BENEFIT COST ANALYSIS OF RIGID POLYURETHANE FOAM SCRAP REUTILIZATION:

A CASE STUDY IN SURFBOARD MANUFACTURING

YUWARIN TATTIAM

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Thesis
Entitled

BENEFIT COST ANALYSIS OF RIGID POLYURETHANE FOAM SCRAP REUTILIZATION:

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.....
Ms. Yuwarin Tattiam
Candidate

.....
Asst. Prof. Dr. Sittipong Dilokwanich, Ph.D.
(Human Geography)
Major-Advisor

.....
Lect. Dr. Narin Boontanon
Ph.D. (Science, Biogeochemistry)
Co-Advisor

.....
Asst. Prof. Patompong Saguanwong
M.A. (Economics)
Co-Advisor

.....
Prof. Banchong Mahaisavariya, M.D.
Dean
Faculty of Graduate Studies

.....
Lect. Dr. Kitikorn Charmondusit,
Ph.D. (Chemical Technology)
Chair
Master of Science Programme in Industrial Ecology and Environment
Faculty of Environment and Resource Studies

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for the degree of Master of Science (Industrial Ecology and Environment)
on
May 8, 2008

.....
Ms. Yuwarin Tattiam
Candidate

.....
Lect. Dr. Chalotorn Kansuntisukmongkol,
Ph.D. (Energy and Resource)
Chair

.....
Asst. Prof. Dr. Sittipong Dilokwanich,
Ph.D. (Human Geography)
Member

.....
Lect. Dr. Narin Boontanon
Ph.D. (Science, Biogeochemistry)
Member

.....
Asst. Prof. Patompong Saguanwong
M.A. (Economics)
Member

.....
Prof. Banchong Mahaisavariya, M.D.
Dean
Faculty of Graduate Studies,
Mahidol University

.....
Asst. Prof. Sittipong Dilokwanich, Ph.D.
Dean
Faculty of Environment and Resource
Studies, Mahidol University

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Yuwarin Tattiam

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YUWARIN TATTIAM 4837981 ENIE/M

M.Sc. (INDUSTRIAL ECOLOGY AND ENVIRONMENT)

THESIS ADVISORS: SITTIPONG DILOKWANICH, Ph.D. (HUMAN GEOGRAPHY), PATHOMPONG SAGWANWONG, M.A. (ECONOMICS), NARIN BOONTANON, Ph.D. (BIOLOGICAL SCIENCES)

ABSTRACT

At a surfboard manufacturing factory in Thailand, 9,000 kilograms of rigid polyurethane (PU) foam scrap is sent to landfill every month. For this reason, this study developed an environmental economic analysis in order to evaluate the question 'is it possible and cost effective to reutilize PU foam scrap in the surfboard manufacturing process?'

The objectives of this study are to explore alternatives for rigid PU foam scrap reutilization and to use economic instruments to support the decision-making regarding best out of 3 selected rigid PU foam scrap reutilization options.

Environmental management accounting was used to evaluate rigid PU foam reutilization. The evaluation comprises 3 mechanical recycling options. Option 1 is reuse in surfboard manufacturing process. Option 2 is reuse as an oil sorbent. Option 3 is integration of option 1 and option 2. Each option was evaluated for physical and monetary environmental management accounting and investment appraisal.

After the environmental investment appraisal, option 1 was found to be worth investing with net present value or NPV (6.4%) = 1,714,423, benefit and cost ratio or B/C = 1.31, internal rate of return or IRR = 252%. Option 2 is worth investing with NPV (6.4%) = 65,735,039, B/C = 2.50, IRR = 3,550%. Option 3 is worth to be invested with NPV (6.4%) = 68,421,504 B/C = 2.62, IRR = 3,697%. In comparison, option 3 gains the highest NPV, B/C and IRR.

However, the appraisal in real world investment should consider market demands and sensitivities for the product, especially for options 2 and 3. Moreover, besides economical return, the reutilizations also provide benefit to the environment such as reducing resource extraction, and reducing environmental and adverse effects from waste disposal processes. If this study is accessed from a social point of view in further research, total economic value, comprised of use value, non-use value, and optional values should be accessed.

KEY WORDS: ENVIRONMENTAL ECONOMIC ANALYSIS/ RIGID POLYURETHANE FOAM/ REUTILIZATION/ SURFBOARD MANUFACTURING

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การวิเคราะห์ค่าใช้จ่ายและผลกำไรในการนำริจิดโพลียูรีเทนโฟมมาใช้ประโยชน์ใหม่ : กรณีศึกษาการผลิตกระดานโต้คลื่น (BENEFIT COST ANALYSIS OF RIGID POLYURETHANE FOAM SCRAP REUTILIZATION: A CASE STUDY IN SURFBOARD MANUFACTURING)

ยุวรินทร์ ทัดเทียม 4837981 ENIE/M

วท.ม. (นิเวศน์วิทยาอุตสาหกรรมและสิ่งแวดล้อม)

คณะกรรมการควบคุมวิทยานิพนธ์: สิทธิพงษ์ ดิลกวณิช, Ph.D. (HUMAN GEOGRAPHY), ปฐมพงษ์ สงวนวงศ์, M.A. (ECONOMICS), นรินทร์ บุญตานนท์, Ph.D. (BIOLOGICAL SCIENCES)

บทคัดย่อ

การศึกษานี้มีวัตถุประสงค์เพื่อสำรวจทางเลือกในการนำเศษริจิดโพลียูรีเทนโฟมจากการผลิตกระดานโต้คลื่นมาใช้ประโยชน์ใหม่และใช้เครื่องมือทางเศษฐศาสตร์ในการสนับสนุนการตัดสินใจ โดยทางเลือกในการนำริจิดโพลียูรีเทนโฟมมาใช้ประโยชน์ใหม่ประกอบด้วย ทางเลือกที่ 1 คือการนำกลับมาใช้ใหม่ในกระบวนการผลิตกระดานโต้คลื่น ทางเลือกที่ 2 คือการนำกลับมาใช้ใหม่ในรูปของวัสดุดูดซับน้ำมัน และทางเลือกที่ 3 คือการบูรณาการระหว่างทางเลือกที่ 1 และ 2 โดยแต่ละทางเลือกจะถูกประเมินด้วยหลักบัญชีการจัดการสิ่งแวดล้อม และประเมินความคุ้มค่าการลงทุน

ผลการศึกษาพบว่า ทางเลือกที่ 1 ได้รับผลตอบแทนคุ้มค่ากับการลงทุน โดยมีค่า NPV (6.4%) = 1,714,423, B/C = 1.31, IRR = 252% ทางเลือกที่ 2 ได้รับผลตอบแทนคุ้มค่ากับการลงทุน โดยมีค่า NPV (6.4%) = 65,735,039, B/C = 2.50, IRR = 3,550% ทางเลือกที่ 3 ได้รับผลตอบแทนคุ้มค่ากับการลงทุน โดยมีค่า NPV (6.4%) = 65,735,039, B/C = 2.50, IRR = 3,550% เมื่อเปรียบเทียบแล้วพบว่าทางเลือกที่ 3 ได้รับผลตอนแทนสูงสุด

การศึกษาในครั้งนี้มีข้อเสนอแนะว่าควรมีการศึกษาความต้องการของตลาดและค่าความอ่อนไหวของผลิตภัณฑ์เพิ่มเติมหากต้องการลงทุนจริง และหากมีการศึกษาในเชิงสิ่งแวดล้อมเพิ่มเติมจากการศึกษาครั้งนี้ควรพิจารณาผลตอบแทนทางด้านสิ่งแวดล้อมด้วย หากมีการศึกษาเพิ่มเติมในเชิงสังคมศาสตร์แล้ว มูลค่าทางเศรษศาสตร์ทั้งหมดควรได้รับการพิจารณาร่วมด้วย

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LIST OF ABBREIVIATIONS

Abbreviation	Term
B/C	Benefit-Cost Ratio
BCA	Benefit-Cost Analysis
BOM	Bill of Material
CNC	Computer Numerical Machine
EMA	Environmental Management Accounting
HP	Horse Power
IRR	Internal Rate of Return
kWh	Kilowatt times Hour
Pa.S	Pascal-second
PEMA	Physical Environmental Management Accounting
pphp	parts per hundred parts polyol
ppm	part per million
PU	Polyurethane
MEFA	Material and Energy Flow Analysis
MEMA	Monetary Environmental Management
MDI	Methylene Diphenyl Isocyanate
MSDS	Material Safety Data Sheet
NPV	Net Present Value
SROI	Social Return on Investment
TDI	Toluene Diisocyanate
THB	Thai Baht

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CHAPTER I
INTRODUCTION

1.1 Statement of Problem

Polyurethane (PU) foam waste is receiving more attention due to the increasing amount and the environmental impacts on its treatment and disposal. Each year 9,000,000 tons of PU foam is produced worldwide. Interestingly, both legal and illegal disposal of PU foam waste in landfill is up to 90 percent of all PU foam materials in the waste stream. On the other hand, the incineration and recovery including recycling is only 10 percent of overall waste stream (Zevenhoven, 2003).

In developing country, most of PU foam waste ends up on landfills. Polyurethane accounts for 5 percent of all plastic waste (Polyurethane Recycle and Recovery Council, 2005). Approximately 8,000,000 tons of PU foam is sent to landfill every year (Zevenhoven, 2003). Improper landfilling with PU foam may cause adverse effect to community and environment. For human health effect, PU foam may cause gastrointestinal irritation, irritating to eyes and skin and may lead to respiratory sensitization or asthma in long term (Era Polymer Pty Ltd, 2001). PU foam landfilling also represents a significant loss of resources. For example, the production of plastic related material accounts for 4 percent of total world oil production. Recycling of plastic is estimated to yield an 80 percent saving in resources over production of virgin material, with substantial associated reductions in emissions and other environmental releases (Australian Department of the Environment and Heritage, 2006).

Rigid PU foam is widely used in surf board manufacturing industry. A typical surfboard has a lightweight, buoyant core covered with a hard shell. The surfboards are believed to have originated in Polynesia in early of A.D. 400. The surfboards in early age were made of wood from various trees on the islands. The birth of the modern surfboard came in 1958 when Hobie Alter started producing boards

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with PU foam cores. Later, he went on to develop fiberglassing techniques using polyester resins to form the outer shell. Today, almost every surfboard uses this construction. The modern surfboards are product of the petrochemical age. The three main components of existing surfboards are foam, fiberglass and epoxy resin. The typical surfboard has a rigid PU foam core with an outer shell of fiberglass cloth and polyester resins (Gault-Williams, 2006; Shaw, 1983)

With existing technology, rigid PU foam scrap is unavoided byproduct in surfboard manufacturing. The surfboard manufacturing processes comprise mixing process, splitting process and shaping process. At first, polyol is mixed with toluene diisocyanate in mixing machine. Then the mixed component is purred in surfboard mold. Byproduct of mixing process is cup shaped foam residue. Secondly, the molded rigid PU foam board is cut into 2 pieces in order to insert a wood core between them to improve board's strength. Byproduct of splitting process is rigid PU foam dust. In the final process of making PU foam core, the board is shaped in hand shaping process and sent to be reshaped by computer numerical machine (CNC) respectively. Byproduct of shaping process is foam dust.

In addition, rigid PU foam scrap can be generated in case that the foam board is not approved in quality control process. All surfboard manufacturing processes that pose PU foam waste and scrap are shown in Figure 1.1.

In the world largest surfboard manufacturer which consumes over 18 tons of PU foam a month, *100 percent* of the rigid PU foam scrap from production waste and rejected boards totally go to landfill (Figure 1.2). The uncertainties on benefit of rigid PU scrap recycling led the landfilling be the existing solution for rigid PU foam's end of life. Besides showing the inefficiency of resource usage, landfilling rigid PU foam scrap will pose the significant environmental impact and human health hazard. Thus, if the PU foam scrap management has other choices, is landfilling still be the most appropriate solution for PU foam scrap management?

