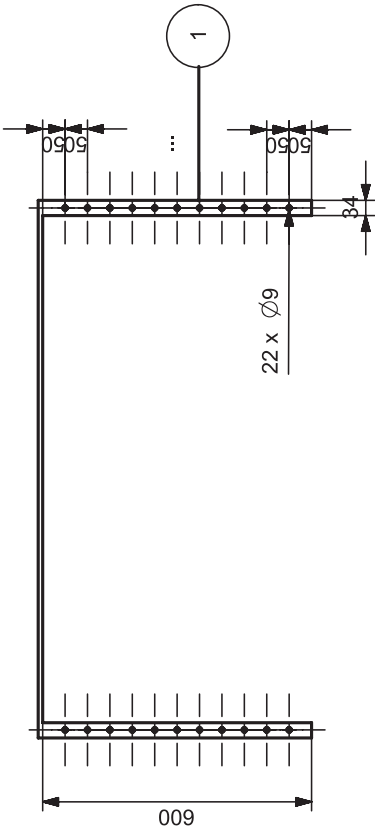


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		Scale	1:10	NTNU	




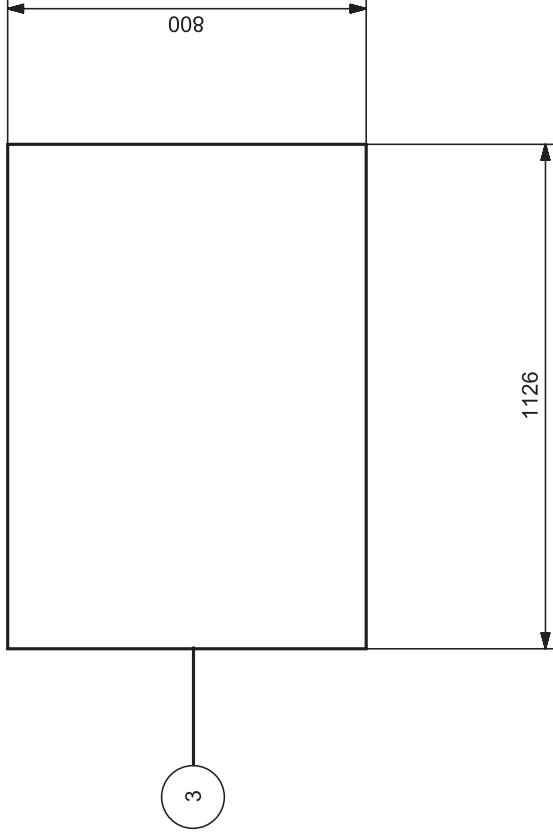
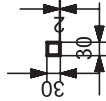
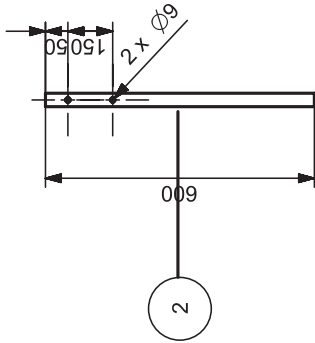
Part no	Part Name	Quantity
1	Table	1
2	Table Legs	4
3	Bottom Plate	1
4	Table-Rack Connection	2
5	Table-Bottom Plate Connection	2
6	Rack Bottom Part	1
7	Rack Middle Part	1
8	Rack Upper Part	1

Name Table Assembly		Sheet 2	
Date 26.05.16	Constructor ELV	Projection method 	Scale 1:15
NTNU			



Part no	Part Name	Quantity
1	Table	1

Table		Sheet: 3	
Name			
Date	26.05.16	Constructor	ELV
Projection method		Scale	NTNU



Part no	Part Name	Quantity
2	Table Leg Extension	4
3	Bottom Plate	1

Name	Table Legs and Bottom Plate	Sheet	4
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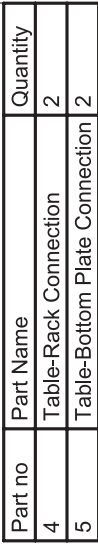

