

ISSUES AND MANAGEMENT FOR USED DISPOSABLE DIAPERS IN SOLID WASTE IN THE CITY OF KUALA LUMPUR

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ABSTRACT

Disposable diapers are indispensable in modern societies. Disposing of soiled diapers is a major global environmental problem as they constitute a large percentage of the municipal solid waste. Kuala Lumpur has a population of 1.79 million in an area of just 243 km². Currently, Kuala Lumpur's municipal solid waste generation is about 3,500 tonnes per day where it is sent 80 km away to Tagar Sanitary Landfill for disposal through Taman Beringin Transfer Station which has a capacity of 1,700 tonnes per day. Waste characteristics study conducted in April 2016 showed baby disposable diapers contributed to 14.35 weight %, the fourth main composition after food and organics waste (32%), plastics (25%) and paper (17%). Comprehensive sampling conducted in 2001/2002 and 2014 showed the average diapers content was about 5.14 and 10.68 % weight, respectively. This paper looks at the issues of used baby diapers in solid waste, the options for its disposal worldwide such as landfilling, composting, recycling and incinerating with energy generation and then selecting the most sustainable, practical, effective and efficient disposal option for Kuala Lumpur.

Keywords: *Municipal solid waste, Diapers, Landfill, Recycling, Composting, Incineration.*

1.0 INTRODUCTION

Disposal diapers have been a popular choice in the modern society. It is estimated that more than 95% of diapering babies use disposable diapers, giving an average usage of between 5,000 to 7,500 diapers before being potty trained [1]. Almost all of these disposable diapers end up in landfills

Landfilling of disposable diaper not only shorten the lifetime of landfill due to its huge volume, there are also potential health and environmental hazards. Disposable diaper takes a long time to degrade. Soiled disposable diapers may contain viruses and microbes which can cause public health problem if they are leached out from landfill into the soil and groundwater.

Many studies have been done on the life cycles assessment of disposable diaper [2 - 8] but there are few studies reported to quantify the amount of disposal diapers in solid waste despite the large quantity of diapers in solid waste.

Kuala Lumpur, the federal capital of Malaysia, faces serious waste problems due to its soaring population and changing lifestyles. Its population has increased 37% from 1.31 million in 2000 [9] to 1.79 million in 2017 [10] and is projected to be 2.2 million in 2020 [11]. This rapid increase in population, urbanization and industrialization brings with it the escalating volume of municipal solid waste (MSW) that has to be disposed off which includes a huge amount of disposable diaper. This paper discusses the content of diapers in solid waste from waste characteristic studies conducted in the city of Kuala Lumpur in the year 2000, 2014 and 2016. Potential hazards and management options from disposable diapers in solid waste worldwide are also discussed.

2.0 WASTE GENERATION AND CURRENT MANAGEMENT PRACTICE IN KUALA LUMPUR

Kuala Lumpur is the most populous city of Malaysia with an estimated population of about 1.79 million in an area of just 243 km². With KL rapid economic growth and modernization results in marked increase in waste generated. According to Muktar et al. [9], KL's rate of solid waste generation has soared to 2.41 kg/capita/day in 2014 from 1.00 kg/capita/day in 2000. In 2016, the municipal solid waste (MSW) generation in KL is 3,500 tonnes per day costing to RM325 million a year for cleaning and waste management [12].

From 1979 to 2005, MSW from KL was sent to a non-sanitary landfill at Taman Beringin, within the city of KL which ceased operation in 2005 [13]. A new transfer station at Taman Beringin was built adjacent to the closed landfill. Since 2002, MSW from KL is transferred to Bukit Tagar Sanitary Landfill for disposal through Taman Beringin Transfer Station. Bukit Tagar Sanitary Landfill, which is located near to Bangkar River, is 80 km away from the city of KL. Waste collected using small trucks in KL are transferred to larger trucks at Taman Beringin Transfer Station. The design capacity of Taman Beringin transfer station is 1,700 tonnes per day which currently is overloaded. A 1,200 tonnes per day capacity of waste-to-energy (WtE) plant is planned to be built at Taman Beringin site adjacent to the transfer station. In future, both WtE and transfer station will operate simultaneously so as to reduce the handling capacity of the transfer station.