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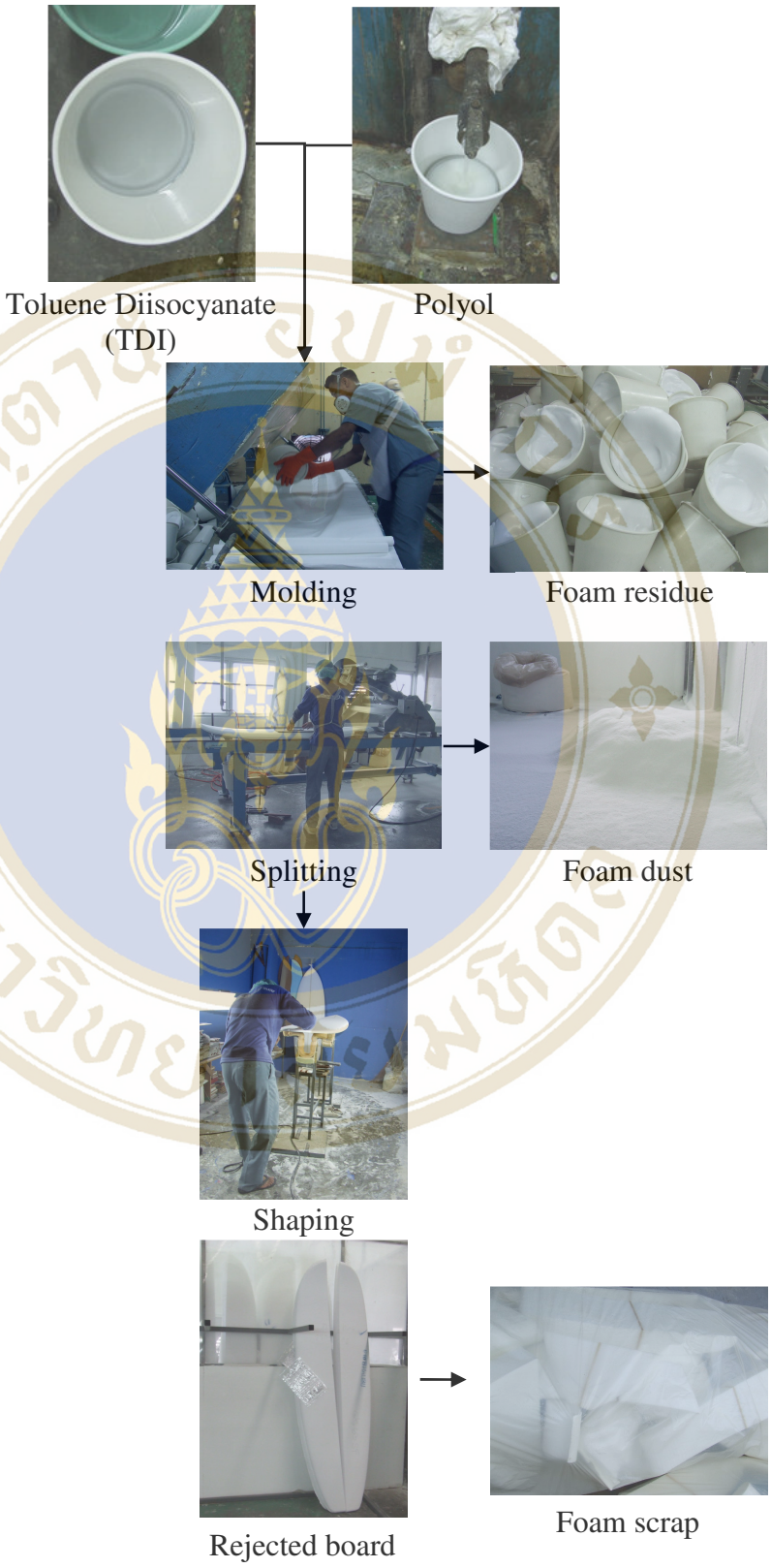

Figure 1.1 Rigid PU Foam Scrap from Surfboard Manufacturing Process

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Figure 1.2 Rigid PU Foam Scrap waiting to be landfilled

Rigid PU foam is recyclable and has been recycled in many countries. There are many technologies to recycle various types of PU foam. However in Thailand, finding available technology and market acceptance for recycled product is still an important obstacle to the recycling of rigid PU foam. Landfilling is the existing solution for PU waste management. For this reason, economic instrument will be used to support decision making in waste management projects based on economic and environmental point of view in order to answer the question.

1.2 Research Question

What are the effective and feasible alternatives for rigid PU foam scrap management in surfboard manufacturing?

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1.3 Objectives

The main objectives of this study are

1.3.1 To investigate alternatives for rigid PU foam scrap management.

1.3.2 To use economic instrument to promote the adoption of alternatives in rigid PU foam scrap management.

1.4 Scope of Study

The study is conducted within the following scope:

1.4.1 The selected rigid PU foam scrap reutilizations are regrinding and use it as filler in custom surfboard manufacturing and as oil sorbent product.

1.4.2 The study area is Cobra International Co., Ltd. a surfboard manufacturer in Chonburi province.

1.4.3 The environmental economics costs and benefits of this study include:

Benefits	Costs
- raw material extraction cost saving from material reutilization - value of produced recycled product - avoided landfill cost savings	- material cost of product output - material cost of non-product output

1.4.4 This study will use monetary information and database of year 2006.

1.5 Conceptual Framework

Efficiency of resource management via recycling is playing an important role in both economic and environmental points of view. Besides eliminating environmental impacts, material recycling also poses economically effective by gaining highest benefit from limited resource. It can be called win-win solution for today's economic and environmental conflicts.

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However, in order to imply recycle project, the feasibility of the project should be studied to make sure that if the project was established, it will gain both environmental and economic benefits. For this reason, the environmental economics analysis is used to evaluate the environmental and financial benefits from particular project. This study will focus on the benefit cost study of rigid PU foam scrap utilization in surfboard manufacturer. These options include (i) PU foam reuse in surfboard manufacturing process (ii) PU foam reuse as oil sorbent and (iii) integration of option 1 and option 2. These three options will be analyzed in environmental economic concept. Lastly, the results will be concluded as information to support decision making in rigid PU foam scrap management. The conceptual framework of this study is shown in Figure 1.3.

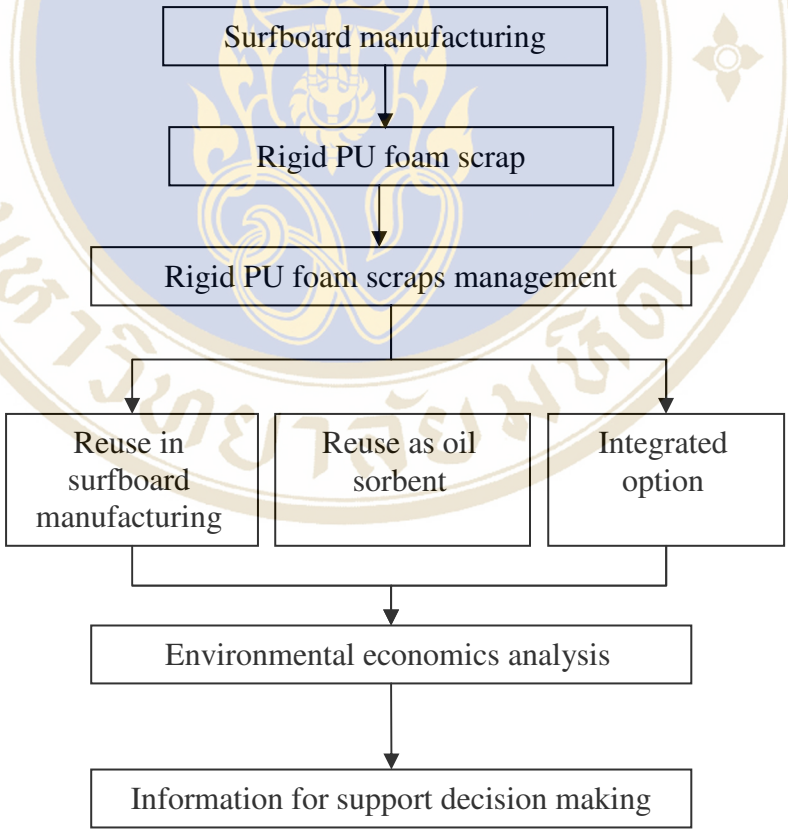

Figure 1.3 Conceptual Frameworks

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1.6 Expected Outcomes

1.6.1 Information of available alternatives for rigid PU foam scraps utilization.

1.6.2 The efficient and feasible alternatives of rigid PU foam scrap utilization.

1.6.3 Encouraging the effective of PU foam scraps utilization and discourage the practice that has adverse effect to environment.

1.6.4 Saving cost and energy resource from waste treatment.

1.6.5 Reducing landfilling and its impact to society and environment.

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CHAPTER II
LITERATURE REVIEW

2.1 Introduction

This chapter will give information about Polyurethane (PU) foam; the chemistry of PU foam, PU foam production, family of PU foam, rigid PU foam, environmental impact of PU foam and environmental economic analysis. The overall of literature review will be discussed in conclusion part at the end of this chapter.

2.2 Polyurethane Foam

2.2.1 Chemistry

PU foam is prepared through reacting of polyols and diisocyanate, the formula is shown in Figure 2.1.

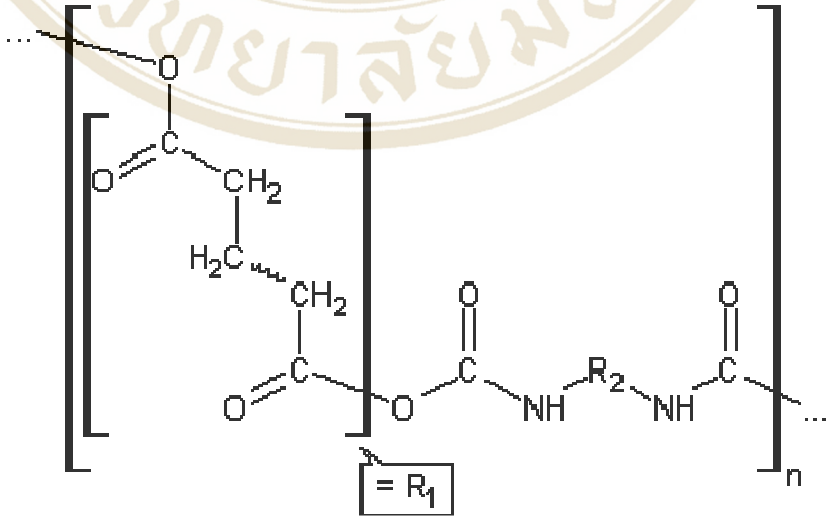

Figure 2.1 Chemical Structure of PU Foam

Source: Derived from Mecadi, 2008

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Foam is a colloidal suspension of a gas in a liquid created by agitation. Foams are cushiony material formed by the creation of gas bubbles in a base material such as natural rubber, synthetic rubber or other elastomeric materials (Meekham, 2002)

In the rigid PU foam production, there are two principle methods; one-shot and prepolymer. For the one-shot method all of components are mixed simultaneously and the result of mixing is allowed to foam. In the PU foam production, two reactions occur. The first one is a reaction of the isocyanate, which is in excess, with the hydroxyl group of the polyols. It lengthens the chain of the latter and ensures termination of the chain by isocyanate (–NCO group). The second reaction that generate gas and expand structure may be chemical and physical in nature. In the chemical reaction, reaction of polyols and isocyanate forms the polymeric structure of the foam. Simultaneously, the isocyanate react with water to form an intermediate product, carbamic acid that will be decomposed and provides amine and the carbon dioxide gas that acts as the blowing agents to expand the structure. The physical reaction includes the volatilization of a blowing agent to create expansion. The blowing agent will be added in the formulation and the foam structure is formed by volatilization of low-boiling fluorocarbon volatilizes, gas is release to crate the cellular construction (Garcia Materials Research Science and Engineering Center, 2004).

Prepolymers are manufactured with different isocyanates and polyols, with free isocyanate content, from the high ones (20 percent), to the moisture cured, low free isocyanate (1 to 2 percent) used in sealants and hot melt adhesives. A portion of polyol is pre-reacted with a large excess of isocyanate to produce a prepolymer. Then the prepolymer is subsequently mixed with additional polyol and other additives to affect foaming (Kennedy, 1996; Meekham, 2002)

2.2.2 Family of Polyurethane Foam

PU foams can be flexible or rigid depending on their cell structure (Figure 2.2). The first one in which most of the foam cells remain closed, and the gases remains trapped, the other being systems which have mostly open cells, resulting after

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a critical stage in the foam-making process. This is a vitally important process, if the flexible foams have closed cells, their softness is severely compromised, they become pneumatic in feel, rather than soft; so, generally speaking, flexible foams are required to be open-celled. The second one is rigid foams. In this type of foam, retention of the cell gas is desired since this gas gives the foams their key characteristic, high thermal insulation performance (Frados, 1976).

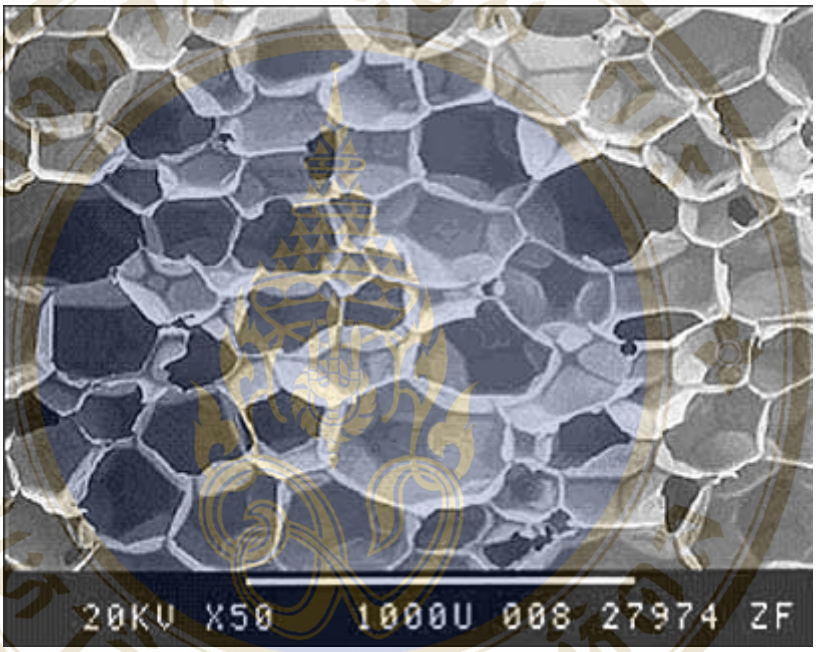

Figure 2.2 Cell Structure of Rigid PU Foam

Source: Adapted from Tailor Made Systems, 2006

2.2.3 Rigid polyurethane foam

Rigid form to PU foam is the highly cross-linked products that differs form flexible one in that they will not recover when deformed. Rigid PU foam are generally produced by reacting low molecular weight polyols with a functionality of two or more with polymeric isocyanate in the presence of catalyst, surfactants, and blowing agents. Either polyether or polyester polyols can be used, however the polyether is dominating at the present time.

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The qualities of rigid PU foam reduce energy transfer, maintain dimensional stability, remain airtight and often support a structural role. PU foams also function in temperature extremes, do not deform or distort, and are not subject to damage by the moisture that may result from condensation (Alliance for the Polyurethanes Industry, 2006).

Because of the characteristics of rigid PU foam above, the applications of this kind of foam have found in such market of construction, insulation, refrigeration, marine, furniture, packaging and transportation. Rigid PU foam is also under consideration in using as a bonding and insulating medium in road beds. In this case, the foam acts as protection layer from frost damage, load stresses and other destructive forces (Frados, 1976).

PU foams are becoming increasingly important as replacement products for wood in several applications where substrate consistency and decay are important. The excellent chemical and solvent resistance of urethane compounds makes them useful where many other resins might fail (General Plastics Manufacturing Company, 2006).