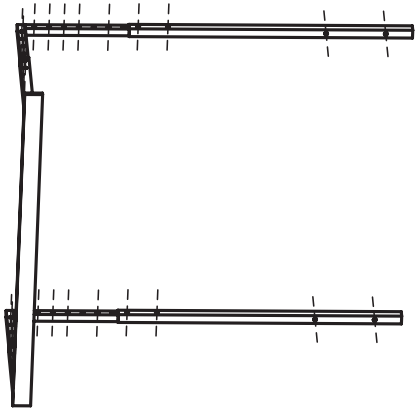
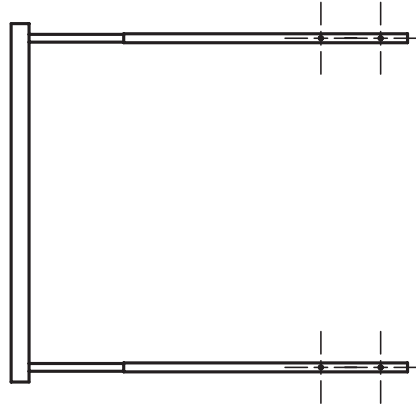

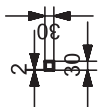
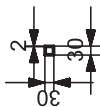
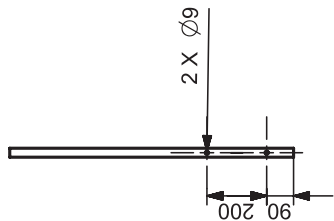
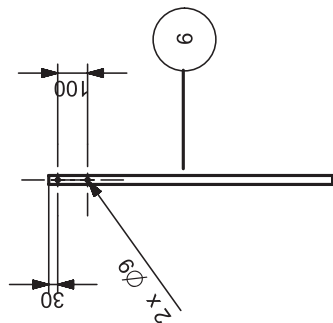
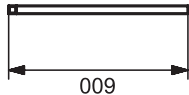
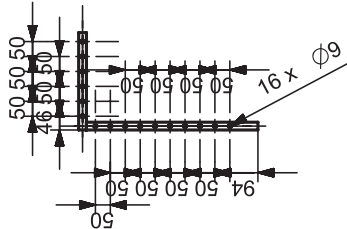
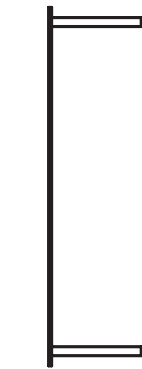
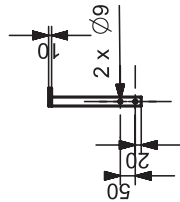
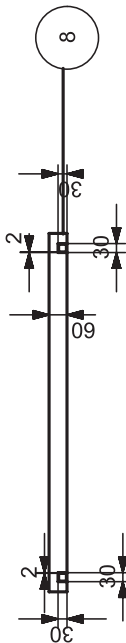
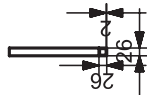


Table Connections				Sheet: 5
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				NTNU



Part no	Part Name	Quantity
6	Rack Bottom Part	1
7	Rack Middle Part	1
8	Rack Upper Part	1

Name		Table Rack Assembly		Sheet		6
Date	26 05 16	Constructor	ELV	Projection method		Scale
						1:15
						NTNU



Part no	Part Name	Quantity
6	Rack Bottom Part	1
7	Rack Middle Part	1
8	Rack Upper Part	1

Name	Table Rack Parts		Sheet	7
Date	26.05.16	Constructor	ELV	
		Projection method		
		Scale	1:15	
				NTNU

Appendix IX

Operational Cost per month

Worker cost

Position	Quantity	Salary \$US	Total \$US
General Manager	1	1078	1078
Sales Manager	1	862	862
Accountant	1	503	503
Technical and Storage Manager	1	862	862
Human Resources	1	862	862
Secretaries	2	503	1006
Dismantling Operators	12	237	2845
Storage Operators	3	237	711
Cleaning and Maintenance	2	237	474
TOTAL	24		9203
Additional worker cost*			33 %
Total worker cost			12274

