T5 OR T8 FLUORESCENT LAMPS: MAKING DECISION WITH THEIR CARBON FOOTPRINTS

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หลอดฟลูออเรสเซ็นต์ T5 หรือ T8: การตัดสินใจด้วยคาร์บอนฟุตพริ้น

นางสาว นนทพัทธ์ สื่อเสรีธรรม

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งานวิจัยนี้ทำการประเมินการปลดปล่อยก๊าซเรือนกระจกตลอดวัฏจักรชีวิตของหลอดฟลูออเรสเซ็นต์ 4 รุ่น ได้แก่ 36WT8, 18WT8, 28WT5 และ 14WT5 กำหนดให้คำนวณปริมาณการปลดปล่อยก๊าซเรือนกระจกต่อหน่วยการทำงานที่ความสว่าง 143,000 ลูเมน สำหรับหลอดฟลูออเรสเซ็นต์ 36WT8 และ 28WT5 และ 26,250 ลูเมน สำหรับหลอดฟลูออเรสเซ็นต์ 18WT8 และ 14WT5 ก๊าซเรือนกระจกถูกปลดปล่อยมากที่สุดจากช่วงการใช้งานหลอดฟลูออเรสเซ็นต์ เนื่องจากการใช้กระแสไฟฟ้าในการทำงาน ปริมาณการปลดปล่อยก๊าซเรือนกระจกตลอดวัฏจักรชีวิตของผลิตภัณฑ์สรุปได้ดังนี้ 36WT8 ปลดปล่อย 21.9 tonCO_2e, 28WT5 ปลดปล่อย 16.7 tonCO_2e, 18WT8 ปลดปล่อย 5.1 tonCO_2e และ 14WT5 ปลดปล่อย 3.3 tonCO_2e แสดงให้เห็นว่าหลอดฟลูออเรสเซ็นต์ T8 ปลดปล่อยก๊าซเรือนกระจกมากกว่าหลอดฟลูออเรสเซ็นต์ T5 เนื่องจากมีการใช้พลังงานไฟฟ้ามากกว่า แต่เมื่อพิจารณาการปลดปล่อยก๊าซเรือนกระจกเฉพาะช่วงการได้มาซึ่งวัตถุดิบและกระบวนการผลิต หลอดฟลูออเรสเซ็นต์ 36WT8 ปลดปล่อย 61 kgCO_2e, 28WT5 ปลดปล่อย 73 kgCO_2e, 18WT8 ปลดปล่อย 17 kgCO_2e และ 14WT5 ปลดปล่อย 26 kgCO_2e แสดงให้เห็นว่าหลอดฟลูออเรสเซ็นต์ T5 ปลดปล่อยก๊าซเรือนกระจกมากกว่าหลอดฟลูออเรสเซ็นต์ T8 ที่เป็นเช่นนี้เนื่องจากหลอดฟลูออเรสเซ็นต์ T5 มีขนาดเล็ก มีการผลิตที่ซับซ้อน ใช้วัตถุดิบและพลังงานในการผลิตมากกว่าหลอดฟลูออเรสเซ็นต์ T8 แต่อย่างไรก็ตามในการเปลี่ยนใช้งานจากหลอดฟลูออเรสเซ็นต์ T8 เป็นหลอดฟลูออเรสเซ็นต์ T5 ตามนโยบายการประหยัดพลังงานของรัฐบาลไทย จำเป็นต้องประเมินผลกระทบของบัลลาสต์ซึ่งเป็นอุปกรณ์สำคัญที่ใช้งานร่วมกับหลอดฟลูออเรสเซ็นต์ด้วย โดยปริมาณก๊าซเรือนกระจกตลอดวัฏจักรชีวิตของหลอดฟลูออเรสเซ็นต์ 36WT8 กับบัลลาสต์แกนเหล็กมีค่าเท่ากับ 28.1 tonCO_2e และหลอดฟลูออเรสเซ็นต์ 28WT5 กับบัลลาสต์อิเล็กทรอนิกส์ปลดปล่อยก๊าซเรือนกระจก 18.9 tonCO_2e ดังนั้นในการเปลี่ยนใช้งานหลอดฟลูออเรสเซ็นต์ T8 เป็นหลอดฟลูออเรสเซ็นต์ T5 สามารถช่วยลดปริมาณการปลดปล่อยก๊าซเรือนกระจกได้ถึง 9.2 tonCO_2e ดังนั้นนโยบายการประหยัดพลังงานของรัฐบาลนี้สามารถช่วยลดปริมาณการปลดปล่อยก๊าซเรือนกระจกต่อหนึ่งชุดหลอดลงได้ แต่อย่างไรก็ตามควรพิจารณาถึงผลกระทบสิ่งแวดล้อมด้านอื่นๆ ร่วมด้วย เพื่อให้ครอบคลุมผลกระทบสิ่งแวดล้อมทุกประเภทที่อาจจะเกิดขึ้นจากนโยบายดังกล่าว

สาขาวิชา การจัดการสิ่งแวดล้อม ลายมือชื่อนิสิต นนทพัทธ์ สื่อเสรีธรรม

ปีการศึกษา 2553 ลายมือชื่อ อ.ที่ปรึกษาวิทยานิพนธ์หลัก ....

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ลายมือชื่อ อ.ที่ปรึกษาวิทยานิพนธ์ร่วม ....

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NONTHAPHAT SUESAREETHAM : T5 OR T8 FLUORESCENT LAMP: MAKING DECISION WITH THEIR CARBON FOOTPRINTS. ADVISOR : ASSOC. PROF. PRASERT PAVASANT, Ph.D., CO-ADVISOR : CHARONGPUN MUSIKAVONG, Ph.D., ASST. PROF. POMTHONG MALAKUL NA AYUDHAYA, Ph.D., 182 pp.

The environmental impact especially on climate change through the life cycle of fluorescent lamps (FL) was studied in this research. Products of interest are 36WT8, 18WT8, 28WT5 and 14WT5 FL. The different products were compared based on the same illuminating function, i.e. with the same brightness of 143,000 lumen for 36WT8 and 28WT5, and 26,250 lumens for 18WT8 and 14WT5. Majority of greenhouse gases (GHG) emission occurs during the usage stage due to the electricity consumption of FL. The overall GHG emission throughout the life cycle of each FL could be summarized as follows: 36WT8 emitted 21.9 tonCO_2e, 28WT5 16.7 tonCO_2e, 18WT8 5.1 tonCO_2e, and 14WT5 3.3 tonCO_2e. This reveals that T8 FLs released more GHG than T5 FLs as T8 consumed more electricity than T5. On the other hand, when considering only from raw material acquisition stage to manufacturing process of each FL, the results were: 36WT8 emitted 61 kgCO_2e, 28WT5 73 kgCO_2e, 18WT8 17 kgCO_2e, and 14WT5 26 kgCO_2e, which indicated that T5 emitted GHG more than T8. This was because the small size T5 FL inherited a more complicating and more energy consuming processes when compared to T8. However, the replacements of T8 with T5 according to the energy saving policy of Thai's government necessitated the assessment of the ballast which is the other main component of the FL set and needed to be used together with the lamp. GHG emission through life cycle of 36WT8 with magnetic ballast equaled to 28.1 tonCO_2e meanwhile 28WT5 with electronic ballast was 18.9 tonCO_2e. This result demonstrates that the change of T8 FL into T5 FL can help reduce the amount of GHG emission up to 9.2 tonCO_2e. Therefore this policy could actually decrease the GHG emission per one lamp set. However, this analysis does not try to incorporate other impact categories and economics into the consideration which could have other implications.

Field of Study : Environmental Management .... Student's Signature ....

Academic Year : 2010 .... Advisor's Signature ....

Co-advisor's Signature ....

Co-advisor's Signature ....

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CHAPTER I

INTRODUCTION

1.1 Rational

Global warming is caused by an increase in greenhouse gas (GHG) level such as carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulfur hexafluoride (SF_6) in the Earth's atmosphere. The main anthropogenic source of CO_2 is the use of fossil fuels for energy. Other sources are manufacturing processes, land use change, agricultural activities, transportation, decomposition of wastes, energy producers and consumers, etc. Presently, atmospheric CO_2 levels continue to rise on a year-over-year basis because GHG emissions from human sources exceed the natural absorption capacity of the land and oceans. Atmospheric CO_2 was already 391 parts per million (ppm) in January 2011 compared with only 316 ppm in January 1960 [1]. The CO_2 level is expected to increase to 550 ppm in 2035, assuming there are no successive management strategies to mitigate this problem [2].

The United Nations Framework Convention on Climate Change (UNFCCC) has expressed concerns about global warming problem and established an international agreement namely 'The Kyoto Protocol' which aims to reduce GHG emissions around five percent against 1990 levels over the five-year period 2008-2012 by the member countries. The protocol offers an additional means of reaching their targets by three market-based mechanisms: 1) emissions trading (ET) 2) joint implementation (JI) and 3) clean development mechanism (CDM) [3]. Countries that could not reach their own GHG reduction targets are required to purchase the carbon credits from other countries that have available credits. This has stimulated worldwide movements on greenhouse gas emission. At present, there are many tools used to demonstrate CO_2 emissions from the goods and products. The carbon footprint (CF), one of the most generalized tools accepted by many countries, indicates the amount of GHG emissions through the product's life cycle. CF can help determine the hot spot that has the most GHG emission from the production process, and this leads to the subsequent development of improvement options to reduce the overall GHG emission.

In Thailand, CF has been employed to support the Thai industrial sector to implement the low carbon trend and to increase the competitiveness of Thai industries in the world market. At the moment (as of July 2010), 22 companies with 42 products already have carbon footprint labels on their products. However, it is imperative that Thai manufacturers should expedite the monitoring and record of GHG emissions in various steps of manufacturing processes, and carry out research to improve the process efficiency to reduce GHG emissions, and sometimes the redesign of packaging, reuse/recycling policy can make a significant impact on environment [4].

Life cycle assessment (LCA) is a technique for assessing the environmental aspects associated with a product life cycle [5]. Data from life cycle assessment can be used in product design or manufacturing process design or services design to be more environmentally friendly (Eco-Design), which could then support the Non-Tariff Measures (NTMS) especially environmental concerns of countries in the European Union and developed countries. One of the industries which could be most affected by this revolution is the electric and electronic equipment industry which is among the fast growing and also creating significant environmental burden. This industry has already been monitored and controlled via several recent international restrictions and registration, such as the Registration, Evaluation and Authorization of Chemicals (REACH) EU direction (for the control of production and import chemical include substance, preparation and substance in article that more than 1 ton/year/type), Restriction of the use of certain hazardous substances in electrical and electronic equipment (RoHS) which limits the use of certain hazardous substances in electrical appliances and electronic products, and Waste from Electrical & Electronic Equipment (WEEE) which forces manufacturers to be responsible for retrieving the remains at the end product lives [6, 7].

Lamp industries are among the large electronic industries with direct effects from recent environment restrictions, e.g. RoHS and WEEE. Fluorescent lamp (FL) is one of the electronic products which should attract significant environmental concerns. 200 million lamps per year or more have been used alone in Thailand. Therefore these industries must always develop their products in order to be more environmentally friendly such as redesigning the lamp to require lesser raw materials and energy.

Thus far, there is no GHG emission assessments developed for FL in Thailand. Hence, it is newsworthy to assess GHG emission of FL in order to represent the amount of GHG emission generated from the FL life cycle. The obtained result could be used to develop the best practice of GHG reduction in Lamp industry, Thai LCI database, as well as preparedness of CF label on products. On this basis, this research focuses on the evaluation of CF or GHG emissions per unit product life cycle of T5 and T8 fluorescent lamp using the LCA method which will potentially lead to a proposal of improvement options for decreasing GHG emission.

Previous work has already assessed environmental impact of FL but this did not include ballast which is the basic devices working together with FL. This research therefore also focuses on life cycle of FL set which takes into account the contribution of ballast in the assessment of overall GHG emission.

1.2 Objectives

- To evaluate carbon footprints of T5 and T8 fluorescent lamp sets.
- To investigate greenhouse gas emission hot spots from the life cycle of fluorescent lamp sets
- To suggest the improvement options for mitigating greenhouse gas emissions from the life cycle of fluorescent lamp sets
- To compare carbon footprint between T5 and T8 fluorescent lamp sets.

1.3 Hypothesis

The amount of carbon footprint of T5 fluorescent lamp set is less than T8 fluorescent lamp set significantly.

1.4 Scope of the research

1. Time period data for assessment of GHG emissions of FLs products: January 2009 to May 2010 (17 months)

2. System boundary:

The assessment boundary of the fluorescent lamp set life cycle is Business-to-consumer (B2C) including raw materials extraction and processing, manufacturing process, distribution/retail, consumer use and disposal/recycling.

Note: A general PCR of fluorescent lamp product is currently not available, and therefore, this research sets out the scope of the evaluation based on the boundary demonstrated in Figure 3-1.

3. Products:

Four types of FLs (36WT8, 18WT8, 28WT5 and 14WT5) and two types of ballast (magnetic and electronic ballasts) are investigated. The properties of these FLs are displayed in Table 1-1 and the diagrams of the different FLs are illustrated in Figure 1-1.

Table 1-1 Properties of four fluorescent lamps in this study

FL type	Diameter (mm)	Length (mm)	Power (Wattage)	Light intensity (Lumen)	Average-life times (hour)
T8	26	1,200	36	2,650	20,000
		600	18	1,050	20,000
T5	16	1,149	28	2,700	20,000
		549	14	1,250	20,000

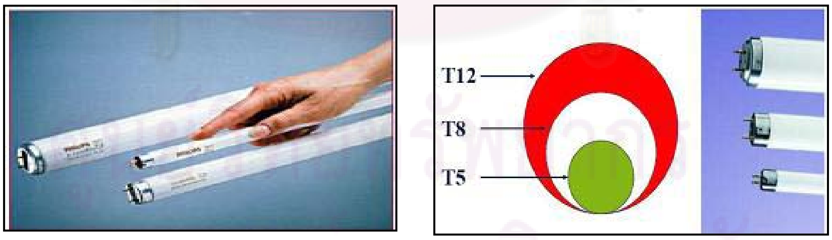

Figure 1-1 Size differences between T12, T8 and T5 lamps

Remark: T12 FL is the old fashion and not so popular type of lamp and not included in this work**.**

4. Functional unit:

Fluorescent lamps which last 20,000 hours and provide an overall 143,100 lumens for 36WT8 and 28WT5 and 26,250 lumens for 18WT8 and 14WT5.

5. System boundary exclusions [8]

The system boundary of the product life cycle excludes the GHG emissions associated with:

a) Human energy inputs to processes and/or preprocessing

b) Transport of consumers to and from the point of retail purchase;

c) Transport of employees to and from their normal place of work;

d) Land use change and;

e) Carbon storage in product because fluorescent lamp average life time is usually less than 10 years.

6. Sources of GHG emissions

The assessment includes GHG emissions arising from processes, inputs and outputs in the life cycle of a product, including:

- Materials production
- Materials use (Chemical reaction)
- Energy production for stationary and mobile source
- Energy use for stationary and mobile sources (including energy sources, such as electricity, that are themselves created using processes that have GHG emissions associated with them)
- Combustion process and transportation
- Waste and waste management

7. GHG emissions:

The six GHG emissions including carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), Hydro fluorocarbons (HFCs), Sulphur hexafluoride (SF_6) and Per fluorocarbons (PFCs) are included in this research.

8. Global warming potential (GWP):

GHG emissions are measured by mass and converted into CO_2e emissions using the GWP from IPCC 2007.

9. Supporting company:

Lamp industry and glass industry at the center of Thailand have been helpfully giving inputs on mass and energy flows within their factories.

10. Emission factor (E.F.):

Emission factors are selected from Thai, international LCI database and carbon footprint guideline of Thailand (December 2009).

11. Collecting data:

Primary data are based on 17 months retroactive data (January, 2009 to May, 2010). For lamps and glass bulbs, actual processing data (materials, energy used and wastes) are obtained from the annual product records from the factory**.** Other import materials data are obtained from questionnaires sent out to related Thai's agents. Other missing data are substituted with appropriate secondary data.

1.5 Expected results

The obtained result could be used to develop the best practice of GHG reduction in lamp industry, as well as preparedness of CF label on products. On this basis, this research focuses on the evaluation of CF or GHG emissions per unit product life cycle of T5 and T8 fluorescent lamp sets using the LCA method which potentially leads to a proposal of improvement options for decreasing GHG emission.

CHAPTER II
THEORIES AND LITERATURE REVIEWS

2.1 Life cycle assessment

Life cycle assessment (LCA) is a technique for assessing the environmental aspects associated with a product over its life cycle. LCA is a tool used to distinguish and analyze the usage of raw materials and energy and waste generated at each stage to assess the overall environmental performance of products in terms of quantity. The most important application is the analysis of the contribution of the life cycle stages to the overall environmental load, usually with the aim to prioritize improvements on products or processes. [9]

The life cycle of a product (both goods and services) ranges from resource extraction via raw material processing, manufacturing, and product use or service delivery, to recycling, and to the disposal of any remaining waste. The life cycle approaches account for all relevant environmental, health and resource depletion issues related to the life cycles of goods and services that meet our consumption needs and also help ensure that problems are effectively solved without creating new ones elsewhere (shifting of burdens). For this reason life cycle approaches are indispensable instruments for identifying and steering effective measures towards more sustainable production and consumption. [10]

An LCA study consists of four steps [9] (as shown in Figure 2-1):

1. Goal and scope definition: Clearly identifying the target of interest such as the reasons for the study, the target group to communicate the result and also define the type of target product, the system boundary, the functional unit, the environmental impact categories, data required, hypothesis and limitation.

2. Life cycle inventory analysis: Making a model of the product life cycle with all the environmental inflows and outflows.

3. Life cycle impact assessment: Understanding the environmental relevance of all the inflows and outflows.

4. The interpretation: Analyzing the results and evaluate the need and opportunities of reducing the impacts

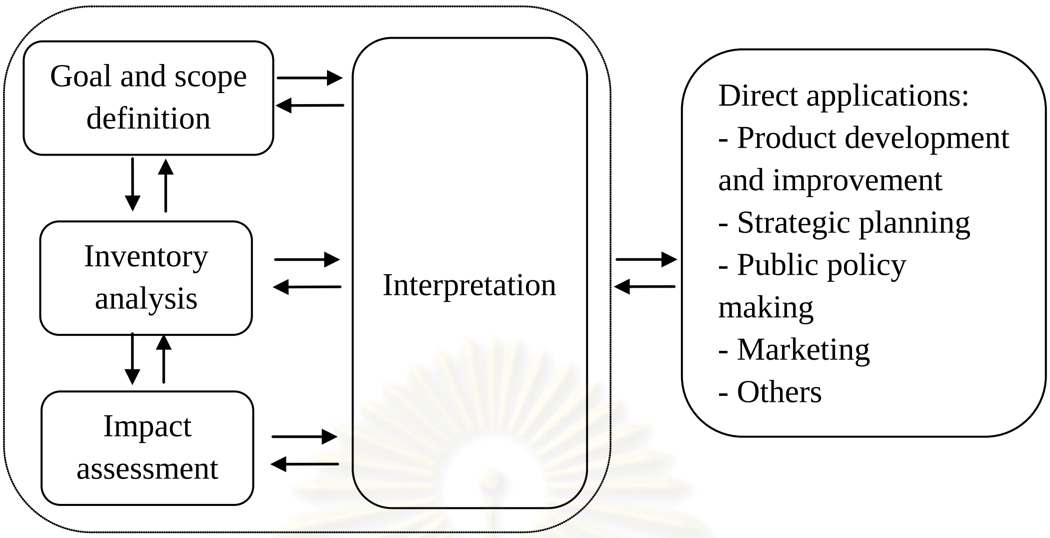

Figure 2-1: Life cycle assessment framework

2.2 Carbon footprint

Carbon footprint is a tool that responds to more environmental awareness, especially in issues related to climate change. ‘product carbon footprint’ (PCF) is a term used to describe the amount of greenhouse gas (GHG) emissions of a product across its life cycle, from raw materials extraction and transportation of raw material through production, distribution, consumer use and disposal/recycling (Figure 2-2). PCF includes the six greenhouse gases are controlled under the Kyoto protocol: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and sulphur hexafluoride (SF_6) together with families of gases including hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs).

PCF expressed in the weight of carbon dioxide equivalents, e.g. kg CO_2e using the global warming potential (GWP) to convert the emission from other GHGs into CO_2e. Each GHG emission comes from different sources and has different GWP value as can be seen in Table 2-1 [IPCC 2007] [11].

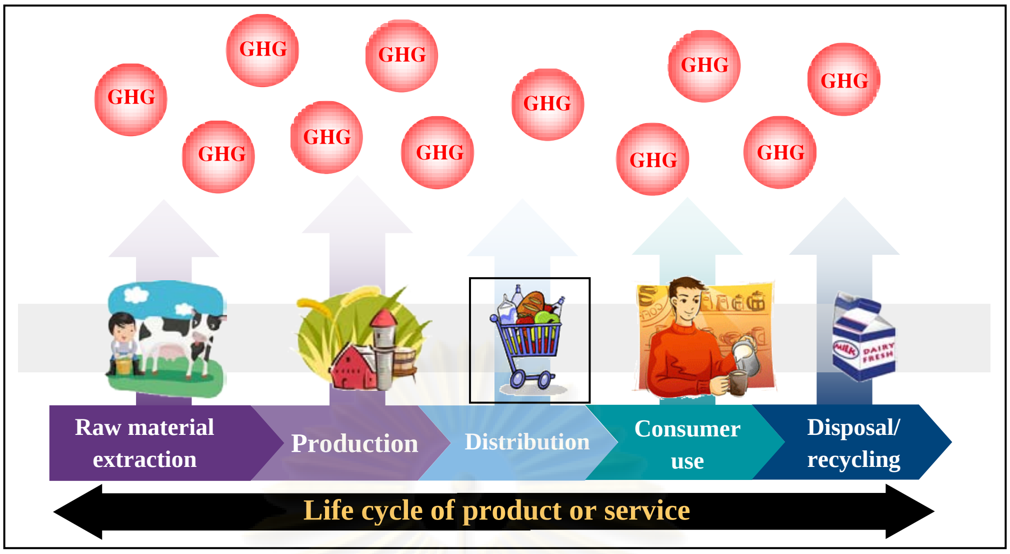

Figure 2-2 GHG emission through life cycle of product or service

Table 2-1: Six major anthropogenic greenhouse gases covered in the Kyoto protocol

Emission	Chemical formula	GWP_{100} (IPCC 2007)	Example of sources
Carbon dioxide	CO_2	1	Combustion processes
Methane	CH_4	25	Landfills, coal mining, wastewater treatment, biomass combustion
Nitrous oxide	N_2O	298	Agricultural soils and nitric acid production
Hydrofluorocarbons (HFCs)	-	124 – 14,800	Substitutes for ozone depleting substance, semiconductor manufacturing
Sulphur hexafluoride	SF_6	22,800	Electrical transmission and distribution
Perfluorocarbons (PFCs)	-	7,390 – 12,200	Substitutes for ozone depleting substance, semiconductor manufacturing

Sources of greenhouse gases can be divided into three categories shown in Figure 2-3 (follow the GHG protocol) as follows:

1. Direct emissions include GHGs that occur within the plant such as fuel combustion in the stationary source (boiler, furnace, burners, etc.) and mobile source (transport), fugitive emission, chemical reactions within the process as well as other activities that occur in the plants.

2. Energy indirect emissions from outside the factory such as purchased electricity, steam heat, etc.

3. Other indirect sources include upstream emission that related to production, transportation of raw materials. Downstream emissions related to transportation, distribution, use of the product and disposal/recycling of remained products.

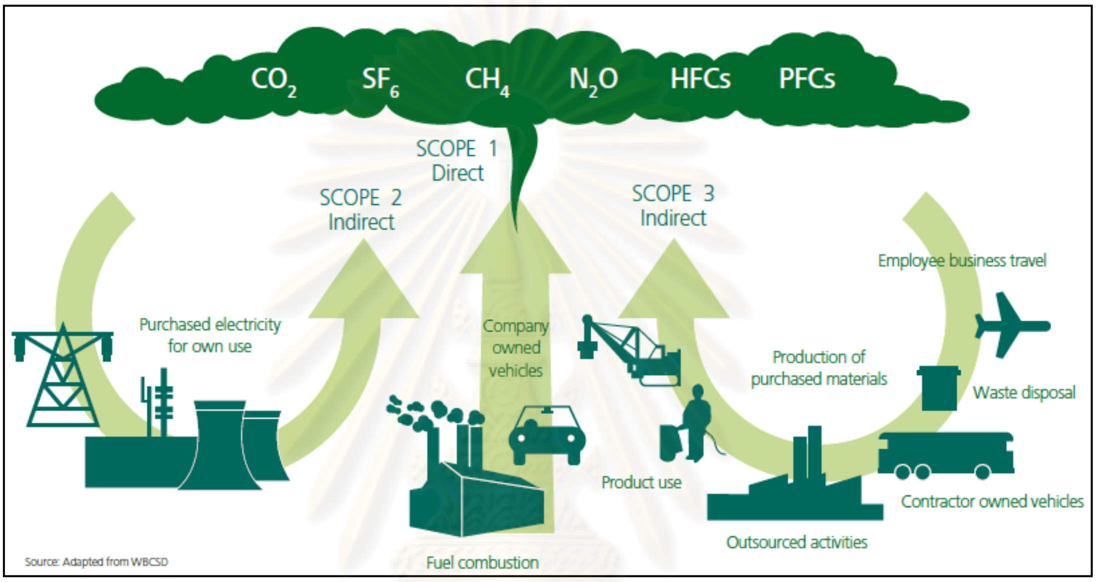

Figure 2-3 GHG emissions sources based on GHG protocol [12]

2.3 Carbon footprint standard

With regard to the methodological issues, a lot of the practical standard framework about how to measure a carbon footprint. The differences are found in the detail. The most distinctive feature is the method for allocating the carbon footprint between co-products (multi-outputs). The ISO 14040 and ISO 14044 are well established as an internationally standardized framework for LCA. It gives flexibility to implement LCA as established in accordance with different applications. Many carbon footprint initiatives thus refer to these standards as a point of departure and aim to set a specific guideline for product carbon footprint in compliant with them. The Publicly Available Specification 2050: 2008 or PAS 2050 is the standard developed through British Standards Institution (BSI) in partnership with the Carbon Trust and the Department of Environment Food and Rural Affairs (Defra). It can be stated that PAS 2050 is a derivative of ISO 14040/44. The main difference between the two standards is PAS 2050 focuses on carbon footprints, i.e. contribution to climate change, and ignores other environmental impacts. The PAS 2050 also contains additional principles and techniques that address essential aspects of GHG assessment, e.g. emissions from land use change, the impact of carbon storage, and double-counting issues associated with renewable electricity generation.

Apart from these ISO 14040/44 and PAS 2050, the World Resources Initiative (WRI) and the World Business Council for Sustainable development (WBCSD) has started in September 2008 to develop a standardized approach for companies to inventory, analyze, and manage their GHG emissions along their value chain at the product level namely the WRI/WBCSD GHG Protocol [13]. Other carbon footprint relevant standards and methodologies include ISO 14064 and ISO 14025. The first standard details principles and requirements dealing with the measurement, management and reporting of GHG emissions of organization or company level whereas the ISO 14025 establishes principles for the use of environmental information, labels and declarations. Furthermore ISO 14067 refers to a set of ISO standards currently under development specifying quantification and other relevant activities in relation to the carbon footprint of products.

2.4 Carbon footprint assessment

A carbon footprint is a sub-set of the data covered by a more complete Life Cycle Assessment (LCA) because the analysis is limited to emissions with an effect on climate change. A product carbon footprint assessment is based on key LCA techniques and principles as follows:

1. Goal and scope definition including:
   - 1.1 Setting objectives
   - 1.2 Define the functional unit
   - 1.3 Building a process map
   - 1.4 Boundaries setting
2. Inventory analysis including:
   - 2.1 Identification of emission sources
   - 2.2 Collection activity data and select emission factor
3. Impact assessment including:
   - 3.1 Calculation the footprint

4. Interpretation including:
   4.1 Reporting of product carbon footprint
   4.2 Identification of problematic parts with high GHG emission
   4.3 Propose the way to reduce emission

The detail of each step can be explained as follows:

2.4.1 Goal and scope definitions

Setting objectives

The objective of the assessment is set based on the overall target of the organization for example to communicate with customers, to reveal information to consumers, for decision making of production, for the design of new products, etc. Appropriate quantitative measures should be identified within a certain time period. For instance, the objective could be "the reduction of GHG by 10% by the end of Year 2010", etc. However, the most important goal in evaluating carbon footprint is to know the steps in the life cycle or in the process of the product that have the most GHG emission which will lead to management or improvement for reduce GHG at this step. This is also another way to help protect the environment.

Define the functional unit [14]

A functional unit reflects the way in which the product is actually consumed by the end user. The functional unit can be thought of as a meaningful amount of a particular product used for calculation purposes. The functional unit is important since it provides the basis for comparison and, if desired, communication of results. It may be easier to do the actual analysis using a larger unit. When choosing a functional unit there may be no single right answer, however it should be a unit that is easily understood and can be used by others.

Supply Chain Process Mapping [14]

The goal of this step is to identify the flow of the resources, i.e. list of input and output activities, covering from the extraction and processes of raw materials to disposal of the product including packaging. The process map serves as a valuable tool throughout the footprinting exercise, providing a starting point for interviews and a graphical reference to guide both data collection and the footprint calculation. There are considerable benefits to repeating the process map step as understanding of the life cycle improves, allowing greater prioritization and focus.

Boundary Setting [14]

This step defines the assessment boundaries or the limits of data needed. To begin with, it is important to set a limit for when measurement will stop. It is recommended that the life cycle boundary should either end when the product becomes the raw material for something else, or when the product reaches a state where it stops emitting carbon. This means that for the business-to-business (B2B) companies or the business-to-consumer (B2C) companies.

Business-to-consumer (B2C)

B2C covers the calculation of carbon footprint from raw materials, through manufacture, distribution and retail, to consumer use and finally disposal and/or recycling.

Business-to-business (B2B)

Business-to-business carbon footprints stop at the point at which the product is delivered to another manufacturer. The boundary of this assessment covers raw materials through production up to the point where the product arrives at a new organization, including distribution and transport to the customer's site. It excludes additional manufacturing steps, final product distribution, retail, consumer use and disposal/recycling.

From the reference information of the Publicly Available Specification (PAS) 2050, the scope of carbon footprint assessment shall include GHG emissions arising from processes, inputs and outputs in the life cycle of a product, including but not limited to:

a) Acquisition of raw materials and production, processing, transportation and storage of raw materials before production.

b) Energy consumption in the manufacturing process, cooling systems, heating system, ventilation system, and lighting system.

c) Manufacture and transportation of packaging.

d) The storage of product before transportation such as waiting in cold storage.

e) Waste recycling.

f) Management of waste generated and wastewater treatment.

g) Maintenance of equipment.

h) Energy consumption in office and service.

i) Transportation to sell to retailers.

j) The use of the product and consumption of the user.

k) Waste management after used.

However, the system boundary of the product life cycle shall exclude the GHG emissions associated with:

a) The production of capital goods used in the life cycle of the product;

b) Human energy inputs to processes and/or preprocessing;

c) Transport of consumers to and from the point of retail purchase;

d) Transport of employees to and from their normal place of work;

e) Animals providing transport services; and

f) The release of greenhouse gases less than 1 percent of total greenhouse gas emissions.

2.4.2 Inventory analysis

Identification of emission sources [11]

Emission sources from each step in the life cycle stage can be identified as follows:

Raw materials acquisition stage: This stage consists of the acquisition of natural resources, the processing of resources, including raw and ancillary materials, the manufacturing of parts and the associated transport of the materials. This stage is often referred to as the upstream processes of the product system. The major outputs of this stage are the parts and materials. Thus, the GHG emission from this stage can be quantified by gathering GHG emission data from the upstream processes, including the part manufacturing process itself.

Manufacturing stage: GHG emissions from the identified emission sources are measured directly or calculated indirectly. The emission sources can be classified into stationary combustion, mobile combustion, process emissions, fugitive emissions and indirect emission due to electricity consumption.

Distribution stages: GHG emissions mainly occur from the fuel combustion of mobile sources. A distribution scenario based on the product weight, mode of transport, transport distance and number of products transported in one transfer is made for the calculation of the GHG emissions during this stage.

Use stage: Steps to use depending on the functionality of the product which is defined by the functional unit. For products that used energy will count the emissions from energy consumption and production.

End of life stage: The process used to handle product and packaging waste is often used the treatment process such as landfill, recycling and burned in incinerator etc.

Collection activity data [15]

Data collection is a critical step in assessing the product carbon footprint. There are two basic types of data required: activity data and emission factors.

Firstly, activity data describes the specific, measurable quantities of materials and energy used across all life cycle stages. These data can be primary data (real data) or secondary data (aggregate data). The PAS 2050 standard allows a company to use primary data for the processes that they own, operate or control. This includes the amount of resources used, energy consumed at each process, estimates of major waste produced, and product transported to and from the manufacture. Beyond these activities, secondary data may be applied. This data is not specific to the product, but rather represent an average or general measurement of similar processes or materials.

Another essential set of data is the emission factors. It provides the link that converts a unit of activity data into the corresponding GHG emissions, e.g. electricity emissions kg CO_2e per kWh, fuel emissions per liter, waste emissions per kg, etc. The emission factors can also come from primary sources or secondary sources. However, it is more common to use secondary data to enable consistency and where possible comparability. A range of secondary data for both activity and emission factors is available. This poses challenges for future research to collect data from industry reports, case studies, etc. to form a local Life Cycle Inventory (LCI) database. Nevertheless, regardless of the sources of data used, it is important to clearly describe the sources and characteristics of the data.

2.4.3 Impact assessment

Calculation of the footprint [14]

The equation for product carbon footprint is the sum of all materials, energy and waste across all activities in a product's life cycle multiplied by their emission factors. The calculation itself simply involves multiplying the activity data by the appropriate emission factors.

Carbon footprint of a given activity = Activity data (mass/volume/kWh/km) × Emission factor (CO_2e per unit) (3.1)

GHG emissions are calculated for each activity, convert to CO_2e using the relevant global warming potential (GWP) factors**.**

2.4.4 Interpretation

Identification of problematic parts with high GHG emission [11]

The parts with greater GHG emissions are identified as the problematic parts or the hot spot. A problematic part becomes a target for improvement, which can be reducing GHG emissions.

Proposing ways to reduce emission or selection of alternative parts to replace problematic parts [11]

Alternative parts that replace the identified problematic parts and/or materials should be chosen first. The choice of alternative parts must be assessed with respect to four different criteria; the technological feasibility, customer requirements, cost and potential for reduction of the GHG emissions as detailed below:

(a) Technical feasibility: Is it technically feasible to apply different technology to replace the problematic parts with different parts? Is the alternative part exchangeable?

(b) Customer requirements: Dose the alternative part meets the customer’s requirement?

(c) Cost: This is related to the cost difference between the original and replacement part.

(d) GHG emission reduction potential: This pertains to the reduction in the GHG emissions between the original and replacement part.

2.5 Fluorescent lamps

This research will evaluate the carbon footprint (CF) of Fluorescent Lamps (FL) for three main reasons. The first is that FLs are one of the most common lighting systems used in household all over the world. They are cheap, energy-efficient, easy to replace and handy, and it was estimated that 200 million FLs were manufactured and used per year (2008) in Thailand [16]. It could rightly be said that FLs are one of the major everyday electrical products. Secondly, a more environmental friendly FL product has continually been introduced to the market. Therefore, CF can be used as one of the environmental indicators to support the global green market. And lastly, there have so far been no research reports on this product.

2.5.1 General information of fluorescent lamp

Fluorescent lamp (FL) is the lighting equipment commonly used in buildings, department stores or even in homes. This lamp is used to replace incandescent lamp due to the better properties in terms of light quality, lifetime and more energy saving. FLs are the electrical equipment that converts electrical power into useful light. FL uses electricity to excite mercury vapor. The excited mercury atoms produce short-wave ultraviolet light that then causes a phosphor to fluoresce, producing visible light. A FL set consists of a lamp; a starter is to preheat the cathodes inside the fluorescent tube before it is started; and ballast is used to regulate the flow of current through the lamp and provides the right voltage to start off the lamp. The FL has various sizes and shapes such as T12, T8, T5 FL, Compact FL, Shatter Proof FL, etc. Their light output is measured in lumens unit.

2.5.2 Types of fluorescent lamp

FLs are divided into three types as follows:

a) Straight fluorescent lamp: High efficiency, 2-8 feet long with a diameter about 1 to 1.5 inches. General symbol is T followed by numbers such as T8, T5 FL (The "T" refers to “tubular,” the shape of the lamp and the number means the diameter of the tube in X/8 of an inch when X is the number following “T”.). General uses are in the buildings, sheds, on the streets and homes.

b) Compact fluorescent lamp: These are used in hospitals, factories, offices, and homes. This type behaves like a straight lamp except for external appearance only. The design looks like incandescent lamp.

c) Circular fluorescent lamp: This type of lamp as well as other tube shape (not compact and strength FL), is used in electric appliances, lighting from the ceiling, or where space is limited. It has the same principle, difference only outward appearance.

2.5.3 The components of fluorescent lamp

Fluorescent lamp consists of several components (see Figure 2-4). Each part is made from different materials and has different functions as follows:

a) Bulb made from a glass tube. Surface on glass tube is coated with phosphor. Internal glass tube will exhaust the air into vacuum and then add the inert gas and mercury vapor inside the lamp.

b) Base or aluminum cap contains aluminum base, copper pin and insulation material. Base is connection with circuit and support the structure of the lamp (Lamp holder).

c) Lead in wire contains three types of materials; nickel, dumet (Metal with a coefficient of thermal expansion higher than the glass) and copper. It is used as connections to transfer electric current to the filament coil.

d) Exhaust tube is the smallest glass tube, used for suction air out and add argon gas into the lamp during the production process.

e) Stem tube is the small glass tube, used as grout filling between the lead in wire, to prevent air entering into the tube. By the melting of glass connected for close the gap completely.

f) Coil or filament made from 100% tungsten, fitted at both sides of the lamp ends, allowing electricity to flow through to heat up the lamp. Heat vaporizes mercury vapor contained in the lamps.

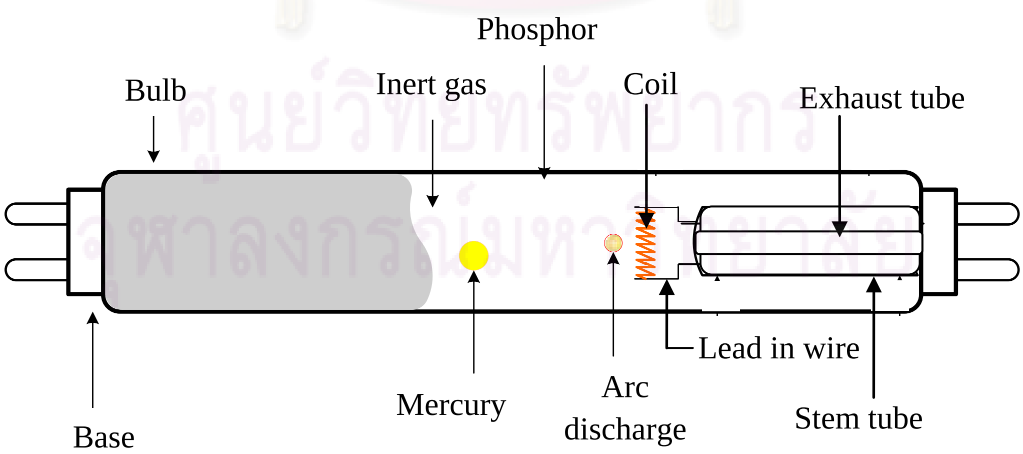

Figure 2-4 Component of fluorescent lamp

g) Mercury, upon receipt the heat from filament, mercury will evaporate and spread all over the lamps.

h) Arc discharge is a released atom from the polarity to stimulate the atoms of mercury vapor for the energy radiation (Ultraviolet radiation).

i) Inert gas mostly is Argon gas that is added in the lamp instead of the air.

j) Phosphor is coated on the surface of the glass tube, to change the energy of atomic mercury into the visible light. The colors of light depend on the type of phosphor.

2.5.4 T8 and T5 fluorescent lamps

This study aimed to evaluate environmental impacts of long straight FLs namely T8 and T5, each with two different powers, i.e. 36WT8, 18WT8, 28WT5 and 14WT5. T8 FL has 26 mm diameter and phosphor type is halophosphor. T5 FL is a newer product developed from T8 with a smaller diameter (16 mm), and used triphosphor type (see at Table 1-1 above).

2.5.5 Manufacturing process of fluorescent lamps

Most of lamp industries in Thailand are the assembly industry. They receive the components as referred to above from many suppliers both in Thailand (e.g. glass bulb, exhaust tube, stem tube, mercury, etc.) and from some foreign countries (e.g. aluminum cap, lead in wire, coil, argon gas, etc.). Fluorescent lamp manufacture is a complex process containing main process and multiple sub-processes such as sleeve production (packaging of lamp), stem production, phosphor mixing and cement mixing.

a) Main manufacturing processes

FL production contains 11 main steps; starting with cleaning glass tube, coating inside glass tube by phosphor solution, assembling the various parts together and finally aging the FL product. The overview of the main manufacturing processes of FL is explained as follows:

1. **Washing** a glass bulb by hot water
2. **Drying** a wet glass bulb by hot air
3. **Coating** the dry glass bulb by phosphor solution
4. **Drying** the coated glass bulb by hot air

5. **Marking** the seal on the surface of the coated glass bulb
6. **Baking** the coated glass bulb at 650 ºC for remove some residue and made the phosphor adhere to the inside of glass bulb
7. **Sealing** both side of glass bulb by stem that is the stem tube contains with lead in wire, exhaust tube and filament coil. The aim of usage the stem is completely close glass bulb. One of side will have a hole for make to vacuum bulb.
8. **Exhausting**: the step that making the glass bulb to the vacuum bulb and then filling argon gases and mercury into the glass bulb
9. **Basing**: entering the aluminum cab that fill the capping cement on both sides of the glass bulb and baking the caps adhere to the glass bulb
10. **Pin staking**: clinching the copper wire of the pin leg adhere to the brass wire of aluminum cap
11. **Aging** the lamp for checking efficiency of the fluorescent lamp and activating the lamp for easier to use of consumer.

b) Sleeve production

Sleeve is the packaging of FL made from corrugated paper used to cover FL. The selected lamp industry has its own sleeve production. The method of production can be explained as follows:

1) Crepe paper making: Brown paper and white papers are combined into corrugated paper machine using glue from the mixture of tapioca flour, water and sodium hydroxide (NaOH).

2) Slice machine: The crepe paper is fed into a slice machine to cut the crepe paper to appropriate width for various sizes sleeve production.