3.0 CONTENT OF DIAPERS IN SOLID WASTE

3.1 Description of Diapers

Disposable diapers offer convenience. Designed to absorb and retain urine and feces, it consists of four functional layers [14] as shown in Figure 1. The layers are:

- i. the topsheet, next to the baby's skin, is a highly liquid-permeable membrane lining made up of polypropylene nonwovens. This layer allows urine to flow into the core of the diaper.
- ii. the acquisition and distribution layer (ADL) is placed between the topsheet and the absorbent core. It provides rapid acquisition, quick transport and thorough distribution of the urine reducing potential leakage. ADL provides a sense of dryness to the skin.
- iii. the absorbent core, placed between the ADL and the backsheet, is made up of fluff pulp made from cellulose fibres and fine granular superabsorbent polymer (SAP). The fluff pulp is normally more than half the weight of the product. All fluff pulp is bleached in order to achieve the maximum absorbency. The super absorbent polymer (SAP) has a superabsorbent capacity for liquid retention to soak and trap the urine. It is a cross-linked sodium polyacrylate which upon contact with urine, the polymer cross-linkages into a hydrogel to retain the urine, not releasing the urine even under pressure.
- iv. the backsheet, a breathable but liquid impervious membrane, prevents the urine from leaking out of the diaper. It is made up of low density polyethylene (LDPE) film and it can be laminated with a thin textile-like nonwoven layer.

There are also other minor components such as lotions, dyes, perfume, elastic threads, adhesives, and tapes to aid ease of use, comfort, fit of the diaper and for aesthetic reasons. The adhesives are blends of various polymers and resin whereas the elastic threads is either made from polyisoprene or from polyurethane.

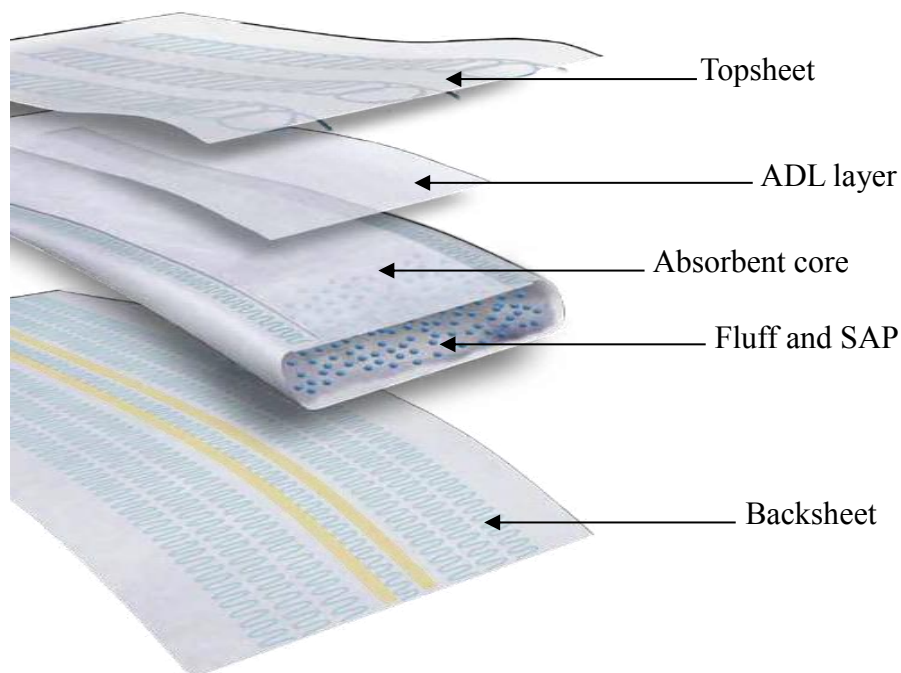


Figure 1. Diaper core components [15].

