International Scientific Journal of Engineering and Management
Volume: 02 Issue: 04 | April – 2023 DOI: 10.55041/ISJEM00402
An International Scholarly || Multidisciplinary || Open Access || Indexing in all major Database & Metadata
ISSN: 2583-6129
www.isjem.com

WASTE MANAGEMENT IN SMART CITIES

CASE STUDY BY:

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Abstract

Rapid urbanization creates new challenges and issues, and the smart city concept offers opportunities to rise to these challenges, solve urban problems and provide citizens with a betterliving environment. This paper presents an exhaustive literature survey of smart cities. First, itintroduces the origin and main issues facing the smart city concept and then presents the fundamentals of a smart city by analyzing its definition and application domains. Second, a data-centric view of smart city architectures and key enabling technologies is provided. Finally,a survey of recent smart city research is presented. This paper provides a reference toresearchers who intend to contribute to smart city research and implementation.

Introduction

The Smart Cities Mission is an initiative by the Government of India to improve the lifestyle of citizens living in that particular city or town. This initiative will be taken further by the bestpractices, information, and smart technologies. Several public-private partnership firms are also going to be a part of the Smart Cities Mission.

This mission was first launched on June 25, 2015, by Indian Prime Minister Narendra Modi. Furthermore, the Union Ministry of Urban Development is in charge of executing the missionthroughout the cities. A Special Purpose Vehicle (SPV) has also been created in each state andis headed by the CEO. It is done in order to look after the proper implementation of the SmartCity projects. In order to make it a successful implementation of new age development, fundingof ₹7,20,000 crore has been provided by the government. After completing a five-round process, 100 cities throughout India have been selected. Development starts taking place according to the list of smart cities in India and the master plan.

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Literature Review

Smart cities are rapidly emerging as the latest trend in urban development. A smart city is an urban area that integrates information and communication technology (ICT) and the Internet of Things (IoT) to improve the quality of life for its residents, promote sustainability, and enhance economic development. The concept of smart cities has been promoted as a solution to many of the problems facing modern cities, such as traffic congestion, air pollution, and waste management. This literature review will provide an overview of the current state of research on smart cities, with a focus on their benefits, challenges, and future prospects.

Benefits of Smart Cities

Smart cities offer a range of benefits to their residents and stakeholders. One of the most significant advantages of smart cities is their potential to reduce traffic congestion and improve transportation. Intelligent transport systems (ITS) can help to reduce congestion, improve traffic flow, and enhance road safety. For example, the use of real-time traffic data and predictive algorithms can enable traffic signals to optimize traffic flow, reducing the time drivers spend waiting at red lights. In addition, the use of electric and autonomous vehicles canhelp to reduce greenhouse gas emissions and improve air quality in urban areas. Smart cities can also improve public safety by leveraging technologies such as surveillance cameras, facialrecognition software, and sensors to detect and respond to emergencies more quickly. For example, the use of smart cameras and gunshot detection sensors can help to reduce crime ratesin high-crime areas. The integration of IoT sensors and real-time data analytics can also help to prevent natural disasters and reduce their impact on cities. Smart cities can also promote sustainability by reducing energy consumption and promoting renewable energy sources. Theintegration of energy management systems, smart grids, and renewable energy sources can helpto reduce the carbon footprint of cities and enhance their resilience to climate change. For example, the use of solar panels and wind turbines can help to reduce dependence on fossil fuels and promote a more sustainable energy future.

Challenges of Smart Cities

Despite their many benefits, smart cities face several challenges that need to be addressed. Oneof the primary challenges is the lack of interoperability and standardization of IoT devices andsystems. The heterogeneity of devices and systems can make it difficult to integrate and manage them effectively, which can lead to data silos and inefficiencies. In addition, the use ofIoT devices and systems can raise privacy and security concerns, as they can be vulnerable to cyber attacks and unauthorized access.

Another challenge facing smart cities is the digital divide, which refers to the unequaldistribution of access to digital technologies and the internet. Smart cities require a significantinvestment in ICT infrastructure, which can be a barrier to entry for some communities, particularly those with low incomes. The digital divide can exacerbate existing inequalities andcreate new ones, as some residents may not have access to the benefits of smart cities. Finally,the implementation of smart cities requires a significant investment of time, money, and resources, which can be a barrier to entry for some cities. The high upfront costs of implementing smart city technologies may be prohibitive for some cities, particularly those with limited resources.

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Future Prospects of Smart Cities

Despite these challenges, the future prospects of smart cities are promising. The global smart city market is expected to grow significantly in the coming years, driven by increasing urbanization, technological advancements, and government initiatives. The development of 5G networks, artificial intelligence, and blockchain technology is expected to transform the way that smart cities operate, enabling greater connectivity, efficiency, and security.

Problems of Waste Management in Indian Smart Cities

One of the challenges in Smart City projects is planning and implementing a comprehensive waste management programme to connect various sectors such as residential buildings, commercial and industrial establishments, hotels, healthcare institutes, the transportationsector, public places, tourism spots, and others. Smart City consultants play an important role in evaluating and developing a waste management strategy that can be incorporated into a smartcity's development plan. Greenfield projects present fewer challenges. Municipal Corporationis in charge of collecting, sorting, transporting, dumping, and processing city waste from doorto door.

Waste is transferred from primary collection vehicles to secondary collection vehicles for disposal at the Waste Processing Plant as part of the process. Municipal Corporation has fieldstaff responsible for collecting door-to-door waste, street sweeping, and collecting street wasteand dumping it in the nearest bins, either directly or through subcontracting. Managing peoplewho are responsible for the activity and proper utilisation of assets/resources assigned to them has become a complex job for Municipal Corporations in the current scenario, which has a direct or indirect impact on the cleanliness and hygiene factors for citizens.

Some of the serious issues with the current solid waste process are as follows:

1) Lack of information about the collection with respect to time and area.