For the marine industry, rigid PU foam is used both for insulating characteristics such as insulate fishing boat freezer holds, and flotation characteristics. At the standard commercial density of 2 lb/ft^3, a cubic foot of rigid PU foam will float 60 lb of deadweight which makes a boat virtually unsinkable (Frados, 1976).

2.2.4 Environmental impacts

The use of PU poses an adverse effect to environment when it becomes a production scrap or at the end of its life. However, in production process, the inputs caused the adverse effects mainly by two important raw material, toluene diisocyanate (TDI) and polyol which resulted in resource depletion, heavy metal effect and acidification (Paoluglam, Nithitanakul and Malakul, 2006). According to the data from Association of Plastics Manufacturers in Europe (APME) life cycle analysis (Olsen, 2005), environmental impacts due to polyol and TDI are released in forms of dust, CO, CO_2, SO_x, NO_x, Hydrocarbon and Methane (Table 2.1).

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Table 2.1 Environmental impacts of polyol and TDI

Emission	mg per kilogram of		mg per metric ton of	
	Polyol	TDI	Polyol	TDI
Dust	11,214	6,944	11,214,000	6,944,000
CO	3,830	6,014	3,830,000	6,014,000
CO_2	3,527,859	5,218,826	3,527,859,443	5,218,826,199
SO_X	13,612	19,990	13,612,000	19,990,000
NO_X	15,065	21,873	15,065,000	21,873,000
Hydrocarbon	2,755	4,638	2,755,000	4,638,000
Methane	11,903	23,045	11,903,000	23,045,000

Source: Olsen, 2005

Additionally, when rigid PU foam is burned, PU releases a great amount of heat and toxic fumes, the hydrogen cyanide gas (HCN). It is one of the most noxious gases which are fatal to human within a short time. HCN only 300 ppm will be fatally noxious within 2-3 minutes. Burning PU can also cause suffocation in a poorly ventilated area (Aeroflex International, 2000)

Landfilling with PU foam improperly may cause adverse effect to community and environment. For human health effect, PU foam may cause gastrointestinal irritation, irritating to eyes and skin and may lead to respiratory sensitization or asthma in long term (Kennedy, 1996). Remarkably, PU foam landfilling also represents a significant loss of resources. The production of plastic related material accounts for 4 percent of total world oil production (Australian Department of the Environment and Heritage, 2006).

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2.3 Rigid Polyurethane Foam Reutilization

Rigid PU foam is a high degree crosslinked polymer which is nonmeltable plastic or thermosetting plastic. For to this reason, in contrast with the thermoplastic which is meltable, rigid PU foam cannot be recycled by one general process such as remelting. Rather, the whole range of different recycle methods is explored. The best method for recycling particular type of PU foam may vary from case to case and depends on the availability of the necessary technology and equipment and above all, on the logistical, economic and environmental factors.

Different from the flexible PU foam, rigid PU foam has lesser choices for recycling opportunity due to the high degree of cross linked form. Up to date, the options that remain are mechanical recycling, thermal chemical recycling and chemical recycling.

Mechanical recycling involves the grinding or granulation of the material to a suitable particle size and reuse as filler. Applications of this method are well-known in rigid PU foam recycling. Thermal chemical recycling involves anaerobic pyrolysis of the thermoset material. Recovery, separation and reuse of the low molecular weight species complete the recycling process. Besides, incineration of the material is able to recover the energy from waste as heat. However, thermal chemical technique is currently not feasible because of investment cost and energy cost going into process. For chemical recycling, the chemical bonds that cross-link the material are broken to the point that produces useful liquid as thermoplastic material. This involve glycolysis (White and Durocher, 1997; European Isocyanate Producers Association, 2001A).

In this study, the researcher will focus only one alternative of regrind and reuse with virgin material compare with base case; landfilling. Regrind or powder incorporation implies the use of finely grinded PU in the production of new PU products. In regrind or powder incorporation, PU foam is added to a liquid reactant, generally polyol, and used as a filler to manufacture new PU foam products. While this opens up the possibility of recycling into the original application, the quantity of

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PU foam filler added will generally be limited to 30 percent or less in the new product (European Isocyanate Producers Association, 2001; Zevenhoven, 2003).

For this reutilization method, foam scrap will be sent to milling or cryogenic processes for digest foam in to small flake. However, development work has shown that two-roll milling can be economically viable alternative to cryogenic processes. After rough grinding, the foam flake will be powdering until it has 50-200 microns size. The necessary particle fineness is obtained by granulation followed by fine grinding. During the early 1990s two-roll milling was found to give the best result for flexible PU foam grinding, whilst for rigid PU foams ball mills may yield particle sizes as small as 85 μm. The grinded powder will be stocked and waiting for mixing with virgin raw material; polyol, di-isocyanate and other additives (European Isocyanate Producers Association, 2001) (Figure 2.3).

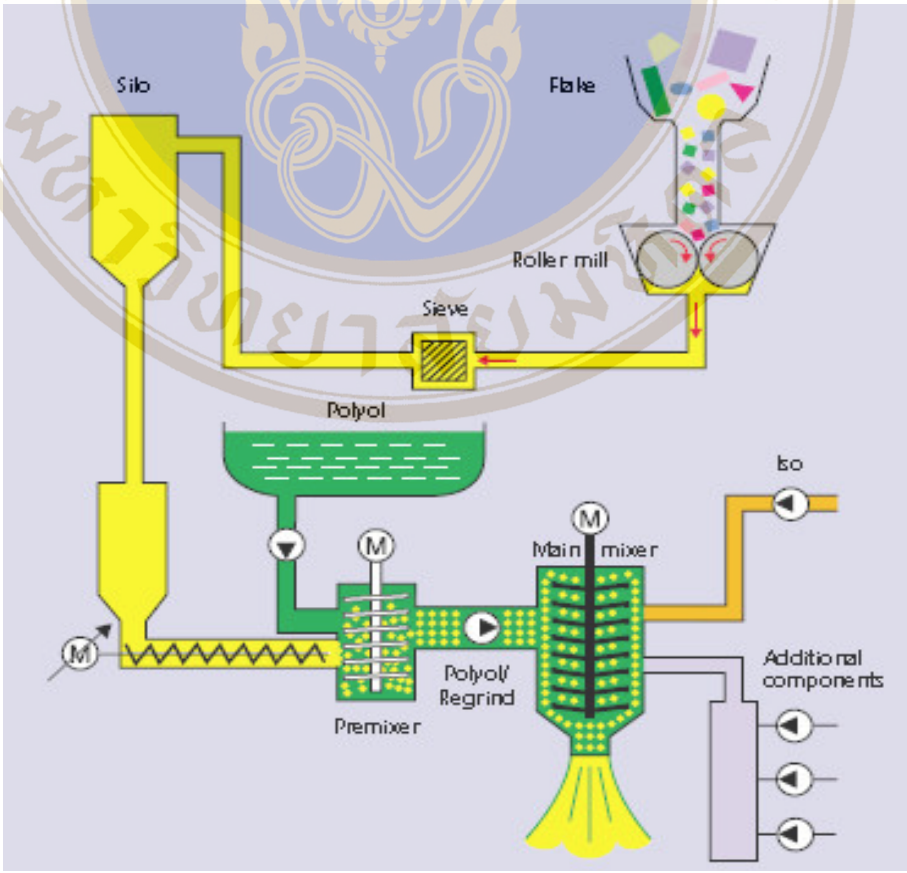

Figure 2.3 Regrind Process

Source: European Isocyanate Producers Association, 2001

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This powder can be used as filler in new PU foam, introduced by mixing it into the polyol at a concentration of around 20 parts per hundred parts polyol. This keeps the viscosity of the powder/polyol slurry in the range 2-5 Pa.s (2000 – 5000 cP), below the practical limit of 20 Pa.s where a transition from viscous fluid to paste was theoretically shown to occur, near a PU foam powder loading of 40-45 pphp. A drawback of using fine scrapped PU foam powder is that this will affect the new PU foam as would also another type of filler since the powder does not contribute energetically to the chemical reaction yet adds heat capacity, and provides no CO_2 for foam blowing. The loss of hardness and firmness can be corrected for by reduction of other blowing agent, in this process here total elimination of dichloromethane (CH_2Cl_2) against an increase in water and isocyanate which is costly (European Isocyanate Producers Association, 2001).

One benefit compared to other mineral filler materials is that the PU powder has a density similar to the new foam that is produced. Overall, the new process showed cost savings of around 2.7-2.8 percent while hardly changing mechanical properties. Practically, this typically allows for up to 15 percent regrind rigid PU foam mixed with virgin material when MDI polyol is used, up to 25 percent with TDI is used (Zevenhoven, 2003).

In regrinding process, the major problem for waste processing is that of economy. The grinded rigid PU foam size below 100-125 μm is no exception to that. In addition, it is a factor that limits the amount of scrapped PU foam that can be recycled by regrinding. It is the viscosity of the polyol fine particle mixture that can be handled by the processing equipment. Not only reuse by regrinding, PU foam powder and larger particles obtained from cutting and shaping of rigid foam are widely known since long to be excellent absorbers of oil or many kinds of liquids that have been accidentally spilled (Zevenhoven, 2003).

They have been marketed in America and Europe for years as oil sorbent in several forms such as loose powder and/or small particles in sacks for the treatment of spillages on land, low density pressboards for the same purpose, loose powder and/or small particles in hoses for the containment of spillages on water surfaces. In

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Germany, the finely ground PU powder from the refrigerator's insulating layer is 100 percent recycled and sold as oil binder to industry and craft business (European Academy of the Urban Environment, 2001) (Figure 2.4).

Figure 2.4 PU foam recycling as oil sorbent

Source: European Isocyanate Producers Association, 2001

Rigid foam powder is obtained from fabrication processes like sawing and milling, or simply by grinding the foam. In recent years, this application has been used for powders and particles from the PU insulation of end-of life refrigerators and freezers (European Isocyanate Producers Association, 2001).

2.4 Surfboard manufacturing processes

Techniques and materials vary from one surfboard builder to another. However the typical modern surfboard manufacturing processes are as Figure 2.5. At first in PU mixing process, polyol and diisocyanate are mixed together in various amount (approximately 1,000 – 3,000 grams for polyol and 2,000 – 7,000 grams for

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diisocyanate) depends on types of board. Two components are sent to mixing machine. The mixed component in a cup is filled in concrete surfboard mould at 25-30 degree Celsius. After that, in the splitting process, the molded boards from previous process are cut into 2 pieces in order to insert wood core. The wood core is stuck between 2 pieces of board and sent to computer numerical control machine (CNC) for rough shaping. The detailed shaping has done by hand shaping which is the last process for the board structure. After the well-shaped board has been prepared, it is sent to design for decorating, then to laminating for pressing the design component with the body of surfboard, and last to hot coating and fitting the plug for input accessories (Cobra International Company Limited, 2006).

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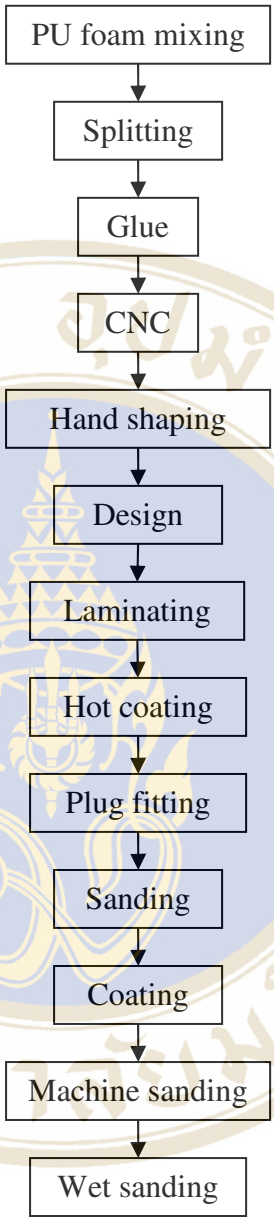

Figure 2.5 Surfboard Manufacturing Process

Source: Cobra International Company Limited, 2006

2.5 Environmental Economic Analysis

While recycling is viewed by much of the public as primarily a social issue, few people outside the recycling and solid waste management field have examined recycling from an economic perspective. Much of the attention afforded recycling has focused on its perceived value in term of cost effective. Recycling must be

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economically viable when compared to other methods of waste management and resource conservation.

Environmental economic analysis is a tool used to evaluate environmental benefit at the same time as the monetary benefit from particular project in order to support decision making in both economical and environmental perspectives. These can be done through various methods, depends on scope and proposes. The recognized methods used in environmental economic analysis are benefit-cost analysis (BCA), social return on investment (SROI) and environmental management accounting (EMA).

According to impact value chain analysis by Clark, Rosenzweig, Long and Olsen's double bottom lines project, it is undeniable that BCA, SROI and EMA can include the environmental aspects in decision making with economical or financial tools. BCA, SROI and EMA are all considering impacts and able to convert values into monetary term. They are also suitable for application for profit investor. In the other word, no tool is better than others when criticized by these criteria (Olsen, Clark, Rosenzweig and Long, 2004).

However, in overall perspective, environmental management accounting (EMA) is the most suitable method for environmental economics analysis in this study because beside this method is an impact-based study and able to apply for profit investor. This method also focuses on the process and requires lesser range and depth of information. The main difference between conventional accounting and EMA is that the EMA separately identify, measure, analyze and interpret information about environmental aspects of company activities (Schalteffer, Hahn and Buritt, 2000).

2.6 Environmental Management Accounting

Environmental management accounting or EMA is the management of environmental and economic performance through the development and implementation of appropriate environment-related accounting systems and practices

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(International Federation of Accountants, 2005). It is the identification, collection, analysis and use of two types of information; physical information and monetary information for internal decision making. EMA is performed by private or public corporations, but not by nations, and has a monetary as well as physical component (United Nations Division for Sustainable Development, 2001).