3.2 Composition of Diapers in Solid Waste

Waste characteristics study was conducted by the authors in April 2016 at Taman Beringin Transfer Station to identify the composition of diapers in the MSW. The waste composition is as shown in Figure 2. MSW of KL consists of 14.35 weight % diapers which is equal to about 500 tonnes of diapers per day. It is the fourth main composition of KL MSW after food and organics waste (32%), plastics (25%) and paper (17%). This finding is similar with the finding done by the National Solid Waste Management Department (JPSPN) in 2012 which found disposable diapers being the fourth main composition (12.1%) of the household waste generated in Malaysia after food and organic waste (44.5%), plastics (13.2%) and paper (8.5%) [16].

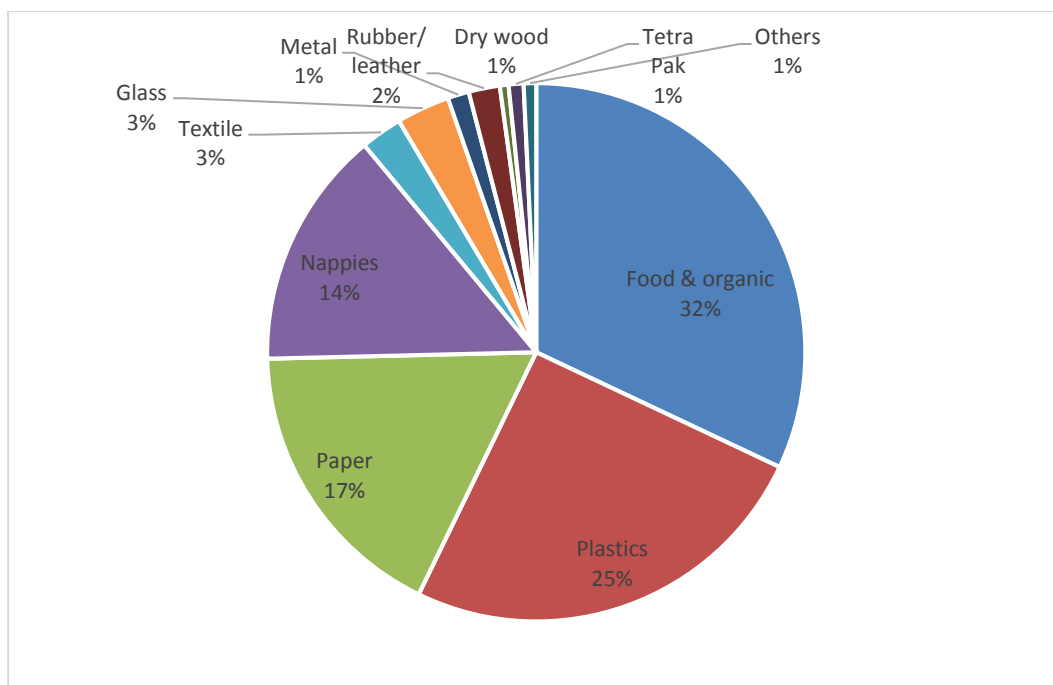


Figure 2. Kuala Lumpur waste composition in 2016.

3.3 Trend of Diapers Content in Municipal Waste in Kuala Lumpur

The authors conducted comprehensive sampling of the MSW composition generated in KL in 2001/2002 and 2014. Monthly samplings were conducted from July 2001 to June 2001 and from June 2014 to December 2014 where 84 and 41 samples were collected, respectively. In 2001/2002, the average diapers content is about 5.14 % weight whereas in 2014, it is about 10.68 % weight as shown in Figure 3.