2) Lack of a proper system for monitoring, and tracking the collection and transportation vehicles

3) Verification of employee attendance and performance

4) On transfer of waste from primary collection to secondary collection, the authenticity of vehicle transfer and improper coordination lead to missed trips and garbage piling.

5) Lack of quick response to urgent cases like vehicle accidents, breakdowns, long-time idling,etc.

In the current scenario, there is a large scope for Technology Partners and System Integrators (SI) to engage with the Municipal Corporation's Solid Waste Department to set up the right systems in place that help the corporation with proper planning, monitoring, controlling, and measuring through a survey of hygiene, cleanliness, and livability index.

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Effects of improper Waste Management Systems in Smart Cities

Since the amount of municipal solid waste (MSW) generated per person has increased as a result of urbanisation, industrialisation, and economic expansion in India, solid waste management (SWM) has become a significant issue for many urban local bodies (ULBs). Effective SWM is a significant difficulty in densely populated areas. India is a varied nation with many different religious groups, cultures, and customs, making it more challenging to achieve sustainable development within a nation witnessing a fast population increase and improvements in living conditions.

Despite substantial progress in the social, economic, and environmental spheres, India's SWMsystems have largely stayed untouched. Since 90% of residual garbage is currently discarded rather than properly landfilled, the informal sector is crucial in recovering value from waste. Current SWM systems are inefficient, with waste having a negative impact on public health, the environment and the economy.

Some of the harmful effects of improper waste management are given below:

1. Health hazards - Unmanaged trash along the roadside, which is a frequent sight in manyparts of India, can serve as a breeding ground for rats, cockroaches, and mosquitoes. It is generally known that these rodents spread diseases like dengue and malaria as well as foodpoisoning. Therefore, incorrect disposal of solid waste and littering can have a significant negative impact on public health due to pests that spread disease. A Planning Commission report released in 2014 showed that more than 80 per cent of the waste collected in India isdisposed of in dump yards improperly.

The groups most impacted by the improper disposal of solid trash are municipal employeesand rag pickers. Human health may be impacted by exposure to harmful substances and pollution. Blood infections and skin discomfort might result from coming into contact withsuch trash. Children are especially vulnerable to contaminants, according to experts.

2. Loss of biodiversity - Loss of biodiversity is one of the major consequences of improperwaste management. Biodiversity refers to the variety of life on earth, including the variety of species, ecosystems, and genetic diversity. When waste is not properly managed, it can have serious impacts on biodiversity, reducing the number of species and disrupting important ecological relationships. Landfills and dumping sites can cover large areas of land, destroying habitats and disruptingecosystems. This can result in the loss of species, as they are forced to find new habitats or

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become extinct. For example, landfills can cover areas of forest, destroying the habitats ofmany species of animals and plants.

Waste can also impact biodiversity by introducing invasive species into an ecosystem. Invasivespecies are species that are not native to a particular area and can have serious impacts on biodiversity by outcompeting native species for resources. For example, waste can transport seeds and other propagules of invasive species to new areas, allowing them to establish and spread, resulting in the loss of native species.

3. Economic impacts - Improper waste management can have severe economic impacts on a community, a region, and even a country. Some of the significant economic impacts of improper waste management include:

- Lost Business Opportunities: Improper waste management can create unsanitary and unpleasant living conditions, which can discourage businesses from setting up operations in the area. The loss of these businesses can lead to a reduction in local economic activity and adecline in the standard of living for residents.
- Increased Cost of Raw Materials: Improper waste management can lead to the contaminationof soil and water resources, which can reduce the quality of raw materials used in various industries. The increase in the cost of these raw materials can negatively impact the competitiveness of local businesses and lead to a decline in economic activity.
- Tourism Impacts: Improper waste management can lead to unsanitary and unpleasant living conditions, which can discourage tourists from visiting the area. The loss of tourist revenue canhave a significant impact on the local economy, particularly in areas that rely heavily on tourism.
- Legal Costs: Improper waste management can result in environmental violations, which canresult in legal action and fines. The costs associated with legal proceedings and fines can be substantial and place a significant burden on the community and the country.

4. Climate change - Improper waste management can contribute significantly to climate change, which is a global environmental challenge that threatens the health and well-beingof people and the planet. Some of the ways that improper waste management contributes

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to climate change include:

- Greenhouse Gas Emissions: Improper waste management can result in the release of methaneand other greenhouse gases into the atmosphere. Methane is a potent greenhouse gas that is estimated to be 28 times more effective at trapping heat than carbon dioxide. Landfills, whichare the primary destination for much of the world's waste, are significant sources of methane emissions.
- Deforestation: Improper waste management can result in the destruction of forests, which areessential to mitigating climate change. Forests act as carbon sinks, removing carbon dioxide from the atmosphere and storing it in vegetation and soil. Deforestation releases this stored carbon into the atmosphere, contributing to climate change.
- Soil Degradation: Improper waste management can lead to soil degradation, which can reducethe soil's ability to absorb carbon dioxide. Soils act as carbon sinks, removing carbon dioxide from the atmosphere and storing it in the soil. Soil degradation reduces this capacity, contributing to climate change.

Improper waste management in India has far-reaching and serious consequences for the environment and public health. It is essential to improve waste management practices, including reducing waste generation, improving waste collection and transportation, andpromoting recycling and composting, to mitigate these impacts and protect the environment and public health. The government, communities, and individuals all have a role to play in improving waste management practices in India.

Strategies to enhance the Waste Management system in Indian Smart Cities

Building smart cities in India requires effective garbage management. Waste creation is risingas a result of urbanisation and population growth, and it is crucial to manage it in anenvironmentally friendly way. Reduced trash generation, waste recycling and reuse, and ecologically safe and sustainable garbage disposal are all components of sustainable waste management. Sustainable waste management practices can not only promote public health andsafeguard the environment but also preserve natural resources. Source separation, composting,waste-to-energy, and community engagement are a few ways that Indian smart cities might useto implement sustainable waste management systems.

