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INGENIEUR

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Waste Management



QR



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PLUS promotes the value of constantly learning with great appreciation for those who are willing to put their best efforts in gaining knowledge. I have obtained my Professional Technologist, my Chartered Professional Civil Engineer, my Professional Engineer and most recently the accreditation as Professional European Engineer from Engineers Europe Engineering Council. The accreditation received would be crucial in promoting the drive for PLUS in being the best in Highway and Transportation Asset Management within a fast-moving Malaysia's transportation infrastructure industry.

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Level 3A, Nexus, Bangsar South City,
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19TH – 22ND August 2025

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- To strengthen regional engineering collaboration and strategic partnership
- To provide a national platform for professional development and regulatory updates
- To celebrate engineering excellence and promote recognition of the profession
- To inspire and nurture future engineering leaders



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- Towards Global Recognition: Benchmarking CPD for the Malaysian Engineering Profession
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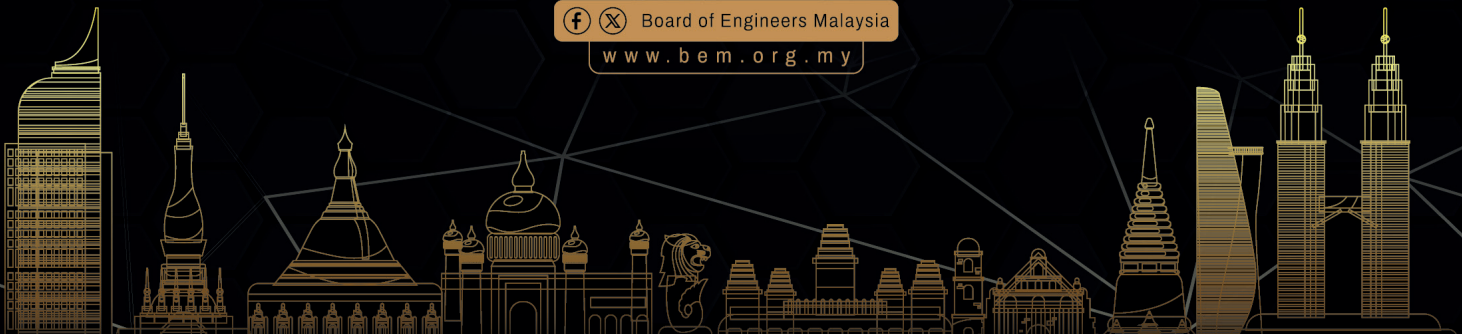
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Solid Waste Management



Datuk Wira Ir. Roslan bin Ismail
President
Board of Engineers Malaysia

As Malaysia strides towards a sustainable future, the role of engineers in addressing critical environmental challenges has never been more vital. This edition focuses on Solid Waste Management, a key pillar in achieving the nation's vision for a circular economy under the Malaysia Solid Waste Management Roadmap 2025-2035.

The transition to a circular economy presents both opportunities and challenges. It demands a paradigm shift from the traditional “take-make-dispose” model to a regenerative approach where waste is minimised, resources are reused, and value is retained within the system. As problem-solvers and innovators, engineers play a crucial role in designing and implementing sustainable solutions that align with global best practices while addressing the unique needs of Malaysia's socio-economic landscape.

In this issue, we explore how engineering expertise can contribute to advancing solid waste management practices. From integrated waste treatment facilities to cutting-edge recycling

technologies, the engineering profession is at the forefront of developing solutions that reduce landfill dependency, minimise environmental impact, and enhance resource efficiency. We highlight the importance of embracing international best practices, such as advanced material recovery processes and waste-to-energy technologies, which can be adapted to local conditions for greater environmental and economic benefits. As Malaysia intensifies its commitment to meeting sustainable development goals (SDGs), engineers must adopt holistic design principles, life-cycle assessments, and innovative waste reduction strategies.

We invite our readers to reflect on how their work contributes to a cleaner, more sustainable Malaysia. By fostering a culture of innovation, upholding professional integrity, and sharing knowledge, engineers can lead the nation towards a resilient future where waste is no longer an afterthought but a resource to be harnessed.

Together, let us advance the agenda of sustainable solid waste management and pave the way for future generations. 🏗️



CALL FOR ARTICLES

The Ingenieur is published quarterly by the Board of Engineers Malaysia. The following are the themes for the coming issues.

Vol. 102 April-June 2025
AI in Engineering

Vol. 103 July-Sept 2025
Maritime Engineering

Vol. 104 Oct-Dec 2025
Construction Industry

Articles and other contributions relevant to the themes are welcomed, but the decision to publish rests with the Editorial Board.

Advertising inquiries are also welcomed. Please refer to the BEM advertisement on Page 28 for the latest rate card and booking form.

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Assoc. Prof. Ir. Dr. Wong Yew Hoong Tokoh Muda Kejuruteraan Negara 2023



Assoc. Prof. Ir. Dr. Wong Yew Hoong has been awarded the Tokoh Muda Kejuruteraan Negara 2023 (National Young Engineering Icon 2023). Having achieved success in academia and research through self-drive and hard work, he is a good role model for young engineers.

Currently, he is Associate Professor in the Department of Mechanical Engineering, Engineering Faculty, Universiti Malaya. He is a registered Professional Engineer in Materials Engineering with BEM, a Chartered Engineer registered with the Engineering Council UK and Fellow of the Institution of Mechanical Engineers UK. He has made significant strides in materials engineering research and development and won many awards for his inventions.

Ir. Dr. Wong was born in Malacca but grew up in Labuan, supported by his father, a welder in a shipyard. In an interview with *The Ingenieur*, he reveals that he was once quiet and taciturn. "I was not talkative in primary school, especially when conversing in English," he discloses. His mother's encouragement and his inner motivation to excel were what changed him. Even in kindergarten, he had wanted to be top in his class. He credits his teachers who encouraged him to study hard. Eventually, his marks improved and he achieved good grades at various levels of his education.

In secondary school, Ir. Dr. Wong slowly gained confidence in speaking. As he excelled in Chemistry and Physics, he was keen to continue his studies in the Science arena. He had many choices when it came to university education and even contemplated becoming a doctor or pharmacist.

So, what led him to engineering and materials engineering instead?

The impetus came from advice given by the cousin of a school friend who was a Senior Engineer at Shell Malaysia. "A doctor can treat and benefit one person at a time. But what engineers do can benefit the whole society," said his friend's cousin. This resonated with him and firmed his decision. He thought of studying Mechanical or Chemical Engineering but was instead directed to Materials Engineering by the Senior Engineer who pointed out that this was a niche discipline that encompassed both Mechanical and Chemical Engineering subjects.

Ir. Dr. Wong took his advice. University education was initially a challenge as he had to relocate to Penang to study in Universiti Sains Malaysia in 2005. The different environment and lifestyle took time getting used to. Through hard work, he excelled in his studies. In the third and final year, he made it to the Dean's List. He graduated from USM in

2012 with Bachelor of Engineering (Hons) in Materials Engineering and continued to earn a PHD in 2012 in Electronic Materials. His motto for success emphasises hard work and perseverance. “Success is 99% hard work and 1% luck, so never give up,” he says.

He joined Universiti Malaya (UM) in 2013. Besides supervising postgraduate students, Dr. Wong is very active in research projects. He heads the Electronic Materials Laboratory and Semiconductor Thin Film Laboratory. His research skills and expertise are wide ranging, including advanced materials, electronic materials, thin films, material characterisation, semiconductor fabrications and nanofabrication.

Ir. Dr. Wong has been involved in 48 projects, with support from Government grants and industry funds that totalled RM8 million. Among his many innovations was developing a polymers chemiresistive gas sensing materials. He has two prototypes ready for commercialisation.

As Malaysia has a sizeable semiconductor sector, there is industry support for research and development. Ir. Dr. Wong notes that the country is not prominent in the front end of the industry as most players are in the back end of wafer fabrication and assembly. However, with available materials such as rare earth in the country, there is much scope for further development of the semiconductor industry.

Ir. Dr. Wong has received many awards for his research work, including the 2020 EPS Outstanding Young Engineer Award from IEEE, US, for his contribution in the field of electronic packaging materials and semiconductor fabrication technologies.

At UM, Ir. Dr. Wong received Excellence Awards in 2017, 2019 and 2020. UM also recommended him for the BEM Engineering Award called the Tokoh Muda Kejuteraan Negara 2023 or National Young Engineering Icon 2023.

Ir. Dr. Wong is also adept in marketing and his inventions have achieved recognition at



*Demonstrating Silicon Wafer (Left)
and Fabricated Chip (Right)*

international exhibitions. In fact, he has won more than 10 awards at international exhibitions such as the Malaysia Technology Expo (MTE) and International Invention, Innovation & Technology Exhibition (ITEX). At MTE 2024 for instance, he introduced a gas sensor device that could be used to detect glucose levels in humans. This meant that there was no need to prick a finger for blood and that the testing could be done conveniently at home.

Ir. Dr. Wong's message to aspiring engineers: “Without science, the world will not advance. Make the world better. Learn science, take up engineering, and elevate the world to another level”.

He foresees vast potential for engineers, especially those in the semiconductor industry under the National Semiconductor Strategy as part of Malaysia's New Industrial Master Plan (NIMP) 2030 which aims to enhance the supply chain from design to production of high value semiconductor products. - *Inforeach* 

Managing Industrial Electroplating Wastewater: Strategies and Compliance for Safe Release into Rivers

by
Nur Zulaika binti
Ab Malik

Industrial wastewater treatment stands as a pivotal concern in environmental management, given the significant quantities of hazardous substances that the various industries discharge into our rivers. The release of such pollutants can lead to severe environmental degradation, impacting aquatic ecosystems and posing serious risks to public health. As industrial activities proliferate and intensify, the effective management of wastewater becomes increasingly crucial.

This article highlights the various management techniques employed in the wastewater treatment, including structure consideration, from simple to advanced processes, and the best practices in operation management. It also outlines the regulatory framework that governs these practices, emphasising the need for compliance with environmental standards and the role of regulatory bodies in ensuring sustainable industrial wastewater operations.

Through the exploration of these facets, this article also aims to provide a comprehensive understanding of the challenges and impacts associated with inadequate industrial wastewater

treatment, underscoring its significance in fostering environmental compliance to reduce the impact on community well-being.

Background of Electroplating Wastewater

This article explores electroplating waste generated by electronic industries, especially semiconductor manufacturing. The electroplating processes deposit metal layers on semiconductor wafers. These processes are important for creating the intricate circuitry and components in semiconductor devices. Depending on the specific product, the process may be slightly different.

Figure 1 is an example of the sequence in the electroplating process for semiconductor wafers, based on project reference of one semiconductor company in Malaysia.

Wastewater is generated during activities such as chemical dipping, rinsing, cleaning, water jet, and plating. Waste that is most concentrated with heavy metals and spent chemicals is generated during chemical dipping and plating.

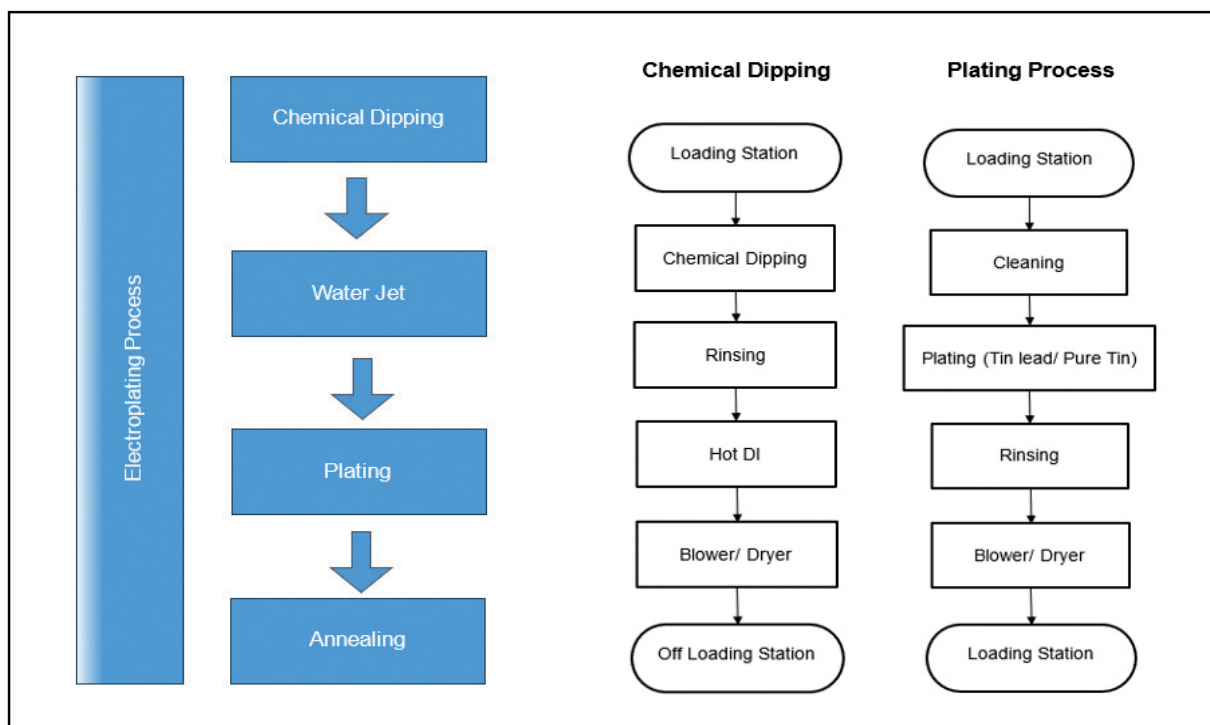


Figure 1: Process flow of electroplating process

Common pollutants include:

1. Heavy metals such as cadmium, chromium hexavalent, nickel, lead, lead, tin and copper.
2. Cyanide and other nutrients such as phosphorus and ammonia-nitrogen.
3. Spent Plating Solutions containing dissolved metals and used chemicals.

Pollutant Impact

Untreated or inadequately treated wastewater pollutant can lead to eutrophication, aquatic disruption and public health risks.

Aquatic Life & Biodiversity: Industrial wastewater, especially that from semiconductor plating activities, often contains high levels of heavy metal and even cyanide which is highly toxic. When released untreated into rivers, these contaminants can cause excessive growth of algae, known as algal blooms, which

is highly toxic to fish and aquatic plants. This results in the death of fish and other aquatic organisms, disrupting the balance of aquatic ecosystems and reducing biodiversity.

Below is an example of where industrial wastewater led to severe environmental consequences.

Sungai Kim Kim Pollution Incident (2019)

The contaminants caused massive fish die-offs and harmed other aquatic life. The river water quality deteriorated, leading to toxic conditions that were lethal to fish. A report lodged stated that the river water had turned turbid, emitted a stench and caused fish to die¹.

The river water showed severe pollution due to the illegal dumping of highly toxic substances such as cyanide and heavy metals including chemicals used in industries like semiconductor plating and other manufacturing processes.

Public Health Risks

Water contamination can pose significant health risks to humans, either through drinking the contaminated water or consuming contaminated fish and shellfish. Health effects include respiratory issues, neurological damage and, in severe cases, cyanide poisoning. Below is one of the most tragic and well-known cases of river pollution.

Minamata Disease, Japan (1950s–1960s).

Symptoms of this neurological syndrome caused by severe mercury poisoning include numbness in the hands and feet, muscle weakness, loss of vision, hearing and speech impairment as well as severe deformities and mental disabilities. In extreme cases, it leads to paralysis, coma, and death.

The Minamata Disease was linked to the consumption of fish and shellfish contaminated with methylmercury that had been discharged into the Minamata Bay by a chemical company, Chisso Corporation.

Regulations & Standards

Governments worldwide have established regulations to control industrial discharge limits. In Malaysia, the Environmental Quality Act 1974 provides the legal framework for environmental protection. Under this Act, the Director-General of Environmental has the mandate to oversee and enforce regulations. Specifically, the Environmental Quality (Industrial Effluent) Regulations 2009 are enacted to set standards for the discharge of industrial effluents.

These regulations are aimed at safeguarding water quality by ensuring that treated wastewater meets discharge standards before it is released into natural water bodies such as rivers. All industries that generate wastewater must comply to the discharge limits specified in the Fifth and Seventh Schedule.

Compliance is monitored through daily monitoring records and enforcement through DOE inspections to ensure that the wastewater treatment meets the required standards. Penalty and fines are imposed for offences contravening the Regulations³ stated in the Environmental Quality (Industrial Effluent) Regulations 2009...

FIFTH SCHEDULE [Paragraph 11(1)(a)]			
ACCEPTABLE CONDITIONS FOR DISCHARGE OF INDUSTRIAL EFFLUENT OR MIXED EFFLUENT OF STANDARDS A AND B			
Parameter	Unit	Standard	
		A	B
(1)	(2)	(3)	(4)
(i) Temperature	°C	40	40
(ii) pH Value	–	6.0-9.0	5.5-9.0
(iii) BOD ₅ at 20°C	mg/L	20	50
(iv) Suspended Solids	mg/L	50	100
(v) Mercury	mg/L	0.005	0.05
(vi) Cadmium	mg/L	0.01	0.02
(vii) Chromium, Hexavalent	mg/L	0.05	0.05
(viii) Chromium, Trivalent	mg/L	0.20	1.0
(ix) Arsenic	mg/L	0.05	0.10
(x) Cyanide	mg/L	0.05	0.10
(xi) Lead	mg/L	0.10	0.5
(xii) Copper	mg/L	0.20	1.0
(xiii) Manganese	mg/L	0.20	1.0
(xiv) Nickel	mg/L	0.20	1.0
(xv) Tin	mg/L	0.20	1.0
(xvi) Zinc	mg/L	2.0	2.0
(xvii) Boron	mg/L	1.0	4.0
(xviii) Iron (Fe)	mg/L	1.0	5.0
(xix) Silver	mg/L	0.1	1.0
(xx) Aluminium	mg/L	10	15
(xxi) Selenium	mg/L	0.02	0.5
(xxii) Barium	mg/L	1.0	2.0
(xxiii) Fluoride	mg/L	2.0	5.0
(xxiv) Formaldehyde	mg/L	1.0	2.0
(xxv) Phenol	mg/L	0.001	1.0
(xxvi) Free Chlorine	mg/L	1.0	2.0
(xxvii) Sulphide	mg/L	0.50	0.50
(xxviii) Oil and Grease	mg/L	1.0	10
(xxix) Ammoniacal Nitrogen	mg/L	10	20
(xxx) Colour	ADMI*	100	200

*ADMI–American Dye Manufacturers Institute

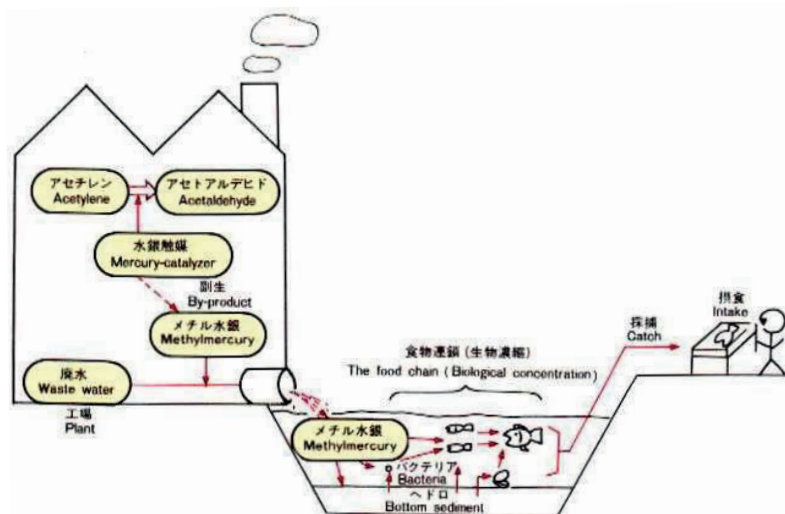
SEVENTH SCHEDULE (Regulation 12)			
ACCEPTABLE CONDITIONS FOR DISCHARGE OF INDUSTRIAL EFFLUENT CONTAINING CHEMICAL OXYGEN DEMAND (COD) FOR SPECIFIC TRADE OR INDUSTRY SECTOR			
(1) Trade/Industry	(2) Unit	(3) Standard A	(4) Standard B
(a) Pulp and paper industry			
(i) pulp mill	mg/L	80	350
(ii) paper mill (recycled)	mg/L	80	250
(iii) pulp and paper mill	mg/L	80	300
(b) Textile industry	mg/L	80	250
(c) Fermentation and distillery industry	mg/L	400	400
(d) Other industries	mg/L	80	200

Taking water samples
from Sungai Kim Kim in
Pasir Gudang. Source:
New Straits Times,
December 5, 2023



Deformities of the body
due to Minamata Disease.
Source: FCCJ exhibition:
Minamata Disease by
Shisei Kuwabara

How methylmercury was
transmitted from the
acetaldehyde manufacturing
process to the human body.
Source: Ministry of the
Environment, Government
of Japan



Wastewater Management

Design Consideration: In Malaysia, general consideration in every process design must adhere to the design criteria, parameter, process range and monitoring instruments as outlined in the Guidance Document on the Design & Operation of Industrial Effluent Treatment Systems. This is to ensure that an industrial effluent treatment system (IETS) is designed and operated in compliance with regulatory standards.