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Table 2.2 Environmental management accounting frame

		Monetary EMA (MEMA)		Physical EMA (PEMA)	
		Short term	Long term	Short term	Long term
Past orientated	Routinely generated information	environmental cost accounting (e.g. variable costing, absorption costing and activity based costing)	environmental induced capital expenditure and revenues	Material and energy flow accounting (impacts on environmental product and company levels)	Environmental (or natural) capital impact accounting
	Ad hoc information	ex post assessment of relevant environmental costing decisions	environmental life cycle costing, post investment assessment of each projects	Ex post assessment of short term environmental impacts (e.g. of a site or product)	Life cycle inventories, physical environmental post investment appraisal
Future orientated	Routinely generated information	monetary environmental operation budget, monetary environmental capital budget	environmental long term financial planning	Physical environmental budgeting (flows and stocks)	Long term physical environmental planning
	Ad hoc information	relevant environmental costing (e.g. special orders, product mix with capacity constraints)	monetary environmental project investment appraisal, environmental life cycle budgeting and target pricing	Relevant environmental impacts (e.g. given short run constraints on activities)	Physical environmental investement appraisal, Life cycle analysis of specific project

Source: United Nations Division for Sustainable Development, 2001

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According to the framework in Table 2.2, EMA comprises two main information; monetary information and physical information. Monetary information or monetary EMA (MEMA) includes environmental induced impacts on economic systems. This tools deal with the environmentally driven impacts on a company expressed in monetary terms. They provide the basis for most internal decision and how to track, trace and treat environmentally driven cost.

On the other hand, physical EMA (PEMA) comprises company related impacts on environmental systems. This tools focus on a company's ecological impact on the natural environment in physical unit. They are designed to collect environmental impact information in physical units for internal management decisions. The importance part of environmental information systems is material flow balances in physical units of material, water and energy flows within a defined system boundary. This can be on the corporate level, but also one step further down to cost centers and production processes or even down to machineries and products. Then it becomes the task of process technicians and not so much accountants to tackle and trace the necessary data (United Nations Division for Sustainable Development, 2001).

EMA is established to compromise accounting and environmental issue by attempting to convert hidden cost and other externalities into money and ensure that all environmental costs related to particular process has already added in accounting. In addition, EMA combines monetary and physical data. EMA is a flexible tool as can be seen from its framework. It can be viewed both past orientated and future orientated, both adhoc generated information and routine generated information, and both short and long term projects. Another advantage of this tool is material and energy flow analysis (MEFA) which can be compared with a life cycle inventory. MEFA gives overview of process inputs and outputs which can be broken down and converted into monetary term in MEMA.

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2.7 Conclusion

PU foam is thermosetting plastic. According to non meltable property, most of PU scraps are sent to landfill. However, up to date recycle industry has attempted to reutilize this kind of foam by various methods as mentioned and many other techniques that have been developed such as chemical recycling process using supercritical water. According to the feasible projects, this study will evaluate only one option which has already been researched and done and tend to be environmental friendly as mentioned in literature review. The option is regrinding or powder incorporation. However, the based-case option, landfilling will also be evaluated in order to give a clearer result of non-project and project alternatives. For more rigid PU foam recycling options, there are noted in Annex I of this research.

For environmental economics analysis, the ideal tool for this study should have ability to convert environmental tangible costs and benefits in monetary value, scope both costs and benefits in project based point of view and could apply for profit investor. EMA can fulfill these requirements with limited data in hand.

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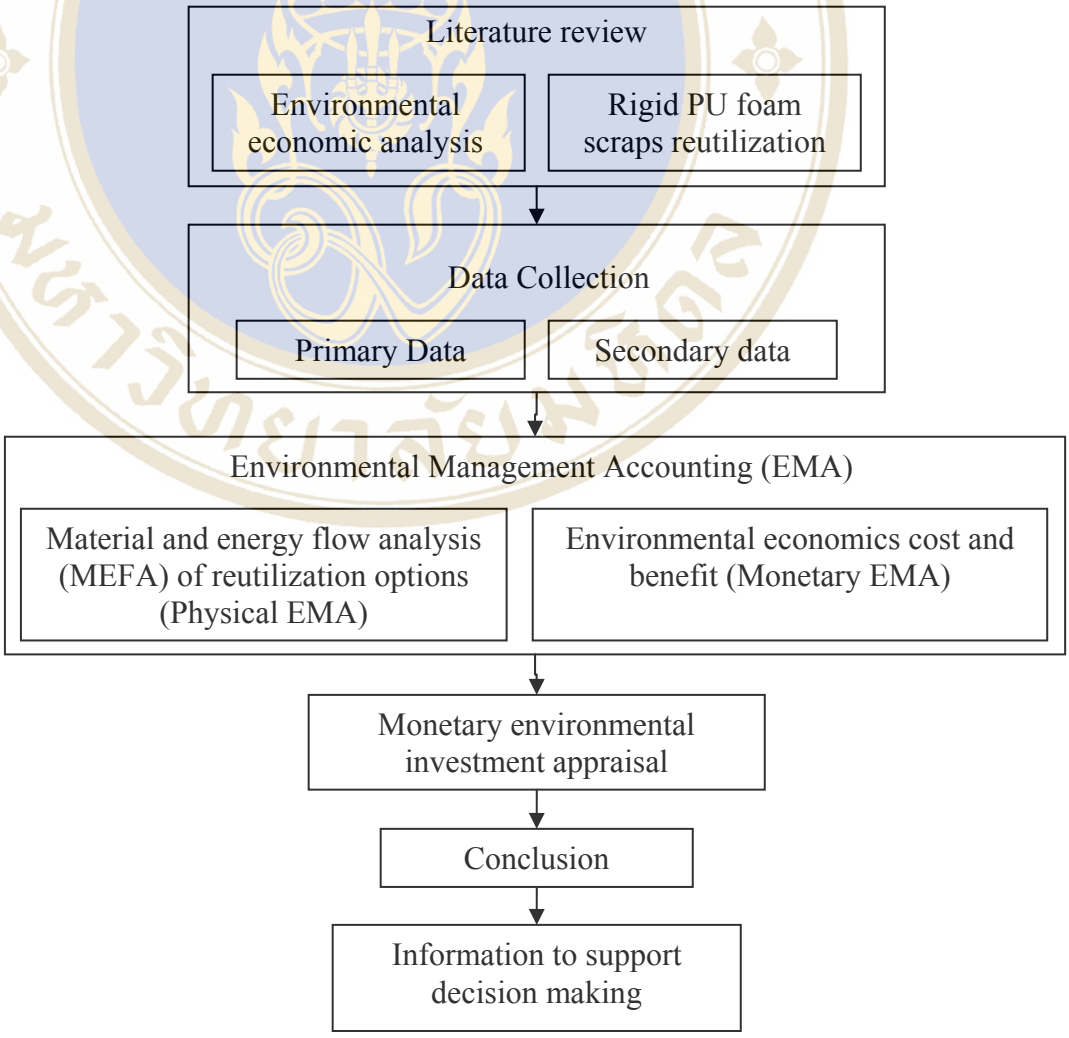
CHAPTER III
METHODOLOGY

3.1 Research procedure

The purpose of this chapter is to describe research methodology to be used in determining the environmental economic cost and benefit of rigid PU foam recycling. Research methodology is in the following diagram.



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Research procedure can be described in following steps:

Step 1: Documentary research on rigid PU foam recycling and environmental economics analysis tools.

Step 2: Collect data as described in Topic 3.2

Step 3: For physical information, create material and energy flow analysis (MEFA) of rigid PU foam reutilization option.

Step 4: Identify environmental cost and benefit of project as shown from input and output of material flow analysis.

Step 5: For monetary information, categorized related cost and benefit (following the scope of study) and convert each of them into monetary value.

Step 6: Analyze monetary environmental investment appraisal**.**

Step 7: Conclusion and discussion.

3.2 Data collection

3.2.1 Primary Data

Quantity of PU foam scrap in Cobra International Co., Ltd. was accessed by on-site interviews, measurement, observation, and review from production planners and manager of Custom Surfboard Unit. Some parts of technical data of rigid PU foam recycling was collected by e-mail correspondence with chemical suppliers.

3.2.2 Secondary Data

Analyzing costs and revenues of PU foam scrap recycling and environmental and economical costs of PU scrap disposal were from the reviewed literature. The focus of the financial benefit-cost analysis is on the financial benefits and costs of the project intervention. Hence, the project's rigid PU foam recycle revenues were determined on a with-project and without-project basis. In this way, both environmental and financial benefits from this project were estimated.

Environmental costs of this study comprise of 2 broad categories as shown in Table 3.1

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Table 3.1 Environmental Costs of rigid PU foam reutilizations

Environmental cost	Description
material cost of product output	purchase costs of natural resources such as energy, water and other materials converted into products, by-products and packaging.
material cost of non-product output	purchase and processing costs of energy, water and other materials that becomes non-product output.

Environmental economics benefits of this study comprise 3 topics and can be accessed as description in Table 3.2

Table 3.2 Environmental Benefits of rigid PU foam reutilizations

Environmental benefit	Description
raw material extraction cost saving from material reutilization	amount of recyclate that can be reutilized.
value of produced recycled product	amount of recycled product that can be produced.
avoided landfill cost savings	landfill fees that can be saved after recycling.

3.3 Environmental Management Accounting Principle and Procedure

EMA is defined to be the identification, collection, analysis and use of 2 types of the information: physical information using in physical environmental accounting (PEMA) and monetary information using in monetary environmental accounting (MEMA).

3.3.1 Physical environmental accounting (PEMA)

Physical information was analyzed in the material flow balance on corporate level. The basis of environmental project is material flow recording by input-output

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analysis. The material and energy flow analysis or MEFA for short is an equation based on "what comes in must go out or be stored" (United Nations Division for Sustainable Development, 2001). MEFA includes the material, energy and water used and the product, waste and emission. All items are measured in physical units in terms of mass, kilogram or ton, liters or in term of energy: kilowatt per hour.

The MEFA can be created for a few selected materials or processes. The purpose of MEFA is to track materials in their way through process. The monitoring of process flow show resource input and production on a daily based basis. According to United Nations Division for Sustainable Development, Table 3.1 shows the general example of input-output balance at the corporate level. The specific subcategories are required for different sector, but it should be aggregated in order to be able to compare them (United Nations Division for Sustainable Development, 2001).

Material and energy flow analysis can be done by following steps:

Step 1: Create flowchart of main production steps and supply process

Step 2: Consider all material and energy flow information. Preparation input-output information and fill in Table 3.3.

Table 3.3 Input-Output Table

Production step:

INPUT				**OUTPUT**			
Item	Amount	Unit	Data source	Item	Amount	Unit	Data source

Step 3: Classify and aggregate material and energy flow information into categories. The input part comprises raw materials, auxiliary materials, intermediate, energy and labor. The output part comprise of products, non-products, waste, emission and energy losses.

Step 4: Allocate of material and energy flow and environmental impacts (Table 3.4).

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Table 3.4 Allocation of Material and Energy Flow and Environmental Impacts

Input (kg, kWh)	Output (kg)
Raw materials	**Product**
Auxiliary materials	Main product
Energy	By product
Cars	**Waste**
Fuel	Municipal waste
Renewables	Recycled waste
Externally produced electricity	Hazardous waste
Internally produced electricity	**Waste water**
Water	Amount
Municipal water	Heavy metals
Ground water	COD
Rain/Surface water	BOD
Operating materials	**Air-emissions**

3.3.2 Monetary environmental accounting (MEMA)

After finishing the PEMA, the next step for EMA was monetary environmental accounting or MEMA. MEMA pays attention to record, at reasonable expenditure, the direct and indirect costs of corporate environmental impacts broken down by polluter, and takes account of effects on the achievement of company objectives. In this stage, the cost from MEFA was calculated. In addition, the hidden cost was identified and allocated to the product cost.

3.3.3 Monetary Environmental Investment Appraisal

The purpose of MEMA is to assess the benefits of a planned project and comparing of difference investment alternatives. In this stage, payback period, net present value (NPV), benefit cost ratio (B-C) and internal rate of return (IRR) were calculated from the following formula.

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Payback period is the period that accumulates cash inflow equals to the cash outflow. Payback period can be calculated from the following formula:

$$\text{Payback period} = \left[\begin{array}{l}\text{Last year with a}\\ \text{negative net cash flow}\end{array}\right] + \left[\frac{\begin{array}{l}\text{Absolute value of net}\\ \text{cash flow in that year}\end{array}}{\begin{array}{l}\text{Total cash flow in the}\\ \text{following year}\end{array}}\right]$$

NPV can be calculated from following formula:

$$NPV = \sum^{n}_{t=0} F_t / (1+r)^n$$

When F_t is net cash flows in time period t

r is discount rate

n is number of period

NPV shows the differences between the present value of cash flows and the present value of cash outflows which is discounted (EMA-SEA, 2005).

B-C can be calculated from following formula:

$$B\text{-}C = \frac{\sum^{n}_{t=0} B_n / (1+r)^n}{\sum^{n}_{t=0} C_n / (1+r)^n}$$

When B_n is net cash flows in time period n

r is discount rate

n is number of period

IRR is the discount rate at which the present value of project equal to the present value of cost. Anyhow, IRR may not exist or may not be unique (Ausfu-Adjaye, 2005). Though NPV and B-C are easy to be calculated with conventional calculator, IRR is more difficult to calculate. A trial and error technique must be used to calculate IRR using different values of *i* (discount rate). In this study, IRR was calculated by using Microsoft Excel program with function IRR.

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In decision making, a project is accepted when NPV ≥ 0 (grater NPV means greater profitable), B-C ≥ 1 and IRR exceeds opportunity cost. In this study, it referred to opportunity cost of fund.

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CHAPTER IV
RESULTS AND DISCUSSION

This chapter gives detail of data collection and shows outcome of environmental management accounting which is divided into 3 parts based on reutilization. Option 1 is reuse in surfboard manufacturing process. Option 2 is reuse as oil sorbent. Option 3 is integration of options 1 and 2. Environmental management accounting for each option comprises physical environmental management accounting (PEMA) and monetary environmental management accounting (MEMA).

