APPLICATION OF MATERIAL FLOW COST ACCOUNTING (MFCA) IN MICROALGAE MANUFACTURING COMPANY IN MALAYSIA

MAGESWARAN MURUGIYA

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2018

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MAGESWARAN MURUGIYA

RESEARCH PROJECT SUBMITTED TO THE FACULTY OF ENGINEERING UNIVERSITY OF MALAYA, IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTERS OF ENGINEERING (SAFETY, HEALTH AND ENVIRONMENT)

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ABSTRACT

Malaysian government showed special interest in manufacturing greener product and raising awareness regarding the environmental pollution due to industrialization. Frameworks from standards such as Life Cycle Assessment (LCA), Environmental Management Accounting (EMA) and a series of ISO14000 to reduce the environmental impact due to manufacturing. Material Flow Cost Accounting (MFCA), ISO 14051 is one of the principal tools used under EMA that focuses on establishing monetary unit on the waste generated in the processes involved in the manufacturing company. MFCA allows the company to track wastes and reducing it in each key process in the manufacturing company but there are few challenges that faced by Malaysian SMEs in implementing MFCA. The selected company for the study is a microalgae manufacturing company, ABC Sdn.Bhd. in Malaysia. The total material, energy, system and waste management costs were drawn out by constructing the material flow and the costs associated with it. Based on the specific objects of the study, all the costs relevant to MFCA is collected from the company and represented in the material flow matrix and calculated to identify the costs associated with the non-product output from the manufacturing process. Percentage of material input into products and material losses were taken into consideration in allocating system and energy costs in the single manufacturing line. For allocation of energy there were aspects taken into consideration; the running time of the machine and the efficiency of the machine in the production line. Result shows that 89.49% of the total cost allocated for the material while other costs about 10.50%. The costs allocated for the product accounted for 82.13% while cost of material losses in this process in general takes another 17.87%. As a result, the company realized that there is a room for improvement for reduction of material losses in the company. It was also found that the highest material lost was in the energy lost which is

about 40.52% compared to assumed by the company which is more or less about 10%. It was clearly seen that the company is losing more than 17% of their investment in the production that rather could be used for the improvement in efficiency of the machines and energy. The company also recommended to apply MFCA in all line of production to evaluate the total costs associated in the overall material losses thus it can be reduced.

ABSTRAK

Kerajaan Malaysia menunjukkan minat khusus dalam menghasilkan produk yang lebih mesra alam dan mewujudkan kesedaran mengenai pencemaran alam sekitar akibat perindustrian. Rangka kerja dari piawaian seperti Penilaian Kitar Hidup (LCA), Perakaunan Pengurusan Alam Sekitar (EMA) dan satu siri ISO14000 untuk mengurangkan kesan alam sekitar akibat pembuatan. Perakaunan Kos Aliran Bahan (MFCA), ISO 14051 merupakan salah satu alat utama yang digunakan di bawah EMA yang memberi tumpuan kepada penubuhan unit monetari pada sisa yang dihasilkan dalam proses yang terlibat dalam syarikat perkilangan. MFCA membenarkan syarikat mengesan sisa dan mengurangkannya dalam setiap proses utama di syarikat pembuatan tetapi terdapat beberapa cabaran yang dihadapi oleh PKS Malaysia dalam melaksanakan MFCA. Syarikat terpilih untuk kajian ini ialah syarikat pembuatan mikroalgae, ABC Sdn.Bhd. di Malaysia. Jumlah bahan, tenaga, sistem dan kos pengurusan sisa telah diambil dengan membina aliran bahan dan kos yang berkaitan dengannya. Berdasarkan objektif kajian ini, semua kos yang berkaitan dengan MFCA dikumpulkan dari syarikat dan diwakili dalam matriks aliran bahan dan dikira untuk mengenal pasti kos yang berkaitan dengan output bukan produk dari proses pembuatan. Peratusan input bahan ke dalam produk dan kerugian bahan telah diambil kira dalam memperuntukkan sistem dan kos tenaga dalam talian pembuatan tunggal. Bagi peruntukan tenaga, ada aspek yang dipertimbangkan; masa operasi mesin dan kecekapan mesin dalam barisan pengeluaran. Keputusan menunjukkan bahawa 89.49% daripada jumlah kos yang diperuntukkan adalah untuk bahan tersebut manakala kos lain 10.50%. Kos yang diperuntukkan untuk produk tersebut menyumbang 82.13% sementara kos kehilangan bahan dalam proses ini secara amnya mengambil 17.87% lagi. Akibatnya, syarikat menyedari bahawa ada ruang untuk penambahbaikan untuk mengurangkan kerugian bahan dalam syarikat. Ia

juga mendapati bahawa bahan yang paling tinggi yang hilang adalah kehilangan tenaga yang kira-kira 40.52% berbanding dengan yang di anggap oleh syarikat yang lebih kurang 10%. Jelas sekali, syarikat itu kehilangan lebih daripada 17% daripada pelaburan mereka dalam pengeluaran yang sebaliknya boleh digunakan untuk peningkatan kecekapan mesin dan tenaga. Syarikat itu juga disarankan untuk menggunakan MFCA dalam semua bidang pengeluaran untuk menilai jumlah kos yang berkaitan dengan kerugian keseluruhan bahan itu sehingga dapat dikurangkan.

ACKNOWLEDGEMENT

I would first like to thank my thesis advisor Professor Dr. Nik Meriam binti NikSulaiman of the Chemical Engineering Department at Faculty of Engineering. The door to Prof. Nik Meriam office was always open whenever I ran into a trouble spot or had a question about my research or writing. She consistently allowed this paper to be my own work, but steered me in the right the direction whenever he thought I needed it.

I would also like to thank the experts who were involved in the validation study for this research project which involves a microalgae manufacturing company, Mr.Nazrin and Mr.Irfan as well as expert in Material Flow Cost Accounting (MFCA), Professor Katsuhiko Kokubu and Professor Kimitaka Nishitani from Kobe University who gave input on this study during the MFCA Conference 2.0 held in Malaya University. Without their passionate participation and input, the validation study could not have been successfully conducted.

I would also like to acknowledge Ms. Rubini Devi, my batch mate who was my point of reference for this study and I am gratefully indebted to her for her very valuable help and guidance on this thesis. Lastly to my family members and fiancé, Ms.Davamalar who helped supports me throughout the completion of my study.

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LIST OF SYMBOLS AND ABBREVIATIONS

LCA	: Life Cycle Assessment
EMA	: Environmental Management Accounting
MFCA	: Material Flow Cost Accounting
QC	: Quantity Centre
EMS	: Environmental Management System
ISO	: International Standard Organization
MOF	: Ministry of Finance
DOE	: Department of Environment
JIS	: Japan Industrial Standard
TPM	: Total Productive Maintenance
TQM	: Total Quality Management
CO_2	: Carbon Dioxide
PBR	: Photobioreactor
OPR	: Open Pond Raceways
RS	: Red Stage
GS	: Green Stage
MC	: Mother Culture
R&D	: Research and Development
RM	: Ringgit Malaysia
LED	: Light Emitting Diode

CHAPTER 1: INTRODUCTION

1.1 Background of Study

The amount of waste generated in Malaysia keeps increasing and has become a major problem since it is associated with many other industries which lead to poor economic growth (Sakawi, 2017). The volume of the waste generated is depending on the economic growth of specific area and its nature of business from 0.45 to 1.44 kilogram per capita per day (Hassan *et al*., 1998). Waste in previous has not become a major issue, as the population increases and development in industrial sector, it plays a major role in determining the business of the country as well as the business.

Ever since the waste has become major issue to be overcome, Malaysia has promoted green technology which encourages industries to minimize the waste generation and using the alternative source of energy for production. According to Ministry of Energy, Green Technology and Water Malaysia, the goal has been set in three phases till the year 2021 and beyond involving key sectors of energy, buildings, water and waste as well as transportations (National Green Technology Policy, 2009).

In recent years, many steps or policies has been practiced to overcome the acceleration of waste generation from the industries. Various methods and guideline was handled to reduce the volume of waste produced such as ISO 14000 Series of Standards, life cycle assessments (LCA), environmental managements systems (EMS) and et cetera (Let, Weng, & Wahid, 2010). Yet, most of these guidelines are a tool to measure qualitatively not quantitatively which often neglected by the manufacturers.

