WASTE MANAGEMENT IN SINGAPORE

"We have built, we have progressed. But no other hallmark will be more distinctive than that of achieving our position as the cleanest and greenest city in South Asia."[1]

ACKNOWLEDGEMENTS

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[1] The then Singaporean Prime Minister Lee Kuan Yew at the launch of the inaugural Keep Singapore Clean campaign in 1968.

INTRODUCTION

It was John Tan's first week as a student at the National University of Singapore. The TechnoEdge canteen was crowded during lunch hour so he and his friends were taking away their food and eating somewhere less crowded. He had waited patiently for his food and was happy when the stall attendant handed over his food and plastic cutleries. "Can I get a plastic bag?" he asked. The attendant merely pointed to a transparent box filled with coins at the side of the counter. "Please drop 10 cents for every bag taken" was clearly stated on the box. Feeling annoyed, John rummaged his coin pouch for a 10 cent coin and reluctantly dropped it into the box.

After lunch, he was curious to learn more about the levy on plastic bags in NUS. He found an article online which explains the initiative.[2] The initiative was suggested by the NUS Students Against the Violation of the Earth (SAVE) and supported by the NUS' Office of Environmental Sustainability. "(Ten cents) might be a small barrier, but it is one that will force people to re-think: Do they really need that bag?" said student Woon Wei Sheng, 23, vice-president of SAVE. The tax on plastic bags has led to a 70% drop in usage in plastic bags in its canteens and bookstores with the money collected being used to fund other eco-projects by students.

Impressed by the effort and its outcome, John was inspired to learn more about environmental sustainability in Singapore and in particular its waste management system. "What would have happened to a plastic bag used unnecessarily and then disposed of in a rubbish bin?" he asked himself.

HISTORY OF WASTE MANAGEMENT IN SINGAPORE

POST-INDEPENDENCE CHALLENGES

Solid waste consists of all non-soluble, incinerable, and non-incinerable waste materials discarded by households, businesses and industries. There are two broad categories:

1) Domestic waste in the form of food waste, household solid waste as well as trade waste from food centres, shophouses, coffee shops, town centres and institutions such as government and statutory boards, hospitals, schools, public recreational facilities and parks.
2) Non-domestic waste in the form of industrial and commercial waste, collected from commercial and industrial premises, such as construction and demolition waste, scrap tyres, industrial sludge, used slag, wood and timber waste.

In the 1960s, rubbish collectors shovelled solid waste from roadside bins and households into handcarts and discarded the waste into swamps. Collection bins were usually exposed and it was not unusual to find roads scattered with rubbish. As waste collection was irregular and inefficient, solid waste was frequently accumulated on roadsides and back alleys, attracting pests such as flies, cockroaches and rats. Together with high decomposition rates due to Singapore's tropical climate, the uncollected waste was a major threat to public health.

[2] http://news.nus.edu.sg/images/resources/news/2013/2013-09/2013-09-03/PLASTIC-st-3sep-pB4.pdf

Solid waste was disposed of at swamps in Kolam Ayer, Koh Sek Lim Road and Lorong 3, Geylang. When these sites were filled up in the early 1970s, new dumping grounds were created in Lorong Halus, Choa Chu Kang and Lim Chu Kang.

Since independence, Singapore's population growth and thriving economy have been contributing to a significant increase in solid waste. From 598,000 tonnes a year in 1972, the nation's total solid waste disposed of rose to 940,000 tonnes in 1980. Between 1970 and 2001, the amount of waste disposed of daily increased by more than six times.[3]

By 2008, the total volume of solid waste generated by households and industries in Singapore had reached 5.97 million tonnes. From this amount, 3.34 million tonnes were recycled. The remaining 2.63 million tonnes or about 7,200 tonnes a day had to be disposed of by incineration and landfilling.[4]

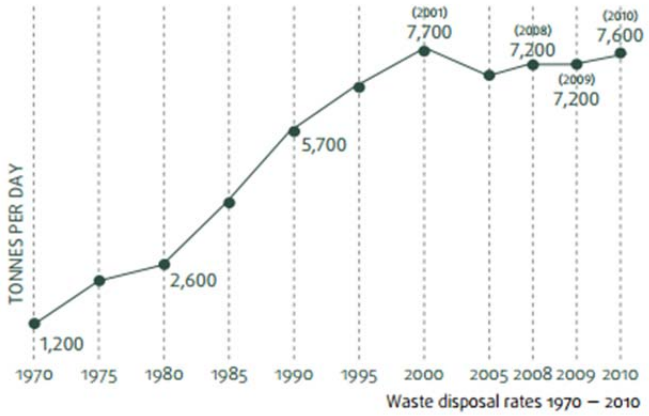

FIGURE 1. DAILY WASTE DISPOSAL RATE IN SINGAPORE FROM 1970 – 2010.

(SOURCE: NATIONAL ENIVRONMENT AGENCY)

[3]Chuan, M. N. (2009). Habitats In Harmony: The Story of Semakau Landfill. Singapore: National Environment Agency

[4] Chuan, M. N. (2009). Habitats In Harmony: The Story of Semakau Landfill. Singapore: National Environment Agency

CURRENT WASTE MANAGEMENT SYSTEM

The current waste management system can be divided into 4 parts; collection of solid waste, incineration at waste-to-energy plants, consolidation and transfer at the Tuas Marine Transfer Station (TMTS) and disposal at Semakau Landfill.

WASTE COLLECTION

Solid waste from households, industrial and institutional premises is collected daily to keep Singapore clean and maintain a high standard of public health. Waste collection is currently carried out by public waste collectors operating in seven geographical sectors.[5] Figure 2 below shows how the areas are divided and the companies that are in-charge for the corresponding sector. In 2018, the seven sectors would be consolidated into six sectors as the new contracts for Pasir Ris-Tampines and Bedok would be combined. In addition, about 350 general waste collectors are engaged by commercial enterprises and factories to collect and dispose of their waste. They are all licensed and regulated by the National Environment Agency (NEA).

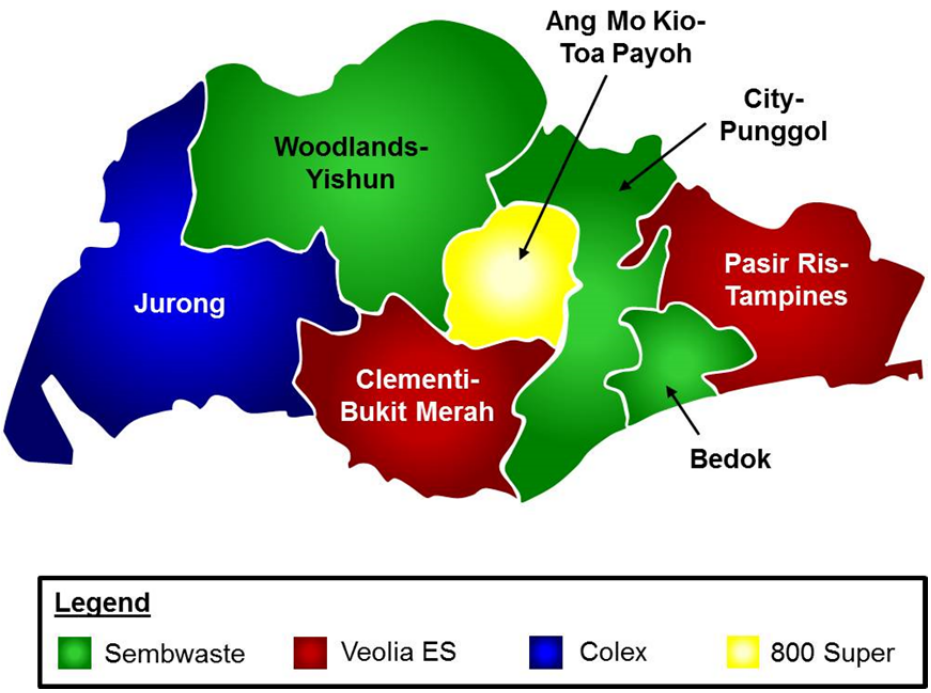

FIGURE 2. MAP INDICATING SEVEN GEOGRAPHICAL SECTORS FOR WASTE COLLECTION AND COMPANIES IN CHARGE. (SOURCE: NATIONAL ENVIRONMENT AGENCY)

Households are charged a uniform monthly fee for solid waste collection, while the rate for trade premises is based on the volume collected.[6] This gives institutions and businesses an incentive to recycle as much solid waste as possible.

[5] National Environment Agency. (30 May, 2016). *Overview: Waste Management.* Retrieved from National Environment Agency: http://www.nea.gov.sg/energy-waste/waste-management/overview
[6] National Environment Agency. (30 May, 2016). *Overview: Waste Management.* Retrieved from National Environment Agency: http://www.nea.gov.sg/energy-waste/waste-management/overview

Case of Interest 1: Pneumatic Waste Conveyance Systems (PWCS) in HDB flats

In Singapore, there are various collection methods for household waste.

Majority of the households in Singapore live in HDB flats that are provided with individual refuse chutes (IRC) usually located in the kitchen or centralised chutes for refuse (CCR) located at each floor along the common corridor. In the IRC, residents dispose of their waste through refuse chutes and into the collection bins at the bottom of the refuse chutes. The waste is then manually collected and stored at the bin centre before being removed by the National Environment Agency's (NEA) Public Waste Collectors. For CCRs, the waste is stored in dust drums and conveyed mechanically into refuse collection vehicles for disposal.