When designing buildings with IETS systems, both open and closed structures can be considered. However, it is important to incorporate adequate chemical protection measures during the construction phase. This includes designing for safe handling, storage, and containment of chemicals to

prevent leaks, spills, and hazard exposure. Proper ventilation of fumes, durability of the materials, and emergency containment should be integrated to ensure the safety of humans and environment.

In addition, day-to-day operations and maintenance consideration must be integrated during the planning stage. This ensures that the design not only meets functional process but also facilitates ongoing daily operations and maintenance. Proper planning includes the designing of a maintenance pathway, ensuring equipment accessibility for repairs, and incorporating features that support efficient long-term operation.

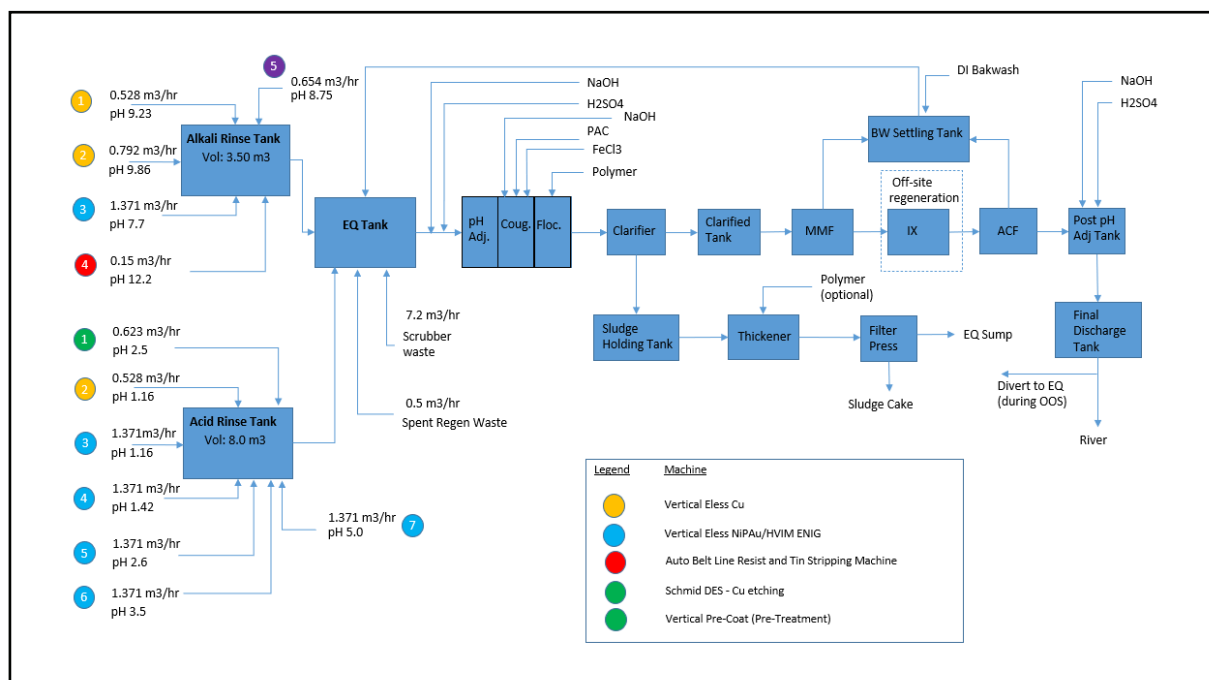
Below are examples of Wastewater Treatment Plant (WWTP) structures designed for two semiconductor facilities in Malaysia.



Closed structure WWTP



Open structure WWTP



Process flow diagram of plating wastewater treatment. This tertiary treatment illustration is based on one of the projects of semiconductor company in Malaysia.

Treatment Technology and Techniques:

To meet regulatory requirements, industrial effluents from electroplating activities must undergo thorough treatment. Depending on the pollutant present in the wastewater, technologies and processes may vary. Below are common ways involved in wastewater treatment system.

1. Primary Treatment or Physical Treatment

Processes like screening, sedimentation and skimming are used to remove large particles, debris and high solids content. At this stage, no chemicals are added as this process is mainly to reduce the load on subsequent treatment processes and does not remove dissolved contaminants.

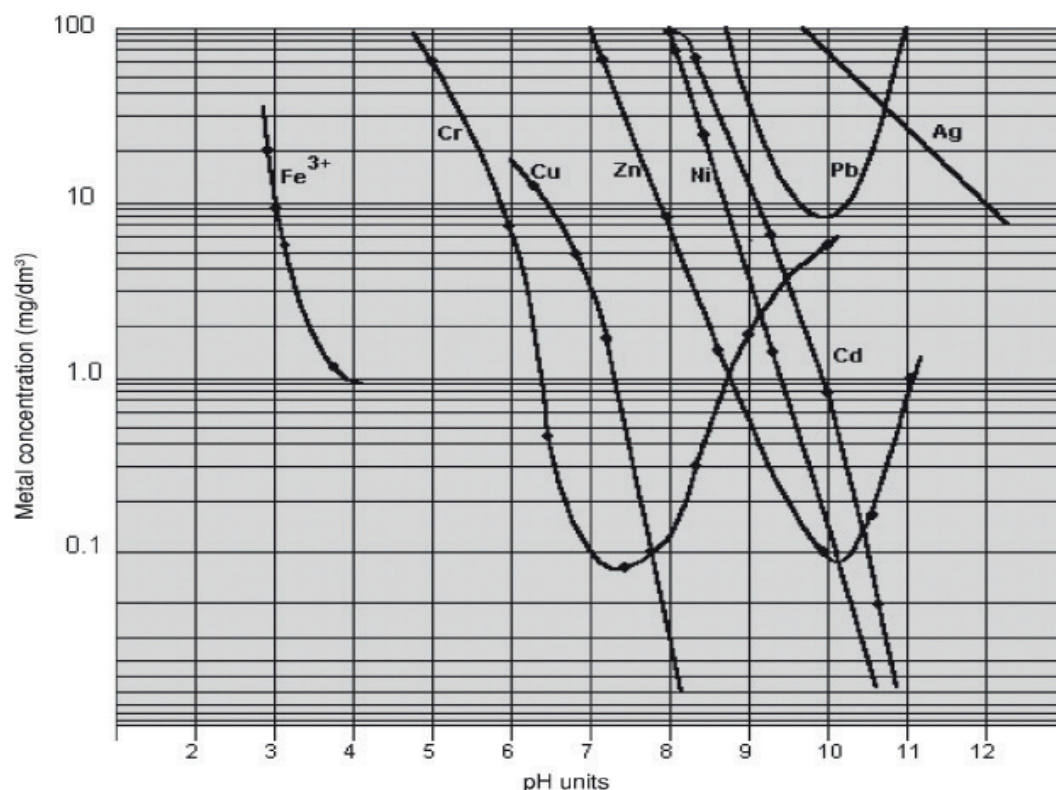
2. Secondary Treatment or Biological Treatment

In this process, bacteria is used to break down the organic matter present in the wastewater. Higher biochemical oxygen demand (BOD) and chemical oxygen demand (COD) levels indicate the

amount of organic matter pollutant in the water. Technologies include activated sludge system and trickling filters where wastewater flows over microbial-covered media and membrane bioreactor. In some cases, biological treatment with chemical treatment is implemented for the of toxic and complex compounds.

3. Tertiary Treatment

This advanced stage uses chemicals to further purify the treated wastewater. Techniques include filtration, pH adjustment, coagulation, flocculation, reverse osmosis, oxidation and reduction, clarification, dewatering and ion exchange. For clarified water polishing, advanced methods such as activated carbon and zeolite ion exchange are employed. Technologies involved in the solid-liquid separation steps are filter press, centrifuge and dryer. The resulting sludge cake is subsequently sent to Kualiti Alam for disposal.



Metals hydroxide solubility as function of concentration and pH

Best Practices in Wastewater Management

Process Optimisation: Improving the wastewater treatment processes to reduce the amount of waste generated. This includes the amount of chemical consumption, process design and control set points.

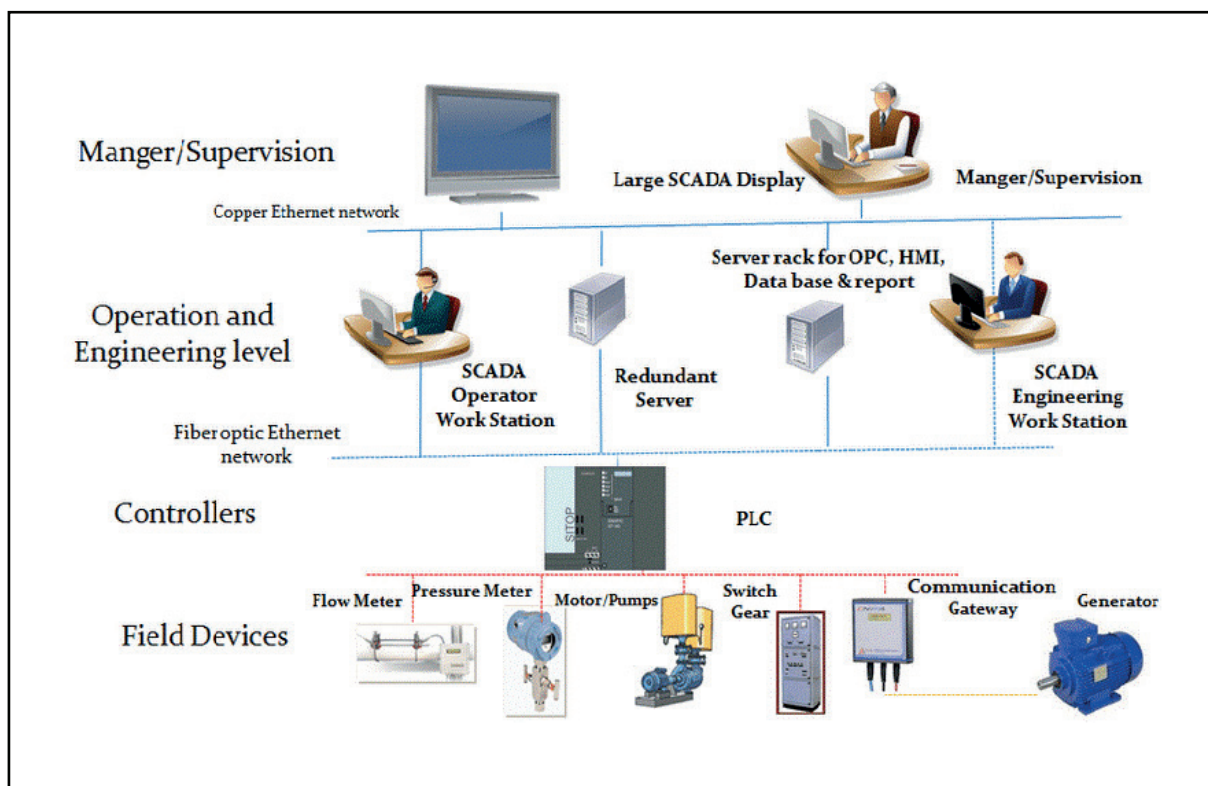
Depending on the process design, an example of chemical usage in the coagulation process is Sodium hydroxide (NaOH). Hydroxide ions (OH⁻) from NaOH react with metal ions in the wastewater to form metal hydroxides which are insoluble and thus can be formed into big flocs which are then easily removed in subsequent processes.

The optimal NaOH dosage is based on the concentration and required pH range for metal hydroxide formation, but it also varies, depending on the specific metal to be treated. This can be optimised through Jar Test or pilot scale to establish the most efficient dosage.

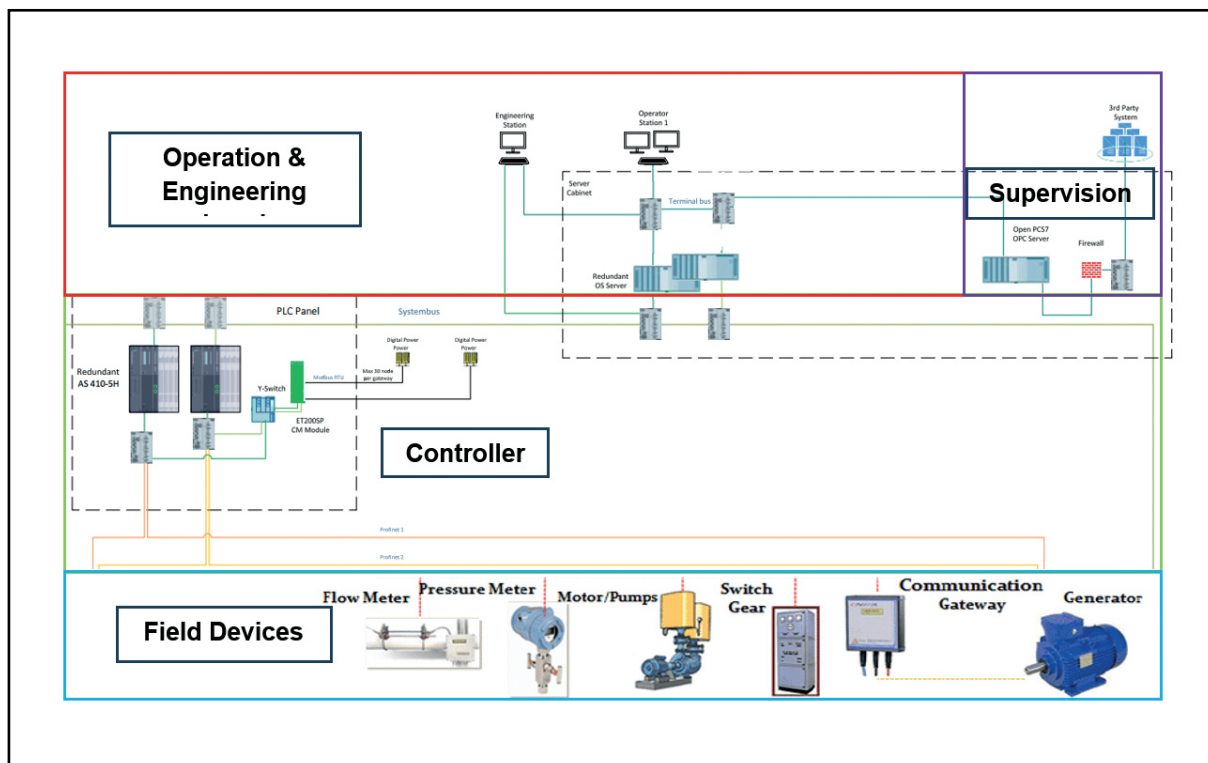
When there are complex compounds, two or more reaction tanks are considered to get the desired concentration and pH.

The concentration of metals in the treated wastewater must be controlled to meet regulatory standards. DOE Guidelines specify maximum allowable concentrations of various metals in the discharged effluents standard.

Monitoring & Maintenance: Continuous monitoring and control ensure that the treatment process remains efficient and compliant. This involves devices such as flowmeter, pH analyser, turbidity meter, PLC controlled etc. Additionally, real-time monitoring and control systems like SCADA (Supervisory Control & Data Acquisition) and DCS (Distributed Control Systems) are examples of solutions that deliver efficiency, reliability, and operational safety of water treatment operations to ensure the systems are functioning properly and compliance is maintained.



Standard SCADA System Architecture



System architecture for control and monitoring systems developed for a water treatment plant in Malaysia. Redundant unit of CPU is designed to serve as hot standby.

“The instrument calibration procedures must follow the standard manufacturer guidelines.”

Profinet, Profibus, Modbus, and Ethernet are communication protocols and technologies used in industrial settings to facilitate communication between field devices and control systems.

Performing routine maintenance on equipment helps prevent breakdowns and ensures efficient operation. The instrument calibration procedures must follow the standard manufacturer guidelines.

System architecture for control and monitoring systems developed for a water treatment plant in Malaysia. Redundant unit of CPU is designed to serve as hot standby.

Employee Training & Safety: Training must be provided for employees on the safe handling of hazardous chemicals and proper waste management practices. Implementing safety protocols protects workers and the environment; these include the use of personal protective equipment (PPE) and spill containment measures.

Compliance & Documentation: Ensure that all waste management practices comply with local statutory body requirements. This includes maintaining monitoring documentation, reporting of water treatment operation as well as sludge disposal. The effectiveness of wastewater treatment is assessed through regular sampling and accredited analysis of sampling point quality. Parameters such as pH, BOD, total suspended solids (TSS), and

COD are monitored to ensure compliance with discharge limits. Regular environmental audits must be conducted to assess the compliance of process operation and to identify areas for improvement.

Conclusion

Treating industrial wastewater before it is released into rivers is essential to safeguard water quality and public health. The Minamata Disease and Sungai Kim Kim cases are powerful examples of the devastating impact of inadequate treatment and non-compliance to the environmental standard discharge.

By employing advanced treatment technologies and adhering to regulatory standards and criteria, every industry can prevent industrial pollution as well as promote the sustainability of the aquatic system and community well-being. The Malaysian government must play a significant role in the stringent enforcement of environmental regulations to protect our water resources and public health.

Ongoing advancements and sustainable practices will further enhance the effectiveness of wastewater management, including the implementation of final treated water recycling for other uses. 🌱

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Subcritical Water for Sustainable Food Waste Management

by
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Food waste is a critical global issue, presenting both environmental and economic challenges that demand urgent attention. An estimated 1.3 billion tons of edible food are discarded each year, representing nearly one-third of all food produced for human consumption. This staggering figure underscores a massive loss of resources, including water, energy, labour, and agricultural inputs, all of which are invested in the production, processing, and transportation of food that ultimately goes to waste.

The environmental impact of food waste is profound. When food is wasted, it is not just the food itself that is lost but also the resources that go into producing it. For instance, food production accounts for about 70% of global freshwater use and a significant portion of land use. The energy expended in growing, harvesting, processing, and transporting food contributes to greenhouse gas (GHG) emissions at every stage. When food waste ends up in landfills, it decomposes anaerobically, producing methane, a potent GHG that is significantly more effective at trapping heat in the atmosphere than carbon dioxide.

Economically, the implications are equally alarming. The global economic loss associated with food waste is estimated at nearly US\$1 trillion annually. This includes the direct costs

of food production (labour, transportation, and inputs) as well as the indirect costs associated with the environmental degradation caused by food waste. The economic burden is felt at every level of the supply chain, from farmers and food producers to retailers and consumers. For many developing countries, where food security is a pressing concern, the loss of such a significant portion of food is particularly troubling, as it exacerbates hunger and malnutrition.

Despite the severity of the problem, traditional methods of managing food waste, such as landfilling, incineration, and composting, often fall short in addressing the full impact. Landfilling, the most common method, not only uses up valuable land space but also contributes to soil and water contamination. Incineration, while reducing the volume of waste, releases harmful pollutants into the air and still requires the disposal of residual ash. Composting, though beneficial in producing nutrient-rich soil amendments, does not capture the full value of the organic material, particularly in terms of energy and biochemical recovery.