In PEMA, data of 2 options for rigid PU foam reutilization are accessed in material and energy flow analysis (MEFA) and input – output table (I/O table). The I/O table will be filled based on 1 batch. In theory, data in PEMA comprise measured data, calculated data and estimated data. In this context, all data are calculated data. Total I/O is concluding for all I/O tables in each process.

In MEMA, data from physical environmental management accounting is converted into monetary value and monetary environmental investment appraisal, a long-term future-oriented MEMA. It is used to calculate the net benefit and cost in less polluting investment option in monetary environmental investment appraisal in purpose to find out the reutilization option that gains highest benefit.

In monetary environmental investment appraisal, all types of cost and benefit, both capital and operational, are calculated and put into net cash flow table. Later; benefit cost analysis is done and evaluated the result with Net Present Value (NPV), B-C Ratio (B/C) and Internal Rate of Return (IRR). The calculation in this part is considered in yearly unit.

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4.1 Fundamental Assumption

The environmental management accounting is evaluated under a series of assumption:

4.2.1 6.4% of opportunity cost for long term loan is set as discounting rate of investment according data from Financial Department.

4.2.2 The project lifetime is 10 years.

4.2.3 The wage for direct labor of this project is 175 THB/day or 21.87 THB/hour according to Chonburi province's minimum wage rate of Department of Labour 2006.

4.2.4 The wages are approximately 7% increased in each year.

4.2.5 Three options are run with small scale manufacturing and take only short time for each process. For this reason, time unit is set as minute based.

4.2.6 The existing electricity cost of Cobra International Company Limited is 3.624 THB/unit (kWh) in 8.00 am to 4.00 pm rate according to Metropolitan Electricity Authority.

4.2.7 Electricity consumption is calculated at 0.749 kW/HP

4.2.8 The maintenance cost of each machine is estimated at 5,000 THB/month.

4.2.9 Price and technical data of machines are accessed by telephone and e-mail corresponding with machine suppliers. According to quotation from a supplier selected from lowest price quotation that matched the specification, machines comprises:

- Hammer milling machine (3 HP) 40,000 THB
- Hammer milling machine (7.5 HP) 80,000 THB
- Milling machine (5 HP) 70,000 THB
- Milling machine (7.5 HP) 95,000 THB
- Powder filling and packaging machine (3HP) 100,000 THB

4.2.10 According to data from Accounting Department, estimated monthly rental fee for a production line in Cobra International Company

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Limited is 50,000 THB including others annual fees for Amata Industrial Estate.

4.2.11 Landfill cost is 30,000 THB/ton or 30 THB/kg. Regarding to the interview with legal waste management company, this cost included air pollution treatment system, water pollution treatment system, ground water pollution monitoring and remediation plan as community rest area.

4.2.12 In project investment appraisal, the project is worth for investment if:

- NPV > 0
- IRR > opportunity cost of fund (6.4%)
- B/C > 0

4.2 Option 1: Rigid PU Foam Scrap Reuse in Surfboard Manufacturing Process

This option includes flaking, milling, and premixing process. The recycled product will be mixed with polyol and used in new surfboard manufacturing as to reduce raw material. The data in this part is collected from bill of material (BOM), SAP® material management software and personal interview with Production Supervisors and Production Planner. EMA of this option will be accessed under the assumption that all processes are preceded by one worker. The quantity of input is based on Surf Business Unit's production plan.

According to the production plan accessed from the interviewing with Production Planner based on statistic of year 2006, 83 kg of polyol is used as raw material each day. Therefore, it can refer that, if PU foam scrap can substitute 20% of polyol, in each day, the substitution of polyol is (20/100)*83 = 16.6 kg/day. The 16.6 kg/day of PU foam scrap is considered as 1 batch of this reutilization option. Two machines will be bought and calculated as initial investment cost.

4.2.1 Physical Environmental Management Accounting

Input and output of each process is as described in material and energy flow in Figures 4.1 to 4.3

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Flaking process starts with feeding rigid PU scrap into hammer milling machine manually by a worker. The specifications of machine for this process are:

- able to flake 16.6 kg of foam in one day,
- suitable for rigid foam digestion,
- able to feed 25 cm in diameter and 22 cm in height of largest foam scrap without pre-flaking process.

Refer to specification of flaking machine following to a quotation, a hammer mill with 3 HP is able to flake 50 kg of PU foam in an hour or 0.83 kg/min. The energy consumption of the machine is 2.3 kW. The product of flaking process is small flake of PU foam which is the input for next process. This process does not produce significant waste or other non-product output.

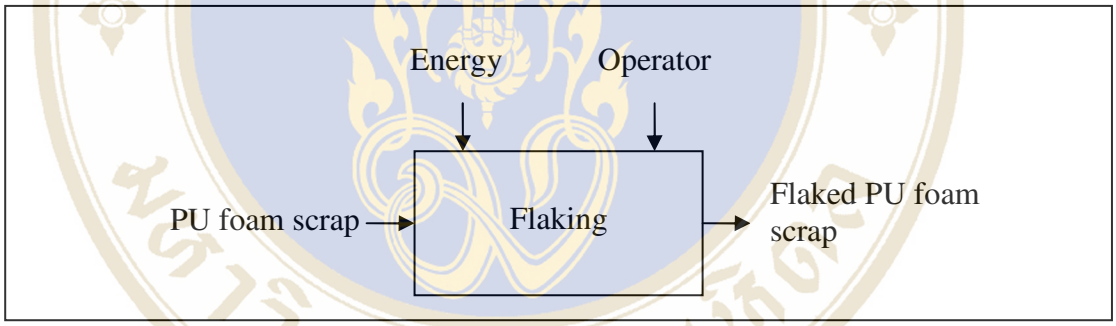

Figure 4.1 MEFA of Flaking Process

In Table 4.1, I/O calculation starts with PU foam scrap at 16.6 kg per day as the first input of process. According to the technical data sheet of flaking machine, the machine is able to digest 16.6 kg of PU foam scrap within 14 minutes. This can be calculated back that the working hour of operator to finish this job is 14 minutes for flaking process. The energy consumption is calculated from 2.3 kW *0.23 hour = 0.53 kWh in a batch.

Beside flaked foam as intermediate product that will not be included in I/O table, there is no output due to flaking process does not post direct product or any significant emission.

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Table 4.1 Input – Output Table of Flaking Process of Option 1

INPUT			
Item	Amount	Unit	Data source
PU scrap	16.6	kg	Production planner
Electrical energy	0.53	kWh	Quotation
Direct labor	14	min	Calculation

Source: Field survey, 2006

In milling or powdering process, flaked foam is sent to rotary milling machine manually by a worker. The specifications of machine for this process are:

- able to digest 16.6 kg of foam in one day,
- suitable for rigid foam digestion,
- able to grind foam into 0.2 mm diameter dust.

Refer to specification of milling machine following to a quotation, a high rotor speed milling machine of 5 HP is able to flake 60 kg of PU foam in an hour. The energy consumption of the machine is 3.73 kW. The milled product goes to a 0.2 mm diameter screen sieve. The product of flaking process is PU foam dust which is mixed with isocyanate. This process does not produce significant waste or other non-product output.

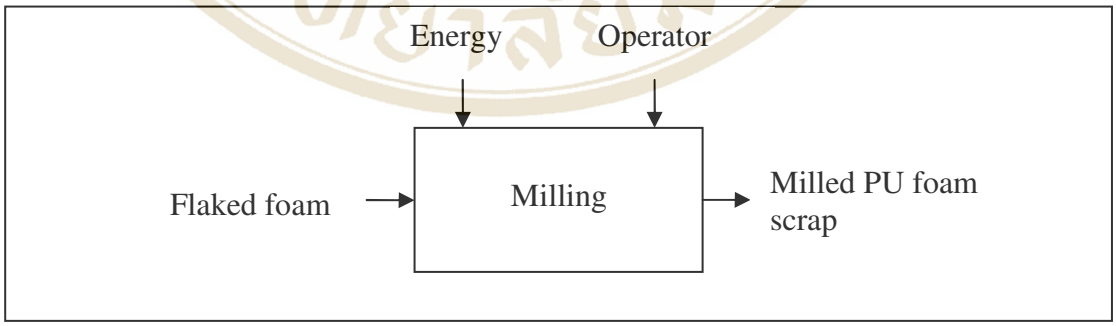

Figure 4.2 MEFA of Milling Process

According to technical data sheet of milling machine, the machine is able to digest 16.6 kg of PU foam scrap within 17 minutes. The working hour of operator to finish this job is 17 minutes. Energy consumption is calculated from 3.73* 0.28 hour = 1.06 kWh in a batch.

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Table 4.2 Input – Output Table of Milling Process of Option 1

INPUT			
Item	Amount	Unit	Data source
Intermediate material from flaking process	16.6	kg	Calculation
Electrical energy	1.06	kWh	Quotation
Direct labor	17	min	Calculation

Source: Field survey, 2006

In pre-mixing process, the PU foam dust is mixed with virgin polyol at proportion 20 parts of recycled foam per hundred parts of polyol. In each time of pre-mixing, a worker mixes PU foam dust with polyol in a cup and sends the cup to mixing machine. According to Engineering Division, the specification of machine is 5.2 HP with energy consumption at 3.88 kW. Polyol is an input in general process. Hence, it is not included in the I/O table.

The product of this process is mixed PU foam dust and polyol. Anyhow, the valuation of product excludes polyol as the same reason as input.

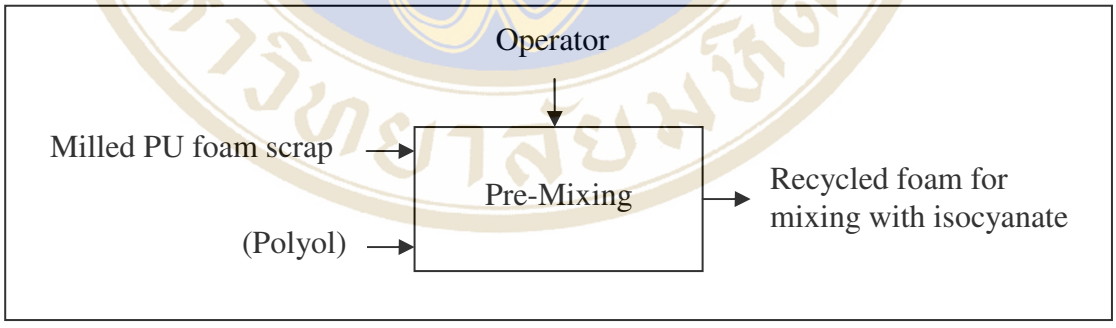

Figure 4.3 MEFA of Pre Mixing Process

From the interview with Production Supervisor of PU foam molding cell, a worker is able to finish pre-mixing process for 1 kg of foam within 3 minutes. The raw materials comprise 83 kg of diisocyanate, 66.4 kg of polyol and 16.6 kg of PU foam as filler which is calculated from 20% of total polyol consumption in 1 batch. For 16.6 kg of PU scrap and 66.4 kg of polyol, or 83 kg total weight can be pre-mixed in 83 kg * 3 minutes = 249 minutes. Electricity consumption is 3.88kW*4.15 hour = 16.1 kWh.

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Table 4.3 Input – Output Table of Pre Mixing Process

INPUT			
Item	Amount	Unit	Data source
Intermediate material from milling process	16.6	kg	Calculation
Electricity cost	16.1	kWh	Engineering Division
Direct labor	249	min	On-site record
OUTPUT			
Item	Amount	Unit	Data source
Polyol+PU scrap for mixing with isocyanate	83	kg	Calculation

Source: Field survey, 2006

After pre-mixing, it continues with mixing process. However, this process is not calculated as part of reutilization option because it can be done in typical surfboard manufacturing process and does not relate to PU scrap reutilization.

4.2.2 Monetary Environmental Management Accounting

Value of recycled product can be accessed via converting its substitute rate to price of polyol. According to literature review, the recycled product can replaced polyol at a concentration around 20 parts per hundred parts of polyol or 20 percent polyol cost saving. According to data from Cobra International Company Limited's summary of bill of material (BOM), accessed via SAP® system, the polyol consumption rate of polyol per day is 83 kg. It costs 180.42 THB/kg. Recycled rigid PU foam can fulfill 20 percent substitution which means it can save 16.6 kg of polyol or 16.6*180.42*25 = 74,874.3 THB of polyol cost per month.

Regarding to PEMA of this option, it can be summarized total input-output of all processes in option one in one year and converted into monetary value as shown in Table 4.4. These include:

- PU foam scraps is calculated from 16.6 kg*25 days*12 months = 4,980 kg/year

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- Electrical energy is calculated from 17.69 kW*25 days*12 months = 5,307 kWh/year
- Direct labor from all process is 280 minutes*25 days*12 months = 84,000 minutes or 1,400 hours/year
- Recycled foam for mixing with isoyanate is 16.6 kg*25 days*12 months = 4,980 kg/year

Table 4.4 Monetary Environmental Management Accounting of Option 1

INPUT				
Item	**Amount**	**Unit**	**Unit cost (THB)**	**Costs**
PU foam scarp	4,980	kg	N/A	0
Electrical energy	5,307	kWh	3.624	19,232.5
Direct labor	1,400	hour	21.87	30,618
OUTPUT				
Item	**Amount**	**Unit**	**Unit cost (THB)**	**Costs**
Recycled foam for mixing with isocyanate	4,980	kg	180.24	897,595.2

Source: Field survey, 2006

Note: Reference unit of year 2006, based on 1 batch of 16.6 kg PU foam scrap

MEMA include 2 types of cost. The first one is capital cost and the second one is operation cost. All are shown in 1 year value/cost.