Wastes from industries which includes the used or unused items, discarded due to off spec products, materials generated from manufacturing processes and even documentations from the administration departments to be a main contributor for waste generation in Malaysia (Mohd Nasir Hassan *et al.*, 2005).

Besides bigger manufacturing plant, small and medium enterprises (SMEs) are also contributing to the waste generation from industry. According to Key Statistics on SMEs., 2011, there was a total of 645,136 SMEs operating their businesses in Malaysia, representing 97.3% of total business establishments. These large numbers of entrepreneurs under SME have very limited access to all the guidelines and knowledge in EMS thus they are unable to implement it in their nature of business (Weerasiri, S., & Zhengang, 2011).

Most SME facing challenges in implementing environmental tool to monitor the waste accumulated from the production thus contributing to industrial pollution. There is a major constrain faced by SMEs ate lack of financing, productivity, access to technology and skilled workers (Wan, 2003). According to (Hoq, 2009), there are main key challenges faced by SMEs; low financial access, manpower constrains, less room for implementing high-tech machineries, lack of information and global competitions which made SMEs unable to perform any environmental correction in the manufacturing line.

In order to overcome the issues, simple management tools were introduced and educated to the top management of SMEs (Musa & Chinniah, 2016). Yet, many SME owners do not pay attention on the issue related to environment and the waste generated from the manufacturing process unless required by their ventures. Material Cost Flow Accounting (MFCA) is one of the environmental management tools besides EMS and LCA which would able to describe the wastes generated from the manufacturing process quantitatively. The main motive of implementing MFCA would be to enhance the productivity of business by reducing the cost of waste generated by the company (Mishelle & Hari Lall, 2015).

1.2 Problem Statement

As Malaysia is now growing towards a developed nation, many industrial revolutions have taken place to contribute economic growth. Ministry of Finance in 2014 stated that manufacturing industry contributes to Malaysian economy after service-based industry (MOF, 2014). But, manufacturing industries corresponds to volume of waste generated from the process which potentially can affect the environment if not handled properly (Yusup, Wan Mahmood, Salleh, & Ab Rahman, 2015). Many companies and stakeholders are interested to improvise the manufacturing not only to reduce environmental effect yet to increase the turnover of the company. Many models have been proposed such as eco-friendly indicators and modeled decision framework which enable the manufacturers to have alternatives such as projects, technologies or systems (Sarkis, 2003), Department of Environment under Malaysian government has taken many steps to introduce cleaner energy to enhance the productivity of manufacturing and to reduce environmental impacts due to the business. But, major drawback of implementing cleaner production and other related environmental tools in the manufacturing industry is the lack of knowledge, expert in the related field and level of acceptance among Malaysians (Ghazilla *et al.,* 2015). Life Cycle Assessments (LCA) is one of many methods used to evaluate the environmental impact from the manufacturing process but it does not predict absolute or precise value (ISO, 2006).

In this research study, the proposed method was MFCA to be used instead of other methods which used to measure the costs of the production in both physical and financial (Nakajima, 2006) and able to trace the area of improvement for ach specific steps in the manufacturing line. In the chosen company (microalgae cultivation) there are many ways where the energy and materials were used in large amount and not all of them contribute to the finished product. By implementing MFCA, the company would be able to establish an indicator for process improvement.

1.3 Objectives

The research study was aim to introduce and implement MFCA in a chosen industry as a key to identify and evaluate costs associated with the processes involve and the waste generated from the line of production. By the end of the project, the company would be able to trace the highest cost involve on the wastes and improve the line of the production to reduce the costs invested.

1.3.1 Specific Objectives

1. To calculate costs associated with the constructed material flow of the selected SME company.
2. To suggest and recommend improvement on the line of production from the output of MFCA.

1.4 Scope of the study

This research study was carried in a microalgae cultivation facility in Kuala Lumpur which is the only facility in Malaysia to cultivate such species of microalgae to be processed into supplements and feedstock. The facility uses strain from abroad to cultivate microalgae in smaller scale to larger volume which involves various stages of growth. The study was taken place in a final stage of cultivation which involves the suffocation of microalgae to produce lipid for further processing. The implementation of MFCA took place in 3 phases; preparation, data collection and calculation. The flow of materials, generation of products and waste were monitored from May 2017 to October 2017. Only one stage of the production was selected due to time constrain.

1.5 Significance of Study

This study is very essential for the company since the cost flow matrix will be showing the costs invested in each defined quantity center and the products and wastes associated in that particular quantity center. From the identified wastes in the process, the company will be able to compare the output from the process which contribute to be in the part of the product and wastes, which will reflect the amount of profit made from the single line of production.

These data is then can be used to minimize the waste generation in each stages by improving the method, replacing new machineries and other steps to reduce the costs associated with the material losses. In longer term, the company also will be able to reduce the material losses and eventually increase the profit to the company. The participating company would be also able to share benefits from implementing MFCA to other stakeholders so it can be implemented in other companies as well.

1.6 Outline of the study

This research report consists of 5 main chapters which are;

a) Chapter 1: Introduction

b) Chapter 2: Literature Review

c) Chapter 3: Methodology

d) Chapter 4: Results and Discussions

e) Chapter 5: Conclusion and Recommendation

CHAPTER 2: LITERATURE REVIEW

2.1 Background of Material Flow Cost Accounting (MFCA)

Material flow cost accounting (MFCA) has been introduced and practiced in Japan since 2000 with the aim to enhance the rate of productivity with was originated from Germany (Strobel, M., Redmann, 2000). MCFA focuses on the reduction of the waste which lead to environmental impact and simultaneously reduction of cost associate to the waste generation from the industry (Michiyasu Nakajima, Kimura, & Wagner, 2015). The endorsement from Japan is then expanded upon publication of international standard (ISO14051) in September 2011 and its adaptation on Japan Industrial Standard, JIS Q14051 in March 2012 (ISO, 2011).

Besides all the environmental tool, MFCA is the one of (Schmidt *et al.,* 2015) that has been used for managing the production flow of the manufacturing processes. The main advantage of implementing MFCA is due to its availability of the data on both quantity of material used and the cost associated in each stage in a constructed material flow. The data can be clearly seen and traced in each sub process in the manufacturing line (Quick Refrence To Material Flow Cost Accounting (ISO 14051).

MFCA provides accurate values of materials costs, energy costs and even waste management's costs attached to each line of manufacturing and the applicability is much wider and easier compared to other management tool available. Application of MFCA can be done in all kind of manufacturing line either single batch or continuous batch of production (ISO 2011).

The results obtained from the implementation of MCFA enable the management to look through the material and cost losses from the waste generation in the manufacturing process. This would immediately create awareness among the organization to work on the losses and plan for the suitable way to reduce the waste generated, as well as the cost associate with it (Kokubu, K., Tachikawa, H., 2013).

2.2 Concept of Material Flow Cost Accounting (MFCA)

Main component of the MFCA is to make a compressed tabulation data of data involving both input and output of the materials in a production line. The flow chart is defined with specific quantity centre where the input of each clearly defined. The inputs such(raw materials, energy, water, and other inputs) and outputs (primary products / byproducts, wastes, wastewaters, emissions) are determined within a quantity centre, and later is integrated to obtain the costs associated to it.

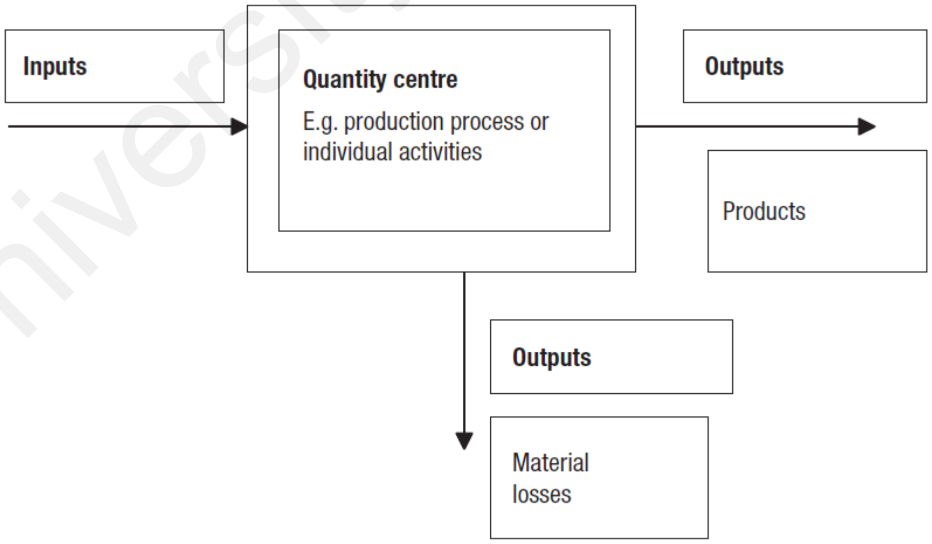

Figure 2.1: MFCA chart (Source:Palásek, 2009)

Product in each quantity centre is refers to any end product that resulted from the process of manufacturing and used as profitable and source of income for the company. In terms of the MFCA, the term material loss is not only seen in the narrow sense, but it refers to any and all invested materials, energy, and other economic resources, which were not transformed into products and leave unused as wastes.