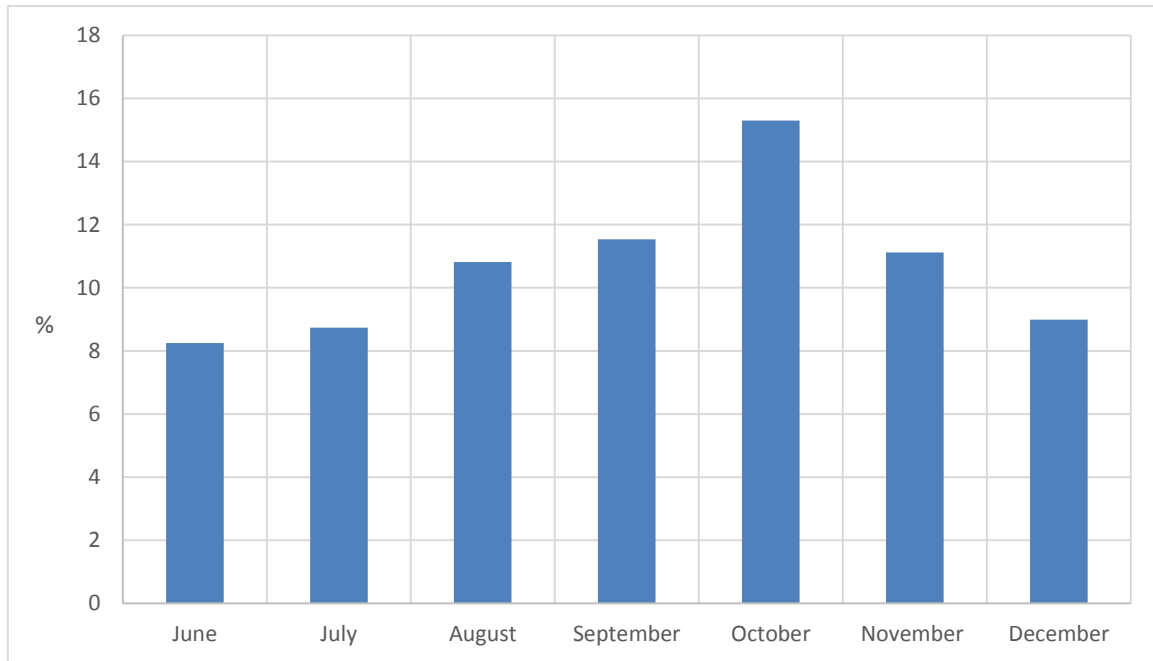


Figure 3. Content of diapers in Kuala Lumpur MSW sampling from June to December 2014.

4.0 ISSUES OF DIAPERS IN SOLID WASTE

4.1 Potential Hazards

Toxic chemicals and other hazardous materials present in disposable diapers pose potential health hazards. Disposable diaper contains traces of dioxin, Tributyl-tin (TBT) and phthalates. Dioxin, a by-product of the chlorine bleaching of the fluff pulp, is highly toxic and, if released into the environment, can accumulate in humans and animals. It has the ability to cause reproductive and developmental problems, damage the liver and immune systems, promote cancer and interfere with hormones [17]. Tributyl-tin is extremely harmful to aquatic life known to cause hormonal disruption. It does not degrade. Long term exposure of sodium polyacrylate powder may cause serious damage to human lungs [18].

A soiled disposal is a biohazard as human feces are known to contain over 120 different types of enteric and entero viruses including live vaccines from routine childhood immunization [19]. These viruses are known to be able to survive for months after the stool has passed from the body. The viruses pose diseases such as typhoid fever, dysenteries, upper respiratory infections, salmonellosis, gastroenteritis, meningitis and cholera to name a few.

4.2 Problems of Diapers Disposal in Landfill

4.2.1 Huge Quantity

About 90-95% of the total solid wastes in Malaysia are dumped in landfill [20]. Soiled disposable diapers are commonly disposed off in landfill. As shown in Figures 2 and 3, diaper constitutes 10.68 % and 14.35 % weight of KL MSW in 2014 and 2016, respectively. This contributes significantly to the amount of space in the landfill, clogging the landfill as the non-biodegradable disposal diapers will remain buried in the landfill in their original weight, volume and form. The problem of landfilling soiled disposable diapers continues to persist inexorably due to the growing population, rising disposable incomes and increasing demand for convenience. The rising cost of solid waste management and the unavailable landfill space contribute further to the problem.