This labour-intensive process of IRC involves collecting and transporting waste from individual refuse chutes to the bin centre openly. The open nature of the collection process can result in waste spillage, bringing odour and pest control problems. Regular washing is also needed to keep the estate clean.

FIGURE 3. MANUAL COLLECTION OF WASTE FROM RUBBISH CHUTE UNDER IRC.

As part of HDB Greenprint to create sustainable public housing, residents at 38 residential blocks in Yuhua will be the first to experience the Pneumatic Waste Conveyance System (PWCS).[7]

With the introduction of PCWS, residents can expect less odour and fewer pest in the vicinity. When residents throw rubbish down their chutes, it goes to a refuse chamber on the ground floor. A sensor will be triggered when the container in the refuse chamber is full. The

[7] Housing Development Board. (28 Oct, 2015). *Waste Management*. Retrieved from Housing Development Board: http://www.hdb.gov.sg/cs/infoweb/about-us/our-role/smart-and-sustainable-living/hdb-greenprint/waste-management

waste is then sucked by vacuum pumps through underground pipes. It travels at speeds of between 50 and 80 kilometres per hour, to a centralised bin, where the rubbish is stored in sealed containers.[8]

When they are full, trucks will transport them to incineration plants. As for the exhaust air, it is passed through dust and odour filters. The clean air is then discharged into the atmosphere. With the process being automated, overall manpower needs are expected to be reduced by 70 per cent.

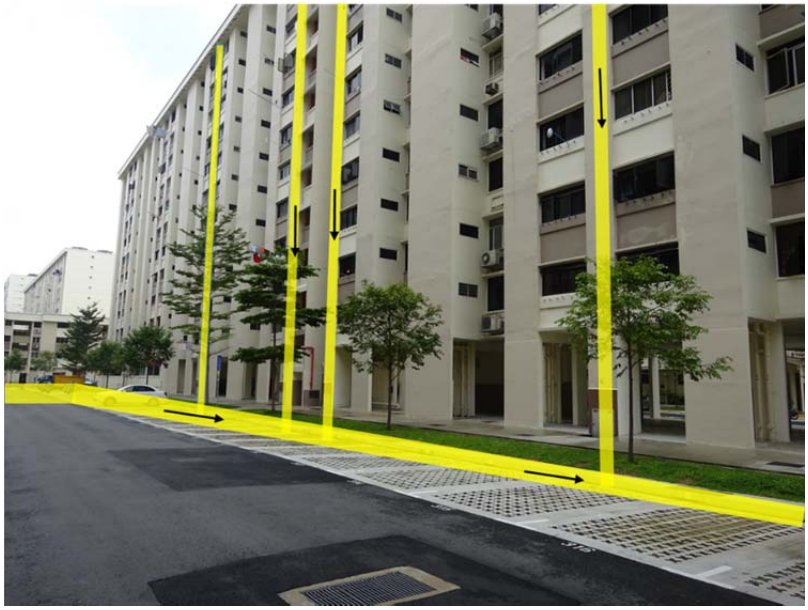

FIGURE 4. LAYOUT OF PCWS FOR HDB FLATS.

HDB is test-bedding the system at Yuhua to determine its feasibility for existing buildings. It is also assessing residents' receptiveness, as major retrofitting works are required to install the system in existing estates.

The system will be implemented in the upcoming housing estates of Tampines North, Bidadari and Punggol Northshore.[9]

[8]Yeo, S. J. (1 June, 2015). Less odour with Yuhua's automated waste collection system. The Straits Times. Singapore.

[9] Housing Development Board. (28 Oct, 2015). *Waste Management*. Retrieved from Housing Development Board: http://www.hdb.gov.sg/cs/infoweb/about-us/our-role/smart-and-sustainable-living/hdb-greenprint/waste-management

WASTE INCINERATION

After collection of waste from various sources, waste collection vehicles deliver the waste to one of Singapore's four waste-to-energy (WTE) plants located in Tuas and Senoko. The WTE plants are able to reduce the volume of incinerable solid waste by 90 percent.[10] The heat generated from incineration is used to produce steam, which is later used to power turbine-generators to produce electricity. Flue gas from the incineration process is treated to remove harmful gases and dust before being discharged into the atmosphere.

WHY INCINERATION?

After studying the experiences of countries such as Denmark, Germany and Japan in the 1970s, the Ministry of Environment chose incineration as the best solution for treating Singapore's growing volume of solid waste.[11]

Alternative technologies, such as composting and baling, were considered but assessed to be incompatible for Singapore. Composting is the decomposition of organic waste to produce compost. However, there was insufficient domestic demand for compost since there is no significant agricultural sector in Singapore. Baling involves physically compacting solid waste to reduce its volume by 40 to 50 percent. In comparison, incineration technology is able to achieve the highest rate of solid waste volume reduction. Therefore, while incineration plants would incur higher capital expenditure costs to setup, it will help reduce the need for future landfills in the land scarce Singapore in the long run.

About 90 percent of solid waste disposed in Singapore is incinerable. Incinerable solid waste in Singapore has a high moisture content of about 50 percent.[12] By removing the water and other combustible matter, the solid waste can be reduced to nearly 10 percent of its original volume which helps boost the capacity and lifespan of existing landfills. There is also minimal risks of pollution, as treatment systems such as bag filters, gas scrubbers and electrostatic precipitators are installed in plants to prevent the discharge of dust and harmful gases into the atmosphere.

[10] National Environment Agency. (7 June, 2016). *Solid Waste Management Infrastructure*. Retrieved from National Environment Agency: http://www.nea.gov.sg/energy-waste/waste-management/solid-waste-management-infrastructure

[11] Chuan, M. N. (2009). *Habitats In Harmony: The Story of Semakau Landfill*. Singapore: National Environment Agency

[12] Chuan, M. N. (2009). *Habitats In Harmony: The Story of Semakau Landfill*. Singapore: National Environment Agency

SINGAPORE'S WTE PLANTS

Singapore's first incineration plant was opened at Ulu Pandan in July 1979.[13] It was also the first incineration plant in Asia that was outside of Japan. A second plant was opened at Tuas in 1986 followed by a third plant at Senoko in 1992. The fourth and largest plant located at Tuas South, which is able to handle 3,000 tonnes of waste per day, began operations in 2000. In 2009, the Ulu Pandan Incineration Plant was closed down and replaced by Keppel Seghers Tuas Waste-to-Energy Plant which is a privately developed facility located next to Tuas South Incineration Plant.

FIGURE 5. AERIAL VIEW OF TUAS SOUTH INCINERATION PLANT.

(SOURCE: NATIONAL ENVIRONMENT AGENCY)

With the four WTE plants currently in operation, Singapore has the capacity to incinerate 7,600 tonnes of solid waste daily. As the WTE plants produce much more power than they need, they sell the excess power to the national electricity grid. Energy recovered from incineration plants contribute about 2-3 percent of Singapore's electricity supply.[14] Table 1 below shows when the current four WTE plants were commissioned, their daily waste capacity and the amount of power they can generate daily.[15]

[13]Chuan, M. N. (2009). *Habitats In Harmony: The Story of Semakau Landfill*. Singapore: National Environment Agency

[14]Ministry of the Environment and Water Resources. (6 June, 2016). *Incineration*. Retrieved from Ministry of the Environment and Water Resources: Ministry for the Environment and Water Resources

[15] National Environment Agency. (November/December, 2011). ENVISION. (First). Singapore: National Environment Agency

Facility	Year Commissioned	Daily Waste Capacity	Daily Power Generated
Ulu Pandan Incineration Plant (closed in 2009)	1979	1,100 tonnes	16 MW
Tuas Incineration Plant	1986	1,700 tonnes	30 MW
Senoko Incineration Plant	1992	2,100 tonnes	36 MW
Tuas South Incineration Plant	2000	3,000 tonnes	80 MW
Keppel Seghers Tuas Waste-to-Energy Plant	2009	800 tonnes	22 MW

TABLE 1. WASTE-TO-ENERGY PLANTS IN SINGAPORE (SOURCE: NATIONAL ENVIRONMENT AGENCY)

HOW WTE PLANTS OPERATE?

Incinerable solid waste is delivered to the WTE plants by licensed collection vehicles. The vehicles are weighed on a weighbridge before they enter a reception hall where they will discharge their loads into large refuse bunkers. Before leaving, the vehicles are weighed again to determine the payload they delivered.

In order to trap odours and prevent them from escaping into the environment, air in the refuse bunker is kept below atmospheric pressure. Bulky solid waste is crushed by high capacity rotary crushers to reduce its size so as to improve burning efficiency.

A grab crane feeds the solid waste into the incinerator which is heated to temperatures of between 800 and 1,000 degrees Celsius.[16] A lining of silicon carbide tiles protects the incinerator walls from extreme heat and corrosion. Advanced combustion control and automation systems regulate the refuse feeding and combustion rate to achieve complete combustion of the solid waste. It takes about five hours to reduce each load of solid waste to about 10 percent of its original volume.[17]

Catalytic fabric filter systems and a two-zone electrostatic precipitator remove pollutants from flue gas before it leaves the incineration plant via 150m tall chimneys.[18] While the ash is ferried on vibratory conveyors to a collection pit, electro-magnetic separators remove ferrous metals which can be sold and recycled at local steel mills.[19] The ash is then sent to Tuas Marine Transfer Station for transfer and transport to Semakau Landfill.