* Worker taxes and costs

Expenses	% of salary
Christmas bonus (13th month)	8,33 %
Social benefits	8,33 %
AFP	6,71 %
Insurance	10,00 %
TOTAL	33,38 %

Outsourced work

Position	Quantity	Salary \$US	Total \$US
Maintenance	1	72	72
Training	1	72	72
TOTAL			144

Plant operating costs

Cost	Total \$US
Worker development	30
Maintenance and cleaning infrastructure	300
Insurance	1000
Maintenance machinery (5% of cost)	170
Gas for transportation	300
Service costs (electricity, telephone, water etc.)	500
Clothing and security equipment	300
Office materials	100
Food	500
TOTAL	3200

Infrastructure

Cost	Total \$US
Rent	1500
TOTAL	1500

TOTAL COST

Expences	\$US/month	\$US/year
Salaries (inc. taxes and extra costs)	12274	147289
Outsourcing	144	1724
Plant costs	3200	38400
Rent	1500	18000
Total	17118	205413

Appendix X

Operational Income each year

Table 1: Amounts of articles and materials

Amount of articles		WEEE TREATED EACH YEAR: 720 000 KG									
		30 %	10 %	40 %	20 %	Promedios	CPU	CEL	72 000,00	288 000,00	144 000,00
		CPU	CEL	MONITORES	Impresora					MONITORES	Impresora
COST \$US/kg		1,25	40	0	0,5						
WEIGHT		12	0,3	15	8						
COST \$US/kg		15	12	0	4						
Steel	0,5	75 %	5 %	5 %	50 %	34 %	162000	3600	14400	72000	72000
Aluminum	1,2	1 %	0 %	1 %	5 %	2 %	2160	0	2880	7200	7200
Plastics	-0,1	15 %	25 %	10 %	40 %	23 %	32400	18000	28800	57600	57600
Circuitboards	3	5 %	15 %	2 %	3 %	6 %	10800	10800	5760	4320	4320
Special	-0,5	0 %	5 %	80 %	0 %	21 %	0	0	3600	230400	0
Cables	2	4 %	0 %	2 %	2 %	2 %	8640	0	5760	2880	2880
Batteries	-0,2	0 %	50 %	0 %	0 %	13 %	0	36000	0	0	0
		100 %	100 %	100 %	100 %	100 %	216 000,00	72 000,00	288 000,00	144 000,00	144 000,00

Table 2: Value of materials

	Costo por kilo	CPU	CEL	MONITORES	Impresora	Promedios	Total
COST \$US/kg							
WEIGHT		12	0,3	15	8		
INCOME \$US/kg				0,8			
Steel	0,5	81 000,00	1 800,00	7 200,00	36 000,00	31 500,00	
Aluminum	1,2	2 592,00	-	3 456,00	8 640,00	3 672,00	
Plastics	-0,1	3 240,00	1 800,00	2 880,00	- 5 760,00	- 3 420,00	
Circuitboards print	3				12 960,00		
Circuitboards cellp	8		86 400,00				
Circuitboards CRT	0,4			2 304,00			
Circuitboards CPU	4	43 200,00				10 800,00	
Special	-0,3	-	1 080,00	- 69 120,00	-	- 17 550,00	
Income from destruction				184 320,00			
Treatement savings from transportation				80 000,00			
Cables	2	17 280,00	-	11 520,00	5 760,00	8 640,00	
Batteries	-0,2	-	7 200,00	-	-	- 1 800,00	
		140 832,00	78 120,00	216 800,00	57 600,00		493 352,00

Appendix IV

Stena Recycling

Outside of Oslo in Norway a company called Stena Recycling are separating hazardous components from WEEE. They let us come and see the plant and how they work. This is an efficient and well worked through company that doesn't want the details about their operations to leak out. It will therefore not be described in too much detail.

The separation plant is a part of a larger group of recycling facilities, and the purpose of the facility is to make sure all the hazardous materials are separated from equipment, so the safe parts of the WEEE can be treated in automatic treatment plants. The hazardous parts are taken out, and the rest of the materials are sent to other facilities.