4.2.2 Decomposition of Diapers

The disposal diapers due to its durable plastics and superabsorbent polymer require 500 years to decompose [21]. In order to decompose, disposal diapers need to be exposed to sunlight and air. This is not possible even for 'eco-friendly biodegradable' diapers as the modern airtight landfill design necessitate daily compaction and covering of refuse with clean fill and the impermeability of the liners.

4.2.3 Contamination of Surface and Groundwater

A soiled disposable diaper containing feces increases the threat of the viruses and bacteria leaching into surface and ground water. Leachate containing viruses from human feces could leak into the earth and seep into surface and underground water supplies especially in rainy seasons. Sackey and Meizah [22] reported landfill leachate contaminated with various pathogens such as total coliform, fecal coliforms, *Escherichia coli*, *Salmonella* spps, *Vibrospp* and *Bacillus* spp. Both Anilkumar et al. [23] and Hossain et al. [24] found the presence of fecal coliform in the ground water located next to landfills.

Another potential health hazard is the chemicals incorporated in the diaper leaching out and entering ground and surface water, concentrating at dangerous levels that would pose a health threat.

Surrounding groundwater or surface water will get contaminated by leaking leachate from landfills without any proper leachate treatment facilities. Only 3% of Malaysian sanitary landfills have leachate recirculation system and 5% are with leachate treatment whereas the rest are open dumpsites, open-tipping sites and landfills without any leachate treatment [25]. Treated leachates are discharged into the nearby rivers. Yusoff et al. [25] found the groundwater within and surrounding the Ampar Tenang landfill, about 40 km southeast of Kuala Lumpur, contaminated due to the landfill leachate. Tengku Ibrahim et al. [26] finding shows Sembilang River water quality not suitable to be used as water supply as it is affected

by the nearby Jeram Sanitary Landfill which has a leachate treatment plant. On 8th July, 2017, the Natural Resources and Environment Minister, Datuk Seri Dr. Wan Junaidi Tuanku Jaafar said six solid waste landfills in Malaysia which include the former Taman Beringin landfill was found to have serious leachate contaminant which cause sediment discharged to flow into nearby rivers [27].

4.2.4 Health Hazard of Diapers

The mountain of soiled diapers with baby's feces added to landfills each year poses a potential health hazard due to the transmission of communicable disease that might be found in human feces. The viruses in the feces could multiply in the moist and warm environment of the landfill. Hepatitis B and polio viruses from vaccines given to newborns can spread in the landfill [1]. Surrounding communities would be at serious health risk of contacting various diseases. The risk of disease being transferred increases when rodents, flies, insects and birds that are attracted to landfill as they also pick-up the virus and spread it.

5.0 OPTIONS FOR TREATMENT AND DISPOSAL OF DIAPERS

Disposing of soiled diapers in landfill is posing a substantial risk to the public's health and to the natural environment. Furthermore, disposable diaper is occupying increasing amount of landfill space. The availability of landfill space is limited as Kuala Lumpur's landfill is fast running out of space. Landfilling is also a waste of resources as the materials that constitute the diaper are neither reused nor recovered. Other options need to be considered for disposing of soiled diapers so as to reduce landfill capacity.

Recycling of soiled diapers to reclaim the valuable fiber and plastics includes collecting the soiled diaper, transporting them to a treatment plant where they are opened, sterilized, SAP deactivated, shredded and separated into recyclable fractions (fluff pulp, SAP, plastics and organic matter) [28]. The reclaimed components can then be used to create new products and the organic residues are either discharged to sewer for treatment or converted into energy.

Composting soiled diapers involves shredding the plastics together with the biodegradable and the organic components. The shredded diapers are then mixed with other organic wastes such as green waste and left to compost in a composting unit. Composting degrades the cellulose fluff pulp but not the plastic and SAP. The plastics are sieved off and sent to either landfill or incinerator. Colón et al. [29] and Gerba et al. [30] attributed the high temperatures experienced during composting to the destruction of pathogenic microorganisms in the final compost. In 2013, Colón et al. [29] found low zinc content in the final compost of organic fraction of municipal solid waste (OFMSW) which is in contrast to an earlier finding in 2011 [31].