3) Sleeve making: Crepe paper with appropriate size is fed into a sleeve making machine where both sides of the crepe paper are attached with latex gum before printing the logo on the sleeve, and cutting the edge of sleeve to match with the length of FL.

c) Stem production

Stem is one of the most important components of FL as it contains filament coil and lead in wire. The selected lamp industries are capable of producing their own T8 stem, but most purchases T5 stems from other factories as T5 stem is very small and needs specific machine to produce. The production process of stem is as follows:

1) Flare making: Feed the stem tube (similar to glass tube but smaller than, 12 mm diameter) into flare making machine. The machine cuts the stem tube into small pieces and uses heat to weaken the glass to allow the enlargement on one side of the tube.

2) Stem making: Assembly the flare, exhaust tube and lead in wire together to produce the stem.

3) Mounting: Assembly the filament coils into the stem and coat the coil with the oxide mixture.

d) Cement mixing is the mixing of capping cement with methanol at appropriate ratios and mixing time and then pumping the cement mixture into the aluminum cap.

e) Phosphor mixing is the mixing of chemical substances such as phosphor powder, “surface solution”, alone C solution and lacquer together under 24 hours of stirring.

The summary of the production method of fluorescent lamps is demonstrated in Figure 2-5**.**

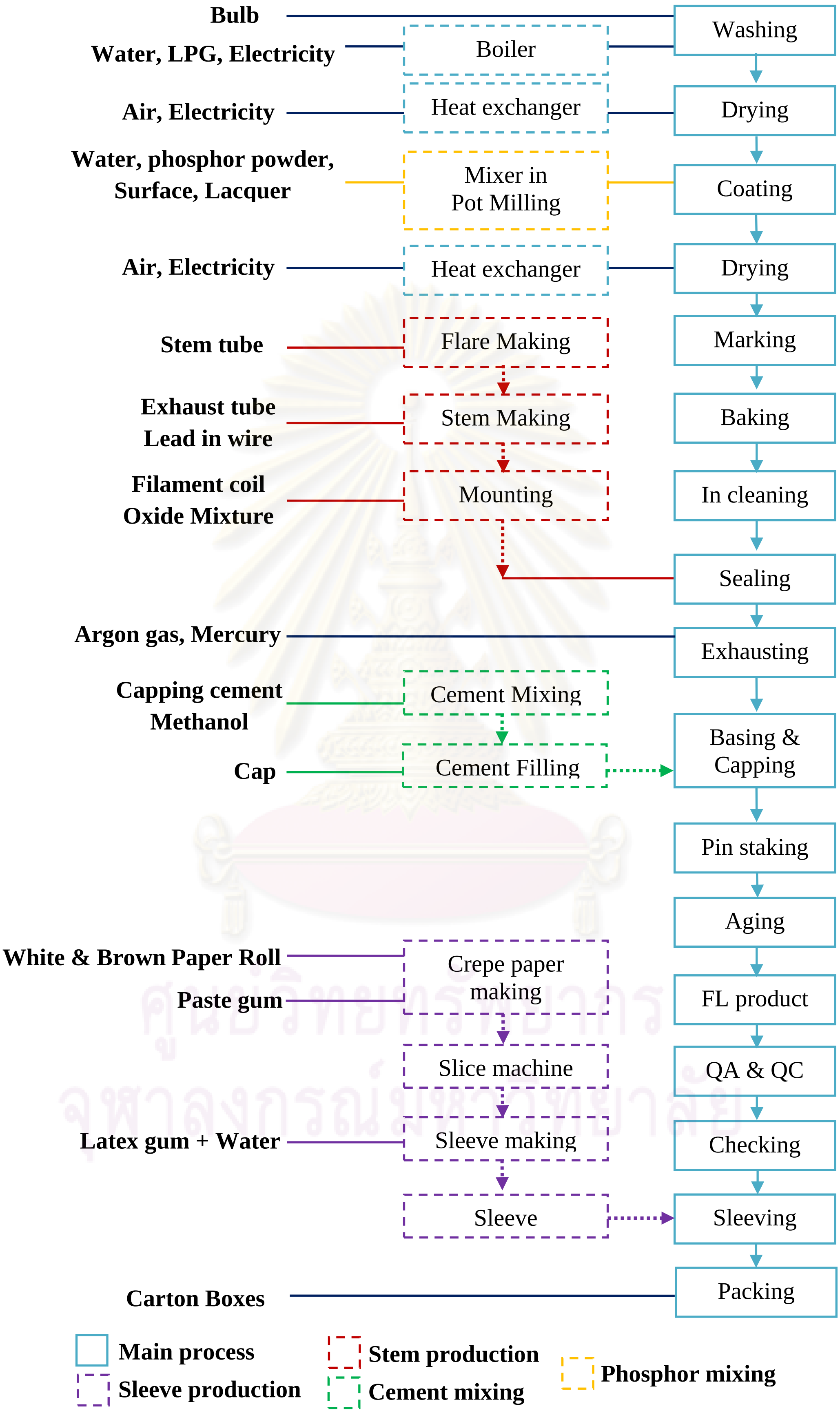

Figure 2-5 Process diagram of fluorescent lamp manufacture

Figure 2-5 suggests that the manufacturing processes for T8 and T5 lamps are similar. However, there are some major differences between T8 and T5 as indicated in Table 2-2 based on activity of lamp industry that supported the data for evaluate carbon footprint of four FLs products. The stem of T8 is produced in factory but the stem of T5 will be purchased from other factories because there is currently no available manufacturing process in Thailand. The quantities of cement filled into the aluminum cap of T8 are greater than T5 because T8 has a bigger size than T5. Phosphor mixing will be related to the specific gravity of phosphor types and the length of lamp.

Table 2-2 Differences of T8 and T5 fluorescent lamps

Topic	T8	T5
Ø Bulb	26 mm	16 mm
Stem	Producing on-site	Purchase (domestic)
Phosphor	Halo-phosphor	Tri-phosphor
Cement	1.3 g/base lid	0.4 g/base lid
Specific gravity of phosphor	Long tube: low specific gravity Short tube: high specific gravity	

Remarks:

1. The brightness value of lamp that uses tri-phosphor solution is more than halo-phosphor solution.

2. The lamp that uses tri-phosphor solution has color alike with the sunlight more than halo-phosphor solution.

2.5.6 Disposal/recycling technologies

Fluorescent lamps have elements of heavy metals such as mercury as stated above. Although there are measures to reduce the amount of mercury in FL to less than 10 mg/lamp, the components inside the lamp are still contaminated with mercury. Therefore spent fluorescent lamps (SFL) are classified as one type of hazardous waste that requires appropriate collection, treatment, and disposal technologies

This research focuses on two end-of-life options: recycle and secure landfill. Both methods must have stabilization and solidification process to prevent the spread of hazardous substances (mercury) to the environment. Some of SFL components can technically be recycled such as glass tube, mercury and aluminum cap, however, the only available technology in Thailand is the recycle of glass tube. Therefore only the glass tube will be assumed to be all recycled whereas the other components are stabilized and solidified and then disposed of in secure landfill. The recycling process will include a disassembly process used to separate glass component that can be recycled from other components. The disassembly process of SFL is a close system to prevent the escape of mercury vapor.

The recycling process shown in Figure 2-6 begins by entering spent FLs into the disassembly process; FLs are cut head - end to separate the aluminum caps from the lamp. The phosphor powder and mercury vapor in the tube are blown out. The outputs of this process can be divided into three parts: mercury + phosphor, aluminum caps and glass tube. Glass tube is passed into the machine is crushed as cullet and reused as raw materials of glass manufacturing. The remaining components are sent to stabilization and solidification process and then disposed of in secure landfill.

Figure 2-7 describes the detail of the disposal-nonrecycling option II where the whole SFLs are fragmented by a crusher (hammer mill). After that the crushed material is mixed with sodium sulfide (Na_2S) for stabilization and mixed with cement in a mixing container for solidification. The mixtures are sampled to leaching test, and the unqualified samples are sent back to stabilization process. Only those that pass the standard are sent to secure landfill.

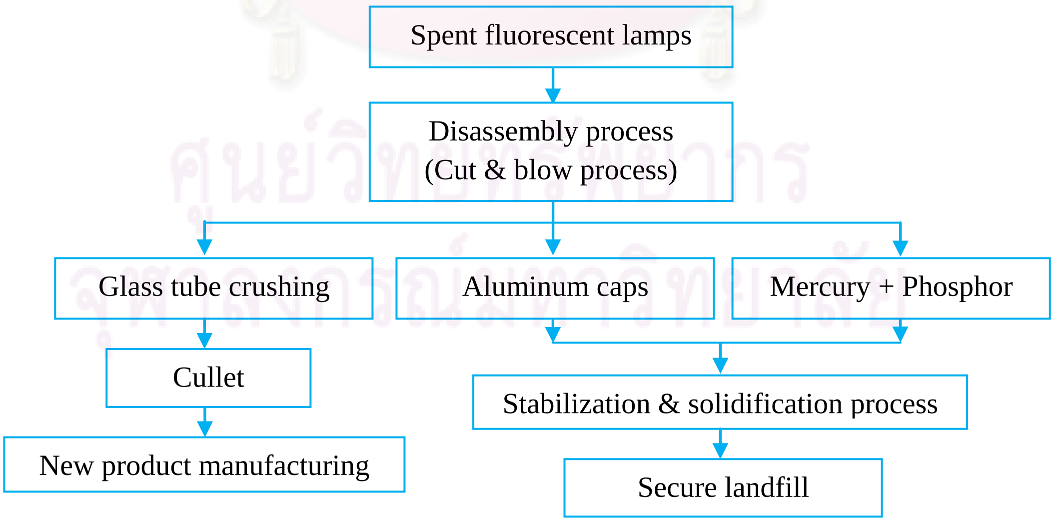

Figure 2-6 Recycling process [17]

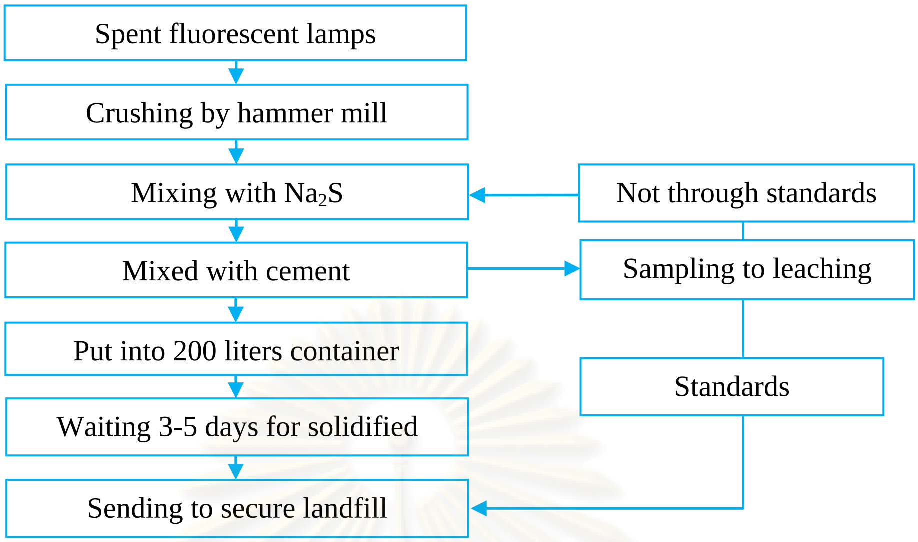

Figure 2-7 Non-recycling process [17]

2.5.7 Glass tube manufacture

Glass is a unique material having many useful applications such as food and drink packaging and glazing industries. This is because glass is relatively cheap, abundantly raw materials available, and inert with no reactions with other substances. Glass is also infinitely recyclable, the properties ideal for making eco-packaging. There are several types of glass and the most common is soda-lime glass with the use in the manufacture of flat glass, most containers and electric light bulbs, and many other industrial and art objects. Lead glass or commonly called crystal glass is made by substituting lead oxide for calcium oxide. Lead glass is easy to melt and has such beautiful optical properties that it is widely used for the finest tableware and art objects. The other types are fiber glass, cathode ray tubes, and optical glasses, etc [18].

Glass tube is the most important components of the lamp, like the main structure that can be incorporated into other elements together to produce FL, and that are the most weight ratio of raw materials. Glass used to produce the lamp is the soda lime glass type. The basic composition of the glass comprises silica (from sand), sodium oxide (from soda ash), calcium oxide (from limestone or dolomite), and minor ingredients. Glass industries usually used recycle scraps glass or cullet as raw materials for reduces the production cost. Glass tube for T8 and T5 FL are produced in five main processes (see Figure 2-8) as follows:

a) Mixing: The mixture of ingredients to make up the glass (silica, Na_2CO_3, $CaMg(CO_3)_2$ and recycled glass, together with small quantities of various other minor ingredients) are mixed in a rotary mixer to ensure an even mix of ingredients and fed into the furnace.

b) Melting: The mixture is heated to 1500-1600 degree celsius, where the ingredients melt, various chemical reactions take place and CO_2 and SO_3 are evolved.

c) Forming tube: The melted glass is formed into straight tubes, diameter as required (diameter of T8 and T5 FL equal to 8/8 and 5/8 inch respectively).

d) Fine cutting: The long straight tubes are cut into appropriate length (36WT8 = 1,264 mm and 28WT5 = 1,140 mm). The products of this stage are glass tubes to produce 36WT8 and 28WT5 FL.

e) Center cutting: Due to 18WT8 and 14WT5 FLs are a half-length of 36WT8 and 28WT5 FL, respectively. This process is often used to cut at the center of 36WT8 and 28WT5 bulb. The products are the glass tube for produced 18WT8 and 14WT5 FLs.

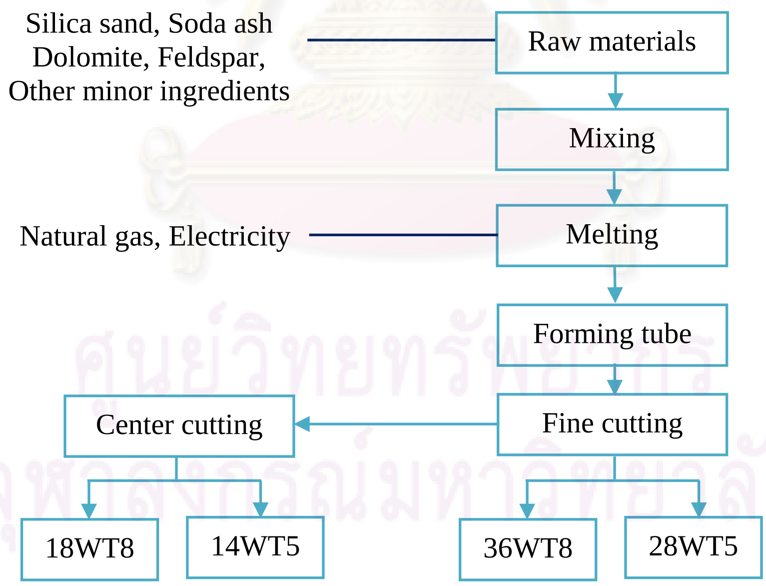

Figure 2-8 Glass manufacturing process

2.5.8 Ballast

Ballast is an essential device that must use together with FL. This study evaluates GHG emission over the life cycle of ballast to be used as supporting information for the decision making process on the change to the use of T5 instead of

T8 FLs. This study does not collect data from the ballast manufacturing process; rather it employs secondary data including the amount of raw materials and energy used in the production and usage of ballast [19].

FL requires ballast which regulates the flow of current through the lamp and provides the right voltage to start off the lamp. There are two types of ballast, magnetic and electronic ballast [20].

Magnetic ballast starts and regulates a lamp through a core-and-coil assembly. This assembly consists of two copper wires coiled around a common core of steel laminations to transfer electrical current from the power supply into the appropriate wattage as required by the lamp. However, magnetic ballast generally produces disturbance such as noise and flicker [21]. The noise results from the vibration of the steel laminations in the core-and-coil assembly. Flicker arises from an insufficiency of lamp efficacy due to the low frequency operation of magnetic ballast [20].

Electronic ballast is similar in function to magnetic ballast except that it uses entirely electronic components to start and regulate the lamp. The use of electronic technology causes this electronic ballast to work at higher efficiency and frequency and so eliminates the noise and flicker [20]. Electronic ballasts are also typically lighter in weight than their magnetic counterparts as the core-and-coil assembly in magnetic ballast is made of metals and is therefore heavier. However, electronic ballast is susceptible to electrical and electronics disturbances and is more expensive [22]. In Thailand, the cost of electronic ballast is about five to six times higher than magnetic ballast for the same type of lamp.

Ballasts are very specific for the particular lamps since ballast controls the wattage of a lamp. If an 18WT8 fluorescent lamp uses 36W ballast, the lamp will operate at 36 W, which will cause lower lamp performance and premature ballast failure [21]. Therefore, the 36W magnetic and electronic ballast are operating with a 36WT8 FL. Table 2-3 and 2-4 show components of magnetic and electronic ballasts [19], respectively. The most important material in magnetic ballast is steel (85.9% by weight) and then copper used as wire winding (10.4% by weight). The others; nylon bobbin, polyester film, paint, thinner and paper are small fraction of the ballast in the range of 0.1-1.5 percent of the total weight. In the electronic ballast, steel contributes 49.8% of the mass in the form of the casing. The other 45.8% is attributed to the electronic components, which include transformer, capacitor, printed circuit board (PCB), resistor, transistor, diode, jumper wire, negative temperature coefficient, integrated circuit (IC's), inductor, and potentiometer. Other smaller components in electronic ballast are nylon, solder paste, fuse, and copper.

Table 2-3 Components of magnetic ballast [19]

No.	Component	Weight (g)	% by weight	Remark
1	Steel	850	85.9	Main structure
2	Copper wire	103	10.4	Wire winding
3	Nylon Bobbin	15	1.5	Nylon
4	Polyester film	10	1.0	Polyester resin
5	Aluminum	5	0.5	-
6	Paint	2	0.2	-
7	Thinner	1	0.1	-
8	Paper	1	0.1	-
Total		987	100	

Table 2-4 Components of electronic ballast [19]

No.	Component	Weight (g)	% by weight	Remark
1	Steel	177.8	49.8	Main structure
2	Transformer	73.8	20.7	Mostly steel and copper
3	Capacitor	33.2	9.3	Dielectric material
4	PCB	29.3	8.2	Print circuit board
5	Insulation material	10.5	2.9	The insulation covering the windings
6	Resistor	6.0	1.7	Resistance wire (high-resistivity alloy)
7	Transistor	5.6	1.6	Semiconductor material
8	Nylon bobbin	5.4	1.5	Nylon
9	Solder paste	4.8	1.3	Brazing solder
10	Diode	4.6	1.3	Semiconductor material
11	Fuse	1.6	0.4	-
12	Jumper wire	1.4	0.4	Copper wire
13	NTC	1.0	0.3	-
14	Wire	1.0	0.3	Copper
15	Integrated circuit	0.5	0.1	Electronic circuit
16	Fixed inductor	0.2	0.1	-
17	Potential meter	0.3	0.1	-
18	Total	357	100	

Remark: Assumption is transformer contains with 50% of steel and 50% of copper.

Energy type in the assembly process of ballast is based only on electricity. Electricity used in the production of magnetic and electronic ballast is equal to 0.03 kWh and 0.67 kWh respectively [19]. Electronic ballasts have more complex components which require the use of a printed circuit board, which results in a more complex processing and thus requires more energy.

2.6 Literature review

Many companies in the world have been interested in carbon footprint assessment of products. Some initiatives on carbon assessment schemes include foods, electronics, vehicles, clothing, etc. as shown in Table 2-5 [15]. In Thailand, there are 22 companies with 42 products that are already been accessed for their carbon footprint such as Coca-Cola can 325 CC, Grilled Teriyaki Chicken, Drumstick, Chicken Curry "Kiew-wan", Steamed Thai Hom Mali Rice, Chicken Curry "Mussaman", Steamed Thai Hom Mali Rice, etc. [23]

Table 2-5: Some examples of carbon assessment schemes of products

Company	Type/Country	Carbon assessment schemes
TESCO [24]	The largest retailer /British	Assessed and labeled 20 own-products with information related to direct carbon footprint
Coca-cola [25]	The drink producer /U.S.	- A new glass bottle design which costs less, use less glass - Changed to use recycles polyethylene terephthalate (PET) plastic bottles - Switched to solar power - Trying out hybrid powered truck and upgrading its logistics to cut down emissions from transportation
Wal-Mart [15]	A chain department store/U.S	Established ‘carbon scorecards’ to indicate carbon emissions of suppliers
Dell [24]	The computers	Committing suppliers to measure and reduce carbon emissions in order to demonstrate climate change awareness.

For FL, its life cycle can be separated into two parts as follows:

2.6.1 Life cycle assessment of fluorescent lamps

Life cycle assessment of FL revealed that major environmental impact lied in the use stage due to the consumption of electricity. Tantempsapya and Yossopol, (2005) used Simapro 5.1 and Environmental Design Industrial Products (EDIP) to assess the life cycle of an 18W standard FL (61 lumen/watt, 15,000 hour of life time) and super FL (63 lumen/watt, 13,000 hour of life time), not include ballast. They found that global warming impact of standard FL was 46 $kgCO_2$ and super FL was 203 $kgCO_2$, ozone depletion impact of standard FL was equal to 1.96E-04 $kgCFC_{11}$ and super FL 1.75E-04 $kgCFC_{11}$ and acidification of standard and super FL was 7.05E-01 $kgSO_2$ and 6.46E-01 $kgSO_2$, respectively. The results indicated that environmental impact occurred mostly in the use stage [26].

2.6.2 Life cycle assessment of spent fluorescent lamp (SFL)

Spent fluorescent lamp had been assessed in several cases. Apisitpuvakul et al. (2008) assessed SFL (not include ballast) with 0-100% recycle rates and found that the environmental impact increased when % of recycle rates decreased. Because FL contains mercury, FL is considered as hazardous waste. Before disposal in secure landfill, SFL must be stabilized and solidified to prevent the escape of mercury to the environment. Stabilization and solidification processes used cement, sodium sulfide, natural gas, electricity and water. If more recycle rates, the remaining hazardous wastes decreased reducing the demand for cement and other ingredient used in stabilization/solidification [27].

However, with the current situation where most of the FLs have not been managed properly, most environmental impacts occurred from cement, sodium sulfide and electricity production. The results are similar to that of Bunprom and Grisadanurak (2009) who provided more detail about quality of ingredient used in stabilization and solidification processes. The researcher used Simapro 7.1 LCA software to assess environmental impacts of a 18W SFL. Disposal without recycle consumed electrical energy of 0.0051 kWh/SFL, sodium sulfide 0.014 kg/SFL, cement 0.2 kg/SFL and water 0.002 m^3/SFL. On the other hand, disposal with recycle used electric energy of 0.00361 kWh/SFL, sodium sulfide 0.019 kg/SFL, cement 0.028 kg/SFL and water 0.000208 m^3/SFL. Therefore, the recycle scheme can reduce environmental impact especially ecotoxicity 10^{11} times when compared with the case without recycle [28].

Techato et al. (2008) studied life cycle analysis of retrofitting with high energy efficiency air-conditioner and fluorescent lamp in existing buildings, using Gabi-lite software. One 36W FL (not include ballast) caused the generation of bulk waste at 1.64E-05 kg, hazardous waste 1.11 E-04 kg, radioactive waste 1.09E-09 kg and slag-ash 6.02E-07 kg. The air-conditioner 12,000 BTU caused the bulk waste to occur at 1.64E-05 kg, hazardous waste 1.11 E-04 kg, radioactive waste 1.09E-09 kg and slag-ash 6.02E-07 kg [29].

Asari et al. (2008) reported the life cycle flow of mercury with various recycling fluorescent lamps scenarios in Japan. The main finding revealed that the amount of mercury-containing products in Japan were around 10-20 tons annually, about 5 tons of which was attributable to FL. Most spent fluorescent lamps were disposed of as waste. Only 4% of the total amount of mercury waste was recovered (Flow of mercury in Japan during 2000-2003). The best method for disposal these wastes are recovery and recycle [30].

Most previous works reported environmental impact assessments of SFL where the major impacts came from cement production used in stabilization and solidification of hazardous waste from FL before disposal in landfill. However, in terms of energy consumption, the use stage contributed the most environmental burden when compared with other life cycle stages.

2.6.3 Advantages of carbon footprint label

The CF label has a lot of advantages in various parts. For instance, communicate buyers could understand the carefulness of manufacturers regarding the global warming problem, building of social consciousness and create a selling point over competitors. CF of product could be used as an effective quantitative indicator for performance benchmarking, managing, and communicating impact on climate change of products [15].

Significant motivations of Thailand factories to establish the CF of products are [15];

a) Regulatory pressures: Environmental regulations are one of the strongest influences affecting the attitudes of corporate decision-makers. Policies such as GHG reductions under Kyoto Protocol, IPCC policy, and carbon tax have been introduced in many countries as directives to stimulate the industries towards the low carbon society.

b) Corporate competitive pressures: The current situation where there is a growing market in eco-friendly products supports the opportunities for companies to use CF of product as a strategy to differentiate their products and enhanced competitive edge. For instance, according to the study in UK, 67% of UK consumers surveyed are more likely to buy a product with a low carbon footprint, and 44% would switch to a lower-carbon product even if the brand was not their first choice [31].

c) Opportunities to improve operational efficiency: It is the most attractive factor that urges companies to have more awareness because companies have already begun to see real benefits from assessing CF of product through better management of resources. There are indications for cost savings as companies become more efficiency on their product and manufacturing process [31].

CHAPTER III

METHODOLOGY

This chapter illustrates in more detail the methods and procedures for the assessment in this research, to evaluate and investigate the environmental impact specifically on the climate change category over the life cycle of fluorescent lamp.

3.1 Goal and scope definition

3.1.1 Setting objectives

The main objective of FL carbon footprint assessment is to evaluate carbon footprints of T5 and T8 FLs. The sub objectives are to investigate GHGs emission hot spots and to suggest the improvement options for mitigating GHG emissions from the life cycle of FL and also to compare carbon footprint between T5 and T8 FL products.

3.1.2 Defining the functional unit

FL is the lighting equipment and so the functional unit of FL is set as the brightness of the lamp in the lumen unit. The four types of FLs examined here have different brightness as indicated in Table 3-1, and therefore to enable the comparison between 36WT8 and 28WT5 and between 18WT8 and 14WT5, the brightness of 143,100 and 26,250 lumens respectively which are the lowest brightness that the two sets of FLs can share an integer value are set as the main functional unit. The number of lamps is then calculated by dividing the target brightness with the brightness of each lamp as illustrated in Table 3-1. The number of ballasts is the same as the number of lamps because one FL uses only one piece of ballast.

Table 3-1 Number of fluorescent lamp in the same brightness

FLs type	Brightness per lamp (lumen)	Target brightness (lumen)	Number of lamp
36WT8	2,650	143,100	54
18WT8	1,050	26,250	25
28WT5	2,700	143,100	53
14WT5	1,250	26,250	21

Average life time of FL is 20,000 hour that obtained from the life time test of lamp factory. Ballast has average life time same as FL.

3.1.3 Setting boundaries:

The assessment boundary of the fluorescent lamps and the ballast life cycle are Business-to-consumer (B2C) including raw materials extraction and processing, manufacturing process, distribution/retail, consumer use and disposal/recycling.

3.1.4 Building a process map

The process map diagram of FL, magnetic ballast and electronic ballast life cycle covering the whole life cycle of them from the extraction and processing of raw materials to disposal of the product including packaging are depicted in Figures 3-1 to 3-3, respectively.

(1) Raw material acquisition: Raw materials as the main component of FL consist of 15 types, ten types for only FL production and five types for sleeve production (Packaging of lamp). The collected data are from one of the lamp industries in the central region of Thailand. The collection method started with the initial contact to the factory, followed by a series of site visits in order to understand the production process and collected data required for the evaluation of GHG emission. The amount of raw materials used in the production of FL product was obtained from the analysis of the real production data. These raw materials data was the weighted average in 17 months. However, most GHG emission of the raw materials inventories was from secondary sources, except for glass manufacturer where primary data are also available from the main supplier of the lamp industry.

Transportation of raw materials

Transportation of raw materials for lamp, glass and ballast manufacture was evaluated based on standard assumptions set out from the TGO's guideline [8] because most industries have no records of these data. Exception for the transport of glass bulb to the lamp factory uses the primary data that obtained from the glass bulb factory. Furthermore, the transportation of raw materials from aboard is not included in the boundary of this study (limited only the transportation in Thailand). Details of standard assumptions that used in the calculation of GHG emission from the transportation of raw materials are shown in Table 3-2.

Table 3-2 Standard assumptions for transportation of raw material

Trip	Distance (km)	Vehicle type	%load	E.F. [8]
Delivering	700	22-wheel semi-trailer trucks, 32 tons	Full load	0.0475 kg CO_2e/ton-km
Returning	700	22-wheel semi-trailer trucks, 32 tons	No load	1.0655 kg CO_2e/km

The calculation of GHG emission follows Equation (3.1):

$$\text{GHG emission (kg } CO_2\text{e)} = \text{Weight of material (ton)} \times \text{Distance (km)} \times \text{E.F. of vehicle} \quad \ldots (3.1)$$

The returning emission must be allocated to the 32 tons of goods being delivered in that particular trip. For the transport of glass tube to lamp industry employed available primary data: 78.5 km distance, 6-wheel trucks, 11 tons vehicle type.

(2) Manufacturing process: GHG from the manufacturing process was derived from the amount of energy and other utilities used in the production process of one FL (Both assembly and packaging process). Packaging process only covered the sleeve production but not the carton box because the quantity of usage from the selected lamp factory was not available.

Wastes from lamp production are separated into three parts. The first one is the wastewater containing phosphor compounds. This wastewater goes to sedimentation pond. The second part contains lamp wastes, paste, residual oil and other wastes that related with the component of lamp. These wastes are sent to the waste management service company. The third part is the recyclable waste such as papers which is sent to the recycling company. These three waste treatment methods did not involve the emission of GHG and are treated as zero GHG sources.

Ballast manufacturing is the assembly process that only uses the electricity in production process.

(3) Distribution/retail: For FL product is the transportation between manufacturers with the nine main distributors around the center region of Thailand (Boundary is not includes the transport of consumer). The transportation data of the four FL products during January 2009 to May 2010 are analyzed. The vehicle types are 4-wheel trucks with a carrying capacity of 7 tons, and 10-wheel trucks with 16 tons capacity. The average distance is estimated from the distance between the distributors and the producer, where the weight of product transported equals to the number of FLs multiplied by the weight per each FL product (FL + sleeve). The calculation of GHG emission follows Equation (3.1).

Ballast employed the assumption standard as shown in Table 3-2 and GHG emission calculation follow Equation (3.1).

(4) Consumer use: FL consumes electricity during its usage stage and the GHG emission comes from the electricity production. The average life time of 20,000 hours was obtained from the life time test of the selected lamp manufacture. Magnetic and electronic ballasts also consume electricity with an average life time of 30,000 hours based on the minimum operating capacity of electronic ballast. Magnetic ballast has no specific lifetime and is long-lasting, but electronic ballast can operate from 30,000 hours (minimum expectancy) up to 50,000 hours (maximum expectancy). Therefore, the average life time of FL set employed 20,000 hour (depended on FL).

(5) Disposal: Wastes that have to be disposed in this stage are spent fluorescent lamp (SFL), packaging waste (sleeve) and spent ballasts. SFL and ballast are considered to be either landfilled or recycled while the packaging waste goes only to landfill option. Landfill option starts from stabilization and solidification of hazardous wastes. Recycling option includes the disassembly process and stabilization and solidification process as FL and ballast compose of hazardous substances (Mercury in FL and PCB in ballast). The quantities inputs and outputs (raw material use, energy use, solid waste and others emission) from each related unit recycle process are applied from Apisitapuvakul et al. (2008). For packaging waste (sleeve of FL), only landfill is considered. For ballast base on assumption that disassembly by hand, therefore no GHG emission related.

Assumption for the recycle option is the recoverable material such as glass (cullet) from FL; steel and copper from ballast can recovery 100% and all of them go to raw material production.

Assumption for the landfill option is all of wastes go to stabilization and solidification process and then dispose in secure landfill.

Table 3-3 shows the sources of data received in each stage of FL and ballast, the method used in this research.

Table 3-3 Summarized of data sources in each stage

Stage on life cycle	**Component**	**From factory**	**Other research/ Documentation**	**LCI database**
Raw material	Glass tube Other component	● ●		● ●
	Ballast		●	●
Manufacturing process	FL Ballast	●	 ●	● ●
Distribution/ Retail	GHG emission from fuel Distance transport		●	●
Consumer use	Electricity production Average life time	●		●
Disposal			●	●

Limitation

Although a starter is also a basic component in the FL set (with magnetic ballasts), its contribution to the overall GHG emission is only marginal. As a rough estimation, one starter consumes only four watts of electricity and it only works a few seconds during the start of the lamp. As the majority of GHG is generated during the operation of the lamp, it is assumed here that GHG emission varies directly with the power consumption of each device. Table 3-4 shows the example calculation of GHG emission from each device in FL set, based on assumptions are five working hours of FL and ballast, two seconds of starter, power of FL, magnetic ballast and starter are 36W, 10W and 4W, respectively.

Table 3-4 the example calculation of GHG emission from each device in FL set

Device	Power (W)	Working (seconds)	Electricity (kWh)	E.F. ($kgCO_2e/kWh$)	GHG emission ($kgCO_2e$)	% GHG
FL	36	18,000	0.18	0.561	0.101	78.3
Ballast	10	18,000	0.05	0.561	0.028	21.7
starter	4	2	2.2E-06	0.561	1.25E-06	0.00

The following simple calculation illustrates that the contribution of starter to the overall GHG emission is far below 1% and therefore can be neglected during the evaluation of carbon footprint of FL set.

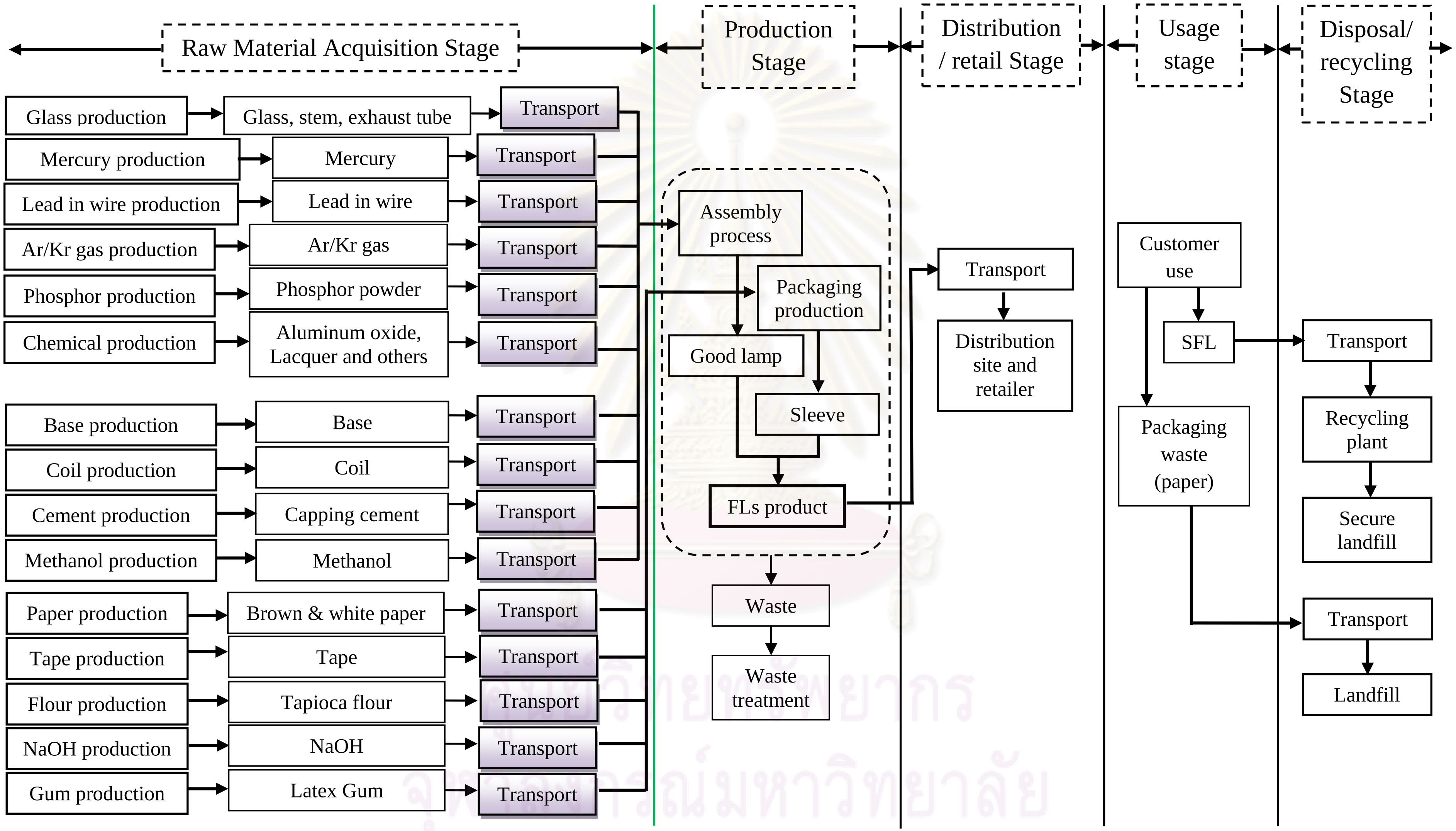

Figure 3-1 Life cycle flow chart of fluorescent lamp

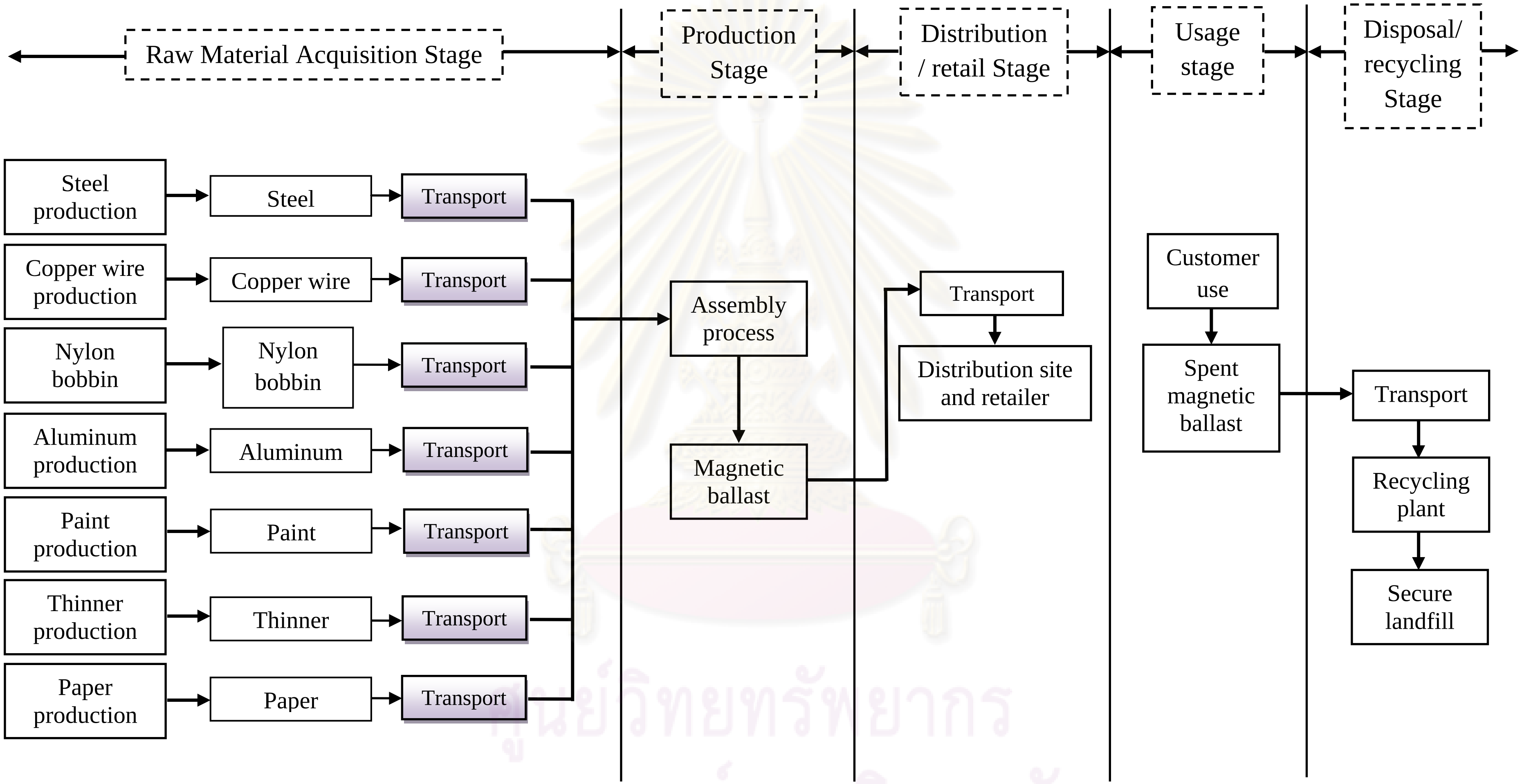

Figure 3-2 Life cycle flow chart of magnetic ballast

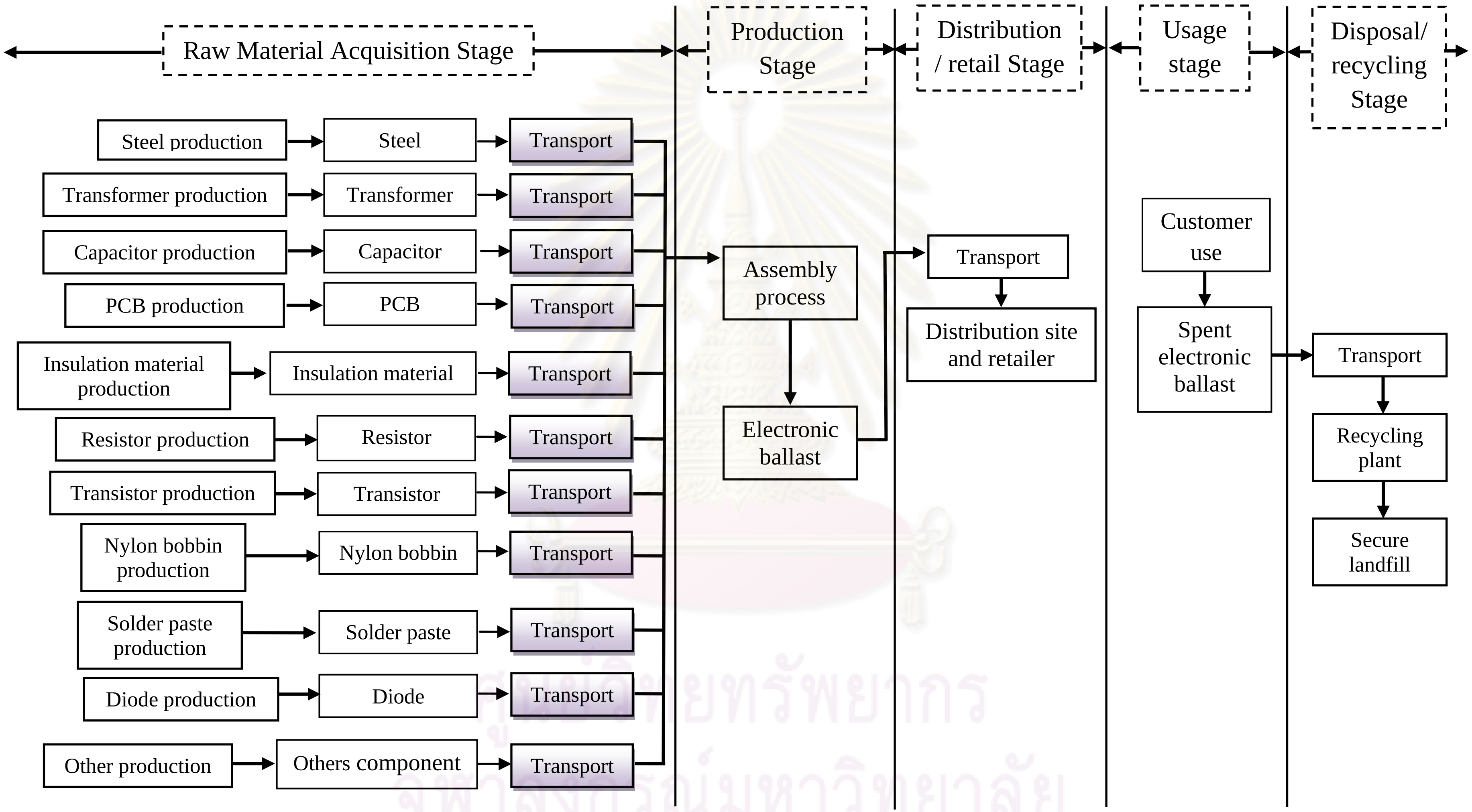

Figure 3-3 Life cycle flow chart of electronic ballast

3.2 Inventory analysis and Impact assessment

3.2.1 Identification of emission sources

The description of GHG emission sources in Chapter II, Sections 2.2 about direct and indirect emissions, can be used here to identify emission sources through FL's life cycle as illustrated in Figure 3-4. Indirect emissions come from upstream and downstream emission and energy consumption from outside the factory (purchased electricity, water, LPG and natural gas). For these processes, the exact emission sources are not described in this research, rather the emission factors will be employed to estimate the emission from such processes. Exception is for glass which is a necessary component of FL, where the production data are collected directly from the one of glass factory in Thailand (data collected during January 2009 to May 2010, system boundary: B2C, including raw material acquisition, transportation of raw material and production process and the function unit is one kg glass produced).