Initial investment

Machine and equipment

- Hammer milling machine 40,000 THB
- Milling machine 70,000 THB

Operation cost

Fixed cost

- Monthly rental fee 6 00,000 THB
  50,000 THB*12 months

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Variable cost (at full capacity)

- Direct labour 30,618 THB
- Electricity cost 19,232 THB
- Maintenance of machine 120,000 THB

  5,000 THB/month*2 machines*12 months

Benefit

- Substituted polyol 897,595 THB
- Avoided landfill cost 149,400 THB

  16.6 kg * 30 THB * 25 days * 12 months

4.2.3. Monetary Environmental Investment Appraisal

According to Table 4.5, payback period is 0.10 year, NPV(6.4%) is 1,714,123.08 THB. IRR is 252%. B/C is 1.31.

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Table 4.5: Net Cash Flow of Option 1

THB	Year										
	-	1	2	3	4	5	6	7	8	9	10
Benefit											
Substituted polyol		898,491.60	898,491.60	898,491.60	898,491.60	898,491.60	898,491.60	898,491.60	898,491.60	898,491.60	898,491.60
Avoided landfill cost		149,400.00	149,400.00	149,400.00	149,400.00	149,400.00	149,400.00	149,400.00	149,400.00	149,400.00	149,400.00
Total Benefit (1)		**1,047,891.60**	**1,047,891.60**	**1,047,891.60**	**1,047,891.60**	**1,047,891.60**	**1,047,891.60**	**1,047,891.60**	**1,047,891.60**	**1,047,891.60**	**1,047,891.60**
Cost											
Machine and equipment	110,000.00										
Rental fee		600,000.00	600,000.00	600,000.00	600,000.00	600,000.00	600,000.00	600,000.00	600,000.00	600,000.00	600,000.00
Electricity cost		19,232.00	19,232.00	19,232.00	19,232.00	19,232.00	19,232.00	19,232.00	19,232.00	19,232.00	19,232.00
Salary and wage		30,618.00	32,761.26	35,054.55	37,508.37	40,133.95	42,943.33	45,949.36	49,165.82	52,607.42	56,289.94
Maintenance		120,000.00	120,000.00	120,000.00	120,000.00	120,000.00	120,000.00	120,000.00	120,000.00	120,000.00	120,000.00
Total Cost (2)	**110,000.00**	**769,850.00**	**771,993.26**	**774,286.55**	**776,740.37**	**779,365.95**	**782,175.33**	**785,181.36**	**788,397.82**	**791,839.42**	**795,521.94**
Net cash flow (1) - (2)	**(110,000.00)**	**278,041.60**	**275,898.34**	**273,605.05**	**271,151.23**	**268,525.65**	**265,716.27**	**262,710.24**	**259,493.78**	**256,052.18**	**252,369.66**
Bt/(1+r)^t	-	952,628.73	866,026.12	787,296.47	715,724.06	650,658.24	591,507.49	537,734.08	488,849.17	444,408.33	404,007.57
∑Bt/(1+r)^t	=	6,438,840.26									
Ct/(1+r)^t	110,000.00	699,863.64	638,010.96	581,732.94	530,524.12	483,924.94	441,517.58	402,922.19	367,793.40	335,817.21	306,708.15
∑Ct/(1+r)^t	=	4,898,815.13									

Source: Field Survey, 2006

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4.3 Option 2: Rigid PU Foam Scrap Reuse as Oil Sorbent

Option 2 is regrind and reuse in surfboard manufacturing process. This option includes flaking and milling processes. The additional process is packaging for sale as oil sorbent. However, the PU foam scrap input for option 2 is more than option 1 due to PU foam scrap input of option 1 depends on production plan which means that only 16.6 kg of PU foam can be used to substitute polyol in each day. On the other hand, the regrinding and reuse as oil sorbent does not depend on the production plan. Hence, 1 batch of this option starts with 300 kg of PU foam scraps per day.

4.3.1. Physical Environmental Management Accounting

Flaking process starts with feeding rigid PU scrap into flaking machine manually by a worker. The specifications of machine for this process are:

- able to flake 300 kg of foam in one day,
- suitable for rigid foam digestion,
- able to grind 25 cm diameter and 22 cm height of largest foam scrap without pre-grinding process.

Refer to specification of flaking machine following to a quotation, a rotary grinder of 7.5 HP is able to flake 100 kg of PU foam in an hour. The energy consumption of the machine is 5.6 kW. The product of flaking process is small flake of PU foam which is the input for next process. This process does not produce significant waste or other non-product output. The MEFA of flaking process is shown in Figure 4.1.

In Table 4.6, calculation starts with PU foam scrap at 300 kg per day as the first input of process. According to the technical data sheet of flaking machine, the machine is able to digest 300 kg of PU foam scrap within 8 hours. Operator finishes this job in 8 hours and energy consumption is 5.6 kW * 8 hour = 44.8 kWh.

There is no output due to flaking process does not post direct product or any significant emission.

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Table 4.6 Input – Output Table of Flaking Process of Option 2

INPUT			
Item	Amount	Unit	Data source
PU scrap	300	kg	Environmental officer
Electrical energy	44.8	kWh	Quotation
Direct labor	8	hour	Calculation

Source: Field survey, 2006

In crushing or milling process, flaked foam is sent to milling machine manually by a worker. The specifications of machine for this process are:

- able to digest 300 kg of foam in one day,
- suitable for rigid foam digestion,
- able to grind foam into 0.2 mm of diameter dust.

Refer to specification of milling machine following to a quotation, a milling machine of 7.5 HP is able to flake 37.5 kg of PU foam in an hour. The energy consumption of the machine is 5.6 kW. The MEFA of milling process is shown in Figure 4.2.

The working hour of operator to finish this job is 8 hours and energy consumption is 5.6 kW * 8 hour = 44.8 kWh.

Table 4.7 Input – Output Table of Milling Process of Option 2

INPUT			
Item	Amount	Unit	Data source
Intermediate material from flaking process	300	kg	Environmental officer
Electrical energy	44.8	kWh	Quotation
Direct labor	8	hour	Calculation

Source: Field survey, 2006

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For packaging process, the grinded rigid PU foam is filled by filling machine in 30*35*4 cm or 4,200 m^3 pillow-shaped cloth container which is purchased from vendor at 20 THB/piece regarding to interview with existing cloth work vendor (Figure 4.4).

According to the measurement, 12,566.67 cm^3 of PU foam weigh 1 kg. This means 300 kg of PU foam is able to be produced for (300*12,566.67)/4,200 = 897 pillows.

The specification of machine for this process is able to fill 300 kg of foam dust in one batch. Regarding to interview with machine vendor, a filling machine 3HP is able to fill 5 pillows in a minute. For 897 pillows, the machine has to operate for 897 pillows/5 pillows per minute = 180 minutes or 3 hours. Energy consumption is 2.247 kW * 3 hour = 6.74 kWh.

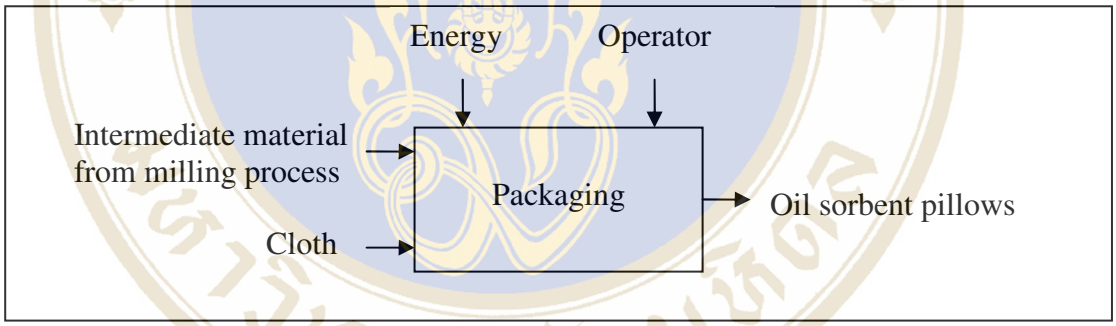

Figure 4.4 MEFA of Packaging Process

Table 4.8 Input – Output Table of Packaging Process of Option 2

INPUT			
Item	Amount	Unit	Data source
Direct labor	3	hour	Calculation
Pillow	897	EA	Calculation
Electrical energy	6.74	kWh	Quotation
OUTPUT			
Item	Amount	Unit	Data source
Oil sorbent	897	pillow	Calculation

Source: Field survey, 2006

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4.3.2. Monetary Environmental Management Accounting

Regarding to PEMA of this option, it can be summarized total input-output of all processes in option one in one year and converted into monetary value as shown in Table 4.9. These include:

- PU foam scraps is calculated from 300 kg*25 days*12 months = 90,000 kg/year
- Electrical energy is calculated from 96.34 kWh*25 days*12 months = 28,902 kWh/year
- Direct labor from all process is 19 hours*25 days*12 months = 5,700 hours/year
- According to the price of similar products at 200 THB reducing the price for selling, brand management cost and risk for marketing demand, it can be set its price at 50 THB per pillow. Oil sorbent pillow production yield is 897 pillows*25 days*12 months = 269,100 pillows/year

Table 4.9 Monetary Environmental Management Accounting of Option 2

INPUT				
Item	Amount	Unit	Unit cost (THB)	Costs
PU foam scarp	90,000	kg	N/A	0
Electrical energy	28,902	kWh	3.624	104,740
Direct labor	5,700	hour	21.87	124,659
Pillow package	269,100	pillow	20	5,382,000
OUTPUT				
Item	Amount	Unit	Unit cost (THB)	Costs
Oil sorbent	269,100	pillow	50	13,455,000

Source: Field survey, 2006

Note: Reference unit of year 2006, based on 1 batch of 300 kg PU foam scrap

Initial investment

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Machine and equipment

- Hammer milling machine 80,000 THB
- Milling machine 95,000 THB
- Powder filling machine 100,000 THB

Operation cost

Fixed cost

- Monthly rental fee 600,000 THB
  50,000 THB*12 month

Variable cost (at full capacity)

- Direct labour 124,659 THB
- Electricity cost 104,740 THB
- Pillow package 5,382,000 THB
- Maintenance of machine 180,000 THB
  5,000 THB/month*3 machines*12 months

Benefit

- Oil sorbent product 13,455,000 THB
- Avoided landfill cost 2,700,000 THB
  300kg*30 THB * 25 days * 12 months

4.3.3. Monetary environmental investment appraisal

According to Table 4.10, payback period is 0.02 year. NPV (6.4%) is 65,735,039.49 THB. IRR is 3,550.31%. B/C is 2.45.

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Table 4.10 Net Cash Flow of Option 2

	Year										
	-	1	2	3	4	5	6	7	8	9	10
Benefit											
Oil sorbent		13,455,000.00	13,455,000.00	13,455,000.00	13,455,000.00	13,455,000.00	13,455,000.00	13,455,000.00	13,455,000.00	13,455,000.00	13,455,000.00
Avoided landfill cost		2,700,000.00	2,700,000.00	2,700,000.00	2,700,000.00	2,700,000.00	2,700,000.00	2,700,000.00	2,700,000.00	2,700,000.00	2,700,000.00
Total Benefit (1)		**16,155,000.00**	**16,155,000.00**	**16,155,000.00**	**16,155,000.00**	**16,155,000.00**	**16,155,000.00**	**16,155,000.00**	**16,155,000.00**	**16,155,000.00**	**16,155,000.00**
Cost											
Machine and equipment	275,000.00										
Rental fee		600,000.00	600,000.00	600,000.00	600,000.00	600,000.00	600,000.00	600,000.00	600,000.00	600,000.00	600,000.00
Electricity cost		104,740.00	104,740.00	104,740.00	104,740.00	104,740.00	104,740.00	104,740.00	104,740.00	104,740.00	104,740.00
Salary and wage		124,659.00	133,385.13	142,722.09	152,712.64	163,402.52	174,840.70	187,079.54	200,175.11	214,187.37	229,180.49
Pillow package		5,382,000.00	5,382,000.00	5,382,000.00	5,382,000.00	5,382,000.00	5,382,000.00	5,382,000.00	5,382,000.00	5,382,000.00	5,382,000.00
Maintenance		180,000.00	180,000.00	180,000.00	180,000.00	180,000.00	180,000.00	180,000.00	180,000.00	180,000.00	180,000.00
Total Cost (2)	**275,000.00**	**6,391,399.00**	**6,400,125.13**	**6,409,462.09**	**6,419,452.64**	**6,430,142.52**	**6,441,580.70**	**6,453,819.54**	**6,466,915.11**	**6,480,927.37**	**6,495,920.49**
Net cash flow (1) - (2)	**(275,000.00)**	**9,763,601.00**	**9,754,874.87**	**9,745,537.91**	**9,735,547.36**	**9,724,857.48**	**9,713,419.30**	**9,701,180.46**	**9,688,084.89**	**9,674,072.63**	**9,659,079.51**
Bt/(1+r)^t	-	14,686,363.64	13,351,239.67	12,137,490.61	11,034,082.37	10,030,983.97	9,119,076.34	8,290,069.40	7,536,426.73	6,851,297.02	6,228,451.84
∑Bt/(1+r)^t	=	99,265,481.59									
Ct/(1+r)^t	275,000.00	5,810,362.73	5,289,359.61	4,815,523.73	4,384,572.53	3,992,612.60	3,636,104.37	3,311,829.89	3,016,863.63	2,748,545.86	2,504,458.55
∑Ct/(1+r)^t	=	39,785,233.51									

Source: Field survey, 2006

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4.4 Option 3: Rigid PU Foam Scrap Reuse in Surfboard Manufacturing Process and Reuse as Oil Sorbent

This option is integration between options 1 and 2. After implementing option 1 according to Surf Business Unit's production plan, PU foam scrap still remains for 283.4 kg per day. This PU foam scrap is sent to reuse as oil sorbent follow to process described in option 2. Total PU foam scrap input is 300 kg.

This option includes flaking, milling, premixing and packaging processes. Sixteen point six kg of PU foam scrap is sent to reuse in new surfboard manufacturing and 283.4 kg of scrap is sent to packaging process for reuse as oil sorbent.