[16]National Environment Agency. (23 November, 2015). Waste-to-energy (WTE)/ Incineration Plants. Retrieved from National Environment Agency: http://www.nea.gov.sg/energy-waste/waste-management/waste-to-energy(wte)-incineration-plants

[17] Chuan, M. N. (2009). *Habitats In Harmony: The Story of Semakau Landfill*. Singapore: National Environment Agency

[18]National Environment Agency. (23 November, 2015). Waste-to-energy (WTE)/ Incineration Plants. Retrieved from National Environment Agency: http://www.nea.gov.sg/energy-waste/waste-management/waste-to-energy(wte)-incineration-plants

[19] National Environment Agency. (23 November, 2015). Waste-to-energy (WTE)/ Incineration Plants. Retrieved from National Environment Agency: http://www.nea.gov.sg/energy-waste/waste-management/waste-to-energy(wte)-incineration-plants

FIGURE 6. DESIGN LAYOUT OF WASTE-TO-ENERGY PLANTS.

(SOURCE: NATIONAL ENVIRONMENT AGENCY)

Case of Interest 2: Recycling of Incineration Ash

Incineration reduces waste volume by 90%. The remaining 10% that remains is incineration ash that is transported to the landfill. This incineration ash consists of 15% fly ash and 85% Incineration Bottom Ash (IBA).[20] In 2008, the amount of incineration ash generated per year is estimated to be more than 0.5 million tonnes.[21] About 1,250 tonnes of IBA is generated daily and disposed of at the offshore Semakau Landfill.[22]

One way of maximising the lifespan of the Semakau Landfill is to find other uses for IBA so that less of it is sent to the landfill for disposal. Several methods have been implemented or studied to reduce the volume of IBA disposed. This includes recovering metal from IBA, using IBA for land reclamation and road construction.

The first metal recovery facility in Singapore has been operational since July 2015. The REMEX Metal Recovery Facility in Tuas has reduced IBA disposed at landfill by 10 per cent by weight[23]. The metal recovery facility uses magnetic and eddy current separators to recover ferrous metals and non-ferrous metals from the IBA generated by Singapore's incineration plants. The plant is able to separate ferrous metals larger than 4mm in size and non-ferrous metals larger than 2mm in size.[24] In contrast, magnets installed in Singapore's four incinerators can only pick up pieces 20 centimetres and up, for recycling. As of end Oct 2015, 14,000 tonnes of metal has been recovered so far.[25]

The NEA has also engaged researchers at Nanyang Technological University (NTU) to do a risk-assessment study, which will include the development of environmental guidelines on how to use IBA as land reclamation material.[26] NTU is working with the Tropical Marine Science Institute as part of the project. The research project is expected to end in 2016.

[20] Building and Construction Authority. (2008). *Sustainable Construction - A guide on the use of recycled materials.* Singapore: Building and Construction Authority

[21] Building and Construction Authority. (2008). *Sustainable Construction - A guide on the use of recycled materials.* Singapore: Building and Construction Authority

[22] Building and Construction Authority. (2008). *Sustainable Construction - A guide on the use of recycled materials.* Singapore: Building and Construction Authority

[23] National Environment Agency. (1 December, 2015). *Singapore's First Metal Recovery Facility Reduces Weight Of Incineration Bottom Ash By 10 Per Cent.* Retrieved from National Enviroment Agency: http://www.nea.gov.sg/corporate-functions/newsroom/news-releases/category/environmental-protection/singapore-s-first-metal-recovery-facility-reduces-weight-of-incineration-bottom-ash-by-10-per-cent

[24] National Environment Agency. (2 June, 2014). *Singapore's First Dedicated Facility To Recover Metals From Incineration Bottom Ash To Be Built.* Retrieved from National Environment Agency: http://www.nea.gov.sg/corporate-functions/newsroom/news-releases/year/2014/month/6/singapore-s-first-dedicated-facility-to-recover-metals-from-incineration-bottom-ash-to-be-built

[25] National Environment Agency. (1 December, 2015). *Singapore's First Metal Recovery Facility Reduces Weight Of Incineration Bottom Ash By 10 Per Cent.* Retrieved from National Enviroment Agency: http://www.nea.gov.sg/corporate-functions/newsroom/news-releases/category/environmental-protection/singapore-s-first-metal-recovery-facility-reduces-weight-of-incineration-bottom-ash-by-10-per-cent

[26] Nanyang Technological University. (11 April, 2016). *IBA Project.* Retrieved from Nanyang Environment and Water Research Institute: http://newri.ntu.edu.sg/r3c/Research/Pages/IBA-Project.aspx

FIGURE 7. VEHICLE ENTRANCE FOR REMEX METAL RECOVERY FACILITY. (SOURCE: REMEX)

In 2009, the Land Transport Authority carried out a trial using processed incineration bottom ash in the sub-base layer of two 50m sections of Tampines Road.[27] The trial showed that, in terms of performance, incineration bottom ash can be used for road construction, although it has not been used in any other roads here since. This is due to the additional processing cost and uncertainty in projected demand for the material in road construction.

"The recovery of precious resources from our waste is in line with the plans under the Sustainable Singapore Blueprint's goal of Singapore being a Zero Waste Nation. While we explore innovative solutions to manage our waste more efficiently, we must all strive to make the practice of the 3Rs (recycle, reduce and reuse) a way of life," said NEA's Chief Executive Officer, Mr Ronnie Tay.[28]

[27] Land Transport Authority. (22 March, 2010). *LTA Allows Use of Green Materials for Road Construction.* Retrieved from Land Transport Authority: https://www.lta.gov.sg/apps/news/page.aspx?c=2&id=3ak3kp27vy8f2qm20r6b500y9sn0bmnoc02rzzr5xs43l4clkt

[28] National Environment Agency. (1 December, 2015). *Singapore's First Metal Recovery Facility Reduces Weight Of Incineration Bottom Ash By 10 Per Cent.* Retrieved from National Enviroment Agency: http://www.nea.gov.sg/corporate-functions/newsroom/news-releases/category/environmental-protection/singapore-s-first-metal-recovery-facility-reduces-weight-of-incineration-bottom-ash-by-10-per-cent

CONSOLIDATION AND TRANSFER

Ash from WTE plants as well as non-incinerable waste is consolidated at the Tuas Marine Transfer Station (TMTS) before they are transported to Semakau Landfill. Non-incinerable waste is brought to the TMTS in licensed collection vehicles that pass through weighbridges before they enter the transfer building. In the reception hall, there are 20 overhanging discharge bays for the vehicles to unload the waste directly into the barges.[29] This design allows for the swift turn-around time. The empty vehicles are weighed again before they leave the TMTS to determine the weight of non-incinerable waste delivered. Vehicles carrying incineration ash to the TMTS are not weighed and discharge their load directly into the barges.

Excavators will then spread the waste evenly throughout the barge to ensure optimal loading. Before the barge leaves, its hatches are closed to protect its load from wind and water during the 30km journey to Semakau Landfill which takes about three hours.[3031] The barging is carried out at night to maximise the usage of marine vessels. The barges used for waste transfer between TMTS and Semakau Landfill are specially designed to be pushed instead of towed.[32] Mechanical couplers on the tugboats slot into grooves at the stern of the barge to form a secure interlocked unit. This tugboat-barge combination gives the tugboat master precise control over the barge's movement and a clear view of the barge during the night voyage. Each barge has a capacity of about 3,500 cubic metres and is 85 metres long.

FIGURE 8. WASTE BEING LOADED ONTO BARGES AT TUAS MARINE TRANSFER STATION. (SOURCE: NATIONAL ENVIRONMENT AGENCY)

[29]National Environment Agency. (23 November, 2015). *Tuas Marine Tansfer Station.* Retrieved from National Environment Agency: http://www.nea.gov.sg/energy-waste/waste-management/tuas-marine-transfer-station-(tmts)

[30]Ng, M. F. (2009). *Habitats In Harmony: The Story of Semakau Landfill.* Singapore: National Environment Agency.

[31]National Environment Agency. (23 November, 2015). *Tuas Marine Tansfer Station.* Retrieved from National Environment Agency: http://www.nea.gov.sg/energy-waste/waste-management/tuas-marine-transfer-station-(tmts)

[32]Ng, M. F. (2009). *Habitats In Harmony: The Story of Semakau Landfill.* Singapore: National Environment Agency.

FIGURE 9. TUGBOAT PUSHING A BARGE TO SEMAKAU LANDFILL.

(SOURCE: NATIONAL ENVIRONMENT AGENCY)

WASTE DISPOSAL AT SEMAKAU LANDFILL

Since incineration can only reduce the volume of incinerable waste by 90%, the remaining 10% and non-incinerable waste would still have to be disposed into landfills. By the 1980s, it was clear that all the existing landfills on the mainland, which were located in Lorong Halus and Lim Chu Kang, would be depleted by the turn of the century.[33] It was this predicament that led to the construction of Semakau Landfill.