Indian smart cities have a number of options for sustainable garbage management:

1. The 3rs: Reducing trash generation, utilising resources, and recycling waste come first in thewidely accepted hierarchy of waste management. By enticing citizens to decrease their waste

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and by providing the necessary infrastructure for waste segregation and recycling, Indian smarttowns can advance this strategy.

2. Source Separation: Source separation is the process of dividing up waste streams at theirorigin, which includes homes, workplaces, and commercial buildings. This strategy makes recyclingand disposal more effective by ensuring that various waste streams, such as biodegradable, non-biodegradable, and hazardous trash, are treated independently.

3. Landfilling and Incineration: These two ways of garbage disposal are among the mostpopular. To minimise the environmental effect and lower the risk of groundwater pollution, Indian smartcities can invest in cutting-edge landfill and incinerator facilities.

4. Conversion: The process of turning organic waste into nutrient-rich compost, which may beused as a natural fertiliser for plants, is known as composting. By offering decentralised composting facilities for families and community organisations, Indian smart cities can encourage composting.

5. Trash-to-Energy: Through the use of techniques like gasification and incineration, waste canbe turned into energy. This strategy can assist Indian smart cities in minimising waste, generating renewable energy, and reducing their reliance on fossil fuels.

6. Public-Private Partnerships: Developing, financing, and putting into practice sustainablewaste management strategies can all be accomplished through public-private partnerships. The private sector can work with Indian smart cities to create and implement trash management initiatives that are economically, ecologically, and socially viable.

7. Waste Collection and Transportation: Effective waste collection and transportation arecrucial for sustainable waste management. Indian smart cities can implement efficient and regular waste collection systems to ensure that waste is collected and transported to the appropriate disposal or recycling facilities in a timely manner.

8. E-Waste Management: Electronic waste (e-waste) is a growing concern in India, and smartcities can take a lead in addressing this issue. This can be done by setting up dedicated e-waste collection and recycling centres, implementing e-waste disposal regulations, and promoting the

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responsible disposal of e-waste.

9. Management of Plastic Waste: One of India's largest environmental problems is PlasticWaste. The use of biodegradable plastics is encouraged, plastic trash collection and recycling facilities are established, and rules for the appropriate disposal of plastic waste can all be implemented by Indian smart cities.

10. Management of Biomedical Waste: The environment and public health are seriouslythreatened by the biomedical waste produced by hospitals, nursing homes, and other healthcare facilities.Indian smart cities can establish facilities for the secure and sanitary disposal of biological waste and enforce laws governing its correct disposal.

11. The Solid Waste Management Rules (2016), which establish the foundation for the management of municipal solid waste in India, can be enforced by smart cities in the country.This will guarantee that all waste management techniques adhere to national norms and regulations.

12. Community Involvement: Any waste management effort must have the support of the community in order to succeed. Indian smart cities can involve locals in waste management initiatives by encouraging composting, recycling, and garbage segregation.

13. Innovative Technology: Indian smart cities can adopt and invest in cutting-edge waste management technologies including robotic waste collecting systems, sensor-equipped smarttrash cans, and drones for rubbish collection and delivery.

Lastly, it is crucial to educate and raise public knowledge about the value of waste managementand the necessity to embrace sustainable waste management techniques. Indian smart cities canlaunch campaigns and educational initiatives to persuade locals to use eco-friendly trash management techniques.

These strategies can help Indian smart cities establish sustainable waste management systemsthat reduce trash, save the environment, and advance public health and well-being.

CASE STUDY - SINGAPORE'S WASTE MANAGEMNET SYSTEM

Singapore is a small island nation with limited land space and no natural resources, which makes waste management a critical issue for the country. Over the years, Singapore has implemented a comprehensive waste management system that includes waste reduction, recycling, and waste-to-energy (WTE) incineration. This document will provide an overview of Singapore's waste management system, its challenges, and its successes.

Waste Management System:

The Singaporean government's waste management system is based on the principle of the "3Rs" - Reduce, Reuse, and Recycle. The government has implemented several measures to encourage waste reduction, such as the introduction of a plastic bag charge, and mandatory reporting of packaging waste data by companies.

Singapore has a high recycling rate, and this is due to the government's efforts to promote recycling. The government has set up recycling bins across the island, making it easy for peopleto recycle their waste. The government also provides subsidies to recycling companies to encourage them to recycle more waste.

Singapore has also implemented the Extended Producer Responsibility (EPR) scheme, where manufacturers are responsible for the disposal of their products after use. This initiative has encouraged manufacturers to produce products that are easier to recycle. The EPR scheme has also led to the development of innovative recycling techniques, such as the recycling of e-wasteand the conversion of food waste into fertilizer.

Singapore has a robust recycling infrastructure that includes a network of recycling bins, recycling plants, and waste sorting facilities. The country has achieved a recycling rate of 61%in 2020, which is a significant improvement from the 22% recycling rate in 2001 (NEA, 2021).The government has also launched several initiatives to promote recycling, such as the National Recycling Programme and the RecycleNSave program.

50 years of waste management in Singapore – landfills

Like in every country around the world, the way to manage waste has dramatically changed over time and Singapore is no exception. As the quality of life improved, the amount of wastegenerated also increased. Waste, particularly putrescible waste, represents a significant health hazard (open fire, pollution of surrounding natural habitat) and a source of discomfort (such asfoul smells). As the population density increases, the need for a centralised place to manage waste become paramount.

Between 1970 and 2020, there have been three sanitary landfills in Singapore:

1. Lim Chu Kang Dumping Ground
2. Lorong Halus Dumping Ground

ISSN: 2583-6129
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3. Semakau Landfill

Lim Chu Kang Dumping Ground

Located in the northwest of Singapore, the Lim Chu Kang Dumping Ground operations beganin 1976 and was finally closed in September 1992. It covers a total area of 30 hectares.