The WEEE enter the facility from large companies that want their WEEE treated. The articles come in large orders at planned times. A similar system to Kanban is used. The types and amounts received are planned and a treatment time is given. One order is finished before a new order is started. The time for each order is planned and given an amount of tags on a timetable in the entrance area. That way it is easy for everyone to have a good overview of what is going on and what the plan is. In the same room there is also a lot of other information for the workers, such as injuries, reports about the plant and such.

The dismantling process is a production line process, where the articles are put on a band and rapidly sorted as they come. Further the articles are separated on manual dismantling tables. The hazardous materials are sent to the storage area. The rest of the materials are placed on different assembly belts depending on where it will be sent next. Large containers where the materials or components are put are placed along the assembly line.

The working stations are simple tables of about 120 cm by 80 cm. The most used tool is a pneumatic drill, and there is a wall in the back of the table for tool storage.

The whole plant is closed off so the water leaving the plant goes through advanced filters before it goes to pools that are cleaned and checked before released. This way the water leaves well within the acceptable contamination limits. Environmental security is very high priority. When sufficient amounts of hazardous materials are accumulated, it is sent for further dismantling in other treatment plants.

Daily there are people doing safety checks on the plant, seeing that everything is done as it should and that everyone is okay. To enter the plant we had to put on helmet, protection glasses and safety boots. The workers used the same, and more if appropriate for the type of work. Only authorized people can enter the plant, and guests has to register before entering. The workers health are checked regularly to make sure their body does not get contaminated by the work.

Appendix XII

Green Recycling Peru

Business Overview

In Lima there are four treatment plants dismantling RAEs. They are all privately owned. One of them is Green Recycling Peru. It was started in 2013, and is therefore still a new business. The first law about WEEE in Peru was passed in 2010. The law tells how the materials should be treated, who can do it, and who has the responsibility. A lot of the responsibility to make sure the equipment is treated is the producer or the importer. The law says they are responsible to deliver a certain amount of WEEE to a dismantling plant in compliance with the normative. The treatment plants has strong requirements of security and of documentation.

Collection

As well as the law say the companies have to deliver WEEE to proper treatment, the companies also have strong requirements to the treatment plants. They often prefer the more secure plants where they can follow the process and be sure none of the equipment leaks out on the market. The companies have to pay for the equipment they want dismantled. This is done by paying per kilo equipment. Different types of equipment has different a price. The companies are the most important customer for Peru Green Recycling.

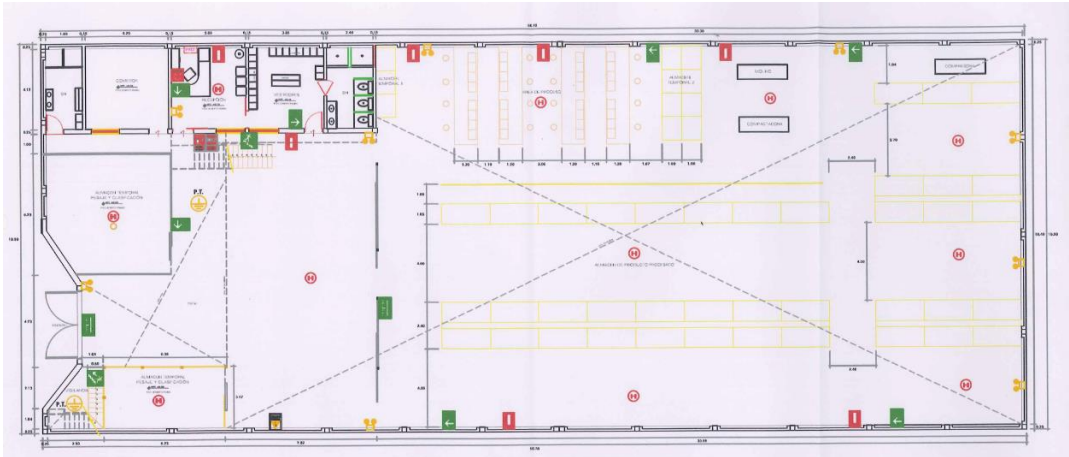
Other places the plant get WEEE is from the official sector. They don't pay, and unless the equipment is of a certain value, the plant does not accept the delivery. Also there are some points around in Lima where people can deliver their end-of-life electronics. The large electronics companies pay for this together. However there are small quantities reaching the collection points. Also there has been some campaigns to gather RAEs in the household, but small amounts has been gathered. This has been received by Green Recycling for free.

