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Environmental Evaluation on Rigid Polyurethane Foam Disposal from Refrigerator Waste in Thailand

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Abstract

Rigid polyurethane foam (RPUF) is used as thermal insulation, especially in a refrigerator. After the refrigerator was discarded, it was dismantled by the dismantler. Most of the time, RPUF waste was found illegally disposed or openly burned, causing environmental problems and human health issues, owing to reckless management. Therefore, RPUF waste is one of the most concerning waste disposal, leading to this study. This study investigates on RPUF waste started from the beginning of the cycle, which was the chemical production, to the end of the cycle, followed by the dismantling site. The result revealed that the blowing agent, for example, HCFC-141b, HFCs, and cyclopentane, was added in a foam production process for refrigerator, an amine group was added as a catalyst and a flame retardant was not added in the RPUF used in the refrigerator. The study was collected survey from the dismantling sites in 5 regions of Thailand (19 dismantling sites). These indicated that the disposal options of the RPUF wastes were landfill (47.83%), open burning (21.74%), sanitary landfill (13.04%) incineration (13.04%) and refuse-derived fuel or RDF (4.35%), respectively. Landfill presents the main disposal method for RPUF waste in Thailand. For environmental aspect, in 2018-2031, the landfill disposal will affect the environment in terms of global warming 22,175.36-39,290.65 kg CO_2 eq/yr, ozone depletion 0.015-0.027 kg CFC11 eq/yr and terrestrial ecotoxicity 52,098.17-92,308.34 kg 1,4-DCB/yr.

Keywords: Rigid polyurethane foam waste, Disposal, Environmental impact

1. Introduction

The rigid polyurethane foams (RPUFs) are vastly used as insulation in an appliance, building, refrigerated-truck, and automotive. Its structure of highly crossed-link and closed cell made RPUF high thermal resistance and appropriate for insulated applications (Szycher, 2013; Sharmin and Zafar, 2012).

RPUF is mainly reacted by polyols and isocyanates. The chemicals added in the production process are a catalyst, blowing agent, flame retardant, and other additives such a surfactant (Kaneyoshi and Kadzuo, 1995; Singh, 2016). The crossed-linked structure of RPUF leads to difficult degradation and occupy landfill spaces. Besides, the blowing agent added; e.g.CFC-11, HCFCs, for foam formation to provide the high efficiency in thermal insulation also causes environmental problems (Kaneyoshi, 2007). Although the CFC-11 was banned and phased out under the Montreal Protocol since 1989 and 1996 for a developed country (Singh, 2002), in Thailand (a developing country in Article 5(1)) CFCs had been freeze in 1999 and was phased out in 2010 (The Department of Industrial Works, 1995).

With the encouragement of the Polyurethane Industry (PUI) in Thailand, information on chemicals usage for polyurethane production was examined in 2017. Approximately 75,000 tons of chemicals are used for 9 applications a year. The chemicals are used in refrigerator, ice box, panel, commercial fridge, spray, pipe, truck & boat, box foam, and rigid headlining for automotive — the number of chemicals are used for each application as shown in Figure 1.

The highest amount of polyurethane usage goes to a refrigerator, approximately 80% of chemical usage. Thus, this study will focus on the RPUF wastes from the refrigerator. According to the Office of Industrial Economics (OIE), the statistic of refrigerator domestic sale in 2000-2018 was around 1-2 million units/year. The expected lifespan of a refrigerator in Thailand is 14 years (The Pollution Control Department, 2007). During the freeze period, it is possible that CFC-11 blowing agent was being added to RPUF in the refrigerator. There is a possibility that CFC gas releases into the environment during the refrigerator lifespan (Kjeldsen and Jensen, 2001).

Flame retardant is another substance from the refrigerators that is concerned in the study. Due to its the effect to animal and human health which can cause bioaccumulation in blood, breast milk and umbilical cord blood (Ike and Jacob, 2012; Beard and Angeler, 2010). Overall, this research aims to investigate the RPUF waste