The former landfill now accommodates the Sarimbun Recycling Park which opened in 1995. There, several companies recycle materials for roads and buildings, scrap tyres into flooring, horticultural waste into compost and charcoal, and manufacturers' plastic scrap into neat sacksof plastic pellets.

Although there are plans to use this land for high-value development, the land will require 30 to 40 years to be stabilised.

Lorong Halus Dumping Ground

Located on the bank of Serangoon River at the former site of the Municipal Sludge Disposal Works, the former landfill covers a total area of 234 hectares. It opened in 1970 and was knownas the Serangoon Sewage or the Tampines/Lorong Halus Refuse Tipping/Dumping Ground.

The landfill operated for 29 years. From 1970 to 1974, waste disposal was not strictly controlled. As a result, a significant amount of municipal waste would eventually decompose and putrefy. After 1974, the landfill will implement stricter management of the municipal waste. By 1982, Lorong Halus was storing almost half of Singapore's rubbish output. As Singapore expanded, the ratio of construction and demolition waste increased over time. Notethat after the start of operations of the first incinerator, the volume of municipal waste was drastically reduced.

Finally, between 1990 and 1999, waste was disposed into cells that would contain a mixture ofmunicipal and construction debris (see the yellow area in Figure 3). In the late 1990s, around 7 million m3 of excavated earth from the construction of the Mass Rapid Transit North-East Line was deposited at the landfill for land reclamation use.

One disposal method at these landfills involved spreading the refuse along the ground, then compacting the garbage by bulldozer, and finally covering it up with a layer of earth before further compaction. In addition, the site, which also housed Singapore's last night-soil disposalstation, practised controlled tipping whereby waste was buried in a pit with soil.

The landfill was initially expected to be completely filled up by 1997. However, the lifespan of the landfill was extended as a result of several factors, namely:

- the building of more incineration plants from the 1970s onwards, which allowedfor more refuse to be burnt instead of being buried;

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- improvement and expansion works at the landfill during the mid-'80s; and the building of a 63-hectare dumping ground beside the existing one in 1989.

Despite these changes over time, the operation of the landfill suffered from illegal dumping and regular complaints about its foul smells, open fires and pollution of the surrounding naturalhabitat. Eventually, completely filled up, Lorong Halus Dumping Ground closed on 31st March1999, one day before the Semakau landfill opened.

After the landfill was closed, part of the landfill was converted into a nature reserve and wildlifesanctuary.

Semakau Landfill

The concept of development of an offshore landfill was announced in 1989 by the then Ministryof the Environment, Aham Mattar, for implementation on the offshore islands, Pulau Semakauand Pulau Seking. This project was motivated due to land constraints on the mainland.

On 25th July 1994, parliament approved the reclamation of the foreshore and seabed east of Pulau Semakau comprising an area of about 350 ha required for the offshore landfill. Estimatedto have a holding capacity of 63.2 million m3, the landfill was projected to cost over S$1 billion. Finally, the total cost was limited to S$610 million.

Construction of the Semakau Landfill began in 1995. It is the world's first man-made offshorelandfill created entirely out of sea space. Operations at the landfill started on 1st April 1999, aday after the Lorong Halus dumping ground was closed.

Waste-to-Energy Incineration:

Singapore's waste management system also includes WTE incineration.

Singapore's waste-to-energy incineration plants are one of the most efficient in the world. These plants incinerate the general waste that cannot be recycled, and the heat generated is used to produce electricity. The ash produced from the incineration is then used as constructionmaterial. This method of waste disposal has helped Singapore to reduce the amount of waste sent to landfills.

To further reduce the environmental impact of waste incineration, Singapore has implementedstringent air emission standards for incinerators. The government also monitors the incinerationprocess to ensure that it meets the required standards

The country has four WTE incineration plants that burn non-recyclable waste to generate electricity. The incineration process produces ash, which is disposed of in a specially designed landfill. The WTE incineration plants are highly efficient, and the energy produced from burning waste contributes to the country's energy needs.

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Roadblocks:

Despite the successes of Singapore's waste management system, there are still challenges thatthe country faces. One of the main challenges is the limited land space available for waste disposal. Singapore's only landfill, Semakau Landfill, is expected to reach its capacity by 2035. The government is exploring alternative waste disposal methods, such as underground rock caverns, to address this issue.

Another challenge is the high cost of waste management. The WTE incineration plants are expensive to build and maintain, and the cost of waste disposal is expected to increase as the country's population and waste generation continue to grow.

Success:

Despite the challenges, Singapore's waste management system has been successful in achieving high recycling rates and reducing the amount of waste sent to landfills. The country has also been recognized internationally for its waste management efforts. In 2020, Singapore was ranked first in the Waste Management Index of the Asian Development Bank (ADB), which measures the effectiveness of waste management systems in Asia and the Pacific.

The Transformation of Waste Management in Singapore

Waste management has been a significant challenge for urban centers globally. Over the years,Singapore has faced challenges in managing its waste due to limited land, a growing population, and an increasing amount of waste generated. However, Singapore has made significant progress in waste management, transforming its system from one of the worst in theworld to one of the best. In this essay, we will examine the transformation of waste managementin Singapore and the factors that have contributed to its success.

The Past: The Challenges of Waste Management in Singapore

Singapore faced significant waste management challenges in the past. As the population grew,the amount of waste generated increased rapidly, and there was limited land available for landfill sites. In 1970, Singapore had only one landfill site, which was located at Pulau Semakau. However, by the mid-1980s, the landfill site had reached its maximum capacity, andSingapore had to look for alternatives.

In the past, waste was collected and transported to the landfill site where it was dumped. However, this method was not sustainable, and it led to environmental degradation. The landfillsite was also located near residential areas, which caused pollution and health hazards for residents. Furthermore, the waste generated in Singapore was mostly unsegregated, which made it challenging to recycle.