MFCA focuses on the flow of material and the costs associated with the production line. Besides just providing the physical unit of quantity on each product in the production line it also provides the corresponding monetary unit of each material. The cost of material involve in each quantity centre in the manufacturing line is to be monitored in both physical and monetary unit thus accumulating the total costs in each production line and total waste generated in each line. Flow of material is drawn in each quantity centre and the data were obtained directly from the company in order to identify the input and output of the materials (Hyršlová, Vágner, & Palásek, 2011).

Besides material flow, all energy flow in the respective quantity centre also monitored by implementing MFCA. At the same time, the system cost also taken into consideration. A system cost in the production line often involves all costs that used to handle the materials into the line within the company. Each input for the company will be defined as carrier of system costs whether as a raw materials, work involves to handle the material, product and wastes generated in each line. System costs associated to the output of the where there are used in the sub flow and stock of the material. Wastes which leaves the quantity centre allocated as waste management cost (Hyršlová *et al.*, 2011). Implementation if MFCA in the data obtained from the company is allow the management to look for any corrective measures to be taken in two ways; increasing efficiency of a material and reducing the waste generated which shall contribute to economic growth of a company.

2.3 Material Flow Cost Accounting (MFCA) Facilitator

Sulong, Sulaiman, & Alwi, 2015 states that there are some factors required to facilitate the implementation of MFCA in the company that involves support from management to provide technical support and availability, access to data and continuous commitment from them. These factors would definitely give positive impact to the company from applying MFCA in each production line in the company.

Availability of technical support is the important facilitator to ensure the application of MFCA and used as an accounting pool since the wastes generated not only considered as negative product but it has the value or monetary unit associated with it (Jasch, C., 2009). This allows the costs involved in waste generation are more clearly to be seen and accounted compared to traditional cost accounting. These features enable the more accurate report to be produced in the end of MCFA implementation.

The availability of data is another important facilitator as Strobel and Redmann, C., 2002discovered that companies with data required for the study will enable MFCA implementation to be more accurate and easy to be traced. Companies with availability of data will shorten the period for the calculation of data in MFCA so that the company will be able to draw the corrective measure for reduction of waste generated in the company.

Next, the complicated and critical facilitator for implementation of MFCA is the commitment from top management to allocate time, money and resources for the study. Environmental Management Accounting (EMA) emphasized that senior management commitment is important so that the decision making on the corrective action shall be taken immediately to enhance the productivity of the company. Besides financial support from top management for the EMA study is also requires participation from various departments to ensure that implementation of corrective action can be efficient. Lack of support from the management, the outcome from EMA will not be considered important for the management. Without top management commitment, EMA projects, and hence MFCA projects, are likely to encounter substantial challenges and obstacles (Lee *et al.*, 2005)

Compatibility of MFCA to the existing management facilities can be the final facilitator for the implementation as it can make the procedure to be done smoothly. M. Nakajima, 2004 found that if the company has the existing system to monitor the quality would complement the implementation of MFCA. Existing system can be such as Total Productive Maintenance (TPM) and Total Quality Management (TQM). These systems if the company adapted to can make sure that the company will not face any difficulties implementing MFCA in their production line.

2.4 Material Flow Cost Accounting (MFCA) Challenges

There are some challenges faced by company to implement MFCA as stated in ISO 14051. These challenges are from all side of manufacturing line from top management as well as production team in a company which limits the use and practice of MFCA in various manufacturing company. These mainly relate to perception challenges (Kokubu and Kitada, 2010; Nakajima, 2004), team cooperation (Lee *et al.*, 2005), performance appraisal (Burritt, 2004, 2005) and technical knowledge and training (Burritt, 2004, 2005).

First of all, the perception challenges from the manufacturing field which misinterpret the main aim of the MFCA, which unable for them to distinguish between commercial accounting with MFCA. The clash on the perception also evolves on the main aim revolving the economic objective; which the manufacturing is to seek profit clashes with objective of MFCA. This is mainly due to clash of objectives from the corner of economics by the top management and environmental by the engineers (Wagner, M., Schaltegger, S., Wehrmeyer, 2001).

Lack of team cooperation is another barrier for implementation of MFCA especially manufacturing company involving multitier departments from general worker top management personnel. Generally, costs related to environment are available in the specific department only; same goes to other production costs such as systems, materials design and accounting. Since the availability of data is restricted in specific departments, the collection of these data from various departments requires intensive cooperation from the entire department in the company. Without support and commitment from all departments, the implementation of MFCA may be difficult to effectively measure the efficiency in the material flow (Lee *et al*., 2005).

Next challenge faced by MFCA implementation is the performance appraisals of both the individual and departments involved in EMA generally excluded environmental impacts. MFCA involves workers from various department and units from environmental department which including the engineers, top management and also from the production line of the company and clear line on the roles and responsibility must be made so that the implementation of MFCA will be effective (Jasch, 2009). Improper establishment of clear line may cause difficulties in implementing and applying MFCA in the production line.

More challenges faced in term of lack of technology and training for the workers on the application and importance of MFCA. This challenge is critical to calculation of MFCA as it may involve inaccuracy in identifying the costs involved in the manufacturing line. This is mainly because of different definitions and scope of environmental costs and also a perception that environmental costs are not important (Burritt, 2005).

2.5 Microalgae Cultivation

2.5.1 Methods of Cultivation

Algae can be grouped into two different categories; microalgae and macro algae which are unicellular and autotrophs. Algae has green pigments which utilizes carbon dioxide (CO_2), sunlight and water to perform photosynthesis (Kröger M, 2012). As the product of photosynthesis, the lipid will be accumulated in the body of algae which can be converted to valuable products such as fuel and energy source (Saharan *et al.*, 2013).

Biomass obtained from microalgae contains high number of lipids (~25%), proteins (~70%) and carbohydrates (~5%) and this may vary according to their species and environmental factor determining its growth (Becker, 2007).

The most used system in the researches to grow microalgae are open ponds (OPR) cultivation, photo-bioreactors (PBR) using transparent vessels, bags and pond system and hybrid systems currently used in research (pilot and laboratory) scale and industrial scale (Jankowska, Sahu, & Oleskowicz-popiel, 2017). Open pond system practiced in an open area with installed ponds supplied with nutrients to support growth. The buildup, installation and maintenance to be cheaper compared to other methods (Kröger M, 2012). Yet, this method has higher failure rate due to its open condition which may exposed to contaminants, vaporization and lack of control of parameter. According to (Borowitzka MA, 1994) the biomass concentration produced from this method is relatively low which approximately 10–25 g dry matter of algae biomass per day per m^2.

Method of cultivation using PBR is the most effective known as it is the closed system and easy to be controlled. Most of the company uses this method because it can produce more biomass compared to open system since the steps of cultivation can be optimized to prevent contamination with other species (Schenk P.M *et al.*, 2008). Even the cost of operation and maintenance is higher, the mass of biomass produced were comparatively higher which is about 20 and 100 g dry per day per m^2 (Mirón AS, *et al.*, 1999). Recently, the combination of OPR and PBR is being implemented and known as a hybrid system.

2.5.2 Cultivation of *Haematococcus pluvialis*

Haematococcus pluvialis is a eukaryotic freshwater microalgae which changes its physical characteristics under different environmental condition. The stages of cultivation differs from green juvenile phase to red phase which happen due to stress (lack of basic need) causes accumulation of astaxanthin (Boussiba, 2000). Astaxanthin is known as most powerful antioxidant found naturally to enhance the health of human due to its usage as in cosmetics and supplements (Martin Koller, Alexander Muhr, 2014).