4.4.1. Physical environmental management accounting

Input and output of each process is as described in material and energy flow in Figures 4.1 to 4.4

Flaking process starts with feeding rigid PU scrap into flaking machine manually by a worker. The specifications of machine for this process are:

- able to flake 300 kg of foam in one day,
- suitable for rigid foam digestion,
- able to grind 25 cm diameter and 22 cm in height of largest foam scrap without pre-grinding process.

Refer to specification of flaking machine following to a quotation, a rotary grinder of 7.5 HP is able to flake 100 kg of PU foam in an hour. The energy consumption of the machine is 5.6 kW. The product of flaking process is small flake of PU foam which is the input for next process. This process does not produce significant waste or other non-product output (Figure 4.1).

In Table 4.6, calculation starts with PU foam scrap at 300 kg per day as the first input of process. According to the technical data sheet of flaking machine, the

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machine is able to digest 300 kg of PU foam scrap within 8 hours. Operator finishes this job in 8 hours and energy consumption is 5.6 kW * 8 hour = 44.8 kWh.

There is no output due to flaking process does not post direct product or any significant emission.

Table 4.11 Input – Output Table of Flaking Process of Option 3

INPUT			
Item	Amount	Unit	Data source
PU scrap	300	kg	Environmental officer
Electrical energy	44.8	kWh	Quotation
Direct labor	8	hour	Calculation

Source: Field survey, 2006

In crushing or milling process, flaked foam is sent to milling machine manually by a worker. The specifications of machine for this process are:

- able to digest 300 kg of foam in one day,
- suitable for rigid foam digestion,
- able to grind foam into 0.2 mm diameter dust.

Refer to specification of milling machine following to a quotation, a milling machine of 7.5 HP is able to flake 37.5 kg of PU foam in an hour. The energy consumption of the machine is 5.6 kW. The working hour of operator to finish this job is 8 hours and energy consumption is 5.6 kW * 8 hour = 44.8 kWh (Figure 4.2).

Table 4.12 Input – Output Table of Milling Process of Option 3

INPUT			
Item	Amount	Unit	Data source
Intermediate material from flaking process	300	kg	Environmental officer
Electrical energy	44.8	kWh	Quotation
Direct labor	8	hour	Calculation

Source: Field survey, 2006

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The milled PU foam is sent to 2 processes; 16.6 kg milled PU foam is sent for premixing and 283.4 kg is sent to packaging process.

In premixing process, the PU foam dust is mixed with virgin polyol at proportion 20 part of recycled foam per hundred parts of polyol. In each time of pre-mixing, a worker mixes PU foam dust with polyol in a cup and sends the cup to mixing machine. According to Engineering Division, the specification of machine is 5.2 HP with energy consumption at 3.88 kW. Polyol is an input in general process. Hence, it is not included in the I/O table. The product of this process is mixed PU foam dust and polyol. Anyhow, the valuation of product excludes polyol as the same reason as input.

From the interview with Production Supervisor of PU foam molding cell, a worker is able to finish pre-mixing process for 1 kg of foam within 3 min. For 16.6 kg of PU scrap and 66.4 kg of polyol, or 83 kg total weight can be pre-mixed in 83 kg * 3 minutes = 249 minutes. Electricity consumption is 3.88 kW*4.15 hour = 16.1 kWh. (Figure 4.3).

Table 4.13 Input – Output Table of Pre Mixing Process of Option 3

INPUT			
Item	Amount	Unit	Data source
Intermediate material from milling process	16.6	kg	Calculation
Electricity cost	16.1	kWh	Engineering Division
Direct labor	249	min	Calculation
OUTPUT			
Item	Amount	Unit	Data source
Polyol+PU scrap for mixing with isocyanate	83	kg	Calculation

Source: Field survey, 2006

PU foam that remains after premixed for 283.4 kg is packed in packaging process. The grinded rigid PU foam is filled by filling machine in 30*35*4 cm or

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4,200 cm^3 pillow-shaped cloth container which is purchased from vendor at 20 THB/piece regarding to interview with existing cloth work vendor.

According to the measurement, 12,566.67 cm^3 of PU foam weigh 1 kg. This means 283.4 kg of PU foam is able to be produced for (283.4 *12,566.67)/4,200 = 847 pillows.

The specification of machine for this process is able to fill 283.4 kg of foam dust in one batch. Regarding to the interview with machine vendor, a filling machine of 3HP is able to fill 5 pillows in a minute. For 847 pillows, the machine has to operate = 847 pillows / 5 pillows per minute = 169 minutes or 2.82 hours. Energy consumption is 2.247 kW * 2.82 hour = 6.34 kWh (Figure 4.4).

Table 4.14 Input – output table of packaging process of Option 3

INPUT			
Item	Amount	Unit	Data source
Direct labor	2.82	hour	Calculation
Pillow	847	EA	Calculation
Electrical energy	6.34	kWh	Quotation
OUTPUT			
Item	Amount	Unit	Data source
Oil sorbent	847	pillows	Calculation

Source: Field survey, 2006

4.4.2. Monetary Environmental Management Accounting

Regarding to PEMA of this option, it can be summarized total input-output of all processes in option one in one year and converted in to monetary value as shown in Table 4.15. These include:

- PU foam scraps is calculated from 300 kg*25 days*12 months = 90,000 kg/year
- Electrical energy is calculated from 112.04 kWh*25 days*12 months = 33,612 kWh/year
- Direct labor from all process is 22.97 hours*25 days*12 months = 6,891 hours/year

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- Recycled foam for mixing with isoyanate is 16.6 kg*25 days*12 months = 4,980 kg/year
- According to the price of similar products at 200 THB reducing the price for selling, brand management cost and risk for marketing demand, it can be set its price at 50 THB per pillow. Oil sorbent pillow production yield is 847 pillows*25 days*12 months = 254,100 pillows/year

Table 4.15 Monetary Environmental Management Accounting of Option 3

INPUT				
Item	Amount	Unit	Unit cost (THB)	Costs
PU foam scarp	90,000	kg	N/A	0
Electrical energy	33,612	kWh	3.624	121,810
Direct labor	6,891	hour	21.87	150,706
Pillow package	254,100	pillow	20	5,082,000
OUTPUT				
Item	Amount	Unit	Unit cost (THB)	Costs
Recycled foam	4,980	kg	180.24	897,595.2
Oil sorbent	254,100	pillow	50	12,705,000

Source: Field survey, 2006

Note: Reference unit of year 2006, based on 1 batch of 300 kg PU foam scrap

Initial investment

Machine and equipment

- Hammer milling machine 40,000 THB
- Milling machine 70,000 THB
- Powder filling machine 100,000 THB

Operation cost

Fixed cost

- Monthly rental fee 600,000 THB
  50,000 THB*12 month

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Variable cost (at full capacity)

- Direct labour 150,706 THB
- Electricity cost 121,810 THB
- Pillow package 5,082,000 THB
- Maintenance of machine 180,000 THB

  5,000 THB/month*3 machines*12 months

Benefit

- Substituted polyol 897,595 THB
- Oil sorbent product 12,705,000 THB
- Avoided landfill cost 2,700,000 THB

  300kg*30 THB * 25 days * 12 months

4.4.3. Monetary environmental investment appraisal

According to table 4.16, payback period is 0.02 year NPV(6.4%) is 68,421,504.67 THB. IRR is 3,697.38%. B/C is 2.62.

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Table 4.16 Net Cash Flow of Option 3

	Year										
	-	1	2	3	4	5	6	7	8	9	10
Benefit											
Oil sorbent		12,705,000.00	12,705,000.00	12,705,000.00	12,705,000.00	12,705,000.00	12,705,000.00	12,705,000.00	12,705,000.00	12,705,000.00	12,705,000.00
Substituted polyol		897,595.20	897,595.20	897,595.20	897,595.20	897,595.20	897,595.20	897,595.20	897,595.20	897,595.20	897,595.20
Avoided landfill cost		2,700,000.00	2,700,000.00	2,700,000.00	2,700,000.00	2,700,000.00	2,700,000.00	2,700,000.00	2,700,000.00	2,700,000.00	2,700,000.00
Total Benefit (1)		**16,302,595.20**	**16,302,595.20**	**16,302,595.20**	**16,302,595.20**	**16,302,595.20**	**16,302,595.20**	**16,302,595.20**	**16,302,595.20**	**16,302,595.20**	**16,302,595.20**
Cost											
Machine and equipment	275,000.00										
Rental fee		600,000.00	600,000.00	600,000.00	600,000.00	600,000.00	600,000.00	600,000.00	600,000.00	600,000.00	600,000.00
Electricity cost		121,810.00	121,810.00	121,810.00	121,810.00	121,810.00	121,810.00	121,810.00	121,810.00	121,810.00	121,810.00
Salary and wage		150,706.00	161,255.42	172,543.30	184,621.33	197,544.82	211,372.96	226,169.07	242,000.90	258,940.97	277,066.83
Pillow package		5,082,000.00	5,082,000.00	5,082,000.00	5,082,000.00	5,082,000.00	5,082,000.00	5,082,000.00	5,082,000.00	5,082,000.00	5,082,000.00
Maintenance		180,000.00	180,000.00	180,000.00	180,000.00	180,000.00	180,000.00	180,000.00	180,000.00	180,000.00	180,000.00
Total Cost (2)	**275,000.00**	**6,134,516.00**	**6,145,065.42**	**6,156,353.30**	**6,168,431.33**	**6,181,354.82**	**6,195,182.96**	**6,209,979.07**	**6,225,810.90**	**6,242,750.97**	**6,260,876.83**
Net cash flow (1) - (2)	**(275,000.00)**	**10,168,079.20**	**10,157,529.78**	**10,146,241.90**	**10,134,163.87**	**10,121,240.38**	**10,107,412.24**	**10,092,616.13**	**10,076,784.30**	**10,059,844.23**	**10,041,718.37**
Bt/(1+r)^t	-	14,820,541.09	13,473,219.17	12,248,381.07	11,134,891.88	10,122,628.98	9,202,389.98	8,365,809.08	7,605,280.98	6,913,891.80	6,285,356.18
∑Bt/(1+r)^t	=	100,172,390.20									
Ct/(1+r)^t	275,000.00	5,576,832.73	5,078,566.46	4,625,359.35	4,213,121.60	3,838,135.02	3,497,019.27	3,186,701.17	2,904,386.73	2,647,535.82	2,413,839.05
∑Ct/(1+r)^t	=	38,256,497.20									

Source: Field survey, 2006

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4.5 Result and Discussion

According to the investment appraisal, the result of reutilization options is as shown in Table 4.11. The findings of the study are discussed below.

Table 4.17 Result of Monetary Environmental Investment Appraisal

Option	Payback period	NPV (6.4%)	B/C	IRR
Option 1	0.1	1,714,423	1.31	252%
Option 2	0.02	65,735,039	2.50	3,550%
Option 3	0.02	68,421,504	2.62	3,697%

Regarding to result of option 1 or reuse in surfboard manufacturing process, the project will recoup its initial investment in 0.1 year or 1.2 month. NPV (6.4%) is 1,714,423 THB. This means that at the end of the project calculated with 6.4% discount rate, this project will be able to get profit 1,714,423 THB. B/C is 1.31. It means this project has benefit more than cost 1.31 times. IRR is 252% which is higher compare with opportunity cost of fund at 6.4%. Hence this option should be taken. In overall results, option 1 is worth to be invested.

For option 2 or reuse as oil sorbent, the project will recoup its initial investment in 0.02 year. NPV (6.4%) is 65,735,039 THB. This means that at the end of the project calculated with 6.4% discount rate, this project will be able to get profit 65,735,039 THB. B/C is. It can be interpreted that this project has benefit more than cost 2.50 times. IRR is 3,550% compare with opportunity cost of fund at 6.4%. This means that this option should be invested more than do nothing. Consider from these indicators, option 2 is worth to be invested.

For option 3 or integration of option 1 and, the project will recoup its initial investment in 0.02 years. NPV (6.4%) is 68,421,504 THB. This means that at the end of the project calculated with 6.4% discount rate, this project will be able to get profit 68,421,504 THB. B/C is 2.62. It can be interpreted that this project has benefit more than cost 2.62 times. IRR is 3,697% compare with opportunity cost of fund at 6.4%. This means that this option should be invested more than do nothing. Consider from these indicators, option 3 is worth to be invested.

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In summary, for the investment appraisal result for all options, the money would do more for the present value of net worth by being put into the project than interest rate. Thus, these reutilization options can gain benefit and also eliminate landfilling.

In comparison, option 3 or the integration between options 1 and 2 has higher benefit return; shortest payback period, higher NPV, B/C and IRR. The result show that rigid PU scrap reuse in surfboard manufacturing process will gain higher than reuse as oil sorbent because it is able to take larger amount of PU foam scrap. Option 3 is set to optimize benefit and it gets the highest return with reasonable investment. However, options 2 and 3 contain uncertainty in market demand.

Besides the tangible benefit that have been calculated in Chapter IV, PU foam reutilizing also reduces environmental problems and create workplace safely, less chance of soil and ground water contamination and is able to improve company's public image and environmental concern.

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CHAPTER V
CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Polyurethane foam scraps from surfboard manufacturing generate the prime focus of this study. Currently, most of rigid polyurethane foam waste generated in various types of industry is sent to be disposed although the foam is able to be reutilized. Due to this reason, this study has developed an environmental economic analysis in order to evaluate that 'is it possible and worth to reutilize PU foam scrap in surfboard manufacturing as selected case study.

The objective of this study is to explore alternative for rigid PU foam scrap reutilization and to use economic instrument for supporting decision making in the selected rigid PU foam scrap reutilization option.

For the first objective, this study found that, up to date, the available PU foam scrap reutilization options comprise of mechanical recycling (e.g. regrinding), chemical recycling (e.g. glycolysis) and thermal chemical recycling (e.g. pyrolysis and incineration). This study focused only on mechanical recycling because it requires lower technology and investment.

For the second objective, environmental management accounting or EMA was selected as a tool for rigid PU foam reutilization investment appraisal. The strength of this tool is its ability to scope both costs and benefit for company project

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point of view and able to ensure that the study has included all cost in the selected scope process by process.