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The Present: Singapore's Innovative Waste Management System

Singapore's waste management system has undergone a significant transformation over the years. Today, Singapore is one of the cleanest and greenest cities globally, with an efficient waste management system. The country has achieved a high recycling rate of 60% and has reduced the amount of waste sent to landfill by 90%.

The transformation of waste management in Singapore can be attributed to several factors. Firstly, the government has implemented strict waste management policies, regulations, and laws. The government has also encouraged the private sector to invest in waste management solutions, such as recycling and waste-to-energy plants.

Secondly, Singapore has implemented a comprehensive waste management system that includes waste reduction, segregation, collection, and disposal. The country has implemented a mandatory waste segregation policy, which requires households and businesses to segregatetheir waste into recyclables, non-recyclables, and food waste. The waste is then collected separately and transported to recycling and waste-to-energy plants.

Thirdly, Singapore has invested in innovative waste management solutions, such as waste-to- energy plants, which convert waste into energy. The country has four waste-to-energy plants, which generate electricity that can power around 20% of Singapore's energy needs. The waste-to-energy plants also help to reduce the amount of waste sent to landfill and contribute to Singapore's goal of becoming a zero-waste nation.

The Future: Singapore's Vision for Waste Management

Singapore has set ambitious targets for waste management, with the aim of becoming a zero- waste nation. The country's vision for waste management includes reducing the amount of waste generated, increasing recycling rates, and developing innovative waste management solutions.

To achieve its vision, Singapore has implemented several initiatives, such as the 3R (reduce, reuse, and recycle) program, which aims to reduce waste at the source. The government has also encouraged the private sector to invest in innovative waste management solutions, such asthe development of new recycling technologies.

The Semakau Landfill is expected to handle Singapore’s waste disposal needs for another twodecades or so. But Singapore is not resting on its laurels. Instead, it is looking at ways to improve its waste management infrastructure and also urge its people to reduce and recycle, toextend the landfill’s capacity as far as possible into the future.

As Singapore’s waste output is projected to increase, it is working towards becoming a Zero Waste Nation through the reduction of consumption, as well as the reusing and recycling of materials to reduce waste generation at its source. As part of the Singapore Green Plan 2030, it aims to increase its recycling rate to 70% by 2030 and concurrently reduce the amount of waste sent to Semakau by 30%.

Singapore will continue to upgrade its infrastructure to remain at the forefront of waste management. The Integrated Waste Management Facility (IWMF) is expected to be completedby 2028 and will utilise new technologies to maximise both energy and resource recovery from

solid waste. Both water reclamation and waste management have been identified to share common processes and have many beneficial synergies. The IWMF will be co-located with the Tuas Water Reclamation Plant (TWRP) and both facilities are designed to be self-sustaining. This state-of-the-art facility will spearhead Singapore's drive towards sustainability in the future and is poised to be as groundbreaking as the Ulu Pandan WTE Incineration Plant in the1970s.

Apart from upgrading infrastructure, education has been stepped up to change attitudes and behaviours towards reducing, reusing and recycling.

To effectively promote a zero-waste lifestyle, MSE and the NEA work closely with schools, businesses, community groups, NGOs, and civil society groups to rally the ground and raise awareness on waste issues through their networks.

Many of these initiatives complement the efforts of the government. For instance, the charity organisation Zero Waste SG started as a website in 2008 and has since run several initiatives, such as a recycling campaign and a BYO (Bring Your Own) initiative – where it rallied over 1,000 businesses to encourage Singaporeans to bring their reusable bags, bottles or containers.

In light of success brought about by ground-up initiatives, the Towards Zero Waste Grant wasset up in 2019 to fund ground-up projects that drive waste reduction and recycling or encouragehouseholds to recycle more and recycle right. In 2019 alone, close to 2,000 activities were organized in support of the Zero Waste initiative.

There are also efforts by the government to draw greater attention and consideration towards waste generation and reduction. The mandatory reporting of waste data and Environmental Public Health Act (EPHA) was amended in 2014 to enact the reporting of waste data by businesses and commercial entities such as hotels and shopping malls and also requires them to propose waste reductions plans. Furthermore, in 2019, the Resource Sustainability Act wasenacted to legislate new measures to address waste streams such as the on-site food waste treatment systems in large commercial and industrial premises.

Technological advancement

Singapore has been a pioneer in waste management technology and innovation and has put several cutting-edge ideas into practise to manage its garbage effectively. In Singapore, some of the innovative technologies and developments in garbage management include:

- The Integrated Waste Management Facility (IWMF) is a cutting-edge facility that can handle a variety of waste streams, including non-recyclable garbage, construction waste, and e-waste. It uses cutting-edge technology to recover resources and reduce thequantity of garbage sent to landfills, including gasification, anaerobic digestion, and recycling.

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- Singapore has four waste-to-energy (WTE) facilities that turn solid waste into power. Each day, these facilities have the capacity to process over 8,000 tonnes of garbage andprovide enough electricity to power almost 150,000 homes.
- National Recycling Program (NRP): The NRP was established in 2001 to promote recycling among Singaporeans and lessen the quantity of waste that is disposed of in landfills. In addition to offering practical recycling amenities like recycling bins and bag distribution sites, the programme has also launched fresh initiatives like the Food Waste Recycling Programme.
- Smart Bin Technology: Around the nation, more than 3,000 smart bins have been erected by the National Environment Agency (NEA) using sensors to monitor waste levels and improve waste collection. With the use of this technology, fewer collection visits are necessary, and it also helps to avoid littering and overflowing trash cans.
- Food Waste Digesters: The NEA has experimented food waste digesters in hawker centres and commercial structures in an effort to reduce food waste. Utilizable as fertiliser, these digesters convert food waste into water and organic materials.
- Reverse vending machines: Singapore has put in place a Reverse Vending Machine (RVM) initiative that pays people to recycle. When someone deposits a recyclable iteminto the RVM, they are awarded points. These points can then be exchanged for rewardslike gift cards for stores or credits for public transportation. Glass bottles, aluminium cans, and plastic bottles are all accepted by the RVMs.
- The Electronic Waste Management System (EWMS) is a system that keeps track of how e-waste is collected, moved, and disposed of in Singapore. The technology makesit possible to handle e-waste properly and guarantees that it is processed in an environmentally friendly way.
- Semakau Landfill: The Semakau Landfill in Singapore is the first offshore landfill in the world and was built to reduce the environmental impact of trash disposal. To manage waste and stop pollution, the landfill uses cutting-edge technologies such a liner system, leachate treatment facilities, and gas recovery systems.
- Public Education and Outreach: To encourage Singaporeans to embrace sustainable waste management methods, the National Environment Agency (NEA) frequently undertakes public education and outreach programmes. These programmes, which promote recycling, trash reduction, and resource conservation, include seminars, workshops, and campaigns.