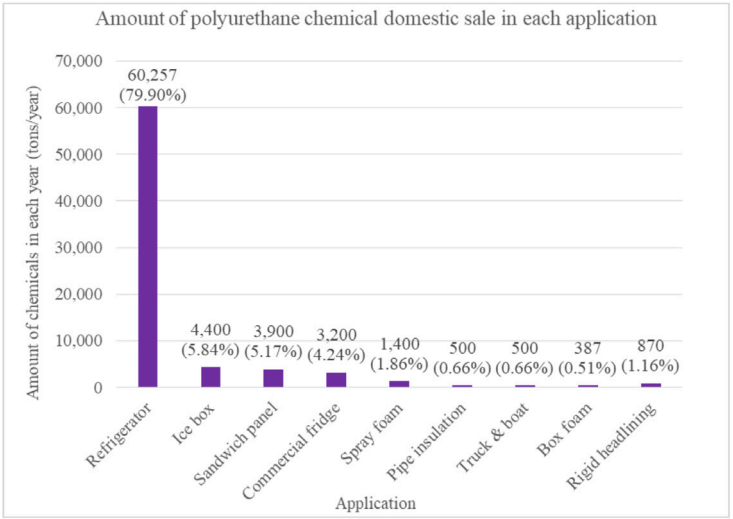

Figure 1. Amount of chemicals domestic sale in each application

Table 1. The data collection from dismantling sites each region

Topic	Total respondent	Required information
Central (Bangkok, Nakhon Pathom)	5	1) The used refrigerator disassembling process
North (Chiang Mai, Lampoon)	9	2) The disposal option or recycling process for RPUWs
East (Sa Kaeo)	6	3) Transportation & disposal fee
North-east (Kalasin)	3	4) The problem of RPUWs management
South (Nakhon Si Thammarat, Phuket)	5	

disposal in Thailand, especially on blowing agent and flame retardant, which can be used as the baseline data for further development of management planning and policy. The information on foam wastes disposal would be used for an assessment of environmental pollutants and suggest alternative disposal or recycling options for the refrigerator foam wastes.

2. Materials and Methods

2.1 Data collection

Regarding the study of RPUF waste baseline management and environmental impact, the scope of stakeholders was set from the chemical manufacturers to the end of the life products. Stakeholders were classified into three groups in which the respondents were interviewed through phone and field visit.

(1) A chemical producer refers to the producer of polyurethane where the chemicals would be imported or produced. Information on chemical; i.e., a blowing agent and a flame retardant, used for rigid polyurethane foam, were given from 5 respondents out of 15 polyurethanes industry memberships.

(2) A refrigerator producer refers to a refrigerator manufacturer that may give information on the refrigerator chemical usage and the disposal or recycle of PU foam wastes from the production process. The information was obtained from 4 respondents out of 10 most prominent companies which accessed from the database of the Department of Business Development.

All respondents come from large and well-known companies; thus, the obtained information can represent the chemical used in the refrigerator and also the disposal or recycling process.

(3) Dismantling site refers to a store or a shop or people who disassemble a used refrigerator. The required information from the dismantling sites was a focus on current foam wastes management, transportation, disposal fee, and trouble of foam wastes management, which was shown in Table 1.

The survey information was obtained from 28 respondents from 5 regions which comprised of 19 dismantling sites, 8 recycling sites, and 1 industrial waste recycling plant. The difference location presents either the similarity route or the different route for foam wastes disposal in each region.

2.2 Environmental impact assessment

The environmental impacts from the main disposal option of RPUF waste were evaluated by using an emission factor from the SimaPro software. The world ReCiPe midpoint impact assessment method was selected to estimate the environmental impacts of this study.

The environmental impact of polyurethane foam waste disposal in this study would assess by the following equation.

$$Environmental\ impact = EF \times (NF \times Di)$$

Where: EF is an emission factor, NF is the amount of RPUF generated from refrigerator wastes in each year (tons/year), Di is the percentage of the largest disposal method (%)

The lifespan of the refrigerator was estimated to be an average of 14 years (The Pollution Control Department, 2007). RPUF waste generated would be calculated from domestic sale of the refrigerator in the past 14 years and the amount of RPUF used in the refrigerator (average 7 kg/refrigerator) which obtained from the refrigerator production interviewed. With the assumption that those refrigerators would become waste in the next 14 years; i.e., from 2018 to 2031, the disposal of RPUF wastes would definitely affect the environment.

3. Results and Discussion

3.1 The chemical used for rigid polyurethane foam

The chemical concern in this study is blowing agents and flame retardants. According to the interview, the chemical used for foam formation consists of blowing agent; i.e. HCFC-141b (20-30 %phr of polyol), HFC-245fa (10-15%phr of polyol), HFC-134a, HFC-365, Cyclopentane (12-15 %phr of polyol), isocyanate and water. All refrigerator producers reported that cyclopentane has been using as the blowing agent for more than 10 years, which conform to the phased out period of CFC-11 in Thailand (The Department of Industrial Works, 1995).