It is recommended there that the definition of emission factor (E.F) be clearly stated. E.F. can be divided into two types. The first is "Cradle to Gate" (C2G) E.F. which represents GHG emission via raw material acquisition stage to the production stage where that particular product is produced (most of these products will become raw materials for other industries). The second is "Gate to Gate" (G2G) E.F. which represents GHG emission from the usage of material/energy such as combustion reaction, chemical reaction, leaking, etc.

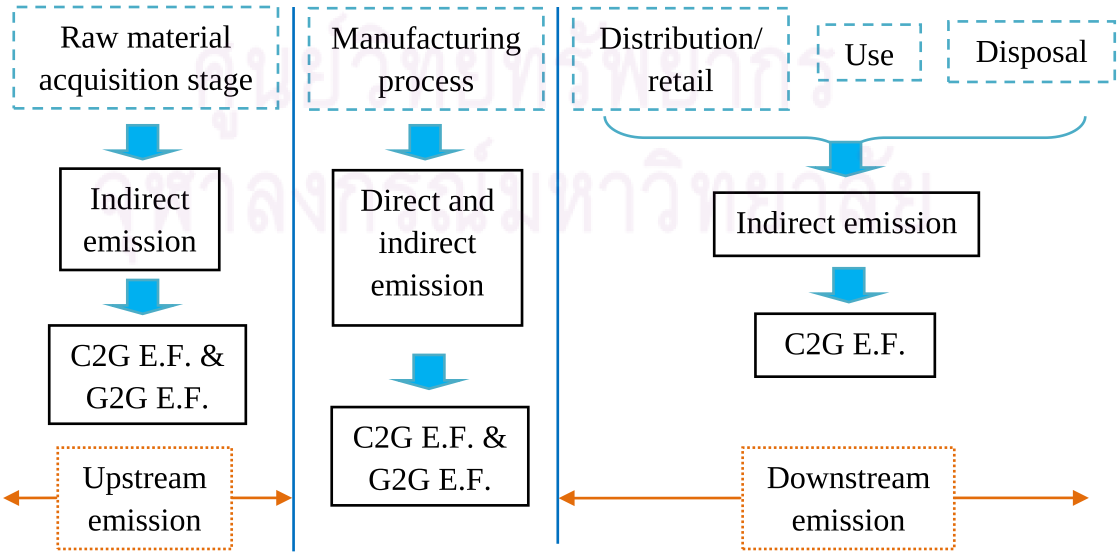

Figure 3-4 GHG emission sources through FL's life cycle

Figure 3-4 states that upstream emissions are estimated from both C2G and G2G E.F.s. Most of the times, C2G E.F. is employed, except for glass production where G2G E.F. is used for specific activities that generate emissions. Emission sources from glass tube production process are as follows:

(1) Chemical reactions (decomposition) of raw materials that contain carbonate compounds (Soda ash, Dolomite and two minor ingredients (not disclosed)) in furnace. This reaction will release CO_2 as shown in these reactions:

Soda ash: Na_2CO_3 ---------> CO_2 + Na_2O …… (1)

Dolomite: $CaMg(CO_3)_2$ ---------> $2CO_2$ + CaO + MgO …… (2)

Reaction (1) 1 mole of Soda ash (105.99 g) will produce 1 mole of CO_2 (44 g).

Reaction (2) 1 mole of Dolomite (184.40 g) will produce 2 moles of CO_2 (88 g).

Two minor ingredients that cannot disclose will produce 2 moles of CO_2 (88 g).

Quantities of these materials used per kg glass production as obtained from the primary source can be used to estimate CO_2 emission from each reaction.

(2) Energy consumption such as electricity, natural gas and water supply in production process (using “C2G” E.F from the TGO’s guideline [8]) and;

(3) Waste management of factory: The main wastes are wastewater (wastewater treatment, “G2G” E.F. from the TGO’s guideline [8]) and solid waste (dispose in landfill, using “G2G” E.F of degradation of each waste from the TGO’s guideline [8]).

For the production process; direct emissions of FL come from LPG combustion, Lamp industry use LPG in baking and exhausting the lamp. Other sources are indirect emissions such as energy and water consumptions.

Downstream emissions or indirect emissions from distribution, use and disposal/recycle stages are from the use of C2G E.F.

Magnetic and electronic ballasts are necessary components that come with FL, and their emission should be from primary sources but due to the difficulties in obtaining the target manufacturers, these are obtained also from secondary sources, i.e. C2G E.F.

3.2.2 Collection activity data: the activities data collected including the annual product records data from the factories, bill of energy consumption of factory (electricity, water bill), power of machine in process, LPG used from flow meter of machine and the weight of some material from scale. The annual product records such as the type and quantity used of raw material and waste generated in the main and sub production process, amount of product produced, and distance and number of product in transportation (lamp production) and amount of waste generated etc.

All of activities data or primary data collected are divided into two parts: glass production and FL production. The FL production will be evaluated in detail; however, the resulting inventory from all activities data per unit lamp and minor ingredient cannot be shown in this report as it is confidential to the company. The activities data of the main manufacturing process is shown in Table 3-5, stem production shown in Table 3-6, sleeve production shown in Table 3-7, cement and phosphor mixing shown in Table 3-8 and Table 3-9 respectively. All of activities data collected for glass production are shown in Table 3-10. These tables represent material, energy and water consumptions at such process.

Table 3-5 Activities data of the main manufacturing process

No.	Activity data	unit	Remark
1	Glass Bulb	kg	Structure of FL
2	Electricity	kWh	All main machine
3	LPG	kg	Baking and exhausting machine
4	Electricity	kWh	Washing and coating machine
5	Electricity	kWh	Lighting system
6	Water supply	m^3	Washing the glass tube
7	Mercury	kg	Put in the FL
8	Inert gas	kg	Gas used instead of air in lamp

Table 3-6 Activities data of the stem production

No.	Activity data	unit	Remark
1	Glass	kg	Stem tube and exhaust tube
2	Electricity	kWh	Stem machine
3	Electricity	kWh	Lighting system
4	Lead in wire	kg	Nickel and copper
6	Coil	kg	Tungsten

Table 3-7 Activities data of the sleeve production

No.	Activity data	unit	Remark
1	Brown paper	kg	The paper for produced crepe paper
2	White paper	kg	
3	Electricity	kWh	Sleeve machine
4	Tape	kg	Paper adhesion.
5	Water supply	m^3	Mixer of gum
6	Latex gum	kg	Purchase gum (Mixed with water before use)
7	Electricity	kWh	Lighting system
8	Paste	kg	Gum from tapioca flour mixed with NaOH and water

Table 3-8 Activities data of the cement mixing

No.	Activity data	unit	Remark
1	Capping Cement	kg	Mixed with methanol
2	Base	kg	Aluminum cap
3	Methanol	kg	Mixed with cement
4	Electricity	kWh	Mixing machine

Table 3-9 Activities data of the phosphor mixing

No.	Activity data	unit	Remark
1	Lacquer	kg	Mixer
2	Demonized water	kg	Mixer
3	Phosphor Powder	kg	Mixer
4	Aluminum oxide	kg	Mixer
5	Electricity	kg	Mixer machine
6	Minor ingredients	kg	Mixer

Table 3-10 Activities data of the glass manufacture

No.	Activity data	unit	Remark
1	Cullet	kg	Glass recycle
2	Silica Sand	kg	Sand
3	Soda ash	kg	Na_2CO_3
4	Dolomite	kg	$CaMg(CO_3)_2$
5	Minor ingredients	kg	Made quality better
6	Electricity	kWh	In line process
7	Water supply	m^3	Cooling system
8	Natural gas	kg	Furnace
9	Chemical reaction	-	Decomposition reaction
10	Packaging	kg	Carton

The inventory is collected in the unit of weight of materials or energy per product produced such as kg/lamp, kWh/lamp, m^3/lamp, etc., and will be separated for the four types of FLs. Tables 3-11 and 3-12 represent the allocation method for the material/energy used in lamp industry and glass industry respectively.

Table 3-11 Allocation method in lamp industry

List	Allocation method	Reasons
Water supply used	The number of lamp	The same quantity of water supply used of washing each lamp
Electricity in lighting system	The number of all lamp product	The amount of work area for line process of each product is same value (The lighting system is 5% of all electricity used)
Raw material used	The number of each lamp type product	- Each line process has recorded the data for each FL that produces in the daily data (Raw material used and number of good lamp produced in each day). - L4: 18WT8, L5: 36WT8, L7: T5.

Table 3-12 Allocation method in glass industry

List	Allocation method	Reasons
Water supply used	By mass of glass produced	50% of all water used is used in glass production process (cooling system machine: same machine, same quantity of water used)
Electricity used	By mass of glass produced	The same of machine and other equipment in each line process
Natural gas used	By mass of glass produced	The furnace is the continuous system and has the same melting temperature
Raw material used	By mass of glass produced	The amount of raw material used depend on mass of glass produced

3.2.3 Select emission factor: GHG emission factor is the amount of GHG emission per activity unit such as GHG emission per kWh of electricity production. Emission factors can be found from LCI databases. Most of E.F.s used in this research comes from the TGO's guideline [8] and some are from the calculation by Simapro 7.1 (Ecoinvent 2.0, IPPC 2007 GWP 100a). Tables 3-13 and 3-14 represent E.F.s of material and energy production (some combustion) for lamp industry and glass industry, respectively. Table 3-15 displays the E.F.s of vehicle (transportation) used in this research. Table 3-16 represents E.F.s of material and energy production (some combustion) in case of ballast.

3.3 Interpretation

Carbon footprint (CF) of each FL presents the total emission of greenhouse gases in terms of kg CO_2e/lamp. CF helps indicate hot spots (the stages with the highest GHG emission), which then becomes a target for improvement. Comparison of each FL CF is equal to the CFs in terms of kg CO_2e/lamp multiplies by the number of each FL with the same brightness (see Table 3-1).

Table 3-13 CO_2 emission estimates of material and energy production (lamp industry)

No.	List	unit	E.F. (kg CO_2e/unit)	Reference data	Reference database
1	Glass	kg	3.4352	Calculation	
2	Mercury	kg	118	Obtained from Simapro	GLO S, IPPC 2007 GWP 100a
3	Aluminum	kg	12.2	TGO's guideline	Ecoinvent 2.0, IPPC 2007 GWP 100a
4	Copper	kg	3.47	TGO's guideline	Ecoinvent 2.0, IPPC 2007 GWP 100a
5	Argon liquid	kg	0.285	Obtained from Simapro	Ecoinvent 2.0, IPPC 2007 GWP 100a
6	Krypton gas	kg	107	Obtained from Simapro	Ecoinvent 2.0, IPPC 2007 GWP 100a
7	Mono Calcium phosphate	kg	1.51	Obtained from Simapro	Ecoinvent 2.0, IPPC 2007 GWP 100a
8	Sodium tripolyphosphate	kg	5.8	Obtained from Simapro	Ecoinvent 2.0, IPPC 2007 GWP 100a
9	Aluminum oxide	kg	1.23	Obtained from Simapro	Ecoinvent 2.0, IPPC 2007 GWP 100a
10	Lacquer	kg	6.74	TGO's guideline	Ecoinvent 2.0, IPPC 2007 GWP 100a
11	Brown paper	kg	0.735	TGO's guideline	Ecoinvent 2.0, IPPC 2007 GWP 100a
12	White paper	kg	0.735	TGO's guideline	Ecoinvent 2.0, IPPC 2007 GWP 100a
13	Tapioca flour	kg	0.541	Obtained from Simapro	Ecoinvent 2.0, IPPC 2007 GWP 100a
14	Sodium hydroxide	kg	1.2	TGO's guideline	Ecoinvent 2.0, IPPC 2007 GWP 100a
15	Tape	kg	3.19	TGO's guideline	Industry data 2.0, IPPC 2007 GWP 100a
16	Latex gum	kg	2.64	Obtained from Simapro	Ecoinvent 2.0, IPPC 2007 GWP 100a
17	Tungsten	kg	21.2	Obtained from Simapro	Ecoinvent 2.0, IPPC 2007 GWP 100a
18	Nickel	kg	24.3	Obtained from Simapro	GLO S, IPPC 2007 GWP 100a
19	Methanol	kg	0.739	Obtained from Simapro	GLO S, IPPC 2007 GWP 100a
20	Electricity	kWh	0.561	TGO's guideline	TC Common data

Table 3-13 CO_2 emission estimates of material and energy production (lamp industry), (Continue)

No.	List	unit	E.F. (kg CO_2e/unit)	Reference data	Reference database
21	LPG (production)	kg	0.270	TGO's guideline	IDEMAT 2001, IPCC 2007 GWP 100a
22	LPG (combustion)	m^3	1,830	Obtained from Simapro	Ecoinvent 2.0, IPPC 2007 GWP 100a
23	Water supply	m^3	0.0264	TGO's guideline	Metropolitan Waterwork Authority (Thailand)
24	Deionized water	kg	5.98E-04	Obtained from Simapro	CHU, IPPC 2007 GWP 100a
25	Natural gas (production)	m^3	0.328	Obtained from Simapro	Ecoinvent 2.0, IPPC 2007 GWP 100a
26	Natural gas (combustion)	MJ	0.0712	Obtained from Simapro	Ecoinvent 2.0, IPPC 2007 GWP 100a
27	Sodium sulphate	kg	0.39	Obtained from Simapro	Ecoinvent 2.0, IPPC 2007 GWP 100a
28	Cement	kg	0.995	Obtained from Simapro	ETH S, IPCC 2007 GWP 100a
29	Glass (100% recovery material)	kg	0.33	The Climate Conservancy (2010)	-
30	Zinc	kg	0.249	Obtained from Simapro	Ecoinvent 2.0, IPPC 2007 GWP 100a

Table 3-14 CO_2 emission estimates of material and energy production (glass industry)

No.	List	unit	E.F. (kg CO_2e/unit)	Reference data	Reference database
1	Silica sand	kg	0.0211	TGO’s guideline	Ecoinvent 2.0, IPPC 2007
2	Soda ash	kg	1.19	TGO’s guideline	Ecoinvent 2.0, IPPC 2007 GWP 100a
3	Dolomite	kg	0.0265	TGO’s guideline	Ecoinvent
4	Feldspar	kg	0.0037	TGO’s guideline	Ecoinvent (V 2)
5	Minor ingredient	-	-	Cannot show the data	-
6	Diesel fuel (production)	Liter	0.4363	TGO’s guideline	BUWAL250
7	Diesel fuel (combustion)	Liter	2.708	TGO’s guideline	IPCC2007, DEDE
8	Wastewater treatment	Liter	0.0012	TGO’s guideline	JEMAI
9	Other solid waste (landfill)	m^3	2.32	TGO’s guideline	2006 IPCC Guidelines for National Greenhouse Gas Inventories - Volume 5: waste
10	Rag waste (landfill)	kg	2.00	TGO’s guideline	2006 IPCC Guidelines for National Greenhouse Gas Inventories - Volume 5: waste
11	Garbage (landfill)	kg	2.53	TGO’s guideline	2006 IPCC Guidelines for National Greenhouse Gas Inventories - Volume 5: waste
12	Wood (landfill)	kg	3.33	TGO’s guideline	2006 IPCC Guidelines for National Greenhouse Gas Inventories - Volume 5: waste

Table 3-15 CO_2 emission estimates of vehicle (transportation)

No.	Vehicle	unit	E.F. (kg CO_2e/unit)	Reference data	Reference database
1	22-wheel semi-trailer trucks, 32 tons (Full load)	ton-km	0.0475	TGO's guideline	TH database, classified and uncertified
2	22-wheel semi-trailer trucks, 32 tons (No load)	km	1.0655	TGO's guideline	TH database, classified and uncertified
3	10-wheel trucks, 16 tons (Full load)	ton-km	0.0473	TGO's guideline	TH database, classified and uncertified
4	10-wheel trucks, 16 tons (No load)	km	0.6001	TGO's guideline	TH database, classified and uncertified
5	4-wheels pickup, 7 tons (Full load)	ton-km	0.1913	TGO's guideline	TH database, classified and uncertified
6	4-wheels pickup, 7 tons (No load)	km	0.3492	TGO's guideline	TH database, classified and uncertified
7	6-wheels trucks, 11 tons (Full load)	ton-km	0.0639	TGO's guideline	TH database, classified and uncertified
8	6-wheels trucks, 11 tons (No load)	km	0.5139	TGO's guideline	TH database, classified and uncertified

Remark: Emission factors in this table are involved GHG emission from upstream emission and combustion**.**

Table 3-16 CO_2 emission estimates of material and energy production in case of ballast.

No.	List	unit	E.F. (kg CO2/unit)	Reference data	Reference database
1	Steel	kg	1.76	TGO's guideline	Ecoinvent 2.0, IPPC 2007
2	Copper wire	kg	3.47	TGO's guideline	Ecoinvent 2.0, IPPC 2007 GWP 100a
3	Nylon Bobbin	kg	1.91	TGO's guideline	LCA Food DK
4	Polyester film	kg	7.54	TGO's guideline	Ecoinvent 2.0, IPPC 2007
5	Aluminum	kg	12.2	TGO's guideline	Ecoinvent 2.0, IPPC 2007 GWP 100a
6	Paint	kg	1.79	Obtained from Simapro	ETHS, IPPC 2007 GWP 100a
7	Thinner	kg	1.5	TGO's guideline	Ecoinvent 2.0, IPPC 2007 GWP 100a
8	Paper	kg	0.735	TGO's guideline	Ecoinvent 2.0, IPPC 2007 GWP 100a
9	Capacitor	kg	83.1	TGO's guideline	Ecoinvent 2.0, IPPC 2007 GWP 100a
10	Printed circuit board (PCB)	kg	27.7	TGO's guideline	Ecoinvent 2.0, IPPC 2007 GWP 100a
11	Insulation material	kg	5.07	Obtained from Simapro	DES, IPPC 2007 GWP 100a
12	Brazing solder	kg	2.12	Obtained from Simapro	Ecoinvent 2.0, IPPC 2007 GWP 100a
13	Jumper wire (copper)	kg	1.99	Obtained from Simapro	Ecoinvent 2.0, IPPC 2007 GWP 100a
14	Integrated circuit (IC)	kg	9.16E03	Obtained from Simapro	Ecoinvent 2.0, IPPC 2007 GWP 100a

CHAPTER IV

RESULTS AND DISCUSSION

This chapter presents the data used in GHG emission assessment of four fluorescent lamp types and reports the results of GHG emission in each life cycle stage, i.e. raw material acquisition, manufacturing process, consumer use, disposal and also related transportation. Figure 4-1 displays the research boundary.

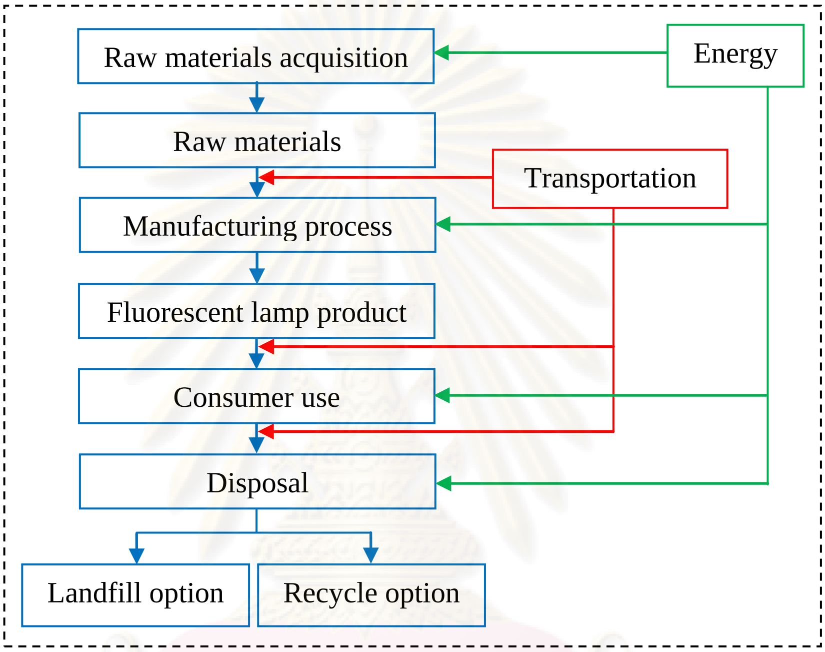

Figure 4-1 Research boundary

4.1 Inventory analysis

4.1.1 Raw material acquisition and preprocessing for FL

Tables 4-1 to 4-4 show the main raw materials used to produce 36WT8, 18WT8, 28WT5 and 14WT5 FL, respectively. Note that this stage contains two groups of primary data, i.e. raw materials and energy used for FL and glass production processes.

The production of T8 involves a slightly different set of raw materials with T5 as described below:

a) The Stem tube for T5 is purchased from another company which already combines flare with exhaust tube, while the stem for T8 is produced onsite which makes it possible to separate the weight between the stem tube and the exhaust tube. However, this does not affect the overall evaluation as the weights of both tube components are rather small compared to the weight of the glass tube for the bulb.

b) Inert gas filled in T5 lamp is 100% argon gas while T8 contains the mixture between argon and krypton gases.

c) Unlike T8, the sleeve of T5 is automatically assembled using latex adhesive, without the use of paste and tape. Therefore the production of sleeve T5 does not require tapioca flour and sodium hydroxide.

d) Mercury filled in T8 FL is pure liquid mercury but T5 FL is the mercury bead containing 49.36% mercury and 50.53% zinc.

The inventory for glass production (all through the four stages of its life cycle based on business-to-business (B2B) basis) is summarized in Table 4-5.

Raw materials and energy used to produce magnetic and electronic ballasts are illustrated in Tables 4-6.

4.1.2 Manufacturing process

FL production consumes energy for the operation of manufacturing machines and lighting systems, water for cleaning and mixing chemicals like phosphor solution and cement, and LPG for baking and exhausting process of FL. Tables 4-7 to 4-10 summarize energy consumption in each sup-process of 36WT8, 18WT8, 28WT5 and 14WT5 FLs, respectively.

Table 4-1 Raw materials used to produce one 36WT8 fluorescent lamp

No.	Raw material	Unit	Main process	Stem production	Sleeve production	Phosphor mixing	Cement mixing	Total
1	Glass tube	kg	0.2038					0.2038
2	Phosphor powder	kg				4.05E-03		4.05E-03
3	Lacquer	kg				5.92E-03		5.92E-03
4	Aluminum oxide	kg				1.31E-04		1.31E-04
5	Stem tube	kg		6.66E-03				6.66E-03
6	Exhaust tube	kg		5.09E-03				5.09E-03
7	Nickel	kg		9.81E-05				9.81E-05
8	Copper	kg		1.73E-04				1.73E-04
9	Tungsten	kg		4.39E-05				4.39E-05
10	Argon gas	kg	4.69E-07					4.69E-07
11	Krypton gas	kg	1.76E-05					1.76E-05
12	Phenolic resin blend	kg					3.65E-04	3.65E-04
13	Mineral fillers	kg					2.73E-03	2.73E-03
14	Methanol	kg					2.45E-04	2.45E-04
15	Mercury	kg	1.00E-05					1.00E-05
16	Aluminum	kg					2.13E-03	2.13E-03
17	Copper	kg					1.30E-03	1.30E-03
18	White paper	kg			9.53E-03			9.53E-03
19	Brown paper	kg			1.59E-02			1.59E-02
20	Latex gum	kg			4.94E-04			4.94E-04
21	Tape	kg			1.98E-03			1.98E-03
22	Tapioca flour	kg			2.17E-04			2.17E-04
23	Sodium hydroxide (NaOH)	kg			5.65E-06			5.65E-06

Table 4-2 Raw materials used to produce one 18WT8 fluorescent lamp

No.	Raw material	Unit	Main process	Stem production	Sleeve production	Phosphor mixing	Cement mixing	Total
1	Glass tube	kg	0.0939					0.0939
2	Phosphor powder	kg				2.33E-03		2.33E-03
3	Lacquer	kg				3.70E-03		3.70E-03
4	Aluminum oxide	kg				6.90E-05		6.90E-05
5	Stem tube	kg		5.54E-03				5.54E-03
6	Exhaust tube	kg		3.95E-03				3.95E-03
7	Nickel	kg		8.79E-05				8.79E-05
8	Copper	kg		1.55E-04				1.55E-04
9	Tungsten	kg		3.13E-05				3.13E-05
10	Argon gas	kg	4.85E-07					4.85E-07
11	Krypton gas	kg	6.06E-06					6.06E-06
12	Phenolic resin blend	kg					3.17E-04	3.17E-04
13	Mineral fillers	kg					2.37E-03	2.37E-03
14	Methanol	kg					2.13E-04	2.13E-04
15	Mercury	kg	1.00E-05					1.00E-05
16	Aluminum	kg					1.85E-03	1.85E-03
17	Copper	kg					1.13E-03	1.13E-03
18	White paper	kg			4.87E-03			4.87E-03
19	Brown paper	kg			8.13E-03			8.13E-03
20	Latex gum	kg			3.14E-04			3.14E-04
21	Tape	kg			1.18E-03			1.18E-03
22	Tapioca flour	kg			1.11E-04			1.11E-04
23	Sodium hydroxide (NaOH)	kg			2.89E-06			2.89E-06

Table 4-3 Raw materials used to produce one 28WT5 fluorescent lamp

No.	Raw material	Unit	Main process	Stem production	Sleeve production	Phosphor mixing	Cement mixing	Total
1	Glass tube	kg	0.1473					0.1473
2	Phosphor powder	kg				4.94E-03		4.94E-03
3	Lacquer	kg				7.54E-03		7.54E-03
4	Aluminum oxide	kg				1.87E-04		1.87E-04
5	Flare and exhaust tube	kg		4.82E-03				4.82E-03
6	Nickel	kg		9.23E-05				9.23E-05
7	Copper	kg		2.32E-04				2.32E-04
8	Tungsten	kg		2.71E-05				2.71E-05
9	Argon gas	kg	1.43E-06					1.43E-06
10	Phenolic resin blend	kg					2.37E-04	2.37E-04
11	Mineral fillers	kg					1.77E-03	1.77E-03
12	Methanol	kg					1.59E-04	1.59E-04
13	Mercury	kg	7.31E-06					7.31E-06
14	Zinc	kg	7.45E-06					7.45E-06
15	Aluminum	kg					2.02E-03	2.02E-03
16	Copper	kg					2.52E-03	2.52E-03
17	White paper	kg			9.43E-03			9.43E-03
18	Brown paper	kg			1.15E-02			1.15E-02
19	Latex gum	kg			1.61E-03			1.61E-03

Table 4-4 Raw materials used to produce one 14WT5 fluorescent lamp

No.	Raw material	Unit	Main process	Stem production	Sleeve production	Phosphor mixing	Cement mixing	Total
1	Glass tube	kg	0.0737					0.0737
2	Phosphor powder	kg				4.28E-03		4.28E-03
3	Lacquer	kg				6.62E-03		6.62E-03
4	Aluminum oxide	kg				1.13E-04		1.13E-04
5	Flare and exhaust tube	kg		5.45E-03				5.45E-03
6	Nickel	kg		1.03E-04				1.03E-04
7	Copper	kg		2.59E-04				2.59E-04
8	Tungsten	kg		2.73E-05				2.73E-05
9	Argon gas	kg	6.04E-07					6.04E-07
10	Phenolic resin blend	kg					3.54E-04	3.54E-04
11	Mineral fillers	kg					2.65E-03	2.65E-03
12	Methanol	kg					2.38E-04	2.38E-04
13	Mercury	kg	7.31E-06					7.31E-06
14	Zinc	kg	7.45E-06					7.45E-06
15	Aluminum	kg					3.01E-03	3.01E-03
16	Copper	kg					3.77E-03	3.77E-03
17	White paper	kg			1.28E-02			1.28E-02
18	Brown paper	kg			1.42E-02			1.42E-02
19	Latex gum	kg			2.48E-03			2.48E-03

Table 4-5 Raw materials/energy/wastes from the production of one kilogram of glass

No.	Raw material	unit	Main process	Production	Waste	Total
1	Silica Sand	kg	0.6068			0.6068
2	Cullet	kg	0.5021			0.5021
3	Soda ash	kg	0.2353			0.2353
4	Dolomite	kg	0.1507			0.1507
5	Feldspar	kg	0.1132			0.1132
6	Minor ingredients	kg	0.0434			0.0434
7	Electricity	kWh		0.4278		0.4278
8	Water supply	m^3		4.35E-04		4.35E-04
9	Natural gas	MJ		31.33		31.33
10	Wastewater	m^3			2.65E-03	2.65E-03
11	Garbage	kg			8.26E-04	8.26E-04
12	Lumber	kg			2.07E-04	2.07E-04
13	Rag and glove	kg			2.11E-04	2.11E-04
14	Solid waste	kg			1.43E-03	1.43E-03
15	Packaging (Carton)	kg	0.0692			0.0692

Table 4-6 Raw materials and energy used to produce one piece of ballast

No.	Item	Unit	Magnetic ballast	Electronic ballast
1	Steel	kg	0.850	0.1778
2	Copper wire	kg	0.103	0.0010
3	Nylon Bobbin	kg	0.015	0.0054
4	Polyester film	kg	0.010	-
5	Aluminum	kg	0.005	-
6	Paint	kg	0.002	-
7	Thinner	kg	0.001	-
8	Paper	kg	0.001	-
9	Transformer	kg	-	0.0738
10	Capacitor	kg	-	0.0332
11	Printed circuit board (PCB)	kg	-	0.0293
12	Insulation material	kg	-	0.0105
13	Resistor	kg	-	0.0060
14	Transistor	kg	-	0.0056
15	Solder paste	kg	-	0.0048
16	Diode	kg	-	0.0046
17	Fuse	kg	-	0.0016
18	Jumper wire	kg	-	0.0014
19	NTC	kg	-	0.0010
20	Integrated circuit (IC)	kg	-	0.0005
21	Fixed inductor	kg	-	0.0002
22	Potential meter	kg	-	0.0003
23	Electricity	kWh	0.03	0.67

Table 4-7 Utilities used in each sub-process of one 36WT8 FL production

No.	Utility	Unit	Main process	Stem production	Sleeve production	Phosphor mixing	Cement mixing	Total
1	Electricity							
	- Operate machine	kWh	6.77E-02	1.64E-03	5.27E-03	3.33E-04	4.96E-05	7.50E-02
	- Washing and coating	kWh	1.62E-02					1.62E-02
	- Lighting system	kWh	1.23E-02	1.27E-03	6.60E-04			1.42E-02
2	Water supply							
	- Washing glass tube	m^3	1.57E-03					1.57E-03
	- Mixer	m^3			1.62E-03			1.62E-03
3	LPG	kg	5.76E-02					5.76E-02
4	Deionized water	kg				5.65E-03		5.65E-03

Table 4-8 Utilities used in each sub-process of one 18WT8 FL production

No.	Utility	Unit	Main process	Stem production	Sleeve production	Phosphor mixing	Cement mixing	Total
1	Electricity							
	- Operate machine	kWh	5.43E-02	1.27E-03	4.37E-03	1.85E-04	4.31E-05	6.02E-02
	- Washing and coating	kWh	1.61E-02					1.61E-02
	- Lighting system	kWh	1.23E-02	9.77E-04	7.22E-04			1.40E-02
2	Water							
	- Washing glass tube	m^3	1.51E-03					1.51E-03
	- Mixer	m^3			8.44E-04			8.44E-04
3	LPG	kg	4.96E-02					4.96E-02
4	Deionized water	kg				3.39E-03		3.39E-03

Table 4-9 Utilities used in each sub-process of one 28WT5 FL production

No.	Utility	Unit	Main process	Stem production	Sleeve production	Phosphor mixing	Cement mixing	Total
1	Electricity							
	- Operate machine	kWh	2.55E-01	7.14E-04	3.06E-03	4.62E-04	3.22E-05	2.60E-01
	- Washing and coating	kWh	3.97E-02					3.97E-02
	- Lighting system	kWh	1.23E-02	5.51E-04	7.02E-04			1.41E-02
2	Water							
	- Washing glass tube	m^3	1.58E-03					1.58E-03
	- Mixer	m^3			4.02E-04			4.02E-04
3	LPG	kg	1.46E-01					1.46E-01
4	Deionized water	kg				7.65E-03		7.65E-03

Table 4-10 Utilities used in each sub-process of one 14WT5 FL production

No.	Utility	Unit	Main process	Stem production	Sleeve production	Phosphor mixing	Cement mixing	Total
1	Electricity							
	- Operate machine	kWh	4.09E-01	8.08E-04	1.05E-02	3.10E-04	4.82E-05	4.21E-01
	- Washing and coating	kWh	7.27E-02					7.27E-02
	- Lighting system	kWh	1.23E-02	6.24E-04	2.41E-03			1.58E-02
2	Water							
	- Washing glass tube	m^3	1.55E-03					1.55E-03
	- Mixer	m^3			6.21E-04			6.21E-04
3	LPG	kg	1.46E-01					1.46E-01
4	Deionized water	kg				6.23E-03		6.23E-03

4.1.3 Distribution/retail

The transportation details (17 month) of the four FL products are presented in Tables 4-11 to 4-14, respectively. The weight of each FL product used to convert the number of lamp into the weight of product is listed in Table 4-15.

Table 4-11 Transportation data for 36WT8 FL product

No.	Location	Distance (km)	Total number of product transport	
			4-wheels truck	10-wheels truck
1	Chakawat Samphanthawong zone	35.1	3,171	-
2	Prakanong	20.8	400	-
3	Rama II	38.9	-	161,999
4	Rangsit.	32.4	218	41,610
5	Ladprao 74	29.6	37,623	461,321
6	Suan Pak, Taling Chan.	47.3	585	106,520
7	Bangplee district	18.8	152	-
8	Muang Samut Sakhon	58.4	-	35,000

Table 4-12 Transportation data for 18WT8 FL product

No.	Location	Distance (km)	Total number of product transport	
			4-wheels truck	10-wheels truck
1	Chakawat Samphanthawong zone	35.1	9,934	-
2	Prachatipatai road	36.6	350	-
3	Srinakarin road	18.2	2,200	-
4	Rama II	38.9	19,690	124,260
5	Rangsit.	32.4	-	44,640
6	Ladprao 74	29.6	20,000	318,271
7	Suan Pak, Taling Chan.	47.3	-	31,980
8	Muang Samut Sakhon	58.4	-	36,200

Table 4-13 Transportation data for 28WT5 FL product

No.	Location	Distance (km)	Total number of product transport	
			4-wheels truck	10-wheels truck
1	Bang-chak, Rang Rotfai Sai Kaow Road	13.6	776	-
2	Chakawat Samphanthawong zone	35.1	100	-
3	Phaholyothin 52	48.4	1,796	-
4	Nonthaburi	43.9	2,616	209,904
5	Rangsit	32.4	16,725	2,000
6	Ramintra	41.2	4,520	-
7	Ladprao 74	29.6	10,365	98,802
8	Suan Pak, Taling Chan.	47.3	25	550
9	Chon buri	103.9	3,000	-

Table 4-14 Transportation data for 14WT5 FL product

No.	Location	Distance (km)	Total number of product transport	
			4-wheels truck	10-wheels truck
1	Chakawat Samphanthawong zone	35.1	275	-
2	Prachatipatai road	36.6	225	
3	Phaholyothin 52	48.4	296	
4	Nonthaburi	43.9	482	28
5	Rangsit	32.4	6,500	500
6	Ramintra	41.2	450	-
7	Ladprao 74	29.6	875	6,066
8	Suan Pak, Taling Chan.	47.3	25	-
9	Nakhon Pathom	34.6	98	-

Table 4-15 Weight of each FL product

FL type	Weight of lamp (kg)	Weight of sleeve (kg)	Total weight (kg)
36WT8	0.1775	0.0233	0.2007
18WT8	0.0886	0.0120	0.1006
28WT5	0.1100	0.0182	0.1282
14WT5	0.0579	0.0111	0.0690

4.1.4 Consumer use

The amounts of electricity consumed by the four FL types and ballast through the period of their use are illustrated in Table 4-16 and 4-17, respectively. The average life time of FL set is 20,000 hours.

Table 4-16 Electricity consumption of the four FL types

FL type	Power per lamp (kW)	Average life time (hours)	Electricity consumption (kWh)
36WT8	0.036	20,000	720
18WT8	0.018	20,000	360
28WT5	0.028	20,000	560
14WT5	0.014	20,000	280

Table 4-17 Electricity consumption of ballast

Ballast	Power (kW)	Average life time (hours)	Electricity consumption (kWh)
Magnetic	0.010	20,000	200
Electronic	0.003	20,000	60

Remark: Power of magnetic ballast data comes from TOSHIBA LIGHTING [32] and the selected lamp factory. For electronic ballast comes from the selected lamp factory**.**

4.1.5 Disposal/recycle

Two disposal options contains with stabilization and solidification process. The amount of materials used in this process depended on the weight of wastes. Table 4-18 and 4-19 summarizes the weight of SFLs and ballasts fed into landfill option and recycling option, respectively. Raw materials and energy used in recycling and landfill options of four FLs are summarized in Tables 4-20 and 4-21, respectively. Similarly, Tables 4-22 and 4-23 display the raw materials needed and energy used for disposal magnetic and electronic ballasts.

