Sustainable Waste Utilization for the Petrochemical Industry in Thailand under Circular Economy Principle: A Case Study

Khamhan Ittiprasert and Orathai Chavalparit

***Abstract*—In order to support circular economy principles, this study proposed alternatives to current waste management and utilization methods used by the olefin production industry in Thailand. Waste types were categorized by GRI 306-2, with energy recovery (67%) and incineration (23%) identified as the largest current waste management methods. Oil contaminated wastewater, yellow oil and caustic soda, and bio-sludge were identified as the largest categories of waste, each with the potential to be recycled in value-adding methods. For oil contaminated wastewater, hydrocyclone technology was identified for potential application. The recovery of caustic soda into process required a separation technology with high separation efficiency, and membrane filtration was preferred. Bio-sludge from wastewater treatment plants can be converted into methane gas by anaerobic co-digestion with used oil, with subsequent utilization of the methane gas in electrical production. In order to propose applicable options, each alternative technologies were evaluated by sustainable indicators. As further consideration, subsidies for specific technologies from administrative agencies can improve the technologies' sustainability, environmental, economic, and social performance.**

***Index Terms*—Waste utilization, sustainability, industrial wastes, olefin plant, waste management.**

I. Introduction

In the preceding decade, the development of sustainable waste management in Thai industries had focused on decreasing waste to landfill [1]. Incineration, amongst other alternative options, have been offered as methods to reduce waste to landfill [2], [3]. Incineration can reduce solid waste in large volumes and can remove harmful contaminants in solid waste; however, landfilling was still required for the disposal of bottom ash after the process. In addition, incineration produced air emissions released into the atmosphere which can promote climate change [4]-[6].

Circular economy systems had become a new trend in economic development, focusing on both environmental and societal benefits. In order to achieve circular economy, industrial activities can be designed for reducing resources usage and minimizing wastes generation from process, increasing recycling of products and materials in use, and transitioning to the use of renewable energy sources [7]. A variety of circular economy concepts had been introduced in various countries including the Netherlands, Austria, and China [8]-[10].

Historically, high volumes of solid wastes had been generated by petrochemical industries in eastern Thailand per year, whom had applied incineration instead of landfilling for waste disposal [11]. The olefin industry was one part of the petrochemical sector that produces organic chemical compounds including ethylene and propylene from natural gas and naphtha. Some wastes from olefin processing, such as oil-contaminated wastewater or used lubricants, had high heating values, and had the potential to be recovered as energy fuels when incinerated [12], [13]. However, this waste recovery option was not sustainable since incineration and energy recovery had a high associated management cost. Other research on the implementation of circular economy on petrochemical wastes had suggested increasing the use of renewable resources to produce bioplastics to replace plastics produced from non-renewable resources [14], burning sludge as an alternative energy in a cement kiln [1], and recycling polyethylene terephthalate (rPET) scrap to synthesize flexible polyurethane (PU) for automotive interior applications [15].

Various options for sustainable waste management had thus already been introduced to improve current waste management strategies. This study looked into the feasibility of alternative waste utilization options in upstream petrochemical industry. The circular economy approach had been used to evaluate such options. The proposed methodologies and technologies were evaluated by sustainable development indicators.

II. Materials and Methods

A. Upstream Petrochemical Case Study

Three olefin plants located in the Map Ta Phut Industrial Estate (MTPIE), Rayong province, in eastern Thailand were selected as case studies. These plants used natural gas and naphtha as raw material feedstock to produce downstream petrochemicals such as propylene, high density polyethylene (HDPE), low density polyethylene (LDPE), and linear low density polyethylene (LLDPE). The annual production of the three olefin plants is approximately 3,000,000 tonnes.

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Khamhan Ittiprasert is with Department of Environmental Engineering, Faculty of Engineering, Chulalongkorn University, Bangkok, Thailand (e-mail: khamkhan.itps@gmail.com).

Orathai Chavalparit is with Research Program: Sustainable Management of Industrial and Agricultural Wastes for Transitioning to a Circular Economy, Center of Excellence on Hazardous Substance Management (HSM), Bangkok, Thailand (e-mail: orathai.c@chula.ac.th).