Cultivation of these microalgae mainly uses water as its medium of growth is divided into two parts; green juvenile stage which undergoes frequent cell division, propagate and produces chlorophyll, red stage when there is no cell division, only accumulation of lipids which later processed to extract astaxanthin (S. Boussiba, A. Vonshak, Z. Cohen, 1991). During green stage (GS),complete need for the growth such as moderate light intensity, pH and temperature is supplied to increase the number of cells and later in red stage (RS) the cell inhibits growth and triggered to accumulate astaxanthin as a result of nutrient starvation (Markou & Kazakis, 2013).

Before the cultivation process started, the culture will be kept under a perfect condition in smaller volume known as Mother Culture (MC), later transferred into a PBR bags where the environmental and nutritional condition can be controlled and can achieve the required growth volume. In this stage, the culture is constantly mixed to avoid settling of the sediment at the bottom of the bag at the same time to encourage gaseous exchange in the bags. This is achieved by applying turbulent flow with the help of mechanical pump (Liam Brennan & Philip Owende, 2010).

Later for the red stage (RS), open pond system is opted in order to offset the high construction and operation cost in GS. The pond is design about 0.3m depth and installed a propeller to enhance the gases exchange. The algae will left suffocate without nutrient which accumulates red substance called astaxanthin will be harvested and processed (Liam Brennan & Philip Owende, 2010).

Upon completion of RS, in order to recover the product as seen in Figure 2.1 either in solid biomass or oleoresin (lipid content) , the culture will need to undergo a process to reduce the water content either flocculation and settling, centrifugation, filtration or air flotation depending on the size and density of the cell (Brentner, Eckelman, & Zimmerman, 2011).

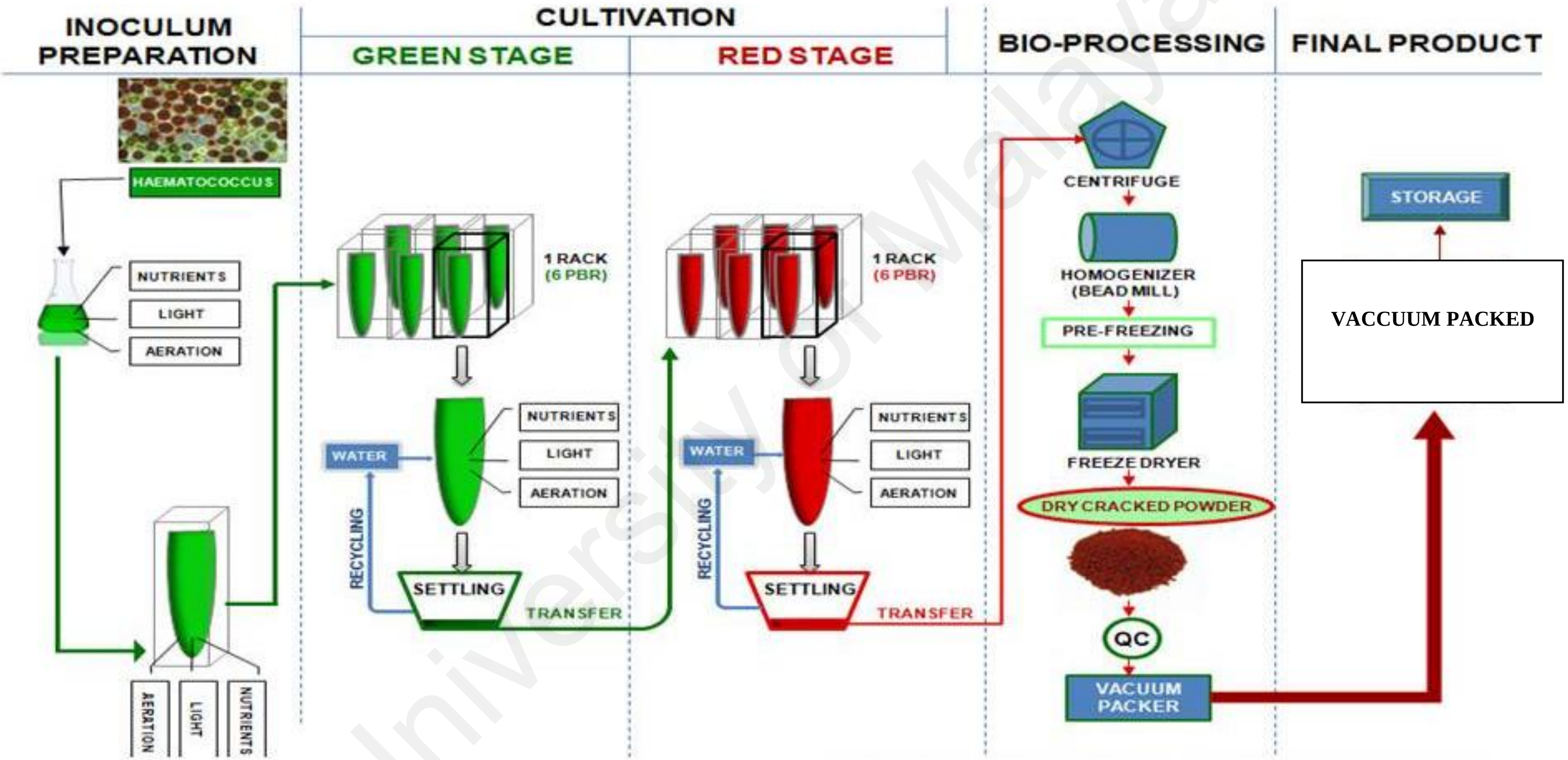

Figure 2.2: Typical Flowchart of *Haematococcus pluvialis* in Production of Astaxanthin

2.5.3 Challenges in Microalgae Cultivation

Use of PBR bags or tubular model can be challenging as the pressure increases as the volume of the cultivation increases. Even closed PBR is the best method of cultivation (Eldridge & Aditya M. Kunjapur*, 2010), yet the initial cost of installation is major drawback of this method compared to open pond system (Elrayies, 2018). Besides that, most of the production facilities to cultivate microalgae harvests only the biomass which contributing about 1% of the total culture, remaining 99% is waste been treated or recycled where both are expensive procedure (Zhang *et al.*, 2014). On the other hand, the energy required to cultivate microalgae indoor using PBR are relatively high about 15 times higher compared to open pond system as reported in 2010 (Jorquera, Kiperstok, Emerson, Marcelo, & Maria, 2010). Some of the discarded water from the PBR without proper treatment may cause eutrophication causes the water or lake system interrupted by residual of chemicals used in the media preparation (Usher *et al.*, 2014). Some of the open pond cultivation causes the release of methane gas can be potential to greenhouse effect.

CHAPTER 3: METHODOLOGY

Methodology for this research study was adapted from ISO 14051 Environmental management: the general framework of material flow cost accounting (MFCA). The implementation of MFCA in the selected company were done in three phases; preparation, data collection and calculation. The selected company's manufacturing line was monitored for 6 months (May – October 2017). The study was carried in the stages as below:

1. Literature Research
2. Finding Company for Research
3. Obtaining Production Data
4. MFCA Implementation

Figure 3.1 will illustrating the flow chart of the methodology in this research project.