Knowaste, Fater Spa and Super Faiths are the only absorbent hygiene products (AHPs) recycling companies globally. Knowaste, a Canadian company founded in 1989, is the world's first AHPs recycling company [32]. It had previously operated recycling AHPs facilities in Canada (Ontario), the Netherlands (Arnhem) and California (Santa Clarita) [which all shut

down as they could not compete against cheaper landfills and high conversion rate of incineration as well as problem securing markets for its end products [33]. Besides these problems, the facility in Arnhem which lasted for 8 years, also deal with problem getting enough feedstock [34]. Its first UK facility in West Bromwich, a £5million investment, which processed 36,000 tonnes of AHPs per year also shut down in 2013 with just 20 months in operation due to “high operating costs and a lack of contracts for sale of the end products” [35]. Knowaste appeal to build a new 40,000 tonnes per year of AHP facility in Hayes, West London, which was dismissed in 2017 by the local authority [36].

Fater Spa, an Italian company founded in 2015, has a pilot diaper recycling plant in Veneto, Northern Italy [37]. According to P&G UK and Ireland News [37], Fater Spa together with EMBRANCED, further upgraded their plant to upcycle the recycled cellulose into bio-products such as bio-plastics, fertilizers and high-end chemicals. Super Faiths Inc., a Japanese company founded in 2004, used SFD machines developed by Super Faith Inc. to shred, dry and sterilize used diapers and turn them into fuel pellets [38].

Envirocomp, a New Zealand company founded in 2009, is the first company in the world to compost AHPs [39]. The collected AHP were shredded, combined with green waste and compost in a HotRot composting unit before the plastic was removed where it still ends up in landfill or incinerator [40]. According to Cannon hygiene [39], Envirocomp had two facilities in New Zealand (Canterbury and Wellington) and one in the UK (Rochester). However, in 2016, EnviroComp stopped the composting business as it is no longer economically viable [41].

Both recycling and composting used diapers involve high fossil fuel consumption to separately pick up the diapers and to operate the electrical machinery for shredding and sieving. In recycling, fossil fuel is also used to heat up the huge amount of water. Recycling and composting soiled diapers need public acceptance besides the need to find a market for the end products. They both require families, hospitals and care institutions to source separate their diapers in separate trash bag from other trash for collection. The pick-up rate needs to be done frequently so as to keep bad odors to a minimum. The cost of collection and haulage will further increase the operating cost. The cost of transporting plastic from the composting facility to landfill will also add to the operating cost. In order to be cost effective, the recycling plant needs to be large which land-scarce KL couldn't afford. Recycling and composting require a constant supply of feedstock to keep them running and markets for the end products.

From 1st September, 2015, it is compulsory for the residents of KL, Putrajaya and six other states to separate their household wastes into recyclable and non-recyclable wastes in accordance to the Solid Waste Management and Public Cleanliness Act 2007 (Act 672) or face being compounded [42]. However, the Solid Waste Management and Public Cleansing Corporation (SWCorp Malaysia) classified disposable diapers as unrecyclable [43]. Thus, recycling disposable diaper is not an option in Kuala Lumpur. Moreover, with Kuala Lumpur's recycling rate of household waste a mere 17% in 2016 [12], Kuala Lumpur is still not ready to recycle nor economically well prepared to handle the foul, dirty fecal matter.