In data analysis, the collected data was evaluated by using EMA. This study is different from typical EMA that is used to compare environmental friendly project with existing practice which post negative effect to environment or 'environmental hot spot' in technical term. Moreover, this study used EMA to compare projects that both provide positive effect to environment without focusing on environmental hot spot. However, EMA is flexible for both perspectives and for non-product output process such as landfilling.

The conclusion of EMA are:

- Option 1 is worth to be invested with NPV (6.4%) = 1,714,423, B-C Ratio = 1.31, IRR = 252%.
- Option 2 is worth to be invested with NPV (6.4%) = 65,735,039, B-C Ratio = 2.50, IRR = 3,550%.
- Option 3 is worth to be invested with NPV (6.4%) = 68,421,504 B-C Ratio = 2.62, IRR = 3,697%.
- In comparison, option 3 gain highest NPV, B-C Ratio and IRR.

5.2 Recommendations

5.2.1 In calculation part of wage and salary, the operation cannot be employed by any number of working time or in small unit such as minute as PEMA indicated. In fact, employees have to be employed full day or hour based employment.

5.2.2 The investment appraisal in real world investment should consider market demand for product especially for option 2 and 3.

5.2.3 The market sensitivity for recycled product should be studied. This can be two side coin depend on market perspective toward environmental issue, one rejects reuse grade product while another welcomes green product.

5.2.4 The scope of study is based on company point of view, hence it focus only direct use cost. If this study is accessed in social point of view in further research, total economic value comprise of use value, non-use value and optional values should

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be accessed. Besides economical return, the reutilizations also provide benefit to environment since reducing resource extraction, reducing environmental and adverse effect from waste disposal process.

5.2.5 With the myth of recycling market that thermosetting or non-meltable plastic cannot be recycled, almost of PU foam scrap is sent to landfill. This is partly true that PU foam scrap cannot turn to be plastic resin as other foams like expanded polystyrene (EPS) foam do. Another hidden part is it can be use as filler, oil sorbent or many other things without turning them to be plastic resin. This is a challenge opportunity and be win-win solution for both business and environment.

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APPENDIX

CHEMICAL AND THERMAL CHEMICAL POLYURETHANE FOAM RECYCLING

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- **Glycolysis/Acoholysis**

In glycolysis, PUs are converted into liquids with the aid of glycols. The resultant recycled polyols can replace some or all of the original polyols in the manufacture of articles such as rigid PU foam and glass mat reinforced PU structural components.

Basically, glycolysis implies the heat-up of pre-grinded PU scrap, preferably rigid PU foam to 180-220°C in high-boiling point glycols with a catalyst. The glycol is usually diethylene glycol (DEG) with co-reagent diethanol amine (DEA). A temperature below 180°C gives too low catalyst activity; a temperature above 220°C gives undesired side reactions towards amines. For the catalyst it is important that the formation of aromatic amines is avoided. Since the glycol is both a reactant and a solvent, glycol/PU scrap ratios 60/40 are necessary. There are two approaches in this process, a single polyol is recovered or flexible and rigid polyols components are recovered. The concept of glycolysis is shown in Figure A1

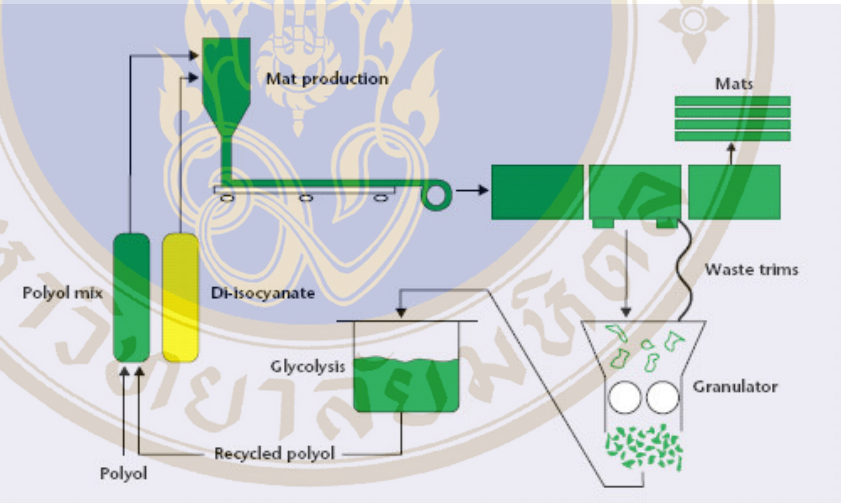

Figure A1 Glycolysis concept

Source: European Isocyanate Producers Association, 2001

Split-phase glycolysis has been developed up to pilot scale for MDI flexible foams. The glycolysis product separates into two phases. The first phase, top layer is a flexible foam polyol which after purification can be used alone to make the same flexible foam again. For second phase, after post treatment with propylene oxide, the bottom layer can be converted into a high quality rigid foam polyol (European Isocyanate Producers Association, 2001) The split-phase glycolysis process allows the recovery of the flexible polyol component, which represents 60 to 70 percent of the

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foam's weight and can be used to replace virgin polyol in MDI slabstock foam mattress production. A schematic diagram of this split-phase glycolysis process is shown in Figure A2

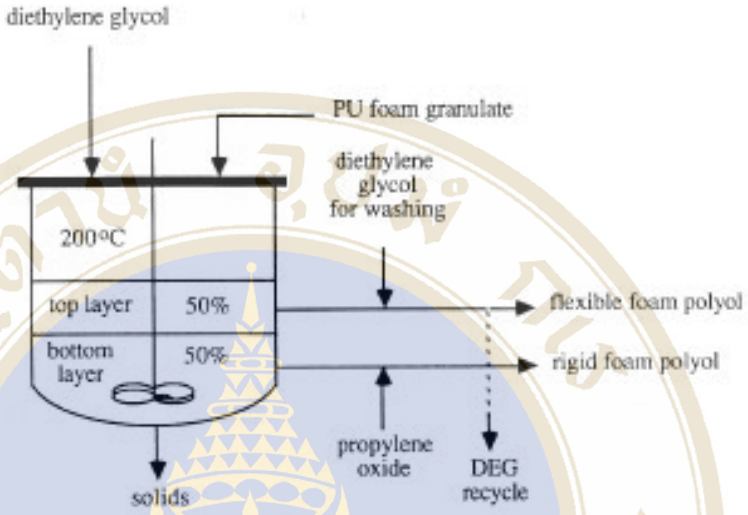

Figure A2 the Schematic of the Split- Phase Glycolysis process for PU foam recycling
Source: Zevenhoven, 2003

Glycolysis is recently being applied more often in those favorable cases, where a suitable application for the glycolysate has been identified. A lot of research has resulted in several process variations. Some of them include purification and chemical processing of the regenerate before use in PU applications. In all cases, appropriate industrial safety measures must be applied, because hazardous substances could be formed (Weigand and Strobbe, 1999; Polyurethane Recycle and Recovery Council, 2005)

The companies and organizations that used this method such as Logtor A/S in Denmark which recycle PU foam form pipe line and Poliuretanos, S.A. which recycle rigid PU foam form insulation manufacturing.

– **Pyrolysis and gasification**

Pyrolysis and gasification are thermal processes. This technique uses high temperatures to break down any waste containing carbon. Both technologies use less oxygen than traditional mass-burn incineration. The pyrolysis process degrades waste

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to produce ash, pyrolysis oil and synthetic gas. The gasification process then breaks down the hydrocarbons left into a synthetic gas using a controlled amount of oxygen.

Gasification involves using a small amount of oxygen whereas pyrolysis uses none. Both produce a synthetic gas made up mainly of carbon monoxide and hydrogen (85 percent), with smaller amounts of carbon dioxide and methane. Synthetic gas has a calorific value, so it can be used as a fuel to generate electricity or steam, or used as a basic chemical in the petrochemical and refining industries. Other by-products include liquids and solid residues such as ash. Most gasification and pyrolysis processes have four stages. The first on is pre-treating the waste, which usually involves sterilizing it and separating out some of the recyclables, especially glass, grit and metal which have no calorific value. Then the remaining waste will be heated to produce gas, oils and ash. After that, some particulates, hydrocarbons and soluble matter are removed in scrubbing process. The last process, the scrubbed gas will be used to generate electricity and, in some cases, heat through combined heat and power (Zevenhoven, 2003)

The study of pyrolysis of flexible PU foam from automobile seats showed the release of significant amounts of CO, CH_4, HCN, NH_3 and NO, plus probably some small amounts of C_2H_4 and C_2H_2. It is argues that first some PU nitrogen is released directly as NO, followed by a large release of HCN, which may be oxidized in the gas phase to NO as well (Friends of Earth, 2002; Zevenhoven, 2003).

Pyrolysis has also been criticized by environmentalists for causing more pollution than fossil fuels. Like incineration, pyrolysis and gasification produce emissions, include acid gases, dioxins and furans, nitrogen oxides, sulphur dioxide, particulates, cadmium, mercury, lead and hydrogen sulphide. Solid residues include inert mineral ash, inorganic compounds, and any remaining unreformed carbon. These can be between 8 and 15 per cent of the original volume of waste. Other emissions include treated water which is used to wash the waste in the pre-treatment stage, and clean the gas (Friends of Earth, 2002; Department of the Environment and Heritage, 2005).

– **Hydrogenation**

Hydrogenation takes pyrolysis one step further to produce pure gases and oils through a combination of heat, pressure and hydrogen. The purity of gases and oils

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derived from pyrolysis and hydrogenation, and the associated costs to produce functional finished products are important issues to be resolved. These can be used as fuel and chemical feedstock while partly used as energy source for the process (Zevenhoven, 2003).

– **Hydrolysis**

Hydrolysis, a reaction of PU with water, can produce polyols and amine intermediates from PU process and post-consumer scrap (Alliance for the Polyurethanes Industry, 2006.) For the flexible PU foam, superheated steam of 200°C was found to convert PU foam from scrapped car seats into a two-phase liquid within around 15 minutes, at a volume reduction by a factor of 30. The liquids can be landfilled or distilled, separating the polyols and diamino toluenes (DATs) for reuse. The recovery and recycling of the polyol showed that superheated steam temperature should be around 288°C, producing a polyol that gave excellent new PU foam for seat cushions when mixed at 5 percent to virgin material. Too high temperature gives a decrease in useful polyol recovery, while polyol recovered at too low steam temperature produces unstable new PU foam.

When recovered, the polyols can be used as effective fuels and the intermediates can be re-used to produce other PU components. However, PU hydrolysis suffers from unfavourable economics and lack of markets for the recyclate products (Zevenhoven, 2003).

– **Adhesive Pressing**

Rigid PU foam can become high quality board ideal for use in damp condition via adhesive pressing, in the other name, particle composite processing technique. This method consumes a high proportion of waste material in recycling process, some case as up to 90 percent. Adhesive pressing process is similar to the chipboard process. However, the important part of adhesive pressing is the effective binder, polymeric diphenyl methane diisocyanate (PMDI), a major PU raw material which applied at 10 percent of weight level (European Isocyanate Producers Association 2001; Zevenhoven, 2003).

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PU raw materials as binders in moisture resistant, emission-free wood-based products play a crucial role in preserving resources, especially forest. They make it possible to convert simple wood chips and strands into strong beams and boards for use in housing construction. With rigid PU foam based as a binder, the production of high-grade wood-based products is both economical and eco-friendly. The PU binders can be used either on its own or in combination with conventional adhesive resins.

In adhesive pressing, the rigid PU foam scrap is chopped into flake or granulated form. Then, combine the foam scrap with a PU binder and converted into boards by subjecting it to heat and pressure in pressing machine. The board from recycled rigid PU foam performs greater moisture resistance than the conventional board, making them suitable for use in applications such as ships' interior fitting, furniture in kitchen, gymnasium floors, pallets and as substrates signs (European Isocyanate Producers Association, 2001).

Moreover, rigid PU foam can be used as a binder for wood – based products. The wood-based products are generally in the form of particle board, medium-density fiberboard (MDF), oriented strand board (OSB) and laminated strand lumber (LSL). They are inexpensive, high performance materials that find extensive application in the construction industry and in furniture manufacture

With a combination of heat, pressure and PU binders, even materials like straw which is difficult to bond can be used to produce boards. According to these, agricultural waste and industrial waste can be efficiently recycled at once. One great advantage of wood-based products with PU binders is that their strength properties are good enough to allow usage in structural applications. The absence of binder-specific emissions also means that wood-based products produced with PU binders are highly suitable for interior fixtures. (Bayer Business Unit Polyurethanes, 2006)

Co-combustion in cement kiln (Energy recovery from incineration)

One example of cost effective recycling of rigid PU foams is incineration with energy recovery in municipal solid waste combustion plants. Studies show that the emissions from high temperature combustion present no health hazard and are within official tolerance limits. Under certain conditions, compacted rigid foams can be used as substitute fuel in cement factories or as a chemical reducing agent for iron ore in

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blast furnaces. Incineration of PU can be carried out safely in modern solid waste combustors. Their energy value is quite significant and it is the advantage for combustion. (Federation of European Rigid Polyurethane Foam Associations, 2006; Van Peteghem, 2001)

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BIOGRAPHY

NAME Ms. Yuwarin Tattiam

DATE OF BIRTH November 6, 1982

PLACE OF BIRTH Rayong, Thailand

INSTITUTIONS ATTENDED Silpakorn University,
Nakornpathom, Thailand
Bachelor of Arts (Geography)

Mahidol University, Thailand
Master of Science (Industrial Ecology and Environment)

POSITION & OFFICE Safety, Health and Environment (SHE) Development Team Leader
Safety and Environment Department
Cobra International Company Limited
700/478 Moo 7, Donhuaror, Muang,
Chonburi, Thailand 20000

HOME ADDRESS 111 Moo 1, Wangwha, Suntornpoo Rd.
Kleang, Rayong,
Thailand 21110
Tel: +6638672121 (Residence)
+6638454210 (Office)
E-mail: y_tattiam@yahoo.com

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