However, flame retardant was not found as an additive in a refrigerator RPUF (appliance application). Whereas, flame retardant in RPUF was found in building application and transportation such panel, spray, pipe ,and refrigerated truck since those applications are required for fire safety issue (Edward and Sergei, 2004). Brominated flame retardant was widely used to reduce the flammability of products in the past. Due to the Stockholm Convention on Persistent Organic Pollutants, the brominated flame retardants were added on the list in 2009 which induced to an alternative flame retardant use such as organophosphorus flame retardants (OPFR) (Haffner and Schecter, 2014).

The producers also reviewed that rigid polyurethane foam wastes from production process were transported to the cement plant by authorized agent and used as a replacement fuel. However, the recycling process of RPUF wastes such as mechanical recycling or chemical recycling was not found from both chemical and refrigerator producer, but waste to energy option was chosen by the transporting foam waste to a cement plant.

3.2 Disposed of rigid polyurethane foam wastes

The information of RPUW from the dismantling sites in 5 regions of Thailand showed that the used refrigerators were compiled from either household or hotel/industry by recycling collector or recycling store. The fridge would be disassembled into 2 parts at the dismantling site (1) valuable materials; i.e., steel and copper, and (2) non-valuable materials. RPUWs were mostly classified as non-valuable materials.

According to the management of RPUW in central of Thailand interviewed, from both Bangkok and Nakhon Pathom with registered population of 5,682,415 and 911,492 in 2017 respectively (Announcement of the Bureau of Registration Administration, 2017), stated that RPUWs were gathered up till approximately 1 ton to transport using a pick-up truck to a disposal site in 1-2 times/month. As a result, all dismantling sites (5 sites) revealed that their foam wastes are disposed at a landfill or a municipality disposal site for domestic waste. The disposal fee is required to pay. Transportation of foam wastes to the disposal site is the main problem for the foam wastes

management, due to its high volume and may not be economically worthwhile.

In the northern part of Thailand (Chiang Mai and Lampoon with registered population of 1,746,840 and 405,918 in 2017 respectively (Announcement of the Bureau of Registration Administration, 2017)). The amount and the managed procedure of RPUWs of the north are similar to the central one, which is dumped to the designated area for domestic waste or sanitary landfill. Besides, open burning is one of the foam waste management options in the north. The results (from 5 dismantling sites) showed that 20% of dismantling sites disposed to landfill, 20% of them conduct open burning and 60% of them transported foam waste to the sanitary landfill. Regarding the waste disposal fee and foam waste problem, they are similar to the central one.

Sa Kaeo province, had the population of 560,531 in 2017 (Announcement of the Bureau of Registration Administration, 2017), was chosen in the study as the Thailand-Cambodia bordered where electronic wastes may be imported into the country. According to the interview, there is only one dismantling site out of six respondents which presents the most significant source of foam waste in the eastern region. As a part of refrigerators, such the partitions and the doors which contained a large amount of RPUF, was dismantled. The foam wastes were piled up and transported to the industrial waste management area where the foam wastes were shredded and mixed with others wastes to produce refuse-derived fuel (RDF) product. RDF is a fuel produced from various type of waste which has adequate heating value to replace fossil fuel. The disposal fee is required if the industrial waste management take care of the foam wastes. On the other hand, if the dismantler is carrying foam waste by themselves, the disposal fee is not necessary.

Kalasin province, the northeastern region of Thailand, with a population of 986,005 in 2017 (Announcement of the Bureau of Registration Administration, 2017), is one of the most significant places for dismantling electronics waste, including refrigerator, non-valuable materials were dump to landfill where it becomes e-waste's landfill at present. The results revealed that all of the dismantlers transported the foam wastes to the disposal site near dismantling sites by a pick-up truck. After the wastes were ended up in landfill, it was burnt in order to get valuable-materials remaining attached beside the foam; i.e., copper. The interview showed that the disposal option for foam wastes was 50% disposed to landfill and open burning 50%. Moreover, there is no policy on the disposal fee at present; thus the payment is not required.