Another option to disposal of used diapers is incineration with energy from waste (EFW) as a way of dealing with the increasing volume of diapers. Since disposable diaper is partly made up of plastics which are derived from petroleum, incinerating it will generate more energy, destroy dangerous pathogens and reduce the diapers to ash amounting to only 6% of its original weigh [44]. The energy generated can be used for electricity and/or heat production for industrial, commercial or domestic consumers, further reducing the use of non-renewable fuel. Waste-to-energy (WtE) facilities prevent air pollution using modern air pollution control (APC) systems to filter and scrub the pollutants before releasing into the air. Emission needs to comply with Malaysia's new stringent environmental quality (clean air) regulations 2014 as shown in Table 1 which is as strict as Europe's standard so as to avoid the discharge of harmful pollutants. Psomopoulos [45] found WtE facilities emit lower toxic pollutant as compared to fossil fuels powered facilities with the exception of natural gas. The incinerator ash can be screened and recycled or reuse safely in asphalt, bricks and concrete which will further reduce the amount of harmful waste entering landfill. Modern WtE plants are so clean that according to the German Federal Ministry for the Environmental, Nature Conservation and Nuclear Safety "because of stringent regulations, waste incineration plants are no longer significant in terms of emissions of dioxins, dust, and heavy metals" [46].

Table 1: Concentration Limit for Air Pollutant Emission from Incineration Process [47].

Pollutant	Limit Value
Total PM	100 mg/m ³
NMVOG as total organic carbon	10 mg/m ³
Hydrogen chloride (HCl)	40 mg/m ³
Hydrogen fluoride (HF)	1 mg/m ³
Sum of SO ₂ and SO ₃ expressed as SO ₂	50 mg/m ³
Sum of NO and NO ₂ expressed as NO ₂	200 mg/m ³
Carbon monoxide (CO)	50 mg/m ³
Cadmium and its compounds, expressed as cadmium (Cd)	Total 0.05 mg/m ³
Thallium and its compounds, expressed as thallium (Tl)	
Mercury and its compounds, expressed as mercury (Hg)	0.05 mg/m ³
Antimony (Sb), Arsenic (As), Lead (Pb), Chromium (Cr), Cobalt (Co), Copper (Cu), Manganese (Mn), Nickel (Ni), Vanadium (V), and their compounds expressed as the element	Total 0.05 mg/m ³
PCDD/PCDF	0.1 ng TEG/m ³

Psomopoulos et al. [45] estimated a WtE plant processing 1 million tonnes/year waste for 30 years requires 100,000 m² of land compared to 3,000,000 m² for landfilling 30 million tonnes of waste. Due to the small space requirement, incineration plant can to be located close to residential areas where the center of the waste production is thus reducing further the cost of waste transportation plus the noise, pollutants associated with its transportation. WtE technologies today allow plants to operate safely even in dense urban areas. New WtE plant can be built on existing site thus reducing the land capital cost and no new greenfield land will be converted for this new facility.

Even though WtE facility has high initial investment cost but it is very economical in the long term as it serves two functions: energy production and waste treatment. Berenyi E. B. [48] noted that WtE facilities contribute significant green economy to the communities in which they operate.

There are 2,200 WtE plants in more than 40 countries where they are located in the greenest and sustainable cities in the world noted for their environmental conditions [49]. Switzerland, Japan, France, Germany, Sweden, Denmark, Italy, and United Kingdom are some countries that incinerate 50% or more of their residual MSW waste. Europe, with its stringent environmental regulations, has 520 operational WtE plants in mid-2013 [50]. Figure 4 shows the numbers of WtE plants in Europe in 2014. France and Germany top the list of European countries with 126 and 99 WtE plants, respectively. Japan, Korea, Taiwan, Singapore and China are some Asian countries that use WtE with Japan having the most WtE facilities where 60% of its solid waste are incinerated [52]. Japan, a densely populated country, has more WtE incinerators in the heart of its big cities than any developed country with 21 incinerators in Tokyo alone [53-54]. According to Wikipedia [55], China, with its rapid growth and urbanization, has 434 WtE plants in early 2016.