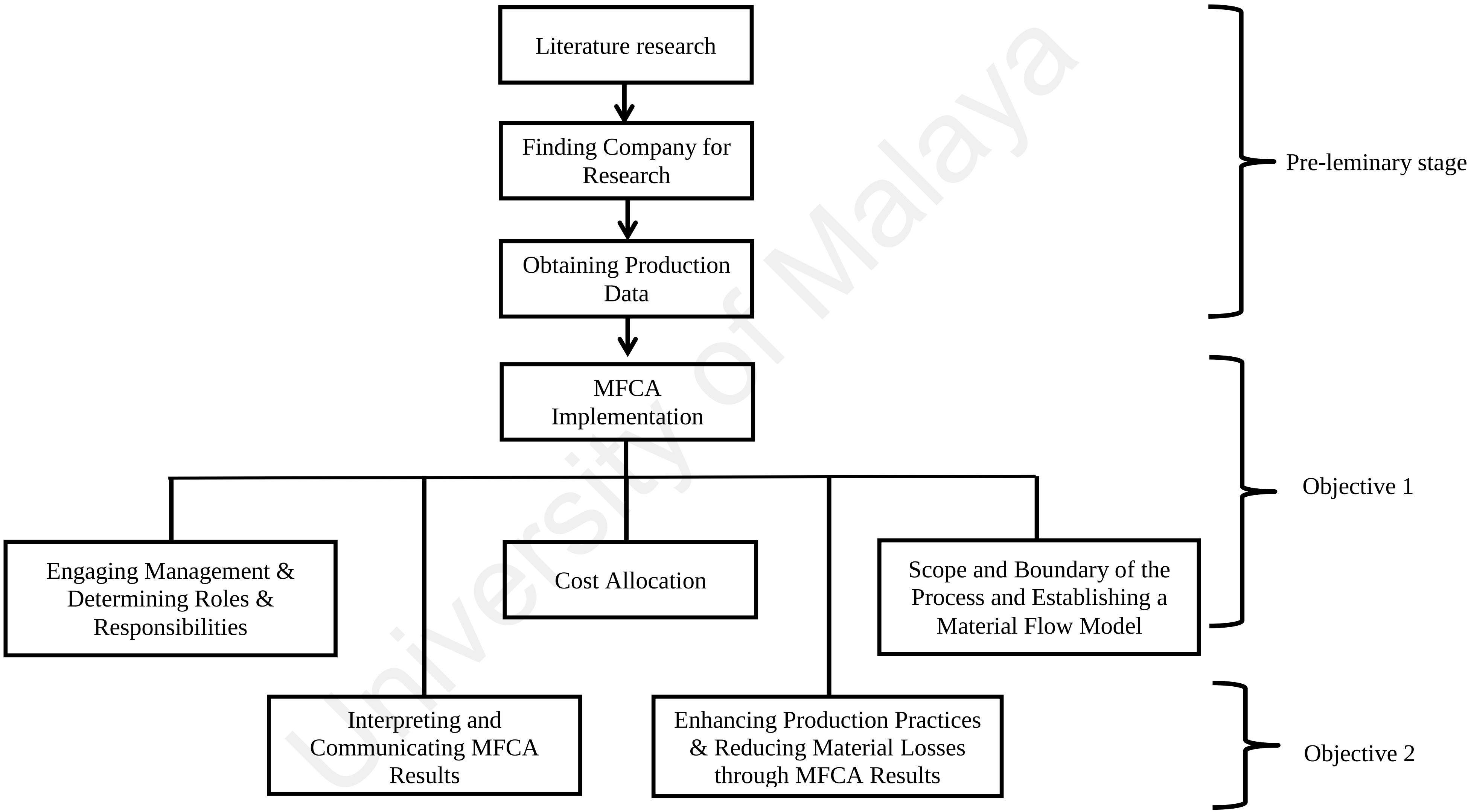

Figure 3.1: Flow Chart of Research Project

3.1 Literature Research

MFCA is a new method that was introduced in late 90s and in Malaysia the knowledge just been implemented in 2015, resulted in lack of references in Malaysian manufacturing sector. Most of the reading material and findings were taken from ISO 14051 and some industries which implemented this in Japan (lens manufacturing company) and Germany as guidance. Very few paper which were available in Malaysia also used in this study.

3.2 Finding for the Company

Choosing a suitable company has been challenging as the chosen manufacturing company should be disclosing production data for the calculation of MFCA. The companies currently aimed for the research are such as semiconductor, food manufacturing and microalgae manufacturing companies. A letter requesting for companies' approval to conduct the research will be sent to each potential company one by one until a company agrees.

3.3 Obtaining Production Data

A chosen company's single manufacturing line (RS) has been chosen and the total production data were monitored and collected for the 6 months. This data includes volume used in the cultivation and cost of input materials, output materials and any wastage in the middle of processes.

3.4 MFCA Implementation Steps

3.4.1 Engaging Management and Determining Roles and Responsibilities

To ensure MFCA is implemented successfully, the management should give full support so that the research project would have the freedom in assessing single manufacturing line. At the end of the project, a strong support and participation of all level of management is recommended to implement MFCA in various steps in the process.

3.4.2 Scope and Boundary of the Process and Establishing a Material Flow Model

Restriction on MFCA need to identify and understands clearly the scale of MFCA activity based on collected material flow data. For this research project, only single line in the manufacturing process has been chosen due to limitation of time and sufficient to cover the objective of the study. Upon identification of boundaries are established, the data can be collected as specified to the requirement of MFCA.

3.4.3 Cost Allocation

MFCA divides costs into the following categories:

- Material cost: cost for a substance that enters and/or leaves a quantity center
- Energy cost: cost for electricity, fuel, steam, heat, and compressed air
- System cost: Cost of labor, cost of depreciation and maintenance, and cost of transport
- Waste management cost: cost of handling waste generated in a quantity center

3.4.4 Interpreting and Communicating MFCA Results

Implementation of MFCA enables the company to identify the costs associated to the material loss besides providing abundant of details throughout the manufacturing line. These information which comprises materials costs, energy costs, system costs and waste management cost for the process as well as corresponding wastes generated from the production line. By identifying the costs associated with generated waste, the management would be able spot the highest waste generation in the production line can be monitored and modified in order to contribute more on the profit for the company rather than been an economical waste. These details of all the costs contributing to product and waste will be represented in details in flow cost matrix on each identified quantity center.

3.4.5 Improving Production Practices and Reducing Material Loss through MFCA Results

From the analysis of data done via implementing MFCA in the single line of the production, the information shall be disclose with the management and the organization may review the data associated with the costs of material loss. The organization which comprises the highest authority with production manager may take a look on the factors contributing to material loss and identify room for improvements to reduce wastes. The improvements shall be taken into consideration both from environmental and financial aspects by improving the efficiency of the machines, modifying production practices, substitution of raw materials and intensive R&D to enhance the productivity of the microalgae.

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Selection of Manufacturing Company

The company used for this study is situated as Puchong, Selangor. It is a well-known company for the manufacturing of microalgae and the only facility to grow microalgae in Malaysia. The company is the pioneer in the microalgae manufacturing and specialized in research and development (R&D), consultation as well commercialization of products derived from microalgae. These products are later been processed into cosmetic and feedstock manufacturing as well as in pharmaceutical business. The company is just started to be concern on the environmental effect due to their practices and giving attention on the manufacturing environmental-friendly products. As observed in the study, the company is now keen on the recycling on raw materials such as PBR bags and waste water treatment to be reused in the plant. As requested, in this study the identity of the company is not disclosed and hence will be identified as ABC Sdn. Bhd.

4.2 Identification of Cost Centre.

The flow of material used in this study is based on the red stage (RS) known as final stage of cultivation of microalgae before it sent for the further process to extract the biomass. The RS is where the microalgae will be undergoing starvation of nutrient and will produce red pigmentation (lipid) which later extracted as Astaxanthin. There were total of five Quantity Centre (QC) chosen for the study in RS which involves; preparation, water treatment, inoculation, adjustment and lastly harvesting.

In the flow of process, the wastes are only generated in QC5: Harvesting which sum up into 16.43% of total material flow in the RS. Water is used as main medium for cultivation of microalgae and the company chooses PBR bags to avoid contamination and evaporation on the microalgae. RS was placed on the second floor of the manufacturing plant; enable the company to harvest sunlight for the stressing of the algae which also a factor to accumulate more astaxanthin in the cells. The PBR bags were arranged in the rack supplied with aeration and ventilation opted for the stage is exhaust fan and cooling pad. In this stage, microalgae were also supplied with artificial lighting which functions during night time to enhance the accumulation of astaxanthin in the cell. The workers will take samples randomly about 10 to 15ml from each bag and sent for quality check to ensure the cells are in good conditions. In addition, the staffs also required to check all other parameters in this stage which involving the record of temperature and light intensity.

4.2.1 Preparation

At this stage, the PBR bags are filled with water and supplied with aeration as the first step in the process. The bags will be arranged in the racks and get prepared with the aeration system for the next step. Usually this process is the most time consuming as it involves more labor works and mostly are manual.

4.2.2 Water treatment

Even the water used from local water supply, the company adapted for systemic water treatment function from the main source to the one used in the premises. The water will undergo series of filtration and ozone treatment, the company performed chlorination and dechlorination at this stage to make sure the water used as medium for the cultivation of microalgae is free from any contaminants.

4.2.3 Inoculation

At this stage which after 2 days of preparation, the inoculum is received from green stage (GS). The cells are now fully grown and meet the specifications after check by the quality department and ready to be cultivated at RS. There will be no more cell division at this stage, the cells will be stressed and suffocated without nutrient and unfavorable environmental conditions such as temperature and higher light intensity. About 600ml of sludge (concentrated liquid with cells) will be channeled to each bag via a drainage system and then will be sealed using another material. This process will be done in batch or continuous system depending on the volume of the culture transferred from GS.