In the southern part of Thailand, Nakhon Si Thammarat and Phuket were chosen to collect

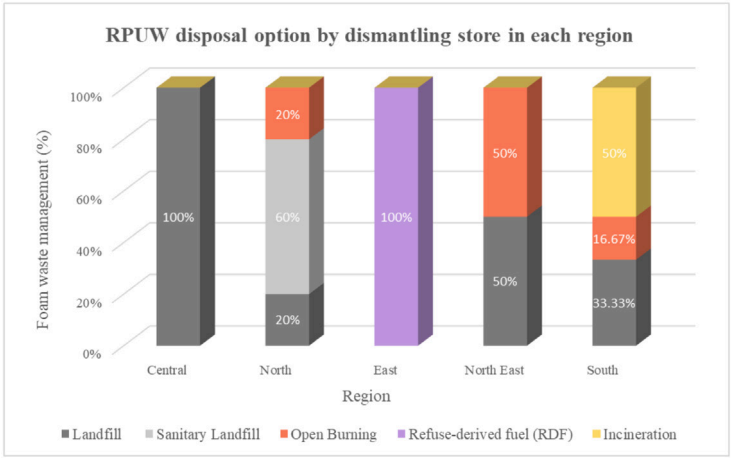

Figure 2. The rigid polyurethane foam wastes management in each region

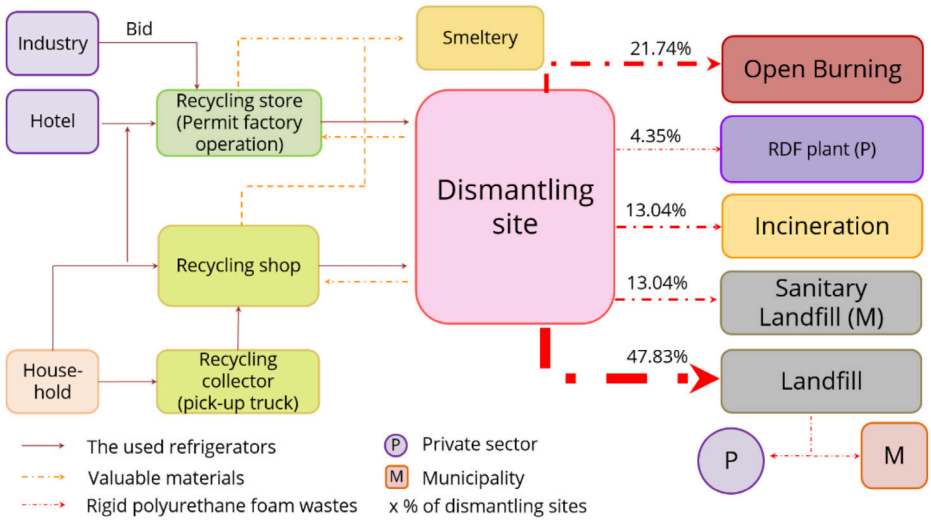

Figure 3. Route of rigid polyurethane foam wastes disposal in Thailand

information because Nakhon Si Thammarat has the highest population of 1,557,482 in 2017 (Announcement of the Bureau of Registration Administration, 2017) and Phuket is the largest island in Thailand, with a population of 402,017 in 2017 (Announcement of the Bureau of Registration Administration, 2017). The foam waste management demonstrated differently from other regions. There are 3 options to dispose RPUF waste in southern; i.e., landfill, open burning, and incineration. The landfill (33.33%) and open burning (16.67%) options were found in Nakhon Si Thammarat, while, the incineration option (50%) was found in Phuket. Regarding the topography, Phuket is an island where the disposal option is quite attractive compared to other provinces. This is due to the used refrigerator from both household and hotel would be sent to the dismantling site. As a result, all of the dismantling sites transported foam wastes to the incineration plant belong to Phuket's municipality. The foam waste would be combusted together with municipal solid waste. The disposal fee also required, and the main problem of the foam waste from the dismantler point of view is also the transportation.

Consequently, the disposal method is related to the location of the dismantling and disposal site. For example, if the dismantling site located close to a landfill, the foam wastes will go to the landfill site. Whereas, dismantler will burn the wastes if there is no disposal site nearby. The summary of RPUW management options from the dismantling sites in 5 regions showed in Figure 2.

The overall disposal options from 19 dismantling sites in Thailand implied that the main disposal for the foam wastes is the landfill method (47.83%) followed by open burning (21.74%), sanitary landfill (13.04%), incineration (13.04%) and RDF plant (4.35%). Figure 3 illustrated the route of RPUF wastes disposal in Thailand.