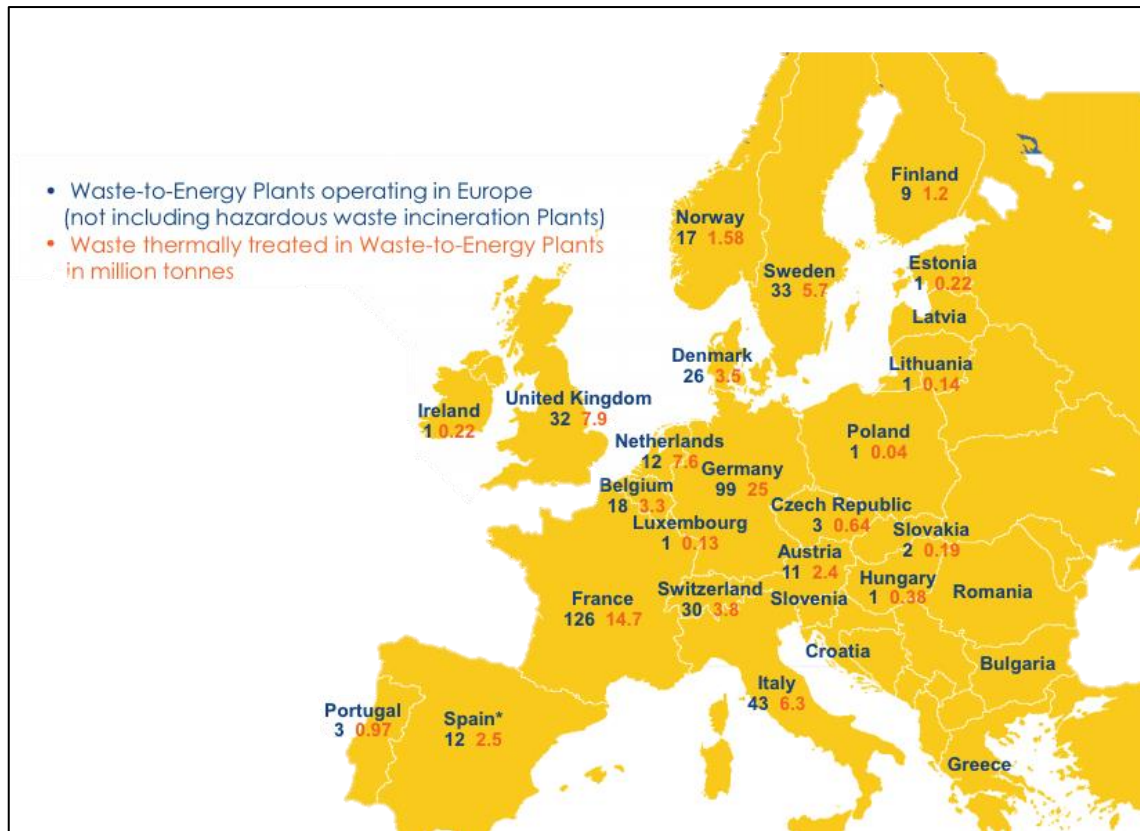


Figure 4. WtE Plants in Europe in 2014 [51].

6.0 CONCLUSIONS

Baby disposable diapers, representing 14.35% of KL municipal solid waste, are currently disposed in landfills where they will continue to accumulate. Dumping disposable diapers in landfill poses significant environmental and health hazards. Thus, landfill is the least desirable waste treatment option. Recycling and composting disposable diapers is not economically sustainable as it requires source-separate collection, high operating cost, steady supply of feedstock and market for its end products. Plastics from composting disposable diapers still end up in landfills or incinerated. WtE is a viable option for disposal of disposable diapers in Kuala Lumpur so as to protect the environment and unsustainable practices such as landfilling. It is more beneficial to incinerate with WtE as it efficiently reduces the soiled disposal diapers by 96%, uses it as renewable fuel, captures energy, provides hygienic treatment of contagious organic matter and space saving. It is the most suitable choice for KL as land is limited and where energy production and waste treatment are done simultaneously. The success of WtE incineration is supported by years of experience and environmentally sustainable operation.

ACKNOWLEDGEMENT

The authors would like to express their thanks to Universiti Teknologi Malaysia and the Ministry of Higher Education, Malaysia, for funding this project using vot 4F906.

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