4.2.4 Adjustment

After few days in RS, the culture will be chosen to be sent for quality check and the parameters are checked thoroughly. These include the appearance of the cells, the cell weight, size and most importantly the pH of the culture. Upon receive of report from the QA department, the adjustment of the pH shall be made by adding chemicals into the culture and again the culture is checked to ensure to adjustment is effective. This quantity center is the lowest material costs used.

4.2.5 Harvesting

At this stage, the aeration will be stopped to enable the cells to settle down at the bottom of the PBR bags. The cells is now been accumulated with astaxanthin and ready to be sent to further processing to extract the oleoresin and later processed into a powder. This is the only quantity centre to face a major material loss which about 16.43%. The end product which is the sludge will be approximately about 600ml will be collected and passed for bioprocessing involve centrifugation, cracking and freeze-drying. The RS completes here with total material recovered about 83.57%

4.3 Cost Calculation and Allocation

4.3.1 Calculation of Material Costs

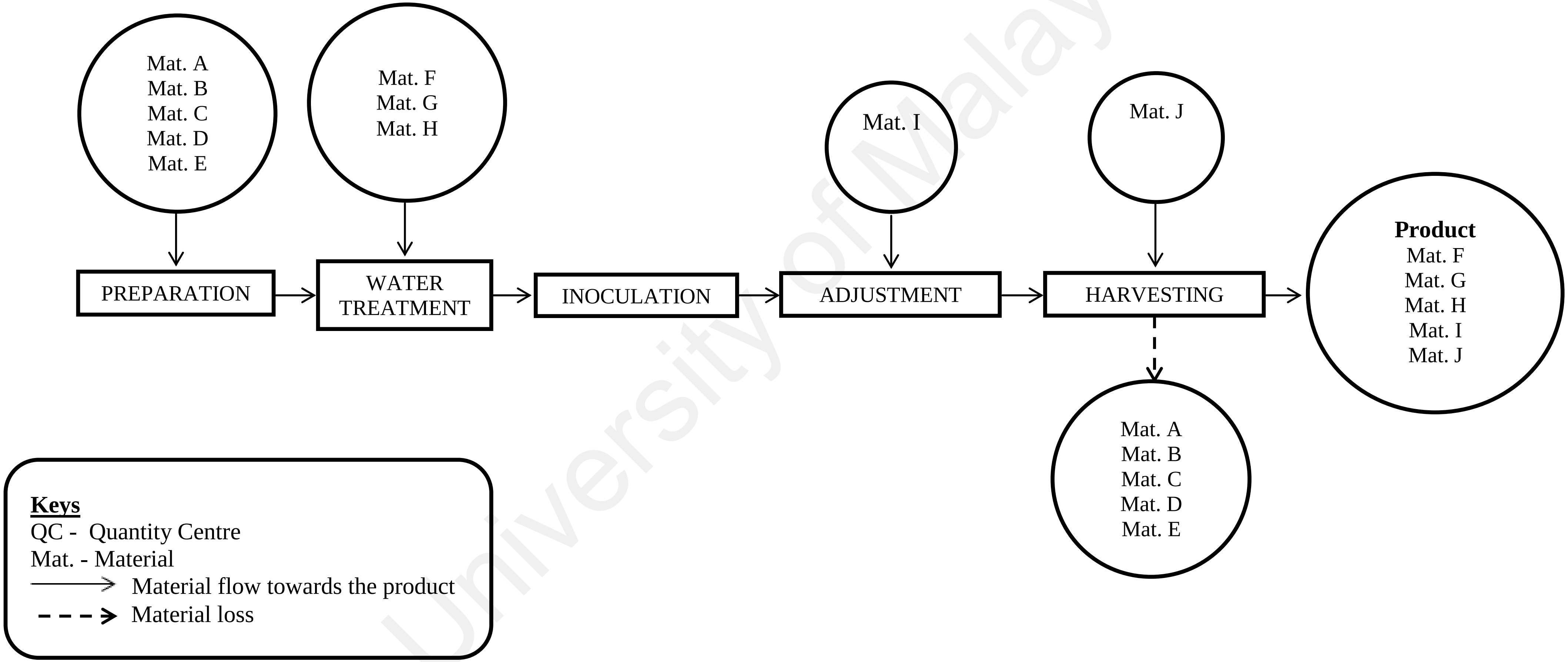

Figure 4.0.1: Material Flow in RS of ABC Sdn.Bhd.

Table 4.1: Material Costs for Constructed Flow Model Process

Period: May – October 2017

Composition of product and material losses	QC 1			QC 2		
	Preparation			Water Treatment		
Products	**Price per bag (RM)**	**Total number of bags**	**Costs (RM)**	**Price per bag**	**Total number of bags**	**Costs (RM)**
Material A	0.15	56640	8496.00	0.15	56640	8496.00
Material B	0.17	56640	9628.80	0.17	56640	9628.80
Material C	1.15	56640	65136.00	1.15	56640	65136.00
Material D	0.2	56640	11328.00	0.2	56640	11328.00
Material E	3.25	56640	184080.00	3.25	56640	184080.00
Material F	-	56640	-	0.1	56640	5664.00
Material G	-	56640	-	0.08	56640	4531.20
Material H	-	56640	-	0.02	56640	1132.80
Material I	-	56640	-	-	56640	-
Material J	-	56640	-	-	56640	-
			278668.80			289996.80
Material Losses	**Price per bag (RM)**	**Total number of bags**	**Costs (RM)**	**Price per bag**	**Total number of bags**	**Costs (RM)**
Material A	-	56640	-	-	56640	-
Material B	-	56640	-	-	56640	-
Material C	-	56640	-	-	56640	-
Material D	-	56640	-	-	56640	-
Material E	-	56640	-	-	56640	-
Material F	-	56640	-	-	56640	-
Material G	-	56640	-	-	56640	-
Material H	-	56640	-	-	56640	-
Material I	-	56640	-	-	56640	-
Material J	-	56640	-	-	56640	-
			-	-		-

Table 4.1, continued: Material Costs for Constructed Flow Model Process

Period: May – October 2017

Composition of product and material losses	QC 3			QC 4		
	Inoculation			Adjustment		
Products	**Price per bag (RM)**	**Total number of bags**	**Costs (RM)**	**Price per bag**	**Total number of bags**	**Costs (RM)**
Material A	0.15	56640	8496	0.15	56640	8496
Material B	0.17	56640	9628.8	0.17	56640	9628.8
Material C	1.15	56640	65136	1.15	56640	65136
Material D	0.2	56640	11328	0.2	56640	11328
Material E	3.25	56640	184080	3.25	56640	184080
Material F	0.1	56640	5664	0.1	56640	5664
Material G	0.08	56640	4531.2	0.08	56640	4531.2
Material H	0.02	56640	1132.8	0.02	56640	1132.8
Material I	19.75	56640	1118640.00	19.75	56640	1118640
Material J	-	56640	-	0.1	56640	5664.00
			1408636.80			1414300.80
Material Losses						
	Price per bag (RM)	**Total number of bags**	**Costs (RM)**	**Price per bag**	**Total number of bags**	**Costs (RM)**
Material A	-	56640	-	-	56640	-
Material B	-	56640	-	-	56640	-
Material C	-	56640	-	-	56640	-
Material D	-	56640	-	-	56640	-
Material E	-	56640	-	-	56640	-
Material F	-	56640	-	-	56640	-
Material G	-	56640	-	-	56640	-
Material H	-	56640	-	-	56640	-
Material I	-	56640	-	-	56640	-
Material J	-	56640	-	-	56640	-

Table 4.1, continued: Material Costs for Constructed Flow Model Process

Period: May – October 2017

Composition of product and material losses	QC 5			TOTAL COST
	Harvesting			
Products	**Price per bag (RM)**	**Total number of bags**	**Costs (RM)**	**1414300.80**
Material A	0.15	56640	8496	8496.00
Material B	0.17	56640	9628.8	9628.80
Material C	1.15	56640	65136	65136.00
Material D	0.2	56640	11328	11328.00
Material E	3.25	56640	184080	184080.00
Material F	0.1	56640	5664	5664.00
Material G	0.08	56640	4531.2	4531.20
Material H	0.02	56640	1132.8	1132.80
Material I	19.75	56640	1118640	1118640.00
Material J	0.1	56640	5664	5664.00
			1414300.80	
Material Losses				
	Price per bag	**Total number of bags**	**Costs**	**278102.40**
Material A	0.15	56640	8496	8496.00
Material B	0.16	56640	9062.4	9062.40
Material C	1.15	56640	65136	65136.00
Material D	0.2	56640	11328	11328.00
Material E	3.25	56640	184080	184080.00
Material F	-	56640	-	-
Material G	-	56640	-	-
Material H	-	56640	-	-
Material I	-	56640	-	-
Material J	-	56640	-	-
			278102.40	***1692403.20***

The total material cost has been calculated in terms of per bag as the unit used for the material A to B were differs from one another, for example material A was in the form of solid (grams) and the following material B was in the liquid form. The costs associated in the production also calculated in term of PBR bags of culture accommodate in the manufacturing plant, thus MFCA for this industry calculated as followed by the company.