3.3 Environmental impacts assessment

This study would focus on an environmental impact from the majority of the disposal method. As mentioned, almost 50 percent of RPUW method is landfill. Moreover, the information from the chemical production and the refrigerator production shows that HCFCs and cyclopentane are used as blowing agent and non-use of flame retardant. Thus, the flame retardant effect would not be evaluated. The SimaPro database for 1 kg of RPUF waste disposed to a landfill was selected with the most common impact categories from polyurethane foam waste comprise of global warming and stratospheric ozone depletion. Besides, this study also concerns about toxicity; thus, the

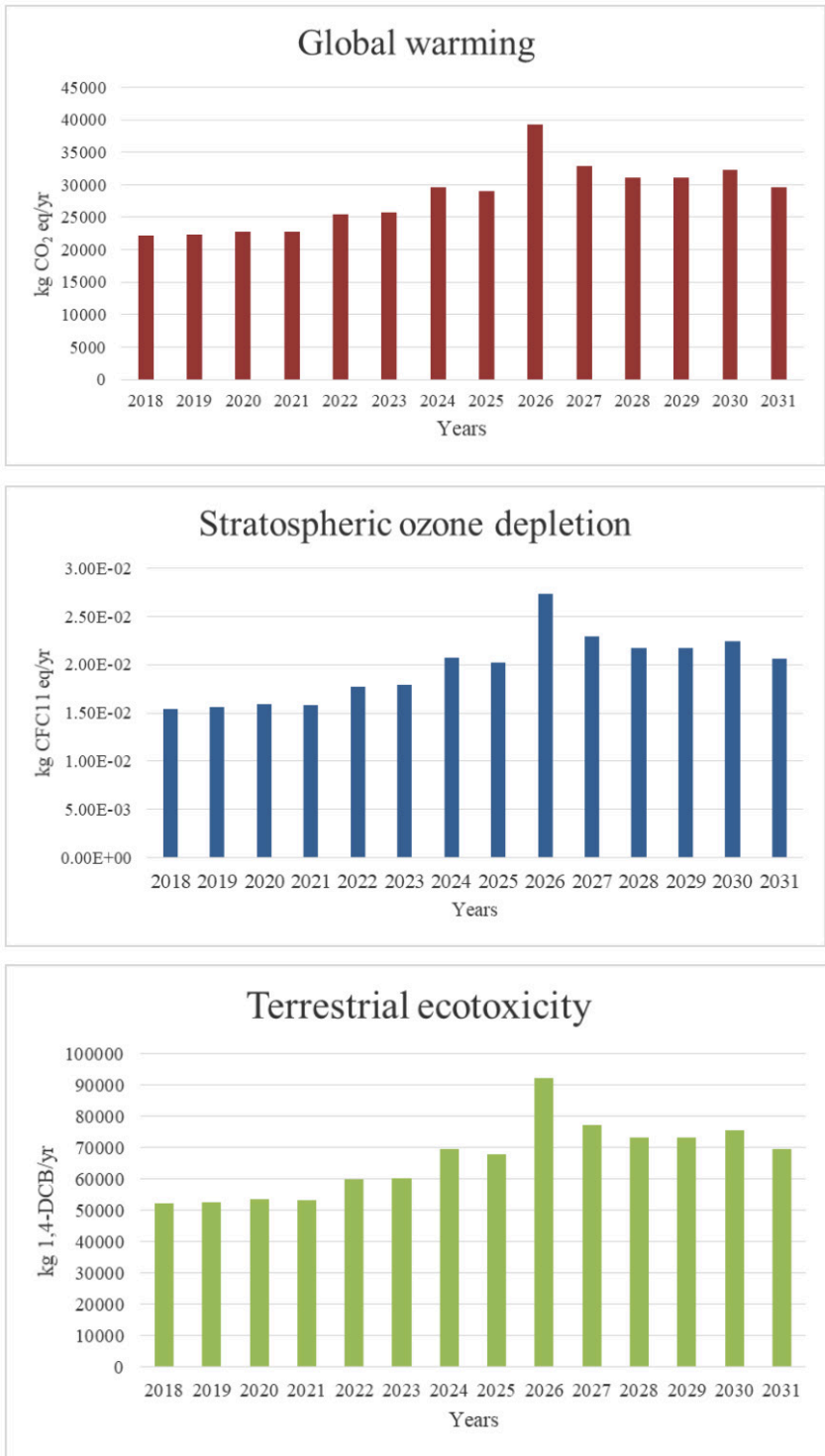

Figure 4. The prediction of environmental impacts; i.e., global warming, stratospheric ozone depletion, and terrestrial ecotoxicity, from landfill method for rigid polyurethane foam waste