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B. Data Collection and Analysis

Waste storage and waste treatment processes at the olefin plants were surveyed and data was collected on waste sources, types of waste, quantity of waste, and existing waste management methods. With this data, a waste inventory was created. Collected data, waste types, and existing waste management methods were categorized follow GRI 306-2 standards which addresses topics of waste types and disposal methods. Hazardous solid wastes were identified before being reported according to their disposal methods such as reuse, recycling, composting, recovery, incineration, landfilling, or others [16]. Afterwards, each category of waste was prioritized based on the volume managed under each waste disposal method, in order to identify potential for waste reutilization.

C. Introduce Possible Options to Improve Waste Management

Various alternative options and best practices suggested by many publications were reviewed to identify possible options that could be applied at the plants, based upon each option's technical, readiness, and economic feasibility. The options served to improve the waste management performance of the olefin factories. Circular economy approaches for waste management included waste reduction, reusing or recycling waste, refusing waste, and using renewable resources. Particular focus was given to recycling which refer to the processing of used or discarded materials into valuable products. In order to quantify appropriate options, this report considered not only economic aspects, but also social and environmental aspects as well.

III. Results and Discussion

A. Hazardous Waste Generation

Most of the solid waste generated from the three olefin plants (82%) was classified as hazardous waste. Waste sources included the production process, maintenance, packaging process, and wastewater treatment. Since these factories had a policy on zero waste to landfill, all of the hazardous waste was sent to waste disposal factories certified by the Department of Industrial Works. As shown in Fig. 1(a), the largest proportion of total hazardous waste generated (67%) was used as a source for energy recovery, consisting of fuel substitution and fuel blending. The second largest portion of waste was disposed of by incineration (23%); this method was further separated into two types in Fig. 1(b): co-incineration in cement kiln, and incineration. It was observed that reuse and recycling were as low as 5% and 1%, respectively.

There was a total of 37 different types of hazardous waste employed in recovery or incineration. Of all these types, oil contaminated wastewater attributed to the highest amount at 5,004 tonnes per year and accounting for 48% of all hazardous waste. Following in second and third were spent caustic soda with yellow oil, and sludge from wastewater treatment (bio-sludge) at 7% and 6%, respectively as shown in Fig. 2. These wastes have properties giving them potential to be recycled into process.

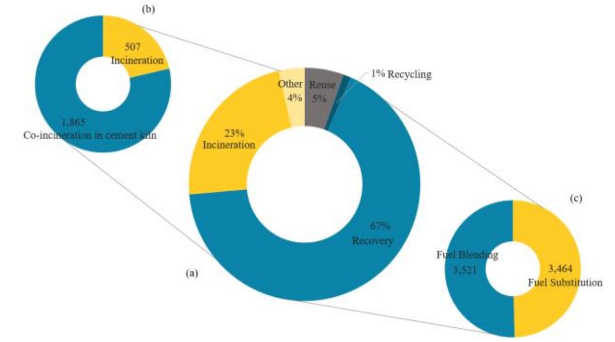

Fig. 1. (a) The hazardous waste management method categorized by GRI 306-2. (b) Amounts of waste to incineration. (c) Amount of waste to energy recovery.

B. Existing Waste Management

The three types of hazardous wastes with the highest volumes previously listed had the potential to be reused or recycled such that costs associated with waste disposal and resource usage were reduced. Outside of the top three hazardous wastes, of lesser volume, waste oligomer and insulation (Fig. 2) may also had potentials to be reused or recycled in the future.

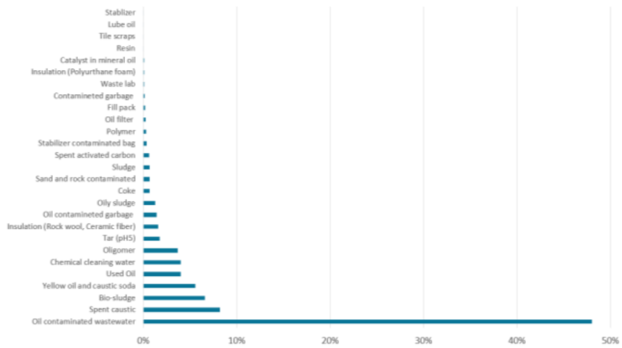

Fig. 2. Quantity of hazardous waste generated from olefin plants.