During the study period which was from May 2017 to October 2017, the plant had produced total of 56640 bags of culture which corresponds to total manufacturing costs of RM 1, 692 403.20 and the wastes generated throughout the process is about 16% mainly on the material loss which not becoming the part of the finished product.

4.3.2 Calculation and Allocation of Energy Costs, System Costs and Waste Management Cost.

Total costs for energy, system and waste management was obtained directly from the company and later for each quantity center was calculated according to the cost data. Table 4.2 shows the allocation of energy costs, system costs and waste management costs leaving from each quantity center.

Table 4.2: Energy costs, system costs and waste management costs in each QC.

Type of Cost	QC1	QC2	QC3	QC4	QC5	Total Cost
Energy Cost (RM)	1059.84	1059.84	1059.84	136569.6	2119.56	141868.68
System Cost (RM)	3000	1800	1800	45000	3600	55200
Waste Management Cost (RM)	0	0	0	0	1680	1680

4.3.3 Calculation and Allocation of Energy Costs, System Costs and Waste Management Costs to Products and Material Losses in each QC.

4.3.3.1 Calculation and Allocation of System Costs and Waste Management Costs to Product and Materials Losses in each QC.

In this research study, it is decided to take consideration on the material losses to be used to determine the system and waste management costs in each QC. Thus, the percentage of products and material losses in each QC as stated in table 4.1.

In the whole manufacturing process in RS, none of the QC contributed to material losses up to QC4 where the inputs are utilized completely which is 100.00% in the cultivation of microalgae. QC5, the harvesting processes contributes to the only material loss in the process which is about 16.43% from the total input and corresponding to the product is about 83.57%.

Table 4.3 shows the summary of material distribution percentage for calculation of system cost. The percentages are calculated based on the Table 4.1.

Table 4.3: Summary of Material Cost Distribution Percentage

Period: May – October 2017

Type of cost	QC 1 (RM)	QC 2 (RM)	QC 3 (RM)	QC 4 (RM)	QC 5 (RM)
Product	278668.80 (100.00%)	289996.80 (100.00%)	1408636.80 (100.00%)	1414300.80 (100.00%)	1136198.40 (83.57%)
Material Losses	0 (0.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)	278102.40 (16.43%)
Total	278668.80 (100.00%)	289996.80 (100.00%)	1408636.80 (100.00%)	1414300.80 (100.00%)	1414300.80 (100.00%)

4.3.3.2 Allocation Criteria for Energy Use

Quantification of energy for each QC can be obtained by considering the efficiency of machines and wastage from the company. The additional data from machinery were obtained directly from ABC Sdn. Bhd and then were used to calculate the energy inefficiency and wastage in the manufacturing process in RS. The inefficiency in the process were measured in 2 aspects; the operation time and machine inefficiency as the third aspect material inefficiency was neglected since the manufacturing process in based on continuous cultivation from previous stage. Energy efficiency for each QC was shown below:

For quantity center 1 (Preparation):

(a) 3% of the running time of the energy was wasted to start up, maintenance and calibration hence only 97% of the energy is used for the production. The premise uses electrical machines which need to undergone some calibration and inspection so that the culture is supplied with sufficient amount for the process.

(b) Almost all the machines used in the premises can work efficiently up to 95% and the remaining energy is wasted due to inefficiency of the machine itself.

For quantity center 2 (Treatment)

(a) Total of 97% of the energy is used for the manufacturing process which become the part of product, balance 3% was used in on off basis for the setup and calibration to prevent any failure during operation

(b) At this stage, some of the machinery is inefficient by 5% which resulting in the usage of the 95% for the manufacturing process. This is pure on the machine inefficiency compared to calculate and expected value for the production.

For quantity center 3 (Inoculation);

(a) At this point, equipment such as funnel, measuring cylinder and beakers were used to transfer the culture from GS into the PBR bags. This equipment needed some time to be sterilized which is about 3% of the energy is used up for this. About 97% of the energy is used as a part of the process.

(b) Usage of semi-automated equipment causes the reading of the volume are inaccurate causes some of the residual are left in the equipment and thrown. This lead to about %5 inefficiency of the equipment used.

For quantity center 4 and 5 (Adjustment and Harvesting);

(a) Artificial lighting and exhaust fan were used to maintain the desired temperature and light intensity but it was just used 12 hours in daily basis. The operation (switching on and off) and maintenance of this equipment used up about 6% of the total operating time thus resulting in only 94% used for the manufacturing purposes.

(b) These are the longest duration where the culture been exposed to extreme temperature and light intensity. Initially the company was using fluorescent lamp to provide higher light intensity and recently it changed to LED lighting. Company also uses exhaust fan to maintain the temperature which was placed in a bigger gap from the rack of PBR bags. However, in both stages the equipment shows only 82% efficient due to energy lost in the form of heat, temperature lost to environment and light source is not fully penetrated into the PBR bags.

For each item mentioned in the energy allocation and loss in (a) and (b) represented in the figure below:

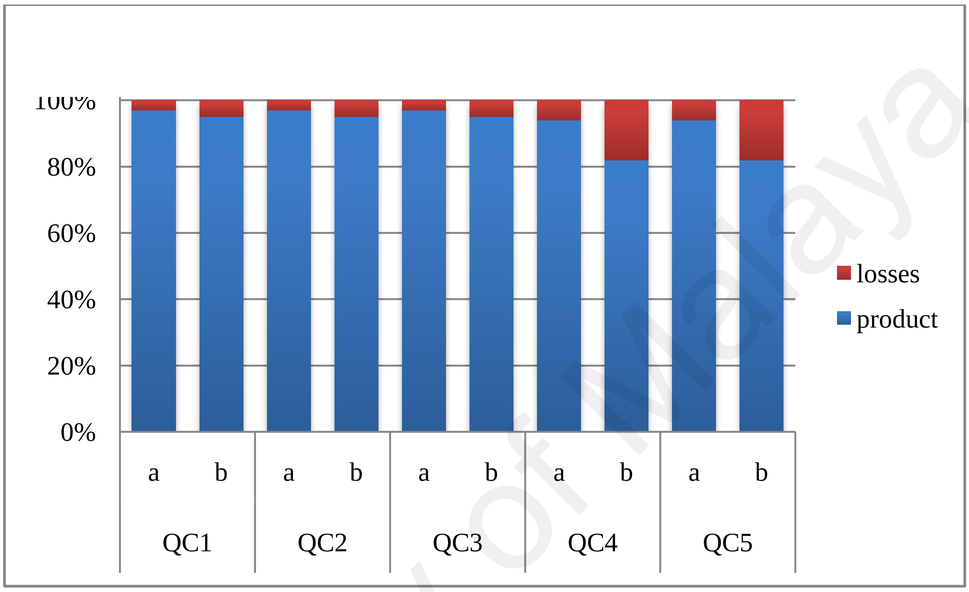

Figure 4.2: Quantification of energy loss in all QCs

In total, energy costs were RM141, 868.68 for the total of 6 months the study carried out in the industry. During QC 4 (adjustments), the energy allocated was the highest which is about 96.26% due to the duration of the culture placement in the premise. However, only 77.08% of the energy was used directly to the product and remaining 22.92% contributes to material losses. This loss is about RM31, 301.75 which is about 28.5% the total cost allocated for energy.

Table 4.4 shows energy allocation for each quantity center calculated from Figure 4.2. This allocation was used to calculate energy cost to product and material loss as criteria.