Most of the electronics delivered to Green Recycling is by companies, and are therefore more in order, newer products and with higher requirements to destruction documentation than with free deliveries.

Layout

Green Recycling is a modern manual dismantling plant, complying with all the requirements from Peru, and are always working to get better. The area of the

plant is 1130 square meters. It consists of delivery area, WEEE storage area, material storage area, dismantling area, hazardous component area, compactor, bathrooms, reception, office and an eating room. The storage and dismantling part is separated from the rest by a fence, and everyone entering the area has to go through a registration gate.



Delivery

The orders are agreed upon by email or phone when the companies has a delivery they want dismantled. They have to send a list of all the equipment with quantities, equipment type, identification numbers and weight. The recycling plant ask for a price per kilo depending on the type of the article. Before the order is accepted, the information has to be checked. It is done by three-four people from the plant plus people from the company. Preferably this is done before transported to the plant, but if not possible, it is checked in the delivery area.

The order is then transported to the plant in trucks and unloaded. The delivery is unpacked and reorganized by similar type on pallets. The cartoon is sent directly to a paper recycling company. The orders are weighted before placed in the storage department.

RAEE Storage

All the equipment is stored on pallets in the storage area. The storage area consists of a four floor high set of shelves as well as some floor space for larger pallets that doesn't fit in the shelves. The pallets are separated by client, and is marked with delivery and date so it is easy to have control. The transportation is done by manual pallet jack or by a pallet truck (always used for the elevated lifts). The storage area has a separate entrance.



Dismantling

Dismantling is done manually on tables with room for four people on each table. There are four rows of tables, with the possibility to add more when high demand. Each person has 1.50 m in the width and a bit less in depth, two drawers for tools and plastic boxes for the material in front. They use a magnet for screw collection. They use pneumatic drills.



One table work together to dismantle one pallet until it is done. For example all four on one table dismantle a pallet with laptops from one client. When the pallet is empty or when a box is full, the amount of the material is weighted, documented and taken to the proper material storage section. When a pallet is done, a pallet with preferably a different article (for variation) is started.

The tools they use are mostly the drill. With the pneumatic drill they have easier access to complicated screws than with a traditional electronic drill. They also use hammers (normal and sharp) to break parts apart. To triple the value of plastics they take stickers of the plastic with a chisel.

Hard drives, motors and some other small components are not dismantled because the time it takes does not justify the value. In the future they wish to get a shredder for the small parts that can separate copper and other metals and plastics. A machine like this was estimated to cost about 30.000 USD.

CRT screens are separated manually by people with special knowledge and protection clothing and mask. It is done by punching a hole in the screen and carefully remove the phosphorus. The cathode tube ray is removed carefully and stored as a hazardous component.

The plant has the equipment and competence to remove the gases from refrigerators. When a sufficient amount of refrigerators are accumulated, they have dismantled refrigerators completely. When this is done the dismantlers cut out the outer walls of the refrigerator and remove the plastic with the foam in safe bags. They know this is not an optimal way of doing it, but in lack of a larger system it is better than doing nothing. In a day eight workers can dismantle about 40 refrigerators. Personal protection clothing is used.

Material storage

Next to the dismantling station the materials are stored in cartoon boxes on pallets. The closest are for the materials that are compacted. As the boxes fill up, more cartoon is added, so the box is filled until it contains the sufficient amount to be compacted. Metals, plastics and cables are compacted. Some materials are stored in boxes and big bags in the back of the plant.



The hazardous materials are stored in safe containers in a closed of area in the back of the plant. Components are stored in metal buckets with lid. The area should not be entered by unauthorized people. It is well marked and closed off with a band. In the future they want to close it off more properly so it will be impossible to enter without the authorization.