SELECTING A LOCATION

Due to the limited land space in Singapore and competing land needs, careful consideration was taken to select a suitable location for the new landfill. For example, one site that was considered was Punggol, an area previously filled with swamps and pig farms. However, it was rejected as it was thought that it would be serve the future needs of Singaporean better as a residential and commercial centre.[34]

Similarly, the opportunity costs of setting up a new landfill in other parts of the mainland was deemed to be too high, given Singapore's anticipated future land needs for residential, industrial and recreational use. Therefore, an offshore solution was suggested. Since certain islands such as Pulau Ubin and Sentosa has already been designated for tourism and recreational needs, the sea space between Pulau Semakau and Pulau Sakeng was identified as a potential location.

[33]Ng, M. F. (2009). *Habitats In Harmony: The Story of Semakau Landfill.* Singapore: National Environment Agency.
[34]Ng, M. F. (2009). *Habitats In Harmony: The Story of Semakau Landfill.* Singapore: National Environment Agency.

FEASIBILITY STUDY

The proposal of constructing an offshore landfill by reclaiming land from the sea to form secure cells was a novel idea that had not been implemented elsewhere in the world and required substantial investments. As such, the Ministry of the Environment was eager to ensure that the concept was both technically feasible and environmentally sound. It sent its officials to study near-shore landfills in Japan as well as barging systems for offshore facilities in the United States.[35]

A specialist consultant, Camp, Dresser and McKee International (CDM), was engaged to conduct a detailed study of the design, construction, and operation of the offshore landfill and its possible impact on the marine environment.[36] CDM's study concluded that the plan was feasible and recommended potential solutions to safeguard the coral reefs and mangroves along Pulau Semakau's shores.

The Ministry decided that the long-term benefits of an offshore landfill would outweigh its costs. Based on the technical studies and a design proposed by CDM, Minister for the Environment Mah Bow Tan submitted a proposal for the development of Semakau Landfill, which was approved in 1994. The approved plan cost of the project was $1.2 billion and construction began in 1995.[37]

CONSTRUCTING THE LANDFILL

The initial stage in constructing Semakau Landfill involved reclaiming the surrounding sea bed to increase the size of Pulau Sakeng to five times its original size.[38] This provided the necessary land space for ancillary facilities, including a wharf, leachate treatment plant, sewage treatment facility, workshops, and the administration, generator and transfer buildings. Figure 10 shows a map of Semakau Landfill.

The construction of the wharf and transfer buildings was a considerable civil engineering feat that required giant floating cranes to conduct deep sea piling work and open–sea construction.[39] Concrete pile caps had to be cast on-site. After the concrete pre-cast beams slabs and in-situ decks were laid in place, the crane lifted and installed the supporting roof structures. The end result was a robust foundation where the barges could be berthed safely in the transfer building for effective solid waste transfer.

The next step was to encircle the sea space between Pulau Sakeng and Pulau Semakau with a 7 kilometre perimeter rock bund.[40] To build this structure, the underlying marine clay of the seabed was first stabilised with a layer of dense sand. This was then covered by a 2mm-thick

[35]Ng, M. F. (2009). *Habitats In Harmony: The Story of Semakau Landfill.* Singapore: National Environment Agency.
[36] National Environment Agency. (November/December, 2011). ENVISION. *(First).* Singapore: National Environment Agency.
[37]Ng, M. F. (2009). *Habitats In Harmony: The Story of Semakau Landfill.* Singapore: National Environment Agency.
[38] National Environment Agency. (November/December, 2011). ENVISION. (First). Singapore: National Environment Agency
[39] Ng, M. F. (2009). *Habitats In Harmony: The Story of Semakau Landfill.* Singapore: National Environment Agency.
[40] Ng, M. F. (2009). *Habitats In Harmony: The Story of Semakau Landfill.* Singapore: National Environment Agency.

impermeable geomembrane to prevent waste matter in the landfill cells from seeping into the sea. A further layer of marine clay was placed over the impermeable geomembrane before an outer layer of rocks was laid on top of it to form the slopes of the bund. Figure 11 shows the typical cross-section of a perimeter bund at Semakau Landfill. A network of 63 monitoring wells was also built along the bund to allow water samples to be collected for regular testing.[41]

The sea space within the perimeter bund is divided by internal sand bunds into two segments. The first segment consists of 11 wet tipping cells separated by more sand bunds. This is the Phase I of Semakau Landfill. The other, Phase II, forms a lagoon connected to the sea via a gap in the perimeter bund. Wet tipping cells not in use receive a daily flushing of seawater from concrete pipes that link them to the lagoon. This exposure to tidal movements ensure that the water there remains fresh and clean.

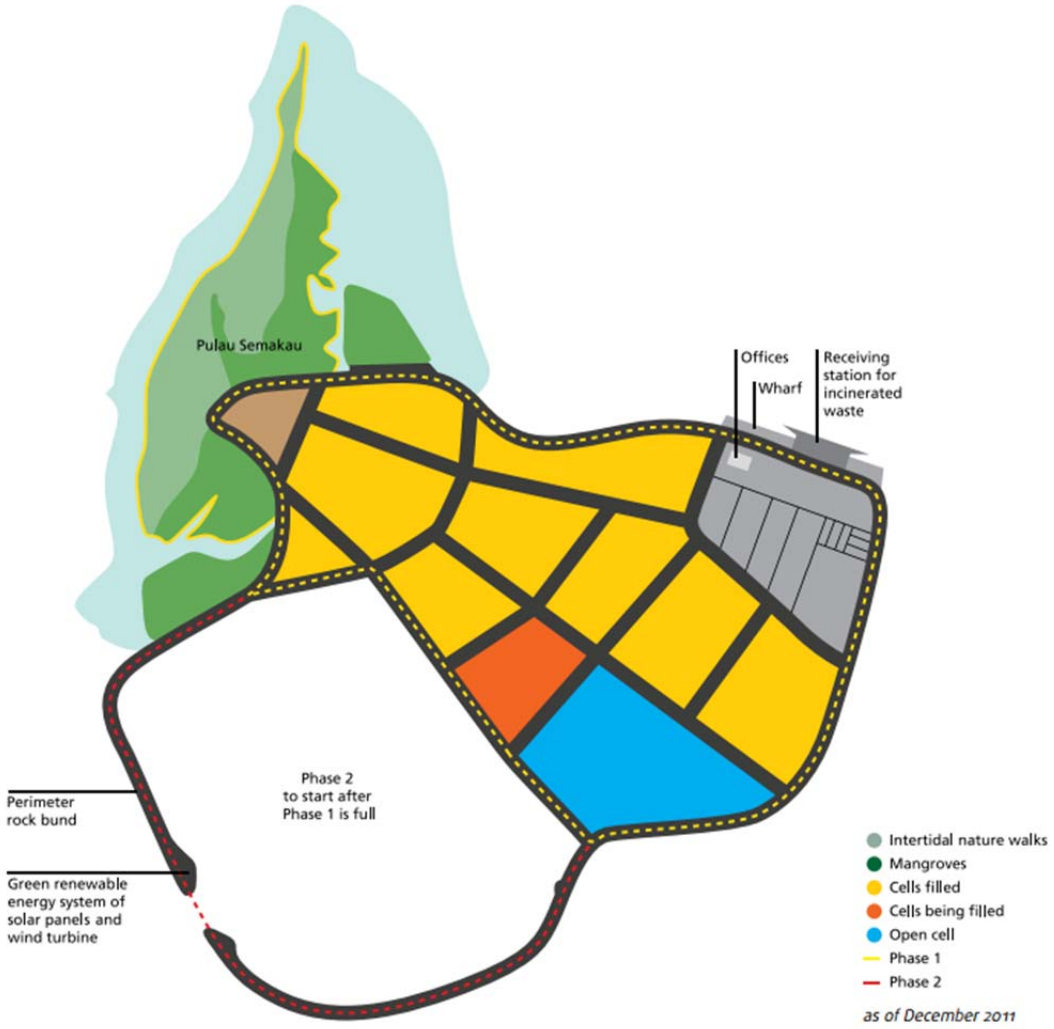

FIGURE 10. MAP OF SEMAKAU LANDFILL.

(SOURCE: NATIONAL ENVIRONMENT AGENCY)

[41] National Environment Agency. (November/December, 2011). ENVISION. (First). Singapore: National Environment Agency

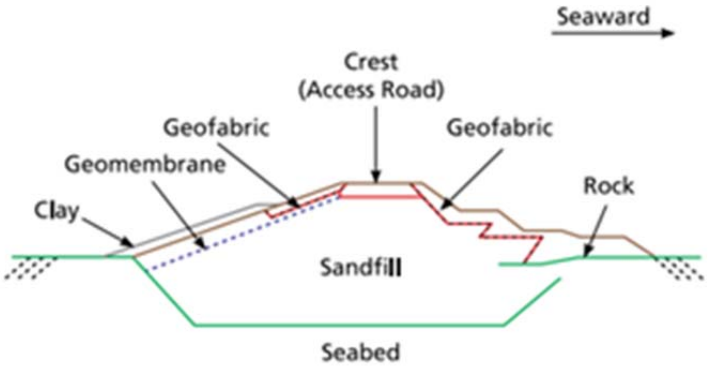

FIGURE 11. CROSS-SECTION OF PERIMETER BUND AT SEMAKAU LANDFILL.