1) Oil Contaminated Wastewater

Oil contaminated wastewater (OCW) was generated from the production process and maintenance. The disposal method of this waste by each plant was different due to variables in the waste oils' heating values and management cost. OCW with a high heating value could be used as fuel substitute, but OCW with a low heating value had to be sent for quality improvement before it was suitable for use in fuel blending or co-incineration in cement kiln (Fig. 3). While the petrochemical process had a high demand for fuel feedstock, the aforementioned plants did not recycle OCW into the fuel feedstock. Therefore, there was untapped potential for these olefin factories to invest in oil recycling in order to reduce costs from waste disposal and by reducing fossil feedstock from fuel usage. Other methods of reducing the cost or impact of OCW, but will not be analysed further in this study, is to improve the quality of waste oil that could be recycled at its source, or treating the OCW via reverse osmosis technology that was already being used in the wastewater treatment plant.

2) Yellow Oil and Caustic Soda

Caustic soda or sodium hydroxide (NaOH) was used for improving water quality in the olefin production process. After processing, caustic soda contaminated with yellow oil was usually disposed of via incineration or fuel substitution (Fig. 3). Some olefin plants had tried to recycle some caustic soda that remained in good quality for reutilize in their process by increasing retention time by waste tank to separate out the yellow oil. However, the removal efficiency of such method was less than desired, and oil vapor byproducts generated from the additional processing had adverse impacts on human health. Instead, it was necessary to use quality separation technology to increase the utilization of caustic soda recycling in order to reduce waste disposal cost and import chemical cost.

3) Bio-Sludge

Bio-sludge generated from the activated sludge wastewater treatment system at the plants was currently disposed of to the cement industry for co-incineration, even though bio-sludge had the potential to be converted into valuable products. Properties of bio-sludge, especially heating value and moisture content, was very important in identifying the appropriate waste management method. The heating value of the bio-sludge examined in this study was considered high at 20.5 MJ/kg-sludge due to the bio-sludge's high hydrocarbon content. However, heating value can decrease with an increasing moisture content that was seen to be as high as 75.3 wt% [17]. In addition, a high concentration of volatile matter (58.6 wt%) and oxygen elements (39.7 wt%) could be managed by decomposition and pyrolysis methods. Nonetheless, the metal content (Fe, Al, Mg, Na and Zn) found in bio-sludge compounds required pre-treatment of the bio-sludge before it could be recycled.

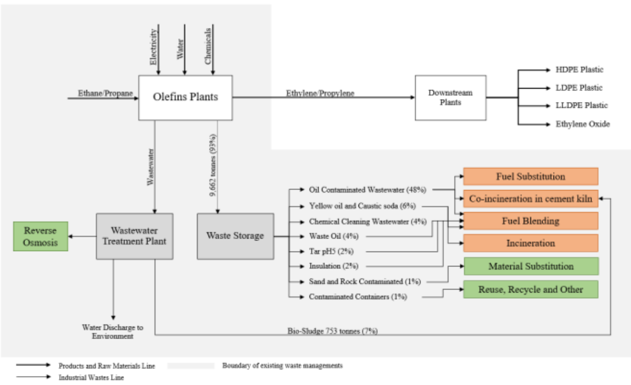

Fig. 3. Existing hazardous waste flows in three olefin plants case studies.

C. *Proposing Feasible Alternatives*

From hazardous waste analysis, oil contaminated wastewater, yellow oil/caustic soda, and bio-sludge were identified as wastes with potentials to be reused or recycled into the olefin production process. The quality of waste oil from separation was an important consideration for waste utilization, especially the waste oil's heating value that can indicate the quality of the oil as a fuel substitute. Separately, some waste caustic soda that was still of good quality can be reused in process, but an efficient method of separating yellow oil and caustic soda was required to make caustic soda reutilization worthwhile. Bio-sludge had the potential to be managed either by being decomposed to produce agricultural products because of its organic-compound contents, or being converted into fuel because of its high heating value.