A preoccupation for the plant is to find a way to earn money from the plastics. At the moment they pay to get rid of the plastics. One step they have taken is to remove all stickers. This reduces the price they have to pay to a third. Further they want to specialize in types of plastics and separate the types more carefully. At the moment plastics from similar products are separated (for example plastics from CPUs are separate from plastics from cell phones). By separating more carefully, the plastics can be sold for a significantly higher price. For further value adding they are thinking about getting a machine to shred and wash the plastic.

There are no good treatment options for the hazardous materials in Peru. When enough is accumulated all the hazardous materials are sent to one of two landfills for hazardous materials. The landfills comply with all the Peruvian standards. In the landfill the materials are stored safely with no further treatment.



Capacity

There are 33 people working in Green Recycling. Out of this there are 16 people dismantling, 4 people physically dealing with the deliveries and recollection, 1 with maintenance, 2 operation experts and the rest with administrative tasks, like marketing and sales, documentation and such.

With the plant today the capacity lies around an amount of 100 tons dismantled per month. With an amount like this, the process in itself is economically sustainable without the payment from the companies. In 2015 however, a total of 160 tons were received by the plant. The numbers are increasing, and as the laws get more followed up, it is expected to increase drastically.

The future plan of the plant is to increase to a capacity of 200 tons per month. This will require a larger location and more people.

Documentation

The requirements for documentation of the whole material flow are very high. When the WEEE enter the plant, the amount and type it is already well documented and controlled. Throughout the dismantling process, the weight and materials are followed up closely. Further the amount and type leaving the plant is documented, and the materials are sent to places with documentation

on proper handling. The documentation is available for the public and for the companies that want to follow the process. The documentation is kept for at least five years. The transparency of the business is important for the public, and it is a very important factor for the companies when choosing where to send their equipment. Also it makes it easy for the plant to know exactly what is going on. They have the data of tendencies in the market, efficiency of the workers, and a good overview of how well the system works. This is also documented and systemized by Peru Green Recycling, and used to improve the efficiency.

Peru Green Recycling fulfill all the requirements from the Peruvian public. They are also looking into getting international certification, and if not already fulfilling the requirements, they are close to doing so. The price for an international certification is however big (estimated about 25.000 USD for R2-certification), and this is the biggest obstacle.

Security

Security is one of the most important factors for the dismantling plant to function. There are different reasons for this. The normative is strict on security because of the environmental aspect, and require documentation showing that all the hazardous materials are handled correctly and sent to a safe place. The companies want to see that all their equipment is dismantled, and that nothing leaves the plant and can be reused or resold. That also go for the components. Another part is for the plant to be sure that none of the valuable materials are taken from the plant. This is what makes it possible for the business to survive. Also there are personal security that is important for the health of the workers.

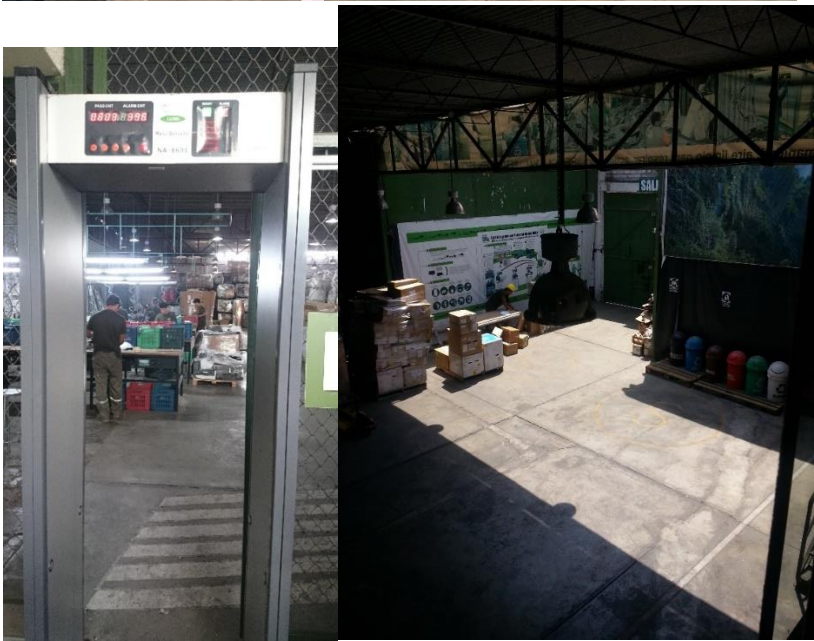
An important part of the security is that everything is documented carefully and its transparency. If anything is done insufficiently, it will be seen and will get consequences. The dismantling and storage area cannot be entered by unauthorized people, and the people entering has to go through an electronic registration gate. The area is also watched by cameras that are available to watch online.