(SOURCE: NATIONAL ENVIRONMENT AGENCY)

ENVIRONMENTAL CONSIDERATIONS

The environmental impact of the construction of Semakau Landfill was a major concern. As such considerable effort was taken to put in place measures to mitigate any adverse effects on the island's natural ecosystems, which included a thick mangrove forest and rich coral reefs.

The design of the landfill was itself influenced by the need to preserve Pulau Semakau's natural habitats.[42] As a matter of fact, when designing the perimeter walls, it was initially planned to leave a narrow seawater channel between the landfill and Pulau Semakau in order to protect the island's mangrove. However, it was assessed that the channel would not have been effective, as it would have restricted tidal flows that the mangroves require to thrive.

As such, it was then decided that the perimeter bund would be anchored to the eastern shore of Pulau Semakau. Since this decision would result in the loss of about 13.6 hectares of mangroves, two leading Singapore biologists, Professors Leo Tan and Lee Sing Kong, who were then the Director and Head of Biology respectively at the National Institute of Education, proposed a plan to replace the trees.[43]

Although replanting the mangrove trees would be costly, the new design resulted in substantial cost savings as it needed a shorter perimeter bund. The new design also provided a larger landfill capacity of 63 million cubic metres compared to 50 million in the original plan.[44] Professors Tan and Lee also highlighted that the replanted mangroves could serve as bio-indicators to help monitor the quality of the marine environment around the landfill.

While it may sound as simple as sticking a sapling into the mud, replanting the mangrove trees at the Semakau was a challenging task for Professors Lee and Tan. Unlike other replanting efforts that took place on existing mudflats, two entirely new plots of mudflats had to be created from scratch on the northern and southern fringes of Pulau Semakau.[45] The plots

[42]Ng, M. F. (2009). *Habitats In Harmony: The Story of Semakau Landfill.* Singapore: National Environment Agency.
[43] Ng, M. F. (2009). *Habitats In Harmony: The Story of Semakau Landfill.* Singapore: National Environment Agency.
[44] Ng, M. F. (2009). *Habitats In Harmony: The Story of Semakau Landfill.* Singapore: National Environment Agency
[45] Ng, M. F. (2009). *Habitats In Harmony: The Story of Semakau Landfill.* Singapore: National Environment Agency

were made by covering a sand base with mud. Artificial creeks were also constructed to deliver seawater circulation to trees.

Most of the trees replanted were Bakau Minyak (Rhizophora apiculata) since it is the dominant species on Pulau Semakau. At first, a test plot of about 200 saplings was planted, but every tree died after three weeks as the fresh mud was too acidic. The biologists postponed the replanting to allow the seawater neutralise the mud's acidity. After four months, when the pH had increased to 6.5, the planting resumed successfully. A total of nearly 400,000 saplings were planted.

Meanwhile, to protect the coral reefs lining the Pulau Semakau's western shore, Professor Chou Loke Ming, a marine biologist at the National University of Singapore, proposed the use of a fine mesh slit screens near the marine work areas so that sediment from the landfill's construction would not affect the sensitive corals.[46]

OPERATING SEMAKAU LANDFILL

Semakau Landfill was completed on schedule and opened on 1 April 1999 by the Minister for the Environment Yeo Cheow Tong, a day after the closure of the Lorong Halus Dumping Ground. With a total landfilling area of 350 hectares and based on the current rate of disposal, Semakau Landfill is expected to be filled by 2045.[47] In 2015, the landfill received an average of 2,282 tonnes of WTE plant ash and non-incinerable waste daily.[48] Due to the steps taken during the landfill's construction to mitigate the environmental impact and protect the marine environment, the coral reefs along Pulau Semakau's western shore remain largely intact.[49] The plots of replanted mangroves are also thriving and can be seen from the bund.

Upon arrival at Semakau Landfill, the barge berths at the enclosed transfer building. The tugboat disengages itself and returns to the TMTS with a newly emptied barge. Large excavators with interchangeable and specially designed grabs unload the solid waste from the barge. The solid waste is then transferred onto 35-tonne payload off-road dump trucks or onto the stockpile floor. Wheel loaders subsequently scoop up this solid waste and load it onto the dump trucks. It takes about six hours to empty each barge.

A 10 metre-wide paved roadway on top of the perimeter bund provides access for the dump trucks to all sections of the landfill. The dump trucks make their way to a designated tipping site and unload the solid waste into the active cell. Bulldozers and compactors then level and compact the solid waste. When a cell has been filled to ground level, it is covered with a layer of soil. Grass and trees then take root to form a green landscape. When new tipping cell is designated to become operational, the concrete pipes are closed and the seawater inside the cell pumped out to create a concave empty space for waste to be dumped.

[46]Ng, M. F. (2009). *Habitats In Harmony: The Story of Semakau Landfill.* Singapore: National Environment Agency

[47] National Environment Agency. (November/December, 2011). ENVISION. (First). Singapore: National Environment Agency

[48] National Environment Agency. (7 June, 2016). *Solid Waste Management Infrastructure*. Retrieved from National Environment Agency: http://www.nea.gov.sg/energy-waste/waste-management/solid-waste-management-infrastructure

[49]Ng, M. F. (2009). *Habitats In Harmony: The Story of Semakau Landfill.* Singapore: National Environment Agency

FIGURE 12. WASTE BEING UNLOADED FROM BARGES AT SEMAKAU TRANSFER BUILDING.

(SOURCE: NATIONAL ENVIRONMENT AGENCY)

FIGURE 13. WASTE BEING TIPPED INTO AN ACTIVE CELL.

(SOURCE: NATIONAL ENVIRONMENT AGENCY)

PHASE II DEVELOPMENTS

In 2011, NEA embarked on the Phase II development of Semakau Landfill to convert the remaining 157-hectare sea lagoon into landfill space by closing the 160-metre gap at the southern perimeter bund of Semakau Landfill.[50] This will create a single cell to form Phase II of the landfill. A single cell would maximise the landfill capacity and minimise the amount of sand used, thus lowering the overall construction cost.

[50]National Environment Agency. (11 July, 2015). *Phase II Semakau Landfill Ready To Meet Singapore's Waste Disposal Needs To 2035 And Beyond.* Retrieved from National Environment Agency: http://www.nea.gov.sg/corporate-functions/newsroom/news-releases/phase-ii-semakau-landfill-ready-to-meet-singapore-s-waste-disposal-needs-to-2035-and-beyond

FIGURE 14. AERIAL VIEW OF PHASE I AND II OF SEMAKAU LANDFILL.

(SOURCE: NATIONAL ENVIRONMENT AGENCY)

Phase II features two engineering feats: a 200-metre long floating platform and a floating wastewater treatment plant.[51] The floating platform allows incineration ash from the dump trucks to be discharged directly into the landfill cell. Due to the large area of the single cell and its uneven seabed, it is essential to use a floating platform to spread the incineration ash to level the seabed to a depth of about two metres before conventional landfill operations using bulldozers and compactors can begin.

After the gap at the southern tip is closed, the water inside the Phase II cell will accumulate and be displaced by ash and rainfall. To prevent flooding, the excess water within the Phase II cell will be treated at the wastewater treatment plant to meet Trade Effluent Discharge Standards before being discharged into the open sea outside the cell.

In order to protect Semakau Island's vibrant ecosystem and rich biodiversity, NEA carried out two major projects to preserve the marine inhabitants in the Phase II development area. Over 700 colonies of corals in the Phase II lagoon were harvested and transplanted to Sisters' Island from September 2014 to January 2015.[52] NEA also worked with nature groups to catch the fish within the Phase II lagoon and transfer them to the open sea.

On the successful completion of the development of Phase II Semakau Landfill, Minister of the Environment and Water Resources Dr Vivian Balakrishnan said, "The expansion of Semakau Landfill is testament to Singapore's engineering capability and the success of its novel approach to waste management. Singapore's only landfill represents a balancing feat between physical development and environmental conservation. While it is necessary to meet

[51] National Environment Agency. (11 July, 2015). *Phase II Semakau Landfill Ready To Meet Singapore's Waste Disposal Needs To 2035 And Beyond.* Retrieved from National Environment Agency: http://www.nea.gov.sg/corporate-functions/newsroom/news-releases/phase-ii-semakau-landfill-ready-to-meet-singapore-s-waste-disposal-needs-to-2035-and-beyond

[52] National Environment Agency. (11 July, 2015). *Phase II Semakau Landfill Ready To Meet Singapore's Waste Disposal Needs To 2035 And Beyond.* Retrieved from National Environment Agency: http://www.nea.gov.sg/corporate-functions/newsroom/news-releases/phase-ii-semakau-landfill-ready-to-meet-singapore-s-waste-disposal-needs-to-2035-and-beyond

the waste disposal needs of Singapore, our priority has always been to ensure that it is done in an environmentally sustainable way."[53]

Case of Interest 3: Semakau Island as a recreational space

In 2005, Semakau Landfill was opened to the public for recreational activities such as guided intertidal walks, birdwatching outings, sport fishing trips, stargazing sessions and educational outings.