1) Oil Contaminated Wastewater

Used oil contamination in wastewater had the potential to be use as a fuel substitute because of its heating value, as high as 30,000-40,000 kJ/kg. However, the moisture content of the oil contaminated wastewater examined in this study reduced the heating value of the oil so much so that the oil was not of high enough quality to be feasible for reuse. To improve the opportunity of recycling contamination oil, an effective water/oil separator will be required, and this study offered three separator technologies for consideration. First, membrane filtration was a highly effective technology, with a separation efficiency as high as 98%, with the advantage of removing oil emulsions in water as well [18]. However, the potential of this technology was limited by membrane lifetime which affects maintenance cost, and the potential for used membrane to release absorbed contaminated oil and heavy metals back into the environment. Another separation method was the use of hydrocyclone technology, where water and oil were separated by centrifugal force. Beyond a great separation efficiency, hydrocyclones also had the advantage of not generating any additional solid wastes throughout its equipment lifetime [19]. After water and oil are separated, water can be reused in process with further treatment by reverse osmosis. Finally, solvent extraction was an interesting potential alternative to improve oil quality because this method is already proven in commercial scale; Osman, Attia and Taman (2018) reported that solvent extraction blends (2-propanol, 1-butanol, and butanone) used at a 1:3 oil to solvent ratio provided good separation efficiency with a high percentage of particle removal [20]. Nevertheless, the effectiveness of solvent extraction technology depended on the portion of oil in water. If the portion of oil in water was less than 10%, a higher dose of solvent was required.

2) Yellow Oil and Caustic Soda

The ability to recover yellow oil and caustic soda (NaOH) for reuse in the olefin production process depended on separation efficiency. Yellow oil utilization depended on its quality after separation. Good quality yellow oil can be sent to the refineries' cracking process to produce more valuable products or be used as fuel in electrical production. Currently, low quality yellow oil had to be disposed of via incineration in cement production. Therefore, an efficient separation technology was necessary to recover and recycle yellow oil. First method was a liquid-liquid extraction using two hydrophobic room temperature ionic liquids under pressure. Unfortunately, the cost of this technology was high and its efficiency depended on exposure time between waste and chemical that further complicated operational costs [21]. Another separation method was nanofiltration through polymeric membranes, where very high separation efficiencies can be achieved, as high as 99.9% in a piloting scale demonstration at a Portuguese oil refinery. To evaluate the feasibility of nanofiltration, the high initial cost of converting membrane technology, as well as the high lifetime cost from disposal of used membranes must be considered. In addition, membranes were sensitive to various chemicals and high temperature conditions that make them require effective control systems [22]. A third separation method was bipolar membrane electrodialysis where a high separation efficiency can be achieved but the process required more electricity than other technologies. Furthermore, the lifetime of the membranes used in this technology was quite short while the maintenance cost was quite high [23].

3) Bio-Sludge

In order to creating value added products from bio-sludge, hydrocarbon content played an important role. Three options of converting hydrocarbon to value-added products were proposed. First, bio-sludge can be composted with additive materials by bacteria to produce fertilizer [24]. This method was already proven commercially at a factory in Rayong province, Thailand, where the local market had a high demand for fertilizer driven by close-by agricultural activities. Second, bio-sludge can be converted into biochar via pyrolysis as another value-added product for agricultural application used to improve soil quality. Pyrolysis also had the added advantage of reducing concerns of heavy metals contaminated in soil from sludge utilization [25]. Third, sludge digestion with co-material can produce biogas or methane gas under thermophilic conditions, with the generated gas then being used as fuel gas in petroleum and electrical production [26].

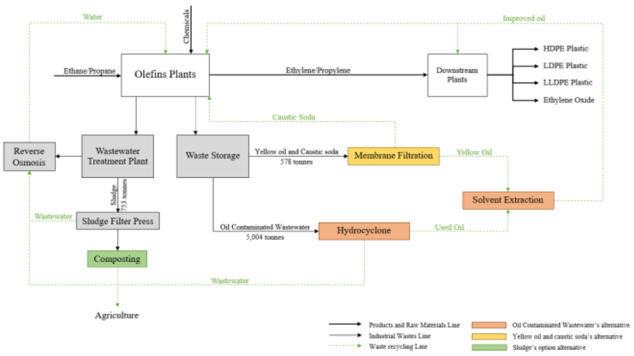

Fig. 4. Schematic diagram for feasible alternatives of waste utilization in the olefin plants.