Table 4-18 Weight of SFL and ballast being disposed in landfill option

List	Total weight (kg)
36WT8 FL	0.177
18WT8 FL	0.089
28WT5 FL	0.110
14WT5 FL	0.058
Magnetic ballast	0.987
Electronic ballast	0.357

Table 4-19 Weight of SFL and ballast being disposed in recycle option

List	Total weight (kg)	Recyclable material (kg)	Residual waste (kg)
36WT8 FL	0.177	0.160	0.018
18WT8 FL	0.089	0.080	0.009
28WT5 FL	0.110	0.099	0.011
14WT5 FL	0.058	0.052	0.006
Magnetic ballast	0.987	0.958	0.029
Electronic ballast	0.357	0.253	0.104

Table 4-20 Raw materials and energy used in recycling option of four SFLs

Disassembly process		Unit	Unit/kg waste (1)	36WT8 (2)	18WT8 (3)	28WT5 (4)	14WT5 (5)
Inputs	Electricity use	kWh	1.45E-02	2.57E-03	1.28E-03	1.60E-03	8.40E-04
	Water use	m^3	9.00E-04	1.60E-04	7.97E-05	9.90E-05	5.21E-05
	Natural gas use	m^3	2.30E-04	4.08E-05	2.04E-05	2.53E-05	1.33E-05
Outputs	Cullet	kg	9.00E-01	1.60E-01	7.97E-02	9.90E-02	5.21E-02
	residual waste	kg	1.00E-01	1.77E-02	8.86E-03	1.10E-02	5.79E-03
	Mercury vapor emission	kg	2.19E-07	3.89E-08	1.94E-08	2.41E-08	1.27E-08
	Mercury emission to water	kg	3.68E-09	6.53E-10	3.26E-10	4.05E-10	2.13E-10
Stabilization and solidification process		**Unit**	**Unit/kg waste**	**36WT8**	**18WT8**	**28WT5**	**14WT5**
Inputs	Electricity use	kWh	0.0255	4.52E-04	2.26E-04	2.81E-04	1.48E-04
	Water use	m^3	0.0010	1.77E-05	8.86E-06	1.10E-05	5.79E-06
	Sodium sulfide use	kg	0.0700	1.24E-03	6.20E-04	7.70E-04	4.05E-04
	Cement use	kg	1.0000	1.77E-02	8.86E-03	1.10E-02	5.79E-03
Output	Generated solid waste	kg	2.0500	3.64E-02	1.82E-02	2.26E-02	1.19E-02

Remark: (2), (3), (4), (5) = (1) * the weight of each FL residual waste in Table 4-19

Table 4-21 Raw materials and energy used in landfill option of four SFLs

Stabilization and solidification process		Unit	Unit/kg waste (6)	36WT8 (7)	18WT8 (8)	28WT5 (9)	14WT5 (10)
Inputs	Electricity use	kWh	0.0255	4.52E-03	2.26E-03	2.81E-03	1.48E-03
	Water use	m^3	0.0010	1.77E-04	8.86E-05	1.10E-04	5.79E-05
	Sodium sulfide use	kg	0.0700	1.24E-02	6.20E-03	7.70E-03	4.05E-03
	Cement use	kg	1.0000	1.77E-01	8.86E-02	1.10E-01	5.79E-02
Output	Generated solid waste	kg	2.0500	3.64E-01	1.82E-01	2.26E-01	1.19E-01

Remark: (7), (8), (9), (10) = (6) * the total weight of each FL waste in Table 4-18

Table 4-22 Raw materials and energy used in recycling option of ballasts

Disassembly process		Unit	Unit/kg waste (11)	Magnetic ballast (12)	Electronic ballast (13)
Inputs	By worker	-	-	-	-
Outputs	Steel recovered	kg	-	0.85	0.215
	Copper recovered	kg	-	0.103	0.038
	Aluminum recovered	kg	-	0.005	-
	Residual waste	kg	-	0.029	0.104
Stabilization and solidification process		**Unit**	**Unit/kg waste**	**Magnetic ballast**	**Electronic ballast**
Inputs	Electricity use	kWh	0.0255	7.40E-04	2.66E-03
	Water use	M^3	0.0010	2.90E-05	1.04E-04
	Sodium sulfide use	kg	0.0700	2.03E-03	7.31E-02
	Cement use	kg	1.0000	2.90E-02	1.04E-01
Output	Generated solid waste	kg	2.0500	5.95E-02	2.14E-01

Remark: (12), (13) = (11) * the weight of each ballast residual waste in Table 4-18

Table 4-23 Raw materials and energy used in landfill option of ballasts

Stabilization and solidification process		Unit	Unit/kg waste (14)	Magnetic ballast (15)	Electronic ballast (16)
Inputs	Electricity use	kWh	0.0255	2.52E-02	9.10E-03
	Water use	M^3	0.0010	9.87E-04	3.57E-04
	Sodium sulfide use	kg	0.0700	6.91E-02	2.50E-02
	Cement use	kg	1.0000	9.87E-01	3.57E-01
Output	Generated solid waste	kg	2.0500	2.023	0.732

Remark: (15), (16) = (14) * the total weight of each ballast waste in Table 4-18

4.2 Impact assessment

GHG emission results from several life cycle stages of FL set as follows:

4.2.1 Cradle to gate of glass production (only glass bulb)

4.2.2 Lamp production (without ballast);

(1) Gate to Gate

(2) Cradle to Gate

(3) Disposal/recycling

(4) Cradle to grave

4.2.3 Ballast manufacture (only ballast)

The results from the assessment are analyzed in the following subsections.

4.2.4 Comparison of carbon footprint of product

(1) Cradle to grave (with landfill option) per

(1.1) One FL set

(1.2) FL set as the same functional unit

(2) Cradle to gate per FL set as the same functional unit

4.2.5 Contribution of ballasts

4.2.1 Glass production

The production of one kilogram of glass releases 3.44 kgCO_2e GHG where the details of these GHG emissions for each life cycle stage of glass and the percentage of GHG emission are shown in Table 4-24.

Table 4-24 GHG emission from one kilogram of glass tube

Stage	CO_2 emission (kg CO_2e)	%GHG emission
Raw materials	0.322	9.4
Transport of raw materials	0.093	2.7
Production	2.956	86.1
Waste management	0.007	0.2
Packaging	0.057	1.7
sum	3.435	100

Table 4-24 reveals that the main source of GHG emission from glass production is the production process which consumes natural gas as fuel in the furnace. One kilogram of glass needs 31.33 MJ of natural gas. The combustion of natural gas releases a large quantity of GHGs. The amount of GHG emission per glass bulb is higher for T8 FLs as they use a larger amount of glass than T5 FL.

4.2.2 Lamp production

GHG emission from the lamp production can be evaluated based on three sub-cases as follows.

(1) Gate to Gate (G2Gate)

GHG emission from manufacturing process, the results can help indicate the hot spot from energy used in manufacturing process of FL and lead to the improvement of the process efficiency that can reduce GHG emission. Tables 4-25 to 4-28 present the amount of GHG emission from the production process of 36WT8, 18WT8, 28WT5 and 14WT5 lamps, respectively. Each table also displays the percentage of GHG emission from the production process.

Table 4-25 GHG emission from production process of one 36WT8 FL

Utilities	GHG emission ($kgCO_2e$/lamp)	%GHG emission
Electricity in machine	0.051	20.1
Electricity in lighting system	0.008	3.1
Water supply	8.41E-05	0.0
Deionized water	3.38E-06	0.0
LPG (Combustion)	0.195	76.7
Total ($kgCO_2e$/lamp)	**0.254**	**100**

Table 4-26 GHG emission from production process of one 18WT8 FL

Utilities	GHG emission ($kgCO_2e$/lamp)	%GHG emission
Electricity in machine	0.043	19.6
Electricity in lighting system	0.008	3.6
Water supply	6.22E-05	0.0
Deionized water	2.03E-06	0.0
LPG (Combustion)	0.168	76.8
Total ($kgCO_2e$/lamp)	**0.219**	**100**

Table 4-27 GHG emission from production process of one 28WT5 FL

Utilities	GHG emission ($kgCO_2e$/lamp)	%GHG emission
Electricity in machine	0.168	25.0
Electricity in lighting system	0.008	1.1
Water supply	5.23E-05	0.0
Deionized water	4.58E-06	0.0
LPG (Combustion)	0.495	73.8
Total ($kgCO_2e$/lamp)	**0.671**	**100**

Table 4-28 GHG emission from production process of one 14WT5 FL

Utilities	GHG emission ($kgCO_2e$/lamp)	%GHG emission
Electricity in machine	0.277	35.4
Electricity in lighting system	0.009	1.1
Water supply	5.73E-05	0.0
Deionized water	3.72E-06	0.0
LPG (Combustion)	0.495	63.4
Total ($kgCO_2e$/lamp)	**0.780**	**100**

Tables 4-25 to 4-28 demonstrate that the hot spot from manufacturing process of each FL product is LPG combustion. Note that GHG emissions derived from LPG combustion of 28WT5 and 14WT5 take the same value as they share the same production line and process activities. As the process of making fluorescent lamps does not distinguish between the sizes of the lamp, the LPG consumption does not depend on the lamp size, but depends on the number of lamps being produced.

(2) Cradle to gate (C2Gate)

GHG emissions from the activity of production including raw material acquisition and processing, transportation of raw materials and manufacturing process help identify the hot spot in the production activity. The details of GHG emission from each stage in life cycle of the four FL types are displayed in Tables 4-29 to 4-32.

Table 4-29 GHG emission from each stage of one 36WT8 FL

Stage	GHG emission ($kgCO_2e$/lamp)	%GHG emission
Raw material acquisition	0.869	76.8
Transport of raw materials	0.008	0.7
Production process	0.254	22.5
Total ($kgCO_2e$/lamp)	1.131	100

The hot spot for the 36WT8 is raw material acquisition stage which can be further distributed as detailed in Figure 4-2.

Remark: GHG emission from total glass is the summation of GHG emission from glass bulb, stem tube and exhaust tube.

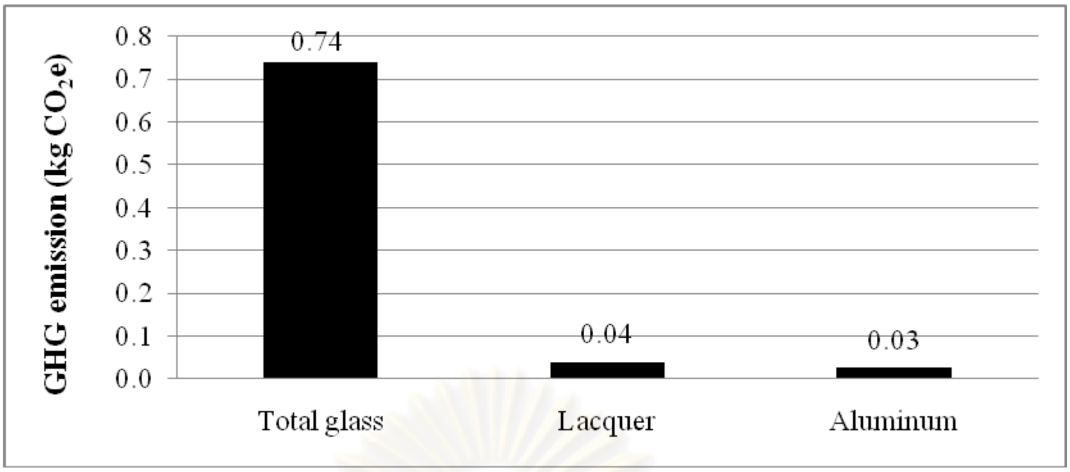

Figure 4-2 Main GHG emission source from the hot spot stage of 36WT8

Table 4-30 GHG emission from each stage of one 18WT8 FL

Stage	GHG emission ($kgCO_2e$/lamp)	%GHG emission
Raw material acquisition	0.445	66.5
Transport of raw materials	0.005	0.80
Production process	0.219	32.7
Total ($kgCO_2e$/lamp)	0.669	100

The hot spot of the 18WT8 is the raw material acquisition stage and this can be further distributed to each main raw material in Figure 4-3. The 36WT8 is produced from the machine in the same process line with the 18WT8 and therefore the GHG emissions for the two are similar. However, the 18WT8 is smaller than the 36WT8 and it consequently uses lesser amount of raw materials than the 36W counterpart and so is its GHG emission.

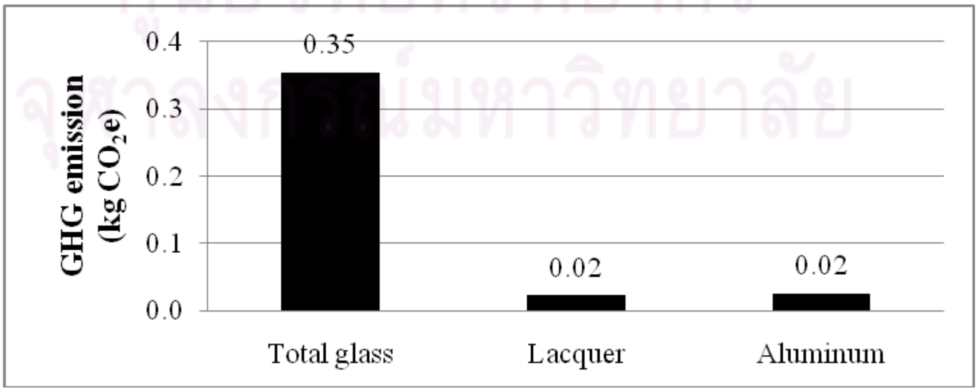

Figure 4-3 Main GHG emission source from the hot spot stage of 18WT8

Table 4-31 GHG emission from each stage of one 28WT5 FL

Stage	GHG emission ($kgCO_2e$/lamp)	%GHG emission
Raw material acquisition	0.701	50.6
Transport of raw materials	0.012	0.9
Production process	0.671	48.5
Total ($kgCO_2e$/lamp)	1.384	100

Like the T8 FL, the raw material acquisition is the hot spot for the 28WT5 where the main GHG emission contributors are illustrated in Figure 4-4.

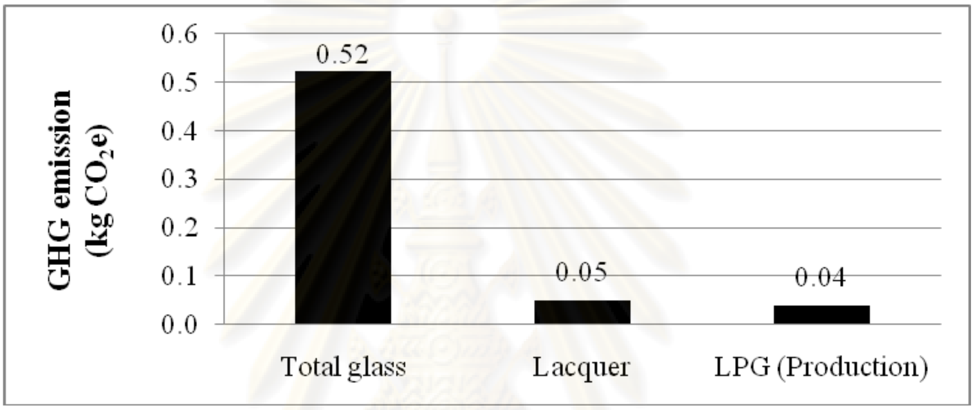

Figure 4-4 Main GHG emission source from the hot spot stage of 28WT5

The energy consumption for the 28WT5 production is higher than the 36WT8 because it requires specific machines which consumes more energy and generates more wastes. Note that the GHG emissions in the production stage come from LPG combustion (0.50 $kgCO_2e$ or 73.4%) and electricity used (0.18 $kgCO_2e$ or 26.2%).

Table 4-32 GHG emission from each stage of one 14WT5 FL

Stage	GHG emission ($kgCO_2e$/lamp)	%GHG emission
Raw material acquisition	0.465	37.0
Transport of raw materials	0.012	1.0
Production process	0.780	62.1
Total ($kgCO_2e$/lamp)	1.257	100

The 14WT5 is the smallest amongst of all FL types but is the most GHG emitter when considered the production of one lamp. GHG emission sources from this stage are shown in Figure 4-5. In the raw material acquisition stage, the major GHG contributors are glass (58% or 0.27 $kgCO_2e$), lacquer (9.6% or 0.045 $kgCO_2e$), aluminum (7.9% or 0.037 $kgCO_2e$) and tri-phosphor (5.3% or 0.025 $kgCO_2e$).

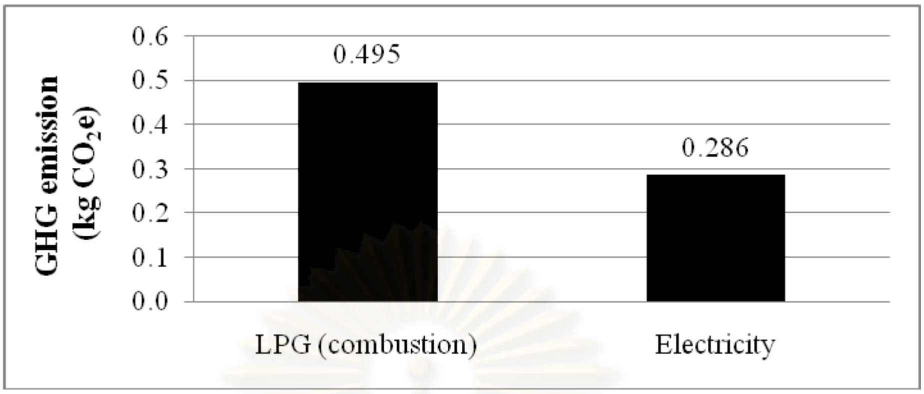

Figure 4-5 Main GHG emission source from the hot spot stage of 14WT5

The results above reveal that the amount of GHG emission does not vary proportionally with the size of FL but depends on several factors particularly the nature of the production process or the machines used in the manufacture, waste generated, raw materials and energy used per one good lamp.

(3) Disposal/recycling

GHG emissions from two disposal options (recycling and landfill options) of each FL are displayed in Table 4-33. Recycling option consists of disassembly process, stabilization and solidification process that required the consumption of electricity, water, natural gas, sodium sulfide and cement. Landfill option only involves stabilization and solidification process which consumed electricity, water, sodium sulfide and cement. GHG emissions associated with the usage of these materials are therefore included in the assessment.

Table 4-33 GHG emission from two disposal options of each FL

FL type	Recycling option ($kgCO_2e$/lamp)	Landfill option ($kgCO_2e$/lamp)
36WT8	-0.476	0.184
18WT8	-0.238	0.092
28WT5	-0.295	0.114
14WT5	-0.155	0.060

Negative value of GHG emission from recycling options show in Table 4-33 represents the reduction of GHG emission. This means that the recovery of materials like glass (as cullet) generates lesser quantity of GHG when compare with the production of such materials. It should be noted that the recycle of T8 can save more GHG than the recycle of T5. This is because more glass can be recovered from T8 than T5 due to its larger tube size.

For landfill option, the main GHG emission source is the use of cement which contributed as much as 96% of the total GHG emission from this option. Note that the E.F. of cement production is 0.995 kgCO_2e/kg cement produced.

(4) Cradle to grave (C2Grave)

GHG emission through all life cycle of each FL is shown in Table 4-34.

Table 4-34 GHG emission through life cycle of each one FL

FL type	GHG emission (kgCO_2e/lamp)	
	Landfill option	Recycle option
36WT8	405.2	404.6
18WT8	202.7	202.4
28WT5	315.7	315.3
14WT5	158.4	158.2

Almost all GHG emission (around 99%) is generated from the usage stage due to the electricity consumption. The recycle option can offer a slightly lower GHG emission than the landfill option for all cases as the recycle process requires quite a large quantity of materials and energy when compared with the landfill. The distribution of GHG emission in each stage through life cycle (with landfill option) of four FLs product is illustrated in Figure 4-6.

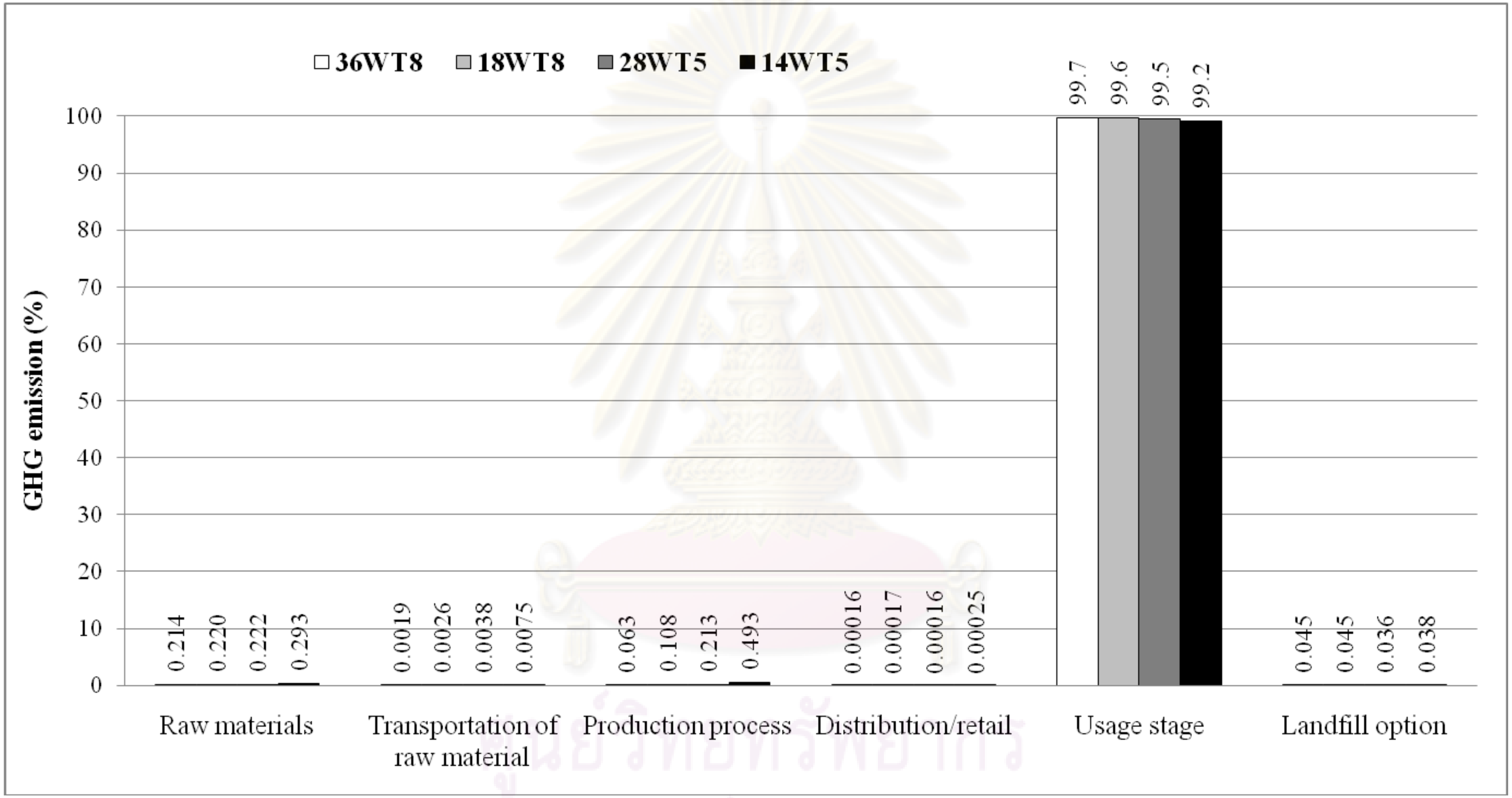

Figure 4-6 Percentage of GHG emission in each stage of four FLs

4.2.3 Ballast manufacture

GHG emissions through life cycle of magnetic and electronic ballasts with two different disposal methods are shown in Table 4-35. Recycling option, although can help reduce GHG emission from recoverable material such as steel, copper and aluminum, but such reductions are relatively small.

Table 4-35 GHG emission through life cycle of ballast

Ballast	Recycle options ($kgCO_2e$/piece)	Landfill option ($kgCO_2e$/piece)
Magnetic ballast	112.4	114.3
Electronic ballast	39.5	40.0

Remark: Some raw materials of electronic ballast (5.41% by weight) have no emission factors. It was assumed that GHG emission from these components is insignificant. Average life time of both ballasts is 20,000 hours.

The comparison of the amount of GHG emission from each stage of magnetic and electronic ballasts is shown in Table 4-36 and the percentage of these GHG emission is shown in Figure 4-7.

Table 4-36 GHG emission from each stage of magnetic and electronic ballasts

Stage	Magnetic ballast ($kgCO_2e$/piece)	Electronic ballast ($kgCO_2e$/piece)
Raw material acquisition	1.350	5.824
Transport of raw material	0.037	0.013
Production	0.011	0.251
Distribution	0.037	0.013
Usage	112.2	33.66
Landfill option	0.682	0.247
Total	114.3	40.00

The hot spot of the two types of ballast is the usage stage; 98.1% of total GHG in magnetic ballast (0.010 kWh) and 84.1% of total GHG in electronic ballast (0.003 kWh). These are due to the consumption of electricity.

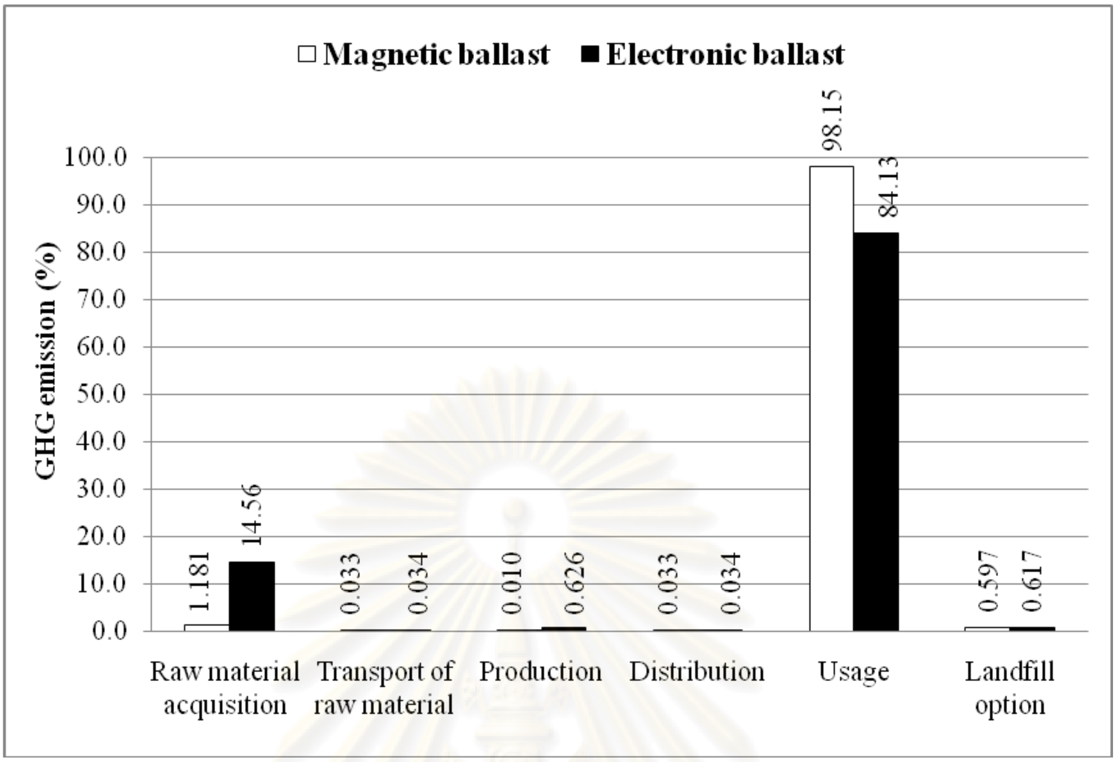

Figure 4-7 GHG emission in each stage of magnetic an electronic ballasts

Figure 4-11 illustrates that GHG emission from the raw material acquisition of the electronic ballast is more than that of the magnetic ballast. This is because the component of electronic ballast is the electronic device with higher GHG emission, i.e. E.F. = 9,160 kgCO_2e/kg of IC, 83.1 kgCO_2e/kg of capacitor, 27.7 kgCO_2e/kg of PCB or Printed circuit board, etc. Meanwhile the magnetic ballasts only constitute basic components with small E.F. value such as aluminum (E.F. = 12.2 kgCO_2e/kg), polyester film (E.F. = 7.54 kgCO_2e/kg), copper wire (E.F. = 3.47 kgCO_2e/kg), etc. The production of electronic ballast also is more complicated with higher energy consumption than that of the magnetic ballast. On the other hand, the magnetic ballast consumes more energy during the usage stage and so it releases higher GHG.

4.2.4 Comparison of carbon footprint of product

FL is the electronic device that has been continually improved to be more environmental friendly. In the case of the straight lamp, FL 28WT5 will replace 36WT8 and 14WT5 is proposed instead of 18WT8. This section provides the detail comparison of GHG emission from the two sets of the FL products. It is worth mentioned here that typical comparison will be based on the same brightness.

However, in practical point of view, the comparison based on one lamp set is also interesting. The following comparison will therefore be based on both criteria.

(1) Cradle to grave consideration (with landfill option)

(1.1) per one FL set: Comparison of GHG emission through life cycle per one FL set is shown in Table 4-37.

Table 4-37 GHG emission through life cycle per one FL

FL type	GHG emission per		GHG emission per one FL set ($kgCO_2e$)
	one FL ($kgCO_2e$)	one ballast ($kgCO_2e$)	
36WT8	405.2	114.3	519.5
28WT5	315.7	40.0	355.7
18WT8	202.7	57.1	259.9
14WT5	158.4	20.0	178.4

(1.2) per FL set as the same functional unit: GHG emission through life cycle at the same brightness of each FL set is displayed in Table 4-38

Table 4-38 GHG emission through life cycle at the same brightness of each FL

FL type set	Number of FL set	Total GHG emission ($tonCO_2e$)
36WT8	54	28.1
28WT5	53	19.0
18WT8	25	6.51
14WT5	21	3.78

Tables 4-37 and 4-38 reveal that, regardless of the comparison criteria, the 36WT8 and 18WT8 FL sets release more GHG than the 28WT5 and 14WT5 FL sets, respectively. This is mainly because the T8 FL sets consume more electricity than the T5 FL sets.

(2) Cradle to gate consideration: When excluded the usage stage and disposal/recycle, GHG emission during the production activities at the same brightness of each FL set are shown in Table 4-39.

Table 4-39 GHG emission during production activities of each FL

FL type	GHG emission ($kgCO_2e$/lamp set)	Number of FL same set	Total GHG emission ($kgCO_2e$)
36WT8	2.53	54	136.6
28WT5	7.47	53	396.1
18WT8	1.37	25	34.2
14WT5	4.30	21	90.3

Table 4-39 demonstrates that the production of T5 FL set releases more GHG than T8 FL set (reasons as stated above). In addition, the electronic ballast used together with T5 FL also requires a complex production which emits a higher amount of GHG than that of T8. Overall, the GHG emission from the T5 FL set is more than T8 FL set. This demonstrates that if the evaluation based on LCA is important as the results could be misleading when the overall stages of life cycle of FL are not included in the assessment.

4.2.5 Contribution of ballasts

Table 4-40 shows the error that might occur if ballasts are excluded from the consideration of the overall GHG emissions of FL.

Table 4-40 GHG emission of FLs with and without ballasts

FL type	GHG emission including ballast ($tonCO_2e$)	GHG emission excluding ballast ($tonCO_2e$)
36WT8	28.1	21.9
28WT5	18.9	16.7
18WT8	6.5	5.1
14WT5	3.7	3.3

Table 4-40 demonstrates that the contribution of the ballast to the overall GHG emission is about 12% for T5 FL set and 22% for T8 FL set. For example, 36WT8 FL set with magnetic ballast releases 28.1 $tonCO_2e$ with ballast but this figure is only 21.9 $tonCO_2e$ without ballast.

4.3 Interpretation

4.3.1 CO_2 emission hot spots

(1) Glass manufacture

The hot spot of glass production is the production process (85.9% of total GHG emission). Main source is the furnace. The improvement therefore should be focused on the efficiency of the furnace.

(2) Fluorescent lamp bulb

(2.1) Gate to Gate: The four types of FL share the common hot spot at the main process (glass bulb, LPG combustion and electricity used respectively, and one kg glass production release 3.435 kg CO_2e). Those suggest that the improvement options should be made at this stage.

(2.2) Cradle to gate: The hot spot for 36WT8 and 18WT8 is the total glass used to produce the FL bulb. This is the same as the results from the gate to gate consideration. Meanwhile the 28WT5 and 14WT5 exhibit the hot spot at the production process, and the main source is the LPG combustion. Therefore, increasing the efficiency of the furnace should be the major improvement option to decrease GHG emission.

(3) Fluorescent lamp set: Figures 4-8 and 4-9 show the pie chart of the percentage of GHG emission through life cycle of each FL set.

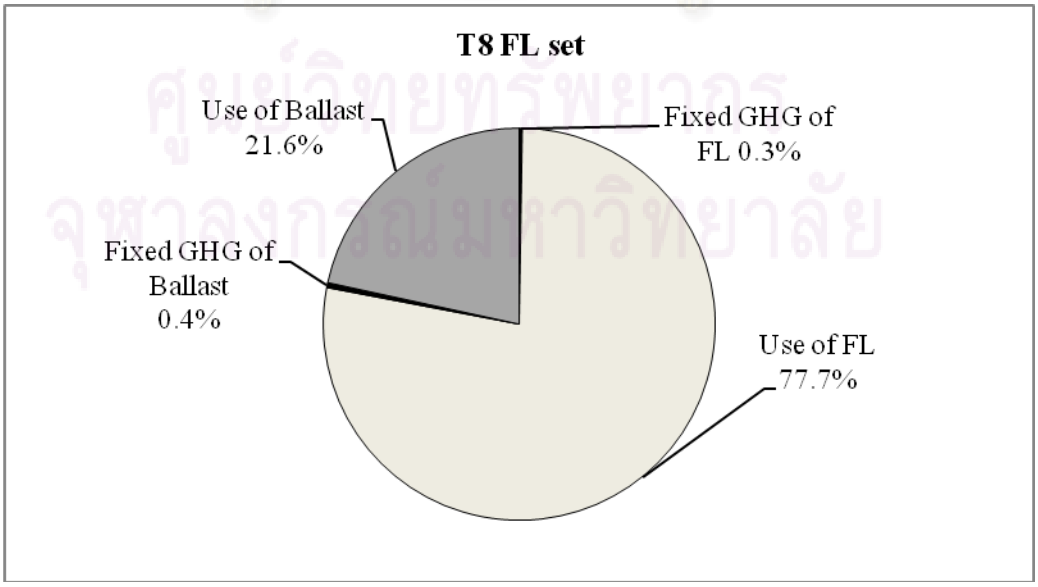

Figure 4-8 GHG emission through life cycle of 36WT8 and 18WT8

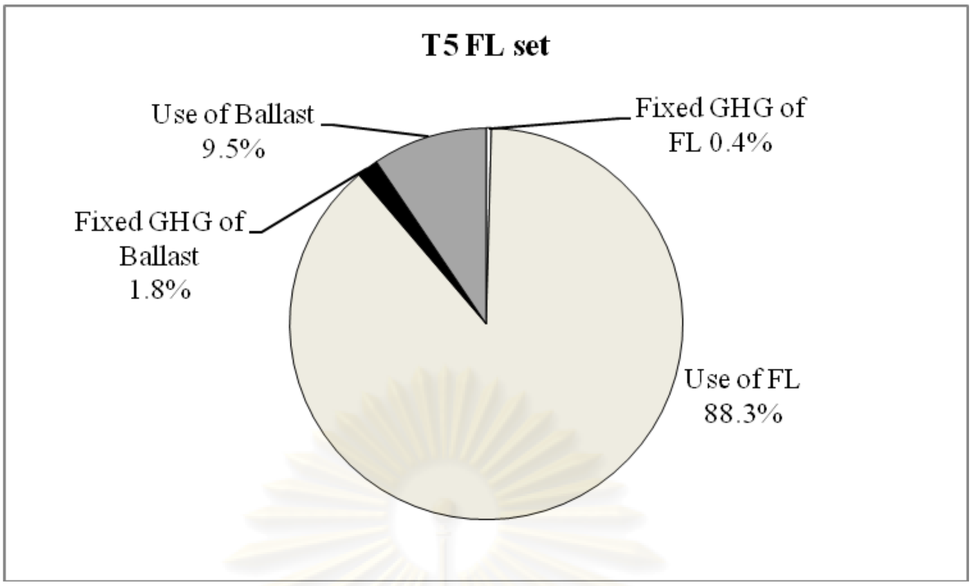

Figure 4-9 GHG emission through life cycle of 28WT5 and 14WT5

Not surprisingly, the hot spot is the usage stage of FL, which is typical for most electrical and electronic devices where the electricity consumed during the usage of such devices contributes most to the overall GHG emission. The best practice is therefore to redesign the FL and ballast to consume lesser power.

4.3.2 Case scenarios

Remark: In these case scenarios, GHG emissions from the cradle to gate and GHG during the end of life of the FL set products are assumed to occur once the product is purchased.

<u>**Case 1:** Making decision between T8 or T5 FL sets</u>

As the manufacture of T5 generates more GHG than T8, the selection of T5 means that more GHG has been emitted at the purchase. Figure 4-10 illustrates this GHG emissions from 36WT8 and 28WT5 at time = 0 whereas Figure 4-11 is for 18WT8 and 14WT5. As the products are operated, GHG is continually emitted according to the number of operating hours of the product, and this GHG is added to the initial GHG in the same figure until the end of life which occurs at 20,000 operating hours.

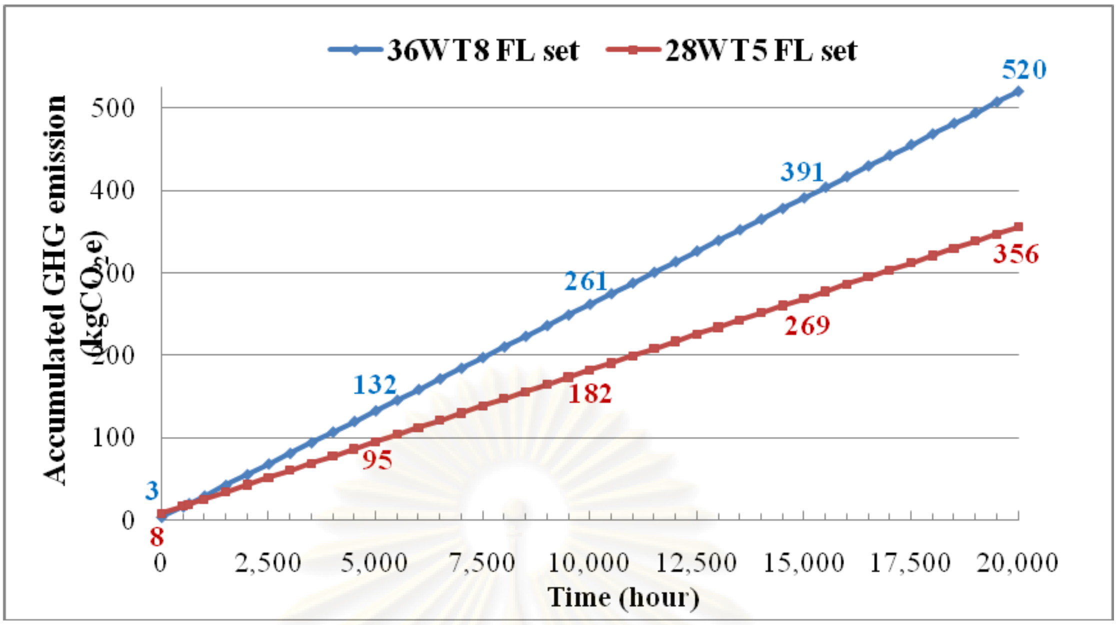

Figure 4-10 GHG emission of one 36WT8 and 28WT5 FL sets

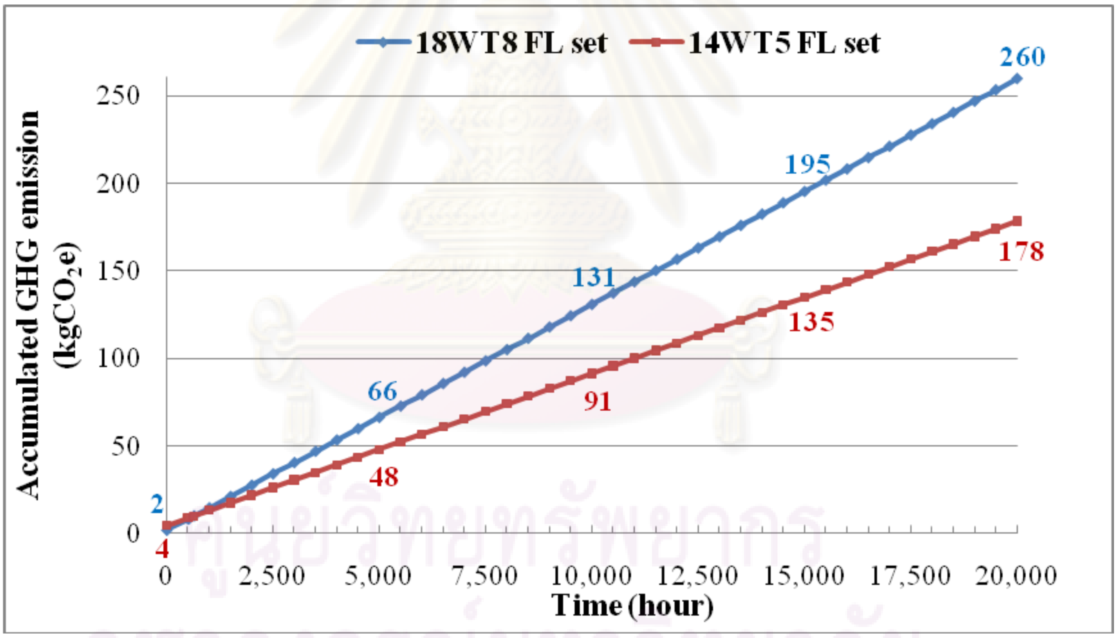

Figure 4-11 GHG emission of one 18WT8 and 14WT5 FL sets

Figure 4-10 reveals that the breakeven point which is the point where the accumulated GHG emissions from the two products meet (or both products have the same amount of GHG emission) is 520 hours (breakeven time). After this time, the 36WT8 FL set will accumulate higher level of GHG than the 28WT5 FL set. Similarly, Figure 4-11 shows that this breakeven point for the 18WT8 and 14WT5 occurs at 640 hours.

This evaluation shows that, in terms of GHG emission, consumers can change from T8 to the greener T5 counterpart as long as the lamp has a life time longer than this breakeven time. This scenario can reduce GHG emission up to 164 and 82 $kgCO_2e$ of 36WT8 and 28WT5 FL set and 18WT8 and 14WT5 FL set, respectively.

Case 2: Changing the new T8 FL set (unused) with T5 FL set

In this case, there is an urgent need to change from T8 to T5 and it is assumed that this change occurs straight after T8 is purchased (without being used or at t = 0). GHG emission from production of T8 FL set (fixed GHG from T8) already occurs at the beginning, t = 0, and this has to be added up with that of T5 FL set (fixed GHG from T5). During usage stage, GHG from T5 is continually emitted according to the number of operating hours of the product (operating GHG from T5). The breakpoint time is therefore the time required for this GHG emission (operating T5 + fixed GHG from T5 and T8) intersects with the GHG emission profile from T8 alone. Figures 4-12 and 4-13 show the amount of GHG emission from changing 36WT8 FL set to 28WT5 FL set and 18WT8 FL set to 14WT5 FL set for this specific case, respectively.