The idea to open up Semakau Landfill to the public was the brainchild of the then Minister for the Environment and Water Resources, Dr Yaacob Ibrahim. After a visit to the landfill shortly after his appointment as Environment Minister in 2004, he was struck by the beauty of the natural landscape and the scenic views of the surrounding sea and saw the potential for Semakau to be a unique location for recreational and educational activities.

"Who would have thought that a landfill - and one that lies 8km away from the mainland - can also be a place where families and friends gather to admire nature's rich biodiversity and take in the scenic beauty of the open sea? Semakau debunks the notion that landfills have to be smelly, dirty, and polluted; and best avoided. Instead, what the island offers is an engineering marvel set amidst the beauty of nature," wrote the then Minister of Environment and Water Resources (MEWR), Dr Yaacob Ibrahim.[54]

Intertidal Walk: A 3-hour tour of the shorelines of Pulau Semakau, organised by the Raffles Museum of Biodiversity and Research, during low tide would allow visitors to marvel at the vast mangroves, seagrass, coral reefs, crabs, starfishes, sponges, shrimps and other flora and fauna.

Birdwatching: The Nature Society organises birdwatching outings for its members to spot the 66 species of birds living in the landfill's grassland, mangroves and surrounding shores.

Sport Fishing: Organised by the Sport Fishing Association (Singapore), sport-fishing enthusiasts can pit their skills against 17 different fish species in the waters surrounding Semakau Landfill. To ensure sustainable catches in the future, anglers release the fish into the waters after recording its size and taking photographs.

Star Gazing: Organised by The Astronomical Society of Singapore since 2007, participants can spot galaxies, globular clusters and nebulae that are not normal visible from the mainland. Few places in Singapore are able to offer an uncluttered night view of the heavens free from the interference of street and other lighting.

Educational Tours: Organised by the NEA, the educational tour consists of a briefing on solid waste management in Singapore and the design and operation of Semakau Landfill, followed by a tour of the landfill. In December 2007, a visitor centre was opened at Semakau

[53]National Environment Agency. (11 July, 2015). *Phase II Semakau Landfill Ready To Meet Singapore's Waste Disposal Needs To 2035 And Beyond.* Retrieved from National Environment Agency: http://www.nea.gov.sg/corporate-functions/newsroom/news-releases/phase-ii-semakau-landfill-ready-to-meet-singapore-s-waste-disposal-needs-to-2035-and-beyond

[54]Ng, M. F. (2009). *Habitats In Harmony: The Story of Semakau Landfill.* Singapore: National Environment Agency.

Landfill by NEA.

Through these activities, visitors are given the opportunity to enjoy the biodiversity of Pulau Semakau while also learning about waste management in Singapore. The rich biodiversity around the sanitary landfill shows that development and environmental protection can co-exist and need not be mutually exclusive.

SYSTEMS VIEW OF WASTE MANAGEMENT CHALLENGES[55]

Despite all the technological advancement and engineering feats achieved to improve waste management in Singapore, technology alone is insufficient for effective and efficient waste management. Equally as important is human behaviour and the interaction between the technological system and the human actors. This dynamic can be observed by applying systems level thinking and analysing the feedback loops present in the system.

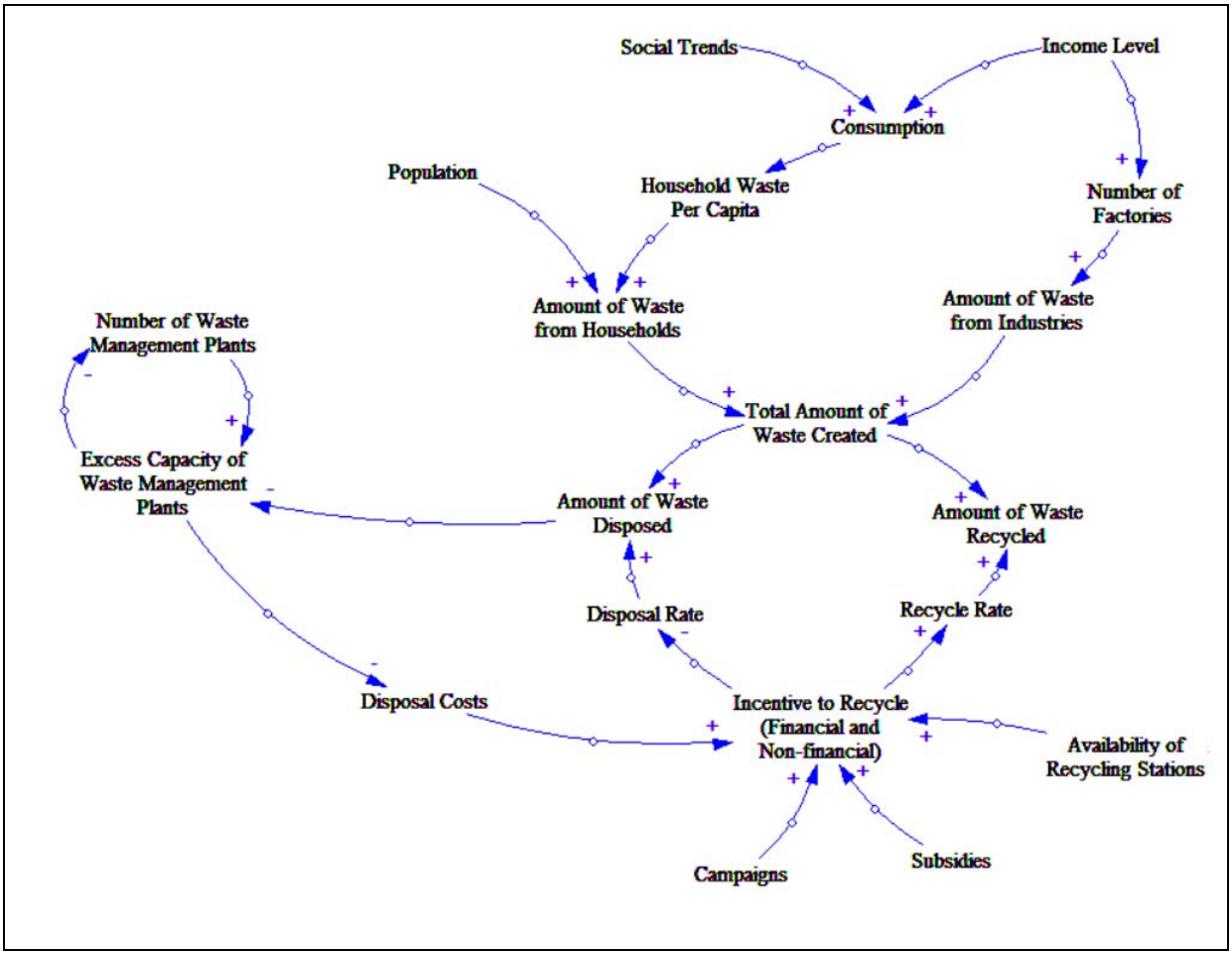

FIGURE 15. SYSTEM DYNAMICS MODEL OF WASTE MANAGEMENT.

In Figure 15, we can observe the relationship between various factors of waste management. Firstly, the two sources of waste are households and industries. Amount of waste generated from households depends on the size of the population and the amount of waste generated per person.

[55]This is a generic model and may not represent the situation in Singapore.

Secondly, the amount of waste a person generates depends on their consumption of goods and services which is based on their income and social trends. This is because a higher disposable income would mean that an individual is able to afford more goods. Social trends such as the pervasive use of technologically advanced electronic and electrical devices which require constant upgrading also help to increase consumption and waste produced. The higher the income level of a country, the more likely it is to be industrialised and have more factories which produces more industrial waste.

Thirdly, waste created can either be disposed of or recycled. The higher the amount of waste created, the more the amount of waste disposed or recycled. This is also dependent on the waste disposal rate and the waste recycling rate in the country.

Fourthly, the higher the amount of waste to be disposed, the lower the excess capacity of waste management plants such as the waste to energy plants and landfill. With lower excess capacity, there is a need to plan and invest in more waste management plants so as to be able to handle the increase in the amount of waste disposed. With every increase in the number of waste management plants, excess capacity would also increase.

Lastly, with increasing excess capacity, waste disposal cost would drop. With this drop in waste disposal costs, the incentive to recycle also decreases. This, in turn, would increase the waste disposal rate and decrease the waste recycling rate, which would then increase the amount of waste disposed and decrease the amount of waste recycled.

IMPLICATIONS OF SYSTEMS THINKING

The implication of this system dynamics model is that policies that only focus only on investments to increase the capacity of the waste management systems can actually have a detrimental effect in the longer term because it encourages an increase in the amount of waste disposed as it lowers the incentive to recycle and therefore increasing the waste disposal rate.

In systems thinking language, this classified as a ‘fixes that fail’ archetype.[56] A similar effect can be seen in the relationship between traffic congestion and investing in road construction. For example, a fix to solve traffic congestion is to build more roads. However, while building more roads would lower traffic congestion, it would also increase the incentive to own a vehicle. An increase in the vehicle ownership rate would then lead back to traffic congestion. Therefore, there are some solutions that may not actually solve the problem at hand and that a holistic approach needs to be taken to address the issue.