Emerging technologies, such as subcritical water extraction (SWE) treatment, offer a more sustainable and efficient approach to food waste management. SWE treatment uses water at elevated temperatures and pressures, just below its critical point, to break down organic material into valuable byproducts. This process

“ Compared to traditional extraction methods, SWE is a greener, faster, and more efficient process which can be tailored to target specific compound classes based on their polarity. ”

can recover fermentable sugars, produce biogas, extract bioactive compounds, and generate nutrient-rich hydrolysates for use in various industrial applications.

Unlike traditional methods, SWE transforms food waste from an environmental burden into a valuable resource, aligning with the principles of a circular economy. Its potential to mitigate the global food waste crisis lies in its ability to unlock the inherent value within waste streams. By converting food waste into renewable energy, high-value biochemicals, and compost, SWE not only reduces the environmental footprint of waste management but also creates new economic opportunities.

Subcritical Water: A Versatile Solution

SWE is a cutting-edge green extraction technique which employs water at elevated temperatures and controlled pressures, just below its critical point (374.15°C, 22.1 MPa), to maintain its liquid state (*Cheng et al. 2021; Mohd Thani et al. 2019*). This method offers distinct advantages over traditional solvent extraction techniques. Water, being

environmentally friendly, inexpensive, and abundant, can have its physicochemical properties finely tuned by adjusting temperature and pressure.

As water is heated above its boiling point of 100°C under high pressure, the hydrogen bonds between its molecules weaken. This results in a lower dielectric constant, making water behave more like moderately polar organic solvents such as methanol, ethanol, or acetone. The viscosity and surface tension of water also decrease, while its diffusion coefficient increases, improving the mass transfer of target compounds. Moreover, at elevated temperatures, the ionic product (K_w) of water significantly increases, leading to higher concentrations of hydronium and hydroxide ions, which can catalyse certain extraction reactions (*Mohd Thani et al. 2019; Cheng et al. 2021*).

The unique properties of subcritical water make it highly effective for extracting a wide range of materials, including polar and moderately polar substances, from various food waste sources. Compared to traditional extraction methods, SWE is a greener, faster, and more efficient process which can be

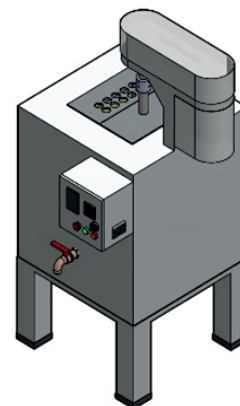
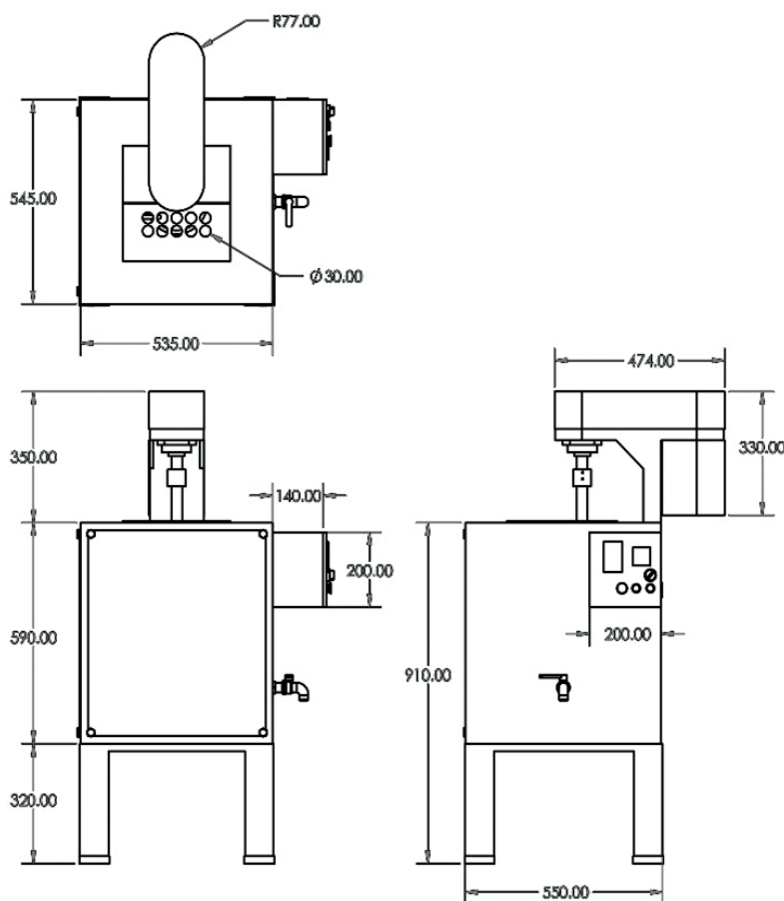


Figure 1: The salt or oil bath for batch system subcritical water extraction (Mohd Thani et al. 2022)

tailored to target specific compound classes based on their polarity. Its versatility and environmental advantages position SWE as a promising technique for isolating valuable bioactive ingredients from renewable food waste resources.

SWE can be conducted using either batch or continuous systems. In a batch system, the process involves a stainless-steel reactor and a salt or oil bath (see Figure 1). The reactor, where the solvent and solute are combined, is securely sealed and immersed in the bath, which is maintained at the desired temperature to achieve subcritical conditions within the reactor.

Subcritical Water for Resource Recovery: Sugar, Biogas, Compost, and Bioactive Compounds from Food and Biomass Waste

One of the most promising applications of subcritical water treatment is the recovery of fermentable sugars from food waste. Bakery waste, such as bread, pastries, and other starchy products, is rich in carbohydrates which can be converted into sugars through hydrolysis. Subcritical water treatment efficiently breaks down the carbohydrates into fermentable sugars which can then be used as feedstock for biofuel production or as precursors for valuable biochemicals.

Studies show that subcritical water treatment can recover high yields of sugars from bakery waste, offering a sustainable alternative to conventional sugar sources. The recovered sugars can be used in the production of bioethanol, a renewable fuel that can help reduce GHG emissions. Additionally, these sugars can serve as building blocks for bioplastics and other bio-based materials, contributing to the development of a circular economy.

Another significant application of subcritical water treatment is its ability to enhance biogas production through the pre-treatment of food waste. Anaerobic digestion, a widely used method for converting organic waste into biogas, can be made more efficient by first treating the waste with subcritical water. This pre-treatment process hydrolyses complex organic materials in food waste, making them more accessible to the microorganisms responsible for biogas production. The hydrolysate generated serves as an ideal substrate for anaerobic digestion, enabling more efficient conversion of food waste into biogas. The biogas can be used as a renewable energy source for heating, electricity generation, or as vehicle fuel, further reducing the environmental impact of food waste disposal.

Composting is a natural process that transforms organic waste into nutrient-rich compost, which can be used to improve soil health and fertility. However, traditional composting methods can be time-consuming, often requiring several months to produce mature compost. Subcritical water treatment has been shown to accelerate the composting process by enhancing the hydrolytic degradation of biomass waste, significantly reducing the time required to produce compost. Under subcritical conditions, the lignocellulosic bonds in biomass are disrupted, and the materials are partially hydrolysed, converting them into more easily degradable forms. This pre-digestion step reduces the complexity and size of the organic material, making it more amenable to

microbial attack during composting. The result is a significant reduction in composting time, potentially cutting the process duration by half or more. Engineering systems for SWE-enabled composting require careful consideration of the reactor design to ensure uniform heat distribution and optimal contact between the waste material and subcritical water. Efficient recovery of the hydrolysate, which may contain valuable nutrients, is also critical for maximising the benefits of this technology. By breaking down these materials more rapidly, subcritical water treatment allows for faster production of compost, which can be used to enrich soils and support sustainable agriculture.

Fish processing generates significant amounts of waste, including viscera, scales, and gills, which are often discarded or under-utilised. However, these waste streams contain valuable bioactive compounds, such as proteins, collagen, and Omega-3 fatty acids which can be extracted and repurposed for various industrial applications. SWE offers a sustainable and efficient method for recovering these valuable compounds. The extracted proteins can be used in pet food, animal feed, or even in human food products. Additionally, collagen extracted from fish waste can be used in cosmetics, pharmaceuticals, and biomedical applications.

By valorising fish waste through SWE, the fish processing industry can reduce its environmental footprint and create new revenue streams. From an engineering standpoint, the design of SWE systems for fish waste valorisation must consider the delicate nature of the compounds, which can be degraded at excessively high temperatures or prolonged exposure. Thus, precise control over the extraction conditions is essential to maintain the quality and functionality of the recovered compounds. Additionally, the process must be integrated into existing waste management systems in fish processing plants, ensuring that the SWE technology enhances overall efficiency and sustainability.

Towards a Circular Economy

The concept of a circular economy represents a fundamental shift in how industries and societies approach resource use and waste management. Unlike the traditional linear economy, which follows a take-make-dispose model, a circular economy emphasises the continuous use of resources by minimising waste, reusing materials, and recycling products.

In the context of food waste management, SWE is a powerful tool for advancing circular economy principles by transforming waste into valuable resources.

The ability of subcritical water to recover sugars, produce biogas, accelerate composting, and extract bioactive compounds exemplifies its role in closing the loop on food and biomass waste. Instead of food waste being discarded, SWE enables the recovery of fermentable sugars for converting into biofuels or bioplastics, reducing our dependence on non-renewable resources. This not only helps mitigate the environmental impact of food production but also provides an additional revenue stream for industries involved in food processing and waste management.

Similarly, biogas produced from SWE-treated food waste can serve as a renewable energy source, contributing to energy sustainability and reducing GHG emissions associated with fossil fuels. The rapid composting facilitated by subcritical water pre-treatment provides nutrient-rich compost, which can be used to enhance soil fertility, support sustainable agriculture, and reduce the need for chemical fertilisers. This further strengthens the circular economy by returning nutrients to the soil, thereby closing the nutrient loop. The extraction of valuable compounds, such as proteins and bioactive substances from fish and other biomass waste, highlights the economic potential of SWE. By repurposing food waste into high-value products, industries not only reduce their environmental footprint but also

tap into new markets. For example, the proteins extracted from fish waste can be used in animal feed, cosmetics, or pharmaceuticals, creating additional value from materials that would otherwise be discarded.

However, the transition to a circular economy through SWE is not without challenges. One of the primary challenges is the initial investment required for implementing subcritical water systems on an industrial scale. These systems require specialised equipment capable of maintaining high temperatures and pressures and these can be costly to install and operate. Additionally, optimising the SWE process for different types of waste and target compounds is complex and may require extensive research and development.

From an engineering perspective, addressing these challenges involves advancing the design and efficiency of subcritical water systems. Engineers must focus on developing more cost-effective reactors and optimising process conditions to maximise yield while minimising energy consumption. The integration of SWE with other waste management technologies such as anaerobic digestion and composting, can also enhance overall system efficiency and reduce operational costs.

Future Directions

The future of subcritical water treatment in food waste management is promising, but it requires continued innovation and strategic development to fully realise its potential. One key area for future research is the optimisation of SWE processes through advanced modelling techniques such as response surface methodology (RSM). By systematically varying process parameters, such as temperature, pressure, and reaction time, RSM can help identify the optimal conditions for maximising the extraction of target compounds from different types of food waste.

Another important direction is the scale-up of SWE technology for industrial applications. While laboratory-scale studies have demonstrated the effectiveness of SWE in recovering valuable compounds, scaling up the process to handle large volumes of food waste presents technical challenges. These include ensuring uniform heat distribution within large reactors, managing the high pressures involved, and developing efficient waste feedstock handling systems.

Engineers must work to design scalable SWE systems that are both economically viable and environmentally sustainable. The integration of SWE with other waste processing technologies is another critical area for future development. For example, combining SWE with anaerobic digestion can create a more comprehensive waste management system that maximises resource recovery. The hydrolysate generated through SWE can serve as a more digestible substrate for anaerobic digestion, leading to increased biogas yields. Similarly, integrating SWE with composting can shorten composting times and improve the quality of the final product.

Despite the potential of SWE, several challenges must be addressed to facilitate its widespread adoption. One significant challenge is the energy requirement of the process. Operating at high temperatures and pressures requires substantial energy input, which can offset some of the environmental benefits if not managed efficiently. Research into energy recovery and recycling within SWE systems is crucial for reducing the overall energy footprint. Moreover, the development of SWE for specific applications must consider the variability in food waste composition. Different types of waste have different chemical compositions, which can affect the efficiency of the SWE process. Engineers and researchers need to develop tailored SWE processes to account for this variability and ensure consistent results across different waste streams.

Finally, regulatory and market acceptance is essential for the broader implementation of SWE. Ensuring that the products derived from food waste, such as biofuels, bioplastics, and compost, meet industry standards and consumer expectations, is critical. Collaboration between industry stakeholders, researchers, and policymakers will be necessary to create the frameworks and standards that support the adoption of SWE in food waste management.

Conclusion

In conclusion, while subcritical water treatment presents a transformative opportunity for advancing a circular economy in food waste management, its success will depend on overcoming technical, economic, and regulatory challenges. Continued research, innovation, and collaboration will be key to unlocking the full potential of this promising technology, paving the way for a more sustainable and resilient future. 🌱

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Solid Waste Management Model by Adopting Circular Economy Approach

by
SWCorp

Systematic and sustainable solid waste management (SWM) continues to be a major challenge today. On an international level, sustainable SWM can help meet several United Nations Sustainable Development Goals (SDG), such as ensuring clean water and sanitation (SDG6), creating sustainable cities and inclusive communities (SDG11), mitigating climate change (SDG13), protecting life on land (SDG15), and demonstrating sustainable consumption and production patterns (SDG 12) (<https://sdgs.un.org/goals>).

In Malaysia, there are two authorities managing SWM. States which have adopted Solid Waste and Public Cleansing Management Act 2007 (Act 672) such as Federal Territories of Kuala Lumpur and Putrajaya, Pahang, Negeri Sembilan, Melaka, Johor, Perlis and Kedah, come under monitoring by Solid Waste Management & Public Cleansing Corporation (SWCorp).

SWCorp monitors three concessionaires - E-Idaman Sdn. Bhd. (northern states), Alam Flora Sdn. Bhd. (Federal Territories of Kuala Lumpur, Putrajaya and Pahang) and SWM Sdn. Bhd. (southern states). The remaining states are managed by local Authorities.

Act 672 was implemented to improve solid waste management practices at the time. Furthermore, deficiencies and mistakes in managing solid waste can cause various

problems such as environmental health and pollution. SWM is a cross-cutting problem that influences different facets of growth in all three domains of sustainability: Environment, economy, and society (Rodric & Wilson, 2017).

Malaysians generate about 39,078 tonnes of solid waste daily; this is equivalent to 1.17kg per person. In addition, this figure is based on the trend of waste generation in Malaysia since 2015 (Table 1). The increase in waste generation is in tandem with the increase in population. With the increase in waste generation yearly, managing domestic waste and providing for the last destination of the waste has become the main challenge.

Based on a study of solid waste composition by SWCorp in 2022, food makes up the biggest component of domestic waste at 30.6%, followed by plastic (21.86%), paper (15.35%), disposable diapers (8.19%) and hazardous household waste (4.22%). Other waste includes commingled waste (3.64%), yard/garden refuse (2.93%), glass (2.74%), metal (2.4%), textiles (2.25%), beverage cartons (1.7%) rubber (1.07%), wood (1.04%) and face masks (0.65%).

The amount of waste sent to disposal sites by the seven states which adopted Act 672, stood at 2.94 million tonnes between January and November 2023. The corresponding figures for 2022 and 2021 were 3.1 million tonnes and 3.0 million tonnes respectively.

Year	Population (Million)	Waste Generation (Tonnage) per day	Waste Generation (Tonnage) per year
2015	31,709,650	37,100.29	13,541,606.33
2016	31,950,000	37,381.50	13,643,195.24
2017	32,049,700	37,498.15	13,686,824.39
2018	32,385,000	37,890.45	13,830,014.25
2019	32,581,400	38,120.24	13,913,886.87
2020	32,584,000	38,123.28	13,914,997.20
2021	32,655,400	38,206.82	13,945,488.57
2022	32,700,000	38,259.00	13,964,535.00
2023	33,400,000	39,078.00	14,263,470.00

*Table 1: Waste Generation in Malaysia. *Calculations are made based on the Survey on Solid Waste Composition, Characteristics and Existing Practice of Solid Waste Recycling in Malaysia, 2012*

In 2015, SWCorp started enforcement for separation at source (SAS) for the public. This was made compulsory for residents in the states which adopted Act 672, to separate their waste according to the categories of recyclable waste and residue waste. The appointed concessionaires would then collect the waste on scheduled dates. This was also in line with the Federal Government's desire to increase the rate of awareness among the public. Residents who fail to comply with the separation at source (SAS) can be liable to fines not exceeding RM1,000.

In addition, SWCorp monitors the annual national recycling rate (Table 2). Our national recycling rate target is 40% by 2025. To ensure that the target is achieved, more initiatives will have to be carried out, especially those related to 3R (recycle, reduce, reuse) activities. There have been collaborations with NGOs, the private sector, local governments, schools and the PPR community.

Year	Recycling Rate (%)
2015	15
2016	17.5
2017	21
2018	24.6
2019	28.06
2020	30.67
2021	31.52
2022	33.17
2023	35.38

Table 2: Recycling rate in Malaysia

No.	Sanitary Landfill
1.	Rimba Mas, Kangar, Perlis
2.	Jabi, Alor Setar, Kedah
3.	Padang Cina, Kulim, Kedah
4.	Belanga Pecah, Langkawi, Kedah
5.	Belenggu, Temerloh, Pahang
6.	Padang Sertik, Bentong, Pahang
7.	Blue Valley, Cameron Highland, Pahang
8.	Sungai Udang, Melaka Tengah, Melaka
9.	Ladang Tanah Merah, Port Dickson, Negeri Sembilan

Table 3: Sanitary landfills under SWCorp supervision

Normally, all recyclable waste ends up in a landfill. Consequently, the lifespan of existing landfills cannot be sustained anymore. Bigger budgets and more land are needed to create new landfills. The pollution risks will also be higher if the landfills are not operated according to proper Standard Operating Procedures (SOP).

Sanitary landfills must be properly constructed to make sure there is no pollution risk to the environment. Previously, most landfills in Malaysia were mere dumpsites. Such operations were a risk of pollution to the environment as they were without appropriate liner systems, leachate collection and treatment facilities.

Proper treatment plants such as leachate treatment plants (LTP) are needed in the compound area. The treated water will be discharged into the nearest river once it complies with the standard regulation by the Department of Environment (DOE). In addition, more segregation technology will be

implemented, such as Material Recovery Facility (MRF) technology in the landfill to increase the cell life span. The list of sanitary landfills monitored by SWCorp are shown in Table 3.

A circular economy can be the best waste management model. The Ministry of Housing & Local Government (KPKT) plans to accelerate the transition to a more sustainable circular economy model in line with the 12th Malaysia Plan. It drew up a five-year plan (2021-2025) to accelerate the circular economy model. The previous model, called linear economy, was not a sustainable model as it was fully dependent on natural resources and produced more waste.

As a result, natural resources decreased while the level of pollution increased. More land was needed for use as landfills. With the traditional (dumpsite) method, more land would be contaminated and cause health problems. The detailed explanations for linear and circular economy are shown in Figure 1.