To avoid articles leaving the plant they want to separate the WEEE storage from the rest by closed doors, so only authorized people can enter. This will lower the accessibility and efficiency of the plant, but the security factor justifies it. They are also looking for ways to make sure small valuable

equipment disappear from the dismantling process or from the material storage. There has not been problems with things disappearing in the plant.

The storage area for hazardous materials are marked and closed off from the rest, and the materials are stored in an acceptable way, so that accidents should not happen. People working with the hazardous materials wear masks and completely covering protection clothes. In the future they want to close off the area with closed doors to better the control of who is entering and what activities are going on.

For the personal security, all the workers has to wear reasonable protection equipment. Different quality tests are frequently done to ensure the safety of the workers. The noise level is kept below 80 dB and the dust levels are controlled and kept on an acceptable level. The health of the workers is also controlled by different tests, and after working with hazardous materials, blood contamination is controlled. A device to measure contamination in the water leaving the plant are planned installed in the close future.





Appendix XIII

Capacity Calculations

Table 1 Population in La Paz and Bolivia

<i>Place</i>	<i>Population</i>
<i>Population La Paz 2015</i>	789541
<i>Population Bolivia 2018</i>	11307314
<i>Population La Paz 2018</i>	804268
<i>Percentage La Paz</i>	7,1 %

Table 2: Capacity calculations

<i>Description</i>	<i>Value</i>
<i>Kg/Pers WEEE Bolivia 2018 UN</i>	5,1
<i>Population La Paz 2018</i>	804268
<i>Kg WEEE/year La Paz 2018</i>	4101767
<i>Ton WEEE/year La Paz 2018</i>	4101,767
<i>Ton WEEE/month La Paz 2018</i>	341,8139
<i>25% Capacity</i>	85,45348
<i>20% Capacity</i>	68,36278
<i>15% Capacity</i>	51,27209
<i>Capacity per person tons/month</i>	5
<i>% capacity: 60 ton/month</i>	17,55 %
<i>Amount of workers: 60 ton/month</i>	12

Appendix XIII

1 Documentation and certification

1.1 Documentation

Documentation of the work done in the plant and the type of articles dismantled is an important topic in WEEE dismantling. The articles dismantled contain hazardous materials, and to be able to show that it is safely handled and stored can be very important in many settings. A lot of the documentation in WEEE dismantling plants are mainly done to show to others that everything is in accordance with regulations and handled in a proper way. This is especially important for dismantling plants that dismantle WEEE for large international companies. These companies have policies to follow, and they want to be as sure as possible that all their electronics are dismantled fully and that nothing can re-enter the market. The plant itself will also have good use of documentation of the work, so they can know in detail how the work is going and what the tendencies in the market are.

Documentation of the work can involve documenting type and weight of the articles entering, what type and weight of materials can be found in the different articles, and times of dismantling and throughput times. Documentation of how the articles and materials are stored should be done to show that all the hazardous materials are stored properly. The weight of the articles and materials can be used to show that all of the hazardous materials are extracted and treated as they should.

The plant in La Paz will not dismantle for companies, and is therefore not as dependent on a very high level of documentation. It is however likely that future regulations in Bolivia will require documentation to show that all hazardous materials are treated properly. Good documentation can also be an important tool to see how the process is working and use it to optimize the production. On the other hand, the documentation process takes time. To find the balance in how much documentation to have and how much time to spend on it can therefore make a significant change in efficiency.