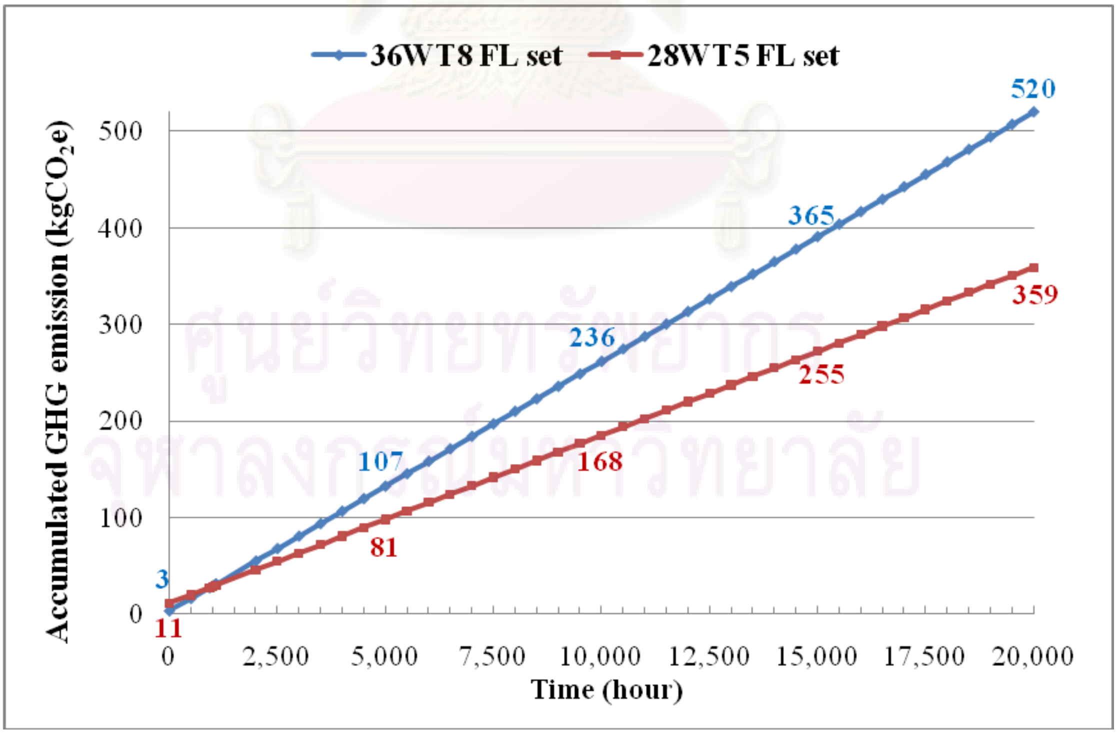

Figure 4-12 GHG emission from changing 36WT8 to 28WT5 FL set at 0 hour

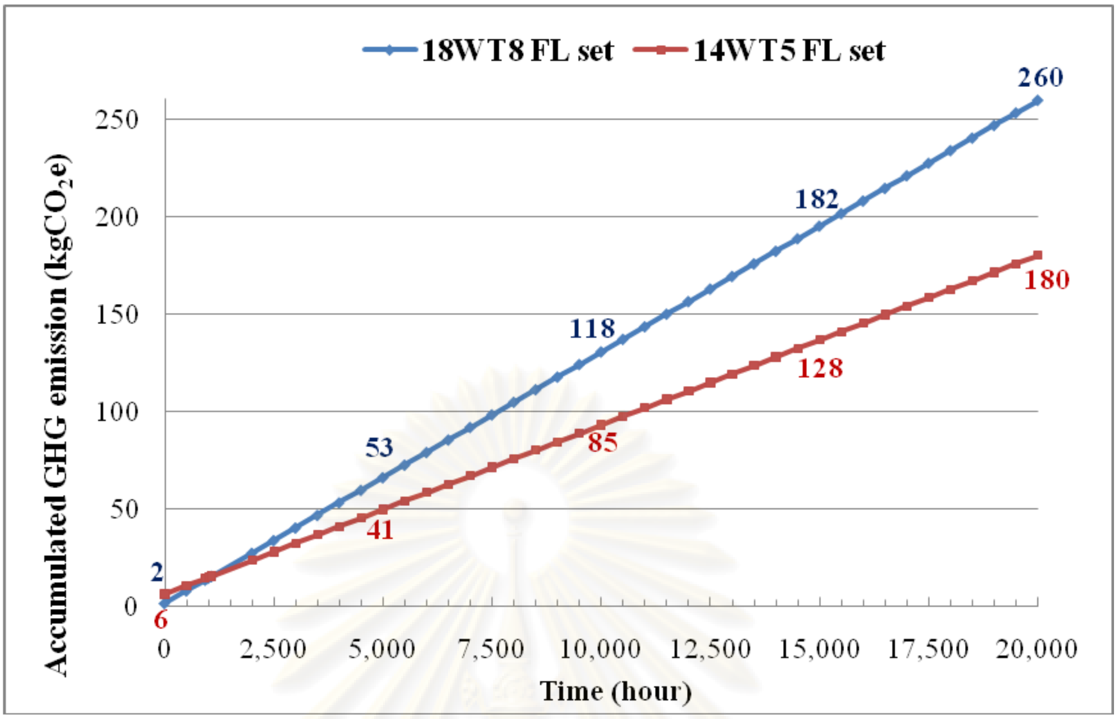

Figure 4-13 GHG emission from changing 18WT8 to 14WT5 FL set at 0 hour

Figure 4-16 demonstrates that the breakeven point is at 931 hours which is the time that GHG emission from the 28WT5 FL set, which is purchased to replace the 36WT8 FL set, is equal to the GHG emission from the use of 36WT8 FL set. After this time the 28WT5 FL set will accumulate lower quantity of GHG than that of 36WT8 FL set. And for the 20,000 hours life time of the lamp, this can help reduce GHG emission up to 161 $kgCO_2e$. Similarly, Figure 4-17 describes the time profile for GHG emission from the change of 18WT8 to 14WT5 FL set at 0 hour operation where the breakeven point occurs at 1,070 hours. For the whole life time of the lamp, this change will help reduce GHG emission up to 80 $kgCO_2e$.

Case 3: <u>Purchasing T5 FL to replace the unbroken T8 FL set</u>

This case is similar to Case 2, only the difference is that the change occurs at any time, t. Let's arbitrarily assume that this chance occurs at t = 2,000 hours. The summation of accumulated GHG emission will include the fixed GHG from the 36WT8 plus the operating GHG from the use of such lamp for 2,000 hours, and the fixed GHG (taken place at t = 2,000 hours) and the operating GHG from the 28WT5 FL for the rest of its life. The results are illustrated in Figure 4-14.

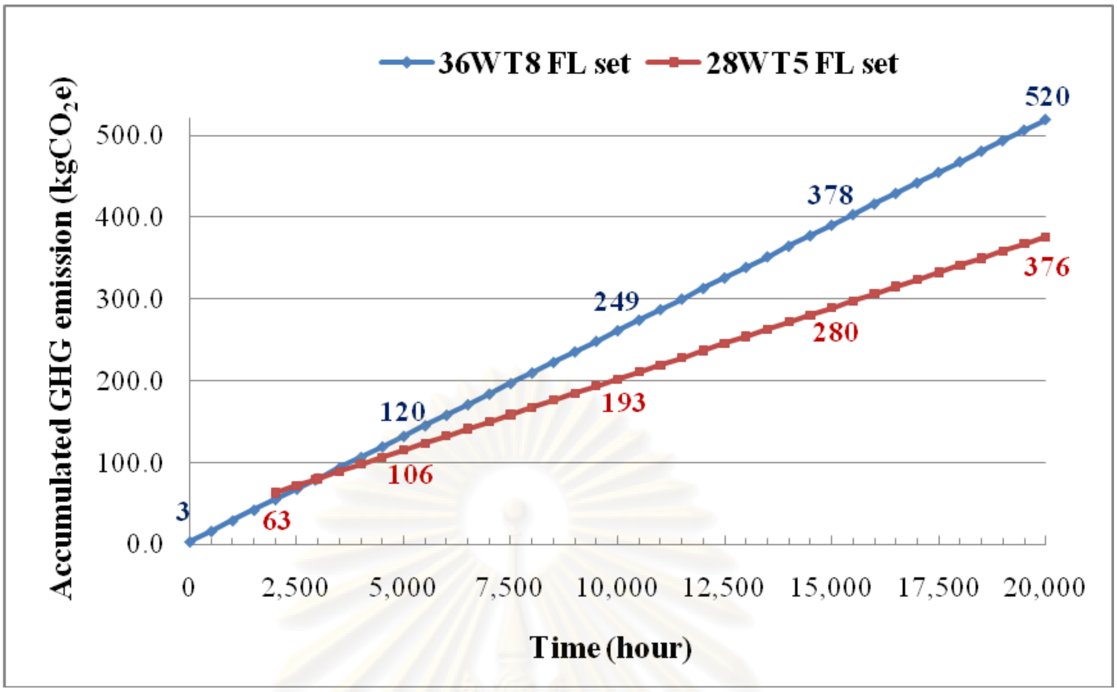

Figure 4-14 GHG emission from replacement T8 by T5 at 2,000 hours

Figure 4-14 reveals that the breakpoint time occurs at 2,931 hours which is 931 hours after the change of the lamp. It can be seen that the 28WT5 will always need 931 hours after the change of the lamp to breakeven with the GHG emission from the 36WT8. This effectively means that if the T8 only has life time less than 931 hours, the breakeven will never occur, and the change to T5 in this case should not be decided. This case reduces GHG emission up to 144 $kgCO_2e$.

Case 4: Selecting new 36WT8 FL or new 28WT5 FL set to replace the broken T8 FL

It is assumed here that the 36WT8 FL set has already expired and needs to be replaced by a new one. There are two choices as follows:

(i) Choose 36WT8 and use the same ballast (as the life time of ballast is longer than the lamp): Due to no change of ballast, GHG emission from this choice comes from the life cycle of new 36WT8 FL (no ballast) and the usage of FL set.

(ii) Choose 28WT5: the change of 36WT8 FL set to 28WT5 FL set requires that the ballast be changed. The accumulated GHG emission from this choice comes from the life cycle of new 28WT5 FL set (including ballast).

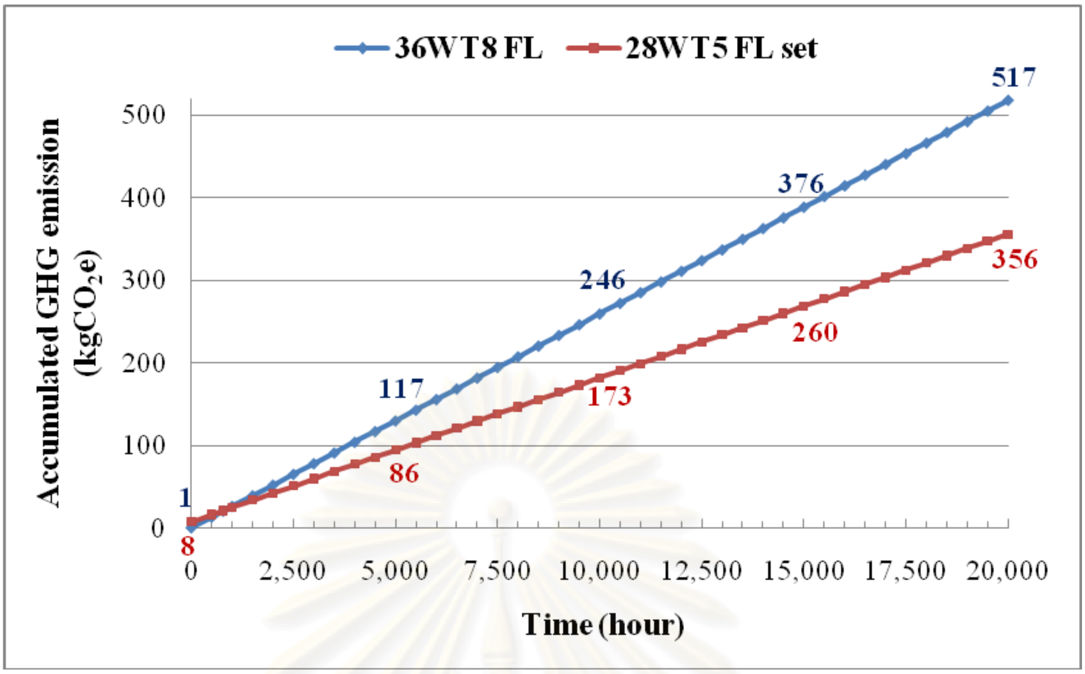

Figure 4-15 GHG emission from Case 4

Comparing the two choices, the breakeven point occurs at 780 hours which means the T5 will offset its high fixed GHG with its low operating GHG after 780 hours of operation. This case reduces GHG emission up to 161 $kgCO_2e$.

4.3.3 Economical consideration of T8 and T5 FL sets

The more recent T5 FL set is almost 50% more expensive than the T8 of the same class. This poses some concerns regarding the payback from the selection of a more expensive but more environmental friendly T5 product. The following analysis (Table 4-41) illustrates that the use of T5 also inherits the saving which occurs due to the lower power consumption during the usage period of the production.

Table 4-41 Cost-saving analysis of T8 and T5 FL sets

List	36WT8 FL set (A)	28WT5 FL set (B)	Saving (A - B)
Component of FL set	36WT5 FL + Starter + Magnetic ballast	28WT5 FL + Adaptor 1 set + Electronic ballast	
Costs per one FL set (baht)	150	230	- 80
Life time (hour)	20,000	20,000	
Power per FL set (kW)	0.046	0.031	0.015
Electricity rates (baht/kWh)*	2.978	2.978	
Electricity used in life time (kWh/one FL set)	920	620	300
Costs for electricity used in life time (baht/one FL set)	2,739.76	1,846.36	+ 893.4
Costs-saving (baht/one FL set)			**813.4**

Remark: *Reference from Metropolitan Electricity Authority

Table 4-41 demonstrates that, all through the life time of FL set, one can save up to 813.4 baht when the 36WT8 is replaced by the 28WT5. On the other hand, when compared the two products based on the same brightness, the final saving can be estimated as demonstrated in Table 4-42.

Table 4-42 Cost-saving analysis at the same functional unit

List	36WT8 FL set (A)	28WT5 FL set (B)	Saving (A - B)
Number of FL set	54	53	1
Costs for buying FL set	8,100	12,190	- 4,090
Time used per day (hour)	12	12	
Power per number of FL set (kW)	2.484	1.643	0.841
Electricity used (kWh/day)	29.808	19.716	10.092
Costs for electricity used per day (baht)	88.77	58.71	+ 30.05
Electricity used in life time (kWh)	49,680	32,860	16,820
Costs for electricity used in life time (baht)	147,947	97,857	+ 50,090
Costs-saving in life time (baht)			**46,000**

CHAPTER V

CONCLUSIONS

5.1 Conclusions

Greenhouse gases emission of 36WT8, 18WT8, 28WT5, 14WT5 fluorescent lamps, magnetic and electronic ballast have been investigated by LCA technique. The conclusions drawn from the results of this study are as follows:

- The production of one kilogram of glass (cradle to gate) releases 3.44 $kgCO_2e$. The main GHG emission source is the production process.

- GHG emissions from the production activity including raw material acquisition and processing, transportation of raw materials and manufacturing process of one 36WT8 and 18WT8 are equal to 1.13 and 0.67 $kgCO_2e$, respectively. The main GHG emission source is raw material acquisition stage. For one 28WT5 and 14WT5, GHG emissions are equal to 1.38 and 1.26 $kgCO_2e$, respectively. The main GHG emission source is the production process.

- The amounts of GHG emission through life cycle (with landfill option) of each fluorescent lamp are: 405 $kgCO_2e$/36WT8, 203 $kgCO_2e$/18WT8, 316 $kgCO_2e$/28WT5 and 158 $kgCO_2e$/14WT5. For all lamps, the main GHG emission source (99%) is from the usage stage. The recycle option could slightly bring the GHG emission down (0.15%) when compared with the landfill option.

- The amount of GHG emission from the production activity is one percent of GHG emission through life cycle of all fluorescent lamp.

- GHG emissions through life cycle of magnetic and electronic ballasts are equal to 114 and 40 $kgCO_2e$/ballast, respectively. The hot spot of the two types of ballast is the usage stage. Electronic ballast manufacturing releases GHG emission more than magnetic ballast, due to more complicates production.

- The amount of GHG emission through life cycle of T8 fluorescent lamp set higher than T5 fluorescent lamp set because the T8 FL sets consume more electricity than the T5. The hot spot is the usage stage.

- GHG emission from the production of T5 FL set is more than the production of T8 FL set because the production of T5 fluorescent and the electronic ballast used together with T5 FL require a complex production which emits a higher amount of GHG than that of T8.

- The contribution of the ballast to the overall GHG emission is about 12-22%.
- Selection of T5 to replace T8 fluorescent lamp set can help reduce GHG emission.

5.2 Contribution

This work provides a full detailed life cycle assessment of the common T8 fluorescent lamp compared with the new, more environmental benign, T5 lamp. The outcome of this work contributes greatly to the future set out of the national green campaign on the selection of lighting systems. To put it more simply, the findings suggest that the fixed impacts during the raw material acquisition, production process, transportation, disposal/recycle are relatively small (only 1% contribution) when compared with the operational impact obtained during the usage stage of the lamp product (another 99%). This virtually means that one can simply neglect the fixed impacts when considered the GHG emission from the use of fluorescent lamps. Besides, it only takes slightly less than 2,000 hours or 100 days for the T5 lamp to breakeven with the T8 in terms of GHG emission. This makes the replacement option of T8 by T5 remarkably attractive, and the results supports the recent governmental campaign on the use of T5 as a part of national energy saving policy. In addition, the future development of an even lower power lamp (with the same intensity) will definitely and greatly help reduce the greenhouse gases emission.

5.3 Suggestion for further studies

This work only focuses on one facet of the environmental impacts created from the use of fluorescent lamp. The fact that T5 has lower global warming potential than T8 does not necessarily mean that T5 will also have lesser impacts in other environmental categories. Estimates of other environmental impact categories all through the life cycle of fluorescent lamp set such as Ozone depletion; Acidification, Eutrophication, Photochemical Smog, Ecotoxicity, Human Toxicity, etc. should therefore be examined.

Nevertheless, based on the global warming impact, the improvement option for the fluorescent lamp should be on the redesign the new version of fluorescent lamp and ballast with lower electricity consumption as the usage stage is by far the major greenhouse gases emitting step.

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APPENDICES

APPENDIX A

ACTIVITY DATA OF GLASS MANUFACTURE

A.1 Glass product of glass production

Glass factory has two main products; SL-A and LF/SF44. Glass bulb used in lamp factory is SL-A glass. Table A-1 displays the amount of monthly glass production capacity.

Table A-1 Glass products

Month	SL-A glass	LF/SF44 glass	Total glass
	tons	tons	tons
Jan-09	1,550	530	2,080
Feb-09	1,500	510	2,010
Mar-09	1,870	570	2,440
Apr-09	2,930	520	3,450
May-09	2,960	640	3,600
Jun-09	2,980	500	3,480
Jul-09	3,030	600	3,630
Aug-09	2,850	1,060	3,910
Sep-09	2,660	1,030	3,690
Oct-09	2,770	1,030	3,800
Nov-09	2,570	1,010	3,580
Dec-09	2,870	1,040	3,910
Jan-10	2,930	810	3,740
Feb-10	2,670	670	3,340
Mar-10	3,150	980	4,130
Apr-10	3,230	930	4,160
May-10	3,220	720	3,940
Total	45,740	13,150	58,890

Remark:

1. “SL-A” and “LF/SF44” are the name of glass type produced in the factory.

2. The amount of total glass is used in calculation of energy consumption of glass production.

A.2 Raw material consumption

Table A-2 Raw material consumption of glass production

Month	Silica Sand	Cullet (SL-A)	Soda ash	Dolomite	Feldspar	Minor ingredients
	tons	tons	tons	tons	tons	tons
Jan-09	961	1,070	372	239	178	74
Feb-09	994	1,280	383	248	188	79
Mar-09	1,050	1,600	403	262	205	85
Apr-09	1,570	2,060	616	393	299	124
May-09	1,760	1,640	690	438	330	135
Jun-09	1,710	1,430	677	427	321	130
Jul-09	1,830	1,140	716	456	340	137
Aug-09	1,770	960	689	440	337	125
Sep-09	1,680	944	655	418	314	114
Oct-09	1,710	1,020	664	424	318	115
Nov-09	1,690	1,170	649	417	311	114
Dec-09	1,760	1,390	675	435	324	119
Jan-10	1,750	1,510	673	433	324	120
Feb-10	1,620	1,310	619	400	299	111
Mar-10	1,960	1,550	757	485	362	136
Apr-10	1,890	1,480	734	470	351	131
May-10	2,050	1,410	790	508	378	140
Total	27,755	22,964	10,762	6,893	5,179	1,985

Remark: Table A-2 shows the amount of raw materials used for only SL-A glass production. The cullet or glass recovery is the same glass type. Minor ingredients cannot be disclosed due to confidentiality reasons.

A.3 Energy consumption

Table A-3 Energy consumption of glass production

Month	Water supply	Electricity	Natural gas
	m^3	kWh	MMBTU
Jan-09	3,400	1,071,800	70,000
Feb-09	2,700	1,004,700	71,000
Mar-09	2,700	1,118,600	65,000
Apr-09	2,800	1,371,800	96,000
May-09	2,500	1,584,400	117,000
Jun-09	4,500	1,618,400	124,000
Jul-09	3,900	1,623,600	120,000
Aug-09	3,400	1,592,800	112,000
Sep-09	2,600	1,586,500	114,000
Oct-09	1,800	1,666,400	117,000
Nov-09	3,000	1,594,100	113,000
Dec-09	3,500	1,636,100	115,000
Jan-10	2,900	1,542,600	105,000
Feb-10	2,800	1,469,400	100,000
Mar-10	3,100	1,662,900	110,000
Apr-10	3,100	1,580,600	109,000
May-10	2,500	1,468,500	91,000
Total	51,200	25,193,200	1,749,000

Remark: 50% of water supply is used in cooling system in glass manufacturing process.

A.4 Packaging

Glass factory uses carton boxes as packaging of glass bulb. The amount of carton boxes used per one kg glass produced equals 0.069 kg/kg glass, the detail of data is shown in Table A-4.

Table A-4 Packaging data for one kg glass product

Glass bulb	Weight of glass bulb (kg)	Weight of carton (kg)	Glass bulb per carton (piece)	Weight of carton per kg glass (kg)
36WT8	0.175	1.35	92	0.084
18WT8	0.091	0.53	120	0.049
28WT5	0.107	1.11	120	0.086
14WT5	0.051	0.63	215	0.058
Average (kg)				0.069

A.5 Waste generation

Glass manufacturing process generates four types of solid wastes and wastewater, details illustrated in Table A-5.

Table A-5 Waste from glass production

Month	Garbage	Lumber	Rag and glove	Other solid waste	Wastewater
	kg	kg	kg	kg	kg
Jan-09	2,620	655	1,300	6,475	9,000
Feb-09	3,088	772	650	4,040	-
Mar-09	1,972	493	700	2,615	-
Apr-09	2,928	732	600	3,820	8,500
May-09	3,472	868	650	4,530	-
Jun-09	3,992	998	690	5,150	-
Jul-09	4,184	1,046	540	5,380	-
Aug-09	3,116	779	630	4,075	11,000
Sep-09	2,216	554	650	2,990	-
Oct-09	3,556	889	830	4,595	-
Nov-09	1,944	486	640	2,610	9,000
Dec-09	2,084	521	670	22,855	-
Jan-10	2,564	641	1,300	23,825	9,000
Feb-10	2,624	656	650	4,560	-
Mar-10	2,768	692	700	4,820	-
Apr-10	2,760	690	600	4,420	8,500
May-10	2,780	695	650	4,655	-
Total	48,668	12,167	12,450	84,477	155,833

Remark: The total of wastewater of 155,833 kg comes from the sum of the monthly average quantity of wastewater in six months period of data collection.

A.6 Input and output per one kg glass production

Raw material, energy consumption and waste generated from one kilogram of SL-A glass is displayed in Table A-6. The calculation is shown in the remark under the table.

Table A-6 Raw material and energy used and waste generated from one kg SL-A glass production

Month	Silica Sand	Cullet (SL-A)	Soda ash	Dolomite	Feldspar	Minor ingredients	Water supply	Electricity	Natural gas	Garbage	Lumber	Rag and glove	Other solid waste	Wastewater
	kg	kg	kg	kg	kg	kg	10^{-4} m^3	kWh	MJ	10^{-4} kg	10^{-4} kg	10^{-4} kg	10^{-4} kg	10^{-3} kg
Jan-09	0.620	0.690	0.240	0.154	0.115	0.047	8.17	0.515	35.50	12.6	3.15	6.25	31.1	4.33
Feb-09	0.663	0.853	0.255	0.165	0.125	0.052	6.72	0.500	37.27	15.4	3.84	3.23	20.1	-
Mar-09	0.561	0.856	0.216	0.140	0.110	0.045	5.53	0.458	28.10	8.08	2.02	2.87	10.7	-
Apr-09	0.536	0.703	0.210	0.134	0.102	0.042	4.06	0.398	29.36	8.49	2.12	1.74	11.1	2.46
May-09	0.595	0.554	0.233	0.148	0.111	0.045	3.47	0.440	34.29	9.64	2.41	1.81	12.6	-
Jun-09	0.574	0.480	0.227	0.143	0.108	0.044	6.47	0.465	37.59	11.5	2.87	1.98	14.8	-
Jul-09	0.604	0.376	0.236	0.150	0.112	0.045	5.37	0.447	34.88	11.5	2.88	1.49	14.8	-
Aug-09	0.621	0.337	0.242	0.154	0.118	0.044	4.35	0.407	30.22	7.97	1.99	1.61	10.4	2.81
Sep-09	0.632	0.355	0.246	0.157	0.118	0.043	3.52	0.430	32.59	6.01	1.50	1.76	8.10	-
Oct-09	0.617	0.368	0.240	0.153	0.115	0.041	2.37	0.439	32.48	9.36	2.34	2.18	12.1	-
Nov-09	0.658	0.455	0.253	0.162	0.121	0.044	4.19	0.445	33.30	5.43	1.36	1.79	7.29	2.51
Dec-09	0.613	0.484	0.235	0.152	0.113	0.042	4.48	0.418	31.03	5.33	1.33	1.71	58.5	-
Jan-10	0.597	0.515	0.230	0.148	0.111	0.041	3.88	0.412	29.62	6.86	1.71	3.48	63.7	2.41
Feb-10	0.607	0.491	0.232	0.150	0.112	0.042	4.19	0.440	31.59	7.86	1.96	1.95	13.7	-
Mar-10	0.622	0.492	0.240	0.154	0.115	0.043	3.75	0.403	28.10	6.70	1.68	1.69	11.7	-
Apr-10	0.585	0.458	0.227	0.146	0.109	0.040	3.73	0.380	27.64	6.63	1.66	1.44	10.6	2.04
May-10	0.637	0.438	0.245	0.158	0.117	0.043	3.17	0.373	24.37	7.06	1.76	1.65	11.8	-
Average	0.607	0.502	0.235	0.151	0.113	0.043	4.35	0.428	31.33	8.26	2.07	2.11	14.3	2.65

Remark: Six raw materials used per one kg glass production equal the amount of raw material divided by the amount of SL-A glass product. Other energy used and waste generated per one kg glass production equal the amount of energy and waste divided by the total glass products.

APPENDIX B

ACTIVITY DATA OF FLUORESCENT LAMP MANUFACTURE

B.1 Main process

B.1.1. Inert gas: Table B-1 displays the pressure argon in each FL type.

Table B-1 Pressure argon in fluorescent lamps

FL type	Pressure Argon (Unit)	Argon type
36WT8	0.90-1.3 (mm. Hg)	Ar.25% + Kr.75%
18WT8	0.90-1.3 (mm. Hg)	Ar.50% + Kr.50%
28WT5	40-45 (mm. Oil)	Argon high purity 99.99%
14WT5	35-40 (mm. Oil)	Argon high purity 99.99%

This research uses the highest value of pressure argon (worse cases) in calculating argon and krypton gases in each FL. The details for calculation are shown in Table B-2. The example of gas calculation is given below.

For 36WT8:

Pressure argon = 1.3 mm. Hg, Diameter of lamp = 0.026 m,

Length of lamp = 1.264 m, Room temperature = 25 °C,

MW of argon gas = 39.95 g/mole, MW of krypton gas = 499.58 g/mole,

Ideal gas constant (R) = 0.0821 atm.L.mol^{-1}K^{-1}

According to the ideal gas law: PV = nRT

$$\text{Volume (V)} = \pi r^2 h = \pi\left(\frac{0.026\ \text{m}}{2}\right)^2 \text{x } 1.264\ \text{m} = 6.71 \text{ x } 10^{-4}\ \text{m}^3 = 0.671\ \text{L}$$

$$\text{Pressure (P)} = \frac{1.3\ \text{mm. Hg}}{760\ \frac{\text{mm.Hg}}{\text{atm}}} = 1.71 \text{ x } 10^{-3} \text{atm}$$

Therefore $$n = \frac{PV}{RT} = \frac{(1.71 \text{ x } 10^{-3}\ \text{atm}) \text{ x } (0.671\ \text{L})}{\left(0.0821\ \frac{\text{atm.L}}{\text{mole.K}}\right) \text{ x } (25+273)\text{K}} = 4.69 \text{ x } 10^{-5}\ \text{mole}$$

From Table B-1, the ratio of the two gases is Ar. 25% and Kr. 75%.

$$\therefore \text{Mole Argon} = 4.69 \text{ x } 10^{-5} \text{ x } 0.25 = 1.17 \text{ x } 10^{-5}\ \text{mole}$$

$$\therefore \text{Mole Krypton} = 4.69 \text{ x } 10^{-5} \text{ x } 0.75 = 3.52 \text{ x } 10^{-5}\ \text{mole}$$

$$\text{Argon gas} = 1.17\text{x } 10^{-5}\ \text{mole x } 39.95 \frac{\text{g}}{\text{mole}} = 4.69 \text{ x } 10^{-4}\text{g} = 4.69 \text{ x } 10^{-7}\ \text{kg}$$

$$\text{Krypton gas} = 3.52 \times 10^{-5} \text{ mole} \times 499.58 \frac{\text{g}}{\text{mole}} = 1.76 \times 10^{-2} \text{g} = 1.76 \times 10^{-5} \text{ kg}$$

The calculation for 18WT8 is similar to that of 36WT8 but different from T5 because the pressure in T5 is reported in mm Oil unit. The example of gas calculation for T5 is as follows:

For 28WT5:

Pressure argon = 45 mm. Hg, Diameter of lamp = 0.016 m,

Length of lamp = 1.14 m, Room temperature = 25 °C,

MW of argon gas = 39.95 g/mole, R = 0.0821 atm.L.mol^{-1}K^{-1}

Calculation equation is PV = nRT

$$\text{Volume (V)} = \pi r^2 h = \pi\left(\frac{0.016 \text{ m}}{2}\right)^2 \times 1.14 \text{ m} = 2.29 \times 10^{-4} \text{ m}^3 = 0.229 \text{ L}$$

Conversion factor: 1 atm = 11,750 mm. Oil

$$\text{Pressure (P)} = \frac{45 \text{ mm. Oil}}{11{,}750 \frac{\text{mm.Oil}}{\text{atm}}} = 3.83 \times 10^{-3} \text{atm}$$

Therefore

$$n = \frac{PV}{RT} = \frac{(3.83 \times 10^{-3} \text{ atm}) \times (0.229 \text{ L})}{\left(0.0821 \frac{\text{atm.L}}{\text{mole.K}}\right) \times (25+273)\text{K}} = 3.59 \times 10^{-5} \text{ mole}$$

From Table B-1, the filling gas is pure argon:

$\therefore$ Mole Argon $= 3.59 \times 10^{-5}$ mole

$$\text{Argon gas} = 3.59 \times 10^{-5} \text{ mole} \times 39.95 \frac{\text{g}}{\text{mole}} = 1.43 \times 10^{-3} \text{g} = 1.43 \times 10^{-6} \text{ kg}$$

Table B-2 Argon and krypton gases in FL (calculated values)

FL type	Pressure Argon	Diameter lamp (m)	Length of lamp (m)	Volume of lamp (Liter)	Pressure (atm)	Temp. (K)	Total of moles (mole)	Mole of argon (mole)	Mole of krypton (mole)	Argon gas (kg)	Krypton gas (kg)
36WT8	1.3 mm. Hg	0.026	1.264	0.671	1.71E-03	298	4.69E-05	1.17E-05	3.52E-05	4.69E-07	1.76E-05
18WT8	1.3 mm. Hg	0.026	0.654	0.347	1.71E-03	298	2.43E-05	1.21E-05	1.21E-05	4.85E-07	6.06E-06
28WT5	45 mm. Oil	0.016	1.14	0.229	3.83E-03	298	3.59E-05	3.59E-05	-	1.43E-06	-
14WT5	40 mm. Oil	0.016	0.54	0.109	3.40E-03	298	1.51E-05	1.51E-05	-	6.04E-07	-

B.1.2 Glass bulb: The amount of glass bulb used per one FL is estimated from the number of glass bulb coated divided by the number of good lamp produced. The monthly data of 36WT8 and 18WT8 are shown in Table B-3, whereas those of 28WT5 and 14WT5 are shown in Table B-4.

Table B-3 Glass bulb data for 36WT8 and 18WT8

Month	**36WT8**			**18WT8**		
	Good lamp (lamp)	**Glass bulb coated (bulb)**	**Glass tube/ good lamp**	**Good lamp (lamp)**	**Glass bulb coated (bulb)**	**Glass tube/good lamp**
Jan-09	105,246	118,647	1.13	31,833	38,831	1.22
Feb-09	101,532	113,577	1.12	-	-	-
Mar-09	20,861	24,441	1.17	57,696	67,660	1.17
Apr-09	9,707	13,697	1.41	12,528	15,643	1.25
May-09	25,779	35,113	1.36	5,441	6,556	1.20
Jun-09	96,829	116,927	1.21	44,360	51,013	1.15
Jul-09	88,625	110,601	1.25	59,948	64,758	1.08
Aug-09	66,667	76,562	1.15	7,997	9,060	1.13
Sep-09	41,072	47,724	1.16	61,150	65,682	1.07
Oct-09	10,233	12,181	1.19	25,953	29,913	1.15
Nov-09	40,102	45,749	1.14	74,825	83,058	1.11
Dec-09	68,978	81,234	1.18	87,786	95,879	1.09
Jan-10	16,805	19,551	1.16	16,554	17,686	1.07
Feb-10	27,123	30,460	1.12	39,203	42,314	1.08
Mar-10	41,952	45,650	1.09	17,100	18,785	1.10
Apr-10	41,717	47,214	1.13	7,005	7,681	1.10
May-10	66,741	73,805	1.11	56,368	60,203	1.07
Total	869,969	1,013,133	1.165	605,747	674,722	1.114

Table B-4 Glass bulb data for 28WT5 and 14WT5

Month	28WT5			14WT5		
	Good lamp (lamp)	Glass bulb coated (bulb)	Glass bulb /good lamp	Good lamp (lamp)	Glass bulb coated (bulb)	Glass bulb/ good lamp
Jan-09	8,328	12,734	1.53	636	852	1.34
Feb-09	13,061	19,575	1.50	516	1,147	2.22
Mar-09	9,974	18,352	1.84	971	1,455	1.50
Apr-09	4,955	6,741	1.36	484	1,074	2.22
May-09	24,069	41,823	1.74	1,460	2,071	1.42
Jun-09	42,432	62,923	1.48	1,825	3,292	1.80
Jul-09	59,602	79,237	1.33	1,077	1,295	1.20
Aug-09	53,845	68,055	1.26	1,015	1,186	1.17
Sep-09	15,364	18,771	1.22	-	-	-
Oct-09	1,387	2,815	2.03	175	210	1.20
Nov-09	3,809	5,390	1.42	990	1,600	1.62
Dec-09	60	74	1.23	-	-	-
Jan-10	16,999	24,884	1.46	2,950	6,673	2.26
Feb-10	12,343	19,852	1.61	3,705	5,516	1.49
Mar-10	68,863	89,599	1.30	5,896	6,663	1.13
Apr-10	32,400	36,155	1.12	4,762	5,468	1.15
May-10	6,048	7,335	1.21	-	-	-
Total	373,539	514,315	1.377	26,462	38,502	1.455

The amount of glass bulb used per one FL in Tables B-3 and B-4 can be converted to weight of glass bulb and the results are given in Table B-5.

Table B-5 Weight of glass bulb per one FL

FL type	Glass bulb used per one FL (bulb)	Weight per glass bulb (kg)	Weight of glass per one FL (kg)
36WT8	1.165	0.1750	0.2038
18WT8	1.114	0.0843	0.0939
28WT5	1.377	0.1070	0.1473
14WT5	1.455	0.0507	0.0737

B.1.3 Mercury and Zinc: Liquid mercury filled in T8 FL is equal to 10 mg or 1.0E-05 kg. Meanwhile, T5 FL fills two mercury beads, each at 7.4 mg of 49.36% mercury and 50.35% zinc. Therefore the amount of mercury and zinc filled in T5 FL are equal to 7.305 and 7.452 mg respectively (see Table B-6).

Table B-6 Mercury and Zinc data in FL

FL type	Mercury type	Quantity filled per FL	Total weight of substance (mg)	Amount of Mercury (kg)	Amount of Zinc (kg)
T8	Pure liquid	10 mg	10	1.00E-05	0
T5	Bead	2 bead	14.8	7.31E-06	7.45E-06

B.1.4 Electricity: Main process uses electricity in three activities, i.e. operating the machine, washing and coating lamp and lighting system.

- "Operating machine" electricity is the overall electricity used for all machines in each production line of lamp factory. L1 produces 36WT8 and 18WT8, L4 produces only 18WT8, L5 produces only 36WT8, and L7 produces both T5 FLs. Each production line requires different machine powers; L1 (45.54 kW), L4 (45.16 kW), L5 (46.39 kW) and L7 (75.29 kW). Working hours and the number of good lamps are summarized in Table B-7. The calculation data of electricity used per one FL production is shown in Table B-8.

- Washing and coating lamp: This process is separated from the production line and used to prepare the glass tube before fed into main line, so that the electricity used is separated from main line. Each FL has different powers of washing and coating machines; 36WT8 (9.33 kW), 18WT8 (12.31 kW) and T5 (11.24 kW). These machines work 9.33 hours per day, where the amount of working days and the number of glass tubes coated are summarized in Table B-9. The calculation data of electricity used washing and coating per one FL is shown in Table B-10.

- Lighting system: Lamp industry predicts the percentage of electricity used for lighting system at 5% of the total electricity consumption. This research allocates electricity based on the production capacity of each FL (by weight). Table B-11 shows the electricity consumptions, the numbers of good lamps produced, and the calculated value of electricity in lighting system per one FL.

Table B-7 Working hours and the number of good lamps

Month	36WT8		18WT8		28WT5		14WT5	
	Good lamp	Working (hour)	Good lamp	Working (hour)	Good lamp	Working (hour)	Good lamp	Working (hour)
Jan-09	105,246	132	25,567	46	8,328	36	636	4
Feb-09	88,217	122	-	-	13,061	58	516	6
Mar-09	13,540	17	52,865	77	9,974	62	971	4
Apr-09	9,707	24	11,804	17	4,955	35	484	8
May-09	23,755	62	6,131	16	24,180	136	1,460	16
Jun-09	86,383	134	40,919	52	42,432	154	1,825	12
Jul-09	88,625	153	58,960	62	59,602	160	1,077	8
Aug-09	63,941	83	4,824	5	53,845	160	1,015	6
Sep-09	29,426	44	55,988	64	14,661	40	-	-
Oct-09	4,265	6	22,337	26	1,076	8	175	8
Nov-09	37,466	50	72,770	86	3,850	21	990	16
Dec-09	64,969	89	76,400	85	60	3	-	-
Jan-10	12,182	25	14,574	16	16,999	52	2,950	7
Feb-10	22,944	36	38,116	44	12,343	37	3,705	13
Mar-10	35,952	44	14,550	19	68,863	177	5,896	21
Apr-10	39,678	61	7,005	8	32,400	85	4,762	14
May-10	63,290	72	56,368	48	6,048	40	-	-
Total	789,586	1,153	559,178	673	372,677	1,264	26,462	144

Table B-8 Electricity used per one FL production

FL type	Data type	L1	L4	L5	L7	Total
	Total power of machine (kW)	45.54	45.16	46.39	75.29	
36WT8	Good lamp	7,600	-	781,986	-	789,586
	Working (hour)	18	-	1,135	-	1,153
	Electricity (kWh)	820	-	52,642	-	53,462
	Electricity per one FL (kWh/FL)	0.108	-	0.067	-	0.068
18WT8	Good lamp	26,381	532,797	-	-	559,178
	Working (hour)	55	618	-	-	673
	Electricity (kWh)	2,491	27,898	-	-	30,388
	Electricity per one FL (kWh/FL)	0.094	0.052	-	-	0.054
28WT5	Good lamp	-	-	-	372,677	372,677
	Working (hour)	-	-	-	1,264	1,264
	Electricity (kWh)	-	-	-	95,166	95,166
	Electricity per one FL (kWh/FL)	-	-	-	0.255	0.255
14WT5	Good lamp	-	-	-	26,462	26,462
	Working (hour)	-	-	-	144	144
	Electricity (kWh)	-	-	-	10,817	10,817
	Electricity per one FL (kWh/FL)	-	-	-	0.409	0.409

Table B-9 Number of days and glass bulb coated of each FL

Month	36WT8		18WT8		28WT5		14WT5	
	Glass bulb coated	Days	Glass bulb coated	Days	Glass bulb coated	Days	Glass bulb coated	Days
Jan-09	115,668	17	30,458	6	9,069	4	-	-
Feb-09	97,887	17	-	-	13,962	6	-	-
Mar-09	15,680	3	60,493	9	11,561	7	-	-
Apr-09	12,329	3	12,730	2	6,019	5	-	-
May-09	29,353	9	7,121	2	25,357	18	-	-
Jun-09	100,939	20	43,111	7	46,733	19	-	-
Jul-09	104,837	18	62,634	7	64,679	20	-	-
Aug-09	70,871	11	7,116	2	56,614	19	-	-
Sep-09	33,187	9	58,858	8	16,082	5	-	-
Oct-09	4,652	2	24,149	4	-	-	-	-
Nov-09	41,312	7	77,636	10	1,288	1	1,515	2
Dec-09	73,920	14	81,413	11	-	-	-	-
Jan-10	14,024	4	15,428	2	17,383	6	3,330	2
Feb-10	25,557	6	40,704	5	-	-	593	1
Mar-10	38,827	7	15,900	3	72,078	19	1,286	1
Apr-10	44,516	8	7,600	1	27,446	9	4,824	2
May-10	69,581	11	59,984	6	7,008	4	-	-
Total	893,140	166	605,335	85	375,279	142	11,548	8

Table B-10 Electricity used washing and coating per one FL

Data	Unit	36WT8	18WT8	28WT5	14WT5
Working hour	hr/day	9.33	9.33	9.33	9.33
Working day	day	166	85	142	8
Power machine	kW	9.33	12.31	11.24	11.24
Glass bulb coated	bulb	893,140	605,335	375,279	11,548
Electricity	kWh	14,447	9,765	14,894	839
Electricity per FL	kWh/FL	1.62E-02	1.61E-02	3.97E-02	7.27E-02

Table B-11 Electricity for lighting system per one FL

Month	Good lamp	Electricity (kWh)	Electricity for lighting system (kWh)	Electricity per one FL (kWh)
Jan-09	714,029	161,000	8,050	1.13E-02
Feb-09	569,747	163,000	8,150	1.43E-02
Mar-09	628,634	180,000	9,000	1.43E-02
Apr-09	473,982	128,000	6,400	1.35E-02
May-09	584,211	171,000	8,550	1.46E-02
Jun-09	686,727	169,000	8,450	1.23E-02
Jul-09	659,551	175,000	8,750	1.33E-02
Aug-09	655,240	172,000	8,600	1.31E-02
Sep-09	668,034	152,000	7,600	1.14E-02
Oct-09	776,431	162,000	8,100	1.04E-02
Nov-09	687,753	157,000	7,850	1.14E-02
Dec-09	547,723	130,000	6,500	1.19E-02
Jan-10	625,817	139,000	6,950	1.11E-02
Feb-10	742,616	160,000	8,000	1.08E-02
Mar-10	676,034	170,000	8,500	1.26E-02
Apr-10	473,504	117,000	5,850	1.24E-02
May-10	655,488	159,000	7,950	1.21E-02
Total	10,825,521	2,665,000	133,250	1.23E-02

B.1.5 Water supply: Main line production process uses water supply for washing the glass bulb and cooling system. Water will be allocated according to the fraction of each FL product. This fraction of each FL type is given in Table B-12 whereas the estimate amount of water used per one FL is shown in Table B-13.