terrestrial ecotoxicity was selected because it shows the highest emission factor among other toxicities (Marine, freshwater, human carcinogenic, and non-carcinogenic toxicity). The emission factors are 0.0054 $kgCO_2$ eq for global warming, 3.78×10^{-9} kgCFC11eq for stratospheric ozone depletion and 0.0127 kg1,4-DCB for terrestrial ecotoxicity.

The prediction of an environmental impact from RPUW disposed to the landfill was calculated from both the SimaPro database and the estimated foam waste, shown in Figure 4. As a result, the used refrigerator disposal in the past 14 years would affect the environment at present (2018) and the next 14 years in term of the global warming about 22,175.36 – 39,290.65 $kgCO_2$ eq/yr, and affect the stratospheric ozone depletion about 0.015-0.027 kgCFC11 eq/yr. These impacts mainly come from the blowing agent, using in RPUF. When compare the greenhouse gas (GHG) emission from RPUF in landfill with total GHG emission from the waste sector in Thailand which was $11,830\times106$ $kgCO_2$ eq/yr in 2013 (Ministry of Natural Resources and Environment, 2017), the RPUF in landfill emission is so small. To compare the impact on the stratospheric ozone depletion with a total emission of ozone-depleting substances, which was about 32×1010 kg CFC11 eq/yr in 2014 (Hegglin *et al.*, 2014), bury of RPUW shows a small emission. An assessment on terrestrial ecotoxicity result that about 52,098.17 – 92,308.34 kg 1,4-DCB/yr would be affected due to the emission of silicon and barium, which are the components of RPUW. Generally, silicon is added as a surfactant for rigid polyurethane foam while barium sulfate (barytes) is used as filler for both flexible foam and semi-rigid foam, especially for noise absorption application. Moreover, Yadav and Samadder (2017) assessed an environmental impact of municipal solid waste (MSW) landfilled, which was the main existing option in India. It indicated that landfill of 1 kg MSW affected the environment and had global warming potential 9.42 $kgCO_2$ eq, ozone depletion potential 7.60×10^{-10} kgCFC11 eq, and terrestrial ecotoxicity 7.87×10^{-6} kg 1,4-DCB (Yadav and Samadder, 2017). It can imply that 1 kg RPUW landfilled has more considerable terrestrial ecotoxicity impact than MSW, less global warming potential, and slightly high for ozone-depleting potential.

From the calculations, the highest impacts show in 2026 because the great flooding occurred in Thailand (2011) and the domestic refrigerator sale was increased by 35% in the following year. The amount of foam wastes, therefore, would be increased in 2026. The highest environmental impacts also demonstrated in the same year.

However, this assessment predicted from the used refrigerator when CFC11, blowing agent, may be added during the foam production. As mentioned, CFC11 was phased out in 2010, and it could signify that the refrigerator produced during that time would affect the environment. Under the Montreal Protocol, an environmental impact, especially ozone depletion and global warming should decrease. Since an alternative blowing agent; i.e., HCFCs, HFCs, and cyclopentane, was proposed as it presents low ozone depletion, and global warming potential compares to CFC11 (The United Nations Environment Programme, 1994).

4. Conclusions

This research aims to obtain the current situation of rigid polyurethane foam wastes disposal in Thailand and evaluate environmental impacts from the wastes disposal options. An exploration from the cradle to the grave found that RPUF wastes from their production process were sent as fuel to a cement plant while the foam wastes from the refrigerator dismantlers were mainly transported to a landfill site. Not only reduce the landfill area but RPUW also affect climate and ozone depletion because of blowing agent added. Besides, silicon and barium used in foam production would affect the terrestrial ecotoxicity. Those impacts would be long term effect due to the structure of polyurethane is challenging to degrade; thus, this research would suggest waste to energy option for foam wastes management. These waste to energy options; i.e., incineration and RDF, would be possible because some

dismantling sites and refrigerator producers are using. However, both options should be installed the control equipment in order to reduce and control the pollutant emission to meet the air quality standard.

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