A question that needs to be asked is if it is too easy and too cheap for Singaporeans to dispose of waste. For example, access to a rubbish chute is available in every floor of a HDB flat. In some older flats, access to a rubbish chute is available in each individual unit. Waste is also collected and removed every single day. Households also pay a flat rate of $7.49 per month and $24.81 per month for HDB and landed premises respectively (both fees inclusive of GST)

[56] Senge, P. M. (1990). *The Fifth Discipline: The Art and Practice of the Learning Organization.* Doubleday/Currency.

regardless of the actual amount of waste they dispose.[57] Unlike utilities such as water or electricity, there is no monitoring of how much waste a household produces.

Ironically, an effective and efficient waste management system can actually lead to complacency. Households are used to seeing their waste cleared smoothly and for a low cost that they do not fully internalise the impact of their waste disposal. Disposed waste is also processed away from residential areas and then transferred to an offshore landfill. Therefore, there is also a lack of a visual feedback for the impact of their waste disposal on the environment.

HOLISTIC APPROACH TO WASTE MANAGEMENT

A holistic approach to waste management is needed. Besides adopting various advanced WTE technologies and waste management solutions, there should also be emphasis to prevent and reduce waste. This is because waste disposal solutions such as WTE plants and sanitary landfills are merely corrective measures to treat waste and mitigate its impact to the environment. Preventive measures such as preventing waste creation and reducing waste disposed of is not only required but preferred. A waste hierarchy graph which states the preferred action priorities in maintaining environmental sustainability is shown in Figure 16.

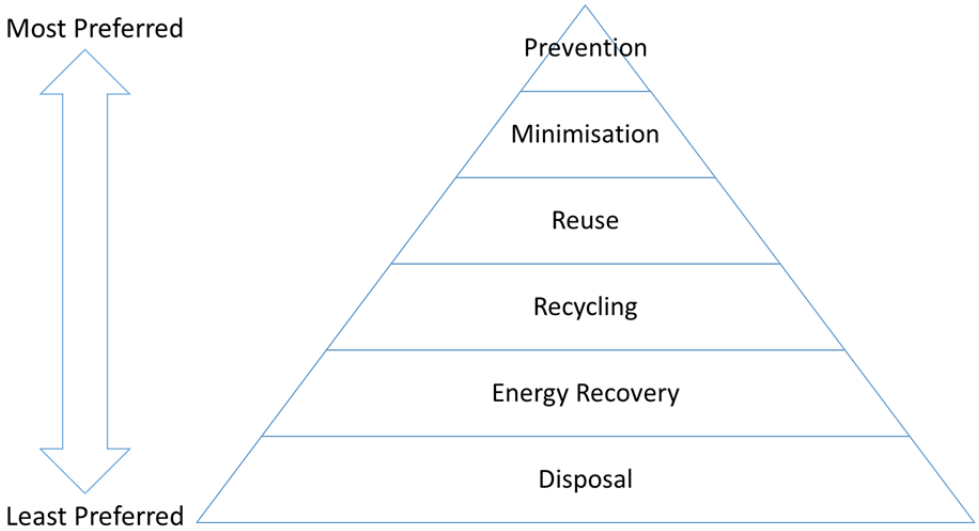

FIGURE 16. WASTE HIERRACHY.

Some government initiatives and policies in Singapore targeted at the top four tiers include the Singapore Packaging Agreement (SPA) and the National Recycling Programme (NRP).

SPA is a joint initiative by government, industry and NGOs to reduce packaging waste, which accounts for a third of the Singapore's domestic waste by weight. Companies are encouraged to practise product stewardship and take greater responsibility for the environmental impact of their packaging. The first SPA was introduced in 2007 and it lasted for 5 years. When the first SPA expired on 30 June 2012, the second SPA took its place with effect from 1 July 2012. The second SPA will be valid until 30 June 2020. As of 1 July 2016,

[57] National Environment Agency. (23 November, 2015). *A New Uniform Fee for Waste Collection.* Retrieved from National Environment Agency: http://www.nea.gov.sg/energy-waste/waste-management/a-new-uniform-fee-for-waste-collection

there were 177 signatories and they had cumulatively reduced 32,000 tonnes of packaging waste and saved S$75 million in material costs of locally consumed products over a 9-year period.[58]

Initiatives to reduce the use of plastic bags has also been implemented by various retailers such as NTUC FairPrice. Under the 'FairPrice Green Rewards' scheme at NTUC FairPrice, customers spending a minimum of S$10 are given a S$0.10 rebate when they bring their own bags. In 2015, FairPrice customers saved 10.1 million plastic bags with over half-a-million dollars in rebates given out.[59] In order to further encourage customers to bring-their-own-bag (BYOB), FairPrice has also started dedicated 'BYOB checkout lanes' in selected stores to serve only customers who BYOB or do not need a plastic bag for their purchase.

The NRP was launched in April 2001. Under this programme, the Public Waste Collectors (PWC) licensed by NEA are required to provide recycling bins and recycling collection service to all households in HDB and private landed properties.[60] The NRP was introduced to raise awareness and encourage recycling of domestic waste such as paper, plastic, glass receptacles and metal cans. Other efforts to encourage domestic recycling include a joint initiative by HDB and NEA to introduce a centralised chute for recyclables in HDB flats. All these initiatives are introduced in an effort to meet the target of a national recycling rate of 70 per cent and a domestic recycling rate of 30 per cent by 2030 as identified in the Sustainable Singapore Blueprint 2015.[61]

Case of Interest 4: Integrated Approach to Environmental Sustainability

While effective waste management is a crucial part of making Singapore a liveable and sustainable city, other components of environmental sustainability such as water resource management and energy security are as equally important. While it may be tempting to view these parts as separate entities, the scarcity of land in Singapore and the need to reduce the environmental footprint makes it a necessity to address these areas with a coordinated and integrated approach.

This can be done by having various government agencies working closely with one another to tackle environmental sustainability issues. In July 2016, National water agency PUB and the National Environment Agency (NEA) announced that multiple tenders would be called from the third quarter of the year onwards for the Deep Tunnel Sewerage System (DTSS) Phase 2 and Integrated Waste Management Facility (IWMF) projects. DTSS Phase 2 will include the construction of the Tuas Water Reclamation Plant (TWRP).

One of the highlights of both projects, is the co-location of PUB's TWRP with NEA's

[58]National Environment Agnecy. (12 July, 2016). *Singapore Packaging Agreement.* Retrieved from National Environment Agnecy: http://www.nea.gov.sg/energy-waste/3rs/singapore-packaging-agreement

[59]NTUC FairPrice. (18 March, 2016). *FairPrice customers saved a record 10.1 million plastic bags last year by bringing their own bags to shop.* Retrieved from NTUC FairPrice: http://www.fairprice.com.sg/wps/portal/fp/pressreleases/2016/

[60]National Environment Agency. (2 June, 2016). *National Recyling Programme.* Retrieved from National Environment Agency: http://www.nea.gov.sg/energy-waste/3rs/national-recycling-programme

[61]Ministry of the Environment and Water Resources; Ministry of National Development. (2014). *Sustainable Singapore Blueprint 2015.* Singapore: Ministry of the Environment and Water Resources; Ministry of National Development.

IWMF, which marks Singapore's first initiative to integrate used water and solid waste treatment processes.

"As one of the world's most anticipated water infrastructure projects, DTSS Phase 2 continues to harness advanced technologies to enhance Singapore's used water management system and ensure its water sustainability for generations to come," said Mr Yong Wei Hin, Director, DTSS Phase 2, PUB. "The co-location of TWRP and IWMF is also the first project of its kind in the world to be planned from ground-up, and is designed to bring about a multitude of synergies harnessing the Water-Energy-Waste Nexus while optimising Singapore's land-use".[62]

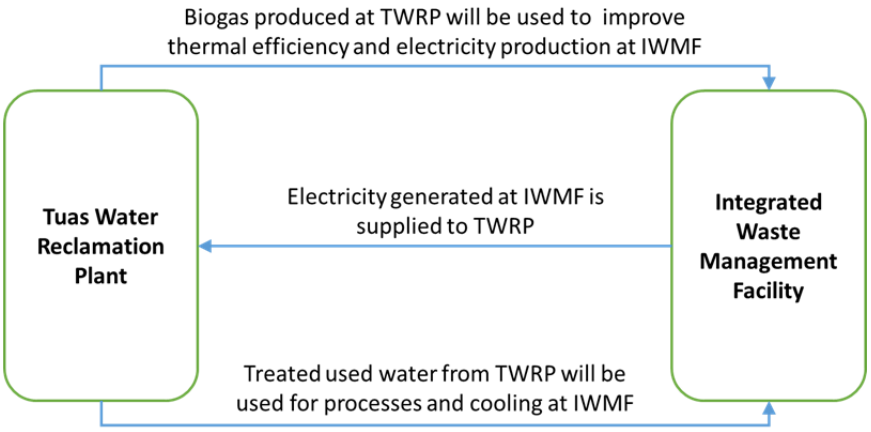

FIGURE 17. SYNERGY BETWEEN TUAS WATER RECLAMATION PLANT AND INTEGRATED WASTE MANAGEMENT FACILITY.

A good example of the synergies is the co-digestion of food waste with used water sludge at TWRP to increase the yield of biogas production. Biogas will be utilised at IWMF to improve steam quality and give rise to higher overall plant thermal efficiency. This will increase electricity production and enable IWMF to export more to the Grid while allowing both facilities to be energy self-sufficient.