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- The Waste Reduction and Recycling Act, which mandates that businesses disclose theirwaste management procedures and establishes goals for trash reduction, was passed bySingapore in 2019. The act also requires certain sectors to establish required waste segregation and recycling.

Disposal of various items in Singapore

In Singapore, *the National Environment Agency (NEA)* is the regulatory body in charge of theenforcement of the law for waste management.

For public facilities such as Public Buildings, Public Areas, and HDB, the NEA awards contract to companies for the collection, transportation, and sorting of waste. Those companies are called Public Waste Collectors (PWCs):

1. 800 Super Waste Management Pte Ltd
2. ALBA W&H Smart City Pte Ltd
3. SembWaste Pte Ltd
4. Veolia ES Singapore Pte Ltd

All other facilities (Private companies, condominiums) can choose whichever licenced waste collector they want for the collection and transportation of waste. Those companies are calledGeneral Waste Collector (GWCs). The list of GWCs can be found here:

1. *All General Waste Collectors*
2. *Used cooking oil collectors*
3. *Companies that collect or process waste for recycling*
4. *General Waste Collectors with waste weighing services*

Recyclable or not?

When a facility generates waste, those discards can be classified according to the following:

- **Recyclable**: materials that can be sent to a sorting and recycling facility to be transformed into a new commodity. This typically includes paper, plastic, glass, metal.
- **Organic waste**: such as food waste and green waste. For smell, health, and safety reasons, those waste should be segregated at the source and handled by a suitable contractor.
- **Hazardous**: waste which represents health or safety risks (e.g. solvent-based paint, mobile phone batteries, motor oils…), and which must be handled by a suitable contractor.
- **General waste**: non-hazardous waste with no or little recyclability which is consideredas final waste.

ISSN: 2583-6129
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In Singapore, any discards going into the General Waste bin will go straight to one of the Wasteto Energy (WTE) incineration plants. There, the waste will be burned. The heat will be used togenerate electricity.

Discards going into the Recyclable bin will go first to a sorting facility where they will be segregated according to the material type and value. What can be recovered will then be sent to a recycling plant (most of them are located overseas) where it will be transformed into a newcommodity. The materials which cannot be recovered will be sent to the WTE incineration plant.

Ashes from the incinerators are then sent to the offshore Semakau Landfill.

Sustainable and Resource Efficient Singapore

Setting Targets to Reduce and Recycle

Under Singapore's Zero Waste Masterplan, the NEA aim to increase their overall recycling rate to 70 per cent and reduce waste-to-landfill per capita per day by 30 per cent by 2030. This goal will be frontloaded to achieve a 20 per cent reduction in waste-to-landfill per capita per day by 2026 under the Singapore Green Plan 2030. Targets are set with plans of extending the lifespan of Singapore's only landfill beyond 2035.

They also have 2030 targets to increase non-domestic recycling rate to 80 per cent and domestic recycling rate to 30 per cent.

Zeroing in on Food Waste

The Food Waste Fund (FWF) was launched in May 2020 during the pandemic as part of the SG Clean Campaign. The FWF is a one-off new fund aimed to incentivise premises to adopt food waste segregation and treatment solutions in order to improve cleanliness and reduce disamenities from food waste. It also supported premises owners and operators to segregate and treat food waste ahead of the mandatory requirements, as well as encourage those that would not be covered under the future mandatory framework to take up voluntary segregationand treatment at a time when environmental sustainability might not be their main focus. A total of 24 approved projects are supported under the FWF.

Encouraging E-waste Recycling Among Households

In January 2020, NEA conducted a trial to encourage e-waste recycling among residents by leveraging the period when residents traditionally do spring cleaning before the Chinese New Year festivities. Publicity posters on nearby Cash-for-Trash (CFT) stations were placed at lift lobbies of selected housing blocks to encourage households to recycle their unwanted e-waste. Survey findings revealed that more residents recycled their e-waste at the CFT station, and the proportion who disposed e-waste at blue recycling bins, an inappropriate mode for e-waste, also decreased. More residents also perceived recycling of e-waste to be convenient after they were made aware of a nearby CFT station.

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Extending the Mandatory Waste Reporting Scheme

Large commercial premises are required to report waste data and submit recycling rate targets.In 2020, the mandatory waste reporting scheme was extended to include industrial premises with a gross floor area of more than 20,000 sqm, warehouses with a gross floor area of more than 50,000 sqm, and convention and exhibition centres with a gross floor area of more than 8,000 sqm. A total of 441 submissions from industrial premises and MICE venues for the 2020reporting cycle were received by end March 2021.

Closing The Waste Loop with Innovative Solutions

NEA has been administering the $45 million Closing the Waste Loop (CTWL) Research and Development (R&D) Initiative to develop innovative solutions in resource recovery, landfill space conservation, and enhancing the sustainability of our waste management system. As of 31 March 2021, NEA has committed $27 million to fund 11 R&D projects on the treatment ofand resource recovery from the priority waste streams – food waste, e-waste and plastic waste,and from residues such as incineration bottom ash and non-incinerable waste. Some of these projects have attracted industry interest, leading to seven industry project collaborations and atotal of $1.6 million industry spending pledged, thus far.