B.1.6 LPG: Baking and exhausting machines are the main LPG consumers. The amount of LPG used per one FL is given by the lamp factory: 0.0576 kg for one 36WT8, 0.0496 kg for 18WT8 and 0.1461 kg for 28WT5 and 14WT5.

Table B-12 Monthly production capacities of four types of FL in the selected lamp factory

Month	All FL (lamp)	36WT8 (lamp)	18WT8 (lamp)	28WT5 (lamp)	14WT5 (lamp)	%36WT8	%18WT8	%28WT5	%14WT5
Jan-09	714,029	107,456	36,471	9,306	681	15.05	5.11	1.30	0.10
Feb-09	569,747	102,904	5,749	13,463	517	18.06	1.01	2.36	0.09
Mar-09	628,634	28,618	64,637	10,464	1,042	4.55	10.28	1.66	0.17
Apr-09	473,982	10,164	13,211	5,182	634	2.14	2.79	1.09	0.13
May-09	584,211	31,211	6,443	24,644	1,487	5.34	1.10	4.22	0.25
Jun-09	686,727	98,956	54,839	43,042	1,903	14.41	7.99	6.27	0.28
Jul-09	659,551	90,408	60,365	60,159	1,089	13.71	9.15	9.12	0.17
Aug-09	655,240	67,595	10,518	54,126	1,030	10.32	1.61	8.26	0.16
Sep-09	668,034	41,429	61,023	15,506	-	6.20	9.13	2.32	0.00
Oct-09	776,431	15,664	26,345	1,480	170	2.02	3.39	0.19	0.02
Nov-09	687,753	44,458	76,194	3,884	1,014	6.46	11.08	0.56	0.15
Dec-09	547,723	71,390	88,825	67	-	13.03	16.22	0.01	0.00
Jan-10	625,817	17,423	6,338	17,158	2,957	2.78	1.01	2.74	0.47
Feb-10	742,616	29,330	39,448	12,473	3,777	3.95	5.31	1.68	0.51
Mar-10	676,034	47,689	17,135	70,010	5,902	7.05	2.53	10.36	0.87
Apr-10	473,504	42,017	7,014	32,896	4,832	8.87	1.48	6.95	1.02
May-10	655,488	67,413	56,646	7,304	2,411	10.28	8.64	1.11	0.37
Total	10,825,521	914,125	631,201	381,164	29,446	8.44	5.83	3.52	0.27

Table B-13 Water used per one FL

Month	All water supply (m^3)	Water used for				Water used per one FL			
		36WT8 (m^3)	18WT8 (m^3)	28WT5 (m^3)	14WT5 (m^3)	36WT8 (m^3/FL)	18WT8 (m^3/FL)	28WT5 (m^3/FL)	14WT5 (m^3/FL)
Jan-09	1,151	173.22	58.79	15.00	1.10	1.61E-03	1.61E-03	1.61E-03	1.61E-03
Feb-09	1,048	189.28	10.57	24.76	0.95	1.84E-03	1.84E-03	1.84E-03	1.84E-03
Mar-09	1,131	51.49	116.29	18.83	1.87	1.80E-03	1.80E-03	1.80E-03	1.80E-03
Apr-09	690	14.80	19.23	7.54	0.92	1.46E-03	1.46E-03	1.46E-03	1.46E-03
May-09	952	50.86	10.50	40.16	2.42	1.63E-03	1.63E-03	1.63E-03	1.63E-03
Jun-09	1,065	153.46	85.05	66.75	2.95	1.55E-03	1.55E-03	1.55E-03	1.55E-03
Jul-09	1,024	140.36	93.72	93.40	1.69	1.55E-03	1.55E-03	1.55E-03	1.55E-03
Aug-09	1,036	106.87	16.63	85.58	1.63	1.58E-03	1.58E-03	1.58E-03	1.58E-03
Sep-09	1,043	64.68	95.28	24.21	-	1.56E-03	1.56E-03	1.56E-03	-
Oct-09	1,100	22.19	37.32	2.10	0.24	1.42E-03	1.42E-03	1.42E-03	1.42E-03
Nov-09	1,057	68.33	117.10	5.97	1.56	1.54E-03	1.54E-03	1.54E-03	1.54E-03
Dec-09	672	87.59	108.98	0.08	-	1.23E-03	1.23E-03	1.23E-03	-
Jan-10	942	26.23	9.54	25.83	4.45	1.51E-03	1.51E-03	1.51E-03	1.51E-03
Feb-10	986	38.94	52.38	16.56	5.01	1.33E-03	1.33E-03	1.33E-03	1.33E-03
Mar-10	1,061	74.85	26.89	109.88	9.26	1.57E-03	1.57E-03	1.57E-03	1.57E-03
Apr-10	779	69.13	11.54	54.12	7.95	1.65E-03	1.65E-03	1.65E-03	1.65E-03
May-10	970	99.76	83.83	10.81	3.57	1.48E-03	1.48E-03	1.48E-03	1.48E-03
Total	16707	1432	954	602	46	1.57E-03	1.51E-03	1.58E-03	1.55E-03

B.2 Cement mixing

B.2.1 Aluminum and copper: The main components of base cap are aluminum and copper. The estimate of the amount of aluminum and copper used per one FL requires that the number of base cap used per one FL be calculated. Table B-14 shows the base cap data of 36WT8, 18WT8, 28WT5 and 14WT5.

- The weight of one base cap for T8 = 1.63 gram (50.92% aluminum, 31.04% copper and 18.04% other)

- The weight of one base cap for T5 = 1.08 gram (34.44% aluminum, 43.06% copper and 22.51% other)

The amounts of aluminum and copper used per FL are calculated and displayed in Table B-15.

B.2.2 Capping cement and Methanol: Each base cap is filled with the capping cement that contains the mixture of 92.66% capping cement powder and 7.34% methanol.

- T8 base cap is filled with 1.3 gram of capping cement

- T5 base cap is filled with 0.4 gram of capping cement

Quantities of capping cement powder and methanol used per one FL are calculated and present in Table B-16. Capping cement powder is the mixture of 11.8%wt. Phenolic resin blend and 88.2%wt. Mineral fillers. Table B-17 displays the amount of such components used per one FL.

B.2.3 Electricity for cement mixing machine: The mixing machine has a capacity of 27 kg cement per batch. The mixing time for one batch is one hour and five minutes, and this requires the motor power of 0.37 kW. Therefore;

Electricity used for a once time mixing = 0.37 kW x 1.083 hour
= 0.401 kWh

Electricity used for mixing one kg cement = 0.401/27 = 0.015 kWh/kg cement

Table B-18 shows the calculation data for calculate electricity used mixing cement per one FL.

Table B-14 Base cap data of each FL

Month	36WT8			18WT8			28WT5			14WT5		
	Good lamp	Base cap (Piece)	Base cap/ good lamp	Good lamp	Base cap (Piece)	Base cap/ good lamp	Good lamp	Base cap (Piece)	Base cap/ good lamp	Good lamp	Base cap (Piece)	Base cap/ good lamp
Jan-09	105,246	219,496	2.09	26,079	72,000	2.76	2,732	15,586	5.71	636	4,414	6.94
Feb-09	85,955	202,838	2.36	-	-	-	975	10,000	10.26	-	-	-
Mar-09	20,861	44,000	2.11	53,676	88,400	1.65	300	3,797	12.66	-	-	-
Apr-09	4,962	28,000	5.64	12,528	24,000	1.92	2,438	26,300	10.79	-	-	-
May-09	16,484	76,000	4.61	5,441	16,000	2.94	8,173	59,459	7.28	942	10,000	10.62
Jun-09	94,804	220,207	2.32	44,360	108,000	2.43	15,071	90,000	5.97	-	-	-
Jul-09	67,575	206,796	3.06	59,948	120,000	2.00	30,733	120,000	3.90	1,077	10,000	9.29
Aug-09	55,133	138,026	2.50	7,997	17,283	2.16	16,609	110,000	6.62	-	-	-
Sep-09	24,761	70,477	2.85	61,150	136,000	2.22	11,907	40,000	3.36	-	-	-
Oct-09	10,233	28,000	2.74	25,953	60,000	2.31	-	-	-	-	-	-
Nov-09	30,337	72,000	2.37	58,577	144,080	2.46	-	-	-	-	-	-
Dec-09	58,810	156,000	2.65	79,973	172,001	2.15	-	-	-	-	-	-
Jan-10	16,805	56,000	3.33	16,554	28,000	1.69	3,358	36,460	10.86	365	3,540	9.70
Feb-10	18,023	49,022	2.72	39,203	96,000	2.45	1,012	20,518	20.28	-	-	-
Mar-10	41,952	91,619	2.18	17,100	48,000	2.81	32,208	146,039	4.53	600	4,961	8.27
Apr-10	34,337	100,000	2.91	-	-	-	14,542	77,053	5.30	2,272	14,829	6.53
May-10	58,791	153,123	2.60	56,368	130,203	2.31	928	9,000	9.70	-	-	-
Total	745,069	1,911,604	2.566	564,907	1,259,967	2.230	140,986	764,213	5.420	5,892	47,744	8.103

Table B-15 Aluminum and copper calculation data of each FL

FL type	Base cap/FL (piece)	Weight of one base cap (g)	Aluminum per one base (g)	Copper per one base (g)	Other per one base (g)	Aluminum per one FL (kg)	Copper per one FL (kg)	Other per one FL (kg)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
36WT8	2.566	1.63	0.830	0.506	0.294	2.13E-03	1.30E-03	7.54E-04
18WT8	2.230	1.63	0.830	0.506	0.294	1.85E-03	1.13E-03	6.56E-04
28WT5	5.420	1.08	0.372	0.465	0.243	2.02E-03	2.52E-03	1.32E-03
14WT5	8.103	1.08	0.372	0.465	0.243	3.01E-03	3.77E-03	1.97E-03

Remark: (2) = (3) + (4) + (5), (6) = [(1) x (3)]/1000, (7) = [(1) x (4)]/1000, (8) = [(1) x (5)]/1000

Table B-16 Capping cement powder and methanol calculation data of each FL

FL type	Base cap/FL (piece)	Capping cement per one base (g)	Capping cement powder per one base (g)	Methanol per one base (g)	Capping cement powder per one FL (kg)	Methanol per one FL (kg)
	(1)	(2)	(3)	(4)	(5)	(6)
36WT8	2.566	1.3	1.205	0.095	3.09E-03	2.45E-04
18WT8	2.230	1.3	1.205	0.095	2.69E-03	2.13E-04
28WT5	5.420	0.4	0.371	0.029	2.01E-03	1.59E-04
14WT5	8.103	0.4	0.371	0.029	3.00E-03	2.38E-04

Remark: (3) = (2)*92.66/100, (4) = (2)*7.34/100, (5) = (1)*(3)/1000, (6) = (1)*(4)/1000

Table B-17 Component of capping cement used per one FL

FL type	Capping cement powder per one FL (kg)	Phenolic resin blend (kg)	Mineral fillers (kg)
36WT8	3.09E-03	3.65E-04	2.73E-03
18WT8	2.69E-03	3.17E-04	2.37E-03
28WT5	2.01E-03	2.37E-04	1.77E-03
14WT5	3.00E-03	3.54E-04	2.65E-03

Table B-18 Electricity used for cement mixing per one FL

FL type	Cement/one base (g)	Electricity used/ one base (kWh)	Base/one FL (piece)	Electricity used/ one FL (kWh)
36WT8	1.3	1.93E-05	2.566	4.96E-05
18WT8	1.3	1.93E-05	2.230	4.31E-05
28WT5	0.4	5.94E-06	5.420	3.22E-05
14WT5	0.4	5.94E-06	8.103	4.82E-05

B.3 Stem production

The main components for stem are stem tube, exhaust tube, lead wire and filament coil. Stem is separated into two sides; S has a holes and L has no holes.

B.3.1 Stem T8: Recorded production data for stem T8 has not separated the amount of both stem sides, only recorded the different sizes of exhaust tubes used for producing each stem T8 side. Therefore the calculation is more complex as described in the remark of table. Stem T8 production contains with three sup-processes; flare making, stem making and stem mounting.

(1) Flare making: Flare is made from the cutting process of stem tube. The amount of stem tube used and flare produced in each month of 36WT8 and 18WT8 are displayed in Table B-19.

(2) Stem making: This process is the assembly of flare, exhaust tube and lead in wire together for the production of one stem. Quantity of these components used per one stem for 36WT8 and 18WT8 are shown in Tables B-20 and B-21.

(3) Stem mounting (stem M.T.)**:** Stem from stem making process will be mounted with filament coil. The amount of stem and coil used for produced one stem M.T of 36WT8 and 18WT8 are shown in Table B-22. The numbers of stem M.T. used for the production of one 36WT8 and 18WT8 FL are shown in Table B-23.

The summary of all stem production data for 36WT8 and 18WT8 is presented in Table B-24. The calculations of materials used for stem production of one 36WT8 and 18WT8 are summarized in Table B-25.

Table B-19 Stem tube used and flare produced of 36WT8 and 18WT8 FL

	36WT8			18WT8		
Month	**Stem tube (kg)**	**Flare (kg)**	**Stem tube/ flare (kg)**	**Stem tube (kg)**	**Flare (kg)**	**stem tube/ flare (kg)**
Jan-09	681.1	595.4	1.14	265.60	181.80	1.46
Feb-09	649.9	576.8	1.13	-	-	-
Mar-09	126.6	123.4	1.03	304.70	295.10	1.03
Apr-09	89.4	62.0	1.44	90.00	64.20	1.40
May-09	172.8	162.2	1.07	40.00	26.80	1.49
Jun-09	723.6	607.5	1.19	270.40	235.20	1.15
Jul-09	629.5	540.2	1.17	300.50	276.50	1.09
Aug-09	399.9	366.1	1.09	64.91	42.87	1.51
Sep-09	287.3	241.8	1.19	332.70	263.30	1.26
Oct-09	73.0	51.0	1.43	151.20	125.10	1.21
Nov-09	252.4	225.9	1.12	376.50	354.50	1.06
Dec-09	503.0	421.9	1.19	425.60	403.90	1.05
Jan-10	120.3	98.3	1.22	78.50	74.60	1.05
Feb-10	177.5	156.7	1.13	203.60	183.60	1.11
Mar-10	237.0	206.3	1.15	107.30	82.30	1.30
Apr-10	268.3	209.7	1.28	39.30	35.40	1.11
May-10	394.0	330.9	1.19	304.40	272.30	1.12
Total	5785.5	4976.1	1.163	3355	2917	1.150

Table B-20 Material for produce one stem of 36WT8

Month	Materials used				Stem produced (piece)	Materials per one piece of stem			
	Flare (kg)	Exhaust tube 0.7 mm (kg)	Exhaust tube 0.35 mm (kg)	Lead in wire (pair)		Flare (kg)	Exhaust tube 0.7 mm (kg)	Exhaust tube 0.35 mm (kg)	Lead in wire (pair)
Jan-09	595.4	310.5	234.7	268,706	252,364	2.36E-03	2.46E-03	1.86E-03	1.065
Feb-09	576.8	311.6	224.8	258,561	244,318	2.36E-03	2.55E-03	1.84E-03	1.058
Mar-09	123.4	67.0	44.0	51,500	51,349	2.40E-03	2.61E-03	1.71E-03	1.003
Apr-09	62.0	30.1	25.0	27,000	27,493	2.26E-03	2.19E-03	1.82E-03	0.982
May-09	162.2	87.5	62.0	72,500	70,178	2.31E-03	2.49E-03	1.77E-03	1.033
Jun-09	607.5	319.2	226.7	263,758	255,878	2.37E-03	2.49E-03	1.77E-03	1.031
Jul-09	540.2	267.6	208.0	234,081	229,391	2.36E-03	2.33E-03	1.81E-03	1.020
Aug-09	366.1	183.7	134.7	158,077	151,956	2.41E-03	2.42E-03	1.77E-03	1.040
Sep-09	241.8	119.2	93.6	104,850	100,198	2.41E-03	2.38E-03	1.87E-03	1.046
Oct-09	51.0	25.0	21.0	23,000	21,211	2.40E-03	2.36E-03	1.98E-03	1.084
Nov-09	225.9	114.0	96.0	98,000	92,385	2.45E-03	2.47E-03	2.08E-03	1.061
Dec-09	421.9	225.0	170.0	182,250	174,740	2.41E-03	2.58E-03	1.95E-03	1.043
Jan-10	98.3	52.0	38.0	42,000	41,036	2.40E-03	2.53E-03	1.85E-03	1.023
Feb-10	156.7	80.5	52.3	69,905	69,465	2.26E-03	2.32E-03	1.51E-03	1.006
Mar-10	206.3	107.1	57.6	98,994	95,942	2.15E-03	2.23E-03	1.20E-03	1.032
Apr-10	209.7	113.0	58.0	98,500	97,000	2.16E-03	2.33E-03	1.20E-03	1.015
May-10	330.9	174.5	91.6	156,425	152,726	2.17E-03	2.28E-03	1.20E-03	1.024
Total	4,976.1	2,587.4	1,838.0	2,208,108	2,127,630	2.34E-03	2.43E-03	1.73E-03	1.038

Table B-21 Material for produce one stem of 18WT8

Month	Materials used				Stem produced (piece)	Materials per one piece of stem			
	Flare (kg)	Exhaust tube 0.7 mm (kg)	Exhaust tube 0.35 mm (kg)	Lead in wire (pair)		Flare (kg)	Exhaust tube 0.7 mm (kg)	Exhaust tube 0.35 mm (kg)	Lead in wire (pair)
Jan-09	181.8	92.0	65.0	82,500	82,413	2.21E-03	2.23E-03	1.58E-03	1.001
Feb-09	-	-	-	-	-	-	-	-	-
Mar-09	295.1	151.0	102.0	136,500	134,878	2.19E-03	2.24E-03	1.51E-03	1.012
Apr-09	64.2	34.0	21.0	30,500	29,445	2.18E-03	2.31E-03	1.43E-03	1.036
May-09	26.8	16.0	9.0	13,500	12,498	2.14E-03	2.56E-03	1.44E-03	1.080
Jun-09	235.2	116.0	68.0	102,000	100,396	2.34E-03	2.31E-03	1.35E-03	1.016
Jul-09	276.5	142.0	82.0	132,000	129,126	2.14E-03	2.20E-03	1.27E-03	1.022
Aug-09	42.9	24.2	7.3	20,254	19,872	2.16E-03	2.44E-03	7.33E-04	1.019
Sep-09	263.3	142.0	82.0	134,500	133,110	1.98E-03	2.13E-03	1.23E-03	1.010
Oct-09	125.1	64.0	35.0	59,000	56,276	2.22E-03	2.27E-03	1.24E-03	1.048
Nov-09	354.5	186.0	100.0	166,500	164,569	2.15E-03	2.26E-03	1.22E-03	1.012
Dec-09	403.9	213.0	116.0	192,500	188,224	2.15E-03	2.26E-03	1.23E-03	1.023
Jan-10	74.6	38.0	23.0	37,000	34,769	2.15E-03	2.19E-03	1.32E-03	1.064
Feb-10	183.6	96.0	52.0	87,500	85,609	2.14E-03	2.24E-03	1.21E-03	1.022
Mar-10	82.3	45.0	25.0	39,500	38,266	2.15E-03	2.35E-03	1.31E-03	1.032
Apr-10	35.4	19.0	10.0	16,500	16,419	2.16E-03	2.31E-03	1.22E-03	1.005
May-10	272.3	137.0	78.0	128,500	125,307	2.17E-03	2.19E-03	1.24E-03	1.025
Total	2,917.5	1,515.2	875.3	1,378,754	1,351,177	2.16E-03	2.24E-03	1.30E-03	1.020

Table B-22 Stem and coil used for produced one stem M.T of 36WT8 and 18WT8

Month	36WT8					18WT8				
	Stem (piece)	Coil (piece)	Stem M.T. (piece)	Stem/one stem M.T. (piece)	Coil/one stem M.T. (piece)	Stem (piece)	Coil (piece)	Stem M.T. (piece)	Stem/one stem M.T. (piece)	Coil/one stem M.T. (piece)
Jan-09	252,364	257,211	235,248	1.073	1.093	82,413	82,100	78,138	1.055	1.051
Feb-09	244,318	255,685	231,981	1.053	1.102	-	-	-	-	-
Mar-09	51,349	52,900	47,560	1.080	1.112	134,878	136,500	131,698	1.024	1.036
Apr-09	27,493	27,400	26,002	1.057	1.054	29,445	28,800	27,424	1.074	1.050
May-09	70,178	73,700	62,805	1.117	1.173	12,498	13,000	12,376	1.010	1.050
Jun-09	255,878	260,998	231,527	1.105	1.127	100,396	101,900	97,711	1.027	1.043
Jul-09	229,391	232,942	212,099	1.082	1.098	129,126	132,500	127,544	1.012	1.039
Aug-09	151,956	157,500	150,604	1.009	1.046	19,872	20,026	18,284	1.087	1.095
Sep-09	100,198	103,690	92,736	1.080	1.118	133,110	134,000	129,174	1.030	1.037
Oct-09	21,211	20,400	22,896	0.926	0.891	56,276	53,800	56,318	0.999	0.955
Nov-09	92,385	92,500	89,520	1.032	1.033	164,569	159,500	160,267	1.027	0.995
Dec-09	174,740	180,600	158,780	1.101	1.137	188,224	190,700	187,250	1.005	1.018
Jan-10	41,036	42,300	38,918	1.054	1.087	34,769	36,300	35,156	0.989	1.033
Feb-10	69,465	71,418	65,335	1.063	1.093	85,609	86,200	84,244	1.016	1.023
Mar-10	95,942	97,657	91,869	1.044	1.063	38,266	38,400	37,656	1.016	1.020
Apr-10	97,000	97,800	95,222	1.019	1.027	16,419	16,000	15,448	1.063	1.036
May-10	152,726	153,988	148,913	1.026	1.034	125,307	123,100	120,138	1.043	1.025
Total	2,127,630	2,178,689	2,002,014	1.063	1.088	1,351,177	1,352,826	1,318,826	1.025	1.026

Table B-23 Stem M.T. used for produced one 36WT8 and 18WT8 FL

Month	36WT8			18WT8		
	Stem M.T. (piece)	Good lamp	Stem M.T. /one FL (piece)	Stem M.T. (piece)	Good lamp	Stem M.T. /one FL (piece)
Jan-09	235,248	105,246	2.24	78,138	31,833	2.45
Feb-09	231,981	101,532	2.28	-	-	-
Mar-09	47,560	20,861	2.28	131,698	57,696	2.28
Apr-09	26,002	9,707	2.68	27,424	12,528	2.19
May-09	62,805	24,879	2.52	12,376	5,441	2.27
Jun-09	231,527	96,829	2.39	97,711	44,360	2.20
Jul-09	212,099	88,625	2.39	127,544	59,948	2.13
Aug-09	150,604	66,667	2.26	18,284	7,997	2.29
Sep-09	92,736	41,072	2.26	129,174	61,150	2.11
Oct-09	22,896	10,233	2.24	56,318	25,953	2.17
Nov-09	89,520	40,102	2.23	160,267	74,825	2.14
Dec-09	158,780	68,978	2.30	187,250	87,786	2.13
Jan-10	38,918	16,805	2.32	35,156	16,554	2.12
Feb-10	65,335	27,123	2.41	84,244	39,203	2.15
Mar-10	91,869	41,952	2.19	37,656	17,100	2.20
Apr-10	95,222	41,717	2.28	15,448	7,005	2.21
May-10	148,913	66,741	2.23	120,138	56,368	2.13
Total	2,002,014	869,069	2.30	1,318,826	605,747	2.18

Table B-24 Stem production data for 36WT8 and 18WT8

FL type	kg stem tube/ kg flare	kg flare/ piece stem	Exhaust tube 0.7 mm /piece stem	Exhaust tube 0.35 mm /piece stem	Pair of lead in wire /piece stem	Piece stem/ stem M.T.	Piece coil/ stem M.T.	Piece of stem M.T./one FL
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
36WT8	1.163	2.34E-03	2.43E-03	1.73E-03	1.038	1.063	1.088	2.30
18WT8	1.150	2.16E-03	2.24E-03	1.30E-03	1.020	1.025	1.026	2.18

Table B-25 Materials for stem production of one 36WT8 and 18WT8 FL

FL type	Stem tube (kg)	Exhaust tube (kg)	Lead in wire (pair)	Coil (piece)	Tungsten (kg)	Nickel (kg)	Copper (kg)	Dumet (kg)
	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
36WT8	6.66E-03	5.09E-03	2.54	2.51	4.39E-05	9.81E-05	1.73E-04	2.14E-05
18WT8	5.54E-03	3.95E-03	2.28	2.23	3.13E-05	8.79E-05	1.55E-04	1.92E-05

Remark: (9) = (1) * (2) * (6) * (8), (10) = [(8) / 2] * (6) * [(3) + (4)]

(11) = (5) * (6) * (8), (12) = (7) * (8)

(13) For 36WT8 = (12) * 0.0175 / 1,000 ; (one coil of 36WT8 = 0.0175 g)

(13) For 18WT8 = (12) * 0.0140 / 1,000 ; (one coil of 18WT8 = 0.0140 g)

(14), (15), (16) = (11) * [0.1153 / 1,000] * [A / 100] ; (one lead in wire of T8 = 0.1153 g and A = 33.5, 59.2 and 7.3 respectively, Lead in wire comprises of 33.5% Nickel, 59.2% Copper and 7.3% Dumet)

B.3.2 Stem T5: The recorded data are separated into two sides of stem (S and L). Stem T5 production has only one process of stem mounting. The amount of stem and coil used for the production of one stem M.T. includes the amount of stem M.T. used per one 28WT5 FL for the L side as shown in Table B-26, and for the S side as shown in Table B-27. For one 14WT5 FL, the data for L side and S side are shown in Table B-28 and B-29.

Table B-30 summarizes the stem production data for 28WT5 and 14WT5 FL. The calculated results of materials used for the production of stems T5 of 28WT5 and 14WT5 FL are also shown in Table B-31.

The weight of each stem, coil and lead in wire used for the calculation of the amounts of materials used for produce stem are shown in Table B-32.

B.3.3 Electricity for stem production

The selected lamp factory only produces the stem of T8 but the stem of T5 is purchased from other factory. However, the productions of stems for T8 and T5 employ similar method with the difference only on the size of stem. Therefore, the electricity for stem production of T5 is based on the same basis as the electricity used for the stem T8 production and allocated by mass of flare. Table B-33 displays the working hour and flare produced of stem T8 production. Flare making machine requires 0.93 kW of power and the power for the lighting system in the flare making room is 0.72 kW. The calculation of electricity used for stem production is summarized in Table B-34.

Table B-26 Stem M.T. L for one 28WT5 FL

Month	Stem L (piece)	Coil L (piece)	Stem M.T. L (piece)	Good lamp	Stem L/one Stem M.T. L (piece)	Coil L/one Stem M.T. L (piece)	Stem M.T. L/one good lamp (piece)
Jan-09	-	-	-	-	-	-	-
Feb-09	1,900	2,000	1,900	1,680	1.000	1.053	1.131
Mar-09	1,715	1,715	1,715	1,342	1.000	1.000	1.278
Apr-09	7,830	7,781	7,574	4,055	1.034	1.027	1.868
May-09	34,322	33,288	32,645	21,892	1.051	1.020	1.491
Jun-09	53,248	56,356	51,608	42,432	1.032	1.092	1.216
Jul-09	65,905	70,008	65,848	59,602	1.001	1.063	1.105
Aug-09	63,938	64,516	63,305	53,845	1.010	1.019	1.176
Sep-09	16,808	17,141	16,683	14,661	1.007	1.027	1.138
Oct-09	-	-	-	-	-	-	-
Nov-09	3,985	5,100	3,680	3,514	1.083	1.386	1.047
Dec-09	-	-	-	-	-	-	-
Jan-10	22,622	22,897	21,568	16,999	1.049	1.062	1.269
Feb-10	15,429	15,249	14,989	12,343	1.029	1.017	1.214
Mar-10	80,420	80,072	77,628	68,769	1.036	1.031	1.129
Apr-10	38,937	36,801	35,426	32,400	1.099	1.039	1.093
May-10	11,073	10,950	10,950	5,837	1.011	1.000	1.876
Total	418,132	423,873	405,519	339,371	1.031	1.045	1.195

Table B-27 Stem M.T. S for one 28WT5 FL

Month	Stem S (piece)	Coil S (piece)	Stem M.T. S (piece)	Good lamp	Stem S/one Stem M.T. S (piece)	Coil S/one Stem M.T. S (piece)	Stem M.T. S/one good lamp (piece)
Jan-09	-	-	-	-	-	-	-
Feb-09	1,900	2,000	1,900	1,680	1.000	1.053	1.131
Mar-09	1,715	1,754	1,715	1,342	1.000	1.023	1.278
Apr-09	8,800	8,736	8,416	4,055	1.046	1.038	2.075
May-09	35,689	33,952	33,510	21,892	1.065	1.013	1.531
Jun-09	58,261	59,822	57,194	42,432	1.019	1.046	1.348
Jul-09	67,010	70,994	67,007	59,602	1.000	1.060	1.124
Aug-09	61,995	63,414	61,338	53,845	1.011	1.034	1.139
Sep-09	15,365	16,684	15,343	14,661	1.001	1.087	1.047
Oct-09	-	-	-	-	-	-	-
Nov-09	3,926	5,100	3,632	3,514	1.081	1.404	1.034
Dec-09	-	-	-	-	-	-	-
Jan-10	22,721	22,771	21,842	16,999	1.040	1.043	1.285
Feb-10	16,427	15,249	14,989	12,343	1.096	1.017	1.214
Mar-10	81,520	80,072	77,628	68,769	1.050	1.031	1.129
Apr-10	38,283	36,801	35,779	32,400	1.070	1.029	1.104
May-10	11,279	10,756	10,950	5,837	1.030	0.982	1.876
Total	424,890	428,105	411,243	339,371	1.033	1.041	1.212

Table B-28 Stem M.T. L for one 14WT5 FL

Month	Stem L (piece)	Coil L (piece)	Stem M.T. L (piece)	Good lamp	Stem L/one Stem M.T. L (piece)	Coil L/one Stem M.T. L (piece)	Stem M.T. L/one good lamp (piece)
Jan-09	-	-	-	-	-	-	-
Feb-09	-	-	-	-	-	-	-
Mar-09	-	-	-	-	-	-	-
Apr-09	-	-	-	-	-	-	-
May-09	2,794	3,250	2,669	1,460	1.047	1.218	1.828
Jun-09	2,262	2,422	2,229	1,825	1.015	1.087	1.221
Jul-09	2,868	2,868	2,868	1,077	1.000	1.000	2.663
Aug-09	2,049	1,969	1,969	1,015	1.041	1.000	1.940
Sep-09	-	-	-	-	-	-	-
Oct-09	-	-	-	-	-	-	-
Nov-09	1,079	1,550	1,003	990	1.076	1.545	1.013
Dec-09	-	-	-	-	-	-	-
Jan-10	4,006	3,976	3,976	2,950	1.008	1.000	1.348
Feb-10	4,108	4,149	3,780	3,705	1.087	1.098	1.020
Mar-10	8,142	7,527	7,263	5,896	1.121	1.036	1.232
Apr-10	6,429	6,063	5,970	4,762	1.077	1.016	1.254
May-10	2,878	2,853	2,600	2,600	1.107	1.097	1.000
Total	36,616	36,627	34,327	26,280	1.067	1.067	1.306

Table B-29 Stem M.T. S for one 14WT5 FL

Month	Stem S (piece)	Coil S (piece)	Stem M.T. S (piece)	Good lamp	Stem S/one Stem M.T. S (piece)	Coil S/one Stem M.T. S (piece)	Stem M.T. S/one good lamp (piece)
Jan-09	-	-	-	-	-	-	-
Feb-09	-	-	-	-	-	-	-
Mar-09	-	-	-	-	-	-	-
Apr-09	-	-	-	-	-	-	-
May-09	3,051	3,240	2,669	1,460	1.143	1.214	1.828
Jun-09	2,412	2,412	2,412	1,825	1.000	1.000	1.321
Jul-09	3,237	3,237	3,237	1,077	1.000	1.000	3.006
Aug-09	2,702	2,621	2,621	1,015	1.031	1.000	2.583
Sep-09	-	-	-	-	-	-	-
Oct-09	-	-	-	-	-	-	-
Nov-09	1,954	1,550	1,003	990	1.948	1.545	1.013
Dec-09	-	-	-	-	-	-	-
Jan-10	3,279	3,469	3,279	2,950	1.000	1.058	1.112
Feb-10	3,780	4,149	3,780	3,705	1.000	1.098	1.020
Mar-10	7,291	7,527	7,263	5,896	1.004	1.036	1.232
Apr-10	5,970	6,063	5,970	4,762	1.000	1.016	1.254
May-10	2,600	2,853	2,600	2,600	1.000	1.097	1.000
Total	36,276	37,122	34,834	26,280	1.041	1.066	1.326

Table B-30 Stem production data for 28WT5 and 14WT5 FL

FL type	Stem L/one Stem M.T. L (piece)	Coil L/one Stem M.T. L (piece)	Stem M.T. L/one good lamp (piece)	Stem S/one Stem M.T. S (piece)	Coil S/one Stem M.T. S (piece)	Stem M.T. S/one good lamp (piece)
	(1)	(2)	(3)	(4)	(5)	(6)
28WT5	1.031	1.045	1.195	1.033	1.041	1.212
14WT5	1.067	1.067	1.306	1.041	1.066	1.326

Table B-31 Materials for stem production of one 28WT5 and 14WT5 FL

FL type	Stem L (piece)	Coil L (piece)	Stem S (piece)	Coil S (piece)	Tungsten (kg)	Glass (kg)	Nickel (kg)	Copper (kg)	Dumet (kg)
	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
28WT5	1.232	1.249	1.252	1.261	2.71E-05	4.82E-03	9.23E-05	2.32E-04	2.14E-05
14WT5	1.393	1.394	1.380	1.413	2.73E-05	5.45E-03	1.03E-04	2.59E-04	2.39E-05

Remark: (7) = (1) * (3), (8) = (2) * (3), (9) = (4) * (6), (10) = (5) * (6)

Table B-32 Weight of each stem, coil and lead in wire

FL type	Stem L (g/piece)			Coil L (g/piece)	Stem S (g/piece)			Coil S (g/piece)
	Total	Lead in wire	Glass		Total	Lead in wire	Glass	
	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)
28WT5	2.2281	0.1392	2.0889	0.0102	1.9324	0.1392	1.7932	0.0114
14WT5	2.2615	0.1392	2.1223	0.0108	1.9464	0.1392	1.8072	0.0087

Remark: (11) = {[(8) * (19)] + [(10) * (23)]} / 1,000, (12) = {[(7) * (18)] + [(9) * (22)]} / 1000,

(13), (14), (15) = {[(7) * (17)] + [(9) * (21)]} * A / (100 * 1,000)

When A = 26.7, 67.1 and 6.2 respectively; Lead in wire of T5 = 26.7% Nickel, 67.1% Copper and 6.2% dumet

Table B-33 Working hour and flare produced of stem T8 production

Month	36WT8		18WT8	
	Flare (kg)	Working (hour)	Flare (kg)	Working (hour)
Jan-09	595.4	144.7	181.8	59.0
Feb-09	576.8	152.2	0.0	0.0
Mar-09	123.4	29.5	295.1	88.5
Apr-09	62.0	29.5	64.2	19.7
May-09	162.2	78.6	26.8	9.8
Jun-09	607.5	182.4	235.2	68.8
Jul-09	540.2	184.4	276.5	68.8
Aug-09	366.1	106.2	42.9	16.3
Sep-09	241.8	72.4	263.3	78.6
Oct-09	51.0	19.7	125.1	39.3
Nov-09	225.9	68.8	354.5	98.3
Dec-09	421.9	137.6	403.9	108.1
Jan-10	98.3	39.3	74.6	19.7
Feb-10	156.7	49.8	183.6	49.2
Mar-10	206.3	61.9	82.3	29.5
Apr-10	209.7	78.6	35.4	9.8
May-10	330.9	93.9	272.3	59.0
Total	4,976.1	1,529.6	2917.5	822.4

Table B-34 Electricity for stem T8 production

FL type	Flare (kg)	Working (hour)	Electricity in machine (kWh)	Lighting system (kWh)	Flare used/one FL (kg)	Electricity in machine/ one FL (kWh/FL)	Lighting system/ one FL (kWh/FL)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
36WT8	4,976.1	1,529.6	1,426.4	1,101.3	5.73E-03	1.64E-03	1.27E-03
18WT8	2917.5	822.4	766.9	592.1	4.82E-03	1.27E-03	9.77E-04
28WT5	-	-	-	-	2.60E-03	7.14E-04	5.51E-04
14WT5	-	-	-	-	2.94E-03	8.08E-04	6.24E-04

Remark: **For T8 FL**

(3) = (2) * 0.93, (4) = (2) * 0.72

(6) = (3) * (5) / (1), (7) = (4) * (5) / (1)

For T5 FL

(6) = (0.2747 kWh/kg flare) * (5); When 0.2747 is average of electricity used in flare machine

(7) = (0.2121 kWh/kg flare) * (5); When 0.2121 is average of electricity used in lighting system

B.4 Sleeve production

Sleeve or packaging of FL is made in the lamp factory. The production method for sleeve of T8 is slightly different from that of the sleeve of T5; sleeve T8 production constitutes three sub-processes; crepe paper making, slice crepe paper and sleeve making. Meanwhile, sleeve T5 is made from an automatic assembly machine.

B.4.1 Sleeve T8

(1) Crepe paper making: Raw materials for crepe paper are brown paper, white paper and paste. The amounts of these materials used per one kg crepe paper are shown in Table B-35.

(2) Slice machine: Crepe paper from the previous process has inappropriate width namely “big roll crepe paper”. The slice machine is needed to prepare the crepe paper into normal size namely “small roll crepe paper” for the production of sleeve. Table B-36 displays the amount of big roll crepe paper used per one small roll crepe paper produced.

(3) Sleeve making: this process uses the small roll crepe paper, tape and latex gum to produce sleeves for each type of FL. Raw inventory data for the production of one kg of 36WT8 and 18WT8 are shown in Tables B-37 and B-38, respectively.

B.4.2 Sleeve T5

Raw materials for sleeve T5 are brown paper, white paper and latex gum. The inventory for these raw materials for making 28WT5 and 14WT5 sleeves are shown in Tables B-39 and B-40, respectively.

Table B-41 summarizes material data for the production of one kg of small roll crepe paper. Materials used to produce one kg 36WT8 and 18WT8 sleeves are displayed in Table B-42. Latex gum contains one part of water and four of latex gum. Table B-43 presents the number of sleeve pieced per one kg weight of sleeve and raw materials used for the production of one piece of sleeve are shown in Table B-44.