"The co-location of the TWRP and IWMF marks a new chapter in the way used water and solid waste are managed in land-scarce Singapore. Leveraging the use of advanced technologies and project innovations, the two facilities will be able to maximise energy and resource recovery efficiencies while minimising their environmental and land footprint," said Mr Joseph Boey, Project Director, IWMF, NEA. "The IWMF plays an integral part in meeting Singapore's future waste management needs, and ensuring long term environmental sustainability."[63]

The co-location of the pair is estimated to save 2.8ha of land with the two plants sharing common facilities such as the administration building and carpark. [64] According to

[62] National Environment Agency; Public Utilities Board. (11 July, 2016). *PUB & NEA to call tenders for DTSS Phase 2 and IWMF projects*. Retrieved from National Environment Agency: http://www.nea.gov.sg/corporate-functions/newsroom/news-releases/pub-nea-to-call-tenders-for-dtss-phase-2-and-iwmf-projects

[63] National Environment Agency; Public Utilities Board. (11 July, 2016). *PUB & NEA to call tenders for DTSS Phase 2 and IWMF projects*. Retrieved from National Environment Agency: http://www.nea.gov.sg/corporate-functions/newsroom/news-releases/pub-nea-to-call-tenders-for-dtss-phase-2-and-iwmf-projects

[64] Boh, S. (12 July, 2016). 2 'green' plants to improve waste treatment efficiency. *The Straits Times*. Singapore.

preliminary studies, it would also save the Government a couple of hundred million dollars.[65] Overall, the co-location of TWRP and IWMF showcases how an integrated approach to environmental sustainability can help save costs, minimise land use and lower the environmental footprint.

HOW DOES SINGAPORE COMPARE?

Singapore prides itself in doing well in global rankings. For example, much is made of how well Singapore performs in economic competiveness and ease of doing business rankings. Similarly for environmental sustainability, Singapore is ranked an admirable 14th in the world in the Environmental Performance Index (EPI) 2016 Rankings published by Yale University.[66] Despite slipping down the rankings from 4th in 2014, Singapore had obtained a higher score of 87.04 compared to 81.78 in 2014. While Singapore is still the top performer in Asia, the slide down the rankings may suggest that many other countries are catching up and improving quickly.

While the EPI tracks countries in multiple key areas of environmental performance, solid waste management is currently omitted as there is lack of data. Solid waste management performance may also be difficult to measure and compare between countries. However, a common performance indicator for waste management is waste generated per capita per day.

As seen from the system dynamics model, waste generated in a country depends on the size of population and income level of the country. As such, when comparing waste generated, it is preferred to use per capita figures and also consider the income level of the countries compared. Table 2 compares Singapore's waste generation against selected countries.[67] Indonesia, Malaysia, Thailand and Vietnam were selected due to their geographical proximity to Singapore while Hong Kong, Japan and South Korea were selected as they are comparable high income Asian countries.

Country	Income Level	Solid Waste Generated Per Capita in 2012 (kg/capita/day)	Projected Solid Waste Generated Per Capita in 2025 (kg/capita/day)	Projected Change
Indonesia	Lower Middle Income	0.52	0.85	63%
South Korea	High Income	1.24	1.4	13%
Vietnam	Low Income	1.46	1.8	23%
Singapore	High Income	1.49	1.8	21%
Malaysia	Upper Middle Income	1.52	1.9	25%
Japan	High Income	1.71	1.7	-1%
Thailand	Lower Middle Income	1.76	1.95	11%
Hong Kong	High Income	1.99	2	1%

TABLE 2. COMPARISION OF WASTE GENERATED PER CAPITA IN SELECTED COUNTRIES. (SOURCE: (HOORNWEG & BHADA-TATA, 2012))

[65] Boh, S. (12 July, 2016). 2 'green' plants to improve waste treatment efficiency. *The Straits Times*. Singapore.

[66] Hsu, A. et al. (2016). 2016 Environmental Performance Index. New Haven, CT: Yale University. Available: www.epi.yale.edu

[67] Hoornweg, D., & Bhada-Tata, P. (2012). What a waste: a global review of solid waste management. *Urban development series knowledge papers, 15*, 1-98.

From the table, we can see that Indonesia, South Korea and Vietnam generate less waste per capita per day based on data from 2012. The performance by Indonesia and Vietnam can be explained by their lower income level and lower urbanisation. Compared to the other three high income countries selected, Singapore performs better than Japan and Hong Kong but is behind South Korea. However, by 2025, Singapore is projected to generate more waste per capita than Japan with the waste generated per capita projected to increase by 21%.

Singapore's waste generated per capita per day is higher than the worldwide average of 1.2 kg.[68] If limited to only high income countries, the average jumps higher to 2.1 kg with the lowest figure for a high income country at 0.7 kg.[69] This shows that while Singapore does better than the average for high income countries, there is still potential and room for improvement to reduce waste generation in Singapore. However, a cause for concern may be the projected increase in waste generation to 1.8 kg per capita per day in 2025.

TAKING STOCK OF ACCOMPLISHMENTS & PREPARING FOR FUTURE CHALLENGES

John heads back to the canteen take away food to bring back to his hall room for dinner. While waiting in a long queue, John reflects on the information he has learnt from his few hours of research about waste management in Singapore. To his mind, there is no doubt that there has been some amazing technology and engineering used to make the waste management system in Singapore as effective and efficient as it is today.

From the use of WTE plants to reduce the volume of waste as well and produce electricity to the construction of a sanitary offshore landfill that is thriving with biodiversity, the accomplishments have truly been impressive. In fact, Semakau Landfill has been recognised as one of the top 50 engineering achievements in Singapore since 1965 in a national competition organised by The Institution of Engineers, Singapore (IES).[70]

Yet, this is also not the time to be complacent and rest on the laurels of past achievements. Waste management would always be a concern for Singapore given high population density and limited land area. With the population targeted to increase from 5.5 million in 2015 to 6.9 million by 2030[71], the amount of waste created in Singapore would also be projected to be steadily rising. This would put more stress into our waste management system.

From the engineering point of view, some future concerns include adopting newer greener technologies, increasing capacity to handle the increase in waste created and replacing waste management plants that have reached the end of their lifespan. While dedicated effort is made to expand the lifespan of Semakau Island, it will still one day reach its maximum capacity. Given our limited land space, we have to carefully consider the options we have in locating a future landfill and also study the impact on the surrounding environment.

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[68] Hoornweg, D., & Bhada-Tata, P. (2012). What a waste: a global review of solid waste management. *Urban development series knowledge papers, 15*, 1-98.

[69] Hoornweg, D., & Bhada-Tata, P. (2012). What a waste: a global review of solid waste management. *Urban development series knowledge papers, 15*, 1-98.

[70] The Institution of Engineers, Singapore. (1 July, 2016). *Singapore's Top 50 Engineering Achievements.* Retrieved from The Institution of Engineers, SIngapore: https://ies.org.sg/sg50/home/engineering-feats/

[71] National Population and Talent Division. (2013). *Population White Paper: A Sustainable Population for a Dynamic Singapore.* Singapore.

From our system dynamics model, a holistic approach to waste management is needed. This means that the engineering solutions have to be complemented by policies that take into account human behaviour so as to inculcate positive attitudes towards waste management and the environment. Achieving the goals of "Zero Landfill" and "Zero Waste" requires the joint efforts of the government, corporations, NGOs and households. There is still much do to meet the target of achieving a national recycling rate of 70 per cent with a domestic rate of 30 per cent and non-domestic rate if 81 per cent by 2030 as identified the Sustainable Singapore Blueprint 2015.[72]

Effective and efficient waste management is a global issue. As such, there is also potential to study and introduce successful technologies and policies present in other countries. For example, a compulsory plastic bag levy of 5 pence or approximately 10 cents has been introduced in the United Kingdom for customers of retail chains with more than 250 employees. As a result of this levy, the plastic bag usage in England was estimated to drop by 85% in the first six months after the change was introduced.[73]

"Boy, do you need a plastic bag?" asked the food stall attendant as she prepares to hand him his packed dinner. "No, it's alright. I don't need it." John shook his head in full understanding of his role to play in reducing waste and maintaining a sustainable Singapore.

[72]Ministry of the Environment and Water Resources; Ministry of National Development. (2014). *Sustainable Singapore Blueprint 2015.* Singapore: Ministry of the Environment and Water Resources; Ministry of National Development.

[73]Smithers, R. (30 July, 2016). England's plastic bad usage drops 85% since 5p charge introduced. The Guardian. United Kingdom.

DISCUSSION QUESTIONS

The following questions are meant to be answered with information from both the case and your own knowledge. You are fully encouraged to share your own viewpoints and perspectives.

1. Why is waste management such a concern in Singapore?
2. How would you measure the performance of a waste management system? How does Singapore fare?
3. What is the role of engineers in creating Semakau Landfill?
4. Do you think that efforts to make Singaporeans recycle have been successful? If not, how can it be improved?
5. Should Singapore consider transporting waste overseas? What are the benefits and challenges?
6. What are the waste management challenges that Singapore would face in the future? Given your training in NUS, how do you suggest that these challenges be overcome?

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