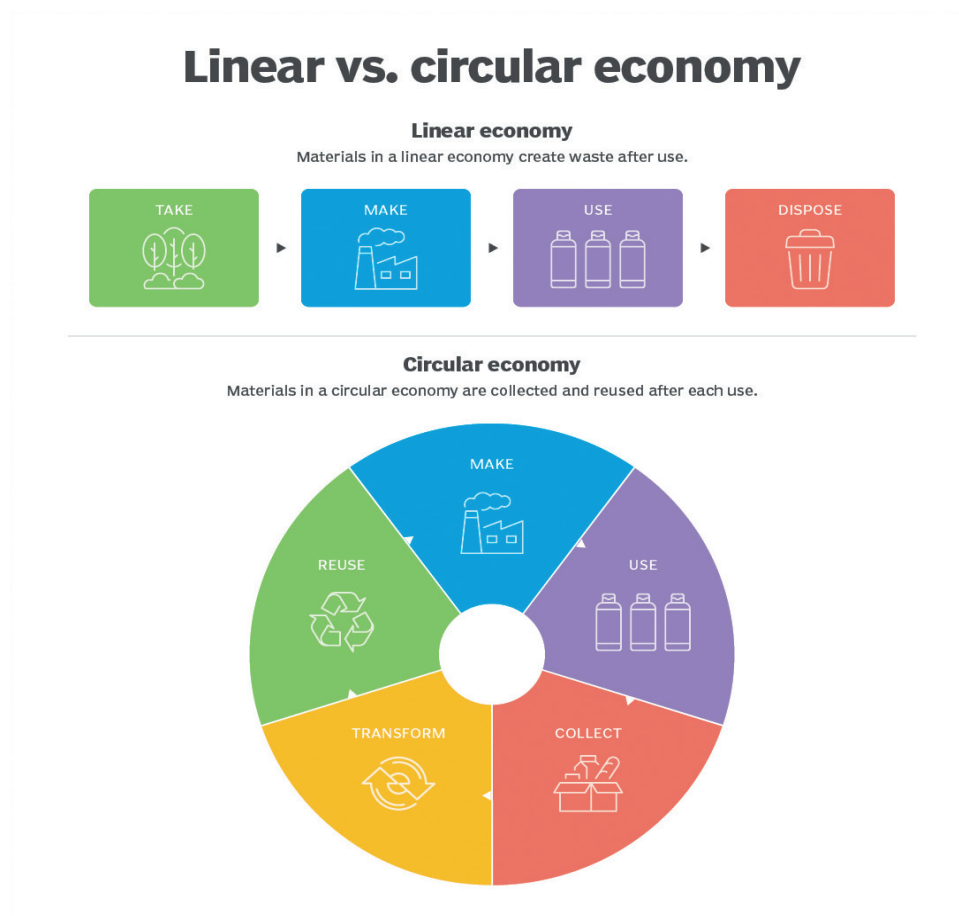


Figure 1: Linear vs Circular Economy
(Source: <https://www.techtarget.com/whatis/definition/circular-economy>)

KPKT is actively drafting a SWM policy for use nationwide, including Sabah, Sarawak, and the states which have not adopted Act 672. The Waste to Energy (WtE) plants will be constructed and implemented to strengthen SWM. Extended Producer Responsibility (EPR) is also part of planned initiative. Most waste products, especially packaging waste, end up in a landfill. By implementing EPR, producers will have to take responsibility for making sure packaging waste is collected and reused.

In addition, waste eco park development guidelines for developers, state authorities and local governments as well as integrated SWM facilities will be developed to make sure the circular economy model is implemented accordingly. 🌱

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Malaysia Circular Economy Blueprint for Solid Waste (2025-2035)

by
Amanda Lee Siek Hsia

Malaysia has introduced the Circular Economy Blueprint for Solid Waste (2025-2035) to enhance sustainable waste management and transition from a linear to a circular economy.

Globally, circular development is a model of economic, social, and environmental production and consumption that aims to build an autonomous and sustainable society in tune with the issue of environmental resources. The circular economy aims to transform our economy into one that is regenerative. It innovates to reduce waste and the ecological and environmental impact of industries prior to happening, rather than waiting to address the consequences of these issues. This is done by designing new processes and solutions for the optimisation of resources, decoupling reliance on finite resources.

The circular economy is a framework of three principles, driven by design: Eliminating waste and pollution, keeping products and materials in use, and regenerating natural systems. It is based increasingly on renewable energy and materials, and is accelerated by digital innovation. It is a resilient, distributed, diverse, and inclusive economic model. The circular economy is an economic concept often linked to sustainable development, provision of the Sustainable Development Goals (Global Development Goals), and an extension of a green economy.

The Housing & Local Government Ministry launched the Circular Economy in Solid Waste Blueprint 2025-2035 on August 6, 2024, to help accelerate the transition to a circular economy in solid waste management through a vision statement and strategic framework supported by five strategic pillars, 20 initiatives, action plans and timelines.

The five strategic pillars are:

1. **Governance & Legislation:** Implementing mandatory Extended Producer Responsibility (EPR) policies and requiring manufacturers to collect and recycle materials from their products post-consumer use.
2. **Guidelines & Procedures:** Establishing a zero-waste-to-landfill certification to recognise manufacturers which enhance resource efficiency and minimise waste generation.
3. **Digitalisation & Technology:** Utilising data systems to collect and analyse information across the entire waste management value chain.
4. **Infrastructure & Facilities:** Developing facilities such as waste-eco parks and integrated waste management facilities to support recycling and waste processing.
5. **Market Creation:** Promoting the growth of recycling and solid waste-based industries by offering incentives

to companies, implementing a pay-as-you-throw scheme to encourage waste reduction, and investing in research and development initiatives.

The blueprint aims to achieve a national recycling rate of 40% by 2025. It also includes plans to establish six waste-to-energy (WtE) plants in the country by 2025 to reduce landfill dependency. Additionally, the government is considering introducing a Pay-As-You-Throw system, starting with the commercial, manufacturing, and construction sectors, charging based on the amount of waste disposed. The successful implementation of this blueprint requires active collaboration among government agencies, private sector entities, non-governmental organisations, academia, and the public to drive Malaysia towards long-term sustainability goals.

National Circular Economy Council

Related to the Circular Economy Blueprint for Solid Waste, the Minister of Housing and Local launched the National Circular Economy Council (NCEC) on September 7, 2023. This high-impact initiative for the solid waste management sector uses the whole nation approach to unite all stakeholders and to accelerate the transition of solid waste management from a linear economy to a holistic cyclical economy. NCEC focuses on matters related to policies, laws, implementation of related strategies and action plans and the commitment and collaboration between the government and the private sector.

With NCEC, Malaysia will be able to balance socio-economy growth and being environmentally sustainable, increase job opportunities through new businesses and increase investments in solid waste management. A circular economy can stimulate community economic activities through the creation of new business opportunities when the demand and market

for recycled goods increases. This opportunity will open up more job offers in the value chain of the cyclical economy such as design, rental services (rent), repair services (repair), remanufacturing and recycling activities (recycle).

NCEC will focus on the following elements that support the circular economy ecosystem: To develop markets and demand for recycled materials, to design products which can optimise their life-cycle through reuse, recycling and environmental friendliness, to promote the segregation of waste at source and to improve the collection system of solid waste. NCEC will also focus on providing appropriate infrastructure facilities and incentives for circular economy, developing an integrated data system, and creating a public, private and community collaboration platform.

Experiences of Advanced Countries in Adopting Circular Economy

Advanced countries have demonstrated that circular economy models are both achievable and beneficial. While the transition poses challenges such as regulatory fragmentation, cultural resistance, and financial barriers, the long-term benefits (economic resilience, environmental sustainability, job creation, and innovation) clearly outweigh the costs. The experiences of The Netherlands, Finland, Japan, Germany, and Sweden show that with the right policy frameworks, investment, and public engagement, the circular economy can be a powerful tool for sustainable development. These examples offer valuable lessons for both developing and developed nations aiming to create a more regenerative and resource-efficient future.

Finland: Pioneering National Policy and Bio-Based Innovation

Finland was the first country to adopt a national circular economy roadmap, developed by the Finnish Innovation Fund, Sitra. The plan promotes

sustainable forestry, circular food systems, and eco-friendly textiles. Finland is also a leader in developing bio-based materials, with companies producing biodegradable textiles from cellulose - a major departure from petroleum-based fabrics.

The challenges included resistance from traditional industrial sectors and the capital-intensive nature of infrastructure transformation. Additionally, there was a need for widespread education and engagement at all societal levels to promote sustainable consumption.

However, Finland's efforts have resulted in considerable benefits, including increased innovation capacity, a growing export market for sustainable products, and improved environmental outcomes. The country has also strengthened its economic resilience by reducing its dependence on imported resources.

The Netherlands: Blueprint for A Circular Nation

The Netherlands has positioned itself as a global leader in circular economy innovation. In 2016, it launched a government-backed programme with the ambitious goal of achieving a fully circular economy by 2050. Cities like Amsterdam have embraced the concept by implementing circular construction codes and encouraging the reuse of materials in urban planning. One prominent initiative is the city's Circular Strategy 2020-2025, which targets areas such as food, consumer goods, and the built environment.

Challenges faced include fragmented regulatory systems between the EU and national levels, and the need for cross-sector collaboration. Additionally, transitioning traditional industries toward circular models requires cultural change and substantial investment.

Despite these hurdles, the benefits have been profound. Circular practices have improved resource efficiency, reduced dependency on raw materials, and spurred innovation in business models such as product-as-a-service and shared ownership platforms. These changes

have contributed to lowering carbon emissions and creating new green jobs.

Japan: Efficient Resource Use Through the 3Rs

Japan's approach to circularity is deeply embedded in its national waste management and manufacturing practices. With limited natural resources and land space, Japan adopted the 3Rs (Reduce, Reuse, Recycle) principle as early as the 1990s. Laws such as the Home Appliance Recycling Law require manufacturers to take back used electronic products and recycle them responsibly.

Japan had faced logistical challenges in collecting and processing end-of-life products, especially in densely populated areas. Another issue was maintaining consumer participation and awareness about sorting and returning goods properly.

Nevertheless, the system has yielded significant benefits, including high recycling rates, efficient use of land, and reduced environmental pollution. It has also contributed to the development of advanced recycling technologies that are now being exported to other countries.

Conclusion

The circular economy is no longer just an environmental ideal - it is an urgent necessity for the well-being of our world. As natural resources dwindle, waste accumulates, and climate change accelerates, linear production and consumption models have proven unsustainable.

Embracing circularity offers a transformative path forward, one that reduces environmental pressure, fosters economic resilience, and encourages innovation in how we design, use, and repurpose materials. By closing the loop on resource use, the circular economy not only safeguards ecosystems but also secures a better quality of life for current and future generations. The time to act is now; shifting to a circular economy is not just a choice, but a responsibility that we all share for a more sustainable, equitable, and liveable planet. 🌱

Global Divide in Waste Management System

by
Mary Foo Mee Sim

The effective management of waste has emerged as a critical global challenge, with waste generation rates escalating due to urbanisation, population growth, and changing consumption patterns. While the overarching goal of waste treatment is consistent worldwide, i.e. to minimise environmental harm, recover resources, and protect public health, the specific types of waste treatment employed and their prevalence vary significantly between Asia and the West, reflecting diverse economic conditions, regulatory frameworks, land availability, and cultural practices. For Malaysia, the way forward is to make comparative studies on common waste treatment types, their suitability, and challenges in both regions, highlight emerging new technologies, and to provide statistical insights into waste treatment practices in Asia.

Common Waste Treatment Types

Landfilling: Landfilling remains the primary disposal method for residual waste globally, especially for mixed municipal solid waste (MSW) that hasn't undergone extensive pre-treatment. It is often the most economically viable option for initial waste disposal. Significant environmental risks include leachate generation (contaminating soil and groundwater), methane emissions (a potent greenhouse gas), and the inefficient use of valuable land. Furthermore, it represents a linear "take-make-dispose" model, contrary to circular economy principles.

In many developing countries in Asia, particularly in South and South-East Asia (e.g.,

India, Indonesia, Philippines, Vietnam, Malaysia), landfilling (often in the form of open dumps or poorly managed landfills) is still the dominant disposal method. This is largely due to lower operational costs, less stringent environmental regulations, and historical reliance on these methods. The high organic content of Asian waste further exacerbates methane emissions from these sites.

Western countries (e.g., Europe, North America) have significantly reduced their reliance on landfilling over the past few decades. Driven by stricter environmental regulations, high land prices, and a strong emphasis on recycling and energy recovery, landfilling is now primarily reserved for non-recyclable or non-combustible residues, often in engineered sanitary landfills with leachate and gas collection systems.

Recycling (Material Recovery): Recycling is ideal for separating and processing valuable materials (plastics, paper, glass, metals) from the waste stream, conserving natural resources, and reducing energy consumption associated with manufacturing using virgin materials. It requires effective source separation by households and industries, significant investment in sorting and processing infrastructure, and robust markets for recycled materials. Contamination of collected recyclables can reduce efficiency.

Recycling in Asia presents a mixed picture. Countries like Japan and South Korea boast some of the highest recycling rates globally due to stringent separation policies, advanced infrastructure, and strong public participation. However, in many other Asian countries,

recycling is often driven by an informal sector (waste pickers) which plays a crucial role but may lack the formal infrastructure for large-scale, high-quality recycling. Recent bans on plastic waste imports by countries like China have also significantly impacted global recycling dynamics.

In comparison, recycling is highly developed and institutionalised in most Western countries, with comprehensive curbside collection programmes and advanced material recovery facilities (MRFs). European countries, in particular, have ambitious recycling targets and high rates. The United States, while having established recycling programmes, generally has lower overall recycling rates compared to leading European and East Asian nations.

Thermal Treatment (Waste-to-Energy or WtE): Thermal Treatment is excellent for significant waste volume reduction (up to 90%), neutralising hazardous components (e.g., medical waste), and generating renewable energy (electricity and heat). It is suitable for mixed MSW with sufficient calorific value. Challenges include high capital investment, potential for air pollution (requiring sophisticated emission control technologies), management of hazardous ash, and public perception issues (NIMBYism). The high organic content and moisture in some Asian waste streams can also lower the calorific value, making direct incineration less efficient without pre-treatment.

In Asia, WtE technology is rapidly expanding in Asia, particularly in land-scarce, high-income countries such as Japan, Singapore, and South Korea, where it's a key strategy for waste reduction and energy security. China has also seen a significant surge in WtE plant construction, becoming a global leader in installed capacity. Other rapidly urbanising Asian countries (e.g., Malaysia, Indonesia, Vietnam) are increasingly exploring WtE to address mounting waste volumes and reduce landfill dependency, often with government incentives.

In the West, WtE is well-established in many European countries (e.g., Sweden, Denmark, Germany, France) where it plays a crucial role in integrated waste management systems, often as a preferred option after recycling and composting. In North America, WtE adoption is more varied, with some states and provinces having active plants, while others prioritise recycling or have faced public opposition.

Biological Treatment (Composting and Anaerobic Digestion): Biological Treatment is ideal for organic waste (food waste, yard waste, agricultural residues, sewage sludge). Composting produces nutrient-rich soil amendment, while anaerobic digestion generates biogas (renewable energy) and digestate. Both reduce methane emissions from landfills. It requires effective source separation of organic waste, can have odour issues (especially composting), requires careful process control, and large-scale facilities demand significant investment. Management of digestate or compost to ensure quality and marketability is also crucial.

Given the high organic content of MSW in many Asian countries (often 45%-60% or more), biological treatment, especially composting, has high potential. While informal composting is common, large-scale, formalised composting and anaerobic digestion facilities are increasingly being developed, particularly in countries like China and India, driven by waste management regulations and agricultural benefits.

In comparison, in the West biological treatment is a cornerstone of waste management in many European countries, which have strong policies for diverting organic waste from landfills. Anaerobic digestion is particularly prevalent for food waste and agricultural residues, contributing significantly to renewable energy targets. North America is also seeing growing adoption, especially for municipal food waste.

“These processes can handle a wider range of waste (including hazardous waste) and produce syngas which can be converted into chemicals or fuels, with potentially lower emissions.”

New Technologies

The waste management sector is continuously innovating, with several new technologies gaining traction globally, aiming for higher resource recovery, better environmental performance, and increased efficiency.

Advanced Sorting Technologies include:

1. **AI and Robotics:** AI-powered optical sorters and robotic arms are revolutionising material recovery facilities (MRFs), enabling more precise and efficient sorting of mixed recyclables, including complex plastics and multi-material packaging.
2. **Near-Infrared (NIR) Spectroscopy:** Used for rapid identification of different plastic polymers, crucial for high-quality plastic recycling.

Chemical Recycling (Advanced Recycling) for Plastics: Goes beyond mechanical recycling to break down plastic waste into its molecular building blocks (monomers or oils) that can then be used to produce new plastics or chemicals. Technologies include pyrolysis, gasification, and solvolysis.

Suitability: Particularly promising for “difficult-to-recycle” plastics (e.g., mixed plastics, contaminated plastics, multi-layer films) which cannot be economically recycled mechanically.

Challenges: High capital costs, energy intensity, and ensuring that the output materials are truly circular and meet market specifications. Still largely in the pilot and commercialisation phases.

Advanced Waste-to-Energy (WtE) Processes: Beyond conventional incineration, more advanced thermal technologies such as plasma gasification are being explored. These processes can handle a wider range of waste (including hazardous waste) and produce syngas which can be converted into chemicals or fuels, with potentially lower emissions.

Challenges include extremely high capital costs, complex operation, and still limited commercial scale.

Internet of Things (IoT) and Smart Waste Management: Smart bins equipped with sensors to monitor fill levels, optimising collection routes and reducing fuel consumption and emissions.

Fleet Management Systems with real-time tracking and optimisation of waste collection vehicles.

Data Analytics using big data to predict waste generation patterns, optimise logistics, and improve overall waste management efficiency.

Microbial Fuel Cells (MFCs) and Bio-electrochemical Systems: Emerging technologies that use microorganisms to treat wastewater or organic waste while simultaneously generating electricity. Still largely in research and pilot phases.

Comparative Study on Waste Management System in Asian Countries

It may be useful to make comparable statistics for all waste treatment types across all Asian countries but this may not present the accurate scenario due to varying data collection methods and reporting standards. The general trends and indicative figures below provide an overall position of the status of waste management in key Asian countries.

Landfilling

Landfilling remains dominant for overall waste disposal.

1. China: While actively investing in WtE, landfills still account for a significant portion of MSW disposal. However, there's a strong push towards sanitary landfills over open dumps.
2. India: Over 90% of collected MSW is estimated to be dumped in open landfills or dumpsites. Composting efforts are growing, but challenges remain in processing capacity and market linkages. As of 2020-21, approximately 50% of generated waste is reported to be "treated" (which can include various processes), while 18.4% is landfilled, and 31.7% remains unaccounted for or is openly dumped.

3. Indonesia, Philippines, Vietnam, Thailand: Historically, these countries had relied heavily on open dumping or poorly managed landfills for the majority of their waste. Efforts are underway to shift towards sanitary landfills and other treatment options. For instance, in Malaysia, approximately 82.5% of collected waste is disposed of in landfills, though the government aims to increase recycling rates and develop more WtE plants.
4. Malaysia disposes of more than 30,000 tons of MSW daily, which amounts to 1.17kg of waste daily per capita. Food waste is the most significant component of MSW, followed by plastic, paper, mixed organic, wood, and others. Currently, there are 165 landfills, eight sanitary landfills, and three inert landfills for materials such as sand and concrete. The Bukit Tagar Sanitary Landfill in Selangor stands as a benchmark for advanced landfill technology within not just Malaysia, but also across the wider South-East Asian region. It is frequently cited as an example of a well-engineered and environmentally-managed landfill, a stark contrast to the prevalent open dumping or less sophisticated landfills found in many developing nations.

Waste-to-Energy (WtE)

1. China has the largest installed WtE capacity globally and continues to expand rapidly, driven by significant government investment and policies to reduce landfilling.
2. Japan is a world leader in WtE, and a very high percentage (around 70%) of its MSW is incinerated due to land scarcity and a focus on energy recovery.
3. In Singapore, virtually all waste is incinerated at WtE plants, and the ash is then landfilled at offshore sites.
4. In South Korea, there is a high adoption of WtE alongside robust recycling.

5. Malaysia is actively pushing to increase its WtE incinerator capacity as a crucial strategy to combat mounting waste volumes and to reduce reliance on landfills.

The WtE market in South-East Asia is projected to grow significantly (CAGR of 12.79% from 2025-2030), with countries like Malaysia, Indonesia, and Vietnam actively developing new projects. The biological segment (anaerobic digestion for organic waste) also holds a dominant share within the South-East Asia WtE market, commanding approximately 63% in 2024, indicating its suitability for the region's high organic waste content.