Table 4.4: Percentage of Energy Allocation for each QC

Quantity Center	Energy Allocation for Product	Energy Allocation for Material Losses
QC 1	92.15%	7.85%
QC 2	92.15%	7.85%
QC 3	92.15%	7.85%
QC 4	77.08%	22.92%
QC 5	77.08%	22.92%

4.3.4 Integrated Presentation and Analysis of Cost Data

All the cost associated in the manufacturing process was presented in the Table 4.5 comprising material, energy, system and waste management cost. The data was derived as in the material cost in Table 4.1 at each quantity center.

Material costs were calculated from the material flow in the process, energy costs is calculated based on the allocation of criterion that established as machinery setup, calibration, maintenance and its inefficiency which contributed to waste of energy. System costs were applicable from the company and later corresponding losses is calculated based on the percentage of material losses and allocation to a product. As for waste management, there is no contribution to product as the total costs were taken to be a part of material losses.

Table 4.5: Material Flow Cost Matrix in ABC Sdn. Bhd

Period: May 2017 – October 2017

	QC 1				QC 2				
	Material Costs (RM)	Energy Cost (RM)	System Costs (RM)	Waste Management Cost (RM)	Material Costs (RM)	Energy Cost (RM)	System Costs (RM)	Waste Management Cost (RM)	Total (RM)
Input from previous QC					278668.8	976.64	3000	0	282645.44
New Inputs in QC	278668.8	1059.84	3000	0	11328	1059.84	1800	0	14187.84
Total in each QC	278668.8	1059.84	3000	0	289996.8	2036.48	4800	0	296833.28
Product	278668.8	976.64	3000	0	289996.8	1876.62	4800	0	296673.42
Material Losses	0	83.2	0	0	0	159.86	0	0	159.86
Total cost of material losses on this process					0	243.06	0	0	243.06
Total costs in this process					289996.8	2119.68	4800	0	296993.14

Table 4.5, continued: Material Flow Cost Matrix in ABC Sdn. Bhd

Period: May 2017 – October 2017

	QC 3					QC 4				
	Material Costs (RM)	**Energy Cost (RM)**	**System Costs (RM)**	**Waste Management Cost (RM)**	**Total (RM)**	**Material Costs (RM)**	**Energy Cost (RM)**	**System Costs (RM)**	**Waste Management Cost (RM)**	**Total (RM)**
Input from previous QC	289996.8	1876.62	4800.00	0	296673.42	1408636.8	2705.95	6600.00	0	1417942.75
New Inputs in QC	1118640	1059.84	1800	0	1121499.84	5664	136569.6	45000	0	187233.6
Total in each QC	1408636.8	2936.46	6600	0	1418173.26	1414300.8	139275.55	51600	0	1605176.35
Product	1408636.8	2705.95	6600	0	1417942.75	1414300.8	107353.59	51600	0	1573254.39
Material Losses	0	230.51	0	0	230.51	0	31921.96	0	0	31921.96
Total cost of material losses on this process	0	473.57	0	0	473.57	0	32395.53	0	0	32395.53
Total costs in this process	1408636.8	3179.52	6600	0	1418403.77	1414300.8	139749.12	51600	0	1637098.31

Table 4.5, continued: Material Flow Cost Matrix in ABC Sdn. Bhd

Period: May 2017 – October 2017

	QC 5				
	Material Costs (RM)	**Energy Cost (RM)**	**System Costs (RM)**	**Waste Management Cost (RM)**	**Total (RM)**
Input from previous QC	1414300.80	107353.59	51600.00	0.00	1573254.39
New Inputs in QC	0	2119.56	3600	1680	7399.56
Total in each QC	1414300.80	109473.15	55200	1680	1580653.95
Product	1136198.40	84381.90	54608.52	0	1275188.82
Material Losses	278102.40	25091.25	591.48	1680	305465.13
Total cost of material losses on this process	278102.40	57486.78	591.48	1680	337860.66
Total costs in this process	1692403.20	141868.68	55200.00	1680.00	1891151.88

From the study that has been done for last 6 months in the company, it can be concluded that over the material costs associated with the processes in RS, about 83.57% of the total costs is used to product and remaining 16.43% contribute to material losses. The costs allocated for products accounted for 82.13% of the total costs which material losses in this process takes another 17.87%. From this study, it can be concluded that material losses is more than expected and yield rate from RS which is about 82% was not measured in details before.

In the production line of cultivation, the final product is totally dependent from the RS that has been used to apply MFCA for this study. The company is dependent on the output from this stage to extract the high value product which is astaxanthin. As considered by the company, material B and PBR bags (material C) is the main wastes from the processes.

Besides, by calculating all the material costs, energy costs, system costs and waste management costs in the quantity centers of RS it can be clearly seen that there is a material wastes which provides the room for improvement to ensure the business is sustainable and reduced in wastes.

From the study done, the main findings were on the losses in both material and energy is not as assumed by the company which is lesser than 10%. The company intention was to provide a process which has reduced in waste and environmental friendly business. By applying MFCA in one of the production line, it resulted in 17.87% of the total costs is extremely higher than expected and this was revealed so that material improvement can be done. These losses were overlooked by the company before, but through this study it can be clearly seen that the production line can be improved.

Table 4.6: Summary of Total Percentage Costs of Materials, Energy, System and Waste Management

	Material Costs	Energy Costs	System Costs	Waste Management Costs	Total
Product	1414300.80 (83.57%)	109473.15 (59.48%)	54608.52 (98.93%)	0 (0.00%)	1275188.82 (82.13%)
Material losses	278102.40 (16.43%)	57486.78 (40.52%)	591.48 (1.07%)	1680.00 (100.00%)	337860.66 (17.87%)
Total	1692403.20 (100.00%)	141868.68 (100.00%)	55200.00 (100.00%)	1680.00 (100.00%)	1891151.88 (100.00%)

CHAPTER 5: CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The microalgae manufacturing industry is the one of the future industry which has many potential in producing both high value products and renewable fuel, which supposed to be environmental friendly. From this study, by applying MFCA into in the manufacturing processes, it can be clearly seen that wastes accumulated from processes makes it not 100% efficient.

Many industries are not aware on the costs contributed by the wastes generated from the company's processes in manufacturing. This was the tradition of the business of people, who just concentrate on the outcome, and the wastes generated were indicated only in the term of volume and not the costs associated with it. From this study, ABC Sdn.Bhd. has applied MFCA in one of the process indicates the losses and improvement method can be drawn from the conclusion in regards with the objective of the study with the following information:

1. All the costs associated with the process in RS were calculated and illustrated in the table of flow cost involving material, energy, system and waste management cost. From the calculation, the company's material flow costs are accounted to 17.87% on the material losses. The highest material loss was from the energy costs which due to operation procedures and machine inefficiency.

2. Based on the calculation by applying MFCA, few recommendations were suggested to the company for improvement in the overall process to enhance the efficiency of the material flow. The suggestions are then discussed in section 5.2.

From the study, it can be seen clearly that the company is losing significant amount of money to the energy lost which can be invested into the machine to improvise the machineries used in the process.

5.2 Recommendations

Based on the MFCA application, it can be clearly seen QC4 (Adjustments) has highest costs allocation and eventually contributing to highest material loss in term of energy. Most of the recommendation for the company is based on the costs associated with the material loss from the manufacturing processes. The possible recommendations are as below:

1. The company may consider using fully automated system rather than depending on human work in transferring culture from GS to RS. In this process, the energy has been wasted since the premises has full run on the exhaust fan before the premise is fully occupied with the culture.

2. The company also can consider using lower transparency bag, which can allow the LED light to penetrate directly into the culture in QC4 to make the stressing period of the cells can be shorten. By implementing this, the company may reduce the power supplied via LED and these may be replaced with centralized lighting system rather than by rack/bags.

3. The water used in the GS and RS can be recycled and reused back in the process for cultivating the microalgae. This can be done by installing water purification internally which can reduce the dependability on the water source.

4. The company also installed membrane filter and aeration tube to provide agitation for the culture and filter the atmospheric air to be supplied to the culture, it is contributing to waste in QC 5 after harvesting, and this can be reduced by using centralized air purification system within the premise. Even the installation cost maybe high, it can definitely reduce the risk of contamination.

5. The company may consider adapting to continuous and automated process which can reduce the material lost in term of raw materials, energy, system and waste management cost, thus can enhance the efficiency of the manufacturing process.

Even some of the material are recycled for more than one time use, the incurred cost are difficult to be recovered. The company may also consider implementing MFCA in all the manufacturing line so that all material losses can be traced and brought to management's attention. This would definitely contribute to the increase in profitability of the company by reducing the wastes generated in each line.

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APPENDIX A