Table B-35 Raw material for produced one kg of crepe paper

Month	Brown paper (kg)	White paper (kg)	Paste (kg)	Crepe paper (kg)	kg brown paper/ kg crepe paper	kg white paper/ kg crepe paper	kg paste/ kg crepe paper
Jan-09	4,995	2,751	1,116	8,623	0.579	0.319	0.129
Feb-09	2,042	1,371	585	3,923	0.521	0.349	0.149
Mar-09	5,261	3,300	1,636	10,027	0.525	0.329	0.163
Apr-09	2,444	1,958	689	5,041	0.485	0.388	0.137
May-09	-	-	-	-	-	-	-
Jun-09	748	413	45	1,172	0.638	0.352	0.038
Jul-09	2,190	1,330	196	3,527	0.621	0.377	0.056
Aug-09	2,867	1,725	172	4,521	0.634	0.382	0.038
Sep-09	4,804	2,860	252	7,543	0.637	0.379	0.033
Oct-09	9,497	5,620	481	14,923	0.636	0.377	0.032
Nov-09	8,288	4,956	426	13,025	0.636	0.380	0.033
Dec-09	5,505	3,403	291	8,710	0.632	0.391	0.033
Jan-10	6,735	3,970	357	10,679	0.631	0.372	0.033
Feb-10	7,652	4,456	411	12,170	0.629	0.366	0.034
Mar-10	5,736	3,277	292	8,842	0.649	0.371	0.033
Apr-10	4,989	2,857	313	7,822	0.638	0.365	0.040
May-10	7,936	4,722	431	12,086	0.657	0.391	0.036
Total	81,687	48,966	7,693	132,633	0.616	0.369	0.058

Table B-36 Big roll crepe paper for produce small roll crepe paper

Month	**Big roll crepe paper (kg)**	**Small roll crepe paper (kg)**	**kg big roll crepe paper/ kg small roll crepe paper**
Jan-09	8,457	7,613	1.111
Feb-09	4,336	3,976	1.091
Mar-09	10,106	9,038	1.118
Apr-09	9,647	8,522	1.132
May-09	8,181	7,408	1.104
Jun-09	6,099	5,677	1.074
Jul-09	2,982	2,726	1.094
Aug-09	5,480	4,912	1.116
Sep-09	7,787	6,914	1.126
Oct-09	14,454	12,794	1.130
Nov-09	14,138	12,234	1.156
Dec-09	9,463	8,212	1.152
Jan-10	9,816	8,762	1.120
Feb-10	12,855	11,191	1.149
Mar-10	9,156	8,182	1.119
Apr-10	8,383	7,481	1.121
May-10	11,800	10,169	1.160
Total	153,139	135,808	1.128

Table B-37 Raw material for produce one kg of 36WT8 sleeve

Month	Small roll crepe paper (kg)	Tape (kg)	Latex gum (kg)	Sleeve (kg)	kg small roll crepe paper/ one kg sleeve	kg tape/ one kg sleeve	kg latex gum/ one kg sleeve
Jan-09	551.2	50.9	14.5	541.6	1.018	0.094	0.027
Feb-09	672.2	49.9	16	616.3	1.091	0.081	0.026
Mar-09	689.1	64	25.5	669.0	1.030	0.096	0.038
Apr-09	166.4	21.4	5	150.0	1.109	0.143	0.033
May-09	321.6	23.7	8	266.5	1.207	0.089	0.030
Jun-09	282.8	37.3	7.5	305.6	0.925	0.122	0.025
Jul-09	364.1	25.6	12.5	333.0	1.093	0.077	0.038
Aug-09	710.8	57.7	11.5	795.8	0.893	0.073	0.014
Sep-09	225.2	19.1	6	270.2	0.833	0.071	0.022
Oct-09	285.3	20.9	9.1	298.4	0.956	0.070	0.030
Nov-09	297.6	34.2	9.5	324.8	0.916	0.105	0.029
Dec-09	402.2	30.3	11	375.5	1.071	0.081	0.029
Jan-10	159.9	12.2	3.5	179.5	0.891	0.068	0.020
Feb-10	197.9	16.7	5	219.3	0.902	0.076	0.023
Mar-10	430.5	38	10.5	482.9	0.891	0.079	0.022
Apr-10	531.5	42.3	14.5	560.0	0.949	0.076	0.026
May-10	-	-	-	-	-	-	-
Total	6288.3	544.2	169.6	6,388.4	0.984	0.085	0.027

Table B-38 Raw material for produce one kg of 18WT8 sleeve

Month	Small roll crepe paper (kg)	Tape (kg)	Latex gum (kg)	Sleeve (kg)	kg small roll crepe paper/ one kg sleeve	kg tape/ one kg sleeve	kg latex gum/ one kg sleeve
Jan-09	244.5	22.6	7.3	248.2	0.985	0.091	0.029
Feb-09	-	-	-	-	-	-	-
Mar-09	295.9	21.7	8.0	267.8	1.105	0.081	0.030
Apr-09	49.3	18.1	2.0	49.2	1.003	0.368	0.041
May-09	-	-	-	-	-	-	-
Jun-09	45.3	5.0	1.5	49.5	0.915	0.101	0.030
Jul-09	73.4	12.0	4.0	79.3	0.925	0.151	0.050
Aug-09	170.7	16.2	7.5	198.2	0.861	0.082	0.038
Sep-09	18.4	1.6	0.5	20.6	0.893	0.078	0.024
Oct-09	18.4	1.0	0.3	13.7	1.340	0.073	0.022
Nov-09	244.5	20.9	6.5	245.7	0.995	0.085	0.026
Dec-09	73.3	7.0	3.5	81.4	0.900	0.086	0.043
Jan-10	60.0	4.9	2.0	67.5	0.888	0.073	0.030
Feb-10	-	-	-	-	-	-	-
Mar-10	-	-	-	-	-	-	-
Apr-10	20.1	1.6	1.0	31.1	0.646	0.051	0.032
May-10	-	-	-	-	-	-	-
Total	1313.8	132.6	44.1	1352.4	0.971	0.098	0.033

Table B-39 Raw material for produce one kg of 28WT5 sleeve

Month	Brown paper (kg)	White paper (kg)	Latex gum (kg)	Sleeve (kg)	kg brown paper/ kg sleeve	kg white paper/ kg sleeve	kg Latex gum/ kg sleeve
Mar-09	282.8	241.0	58.0	402.1	0.703	0.599	0.144
May-09	188.5	84.5	34.0	116.2	1.623	0.727	0.293
Jun-09	412.4	258.2	69.0	665.6	0.620	0.388	0.104
Jul-09	674.8	888.6	176.0	1,440.0	0.469	0.617	0.122
Aug-09	308.5	220.0	65.0	579.6	0.532	0.380	0.112
Sep-09	89.5	69.5	19.5	116.7	0.767	0.595	0.167
Mar-10	832.5	553.0	88.5	1,062.3	0.784	0.521	0.083
Apr-10	401.0	296.0	47.0	652.2	0.615	0.454	0.072
Total	3,190.0	2,610.8	557.0	5,034.8	0.634	0.519	0.111

Table B-40 Raw material for produce one kg of 14WT5 sleeve

Month	Brown paper (kg)	White paper (kg)	Latex gum (kg)	Sleeve (kg)	kg brown paper/ kg sleeve	kg white paper/ kg sleeve	kg Latex gum/ kg sleeve
Mar-09	55.6	46.4	12.0	13.3	4.170	3.480	0.900
Jul-09	17.5	22.0	2.0	6.7	2.625	3.300	0.300
Mar-10	22.0	15.0	8.0	35.4	0.622	0.424	0.226
Apr-10	19.0	20.0	3.0	34.1	0.557	0.586	0.088
Total	114.1	103.4	25.0	89.5	1.275	1.155	0.279

Table B-41 Material used per one kg small roll crepe paper

Per one kg big roll paper			kg big roll crepe paper/ kg small roll crepe paper	Per one kg small roll crepe paper		
Brown paper (kg)	White paper (kg)	Paste (kg)		Brown paper (kg)	White paper (kg)	Paste (kg)
(1)	(2)	(3)	(4)	(5)	(6)	(7)
0.616	0.369	0.058	1.128	0.694	0.416	0.065

Remark: (5) = (1) * (4), (6) = (2) * (4), (7) = (3) * (4)

Table B-42 Material used per one kg sleeve

FL type	small roll crepe paper (kg)	Tape (kg)	Latex gum (kg)	Brown paper (kg)	White paper (kg)	Paste (kg)	Water (kg)	Tapioca flour (kg)	Sodium hydroxide (kg)	Pure latex gum (kg)
	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)
36WT8	0.984	0.085	0.027	0.684	0.410	6.44E-02	6.97E-02	9.33E-03	2.43E-04	2.12E-02
18WT8	0.971	0.098	0.033	0.675	0.404	6.35E-02	7.01E-02	9.21E-03	2.40E-04	2.61E-02
28WT5	-	-	0.111	0.634	0.519	-	2.21E-02	-	-	8.85E-02
14WT5	-	-	0.279	1.275	1.155	-	5.59E-02	-	-	2.23E-01

Remark: (11) for T8 = (5) * (8), (12) for T8 = (6) * (8), (13) = (7) * (8),

(14) = [(10) * 1 / 5] + [(13) * 1]; Water in latex gum has 1/5 part and one kg of paste uses one kg of water,

(15) = (13) * 0.145; one kg of paste uses 0.145 kg of tapioca flour,

(16) = (13) * 3.77E-03; one kg of paste uses 3.77E-03 kg of sodium hydroxide

(17) = (10) * 4 / 5; Pure latex gum contain in latex gum 4/5 part

Table B-43 Piece of sleeve per kg of sleeve

FL type	36WT8	18WT8	28WT5	14WT5
Piece of sleeve/kg sleeve	43	83	55	90

Table B-44 Material used per one piece of sleeve

FL type	Brown paper (kg)	White paper (kg)	Tape (kg)	Water (kg)	Tapioca flour (kg)	Sodium hydroxide (kg)	Pure latex gum (kg)
36WT8	1.59E-02	9.53E-03	1.98E-03	1.62E-03	2.17E-04	5.65E-06	4.94E-04
18WT8	8.13E-03	4.87E-03	1.18E-03	8.44E-04	1.11E-04	2.89E-06	3.14E-04
28WT5	1.15E-02	9.43E-03	-	4.02E-04	-	-	1.61E-03
14WT5	1.42E-02	1.28E-02	-	6.21E-04	-	-	2.48E-03

B.4.3 Electricity

Machine used for sleeve production has corrugating machine, slitting machine, paste mixing, sleeve machine and auto sleeve machine. The details of power machine, working hour and the amount of product in each machine are shown in Table B-45. Electricity used for produce one piece sleeve of FL calculated and displayed in Table B-46. For lighting system in sleeve production has the calculation in Table B-47.

Table B-45 Electricity used in machine

Machine	FL type	Power (kW)	Working (hour)	Product (kg)	Electricity (kWh/kg product)
Corrugating	T8	2.238	2,511	132,633	4.24E-02
Slitting	T8	2.238	3,276	135,808	5.40E-02
Paste mixing	T8	0.373	2,511	20,854	4.49E-02
Sleeve machine	36WT8	1.567	504	6,388.4	0.124
	18WT8	1.567	225	1,352.4	0.261
Auto sleeve machine	28WT5	1.567	540	5,034.8	0.168
	14WT5	1.567	54	89.5	0.945

Remark: Total data in 17 months

Table B-46 Electricity used for produce one piece of sleeve

FL type	Electricity/kg sleeve (kWh)				Total Electricity /kg sleeve (kWh)	Total Electricity/ piece sleeve (kWh)
	Corrugating machine	Slitting machine	Paste mixing	Sleeve machine		
	(1)	(2)	(3)	(4)	(5)	(6)
36WT8	0.047	0.053	2.89E-3	0.124	0.227	5.27E-03
18WT8	0.046	0.052	2.85E-3	0.261	0.362	4.37E-03
28WT5	-	-	-	0.168	0.168	3.06E-03
14WT5	-	-	-	0.945	0.945	1.05E-02

Remark: (1) For 36WT8 uses 1.11 kg of corrugating product,

So that electricity = 1.11 * 4.24E-02 = 0.047 kWh/kg sleeve

(1) For 18WT8 uses 1.095 kg of corrugating product,

So that electricity = 1.095 * 4.24E-02 = 0.046 kWh/kg sleeve

(2) For 36WT8 used 0.984 kg of slitting product,

Thus, electricity = 0.984 * 5.40E-02 = 0.053 kWh/kg sleeve

(2) For 18WT8 used 0.971 kg of slitting product,

Thus, electricity = 0.971 * 5.40E-02 = 0.052 kWh/kg sleeve

(3) For 36WT8 used 0.064 kg of paste, electricity = 0.064 * 4.49E-02 = 2.89E-03 kWh/kg sleeve

(3) For 18WT8 used 0.063 kg of paste, electricity = 0.063 * 4.49E-02 = 2.85E-03 kWh/kg sleeve

(5) = (1) + (2) + (3) + (4)

(6) = (5) / piece of sleeve per one kg or the data in Table B-43

For lighting system of sleeve production, the calculated data of electricity used per one piece sleeve produced is shown in Table B-47.

Table B-47 Electricity for sleeve production

FL type	Power (kW)	Working (hour)	Sleeve (kg)	Electricity/kg sleeve (kWh)	Electricity/piece sleeve (kWh)
	(1)	(2)	(3)	(4)	(5)
36WT8	0.36	504	6,388.4	2.84E-02	6.60E-04
18WT8	0.36	225	1,352.4	5.99E-02	7.22E-04
28WT5	0.36	540	5,034.8	3.86E-02	7.02E-04
14WT5	0.36	54	89.5	2.17E-01	2.41E-03

Remark: (4) = (1) * (2) / (3),

(5) = (4) / piece of sleeve per one kg or the data in Table B-43

B.5 Phosphor mixing

B.5.1 Phosphor solution

Phosphor solution is the chemical compound that comprises phosphor powder, alone-C solution, “surface solution”, deionized water and lacquer. Phosphor powders of T8 and T5 are of different types; halo phosphor and tri phosphor, respectively.

Tables B-48 to B-51 present the amounts of chemical compounds and glass bulb used for the preparation of phosphor solution for 36WT8, 18WT8, 28WT5 and 14WT5, respectively, whereas Tables B-52 to B-55 present the amount of chemical compounds used per one FL of 36WT8, 18WT8, 28WT5 and 14WT5 respectively. Table B-56 summarizes the amounts of chemical compound used per one FL.

One liter of alone-C solution contains 0.97 liter of deionized water, 0.13 kg of aluminum oxide or alone-C powder and other small ingredients. One liter of “surface solution” contains 0.9 liter of deionized water and other small ingredient. From these data, the amounts of phosphor powder, aluminum oxide, lacquer and deionized water used per one FL are summarized in Table B-57.

B.5.2 Electricity

Phosphor mixing requires the use of electricity during the mixing of chemical compounds, including “surface solution” mixing, alone-C mixing and lacquer mixing. This mixing is carried out in a 0.75 kW mixing tank and the details of electricity from the mixing of each solution are shown in Table B-58, and the amount of electricity used for mixing phosphor solution of each FL is shown in Table B-59.

Table B-48 Chemical compounds for the preparation of 36WT8 phosphor solution

Month	Phosphor powder (kg)	Alone C solution (Liter)	Surface (Liter)	Deionized water (Liter)	Lacquer (Liter)	Glass bulb coating (bulb)
Jan-09	572.3	172.2	6.22	579.7	645.6	115,668
Feb-09	404.2	120.7	8.18	572.8	673.2	97,887
Mar-09	119.5	27.3	2.61	161.1	198.2	15,680
Apr-09	96.6	22.7	1.14	116.8	198.2	12,329
May-09	80.8	21.7	0.75	98.6	176.7	29,353
Jun-09	545.5	147.6	5.46	512.3	670.6	100,939
Jul-09	469.7	110.7	4.59	436.6	628.6	104,837
Aug-09	149.9	37.6	1.51	162.3	246.6	70,871
Sep-09	74.9	16.3	0.76	87.3	134.2	33,187
Oct-09	31.0	6.4	0.31	50.0	40.4	4,652
Nov-09	148.4	33.7	1.58	214.6	186.9	41,312
Dec-09	238.0	50.8	2.38	208.0	279.5	73,920
Jan-10	30.8	6.3	0.31	46.8	33.0	14,024
Feb-10	72.4	14.8	0.75	88.6	116.3	25,557
Mar-10	156.5	31.9	1.57	193.3	271.3	38,827
Apr-10	131.2	26.8	1.36	202.2	257.4	44,516
May-10	292.9	58.8	2.87	403.1	533.4	69,581
Total	3,6145	906	42.4	4,134	5290	893,140

Table B-49 Chemical compound for mix 18WT8 phosphor solution

Month	Phosphor powder (kg)	Alone C solution (Liter)	Surface (Liter)	Deionized water (Liter)	Lacquer (Liter)	Glass bulb coating (bulb)
Jan-09	104.8	31.45	1.05	108.46	137.59	30,458
Feb-09	-	-	-	-	-	-
Mar-09	134.4	30.09	2.37	187.38	223.98	60,493
Apr-09	64.4	14.88	0.63	97.56	169.49	12,730
May-09	-	-	-	-	-	-
Jun-09	117.8	31.88	1.18	184.63	250.15	43,111
Jul-09	125.2	29.68	1.37	149.68	227.02	62,634
Aug-09	26.5	6.63	0.27	38.29	58.40	7,116
Sep-09	130.0	28.36	1.32	142.61	212.62	58,858
Oct-09	58.0	12.06	0.57	76.71	63.05	24,149
Nov-09	159.1	36.14	1.70	201.78	163.52	77,636
Dec-09	208.1	44.38	2.08	133.75	220.41	81,413
Jan-10	51.6	10.53	0.52	85.01	66.29	15,428
Feb-10	35.3	7.19	0.36	42.86	60.35	40,704
Mar-10	49.1	10.02	0.49	70.91	97.45	15,900
Apr-10	-	-	-	-	-	-
May-10	111.8	22.46	1.09	165.29	235.68	59,984
Total	1,376	316	15.0	1,685	2,186	590,614

Table B-50 Chemical compound for mix 28WT5 phosphor solution

Month	Phosphor powder (kg)	Alone C solution (Liter)	Surface (Liter)	Deionized water (Liter)	Lacquer (Liter)	Glass bulb coating (bulb)
Jan-09	169.7	55.9	2.64	188.6	301.6	9,069
Feb-09	142.4	44.5	2.94	174.2	186.7	13,962
Mar-09	60.6	18.7	1.46	104.2	122.2	11,561
Apr-09	40.6	12.9	0.71	61.4	102.7	6,019
May-09	78.2	23.6	1.74	106.8	135.8	25,357
Jun-09	125.7	38.8	1.83	189.4	264.1	46,733
Jul-09	281.6	86.5	3.17	382.0	378.0	64,679
Aug-09	250.6	78.3	3.51	343.4	448.4	56,614
Sep-09	70.5	21.5	0.70	100.4	108.4	16,082
Jan-10	119.7	24.6	1.42	91.8	87.8	17,383
Mar-10	156.5	31.9	1.57	193.3	271.3	38,827
Apr-10	115.8	35.4	2.32	103.5	97.5	27,446
May-10	78.3	24.0	1.57	75.0	74.0	7,008
Total	1,690	497	25.6	2,114	2,578	340,740

Table B-51 Chemical compound for mix 14WT5 phosphor solution

Month	Phosphor powder (kg)	Alone C solution (Liter)	Surface (Liter)	Deionized water (Liter)	Lacquer (Liter)	Glass bulb coating (bulb)
Jan-10	33.1	6.8	0.364	31.9	29.9	3,330
Mar-10	49.1	10.0	0.491	70.9	97.5	15,900
Total	82.2	16.8	0.855	102.8	127.3	19,230

Table B-52 Chemical compound used per one 36WT8 FL

Month	Phosphor powder (kg)	Alone C solution (Liter)	Surface (Liter)	Deionized water (Liter)	Lacquer (Liter)
Jan-09	4.95E-03	1.49E-03	5.38E-05	5.01E-03	5.58E-03
Feb-09	4.13E-03	1.23E-03	8.36E-05	5.85E-03	6.88E-03
Mar-09	7.62E-03	1.74E-03	1.66E-04	1.03E-02	1.26E-02
Apr-09	7.84E-03	1.84E-03	9.24E-05	9.48E-03	1.61E-02
May-09	2.75E-03	7.39E-04	2.57E-05	3.36E-03	6.02E-03
Jun-09	5.40E-03	1.46E-03	5.41E-05	5.08E-03	6.64E-03
Jul-09	4.48E-03	1.06E-03	4.38E-05	4.16E-03	6.00E-03
Aug-09	2.12E-03	5.30E-04	2.13E-05	2.29E-03	3.48E-03
Sep-09	2.26E-03	4.93E-04	2.29E-05	2.63E-03	4.04E-03
Oct-09	6.66E-03	1.39E-03	6.58E-05	1.08E-02	8.69E-03
Nov-09	3.59E-03	8.16E-04	3.83E-05	5.19E-03	4.52E-03
Dec-09	3.22E-03	6.87E-04	3.22E-05	2.81E-03	3.78E-03
Jan-10	2.20E-03	4.48E-04	2.20E-05	3.34E-03	2.35E-03
Feb-10	2.83E-03	5.78E-04	2.93E-05	3.47E-03	4.55E-03
Mar-10	4.03E-03	8.22E-04	4.03E-05	4.98E-03	6.99E-03
Apr-10	2.95E-03	6.01E-04	3.07E-05	4.54E-03	5.78E-03
May-10	4.21E-03	8.45E-04	4.12E-05	5.79E-03	7.67E-03
Total	4.05E-03	1.01E-03	4.74E-05	4.63E-03	5.92E-03

Table B-53 Chemical compound used per one 18WT8 FL

Month	Phosphor powder (kg)	Alone C solution (Liter)	Surface (Liter)	Deionized water (Liter)	Lacquer (Liter)
Jan-09	3.44E-03	1.03E-03	3.44E-05	3.56E-03	4.52E-03
Feb-09	-	-	-	-	-
Mar-09	2.22E-03	4.97E-04	3.92E-05	3.10E-03	3.70E-03
Apr-09	5.06E-03	1.17E-03	4.92E-05	7.66E-03	1.33E-02
May-09	-	-	-	-	-
Jun-09	2.73E-03	7.39E-04	2.74E-05	4.28E-03	5.80E-03
Jul-09	2.00E-03	4.74E-04	2.19E-05	2.39E-03	3.62E-03
Aug-09	3.72E-03	9.32E-04	3.74E-05	5.38E-03	8.21E-03
Sep-09	2.21E-03	4.82E-04	2.24E-05	2.42E-03	3.61E-03
Oct-09	2.40E-03	4.99E-04	2.37E-05	3.18E-03	2.61E-03
Nov-09	2.05E-03	4.66E-04	2.19E-05	2.60E-03	2.11E-03
Dec-09	2.56E-03	5.45E-04	2.56E-05	1.64E-03	2.71E-03
Jan-10	3.35E-03	6.83E-04	3.35E-05	5.51E-03	4.30E-03
Feb-10	8.66E-04	1.77E-04	8.95E-06	1.05E-03	1.48E-03
Mar-10	3.09E-03	6.30E-04	3.09E-05	4.46E-03	6.13E-03
Apr-10	-	-	-	-	-
May-10	1.86E-03	3.74E-04	1.83E-05	2.76E-03	3.93E-03
Total	2.33E-03	5.35E-04	2.54E-05	2.85E-03	3.70E-03

Table B-54 Chemical compound used per one 28WT5 FL

Month	Phosphor powder (kg)	Alone C solution (Liter)	Surface (Liter)	Deionized water (Liter)	Lacquer (Liter)
Jan-09	1.87E-02	6.16E-03	2.91E-04	2.08E-02	3.33E-02
Feb-09	1.02E-02	3.18E-03	2.10E-04	1.25E-02	1.34E-02
Mar-09	5.24E-03	1.62E-03	1.26E-04	9.01E-03	1.06E-02
Apr-09	6.74E-03	2.15E-03	1.17E-04	1.02E-02	1.71E-02
May-09	3.08E-03	9.29E-04	6.85E-05	4.21E-03	5.36E-03
Jun-09	2.69E-03	8.30E-04	3.93E-05	4.05E-03	5.65E-03
Jul-09	4.35E-03	1.34E-03	4.90E-05	5.91E-03	5.84E-03
Aug-09	4.43E-03	1.38E-03	6.19E-05	6.07E-03	7.92E-03
Sep-09	4.38E-03	1.34E-03	4.38E-05	6.25E-03	6.74E-03
Jan-10	6.89E-03	1.42E-03	8.15E-05	5.28E-03	5.05E-03
Mar-10	4.03E-03	8.22E-04	4.03E-05	4.98E-03	6.99E-03
Apr-10	4.22E-03	1.29E-03	8.43E-05	3.77E-03	3.55E-03
May-10	1.12E-02	3.42E-03	2.23E-04	1.07E-02	1.06E-02
Total	4.94E-03	1.45E-03	7.47E-05	6.18E-03	7.54E-03

Table B-55 Chemical compound used per one 14WT5 FL

Month	Phosphor powder (kg)	Alone C solution (Liter)	Surface (Liter)	Deionized water (Liter)	Lacquer (Liter)
Jan-10	9.94E-03	2.03E-03	1.09E-04	9.57E-03	8.97E-03
Mar-10	3.09E-03	6.30E-04	3.09E-05	4.46E-03	6.13E-03
Total	4.28E-03	8.72E-04	4.45E-05	5.34E-03	6.62E-03

Table B-56 Chemical compound used per one FL

FL type	Phosphor powder (kg)	Alone C solution (Liter)	Surface (Liter)	Deionized water (Liter)	Lacquer (Liter)
	(1)	(2)	(3)	(4)	(5)
36WT8	4.05E-03	1.01E-03	4.74E-05	4.63E-03	5.92E-03
18WT8	2.33E-03	5.35E-04	2.54E-05	2.85E-03	3.70E-03
28WT5	4.94E-03	1.45E-03	7.47E-05	6.18E-03	7.54E-03
14WT5	4.28E-03	8.72E-04	4.45E-05	5.34E-03	6.62E-03

Table B-57 Final chemical compound used per one FL

FL type	Phosphor powder (kg)	Aluminum oxide (kg)	Deionized water (kg)	Lacquer (kg)
	(6)	(7)	(8)	(9)
36WT8	4.05E-03	1.31E-04	5.65E-03	5.92E-03
18WT8	2.33E-03	6.90E-05	3.39E-03	3.70E-03
28WT5	4.94E-03	1.87E-04	7.65E-03	7.54E-03
14WT5	4.28E-03	1.13E-04	6.23E-03	6.62E-03

Remark: (7) = (2) * 0.13, (8) = [(2) * 0.97] + [(3) * 0.9] + (4)

Density of deionized water and lacquer = 1 kg/L

Table B-58 Data for calculate the electricity from the mixing

Machine	Power (kW)	Mixing (hour)	Volume of solution (Liter)	Electricity used (kWh/L)
Surface mixing	0.75	2	20	7.50E-02
Alone C mixing	0.75	24	77.5	2.32E-01
Lacquer mixing	0.75	2	95	1.58E-02

Table B-59 Electricity used for mixing phosphor solution of each FL

FL type	Electricity used (kWh)			
	Surface mixing	Alone C mixing	Lacquer mixing	Total
36WT8	3.56E-06	2.36E-04	9.35E-05	3.33E-04
18WT8	1.91E-06	1.24E-04	5.84E-05	1.85E-04
28WT5	5.60E-06	3.37E-04	1.19E-04	4.62E-04
14WT5	3.34E-06	2.03E-04	1.05E-04	3.10E-04

APPENDIX C

CARBON FOOTPRINT CALCULATION

C.1 Glass manufacture

GHG emission through life cycle (Cradle to gate) of one kg glass production including raw material acquisition, production, transportation of raw material, transportation of solid waste, waste management and packaging are calculated and displayed in Table C-1 to C-6, respectively.

Table C-1 GHG emission from raw material acquisition of one kg glass production

NO.	Raw materials	Unit	Amount of used	E.F. ($kgCO_2e$/unit)	CO_2 emission ($kgCO_2e$)
1	Silica sand	kg	0.6068	0.0211	1.28E-02
2	Cullet	kg	0.5021	0	0
3	Soda ash	kg	0.2353	1.19	2.80E-01
4	Dolomite	kg	0.1507	0.0265	3.99E-03
5	Feldspar	kg	0.1132	0.0037	4.19E-04
6	Minor ingredients	kg	0.0434	-	2.48E-02
Total CO_2 emission ($kgCO_2e$)					**0.322**

Table C-2 GHG emission from production process of one kg glass production

NO.	Raw materials	Unit	Amount of used	E.F. ($kgCO_2e$/unit)	CO_2 emission ($kgCO_2e$)
1	Electricity	kWh	0.4278	0.561	2.40E-01
2	Water supply	m^3	4.35E-04	0.0264	1.15E-05
3	Natural gas (Production)	MJ	31.33	0.0099	3.10E-01
4	Natural gas (Combustion)	MJ	31.33	0.0712	2.23
5	Chemical reaction	-	-	-	0.175
Total CO_2 emission ($kgCO_2e$)					**2.956**

Table C-3 GHG emission from transportation of raw material of one kg glass production

NO.	List	Amount (kg)	CO_2 emission		Total CO_2 emission ($kgCO_2e$)
			Full load ($kgCO_2e$)	No load ($kgCO_2e$)	
1	Silica Sand	0.6068	2.02E-02	1.41E-02	3.43E-02
2	Cullet	0.5021	1.67E-02	1.17E-02	2.84E-02
3	Soda ash	0.2353	7.82E-03	5.48E-03	1.33E-02
4	Dolomite	0.1507	5.01E-03	3.51E-03	8.52E-03
5	Feldspar	0.1132	3.76E-03	2.64E-03	6.40E-03
6	Minor ingredients	0.0434	1.44E-03	1.01E-03	2.45E-03
Total CO_2 emission ($kgCO_2e$)					**9.34E-02**

Remark: Vehicle type is 22-wheel semi-trailer trucks, 32 tons and distance of transport equal 700 km.

Table C-4 GHG emission from transportation of waste of one kg glass production

NO.	List	Amount (kg)	CO_2 emission		Total CO_2 emission ($kgCO_2e$)
			Full load ($kgCO_2e$)	No load ($kgCO_2e$)	
1	Solid waste	2.68E-03	5.29E-06	3.44E-06	8.74E-06
Total CO_2 emission ($kgCO_2e$)					**8.74E-06**

Remark: Vehicle type is 10-wheel semi-trailer trucks, 16 tons and distance of transport equal 40 km.

Table C-5 GHG emission from waste management of one kg glass production

NO.	Raw materials	Unit	Amount	E.F. ($kgCO_2e$/unit)	CO_2 emission ($kgCO_2e$)
1	Wastewater	Liter	2.65E-03	0.0012	3.18E-06
2	Other solid waste	kg	1.43E-03	2.32	3.33E-03
3	Rags and gloves	kg	2.11E-04	2.00	4.23E-04
4	Garbage	kg	8.26E-04	2.53	2.09E-03
5	Lumber	kg	2.07E-04	3.33	6.88E-04
Total CO_2 emission ($kgCO_2e$)					**6.53E-03**

Table C-6 GHG emission from packaging of one kg glass production

NO.	Raw materials	Unit	Amount	E.F. ($kgCO_2e$/unit)	CO_2 emission ($kgCO_2e$)
1	Corrugated paper packaging	kg	0.0692	0.826	5.72E-02
Total CO_2 emission ($kgCO_2e$)					**5.72E-02**

C.2 Fluorescent lamp production

C.2.1 Gate to Gate: GHG emission calculation from FL production process is displayed as following:

- One 36WT8 FL production in Table C-7.
- One 18WT8 FL production in Table C-8.
- One 28WT5 FL production in Table C-9.
- One 14WT5 FL production in Table C-10.

Table C-7 GHG emission from production process of one 36WT8 FL

NO.	Inputs	Unit	Amount of used	E.F. ($kgCO_2e$/unit)	CO_2 emission ($kgCO_2e$)
1	Electricity in machine	kWh	9.12E-02	0.561	0.051
2	Electricity in lighting system	kWh	1.42E-02	0.561	0.008
3	Water supply	m^3	3.19E-03	0.0264	8.41E-05
4	Deionized water	kg	5.65E-03	5.98E-04	3.38E-06
5	LPG (combustion)	kg	5.76E-02	3.389	0.195
Total CO_2 emission ($kgCO_2e$)					**0.254**

Table C-8 GHG emission from production process of one 18WT8 FL

NO.	Inputs	Unit	Amount of used	E.F. ($kgCO_2e$/unit)	CO_2 emission ($kgCO_2e$)
1	Electricity in machine	kWh	7.63E-02	0.561	0.043
2	Electricity in lighting system	kWh	1.40E-02	0.561	0.008
3	Water supply	m^3	2.35E-03	0.0264	6.22E-05
4	Deionized water	kg	3.39E-03	5.98E-04	2.03E-06
5	LPG (combustion)	kg	4.96E-02	3.389	0.168
Total CO_2 emission ($kgCO_2e$)					**0.219**

Table C-9 GHG emission from production process of one 28WT5 FL

NO.	Inputs	Unit	Amount of used	E.F. ($kgCO_2e$/unit)	CO_2 emission ($kgCO_2e$)
1	Electricity in machine	kWh	2.99E-01	0.561	0.168
2	Electricity in lighting system	kWh	1.36E-02	0.561	0.008
3	Water supply	m^3	1.98E-03	0.0264	5.23E-05
4	Deionized water	kg	7.65E-03	5.98E-04	4.58E-06
5	LPG (combustion)	kg	1.46E-01	3.389	0.495
Total CO_2 emission ($kgCO_2e$)					**0.671**

Table C-10 GHG emission from production process of one 14WT5 FL

NO.	Inputs	Unit	Amount of used	E.F. ($kgCO_2e$/unit)	CO_2 emission ($kgCO_2e$)
1	Electricity in machine	kWh	4.93E-01	0.561	0.277
2	Electricity in lighting system	kWh	1.53E-02	0.561	0.009
3	Water supply	m^3	2.17E-03	0.0264	5.73E-05
4	Deionized water	kg	6.23E-03	5.98E-04	3.72E-06
5	LPG (combustion)	kg	1.46E-01	3.389	0.495
Total CO_2 emission ($kgCO_2e$)					**0.780**

C.2.2 Cradle to grave

GHG emission calculation through life cycle of each FL production including raw material acquisition, transportation of raw material, production process, distribution/ retail, usage stage, recycle option and disposal option are displayed as following:

- One 36WT8 FL production in Table C-11 to C-18, respectively.
- One 18WT8 FL production in Table C-19 to C-26, respectively.
- One 28WT5 FL production in Table C-27 to C-34, respectively.
- One 14WT5 FL production in Table C-35 to C-42, respectively.

Table C-11 GHG emission from raw material acquisition stage of one 36WT8 FL production

NO.	Inputs	Unit	Amount of used	E.F. ($kgCO_2e$/unit)	CO_2 emission ($kgCO_2e$)
1	Glass tube	kg	0.2038	3.4352	0.70
2	Mercury	kg	1.00E-05	118	1.18E-03
3	Aluminum	kg	2.13E-03	12.2	0.03
4	Copper	kg	1.30E-03	3.47	4.50E-03
5	Argon gas	kg	4.69E-07	0.285	1.34E-07
6	Krypton gas	kg	1.76E-05	107	1.88E-03
7	Phosphor powder	kg	4.05E-03	1.51	6.11E-03
8	Other ingredients	kg	3.27E-05	1.52	4.98E-05
9	Aluminum oxide	kg	1.31E-04	1.23	1.61E-04
10	Lacquer	kg	5.92E-03	6.74	0.04
11	Brown paper	kg	1.59E-02	0.735	1.17E-02
12	White paper	kg	9.53E-03	0.735	7.00E-03
13	Tapioca flour	kg	2.17E-04	0.541	1.17E-04
14	Sodium hydroxide (NaOH)	kg	5.65E-06	1.2	6.78E-06
15	Tape	kg	1.98E-03	3.19	6.32E-03
16	Latex gum	kg	4.94E-04	2.64	1.30E-03
17	Tungsten	kg	4.39E-05	21.2	9.30E-04
18	Nickel	kg	9.81E-05	24.3	2.38E-03
19	Copper	kg	1.73E-04	3.47	6.02E-04
20	Glass (stem tube and exhaust tube)	kg	1.17E-02	3.4352	4.04E-02
21	Phenolic resin blend	kg	3.65E-04	3.78	1.38E-03
22	Mineral fillers	kg	2.73E-03	0.387	1.05E-03
23	Methanol	kg	2.45E-04	0.739	1.81E-04
24	LPG (Production)	kg	5.76E-02	0.27	1.56E-02
Total CO_2 emission ($kgCO_2e$)					**0.869**

Table C-12 GHG emission from transportation of raw material of one 36WT8 FL production

NO.	List	Amount (kg)	CO_2 emission		Total CO_2 emission ($kgCO_2e$)
			Full load ($kgCO_2e$)	No load ($kgCO_2e$)	
1	Glass (Lamp bulb, stem tube and exhaust tube)	0.2156	1.08E-03	7.91E-04	1.87E-03
2	Mercury	1.00E-05	3.33E-07	2.33E-07	5.66E-07
3	Aluminum	2.13E-03	7.08E-05	4.96E-05	1.20E-04
4	Copper	1.30E-03	4.32E-05	3.03E-05	7.34E-05
5	Argon gas	4.69E-07	1.56E-08	1.09E-08	2.65E-08
6	Krypton gas	1.76E-05	5.85E-07	4.10E-07	9.94E-07
7	Phosphor powder	4.05E-03	1.35E-04	9.43E-05	2.29E-04
8	Other ingredients	3.27E-05	1.09E-06	7.63E-07	1.85E-06
9	Aluminum oxide	1.31E-04	4.35E-06	3.05E-06	7.40E-06
10	Lacquer	5.92E-03	1.97E-04	1.38E-04	3.35E-04
11	LPG	5.76E-02	1.92E-03	1.34E-03	3.26E-03
12	Brown paper	1.59E-02	5.29E-04	3.71E-04	8.99E-04
13	White paper	9.53E-03	3.17E-04	2.22E-04	5.39E-04
14	Tapioca flour	2.17E-04	7.21E-06	5.06E-06	1.23E-05
15	Sodium hydroxide	5.65E-06	1.88E-07	1.32E-07	3.20E-07
16	Tape	1.98E-03	6.59E-05	4.62E-05	1.12E-04
17	Latex gum	4.94E-04	1.64E-05	1.15E-05	2.79E-05
18	Tungsten	4.39E-05	1.46E-06	1.02E-06	2.48E-06
19	Nickel	9.81E-05	3.26E-06	2.29E-06	5.55E-06
20	Copper	1.73E-04	5.77E-06	4.04E-06	9.81E-06
21	Phenolic resin blend	3.65E-04	1.21E-05	8.50E-06	2.06E-05
22	Mineral fillers	2.73E-03	9.06E-05	6.35E-05	1.54E-04
23	Methanol	2.45E-04	8.14E-06	5.70E-06	1.38E-05
24	Others component	7.80E-04	2.59E-05	1.82E-05	4.41E-05
Total CO_2 emission ($kgCO_2e$)					**7.74E-03**

Remark: For transportation of glass uses 78.5 km distance, 6-wheel trucks, 11 tons vehicle type. For other raw material uses 22-wheel semi-trailer trucks, 32 tons and distance of transport equal 700 km.

Table C-13 GHG emission from production process of one 36WT8 FL production

NO.	Inputs	Unit	Amount of used	E.F. ($kgCO_2e$/unit)	CO_2 emission ($kgCO_2e$)
1	Electricity	kWh	1.05E-01	0.561	5.91E-02
2	LPG (combustion)	kg	5.76E-02	3.389	1.95E-01
3	Water supply	m^3	3.19E-03	0.0264	8.41E-05
4	Deionized water	kg	5.65E-03	5.98E-04	3.38E-06
Total CO_2 emission ($kgCO_2e$)					**0.254**

Table C-14 GHG emission from distribution/retail of one 36WT8 FL

Month	Vehicle type	Number of lamp	Distance (km)	Weight (kg)	GHG emission ($kgCO_2e$)		GHG emission ($kgCO_2e$/lamp)	
					Full load	No load	Full load	No load
		(1)	(2)	(3)	(4)	(5)	(6)	(7)
Jan-09	10-wheel, 16 tons	20,080	68.47	4,030	5.85	4.64	6.50E-04	5.15E-04
	4-wheel, 7 tons	2,080	29.60	417	2.36	0.62	1.14E-03	2.96E-04
Feb-09	10-wheel, 16 tons	172,895	76.87	34,701	53.03	42.05	7.30E-04	5.79E-04
	4-wheel, 7 tons	1,235	35.07	248	1.66	0.43	1.35E-03	3.51E-04
Mar-09	10-wheel, 16 tons	121,464	115.73	24,379	39.97	31.69	1.10E-03	8.71E-04
Apr-09	10-wheel, 16 tons	22,520	115.73	4,520	7.38	5.85	1.10E-03	8.71E-04
May-09	10-wheel, 16 tons	41,849	68.47	8,399	13.52	10.72	6.50E-04	5.15E-04
	4-wheel, 7 tons	685	79.67	137	1.19	0.31	3.06E-03	7.98E-04
Jun-09	10-wheel, 16 tons	83,829	115.73	16,825	33.93	26.91	1.10E-03	8.71E-04
Jul-09	10-wheel, 16 tons	28,880	29.60	5,796	8.12	6.44	2.81E-04	2.23E-04
	4-wheel, 7 tons	400	20.80	80	0.32	0.08	7.99E-04	2.08E-04
Aug-09	10-wheel, 16 tons	62,646	126.83	12,573	21.77	17.27	1.20E-03	9.55E-04
Sep-09	4-wheel, 7 tons	28,468	97.07	5,714	32.45	8.46	3.73E-03	9.72E-04
Oct-09	10-wheel, 16 tons	75,112	174.10	15,075	24.84	19.69	1.65E-03	1.31E-03
Nov-09	10-wheel, 16 tons	23,120	29.60	4,640	6.50	5.15	2.81E-04	2.23E-04
Dec-09	10-wheel, 16 tons	14,400	29.60	2,890	4.05	3.21	2.81E-04	2.23E-04

Table C-15 GHG emission from distribution/retail of one 36WT8 FL (Cont.)

Month	Vehicle type	Number of lamp	Distance (km)	Weight (kg)	GHG emission ($kgCO_2e$)		GHG emission ($kgCO_2e$/lamp)	
					Full load	No load	Full load	No load
		(1)	(2)	(3)	(4)	(5)	(6)	(7)
Jan-10	10-wheel, 16 tons	13,500	76.87	2,710	5.81	4.60	7.30E-04	5.79E-04
	4-wheel, 7 tons	500	35.07	100	0.67	0.18	1.35E-03	3.51E-04
Feb-10	10-wheel, 16 tons	20,560	87.97	4,127	8.51	6.75	8.35E-04	6.62E-04
	4-wheel, 7 tons	1,036	35.07	208	1.39	0.36	1.35E-03	3.51E-04
Mar-10	10-wheel, 16 tons	31,082	68.47	6,238	9.63	7.64	6.50E-04	5.15E-04
	4-wheel, 7 tons	152	18.83	31	0.11	0.03	7.23E-04	1.89E-04
Apr-10	4-wheel, 7 tons	7,593	29.60	1,524	8.63	2.25	1.14E-03	2.96E-04
	10-wheel, 16 tons	24,603	87.97	4,938	10.74	8.51	8.35E-04	6.62E-04
May-10	10-wheel, 16 tons	49,910	100.87	10,017	15.76	12.50	9.58E-04	7.59E-04
Total		848,599			318	226	**3.75E-04**	**2.67E-04**

Remark: (4) = (2) * (3) * E.F. Full load / 1000, (5) = (2) * (3) * E.F. No load / (1000 * Wt. of load)

(6) = (4) / (1), (7) = (5) / (1)

Table C-16 GHG emission from usage stage of one 36WT8 FL

Average life time (hour)	Power (kW)	Electricity (kWh)	E.F. ($kgCO_2e/kWh$)	CO_2 emission ($kgCO_2e$)
20,000	0.036	720	0.561	403.92
Total CO_2 emission ($kgCO_2e$)				**403.92**

Table C-17 GHG emission from recycle option of one 36WT8 FL

NO.	Inputs/Output	Unit	Amount of used	E.F. ($kgCO_2e$/unit)	CO_2 emission ($kgCO_2e$)
1	Electricity	kWh	3.03E-03	0.561	1.70E-03
2	Water supply	m^3	1.77E-04	0.0264	4.68E-06
3	Natural gas (production)	m^3	4.08E-05	0.328	1.34E-05
4	Natural gas (combustion)	MJ	1.57E-03	0.0712	1.12E-04
5	Sodium sulfide	kg	1.24E-03	0.39	4.84E-04
6	Cement	kg	1.77E-02	0.995	1.77E-02
7	Cullet	kg	1.60E-01	- 3.11	- 4.96E-01
Total CO_2 emission ($kgCO_2e$)					**- 0.476**

Remark: Conversion factor of change natural gas in m^3 unit into MJ unit:

(a) 1 m^3 = 35.315 ft^3

(b) Heating value of natural gas = 1,030 Btu/ft^3

(c) 1 Btu = 1,055.06 J

(d) 1 MJ = 1,000,000 J

E.F. of cullet (or glass recovered) = E.F. secondary production of glass - E.F. primary production of glass = 0.33 - 3.4352 = -3.11 $kgCO_2e$/kg cullet.