Recycling

1. Japan boasts very high recycling rates, for example, exceeding 80% for PET bottles, significantly higher than Europe (around 40%) and the US (below 20%). Overall, about 50% of solid waste in Japan is recycled.
2. South Korea is known for its highly efficient and mandatory waste separation and recycling programmes, achieving high recycling rates.
3. Malaysia reported a recycling rate of 30.67% in 2020, with a government target to reach 40% by 2025.
4. In other ASEAN countries, recycling is common, but this is often driven by informal sectors, with collection and formal processing rates varying widely.

Biological Treatment

China is the world's largest biogas generator, with approximately 13 million operational biogas plants, predominantly agricultural, and it is aiming for significant increases in bio-natural gas output by 2030.

While the potential for composting in India is vast (4.3 million MT annually), only a small fraction of biodegradable waste is formally composted. As of 2018, there were 639 approved composting plants, but only 117 were

in operation, processing about 7% of waste through centralised plants.

Malaysia is making strides in biological waste treatment, particularly for organic waste and wastewater, though the widespread adoption of these methods for MSW continues to face challenges. Given that food waste alone constitutes over 40% of Malaysia's MSW, biological treatment holds immense potential for sustainable waste management. Malaysia is a major palm oil producer, and the palm oil industry has been a significant driver for Anaerobic Digestion (AD) adoption. Many palm oil mills have installed AD plants to treat palm oil mill effluent (POME), capturing methane (a potent greenhouse gas) and generating electricity for their own use or for the national grid via Feed-in Tariff (FiT) schemes. Companies like Green Lagoon Technology specialise in developing biogas power plants from POME.

Conclusion

The global waste treatment landscape is characterised by a fundamental divergence between Asia and the West. While Western nations have largely shifted away from landfilling towards integrated systems emphasising recycling, composting, and WtE, many parts of Asia are still grappling with the sheer volume of waste and a heavy reliance on landfills. However, spurred by rapid urbanisation, increasing environmental awareness, and government initiatives, Asian countries are rapidly adopting advanced technologies like WtE, modern recycling infrastructure, and biological treatment, moving towards more sustainable and resource-efficient waste management practices.

The journey is complex, but the adoption of new technologies and a shift towards circular economy principles are paving the way for a more sustainable future for waste management across the continent. 🌱

Overview of E-Waste Management

by
Amanda Lee Siek Hsia

In the digital age, electronic devices have become indispensable to modern life. However, their rapid obsolescence has led to an alarming increase in electronic waste, or e-waste, which includes discarded computers, mobile phones, televisions, and other electronic gadgets. Managing this complex and hazardous waste stream is a growing global challenge. Effective e-waste management requires comprehensive guidelines, robust policy frameworks, and coordinated global action to mitigate its environmental and human health impacts.

E-waste management typically focuses on minimising the generation of electronic waste, ensuring safe handling and disposal, and promoting recycling and reuse. Key components include:

- **Segregation and Collection:** Proper classification of e-waste is vital. Guidelines emphasise segregating electronic waste from general waste at source to facilitate safe handling, recycling, and disposal.
- **Extended Producer Responsibility (EPR):** Under this principle, manufacturers are responsible for the end-of-life management of their products. They are required to establish collection systems and take-back schemes, ensuring the recycling or safe disposal of electronics.
- **Safe Recycling and Disposal:** Guidelines recommend the use of authorised recycling facilities that follow environmentally sound practices. Informal recycling, which is common in many developing countries, poses risks to workers and the environment due

to improper handling and exposure to toxic substances.

- **Public Awareness and Education:** Public participation is critical for effective e-waste management. Guidelines often call for awareness campaigns to educate consumers about the hazards of improper disposal and the benefits of recycling.
- **Data Security:** Since many electronic devices store sensitive data, guidelines also address the secure destruction of data to prevent privacy breaches during recycling or disposal.
- **E-waste policies vary from country to country but generally follow international standards and best practices.** These policies aim to regulate the life-cycle of electronic products and to ensure environmentally responsible disposal. Key policy components include:
- **Legislation and Regulation:** Many countries have enacted specific laws to regulate e-waste. These laws set standards for collection, recycling, and disposal, and impose penalties for non-compliance.
- **Licensing and Monitoring:** Policies often require recycling and disposal facilities to obtain licences and adhere to strict environmental regulations. Regular monitoring and reporting are mandated to ensure compliance.
- **Incentives and Penalties:** To encourage proper e-waste management, policies may offer tax incentives or subsidies for recycling companies, while penalising illegal dumping and improper disposal practices.

- **Integration with Circular Economy:** Many governments are aligning e-waste policies with circular economy principles, promoting product design for durability, repairability, and recyclability to minimise waste.
- **Collaboration with Stakeholders:** Effective policy implementation requires coordination among producers, consumers, recyclers, and regulatory bodies. Policies encourage multi-stakeholder engagement to streamline efforts.

Global Direction & International Cooperation

The global nature of electronic markets necessitates international cooperation in addressing the e-waste challenge. Several international agreements and organisations provide direction and support.

- **The Basel Convention:** This international treaty controls the transboundary movement of hazardous wastes, including e-waste. It prohibits the export of e-waste from developed to developing countries unless the receiving country consents and can manage the waste safely.
- **The StEP Initiative (Solving the E-Waste Problem):** Supported by the United Nations, this initiative fosters collaboration among stakeholders worldwide to develop innovative solutions for e-waste prevention, reuse, and recycling.
- **Sustainable Development Goals (SDGs):** E-waste management contributes to achieving several SDGs, particularly SDG 12 (Responsible Consumption and Production) and SDG 13 (Climate Action).
- **Global E-Waste Monitor:** Jointly published by the United Nations University (UNU), the International Telecommunication

Union (ITU), and the International Solid Waste Association (ISWA), this report provides data on global e-waste generation and recycling, guiding policy and decision-making.

- **Technology Transfer and Capacity Building:** Developed nations and international organisations are supporting developing countries with technology transfer, funding, and training to improve their e-waste management capabilities.

E-waste Management in Malaysia

As Malaysia continues to develop rapidly in the digital and industrial sectors, the generation of e-waste has seen a significant rise. E-waste includes discarded electrical and electronic equipment such as computers, mobile phones, televisions, refrigerators, and other consumer electronics that have reached the end of their useful life. These devices contain both valuable and hazardous materials, making their management critical to environmental protection and public health. Malaysia has implemented various guidelines and policies to address this challenge, while aligning itself with international commitments and global trends in sustainable e-waste management.

The management of e-waste in Malaysia is governed by structured guidelines that aim to ensure proper handling, collection, transportation, recycling, and disposal of electronic waste.

- **Segregation and Collection Systems:** The Department of Environment (DOE) has established guidelines for separating e-waste at source. For household e-waste, public collection programmes are promoted to encourage residents to dispose of their devices at designated drop-off points or via collection drives. For non-household or industrial e-waste, licensed collectors are responsible for retrieval and documentation.

- **Licensing and Regulation of E-Waste Facilities:** Only licensed recovery and recycling facilities are allowed to manage e-waste. These facilities must comply with the Environmental Quality (Scheduled Wastes) Regulations 2005 under the Environmental Quality Act 1974, ensuring they handle and process e-waste in a manner that minimises environmental harm.
- **Data Protection and Secure Handling:** Guidelines emphasise the need for secure disposal of data-bearing devices. Consumers and businesses are encouraged to ensure data is removed or destroyed before recycling to prevent data leaks.
- **Public Awareness Campaigns:** The Malaysian government collaborates with NGOs, private companies, and media to educate the public on the importance of proper e-waste disposal. Campaigns such as Program e-Waste Alam Alliance target household awareness and encourage responsible consumer behaviour.

Our e-waste management is driven by several key policy initiatives that form the legal and strategic framework for action:

- **Environmental Quality Act 1974 and Scheduled Waste Regulations 2005:** E-waste is classified as scheduled waste under this act, specifically under the code SW110. This classification mandates that any entity handling e-waste must obtain proper licensing and adhere to waste treatment protocols approved by the DOE.
- **Household E-Waste Management Policy (from 2018):** This policy was developed to extend e-waste regulations beyond industrial sources to include household electronics. It promotes a structured and systematic collection and recycling mechanism for domestic e-waste.
- **Extended Producer Responsibility:** Malaysia is in the process of formalising EPR policies where manufacturers and

importers will be legally responsible for the life-cycle of their electronic products. Under this scheme, producers must establish collection channels, fund recycling efforts, and report on e-waste recovery rates.

- **National Strategic Plan for E-Waste Management:** The DOE, with support from the Japanese International Cooperation Agency (JICA), has developed a long-term plan to improve e-waste infrastructure, legislation, and public engagement. Its aim is to establish sustainable financing mechanisms, enhance recycling capacities, and create a nationwide collection network.

Conclusion

Malaysia is making considerable strides in e-waste management through a combination of clear guidelines, strong regulatory policies, and engagement with global initiatives. This evolving approach reflects a commitment to sustainability, public health, and environmental stewardship. While challenges remain - such as informal recycling practices and public compliance - the ongoing implementation of EPR, strategic partnerships, and public education campaigns signal a positive direction. As electronic consumption continues to grow, this proactive e-waste management strategy will be critical in shaping a cleaner and more responsible digital future.

The growing threat of e-waste demands a coordinated global response, underpinned by clear guidelines, sound policies, and international cooperation. As electronic consumption continues to rise, sustainable e-waste management must be prioritised to protect human health, preserve natural resources, and support a circular economy. Only by adopting best practices, enforcing regulations, and fostering awareness, can nations turn the e-waste challenge into an opportunity for innovation and environmental stewardship. 🌱

SURAT Systems, a Valuable Lesson in Effective Solid Waste Management

by
Ng Li Li

Urbanisation presents both opportunities and challenges. One of the most pressing challenges is managing the ever-growing volume of municipal solid waste (MSW). Many developing cities struggle to cope with inadequate waste management systems, resulting in risk to public health, environmental degradation, and a reduced quality of life.

However, some cities have shown that transformation is possible through determined leadership and citizen participation. One of the most inspiring examples is Surat, a city in Gujarat, India, which underwent a remarkable turnaround in solid waste management after a public health crisis in the mid-1990s. Surat's story is a valuable lesson in effective urban waste governance, citizen engagement, and sustainable development.

Background: City in Crisis

In 1994, Surat suffered a devastating outbreak of the plague, which claimed many lives and triggered panic across the country. The outbreak was traced back, in part, to unhygienic conditions, blocked drains, and heaps of uncollected waste. At that time, Surat was one of the dirtiest cities in India, with inefficient and poorly managed municipal services. The crisis exposed the severe consequences of neglecting urban sanitation and waste management.

The urgency created by the epidemic prompted the city leadership, particularly under the dynamic Municipal Commissioner, S.R. Rao, to initiate sweeping reforms. Within just a few years, Surat transformed from a city of squalor into one of the cleanest in the country, earning accolades and serving as a model for other urban centres. The following sections outline the key lessons learnt from this transformation.

1. Crisis Can Catalyse Change

One of the first lessons from Surat's experience is that a crisis can act as powerful catalyst for reform. The plague outbreak generated both political will and public demand for change. It created an atmosphere where drastic measures were not only accepted but expected. Often, municipal reforms are hindered by inertia and resistance to change. In Surat, the urgency of the situation provided the momentum needed to overcome these barriers.

This highlights the importance of leveraging moments of crisis to initiate long-term institutional improvements, rather than temporary fixes. Leadership must be prepared to use such windows of opportunity to build support for comprehensive reforms.

2. Strong Leadership is Indispensable

The role of leadership cannot be overstated in Surat's transformation. The Municipal

“
 Door-to-door collection, though more resource-intensive, delivers better outcomes in terms of cleanliness and public health.
 ”

Commissioner adopted a mission-driven, no-nonsense approach. He held sanitation workers and officials accountable, instituted regular performance monitoring, and engaged directly with the public. His commitment inspired both municipal staff and citizens to contribute to the change.

This underscores the broader lesson that competent, visionary leadership is critical for driving systemic reform. Without strong leadership, even the best designed policies and financial resources may not translate into results.

3. Citizen Engagement and Awareness Are Key

Another vital factor in Surat's success was citizen engagement. Public awareness campaigns were launched to educate residents about hygiene, sanitation, and the importance of waste segregation. Regular community meetings and media outreach fostered a culture of civic responsibility.

When citizens understand the value of waste management and feel ownership of public spaces, they are more likely to cooperate with municipal efforts. This lesson is crucial for cities worldwide: Waste management is not solely a technical challenge - it is a social one. Without public buy-in, even the most sophisticated systems will falter.

4. Shift to Door-to-Door Collection

A pivotal operational reform in Surat was the shift from communal waste bins to door-to-door collection. Previously, overflowing public bins were common sources of filth and disease. The new system ensured that waste was collected directly from households on a daily basis, significantly reducing littering and improving neighborhood cleanliness.

This change demonstrated the importance of service design in waste management. Systems must be designed with the behaviour and convenience of citizens in mind. Door-to-door collection, though more resource-intensive, delivers better outcomes in terms of cleanliness and public health.

5. Focus on Cleanliness and Hygiene

Surat's reforms placed strong emphasis on visual cleanliness and daily maintenance. Streets were swept daily, drains were cleared, and waste was collected regularly. Cleanliness became a civic priority, not just a bureaucratic function.

This reflects the broader principle that standards matter. When citizens see clean streets, they are more likely to maintain them. Visible improvements help sustain public support and build a virtuous cycle of civic pride and cooperation.

6. Leveraging Public-Private Partnerships

Surat also adopted Public-Private Partnership (PPP) models to improve efficiency in waste collection and processing. Private contractors brought in modern equipment, professional management, and performance-based accountability.

The lesson here is that partnerships with the private sector can enhance capacity and innovation in municipal services, provided they are well-regulated and aligned with public goals.

7. Performance Monitoring and Accountability

An essential component of Surat's transformation was the establishment of transparent monitoring and accountability mechanisms. Field workers were regularly evaluated, and their performance was made visible to higher authorities and the public. Non-performing employees were penalised, and high performers were recognised.

This highlights the importance of performance management in public service delivery. Without clear accountability structures, reforms are unlikely to be sustained. Monitoring must be continuous, data-driven, and linked to both incentives and consequences.

8. Promoting Waste Segregation and Recycling

In later stages, Surat began promoting source segregation of waste into wet and dry streams. Composting and recycling initiatives were introduced to reduce dependence on landfills and to promote a more circular economy.

This points to the long-term sustainability lesson: Solid waste management must evolve beyond collection and disposal. Cities must invest in segregation, recycling, and waste-to-energy solutions to create environmentally sustainable systems.

9. Building Institutional Capacity

Surat invested in training and capacity building for municipal employees. Workers were trained in modern techniques and sensitised to the importance of their roles. A professional culture replaced the previous atmosphere of neglect and complacency.

This underscores the need for continuous capacity development. Waste management is a dynamic field, requiring constant updating of skills, processes, and technologies.

10. Replicability and Scalability

Finally, Surat's experience demonstrates that urban waste management reforms are replicable. Cities facing similar challenges can adopt and adapt the principles from Surat's model. However, success depends on tailoring interventions to local contexts and ensuring genuine leadership and public participation.

Conclusion

The transformation of Surat's solid waste management system offers profound lessons for urban governance and sustainable development. It shows that even cities plagued by inefficiency and neglect can achieve rapid and lasting improvements when driven by crisis-induced urgency, strong leadership, citizen engagement, operational innovation, and accountability.

Surat's experience is not a blueprint to be copied mechanically but a source of adaptable principles. For cities worldwide struggling with waste management, Surat provides hope - and a clear message that change is possible. The true lesson is that with the right mix of vision, commitment, and cooperation, clean and healthy urban environments are within reach for all. 🌱

Global Direction on Toxic and Hazardous Waste Management

by
Lim Tau Wee

In November 2024, the Malaysian government announced considerations for establishing a centralised chemical disposal centre to address the increasing volume of toxic waste. This initiative was aimed at enhancing the capacity for safe and efficient waste disposal, especially in light of recent pollution incidents in Johor Bahru. The proposal includes strengthening the DOE's capabilities and revising penalties under the Environmental Quality Act to deter illegal dumping.

Global Context

The global management of toxic and hazardous waste emerged as a critical environmental and public health issue in the 21st century. As industrial activities expanded and consumer products proliferated, the generation of hazardous waste had risen sharply. This included chemical by-products, electronic waste, heavy metals, medical waste, and various industrial solvents. Poor management of these wastes could lead to severe ecological degradation, groundwater contamination, air pollution, and serious health risks. The international community responded with robust frameworks, innovative technologies, and best practices aimed at improving the safe handling, treatment, and disposal of hazardous substances.

This essay explores the current global direction in toxic waste management through four key areas: Emerging technologies, classification standards, e-waste challenges, and lessons from major incidents.

Innovative Technologies for Treatment and Disposal of Toxic Waste

Recent advances in science and engineering have introduced a range of innovative

technologies designed to make toxic waste treatment more efficient, cost-effective, and environmentally sustainable. Among these are plasma arc treatment, supercritical water oxidation, and advanced thermal desorption techniques. Plasma arc technology, for instance, uses extremely high temperatures to break down hazardous compounds into inert gases and non-leachable slag, offering a virtually emission-free method of waste destruction.

Bioremediation is another promising area, where microorganisms are employed to degrade or neutralise toxic substances in soil and water. Phytoremediation, a plant-based method, is gaining traction for removing heavy metals from contaminated sites. Additionally, encapsulation techniques using specialised polymers are being used to immobilise radioactive and industrial wastes, preventing leaching into the environment.

In the context of electronic waste (e-waste), hydrometallurgical and pyrometallurgical processes have been refined to recover valuable metals like gold, silver, and palladium while minimising harmful emissions. These technologies not only reduce environmental impact but also promote circular economy practices by reclaiming resources from waste streams.

Global Best Practices in Hazardous Waste Classification and Handling

Proper classification of hazardous waste is essential for effective management, transportation, and disposal. International standards, such as those developed by the United Nations through the Basel Convention and the Globally Harmonised System (GHS) of Classification and Labelling of Chemicals, provide a framework for identifying and labeling hazardous substances.

The Basel Convention, ratified by over 180 countries, sets stringent rules on the transboundary movement of hazardous waste, requiring informed consent between exporting and importing countries. It promotes environmentally sound management (ESM) principles and capacity building in developing nations. ISO 14001 and ISO 45001 standards guide organisations in implementing environmental and occupational safety systems related to hazardous materials.

In terms of handling, best practices include secondary containment, leak detection systems, emergency response protocols, and worker training in personal protective equipment (PPE) and hazardous material procedures. Many countries have also implemented cradle-to-grave tracking systems to monitor hazardous waste from generation to final disposal, reducing the risk of illegal dumping and environmental contamination.

Challenges & Opportunities in Managing E-Waste and Heavy Metal Contaminants

Electronic waste represents one of the fastest-growing segments of hazardous waste globally, driven by rapid technological obsolescence and consumer demand. E-waste contains both valuable and toxic components, including lead, cadmium, mercury, and brominated flame retardants. Informal recycling sectors, particularly in developing nations, often dismantle e-waste without safety measures, exposing workers and communities to harmful substances.

To address this, countries are adopting Extended Producer Responsibility (EPR) policies, which place the onus on manufacturers to ensure the safe collection, recycling, and disposal of end-of-life electronics. Nations like Germany, Japan, and South Korea have well-established EPR frameworks that ensure high recovery rates and minimal environmental impact.

Heavy metal contamination, often associated with mining, battery disposal, and industrial effluents, remains a persistent threat. Emerging technologies such as nanofiltration, electrodialysis, and bioaccumulation using algae or fungi are offering new methods to treat water and soil polluted with metals like arsenic, lead, and mercury.

Global cooperation through initiatives such as the Strategic Approach to International Chemicals Management (SAICM) and partnerships like the

Global E-Waste Statistics Partnership (GESp) are helping to harmonise data, enhance monitoring, and support policy reforms in low- and middle-income countries.

Toxic Waste Incidents & Lessons Learnt: A Global Regulatory Perspective

Historical incidents have shaped the global regulatory landscape of toxic waste management. The Love Canal disaster in the United States in the 1970s exposed the dangers of building residential areas atop chemical dump sites, prompting the creation of the U.S. Superfund programme. In Europe, the Seveso Disaster in Italy led to the adoption of the Seveso Directive, mandating strict industrial safety protocols for sites handling large quantities of dangerous substances.