One of these innovative solutions is developed by the NTU Singapore-CEA Alliance for Research in Circular Economy (SCARCE), which employs green chemical processes that minimise the use and generation of hazardous substances to recover precious metals from the e-waste. SCARCE has experimented using orange peel waste with citric acid to successfully dissolve and recover 90 per cent weight of metals, including nickel, manganese, cobalt and lithium from spent lithium-ion batteries, and has licensed the technology rights to a venture capital company. The team is currently working with local companies to commercialise the technology in Singapore.

In addition, NEA has also launched grant calls on diversion of non-incinerable waste from Semakau Landfill and site investigation and characterisation at Phase 1 of Semakau Landfill for material recovery. Proposals received are being put through an evaluation and approval process.

Exploring New Uses for NEWSand^{TM}

With Semakau Landfill projected to run out of space by 2035, NEA has been taking steps to extend its lifespan. One such effort was through finding alternative uses for treated incinerationbottom ash (IBA) and other waste treatment residues known as NEWSand^{TM}. In September 2020, we commenced a field trial using treated IBA for the construction of road-base and sub-base layers along a stretch of Tanah Merah Coast Road. This field trial is to establish the on- site environmental conditions before, during and after the road construction. The environmentalmonitoring data and the long-term modelling results will be used to review the provisional environmental standards for NEWSand^{TM}. NEA is also conducting lab-scale tests on the use of treated IBA in non-structural concrete.

ISSN: 2583-6129
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Turning Waste into Resources

NEA awarded three projects on pilot trials to be conducted at the Waste-to-Energy (WTE)Research Facility in its first WTE test-bedding and demonstration grant call.

Two of these projects arose from upstream research conducted earlier under the WTE Competitive Research Programme. One is on membrane separation technology to produce oxygen-enriched air for enhancing WTE gasification processes, and the other is on upgradingof syngas for higher energy recovery and possible synthesis into high-value chemicals. The third project involves the production of biocoke derived from sewage sludge and biomass waste generated in Singapore to partially replace biomass charcoal as the auxiliary fuel for the high-temperature slagging gasification process.

Exploring Chemical Recycling of Plastic Waste

NEA has been exploring chemical recycling to complement existing mechanical recycling capabilities to close the plastic waste loop. Through chemical recycling, contaminated plastics that cannot be mechanically recycled, can be treated and converted into higher-value productssuch as pyrolysis oil, which can be used to manufacture new plastics and chemicals.

To ensure a steady supply of material, NEA is conducting a feasibility study on a pilot PlasticRecovery Facility that can take in domestic waste to recover various polymer types as plastic feedstock for chemical recycling.

Encouraging Households to Take Climate Action

NEA and PUB launched the Climate Friendly Households (CFH) Programme on 28 November2020 to encourage households to reduce their energy and water consumption, while saving costs in the long run. Under the CFH Programme, all one-, two- and three-room households inpublic housing estates can receive three types of e-vouchers amounting to $225, to offset the cost of purchasing energy or water efficient essential appliances. If all eligible households make the switch, the collective reduction in carbon emissions will be equivalent to taking 31,000 cars off the road and the water savings amount to 400 million gallons of water annually.This will help to fight climate change, and allow households to benefit from utility savings of around $40 to $120 per household annually.

Harnessing Waste Process Synergies with Tuas Nexus

As part of NEA's long-term plan to meet Singapore's solid waste management needs, NEA started planning the development of the Integrated Waste Management Facility (IWMF) with PUB in 2013. We embarked on a joint preliminary engineering design study to assess the potential of harnessing process synergies by co-locating a solid waste treatment facility with awater reclamation facility. This led to the co-location of two mega facilities – the IWMF and Tuas Water Reclamation Plant, now collectively known as Tuas Nexus. Tuas Nexus will be able to reap co-location synergies across the water-energy-waste nexus to maximise energy and resource recovery, and optimise land use.

ISSN: 2583-6129
www.isjem.com

In FY2020, NEA commenced the construction of the WTE Facility (2,900 t/d) and Materials Recovery Facility (250 t/d) under Phase 1 of IWMF. The construction of the Sludge Incineration Facility (800t/d) and Food Waste Treatment Facility (400t/d) is scheduled to commence in the second half of 2021. Phase 1 of IWMF is expected to be completed in 2025,with the development of Phase 2, which comprises another WTE Facility (2,900 t/d), to followthereafter.

IWMF has achieved the NEA Innovative Spirit Award at InNEAvation Awards 2020, the MSEInnovator Award at MSE Excellence Day 2021 and Minister's Special Commendation Awardat the then-Ministry of Environment and Water Resources Excellence Day 2020.

Moving Towards Sustainable Packaging

In FY2020, NEA implemented the Mandatory Packaging Reporting (MPR) framework as partof our effort to focus companies' attention on the packaging of their products and the potentialfor reducing packaging use in their operations. Under the framework, producers of packaged products, which include brand owners, manufacturers and importers, as well as retailers such as supermarkets with an annual turnover of more than $10 million, are required to start collecting packaging data and develop plans to reduce, reuse or recycle packaging for annual submission to NEA.

The MPR will also lay the foundation for an Extended Producer Responsibility (EPR)framework to manage packaging waste including plastics, which will be put in place no later than 2025. NEA will be introducing the legislative framework for the implementation of a beverage container return scheme by 2022 as the first phase of the EPR approach for packagingwaste management.

To support companies in fulfilling their mandatory packaging reporting obligations, NEA haspartnered the Singapore Manufacturing Federation on a joint capability development programme. The Packaging Partnership Programme will offer companies workshops and training courses to familiarise them with the MPR and serve as a platform for companies to exchange best practices in sustainable packaging waste management.