Table C-18 GHG emission from landfill option of one 36WT8 FL

NO.	Inputs	Unit	Amount of used	E.F. ($kgCO_2e$/unit)	CO_2 emission ($kgCO_2e$)
1	Electricity	kWh	4.52E-03	0.561	2.54E-03
2	Water supply	m^3	1.77E-04	0.0264	4.68E-06
3	Sodium sulfide	kg	1.24E-02	0.39	4.84E-03
4	Cement	kg	1.77E-01	0.995	1.77E-01
Total CO_2 emission ($kgCO_2e$)					**0.184**

Table C-19 GHG emission from raw material acquisition stage of one 18WT8 FL production

NO.	Inputs	Unit	Amount of used	E.F. ($kgCO_2e$/unit)	CO_2 emission ($kgCO_2e$)
1	Glass tube	kg	0.0939	3.4352	3.22E-01
2	Mercury	kg	1.00E-05	118	1.18E-03
3	Aluminum	kg	1.85E-03	12.2	2.26E-02
4	Copper	kg	1.13E-03	3.47	3.92E-03
5	Argon gas	kg	4.85E-07	0.285	1.38E-07
6	Krypton gas	kg	6.06E-06	107	6.49E-04
7	Phosphor powder	kg	2.33E-03	1.51	3.52E-03
8	Other ingredients	kg	1.72E-05	1.52	2.62E-05
9	Aluminum oxide	kg	6.90E-05	1.23	8.49E-05
10	Lacquer	kg	3.70E-03	6.74	2.49E-02
11	Brown paper	kg	8.13E-03	0.735	5.97E-03
12	White paper	kg	4.87E-03	0.735	3.58E-03
13	Tapioca flour	kg	1.11E-04	0.541	6.00E-05
14	Sodium hydroxide (NaOH)	kg	2.89E-06	1.2	3.47E-06
15	Tape	kg	1.18E-03	3.19	3.77E-03
16	Latex gum	kg	3.14E-04	2.64	8.30E-04
17	Tungsten	kg	3.13E-05	21.2	6.63E-04
18	Nickel	kg	8.79E-05	24.3	2.14E-03
19	Copper	kg	1.55E-04	3.47	5.39E-04
20	Glass (stem tube and exhaust tube)	kg	9.49E-03	3.4352	3.26E-02
21	Phenolic resin blend	kg	3.17E-04	3.78	1.20E-03
22	Mineral fillers	kg	2.37E-03	0.387	9.17E-04
23	Methanol	kg	2.13E-04	0.739	1.57E-04
24	LPG	kg	4.96E-02	0.27	1.34E-02
Total CO_2 emission ($kgCO_2e$)					**0.445**

Table C-20 GHG emission from transportation of raw material of one 18WT8 FL production

NO.	List	Amount (kg)	CO_2 emission		Total CO_2 emission ($kgCO_2e$)
			Full load ($kgCO_2e$)	No load ($kgCO_2e$)	
1	Glass (Lamp bulb, stem tube and exhaust tube)	0.1033	5.18E-04	3.79E-04	8.97E-04
2	Mercury	1.00E-05	3.33E-07	2.33E-07	5.66E-07
3	Aluminum	1.85E-03	6.16E-05	4.31E-05	1.05E-04
4	Copper	1.13E-03	3.75E-05	2.63E-05	6.38E-05
5	Argon gas	4.85E-07	1.61E-08	1.13E-08	2.74E-08
6	Krypton gas	6.06E-06	2.02E-07	1.41E-07	3.43E-07
7	Phosphor powder	2.33E-03	7.75E-05	5.43E-05	1.32E-04
8	Other ingredients	1.72E-05	5.73E-07	4.02E-07	9.75E-07
9	Aluminum oxide	6.90E-05	2.29E-06	1.61E-06	3.90E-06
10	Lacquer	3.70E-03	1.23E-04	8.63E-05	2.09E-04
11	LPG	0.04960	1.65E-03	1.16E-03	2.81E-03
12	Brown paper	8.13E-03	2.70E-04	1.89E-04	4.60E-04
13	White paper	4.87E-03	1.62E-04	1.14E-04	2.76E-04
14	Tapioca flour	1.11E-04	3.69E-06	2.59E-06	6.27E-06
15	Sodium hydroxide	2.89E-06	9.61E-08	6.73E-08	1.63E-07
16	Tape	1.18E-03	3.93E-05	2.75E-05	6.68E-05
17	Latex gum	3.14E-04	1.05E-05	7.33E-06	1.78E-05
18	Tungsten	3.13E-05	1.04E-06	7.29E-07	1.77E-06
19	Nickel	8.79E-05	2.92E-06	2.05E-06	4.97E-06
20	Copper	1.55E-04	5.17E-06	3.62E-06	8.79E-06
21	Phenolic resin blend	3.17E-04	1.05E-05	7.39E-06	1.79E-05
22	Mineral fillers	2.37E-03	7.88E-05	5.52E-05	1.34E-04
23	Methanol	2.13E-04	7.07E-06	4.96E-06	1.20E-05
24	Others component	6.77E-04	2.25E-05	1.58E-05	3.83E-05
Total CO_2 emission ($kgCO_2e$)					**5.26E-03**

Remark: For transportation of glass uses 78.5 km distance, 6-wheel trucks, 11 tons vehicle type. For other raw material uses 22-wheel semi-trailer trucks, 32 tons and distance of transport equal 700 km.

Table C-21 GHG emission from production process of one 18WT8 FL production

NO.	Inputs	Unit	Amount of used	E.F. ($kgCO_2e$/unit)	CO_2 emission ($kgCO_2e$)
1	Electricity	kWh	9.03E-02	0.561	5.07E-02
2	LPG (combustion)	kg	4.96E-02	3.389	1.68E-01
3	Water supply	m^3	1.51E-03	0.0264	3.99E-05
4	Deionized water	kg	3.39E-03	5.98E-04	2.03E-06
Total CO_2 emission ($kgCO_2e$)					**0.219**

Table C-22 GHG emission from distribution/retail of one 18WT8 FL

Month	Vehicle type	Number of lamp	Distance (km)	Weight (kg)	GHG emission ($kgCO_2e$)		GHG emission ($kgCO_2e$/lamp)	
					Full load	No load	Full load	No load
		(1)	(2)	(3)	(4)	(5)	(6)	(7)
Jan-09	10-wheel, 16 tons	28,420	68.47	2,860	4.27	3.39	3.26E-04	2.58E-04
	4-wheel, 7 tons	4,350	53.27	438	2.90	0.76	1.03E-03	2.67E-04
Feb-09	10-wheel, 16 tons	7,840	76.87	789	1.27	1.01	3.66E-04	2.90E-04
	4-wheel, 7 tons	3,840	38.87	386	2.87	0.75	7.48E-04	1.95E-04
Mar-09	10-wheel, 16 tons	10,200	29.60	1,027	1.44	1.14	1.41E-04	1.12E-04
	4-wheel, 7 tons	1,000	18.20	101	0.35	0.09	3.50E-04	9.14E-05
Apr-09	10-wheel, 16 tons	58,395	115.73	5,877	9.43	7.48	5.51E-04	4.37E-04
	4-wheel, 7 tons	500	35.07	50	0.34	0.09	6.75E-04	1.76E-04
May-09	10-wheel, 16 tons	10,430	68.47	1,050	1.90	1.51	3.26E-04	2.58E-04
	4-wheel, 7 tons	500	35.07	50	0.34	0.09	6.75E-04	1.76E-04
Jun-09	10-wheel, 16 tons	15,320	115.73	1,542	2.85	2.26	5.51E-04	4.37E-04
	4-wheel, 7 tons	700	53.27	70	0.41	0.11	1.03E-03	2.67E-04
Jul-09	10-wheel, 16 tons	18,630	29.60	1,875	2.63	2.08	1.41E-04	1.12E-04
	4-wheel, 7 tons	200	36.60	20	0.14	0.04	7.05E-04	1.84E-04
Aug-09	10-wheel, 16 tons	66,370	126.83	6,680	11.44	9.07	6.04E-04	4.79E-04
	4-wheel, 7 tons	100	18.20	10	0.04	0.01	3.50E-04	9.14E-05

Table C-23 GHG emission from distribution/retail of one 18WT8 FL (Cont.)

Month	Vehicle type	Number of lamp	Distance (km)	Weight (kg)	GHG emission ($kgCO_2e$)		GHG emission ($kgCO_2e$/lamp)	
					Full load	No load	Full load	No load
		(1)	(2)	(3)	(4)	(5)	(6)	(7)
Sep-09	4-wheel, 7 tons	35,850	68.47	3,608	23.26	6.07	1.32E-03	3.44E-04
Oct-09	10-wheel, 16 tons	58,520	165.70	5,890	10.79	8.55	7.89E-04	6.26E-04
Nov-09	10-wheel, 16 tons	20,040	29.60	2,017	2.82	2.24	1.41E-04	1.12E-04
	4-wheel, 7 tons	1,510	89.87	152	0.93	0.24	1.73E-03	4.51E-04
Dec-09	10-wheel, 16 tons	13,290	86.13	1,338	2.58	2.05	4.10E-04	3.25E-04
	4-wheel, 7 tons	300	35.07	30	0.20	0.05	6.75E-04	1.76E-04
Jan-10	10-wheel, 16 tons	57,020	135.23	5,739	9.28	7.35	6.44E-04	5.10E-04
Feb-10	10-wheel, 16 tons	58,812	87.97	5,919	9.00	7.14	4.19E-04	3.32E-04
Mar-10	10-wheel, 16 tons	18,739	87.97	1,886	3.60	2.85	4.19E-04	3.32E-04
	4-wheel, 7 tons	500	53.27	50	0.31	0.08	1.03E-03	2.67E-04
Apr-10	10-wheel, 16 tons	31,332	135.23	3,154	6.21	4.93	6.44E-04	5.10E-04
	4-wheel, 7 tons	2,424	35.07	244	1.64	0.43	6.75E-04	1.76E-04
May-10	10-wheel, 16 tons	81,993	100.87	8,252	12.47	9.89	4.80E-04	3.81E-04
	4-wheel, 7 tons	400	18.20	40	0.14	0.04	3.50E-04	9.14E-05
Total		607,525			126	82	**2.07E-04**	**1.35E-04**

Remark: (4) = (2) * (3) * E.F. Full load / 1000, (5) = (2) * (3) * E.F. No load / (1000 * Wt. of load), (6) = (4) / (1), (7) = (5) / (1)

Table C-24 GHG emission from usage stage of one 18WT8 FL

Average life time (hour)	Power (kW)	Electricity (kWh)	E.F. ($kgCO_2e/kWh$)	CO_2 emission ($kgCO_2e$)
20,000	0.018	360	0.561	201.96
Total CO_2 emission ($kgCO_2e$)				201.96

Table C-25 GHG emission from recycle option of one 18WT8 FL

NO.	Inputs/Output	Unit	Amount of used	E.F. ($kgCO_2e$/unit)	CO_2 emission ($kgCO_2e$)
1	Electricity	kWh	1.51E-03	0.561	8.47E-04
2	Water supply	m^3	8.86E-05	0.0264	2.34E-06
3	Natural gas (production)	m^3	2.04E-05	0.328	6.68E-06
4	Natural gas (combustion)	MJ	7.82E-04	0.0712	5.57E-05
5	Sodium sulfide	kg	6.20E-04	0.39	2.42E-04
6	Cement	kg	8.86E-03	0.995	8.82E-03
7	Cullet	kg	7.97E-02	-3.11	-2.48E-01
Total CO_2 emission ($kgCO_2e$)					**-0.238**

Remark: Same as Table C-17

Table C-26 GHG emission from landfill option of one 18WT8 FL

NO.	Inputs	Unit	Amount of used	E.F. ($kgCO_2e$/unit)	CO_2 emission ($kgCO_2e$)
1	Electricity	kWh	2.26E-03	0.561	1.27E-03
2	Water supply	m^3	8.86E-05	0.0264	2.34E-06
3	Sodium sulfide	kg	6.20E-03	0.39	2.42E-03
4	Cement	kg	8.86E-02	0.995	8.82E-02
Total CO_2 emission ($kgCO_2e$)					**0.092**

Table C-27 GHG emission from raw material acquisition stage of one 28WT5 FL production

NO.	Inputs	Unit	Amount of used	E.F. ($kgCO_2e$/unit)	CO_2 emission ($kgCO_2e$)
1	Glass tube	kg	0.1473	3.4352	0.51
2	Mercury	kg	7.31E-06	118	8.62E-04
3	Zinc	kg	7.45E-06	0.249	1.86E-06
4	Aluminum	kg	2.02E-03	12.2	0.02
5	Copper	kg	2.52E-03	3.47	8.75E-03
6	Argon gas	kg	1.43E-06	0.285	4.08E-07
7	Phosphor powder	kg	4.94E-03	5.8	0.03
8	Other ingredients	kg	4.68E-05	1.52	7.12E-05
9	Aluminum oxide	kg	1.87E-04	1.23	2.30E-04
10	Lacquer	kg	7.54E-03	6.74	0.05
11	Brown paper	kg	1.15E-02	0.735	8.47E-03
12	White paper	kg	9.43E-03	0.735	6.93E-03
13	Latex gum	kg	1.61E-03	2.64	4.25E-03
14	Tungsten	kg	2.71E-05	21.2	5.75E-04
15	Nickel	kg	9.23E-05	24.3	2.24E-03
16	Copper	kg	2.32E-04	3.47	8.05E-04
17	Glass (stem tube and exhaust tube)	kg	4.82E-03	3.4352	1.66E-02
18	Phenolic resin blend	kg	2.37E-04	3.78	8.96E-04
19	Mineral fillers	kg	1.77E-03	0.387	6.86E-04
20	Methanol	kg	1.59E-04	0.739	1.18E-04
21	LPG	kg	1.46E-02	0.27	3.94E-02
Total CO_2 emission ($kgCO_2e$)					**0.701**

Table C-28 GHG emission from transportation of raw material of one 28WT5 FL production

NO.	List	Amount (kg)	CO_2 emission Full load ($kgCO_2e$)	CO_2 emission No load ($kgCO_2e$)	Total CO_2 emission ($kgCO_2e$)
1	Glass (Lamp bulb, stem tube and exhaust tube)	0.1521	7.63E-04	5.58E-04	1.32E-03
2	Mercury	7.31E-06	2.43E-07	1.70E-07	4.13E-07
3	Zinc	7.45E-06	2.48E-07	1.74E-07	4.21E-07
4	Aluminum	2.02E-03	6.70E-05	4.70E-05	1.14E-04
5	Copper	2.52E-03	8.38E-05	5.87E-05	1.43E-04
6	Argon gas	1.43E-06	4.77E-08	3.34E-08	8.11E-08
7	Phosphor powder	4.94E-03	1.64E-04	1.15E-04	2.80E-04
8	Other ingredients	4.68E-05	1.56E-06	1.09E-06	2.65E-06
9	Aluminum oxide	1.87E-04	6.23E-06	4.37E-06	1.06E-05
10	Lacquer	7.54E-03	2.51E-04	1.76E-04	4.26E-04
11	LPG	0.14610	4.86E-03	3.41E-03	8.26E-03
12	Brown paper	1.15E-02	3.83E-04	2.69E-04	6.52E-04
13	White paper	9.43E-03	3.13E-04	2.20E-04	5.33E-04
14	Latex gum	1.61E-03	5.35E-05	3.75E-05	9.10E-05
15	Tungsten	2.71E-05	9.02E-07	6.32E-07	1.53E-06
16	Nickel	9.23E-05	3.07E-06	2.15E-06	5.22E-06
17	Copper	2.32E-04	7.71E-06	5.41E-06	1.31E-05
18	Phenolic resin blend	2.37E-04	7.88E-06	5.53E-06	1.34E-05
19	Mineral fillers	1.77E-03	5.89E-05	4.13E-05	1.00E-04
20	Methanol	1.59E-04	5.29E-06	3.71E-06	9.00E-06
21	Others component	1.35E-03	4.48E-05	3.14E-05	7.62E-05
Total CO_2 emission ($kgCO_2e$)					**1.21E-02**

Remark: For transportation of glass uses 78.5 km distance, 6-wheel trucks, 11 tons vehicle type. For other raw material uses 22-wheel semi-trailer trucks, 32 tons and distance of transport equal 700 km.

Table C-29 GHG emission from production process of one 28WT5 FL production

NO.	Inputs	Unit	Amount of used	E.F. ($kgCO_2e$/unit)	CO_2 emission ($kgCO_2e$)
1	Electricity	kWh	0.31	0.561	0.176
2	LPG (combustion)	kg	1.46E-01	3.389	0.50
3	Water supply	m^3	1.98E-03	0.0264	5.23E-05
4	Deionized water	kg	7.65E-03	5.98E-04	4.58E-06
Total CO_2 emission ($kgCO_2e$)					**0.671**

Table C-30 GHG emission from distribution/retail of one 28WT5 FL

Month	Vehicle type	Number of lamp	Distance (km)	Weight (kg)	GHG emission ($kgCO_2e$)		GHG emission ($kgCO_2e$/lamp)	
					Full load	No load	Full load	No load
		(1)	(2)	(3)	(4)	(5)	(6)	(7)
Jan-09	4-wheel, 7 tons	4,625	194.37	593	4.00	1.04	4.77E-03	1.24E-03
Feb-09	10-wheel, 16 tons	2,156	120.77	276	0.46	0.36	7.32E-04	5.81E-04
	4-wheel, 7 tons	3,760	108.20	482	3.25	0.85	2.65E-03	6.92E-04
Mar-09	10-wheel, 16 tons	625	29.60	80	0.11	0.09	1.79E-04	1.42E-04
	4-wheel, 7 tons	2,000	32.40	256	1.59	0.41	7.94E-04	2.07E-04
Apr-09	10-wheel, 16 tons	10,193	73.50	1,307	1.83	1.45	4.46E-04	3.53E-04
	4-wheel, 7 tons	160	48.43	21	0.19	0.05	1.19E-03	3.10E-04
May-09	4-wheel, 7 tons	1,936	76.30	248	1.62	0.42	1.87E-03	4.88E-04
Jun-09	10-wheel, 16 tons	2,825	29.60	362	0.51	0.40	1.79E-04	1.42E-04
	4-wheel, 7 tons	394	43.90	51	0.42	0.11	1.08E-03	2.81E-04
Jul-09	10-wheel, 16 tons	69,775	29.60	8,944	12.52	9.93	1.79E-04	1.42E-04
	4-wheel, 7 tons	156	43.90	20	0.17	0.04	1.08E-03	2.81E-04
Aug-09	10-wheel, 16 tons	7,800	29.60	1,000	1.40	1.11	1.79E-04	1.42E-04
	4-wheel, 7 tons	4,480	180.23	574	5.65	1.47	4.42E-03	1.15E-03
Sep-09	10-wheel, 16 tons	9,662	73.50	1,238	2.48	1.97	4.46E-04	3.53E-04
	4-wheel, 7 tons	3,200	32.40	410	2.54	0.66	7.94E-04	2.07E-04

Table C-31 GHG emission from distribution/retail of one 28WT5 FL (Cont.)

Month	Vehicle type	Number of lamp	Distance (km)	Weight (kg)	GHG emission ($kgCO_2e$)		GHG emission ($kgCO_2e$/lamp)	
					Full load	No load	Full load	No load
		(1)	(2)	(3)	(4)	(5)	(6)	(7)
Oct-09	10-wheel, 16 tons	2,970	43.90	381	0.79	0.63	2.66E-04	2.11E-04
	4-wheel, 7 tons	4,075	73.60	522	3.45	0.90	1.80E-03	4.71E-04
Nov-09	10-wheel, 16 tons	7,150	105.90	917	1.33	1.05	6.42E-04	5.09E-04
Dec-09	10-wheel, 16 tons	375	47.27	48	0.11	0.09	2.87E-04	2.27E-04
	4-wheel, 7 tons	2,200	145.13	282	3.76	0.98	3.56E-03	9.28E-04
Jan-10	4-wheel, 7 tons	100	35.07	13	0.09	0.02	8.60E-04	2.24E-04
Feb-10	10-wheel, 16 tons	82,200	43.90	10,537	21.88	17.35	2.66E-04	2.11E-04
	4-wheel, 7 tons	10,276	147.17	1,317	8.98	2.34	3.61E-03	9.41E-04
Mar-10	10-wheel, 16 tons	12,000	43.90	1,538	3.19	2.53	2.66E-04	2.11E-04
	4-wheel, 7 tons	2,321	119.23	298	2.46	0.64	2.92E-03	7.62E-04
Apr-10	10-wheel, 16 tons	103,300	43.90	13,241	27.49	21.80	2.66E-04	2.11E-04
	4-wheel, 7 tons	240	29.60	31	0.17	0.05	7.26E-04	1.89E-04
May-10	10-wheel, 16 tons	225	29.60	29	0.04	0.03	1.79E-04	1.42E-04
Total		351,179			112	69	**3.20E-04**	**1.96E-04**

Remark: (4) = (2) * (3) * E.F. Full load / 1000, (5) = (2) * (3) * E.F. No load / (1000 * Wt. of load), (6) = (4) / (1), (7) = (5) / (1)

Table C-32 GHG emission from usage stage of one 28WT5 FL

Average life time (hour)	Power (kW)	Electricity (kWh)	E.F. ($kgCO_2e/kWh$)	CO_2 emission ($kgCO_2e$)
20,000	0.028	560	0.561	314.16
Total CO_2 emission ($kgCO_2e$)				314.16

Table C-33 GHG emission from recycle option of one 28WT5 FL

NO.	Inputs/Output	Unit	Amount of used	E.F. ($kgCO_2e/unit$)	CO_2 emission ($kgCO_2e$)
1	Electricity	kWh	1.88E-03	0.561	1.05E-03
2	Water supply	m^3	1.10E-04	0.0264	2.90E-06
3	Natural gas (production)	m^3	2.53E-05	0.328	8.30E-06
4	Natural gas (combustion)	MJ	9.71E-04	0.0712	6.91E-05
5	Sodium sulfide	kg	7.70E-04	0.39	3.00E-04
6	Cement	kg	1.10E-02	0.995	1.09E-02
7	Cullet	kg	9.90E-02	-3.11	-3.07E-01
Total CO_2 emission ($kgCO_2e$)					**-0.295**

Remark: Same as Table C-17

Table C-34 GHG emission from landfill option of one 28WT5 FL

NO.	Inputs	Unit	Amount of used	E.F. ($kgCO_2e/unit$)	CO_2 emission ($kgCO_2e$)
1	Electricity	kWh	2.81E-03	0.561	1.57E-03
2	Water supply	m^3	1.10E-04	0.0264	2.90E-06
3	Sodium sulfide	kg	7.70E-03	0.39	3.00E-03
4	Cement	kg	1.10E-01	0.995	1.09E-01
Total CO_2 emission ($kgCO_2e$)					**0.114**

Table C-35 GHG emission from raw material acquisition stage of one 14WT5 FL production

NO.	Inputs	Unit	Amount of used	E.F. ($kgCO_2e$/unit)	CO_2 emission ($kgCO_2e$)
1	Glass tube	kg	7.37E-02	3.4352	2.53E-01
2	Mercury	kg	7.31E-06	118	8.62E-04
3	Zinc	kg	7.45E-06	0.249	1.86E-06
4	Aluminum	kg	3.01E-03	12.2	0.037
5	Copper	kg	3.77E-03	3.47	1.31E-02
6	Argon gas	kg	6.04E-07	0.285	1.72E-07
7	Phosphor powder	kg	4.28E-03	5.8	0.025
8	Other ingredients	kg	2.81E-05	1.52	4.28E-05
9	Aluminum oxide	kg	1.13E-04	1.23	1.38E-04
10	Lacquer	kg	6.62E-03	6.74	0.045
11	Brown paper	kg	1.42E-02	0.735	1.04E-02
12	White paper	kg	1.28E-02	0.735	9.43E-03
13	Latex gum	kg	2.48E-03	2.64	6.55E-03
14	Tungsten	kg	2.73E-05	21.2	5.80E-04
15	Nickel	kg	1.03E-04	24.3	2.51E-03
16	Copper	kg	2.59E-04	3.47	8.99E-04
17	Glass (stem tube and exhaust tube)	kg	5.45E-03	3.4352	1.87E-02
18	Phenolic resin blend	kg	3.54E-04	3.78	1.34E-03
19	Mineral fillers	kg	2.65E-03	0.387	1.03E-03
20	Methanol	kg	2.38E-04	0.739	1.76E-04
21	LPG	kg	1.46E-02	0.27	3.94E-02
Total CO_2 emission ($kgCO_2e$)					**0.465**

Table C-36 GHG emission from transportation of raw material of one 14WT5 FL production

NO.	List	Amount (kg)	CO_2 emission		Total CO_2 emission ($kgCO_2e$)
			Full load ($kgCO_2e$)	No load ($kgCO_2e$)	
1	Glass (Lamp bulb, stem tube and exhaust tube)	7.92E-02	3.97E-04	2.90E-04	6.87E-04
2	Mercury	7.31E-06	2.43E-07	1.70E-07	4.13E-07
3	Zinc	7.45E-06	2.48E-07	1.74E-07	4.21E-07
4	Aluminum	3.01E-03	1.00E-04	7.02E-05	1.70E-04
5	Copper	3.77E-03	1.25E-04	8.78E-05	2.13E-04
6	Argon gas	6.04E-07	2.01E-08	1.41E-08	3.41E-08
7	Phosphor powder	4.28E-03	1.42E-04	9.97E-05	2.42E-04
8	Other ingredients	2.81E-05	9.36E-07	6.56E-07	1.59E-06
9	Aluminum oxide	1.13E-04	3.74E-06	2.62E-06	6.37E-06
10	Lacquer	6.62E-03	2.20E-04	1.54E-04	3.74E-04
11	LPG	0.14610	4.86E-03	3.41E-03	8.26E-03
12	Brown paper	1.42E-02	4.71E-04	3.30E-04	8.01E-04
13	White paper	1.28E-02	4.27E-04	2.99E-04	7.26E-04
14	Latex gum	2.48E-03	8.25E-05	5.79E-05	1.40E-04
15	Tungsten	2.73E-05	9.09E-07	6.37E-07	1.55E-06
16	Nickel	1.03E-04	3.43E-06	2.40E-06	5.83E-06
17	Copper	2.59E-04	8.61E-06	6.04E-06	1.47E-05
18	Phenolic resin blend	3.54E-04	1.18E-05	8.26E-06	2.00E-05
19	Mineral fillers	2.65E-03	8.81E-05	6.17E-05	1.50E-04
20	Methanol	2.38E-04	7.91E-06	5.54E-06	1.35E-05
21	Others component	2.00E-03	6.64E-05	4.66E-05	1.13E-04
Total CO_2 emission ($kgCO_2e$)					**1.19E-02**

Remark: For transportation of glass uses 78.5 km distance, 6-wheel trucks, 11 tons vehicle type. For other raw material uses 22-wheel semi-trailer trucks, 32 tons and distance of transport equal 700 km.

Table C-37 GHG emission from production process of one 14WT5 FL production

NO.	Inputs	Unit	Amount of used	E.F. ($kgCO_2e$/unit)	CO_2 emission ($kgCO_2e$)
1	Electricity	kWh	5.10E-01	0.561	0.285
2	LPG (combustion)	kg	1.46E-01	3.389	0.495
3	Water supply	m^3	2.17E-03	0.0264	5.73E-05
4	Deionized water	kg	6.23E-03	5.98E-04	3.72E-06
Total CO_2 emission ($kgCO_2e$)					**0.780**

Table C-38 GHG emission from distribution/retail of one 14WT5 FL

Month	Vehicle type	Number of lamp	Distance (km)	Weight (kg)	GHG emission ($kgCO_2e$)		GHG emission ($kgCO_2e$/lamp)	
					Full load	No load	Full load	No load
		(1)	(2)	(3)	(4)	(5)	(6)	(7)
Jan-09	4-wheel, 7 tons	1,025	79.67	70.74	0.44	0.12	1.05E-03	2.74E-04
Feb-09	10-wheel, 16 tons	28	43.90	1.93	0.00	0.00	1.43E-04	1.14E-04
	4-wheel, 7 tons	740	67.00	51.07	0.32	0.08	8.85E-04	2.31E-04
Mar-09	10-wheel, 16 tons	5,516	29.60	380.67	0.53	0.42	9.66E-05	7.66E-05
	4-wheel, 7 tons	2,400	32.40	165.63	1.03	0.27	4.28E-04	1.12E-04
Apr-09	10-wheel, 16 tons	300	29.60	20.70	0.03	0.02	9.66E-05	7.66E-05
	4-wheel, 7 tons	100	32.40	6.90	0.04	0.01	4.28E-04	1.12E-04
May-09	4-wheel, 7 tons	6	43.90	0.41	0.00	0.00	5.80E-04	1.51E-04
Jun-09	4-wheel, 7 tons	104	78.50	7.18	0.05	0.01	1.04E-03	2.70E-04
Jul-09	10-wheel, 16 tons	200	29.60	13.80	0.02	0.02	9.66E-05	7.66E-05
Aug-09	4-wheel, 7 tons	506	76.30	34.92	0.22	0.06	1.01E-03	2.63E-04
Sep-09	4-wheel, 7 tons	500	32.40	34.51	0.21	0.06	4.28E-04	1.12E-04
Oct-09	4-wheel, 7 tons	1,500	32.40	103.52	0.64	0.17	4.28E-04	1.12E-04
Nov-09	10-wheel, 16 tons	500	32.40	34.51	0.05	0.04	1.06E-04	8.39E-05
Dec-09	4-wheel, 7 tons	689	80.50	47.55	0.38	0.10	1.06E-03	2.77E-04

Table C-39 GHG emission from distribution/retail of one 14WT5 FL (Cont.)

Month	Vehicle type	Number of lamp	Distance (km)	Weight (kg)	GHG emission ($kgCO_2e$)		GHG emission ($kgCO_2e$/lamp)	
					Full load	No load	Full load	No load
		(1)	(2)	(3)	(4)	(5)	(6)	(7)
Jan-10	4-wheel, 7 tons	550	64.67	37.96	0.22	0.06	8.54E-04	2.23E-04
Mar-10	4-wheel, 7 tons	881	119.23	60.80	0.45	0.12	1.57E-03	4.10E-04
Apr-10	4-wheel, 7 tons	225	35.07	15.53	0.10	0.03	4.63E-04	1.21E-04
May-10	10-wheel, 16 tons	50	29.60	3.45	0.00	0.00	9.66E-05	7.66E-05
Total		15,820			4.75	1.58	**3.01E-04**	**1.00E-04**

Remark: (4) = (2) * (3) * E.F. Full load / 1000

(5) = (2) * (3) * E.F. No load / (1000 * Wt. of load)

(6) = (4) / (1)

(7) = (5) / (1)

Table C-40 GHG emission from usage stage of one 14WT5 FL

Average life time (hour)	Power (kW)	Electricity (kWh)	E.F. ($kgCO_2e/kWh$)	CO_2 emission ($kgCO_2e$)
20,000	0.014	280	0.561	157.08
Total CO_2 emission ($kgCO_2e$)				157.08

Table C-41 GHG emission from recycle option of one 14WT5 FL

NO.	Inputs/Output	Unit	Amount of used	E.F. ($kgCO_2e$/unit)	CO_2 emission ($kgCO_2e$)
1	Electricity	kWh	9.87E-04	0.561	5.54E-04
2	Water supply	m^3	5.79E-05	0.0264	1.53E-06
3	Natural gas (production)	m^3	1.33E-05	0.328	4.37E-06
4	Natural gas (combustion)	MJ	5.11E-04	0.0712	3.64E-05
5	Sodium sulfide	kg	4.05E-04	0.39	1.58E-04
6	Cement	kg	5.79E-03	0.995	5.76E-03
7	Cullet	kg	5.21E-02	-3.11	-1.62E-01
Total CO_2 emission ($kgCO_2e$)					**-0.155**

Remark: Same as Table C-17

Table C-42 GHG emission from landfill option of one 14WT5 FL

NO.	Inputs	Unit	Amount of used	E.F. ($kgCO_2e$/unit)	CO_2 emission ($kgCO_2e$)
1	Electricity	kWh	1.48E-03	0.561	8.28E-04
2	Water supply	m^3	5.79E-05	0.0264	1.53E-06
3	Sodium sulfide	kg	4.05E-03	0.39	1.58E-03
4	Cement	kg	5.79E-02	0.995	5.76E-02
Total CO_2 emission ($kgCO_2e$)					**6.00E-02**

C.3 Ballast manufacture

GHG emission calculation through life cycle of ballast manufacturing including raw material acquisition, transportation of raw material, production process, consumer use, recycle option and disposal option are shown as following:

- For magnetic ballast in Table C-43 to C-49
- For electronic ballast in Table C-50 to C-57

GHG emission through all life cycle of each ballast that considering with FL come from two in three ratio of GHG emission from each stage of ballast, exception for the usage stage. Because the average life time of ballast in FL set equal to 20,000 hours, as two in three of the real average life time (30,000 hour).

Table C-43 GHG emission from raw material acquisition of one magnetic ballast

NO.	Inputs	Unit	Amount of used	E.F. ($kgCO_2e$/unit)	CO_2 emission ($kgCO_2e$)
1	Steel	kg	0.85	1.76	1.50
2	Copper wire	kg	0.103	3.47	0.36
3	Nylon Bobbin	kg	0.015	1.91	2.87E-02
4	Polyester film	kg	0.01	7.54	7.54E-02
5	Aluminum	kg	0.005	12.2	6.10E-02
6	Paint	kg	0.002	1.79	3.58E-03
7	Thinner	kg	0.001	1.5	1.50E-03
8	Paper	kg	0.001	0.735	7.35E-04
Total CO_2 emission ($kgCO_2e$)					**2.024**

Table C-44 GHG emission from transportation of raw material of one magnetic ballast

NO.	List	Amount (kg)	CO_2 emission		Total CO_2 emission ($kgCO_2e$)
			Full load ($kgCO_2e$)	No load ($kgCO_2e$)	
1	Steel	0.85	2.83E-02	1.98E-02	4.81E-02
2	Copper wire	0.103	3.42E-03	2.40E-03	5.83E-03
3	Nylon Bobbin	0.015	4.99E-04	3.50E-04	8.48E-04
4	Polyester film	0.01	3.33E-04	2.33E-04	5.66E-04
5	Aluminum	0.005	1.66E-04	1.17E-04	2.83E-04
6	Paint	0.002	6.65E-05	4.66E-05	1.13E-04
7	Thinner	0.001	3.33E-05	2.33E-05	5.66E-05
8	Paper	0.001	3.33E-05	2.33E-05	5.66E-05
Total CO_2 emission ($kgCO_2e$)					**5.58E-02**

Remark: Vehicle type is 22-wheel semi-trailer trucks, 32 tons and distance of transport equal 700 km.

Table C-45 GHG emission from production process of one magnetic ballast

NO.	Inputs	Unit	Amount of used	E.F. ($kgCO_2e$/unit)	CO_2 emission ($kgCO_2e$)
1	Electricity	kWh	0.03	0.561	1.68E-02
Total CO_2 emission ($kgCO_2e$)					1.68E-02

Table C-46 GHG emission from distribution/retail of one magnetic ballast

NO.	List	Amount (kg)	CO_2 emission		Total CO_2 emission ($kgCO_2e$)
			Full load ($kgCO_2e$)	No load ($kgCO_2e$)	
1	Magnetic ballast	0.987	3.28E-02	2.30E-02	5.58E-02
Total CO_2 emission ($kgCO_2e$)					5.58E-02

Table C-47 GHG emission from usage stage of one magnetic ballast

Average life time (hour)	Power (kW)	Electricity (kWh)	E.F. ($kgCO_2e$/kWh)	CO_2 emission ($kgCO_2e$)
20,000	0.010	200	0.561	112.2
Total CO_2 emission ($kgCO_2e$)				112.2

Table C-48 GHG emission from recycle option of one magnetic ballast

NO.	Inputs/Output	Unit	Amount of used	E.F. ($kgCO_2e$/unit)	CO_2 emission ($kgCO_2e$)
1	Electricity	kWh	7.40E-04	0.561	4.15E-04
2	Water supply	m^3	2.90E-05	0.0264	7.66E-07
3	Sodium sulfide	kg	2.03E-03	0.39	7.92E-04
4	Cement	kg	2.90E-02	0.995	2.89E-02
5	Steel recovered	kg	0.85	-1.69	-1.44
6	Copper recovered	kg	0.103	-3.03	-3.12E-01
7	Aluminum recovered	kg	0.005	-11.91	-5.96E-02
Total CO_2 emission ($kgCO_2e$)					**-1.778**

Remark: (a) E.F. of steel recovered = E.F. of secondary production of steel - E.F. of primary production of steel = 0.07 – 1.76 = -1.69

(b) E.F. of copper recovered = E.F. of secondary production of copper - E.F. of primary production of copper = 0.44 – 3.47 = -3.03

(c) E.F. of aluminum recovered = E.F. of secondary production of aluminum - E.F. of primary production of aluminum = 0.29 – 12.2 = -11.91

Table C-49 GHG emission from landfill option of one magnetic ballast

NO.	Inputs	Unit	Amount of used	E.F. ($kgCO_2e$/unit)	CO_2 emission ($kgCO_2e$)
1	Electricity	kWh	2.52E-02	0.561	1.41E-02
2	Water supply	m^3	9.87E-04	0.0264	2.61E-05
3	Sodium sulfide	kg	6.91E-02	0.39	2.69E-02
4	Cement	kg	9.87E-01	0.995	9.82E-01
Total CO_2 emission ($kgCO_2e$)					**1.023**

Table C-50 GHG emission from raw material acquisition of one electronic ballast

NO.	Inputs	Unit	Amount of used	E.F. ($kgCO_2e$/unit)	CO_2 emission ($kgCO_2e$)
1	Steel	kg	2.15E-01	1.76	3.78E-01
2	Capacitor	kg	3.32E-02	83.1	2.76
3	PCB	kg	2.93E-02	27.7	8.12E-01
4	Insulation material	kg	1.05E-02	5.07	5.32E-02
5	Nylon bobbin	kg	5.40E-03	1.91	1.03E-02
6	Solder paste	kg	4.80E-03	2.12	1.02E-02
7	Jumper wire	kg	1.40E-03	1.99	2.79E-03
8	Copper	kg	3.79E-02	3.47	1.32E-01
9	Integrated circuit	kg	5.00E-04	9,160	4.58
10	Minor components	kg	1.93E-02	N/A	N/A
Total CO_2 emission ($kgCO_2e$)					**8.736**

Remark: E.F. of minor component is not available (5.4% by weight of electronic ballast)

Table C-51 GHG emission from transportation of raw material of one electronic ballast

NO.	List	Amount (kg)	CO_2 emission		Total CO_2 emission ($kgCO_2e$)
			Full load ($kgCO_2e$)	No load ($kgCO_2e$)	
1	Steel	1.78E-01	5.91E-03	4.14E-03	1.01E-02
2	Transformer	7.38E-02	2.45E-03	1.72E-03	4.17E-03
3	Capacitor	3.32E-02	1.10E-03	7.74E-04	1.88E-03
4	PCB	2.93E-02	9.74E-04	6.83E-04	1.66E-03
5	Insulation material	1.05E-02	3.49E-04	2.45E-04	5.94E-04
6	Resistor	6.00E-03	2.00E-04	1.40E-04	3.39E-04
7	Transistor	5.60E-03	1.86E-04	1.31E-04	3.17E-04
8	Nylon bobbin	5.40E-03	1.80E-04	1.26E-04	3.05E-04
9	Solder paste	4.80E-03	1.60E-04	1.12E-04	2.71E-04
10	Diode	4.60E-03	1.53E-04	1.07E-04	2.60E-04
11	Fuse	1.60E-03	5.32E-05	3.73E-05	9.05E-05
12	Jumper wire	1.40E-03	4.66E-05	3.26E-05	7.92E-05
13	NTC	1.00E-03	3.33E-05	2.33E-05	5.66E-05
14	Wire	1.00E-03	3.33E-05	2.33E-05	5.66E-05
15	IC's	5.00E-04	1.66E-05	1.17E-05	2.83E-05
16	Fixed inductor	2.00E-04	6.65E-06	4.66E-06	1.13E-05
17	Potential meter	3.00E-04	9.98E-06	6.99E-06	1.70E-05
Total CO_2 emission ($kgCO_2e$)					**2.02E-02**

Remark: Vehicle type is 22-wheel semi-trailer trucks, 32 tons and distance of transport equal 700 km.

Table C-52 GHG emission from production process of one electronic ballast

NO.	Inputs	Unit	Amount of used	E.F. ($kgCO_2e$/unit)	CO_2 emission ($kgCO_2e$)
1	Electricity	kWh	0.67	0.561	0.376
Total CO_2 emission ($kgCO_2e$)					**0.376**

Table C-53 GHG emission from distribution/retail of one electronic ballast

NO.	List	Amount (kg)	CO_2 emission		Total CO_2 emission ($kgCO_2e$)
			Full load ($kgCO_2e$)	No load ($kgCO_2e$)	
1	Magnetic ballast	0.356	1.18E-02	8.30E-03	2.01E-02
Total CO_2 emission ($kgCO_2e$)					2.01E-02

Remark: Vehicle type is 22-wheel semi-trailer trucks, 32 tons and distance of transport equal 700 km.

Table C-54 GHG emission from usage stage of one electronic ballast

Average life time (hour)	Power (kW)	Electricity (kWh)	E.F. ($kgCO_2e/kWh$)	CO_2 emission ($kgCO_2e$)
20,000	0.003	60	0.561	33.66
Total CO_2 emission ($kgCO_2e$)				33.66

Table C-55 GHG emission from recycle option of one electronic ballast

NO.	Inputs/Output	Unit	Amount of used	E.F. ($kgCO_2e$/unit)	CO_2 emission ($kgCO_2e$)
1	Electricity	kWh	2.66E-03	0.561	1.49E-03
2	Water supply	m^3	1.04E-04	0.0264	2.76E-06
3	Sodium sulfide	kg	7.31E-03	0.39	2.85E-03
4	Cement	kg	1.04E-01	0.995	1.04E-01
5	Steel recovered	kg	2.15E-01	-1.69	-3.63E-01
6	Copper recovered	kg	3.79E-02	-3.03	-1.15E-01
Total CO_2 emission ($kgCO_2e$)					**-0.369**

Remark: Same as Table C-48

Table C-56 GHG emission from landfill option of one electronic ballast

NO.	Inputs	Unit	Amount of used	E.F. ($kgCO_2e$/unit)	CO_2 emission ($kgCO_2e$)
1	Electricity	kWh	9.10E-03	0.561	5.11E-03
2	Water supply	m^3	3.57E-04	0.0264	9.42E-06
3	Sodium sulfide	kg	2.50E-02	0.39	9.75E-03
4	Cement	kg	3.57E-01	0.995	3.55E-01
Total CO_2 emission ($kgCO_2e$)					**0.370**

BIOGRAPHY

Miss Nonthaphat Suesareetham was born on August 29th, 1987 in Songkhla, Thailand. She obtained the Bachelor's Degree in Environmental Engineering from the Faculty of Engineering, Prince of Songkla University in 2008. She pursued her master degree in the International Postgraduate Program in Environmental Management (Hazardous Waste Management), Inter-Department of Environmental Management at Chulalongkorn University. She has presented her research at the 2011 International Winter Conference on Environmental Innovations and Sustainability held during January 28 to 29, 2011 in Beppu, Oita, Japan under the topic of "Greenhouse gas emission from the management of spent T8 fluorescent lamp set".