In the start-up of the separation plant in La Paz there will most likely not be very high requirements for documentation. This does however depend on the future regulations. The minimum recommendation is to document the types of articles coming in to the plant and their quantity measured in weight, and the weight of the materials leaving the plant. If using the minimum requirements, sample tests can be done regularly to check the weight of materials in one pallet of articles and the time it takes to dismantle, to get an indication of how the work is going. To have an overview of the hazardous materials, there should always be documented how much hazardous materials are stored in the plant. This can for instance be achieved by measuring the weight of materials added to the hazardous storage every time something is added.

1.2 Certification

In addition to the national regulations that the companies has to follow, there exist international certifications. An international certificate is a proof that the recycling plant is environmentally safe, is a safe work place and that it is a safe place to send your waste electronics, knowing they will be properly handled. The R2-certification is one of the most recognized certifications in the world. Only a few countries in Latin-America are in possession of this certificate. To fulfill the requirements of the certificate, the company has to document that all parts of their business is in accordance with their specifications. This requires a lot of documentation.

The plant design in this project is designed to be able to meet all the requirements of the R2-certificate. More experience should however be gained before applying for the certification. A lot of documentation of the work process is required, and a higher level of documentation in the plant can therefore be beneficial to gain experience for this process. The certification does also have a relatively high price, and it is therefore beneficial to have enough experience and knowing every part of the process before applying. As a partly public company with a socially beneficial model, a certificate is a strong quality mark. Having an internationally approved recycling system can also be appreciated internationally, and bring Bolivia towards the status of a more developed country. (36)

Appendix XVI

RISK ASSESSMENT MASTER THESIS

Deltakere ved kartleggingen: Geir Storesund, Eirik Vigerust

Dato: 01.02.2016

Tittel masteroppgave: Separation Plant for EE-waste for people with disabilities in Bolivia

Deltagere masteroppgave: Geir Storesund, Eirik Vigerust

Kort beskrivelse av hovedaktivitet/hovedprosess: Feltarbeid i Bolivia

Signaturer: Ansvarlig veileder:

Student:

Geir Storesund
Eirik Vigerust



Issue	Description	Consequence	Probability	Precaution
Weather and climate	Rainy season – more rain 90% chance of El Niño – increased prob. of unstable weather, flood and droughts	A	4	Very low probability of serious consequences. Need to pay attention to weather forecasts and follow local advices.
Altitude sickness	Much of Bolivia is in high altitude.	A	2	Will stay in a lower altitude city the first days. Have good experience with high altitude.
Language issues	Official language is Spanish.	A	3	We both speak Spanish deasently, but will practice more. Will be in close contact with English speaking people
Emergency help	If something happens, how is it to find consulates or hospitals?	C	2	Will stay close to bigger cities with hospitals. Stay close with foreign people working in Bolivia. Find consulates close to where we are.
Deceases and contamination	Different bacterial flora, worse hygiene and different culture.	B	2	Both have all recommended vaccination. Need to take precautions regarding hygiene and be careful with what we eat, drink and how we interact with people and places.
Transportation	Bad roads, much traffic, cars in bad shape, badly regulated and high amount of drunk driving	D	3	Need to travel between places, so transportation is hard to get around, and is always connected with risk. Will try to travel with good reputation transportation with bus, or drive with people we trust. Also travel in favorable parts of the day.
Crime – theft and smaller crime	Little culture for crime. We will stand out from the locals (by looks), so prob. increase a bit.	B	2	Only bring necessary valuables, stay together or preferably with locals, don't be out in insecure places after dark and be careful with money transactions.
Crime – violent or kidnapping	Little culture for crime. We will stand out from the locals (by looks), so prob. increase a bit.	E	1	Only bring necessary valuables, stay together or preferably with locals, don't be out in insecure places after dark and be careful with money transactions.

Crime - drugs	One of the bigger drug exporters in the world. Drugs can be planted in luggage.	D	2	Stay away from drugs and drug related environments. Keep luggage close and double check before safety controls.
Political instability	Some political issues and protests are common	B	2	Follow local recommendations and check local news. If caught in protests, keep low profile, and wait until it settles.