More recently, the 2006 Probo Koala incident in Côte d'Ivoire, where toxic waste from a European tanker was improperly dumped, highlighted the vulnerabilities in transboundary waste movements and the need for stricter enforcement of international conventions.

Each of these events underscored the importance of transparency, community engagement, corporate accountability, and robust regulatory oversight. Modern frameworks now emphasise risk assessment, stakeholder involvement, public disclosure, and the right to know.

Conclusion

The management of toxic and hazardous waste is a multidimensional challenge requiring technological innovation, international cooperation, and strict regulatory compliance. As the global community faces mounting pressure from industrialisation, urbanisation, and electronic consumption, the direction of toxic waste management is increasingly leaning toward sustainability, circularity, and equity.

By investing in advanced treatment technologies, adhering to best classification and handling practices, addressing the complexities of e-waste, and learning from past disasters, the world can move toward a safer and more sustainable future. The path forward lies in aligning environmental stewardship with economic development while ensuring that no community bears an undue burden from the toxic byproducts of modern life. 🌱

Charring Rate of Laminated Veneer Lumber and Glued Laminated Timber from Selected Malaysian Tropical Timber in Accordance with Eurocode

by
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Wood is being used increasingly for structural engineering applications in buildings and other special engineering productions. The main advantages of timber construction relative to the use of other materials, are: Ease of construction and maintenance, pleasant appearance, renewable resource, lightweight and construction is not weather dependent (*DeDolt, 2008*).

One of the most significant current discussions in engineered timber products is their capability and durability as building materials and they are broadly used at present (*Hopkins, 2011*). These products are also said to have the same capability as solid timber for structural building (*White, 2006*). Popular products include glue laminated timber (also known as glulam), laminated veneer lumber (LVL), and cross-laminated timber (CLT). Figure 1 shows examples of the application of glulam in buildings in Malaysia {(a) and (b)}, Earth Sciences

Building, University of British Columbia (c), and The Bridport House Building (d).

These products can be classified as flexible and versatile building materials available in the market. However, since timber is a combustible material, the fire performance of timber as a structural element becomes a vital issue in building design in order to ensure the required safety level is achieved. Studies show that timber structures can have adequate fire resistance if designed appropriately (*Friquin, 2010*).

The combustion and the chemical phenomena occurring in the wood during an accidental situation of elevated temperature is a complex study issue. Although timber is a combustible material, it has significant insulating properties and burns steadily, predictably, and measurably. When timber is exposed to fire, charcoal (also known as the char layer) is formed on the surface of the timber, providing a heatproof layer that protects the inner core of the timber.

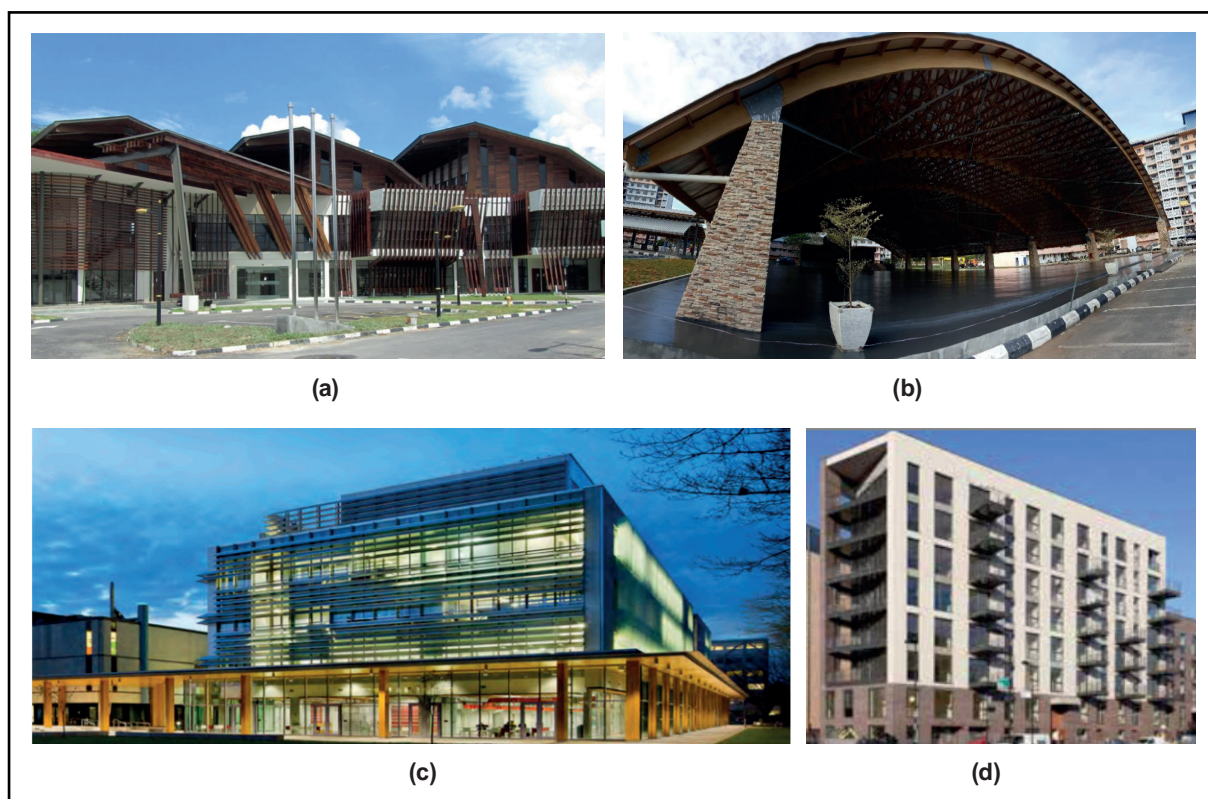


Figure 1: Examples of the glulam applications: (a) Glulam gallery, (b) Multipurpose hall, TLDM Lumut, (c) Earth Sciences Building, University of British Columbia, and (d) The Bridport House Building (Bulletin of lessons learned: UBC Earth Sciences Building, Vancouver, Canada)

Therefore, it is possible to make precise calculations of the dimensions for structural timber to ensure it holds the building up for a specific period of time, i.e. 30 minutes to 2 hours, so that residents are able to flee the burning building and save their belongings.

For design purposes, the value of the charring rate of timber is an important distinctive feature of its fire resistance since this can help determine the dimension of the residual section of timber. In the past years, charring rates had attracted much attention from researchers and structural designers who wanted to calculate the loss over time, the load-carrying capability of timber beams and columns during and after fire tests (Aseeva *et al.*, 2014; Hagen *et al.*, 2009; Babrauskas, 2005). To perform an engineering analysis of the fire resistance of exposed wood, information is needed on charring rate, a ratio of

ultimate strength to design values, and reduction in strength due to temperature gradient within the uncharred cross-section (White, 2016).

Timber Behaviour in Fire and Charring Rate

The application of sufficient heat to wood leads to thermochemical decomposition called pyrolysis, which results in the alteration of its chemical composition and physical appearance (formation of char). This phenomenon is accompanied by mass loss. In timber structural members, charring appears on all exposed surfaces in the form of a layer that increases in depth as the fire progresses. Commonly, the char layer effectively protects the remaining unburned residual cross-section (Frangi *et al.*, 2009).

According to EN1995-1-2, the position of the charred layer coincides with that of the 300°C isotherm. This is verified by other authors (Subyakto *et al.*, 2003; Friquin, 2010; Lane, 2005; Menis, 2012). The charred layer cannot carry structural loads (resulting in a reduction of the cross-section). An experiment conducted by Cachim & Franssen (2009) stated the charring rate is the distance between the outer surface of the original member and the position of the char-line as illustrated in Figure 2a. In the same opinion stated by White (2016), the timber underwent several degradation processes before completely burning as illustrated in Figure 2b.

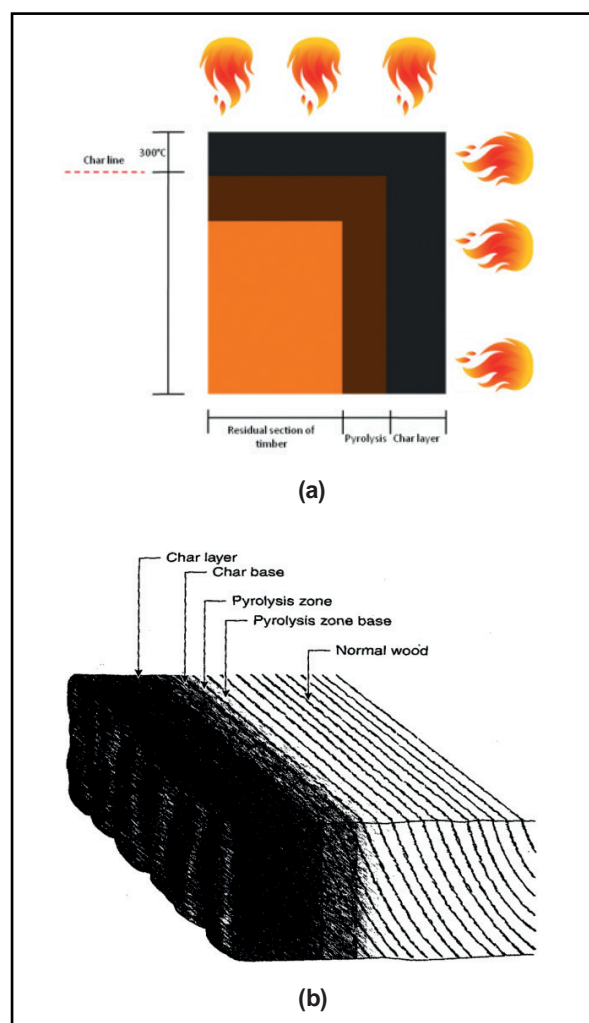


Figure 2: Changes in the region of timber subjected to fire; (a) illustrated by Cachim & Franssen, 2009 and (b) White, 2016)

The charring rate of timber is a considerably complex phenomenon because it is mostly determined by timber species, density, heat flux, and ventilation factor. There are other factors too, such as moisture, permeability, composition, or direction of the heat transfer (parallel or perpendicular to the grain). Timber members exposed to fire show charring unless they are protected during the relevant time of fire exposure.

The charring rate is more or less constant and depends mainly on the density and moisture content of the wood (Fonseca & Barreira, 2009). Safety rules and guidelines should be useful for different wood applications. The fire safety of this type of material involves prevention, inhibition, detection, and evacuation. It also involves appropriate design rules, installation, construction, and maintenance of the wood material applications. To assess safety rules, this type of element should have sufficient mechanical resistance to guarantee the design loads. The requirement for fire safety (Figure 3) can be obtained by full-scale testing of building construction or by the design of building construction by means of calculations according to design standards which are by using the charring rate value. The design method is given in MS 544 Part 9 or as given in Eurocode as shown in Figure 4.

Malaysian Standard MS 544 Part 9: Fire resistance of timber structures provides recommendations on charring rate for designing solid timber structural members. MS 544 Part 9 only states a notional charring rate value, without one-dimensional and two-dimensional charring rate, and the charring rate values are based on strength grouping as compared with Eurocode 5 (EC5) which features one and two-dimensional notional charring rate values based on densities. The design value for the charring rate is given in MS 544 Part 9 (Table 1), BS 5268 (Table 2), and EC5 (Table 3) respectively.

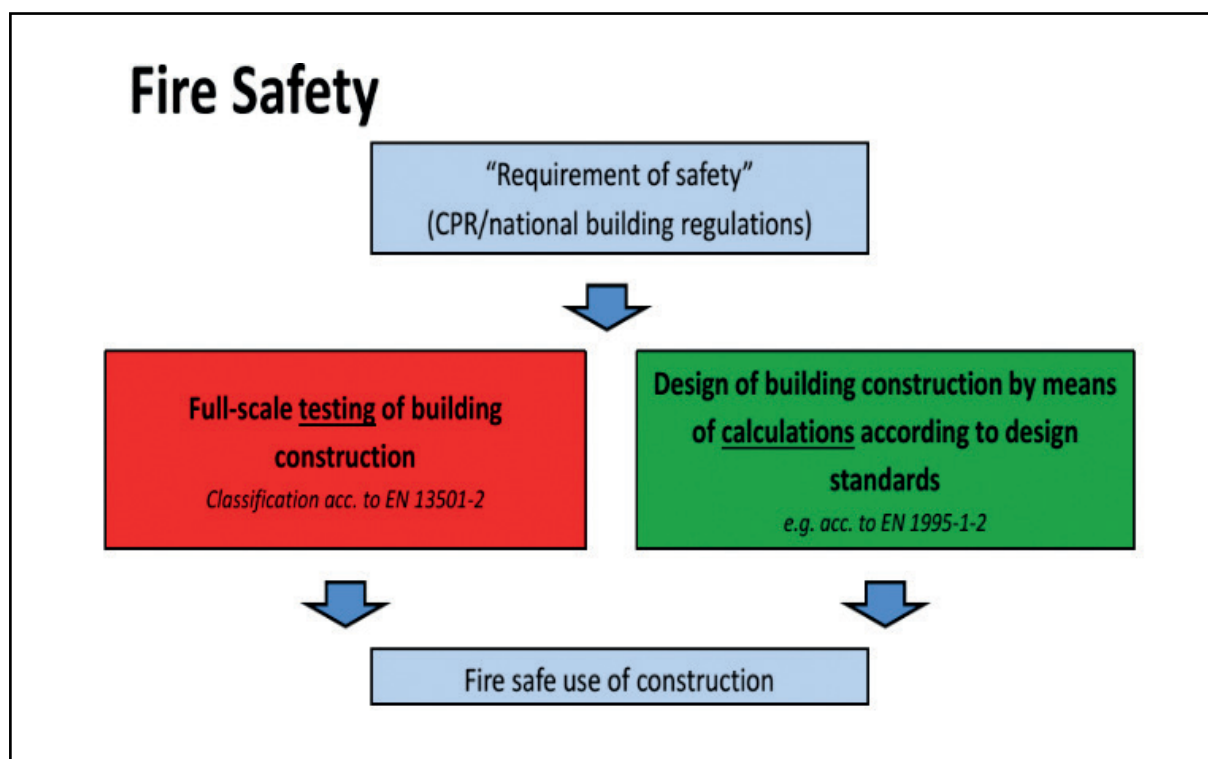


Figure 3: Fire safety requirement of building

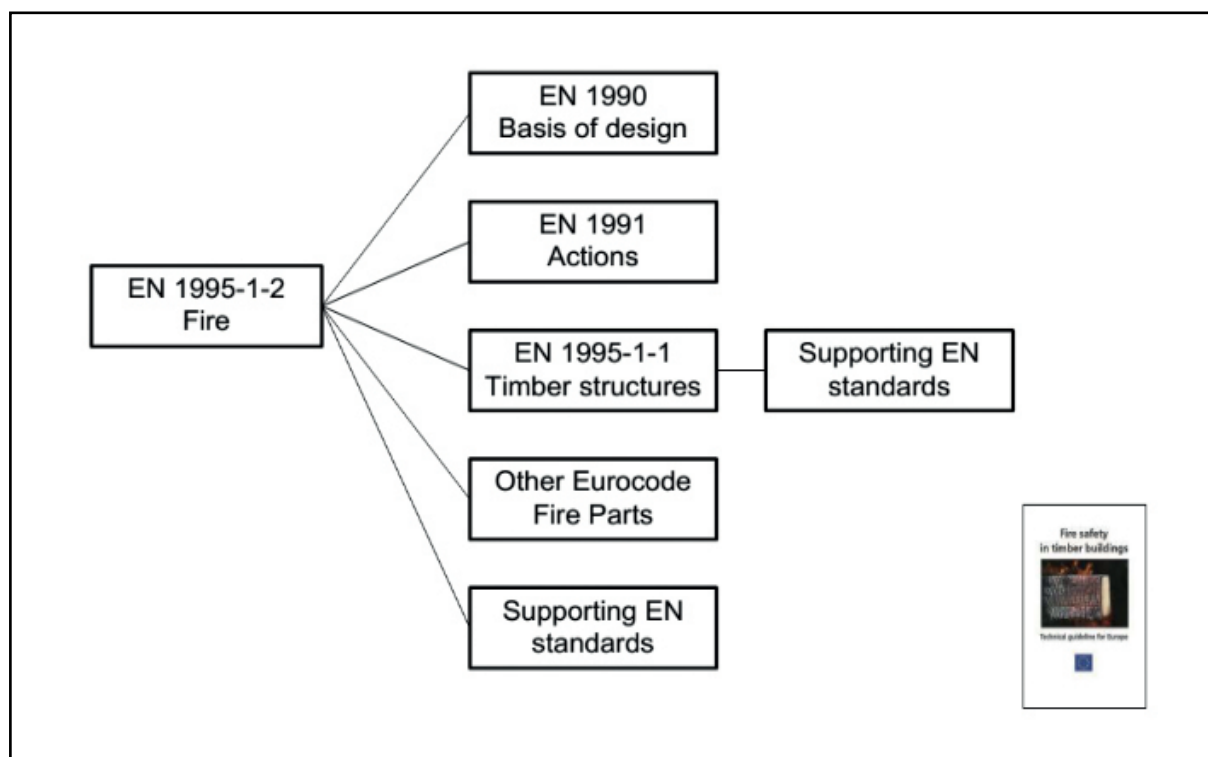


Figure 4: Design standards related to fire safety according to European Standards

Strength Group (SG)	Charring rate (mm/min)
SG 1 to SG 3	0.5
SG 4 to SG 5	0.7

Note: SG refers to MS 544 Part 2

Table 1: Notional rate of charring for the calculation of residual section in MS 544 Part 9

Species	Charring rate (mm/min)
Softwood < 640 kg/m ³	0.83
Hardwood > 640 kg/m ³	0.55
Softwood glued laminated	0.70

Table 2: Notional rate of charring for the calculation of residual section based on BS 5268 Part 4

Species	Charring rate (mm/min)	
	β_o	β_n
a. Softwood and beech		
i. Glued laminated timber with a characteristic density of $\geq 290 \text{ kg/m}^3$	0,65	0,7
ii. Solid timber with a characteristic density of $\geq 290 \text{ kg/m}^3$	0,65	0,8
b. Hardwood		
i. Solid or glued laminated hardwood with a characteristic density of 290 kg/m^3	0,65	0,7
ii. Solid or glued laminated hardwood with a characteristic density of $\geq 450 \text{ kg/m}^3$	0,5	0,55
c. LVL With a characteristic density of $\geq 480 \text{ kg/m}^3$	0,65	0,7
d. Panels		
i. Plywood	0,9 ^a	-
ii. Wood panelling	0,9 ^a	-
iii. Wood-based panel other than plywood	1,0 ^a	-

Note: ^a The values apply to the characteristic density of 450 kg/m^3 and a panel thickness of 200mm; 3.4.2(9) for other thicknesses and densities.

Table 3: Notional charring rates β_o and β_n of timber in EC5

Generally, charring of timber is divided into:

- One-dimensional charring as a physical property for a specific species or timber of specific density
- Two-dimensional charring, including the effects of cross-sectional dimensions and other effects.

Charring rates are applicable for any orientation of fire-exposed surfaces and direction of fire exposure; there is no distinction between vertical and horizontal surfaces.

One-dimensional charring rate β_o is the charring rate observed for one-dimensional heat transfer under standard fire exposure of an unprotected semi-infinite timber slab without any fissure or gap.

$$d_{char,0} = \beta_o t \quad (1)$$

Following EC5, the design equation proposed for in direction charring layer determination, the function of the charring rate for non-protected surfaces to normalised fire conditions, is presented in the equation shown above (1) where t is the time of fire exposure and β_o is the one-dimensional charring rate perpendicular to the grain. For charring in the direction of the grain, this charring rate should be doubled.

When the propagation of fire conditions is more than in one direction equation (2) should be used.

$$d_{char,n} = \beta_n t \quad (2)$$

The residual cross-section with corner rounding, for simplicity, is replaced by a rectangular cross-section with an equivalent notional charring depth.

$$\beta = \frac{d_{char}}{t}$$

For the calculation of the resistance of timber members, the original cross-section is reduced by the charring depth. Charring rate β is the ratio between charring depth and time.

$$\beta = \frac{d_{char}}{t} = \frac{50}{62} = 0.8 \text{ mm/min}$$

Example of calculation of charring rate is based on Figure 5.