IV. Conclusions

This case study identified three main types of hazardous waste from the Thai olefin industry attributing to ~61% of all of the industry's hazardous wastes: oil contaminated wastewater, yellow oil/caustic soda, and bio-sludge. Based on data, hazardous wastes from the olefin plants were normally managed via energy recovery at 67%, followed by incineration at 23%. The implementation of circular economy concepts can move these olefin factories' hazardous waste management methods in a more sustainable direction. Of all the possible alternative options for managing each of the three main hazardous waste types examined in this case study, using hydrocyclone technology to improve the quality of oil contaminated wastewater deserved further investigation because of this technology's high efficiency and long-term cost-effectiveness. In regards to environmental aspects, hydrocyclone did not generate waste or pollution after processing. For caustic soda recovery, improved quality and purity were requirements in feasibly recycling the waste. Nanofiltration by polymeric membranes had very high performance in regards to improved quality and purity. However, membranes become solid waste at the end of their individual lifetime which still created an impact on the environment and increased waste management costs. The properties of bio-sludge allowed for many possibilities to convert this waste into valuable products. The technology to convert bio-sludge into biogas was interesting, but this technology required complicated control systems and the volume of bio-sludge was too little to make investment worthwhile. Hence, converting bio-sludge into fertilizer was offered as an option because the composting process is easy to operate and did not require investment into high technology. Not only did composting had economic benefits, it also had social benefits as well since the fertilizer produced by this method promoted agricultural production in Rayong province. However, the investment into these technologies was expensive in order to increase cost-effective, and as a result of government subsidies may be required to make these alternatives feasible.

TABLE I: Advantage and Disadvantage of Feasible Technologies

Technology	Advantage	Disadvantage	Reference
Oil Contaminated Wastewater			
Membrane Filtration	98% effective and can remove oil emulsions in water	Spent membrane affect the environment and disposal cost	[18], [27], [28]
Hydrocyclone Technology	High efficiency and does not generate solid waste	Requires electrical energy; separation efficiency depends on waste composition	[19], [29], [30]
Solvent Extraction	Improved quality of used oil by removal of particles	Requires higher dosage of chemicals when portion of oil in water is less than 10%	[20], [31], [32]
Yellow oil and Caustic soda			
Liquid-liquid Extraction	High efficiency and does not generate solid waste	Very expensive technology; efficiency depends on exposure time	[21]
Nanofiltration Membrane	99.9% effective (piloting scale) in product purity	Membrane generates solid waste at the end of its lifetime; membranes are sensitive to chemicals and high temperatures	[22], [33]-[36]
Bipolar Electrodialysis	High efficiency and product purity	Very high costs from technology set-up, membrane lifetime, and electrical energy required	[23], [37]
Bio-Sludge			
Fertilization	Produces products needed in agriculture that are in high demand in local markets of Thailand	Requires large land area, time, odor control, and additives	[24]
Biochar	Product can improve soil quality that benefits agriculture	Requires high energy and pre-treatment; generates air emissions	[25], [38]
Biogas	Produces fuel gas (methane gas) for utilization in factories	Very sensitive and complicated, requiring secured control of gas release	[26], [39]

CONFLICT OF INTEREST

The authors declare no conflict of interest

AUTHOR CONTRIBUTIONS

This research was analyzed the data and wrote the paper by Khamkhan Ittiprasert; Orathai Chavalparit had analyzed the data and approved the final version.

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Khamkhan Ittiprasert received the BSc in environmental science from Chulalongkorn University, Thailand in 2016 and the MSc in environmental engineering from Chulalongkorn University, Thailand in 2019.

Orathai Chavalparit received the BSc from Chulalongkorn University, Thailand in 1982, the MSc in environmental biology from Mahidol University, Thailand in 1986 and the PhD in environmental science from Wageningen University, Netherlands in 2006. Her research interests including biogas and sustainable management. She has published in national and international journals and conference proceedings. She supervises research students both at the PhD and MSc levels in Chulalongkorn University, Thailand.