Taking E-waste Recycling to the Next Level

From 1 July 2021, the public can recycle regulated e-waste comprising Information and Communications Technology (ICT) equipment, large appliances, light bulbs and tubes and batteries, through multiple collection avenues. The e-waste collection and recycling[3] is carriedout by ALBA E-waste Smart Recycling Pte Ltd, which has been awarded the licence to operate a Producer Responsibility Scheme (PRS) in Singapore for a period of five years, from 1 July 2021 to 30 June 2026. Under the PRS, ALBA will send all e-waste collected to licensed e- waste recyclers. ALBA will also set up a data management system to track and report to NEAthe amount of e-waste collected for treatment.

Singapore Waste Management Market Analysis

Singaporean waste management market is growing at a decent pace as the country's smaller size gives it a little room for waste disposal, and encourages recycling. In 2017, the country had recycled 61% of its waste, according to the National Environment Agency. The rest is incinerated, with a slight fraction sent to landfill. The landfill "island," called Semakau, was created in 1999 and extended in 2015, with enough space to meet Singapore's waste disposal needs until at least 2035.The waste management industry in Singapore majorly consists of all municipal solid waste (MSW) - including non-hazardous waste generated in households, commercial establishments and institutions, and non-hazardous industrial process wastes, agricultural wastes and sewage sludge. The industry's value represents the amount of total typical charge per ton for landfill multiplied by the volume of MSW generated. The industry'svolume represents the total MSW generation. All currency conversions used in the creation ofthis report have been calculated using constant 2017 annual average exchange rates.

Singapore Waste Management Market Trends

The country had taken significant steps to tackle with the waste moving towards upstream. Several measures have been considered to minimize waste and recycle the waste at various business and industrial set ups, schools and households.

Recyling by Industries and businesses
Pay-as-you-throw fee structure encourages waste generators to reduce waste disposal Recycling services are provided at industrial estates

National recycling programme at households
Nationwide residential recycling programme implemented in all neighbourhoodsRecycling bins conveniently located near every block of flats
100% of primary & secondary schools have recycling corners Students volunteer as “Green Ambassadors”
Builds awareness & promotes action from young

Singapore Waste Management Market Competitor Analysis

Building on their experience gained in Singapore, many local companies have been bringing their comprehensive suite of cost-effective value-add services to its clients around the world. Companies looking to tap into Singapore’s capabilities will find partners that are experienced,international and able to customise solutions to meet clients’ needs. The market for companiesin Singapore however looks fragmented offering many opportunities for new companies to enter the market.

Singapore-based companies operate across the entire waste management value chain, from collection and recycling, to waste treatment, energy recovery and landfill management. They offer integrated services to optimise efficiency and deliver long-term, sustainable solutions.

ecoWise - The company’s wholly owned subsidiary, Bee Joo Industries Pte Ltd is the first Singapore-based company to successfully register a Clean Development Mechanism project and complete the Emissions Reduction Purchase Agreement. The carbon credits

generated from its energy recovery activity in the biomass cogeneration plantin Singapore were sold to Kansai Electric of Japan.
Many pre-qualified waste collection companies compete to provide collection services for thedesignated domestic and trade premises in the nine geographical sectors of Singapore.

Challenges Ahead

There are still barriers in Singapore's drive towards zero waste. For instance, Singaporeans are still generally unaware when it comes to recycling. This lack of knowledge contributes to a lowered domestic recycling rate and more commonly, leads to the contamination of recycled goods. The NEA states that 40 per cent of recycling placed in blue bins gets contaminated by non-recyclables such as food waste and hence, cannot be recycled.

As part of this framework, legislative action has been taken in the form of the 2019 Resource Sustainability Act which addresses priority waste streams, such as food and e-waste.

NEA launched a Food Waste Reduction (FWR) outreach programme in November 2015 to encourage the adoption of smarter shopping, storage and preparation habits that help consumers save money while reducing food wastage.

In addition, NEA and the Singapore Food Agency (SFA) have worked with the food industry to publish food waste minimisation guidebooks for food retail establishments, supermarkets and food manufacturing establishments to reduce food waste across the supply chain.

E-waste is also being targeted as it contains small amounts of heavy metals and othersubstances of concern (e.g., in printed circuit boards). The wide variety of e-waste also makesit hard to generalise material content. For instance, the material composition of a mobile phoneis very different from that of an electric kettle. Hence, the management of e-waste is effort- consuming and costly.

Management of e-waste starts upstream and at the very beginning during the manufacturing stages. Singapore has several restrictions on hazardous substances for electrical and electronicequipment. For instance, the local sale of batteries exceeding a stipulated mercury content is not allowed. This way, used batteries can be safely discarded along with normal household waste at our WTE incineration plants.

At this point, e-waste recycling has been largely voluntary, with the NEA working closely withindustry partners and the community. While voluntary e-waste recycling measures haveyielded encouraging results, the NEA recognises the limitations of a voluntary approach and in turn, the need for a regulated system in the long run. At the moment, studies are underway to develop feasible systems for the collection and recycling of e-waste.

ISSN: 2583-6129
www.isjem.com

Conclusion:

Singapore's transformation of waste management is a success story that demonstrates how a city can overcome significant challenges to achieve sustainable waste management. Singapore's innovative waste management solutions, comprehensive waste management system, and ambitious targets for the future have contributed to its success. The country's wastemanagement system is an excellent example for other cities to follow as they work towards achieving sustainable waste management.

Singapore's waste management system is a model for other countries to follow. The country has implemented a comprehensive waste management system that includes waste reduction, recycling, and WTE incineration. Despite the challenges, Singapore has achieved high recycling rates and has been recognized internationally for its waste management efforts. Thegovernment's commitment to waste management is critical to ensuring a sustainable future forSingapore.

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ISSN: 2583-6129
www.isjem.com