In order to move towards limit state design, there is a need to determine the one-dimensional and two-dimensional charring rates.

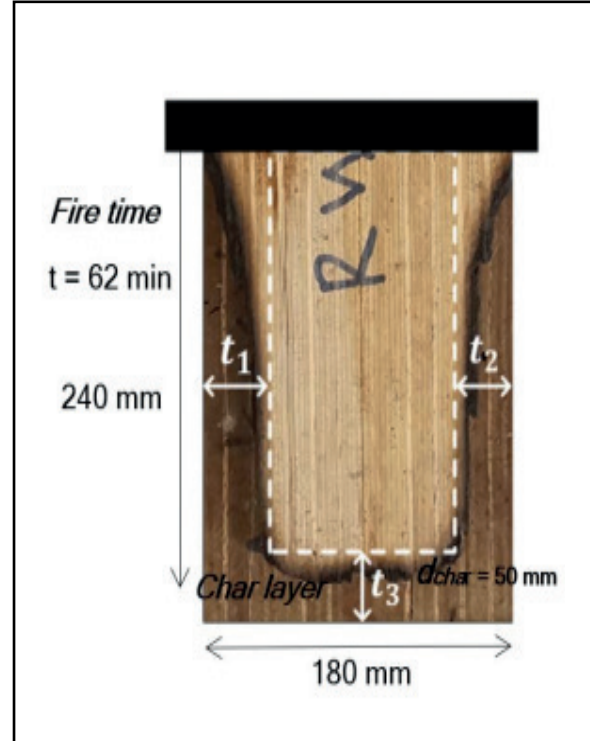


Figure 5: Cross-section of charred element

Charring Rate Study for Glulam And LVL

A series of fire tests were conducted in accordance with BS 476 for glulam and LVL for Malaysian tropical timber.

Glulam (see Figure 6a) is an engineered, stress-rated timber product assembled from selected and prepared wood laminations bonded together with adhesives, with the grain of the laminations approximately parallel in the longitudinal direction to form solid timber.

LVL (see Figure 6b) is a high-strength engineered wood product comparable to solid timber and is manufactured by bonding together rotary peeled or sliced thin wood veneers under heat and pressure. The 1-D and 2-D fire tests and the positioning of the specimens on the test frame for 2-D and 1-D tests are shown in Figure 7a and Figure 7b respectively. Figure 8 shows the actual test set-up. Figure 9a and Figure 9b show the sample after the fire exposure.

The charring rates of glulam and LVL from selected tropical hardwood are tabulated in Table 4. 🗨

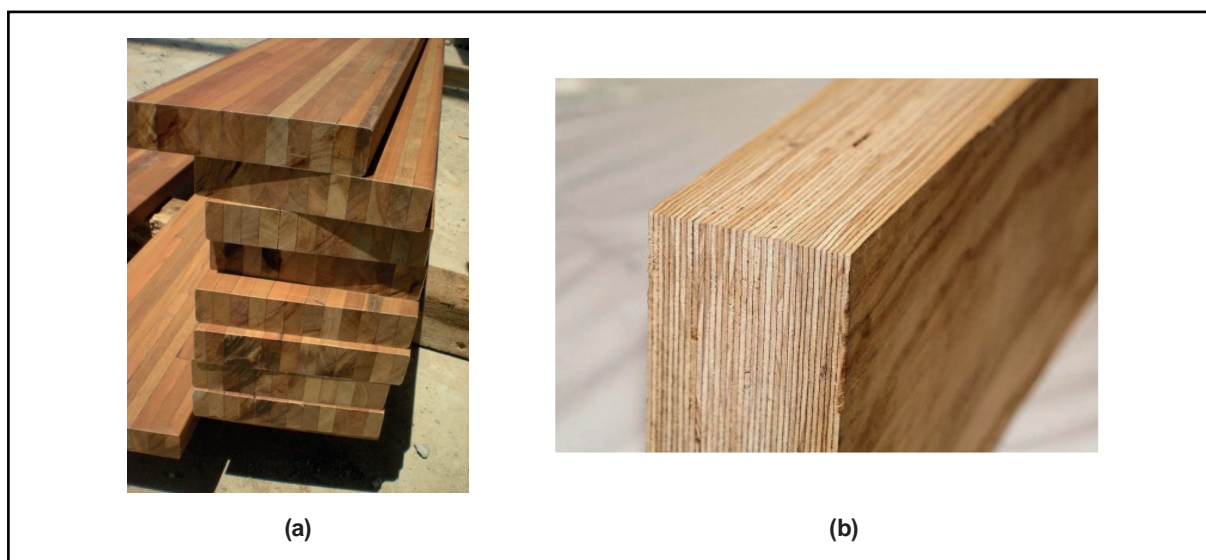


Figure 6: Engineered timber products; (a) glulam and (b) LVL



Figure 7: Mounting specimens on test frame flush with cement; (a) 2-D samples and (b) 1-D samples



Figure 8: Actual fire test set-up: (a) 2-D specimens with attached thermocouples and (b) specimens after fire test



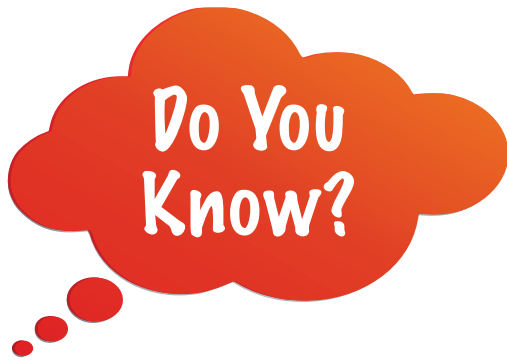
Figure 9: Examples of the conditions of the samples after fire exposure: (a) glulam and (b) LVL

Species	ETP	Density (kg/m ³)	β_o	β_n
Malagangai Keruing	glulam	800 740	0.55 -	0.65 0.70
Kasai	LVL	654	0.39	0.74
Mengkulang		553	0.46	0.80
Rubber Wood		724	0.42	0.60
Eucalyptus		719	0.57	0.67
Kedondong		540	0.56	0.91
Balau	glulam	952	0.1	0.3
Mengkulang		759	0.11	0.35
Dark Red Meranti		632	0.33	0.48
Light Red Meranti		469	1.02	0.53

Table 4: Charring rate of glulam and LVL from Malaysian timber

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Waste Management

by
Pang Soo Mooi

The Malaysian government has unveiled its first Circular Economy Blueprint for Solid Waste (2025-2035) which forecasts the implementation of measures such as Extended Producer Responsibility, Pay-As-You-Throw, and Zero Waste to Landfill Certification. The government plans to enforce these requirements through legislation and intends to increase the number of waste-to-energy plants. It also aims to support the formation of a circular economy association to help achieve a national recycling rate of 40% by 2025. The plan has five main strategies and 20 initiatives, covering the entire supply chain from product production to disposal.

1. Solid Waste Worldwide: UNEP

The increasing volume and complexity of waste associated with the modern economy poses a serious risk to ecosystems and human health. Every year, an estimated 11.2 billion tonnes of solid waste are collected worldwide and decay of the organic proportion of solid waste

is contributing about 5% of global greenhouse gas emissions (GHG). Waste from electrical and electronic equipment containing new and complex hazardous substances, presents the fastest-growing challenge in both developed and developing countries.

Poor waste management, ranging from non-existing collection systems to ineffective disposal, causes air pollution as well as water and soil contamination. Open and unsanitary landfills contribute to the contamination of drinking water and can cause infection and transmit diseases. The dispersal of debris pollutes ecosystems and dangerous substances from electronic waste or industrial garbage puts a strain on the health of urban dwellers and the environment.

The solution, in the first place, is minimisation of waste. Where waste cannot be avoided, recovery of materials and energy from waste as well as remanufacturing or recycling waste into usable products should be the second option. Recycling leads to substantial resource savings. For example, for every tonne of paper recycled, 17 trees and 50 per cent of water can be saved. Moreover, recycling creates jobs and employs 12 million people in Brazil, China and United States alone.

2. Malaysia's Solid Waste Situation: International Trade Administration

Malaysia disposes of more than 39,000 tons of municipal solid waste daily. It's the equivalent of 1.17kg per person, with over 30% being food waste. Malaysians waste a staggering 8.3 million metric tons (about 260kg) of food per person annually. The increase in solid waste is caused by population growth, lifestyle changes, and the rapid urbanisation and development process.

We will run out of space for solid waste disposal at landfills by 2050. The limited land and high cost of landfill operations have increased the government's environmental and financial concerns. We need strategic waste management solutions as we have a lower recycling rate compared with our neighbours. We also experience waste management challenges due

to a lack of technology, experienced labour, and infrastructure to address the problem adequately.

3. Evolution of Waste Management

The evolution of waste management has progressed significantly from ancient times to modern-day practices. Below is an overview of how waste management has changed through different historical periods.

- a. Prehistoric Societies Era: Early humans were mostly nomadic, generating minimal waste that was naturally biodegradable.
- b. Early Settlements (3000 BCE – 500 CE): With the rise of civilisations (e.g., Mesopotamians, Egyptians, Greeks, Romans), waste began accumulating in urban areas.
 - Mesopotamians created the first known waste pits.
 - Ancient Egyptians practiced basic waste disposal methods, including dumping trash in designated areas.
 - Ancient Greece introduced organised collection and disposal.
 - The Roman Empire (500 BCE - 476 CE) developed early sanitation infrastructure, such as sewers (Cloaca Maxima) and designated waste dumps outside city walls.
- c. Medieval Waste Management (500 CE - 1500 CE).
 - Waste disposal declined during the Middle Ages due to the collapse of centralised Roman sanitation systems.
 - In Europe, streets were often filled with waste, contributing to disease outbreaks such as the Black Death (1347-1351).
 - Some cities, such as medieval London, implemented early waste regulations, requiring households to dispose of waste outside city walls.
- d. Early Modern Waste Management (1500 CE - 1800 CE)
 - The Renaissance and Enlightenment
- e. Industrial and Urban Waste Management (1800s - 1900s).
 - periods saw a growing awareness of public health and sanitation.
 - Some European cities introduced waste collection services, where “scavengers” removed waste.
 - The Industrial Revolution (1700s-1800s) led to increased urbanisation and waste production, prompting cities to develop rudimentary waste management systems.
 - In 1751, Benjamin Franklin helped organise one of the first municipal waste collection services in Philadelphia.
 - With industrialisation, cities saw a surge in population and waste, leading to more systematic waste collection.
 - 19th century London established the first regulated waste collection and disposal system.
 - The late 1800s saw the introduction of incinerators to reduce waste volume.
 - The concept of landfills emerged as a primary disposal method.
 - Recycling began gaining attention in the early 20th century (e.g., paper recycling in the U.S.).
- f. Modern Waste Management (20th Century - Present).
 - 1950s - 1970s: Rapid urbanisation and industrial waste led to stricter regulations. Governments introduced waste segregation and disposal laws.
 - 1980s - 1990s: Recycling programmes expanded globally. Waste-to-energy plants were developed to convert waste into electricity.
 - 2000s - Present: Sustainable waste management strategies emerged, including:
 - Circular economy concepts (reducing, reusing, recycling).
 - Smart waste technologies (AI and IoT in waste collection and sorting).

- Advanced waste treatment methods, such as composting, anaerobic digestion, and plastic-to-fuel conversion.

4. Batteries are a Fire Hazard: ISWA (International Solid Waste Association)

Increasingly, lithium batteries are causing fires in households and waste disposal facilities, with Austrian data showing a five-fold rise in such incidents over the past decade. Around three million lithium batteries are improperly discarded in residual waste annually, leading to the loss of valuable materials like lithium, cobalt, nickel and lead. A deposit system for both rechargeable and single-use batteries is crucial to prevent fires, improve collection rates and conserve resources. Similar issues have been reported across Europe, with battery fires surging in Germany, France and the UK. In response, the EU has mandated an increase in portable battery collection rates from 45% to 73% by 2030. Austria, however, fell short with just 44% collected in 2022, highlighting an urgent need for action. To mitigate risks, all lithium batteries - including those from e-cigarettes, electric toothbrushes, phones, e-scooters and toys - must be disposed of in designated collection boxes at shops or waste centres.

5. Global Snapshot of Solid Waste Management to 2050: World Bank

Waste composition differs across income levels, reflecting varied patterns of consumption. High-income countries generate relatively less food and green waste, at 32% of total waste, and generate more dry waste that can be recycled, including plastic, paper, cardboard, metal, and glass, which account for 51% of waste. Middle- and low-income countries generate 53% and 57% of food and green waste respectively, with the fraction of organic waste increasing as economic development levels decrease. In low-income countries, materials that can be recycled account for only 20% of

the waste stream. Across regions, there is not much variety within waste streams beyond that aligned with income. On average, all regions generate about 50% or more organic waste, except for Europe and Central Asia and North America, which generate higher portions of dry waste.

Based on the volume of waste generated, its composition, and how it is managed, it is estimated that 1.6 billion tonnes of carbon dioxide (CO₂) equivalent GHG emissions were generated from solid waste treatment and disposal in 2016, or 5% of global emissions. This is driven primarily by disposing of waste in open dumps and landfills without landfill gas collection systems. Food waste accounts for nearly 50% of emissions. Solid waste-related emissions are expected to increase to 2.38 billion tonnes of CO₂-equivalent per year by 2050 if no improvements are made in the sector.

6. Taipei recycling rate highest in the world with No Touch Ground policy

Taipei's recycling rate is one of the highest in the world. In 2020, the city's recycling rate reached over 55%. The No Touch Ground policy supports this by ensuring that recyclables are collected cleanly and efficiently. It reduces the risk of contamination that can make the materials unsuitable for recycling, such as food scraps or non-recyclable substances. Taipei's No Touch Ground policy, part of its broader waste management and recycling system, encourages residents to sort their waste and ensure recyclables are properly cleaned and segregated to avoid contamination. Under this system, recyclables are often collected by designated recycling trucks without residents having to handle or touch the waste after it's placed in separate bins. The use of mobile recycling trucks and dedicated drop-off points with clear signages have helped increase accessibility for residents. In addition, the No Touch Ground aspect helps ensure that recycling is streamlined, which is crucial in maintaining the purity of materials for reuse.

7. Methane Mitigation in Waste Management – ISWA

Methane is a major cause of global warming, with the waste sector contributing significantly. Biogas and biomethane offer a sustainable alternative to natural gas, but financing is a challenge. At a side event during COP29, experts took a closer look at this issue. The urgency of addressing methane emissions has never been clearer. Methane, a potent GHG, accounts for approximately 30% of global warming since the pre-industrial era, and the waste sector contributes significantly to its release. Biogas and biomethane offer a sustainable alternative to natural gas, with the potential to mitigate methane emissions while generating renewable energy. Yet, despite the promise of anaerobic digestion (AD) technology, financing such projects remains a major challenge. These issues took centre stage at the COP29 side event hosted by the World Biogas Association (WBA) and the International Solid Waste Association. The discussion highlighted the barriers, opportunities and policy interventions needed to unlock the potential of biogas and biomethane in tackling methane emissions globally.

The Case for Biogas & Biomethane: Biogas is produced through anaerobic digestion, a process where organic waste is broken down in the absence of oxygen, yielding biogas (mix of methane and carbon dioxide) and digestate (nutrient-rich byproduct). Upgraded biogas, or biomethane, can replace natural gas in heating, electricity generation and transport. Beyond energy generation, anaerobic digestion delivers additional environmental benefits, including reducing methane emissions from decomposing organic waste in landfills and offering a sustainable alternative to synthetic fertilisers through the use of digestate. Globally, organic waste accounts for over 50% of total waste in most regions, yet 2.7 billion people lack access to formal waste collection. Capturing and processing this waste through anaerobic digestion can have a transformative impact. According to the WBA, capturing just 50% of food waste could abate 20 million tonnes of methane annually.

8. E-Waste Health Effect: WHO

By 2030, global employment in the waste management sector (which employs 64 million people today) is projected to increase by some 70%, or another 45 million jobs. Since e-waste is the world's fastest growing waste stream, increasing three times faster than the world's population, many of these jobs, formal or informal, will be in e-waste processing.

E-waste typically includes discarded electronic devices such as computers, televisions, mobile phones, tablets and other video and voice recorders, as well as electrical appliances, both heavy and light. While large household electrical appliances, such as washing machines and refrigerators, used to be called “durable goods” as they were built to last, the reverse is now often the case. Both large appliances and small devices are often designed in ways that make repairs difficult and, instead, encourage frequent device replacement. Yet, it is in the smallest devices that the greatest levels of dangers may lurk, in the form of toxic chemicals such as mercury, polychlorinated biphenyls (PCBs), and lead.

Millions of young children and adolescents, as well as women of childbearing age, work in the growing e-waste dumps in Africa, Asia and Latin America, as well as in some developed economies of Europe and elsewhere, extracting precious metals such as gold from computer chips and copper from cables by burning the devices or using toxic chemical baths. In the process, they are exposed to dangerous chemicals such as mercury, lead, dioxins and flame retardants, and breathe in air polluted with toxic particles.

Reducing e-waste upstream through the promotion of circular economy measures that ensure more durable and repairable devices, is also urgent. Finally, children and women waste workers remain largely invisible. Better monitoring and tracking of the swelling numbers of waste workers in the informal labour force - women and children in particular - is critical to protect those most at risk of exposure, as this can lead to a vicious cycle of potentially lifelong, reproductive and developmental health impacts. 🌱

What Others Say...

Waste Management

by
Samniang Saenram

With fast-growing cities and the ballooning population, developing countries such as Malaysia face numerous challenges in sustainably managing wastes. The waste generated in Malaysia in 2005 was 19,000 tons per day at a recycling rate of 5%. This increased to 38,000 tons per day 13 years later in 2018, despite the increased recycling rate of 17.5%. This is alarming as the rate has exceeded the Japan International Cooperation Agency (JICA) study's proposed rate of 30,000 tons per day in 2020.

With limited space for landfills and the rising cost of disposal, there is increased pressure and an urgent need to tackle the waste management issue and to reduce the impact on the environment and general well-being of the population. In Malaysia, the highest emission was fugitive emissions from the oil and gas industries, which accounted for 41% of the CH₄ emissions, followed by emissions from industrial waste water treatment and discharge amounting to 28% and solid waste disposal sites at 18%. Over 99% of the emissions from industrial waste water treatment and discharge is from palm oil mill effluent.

Waste Management Strategies & Circular Economy

The Waste Framework Directive (WFD) aims to shift from a linear economy (take-make-dispose) to a circular economy (reduce-

reuse-recycle). This shift is essential for addressing environmental issues like resource depletion, waste accumulation, and pollution. A circular economy is based on keeping products, materials, and resources in use for as long as possible, extracting maximum value from them, and minimising waste. The circular economy model involves:

1. Designing for longevity: Creating products that last longer and can be repaired or upgraded.
2. Maintaining value: Extending the life of products through reuse, refurbishment, and recycling.
3. Eliminating waste: Designing processes that minimise waste generation, encouraging better material recovery, and using waste as a resource.

The WFD supports this transition by promoting the adoption of:

- a. Eco-design. Encouraging manufacturers to design products that are easier to reuse, recycle, and repair.
- b. Extended Producer Responsibility (EPR). Holding manufacturers accountable for the entire life-cycle of their products, including their end-of-life disposal.
- c. Public Awareness. Educating the public and businesses about the benefits

of waste prevention, recycling, and responsible consumption.

EU member states are required to:

Develop national waste management plans and waste prevention programmes.

- a. Set up infrastructure for separate collection and recycling of waste.
- b. Report progress on waste management and recycling targets.
- c. Ensure compliance with the waste hierarchy by integrating it into national legislation and policies.

End-of-Waste (EoW) Criteria

In waste management, EoW refers to the conditions under which certain waste materials, after undergoing recycling or treatment processes, no longer qualify as waste but instead become products or secondary raw materials that can be used. Once a material reaches EoW status, it is considered to have undergone sufficient recovery or recycling, meeting specific requirements that ensure it no longer poses a risk to the environment or human health.

EoW is defined as:

1. Any material is considered to have reached EoW status when it no longer needs to be managed under waste regulations because it is no longer considered waste. This means it can be placed on the market and be used in production without being subject to waste disposal rules.
2. EoW criteria are generally set for specific materials that have been treated or recycled and include such as metals, plastics, glass, or organic waste. These materials must meet specific quality standards before they can be considered non-waste.

The EoW criteria are established based on the following conditions:

- a. The material must be recovered or recycled: This is the core condition that distinguishes materials eligible for EoW from waste.
- b. The material must meet specific quality standards: It should meet standards for composition, safety, and environmental impact, ensuring that the material will not harm human health or the environment when used.
- c. The material must have a market demand or use: The material must have an established market or can be used in a production process, indicating that it is now functioning as a product or secondary raw material.
- d. The recycling or recovery process must be completed: The recycling or recovery process should be properly documented and demonstrate that the material is fit for its intended use.

The European Union has established specific EoW criteria for different types of materials, particularly for recycled materials:

- a. Metals: Metals that have been separated, treated, and refined may be considered EoW once they meet the required purity levels and quality standards.
- b. Glass: Recycled glass can be considered EoW once it has been processed to a quality where it can be used in manufacturing products, such as bottles or construction materials.
- c. Paper and cardboard: Recycled paper and cardboard that meet the required composition and quality standards can be considered EoW.
- d. Organic waste: After being composted or digested, organic waste like food scraps or agricultural waste may acquire EoW

status if it meets the quality standards for soil conditioners or fertilisers.

The benefits of EoW status are:

- a. **Promotes Recycling & Circular Economy:** By providing clarity on when a material can be considered non-waste, EoW criteria help incentivise recycling and promote the circular economy.
- b. **Market Confidence:** Once a material is classified as EoW, it can be used in manufacturing and other industries without the regulatory burden associated with waste. This increases confidence in the market, making the material more attractive to industries as a resource.
- c. **Environmental Protection:** EoW status ensures that only materials that meet strict environmental and health standards can be used, which protects both the environment and human health.

The Challenges & Considerations for EoW are:

- a. **Lack of Universal Criteria:** While the EU has established specific criteria for certain materials, other countries may not have clear EoW regulations, creating inconsistencies in global waste management practices.
- b. **Monitoring and Enforcement:** Ensuring that recycled materials continue to meet EoW criteria requires regular monitoring and enforcement to avoid situations where non-compliant materials are placed back into the market.

International Policies Related to Maritime Waste

1. **International Maritime Organisation (IMO) Regulations.**

The IMO, a specialised agency of the United Nations responsible for regulating shipping, has implemented several international

treaties to address waste management and pollution from ships. MARPOL (International Convention for the Prevention of Pollution from Ships) is the most important international treaty for the prevention of marine pollution, covering a broad range of shipborne pollutants. Specifically, Annex V of MARPOL addresses the discharge of garbage from ships into the sea and sets stringent rules regarding waste disposal. Annex V: Prohibits the disposal of plastics into the sea and regulates the disposal of other types of waste (such as food waste, paper, and cargo residues). It requires ships to carry waste management plans and set guidelines for waste collection and disposal at port facilities. Annex I: Addresses oil pollution from ships and regulates how oil wastes should be handled onboard and disposed of. Annex IV: Covers the discharge of sewage from ships and mandates the use of sewage treatment systems or offloading waste to port facilities.

2. **The Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal.**

This international treaty focuses on reducing the movement of hazardous waste between countries, particularly from developed to less-developed countries. It addresses the movement of hazardous waste which may end up in a maritime environment. It prohibits the export of hazardous waste from developed to developing countries and sets requirements for proper treatment and disposal of hazardous maritime waste.

3. **The London Convention and London Protocol.**

The London Convention (Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter) and the London Protocol aim to prevent marine pollution from dumping waste at sea. This includes the disposal of hazardous substances, such

as chemicals, and requires ships to comply with guidelines on waste disposal.

4. Regional Agreements and National Regulations.

Many countries and regions also have their own regulations concerning maritime waste. For instance, the Ballast Water Management Convention (BWMC), developed by the IMO, requires ships to treat ballast water to prevent the spread of invasive species, which can sometimes be carried along with waste. National regulations (such as the Clean Water Act in the United States) govern pollution from ships and vessels in their territorial waters, while international treaties like MARPOL provide a framework for enforcing waste management standards at the global level.

5. Global Partnership on Marine Litter.

This partnership aims to reduce marine litter and raise awareness about its impacts. It encourages actions across countries to minimise waste entering the marine environment and supports initiatives to clean up ocean waste.

6. The United Nations Sustainable Development Goals (SDGs).

SDG 14 (Life Below Water) focuses on conserving and sustainably using the oceans, seas, and marine resources. This includes reducing marine pollution from ships, land-based activities, and waste, ensuring healthy marine ecosystems, and addressing waste management as part of sustainable development.

Global, legally binding treaty on plastic pollution under United Nations Environment Assembly (UNEA)

At the UNEA-5 in March 2022, member states marked a milestone by adopting a resolution

that called for the development of a global, legally binding treaty on plastic pollution. UNEA sets the global environmental agenda, fostering international cooperation and ensuring that environmental challenges receive the highest political priority. The issue of plastic pollution (particularly its impact on marine ecosystems, biodiversity, and human health) has been a key topic in recent UNEA sessions. Plastic waste has become a pervasive global problem. With billions of tons of plastic produced and a significant portion ending up in the environment (especially in the oceans), the crisis demands coordinated international action that goes beyond voluntary measures and non-binding guidelines.

The UNEA-5 Resolution on a Plastic Pollution Treaty calls for a legally binding global instrument that would comprehensively address plastic pollution throughout its entire life cycle, from design and production to consumption and disposal. It emphasises the need for a treaty that does not only focus on end-of-life management (e.g., waste disposal and cleanup) but also incorporates measures to reduce the generation of plastic waste at the source.

Life-Cycle Approach addresses the Integrated Measures. This resolution recognises that tackling plastic pollution requires interventions at every stage. This includes promoting sustainable production and design, enhancing reuse and recycling, and ensuring proper waste management. It calls for decisions to be informed by the best available science, ensuring that policies and measures are both effective and proportionate to the risks posed by plastic pollution. Preventive and Precautionary Principles involve:

- a. **Prevention First:** Reflecting principles similar to those in the European Waste Hierarchy, the resolution stresses that prevention (i.e. reducing plastic production and consumption) is the most effective way to address the problem.
- b. **Polluter Pays:** It also encourages the

adoption of measures whereby producers take responsibility for the full life-cycle of their products, fostering extended producer responsibility (EPR) schemes.

The policy requires alignment with Existing Frameworks for Synergies with Other Instruments. The resolution calls for building on and complementing existing international agreements – such as the Basel Convention (which has been amended to include plastic waste), MARPOL (addressing marine pollution), and regional initiatives - thereby creating a more coherent and comprehensive legal framework. It aims to avoid duplication of efforts by ensuring that the new treaty will be harmonised with ongoing international efforts and that it supports the broader global goals of sustainable development and the circular economy.

The resolution mandates that the international community, under the auspices of UNEP and through subsequent meetings, begins formal negotiations to draft the treaty. It sets the stage for a timeline that aims to produce a draft treaty for consideration by member states. It also includes provisions for regular review of progress, ensuring that the implementation of the treaty can be monitored and that its measures can be adapted in response to emerging scientific findings and technological developments.

Innovative technologies on construction waste management

There are several innovative technologies that help manage and reduce construction waste by transforming it into reusable materials, enhancing recycling efficiency, and optimising waste handling processes. Here are some key technologies:

a. On-Site Material Sorting & Separation

- **Automated Sorting Systems:** Advanced optical sorters and sensor-based systems are used to

identify and separate different waste streams (e.g., wood, metal, plastics, and concrete) right at the demolition site.

- **Robotic Sorting:** Robotics equipped with AI and vision systems can sort and segregate waste materials, reducing human error and increasing recovery rates.

b. Mobile Recycling Equipment

- **Mobile Crushers and Screeners:** These are deployed on-site to crush concrete, bricks, and other demolition materials. Mobile crushers transform bulky waste into recycled aggregates, which can be used in new construction projects.
- **Mobile Asphalt Recycling Units:** Similar technologies are applied in road construction, where old asphalt is reclaimed and reused, reducing the need for new materials.

c. Concrete and Asphalt Recycling Technologies

- **Concrete Recycling Plants:** Dedicated recycling plants process concrete waste through crushing, washing, and sorting to produce high-quality recycled aggregates.
- **Asphalt Reclamation:** Techniques such as hot in-place recycling or cold recycling allow for the extraction of reusable asphalt material from old pavements.

d. Deconstruction and Dismantling Innovations

- **Selective Demolition Techniques:** Instead of traditional demolition, selective or deconstruction methods focus on carefully dismantling

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Sensors and smart bins monitor waste levels and composition in real-time, providing data that helps optimise waste collection and recycling logistics.

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structures to salvage materials for reuse.

- Robotics-Assisted Deconstruction: Automated machinery and robotics assist in the controlled dismantling of buildings, improving material recovery and reducing contamination of recyclable materials.
- e. Advanced Processing and Material Recovery
 - Magnetic and Eddy Current Separators: These technologies extract ferrous and non-ferrous metals from mixed demolition waste, allowing for efficient recovery of valuable metals.
 - Chemical and Thermal Recycling: Emerging processes can break down composite materials and certain plastics through chemical recycling or pyrolysis, turning them into new raw materials or fuels.
 - Building Information Modeling (BIM): While not a recycling technology per se, BIM is used to plan projects more efficiently by predicting waste generation, thus helping to optimise demolition, reuse, and recycling strategies.
- f. Digital and Smart Waste Management Systems
 - IoT-Enabled Waste Monitoring: Sensors and smart bins monitor waste levels and composition in real-time, providing data that helps optimise waste collection and recycling logistics.
 - AI-Driven Analytics: Data analytics platforms can predict waste streams, improve material recovery rates, and reduce overall waste generation through more informed decision-making during the design and demolition phases.
- g. Innovative Reuse Applications
 - Recycled Material Integration: Recycled aggregates are increasingly used in new concrete mixes, while reclaimed wood, metals, and glass can be integrated into new construction designs.
 - 3D Printing with Recycled Materials: Emerging 3D printing technologies are being tested using recycled materials to create new building components, reducing the reliance on virgin resources. ♻️

Ancient Engineering Marvel: Tulou Construction, Yongding China

by
Dato' Ir. Fong Tian Yong



Tulou (Mandarin for earth building) in China are structures found mainly in the mountainous areas of Fujian Province, particularly in the counties of Yongding, Nanjing, and Hua'an. Tulou can also be found in parts of Jiangxi and eastern Guangdong provinces, but these structures are more closely associated with western Fujian.

A tulou is a dwelling apartment with thick, fortified earth-rammed walls. It is usually 4 storeys high, with 60-100 rooms for members of the same extended family. It is commonly designed in a circular (sometimes square) layout with a single entrance to help protect its occupants against raids by bandits which were rampant during the Ming (1368) and Qing (1644) dynasties.

The Hakka people originally settled in the central plains of China but due to unrest during the Yuan (1271) and Ming dynasties, they migrated southwards. They were mainly farmers who relied on agriculture for a living. Many settled in the mountainous regions of eastern Guangdong and south-eastern Fujian but these areas, being far from the government administrative centres of both provinces, were prone to attack by bandits. So the tulou was created to shield off enemies' attacks.

There are over 23,000 tulou scattered across the Fujian Province; around 3,000 have been classified as large-scale or historically significant ones. UNESCO has recognised 46 Fujian tulou as World Heritage Sites due to their cultural and architectural importance.

Tulou was originally built by the Hakka people and it gave them a strong sense of family unity and community living. Typically, each tulou houses multiple families, with each extended household occupying one vertical column of rooms from the ground floor to the top. The tulou encourages communal living, shared resources, and cultural traditions, making them important centres of social organisation and identity for generations.

One of the largest tulou can be found in Yentai village. The Fooksinlou is 80m in diameter. The Chengqilou in Kaotou village is 71m in diameter and has four circular buildings and 400 rooms which can accommodate 80 families and a capacity of 600 occupants.

The Fujian tulou was designated as a UNESCO World Heritage Site in 2008 based on the following features:

- Unique communal living system.
- Traditional Hakka and Minnan cultural heritage.
- Ingenious defensive yet environmentally harmonious architecture.
- Reflection of clan-based social organisation in southern China.

These structures serve as multi-family communal dwellings that allow several generations to live together in a fortified yet comfortable setting. The ground floor is used as the kitchen and the first floor for storage while the second and third floors serve as living quarters.

The idea was to construct two lower levels without windows to prevent possible entry by intruders. Windows were built only on the third and fourth storeys to provide ventilation for the living quarters as well as for the shooting of arrows when under attack.

Inside the first outer ring of the round or square structure would be a second ringed structure but of a lower height. The ancestral hall would

be situated in the middle structure which also served as a communal space for ceremonies, gatherings, and other daily activities.

It was said that if a tulou was under attack, its occupants could survive for more than a month on their stored food supplies and using water from wells.

Unique Method of Construction

Tulou were built using an innovative technique of rammed earth walls, making them highly durable and providing natural insulation. The walls were typically 1.5m-2.5m thick, made of compacted earth mixed with bamboo, sand, glutinous rice, and wooden reinforcements.

The clay materials were carefully selected from padi fields and these helped to calcify the mixture after a period of curing to form a hard mass. Timber frames were used for upper floors. Considering the difficulty in sourcing materials and the tedious workmanship as manual labour was required, it could take a few years to construct a tulou.

The foundation comprised 2-3 thick layers of stone on top of the compacted earth ground, in 2-3 tiers for stability. A circular drain was created around the top tier foundation to prevent rainwater from damaging the wall. A well-planned internal water drainage system was built to prevent flooding. This construction method ensured that the tulou could withstand earthquakes, typhoons, and enemy attacks.

In most cases, the load-bearing outer wall consisted of two sections. The lower section was built from cut stone blocks or river cobbles held together with a mixture of lime, sand and clay to a height of about one or two metres, depending on the regional flood water levels. The compacted earth was stacked on top of the stone section. The earth wall was made of compacted earth mixed with sticky rice and reinforced with horizontal bamboo sticks.



Figure 1: Archive photograph showing the timber formwork used for ramping the earth-mixture to make the walls

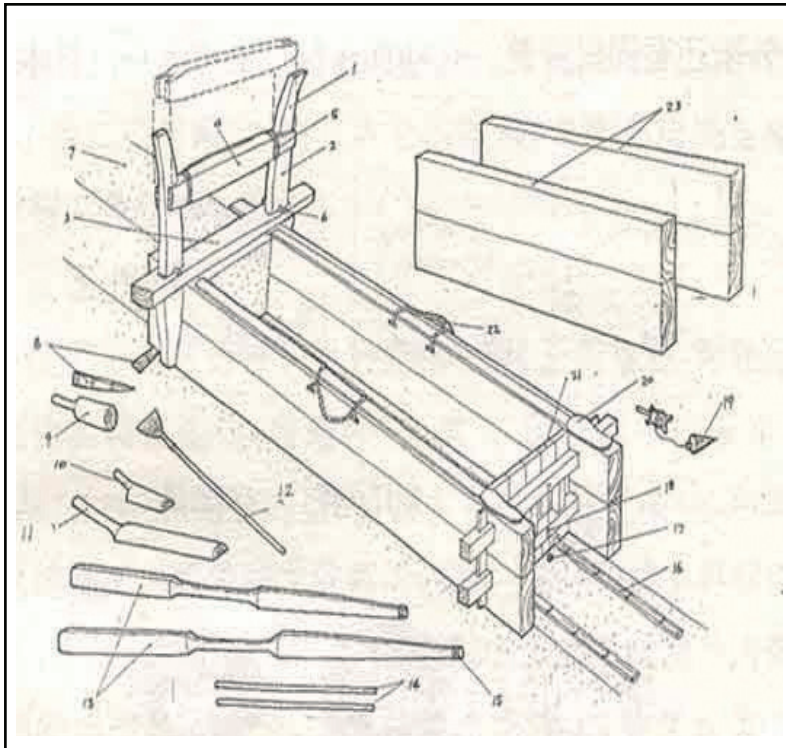


Figure 2: Formwork and tools used for ramping earth mixture to make the walls

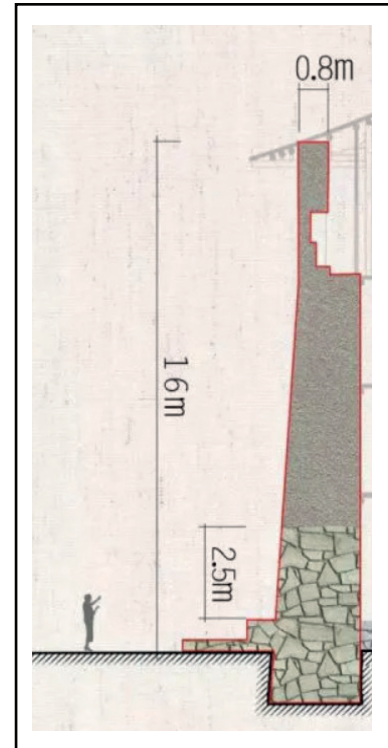


Figure 3: Thick stone footing for the load-bearing-strip footing foundation



Figure 4: Hekeng tulou cluster in Shuyang Town, Nanjing County, Fujian

The walls were built inclined toward the centre, so that the natural force of gravity pushed the wall together. The thickness of the tulou wall decreased with height. The two lower stories had solid walls without windows. Windows were made only from the third storey upwards as these served as living quarters and so required ventilation.

Constructing a tulou was not without significant challenges. The thick rammed-earth walls, often several metres thick, required immense amounts of labour and precise engineering. The builders had to carefully select and prepare the earth materials, ensuring a proper mix of clay, sand, and other components for optimal strength and durability. The construction involved intricate scaffolding, precise layering of the earth, and careful compaction to prevent cracks as well as to ensure stability. The use of locally sourced materials minimised transportation costs and environmental impact.

The massive circular structure housed multiple floors, each with its own designated function. There was a complex system of internal passageways, staircases, and ventilation shafts, facilitating efficient movement and air circulation within the structure. Decorative elements, including carved wooden beams and intricate brickwork, showcased the craftsmanship of the builders. The defensive features, such as strategically placed loopholes and a strong outer wall, were also noteworthy.

According to historical records at the Fujian tulou museum, Yongding was the cradle of communal dwelling. The region was home to numerous skilled craftsmen. When the craftsmen migrated, they brought with them sophisticated construction techniques and spread their architectural know-how.

Cluster Pattern of Tulou Village

Tulou exist in cluster forms within the village layout. There are different designs of tulou - round, square, semi-circular or just a simple, rectangular two-storey structure. A cluster of tulou created a fortified community where multiple buildings could support each other in times of need. Some clusters were arranged in a way that allowed overlapping fields of vision for enhanced surveillance.

Hakka culture put strong emphasis on strong family/clan ties. Living in a tulou cluster reinforced communal living and mutual support. Different tulou within a cluster might house different branches of a family and this allowed maintaining kinship with some degree of separation.

Fujian has mountainous terrain but limited flat, arable land. Building in clusters minimised land occupation while maximising living space. Shared resources (wells and ancestral halls) could be used more efficiently. Many tulou clusters



Figure 5: Tianluokeng tulou cluster, built in 1796, is a quintet cluster in Tian Luo Keng (or Snail Pit) Village in Nanjing County, Zhangzhou City



Figure 6: Chuxi Tulou cluster in Xiyang Town, Yongding

were built near terraced padi fields. Living close together made it easier for farmers to collaborate on labour-intensive tasks such as rice cultivation. Some clusters were arranged in patterns (circular or square formations) believed to bring harmony and good fortune according to Feng Shui principles. Ancestral halls in the central tulou often held ceremonial importance, with surrounding buildings reinforcing social hierarchy.

Zhengchenglou Tulou in Hongkeng Village

Zhengchenglou is a UNESCO World Heritage Site inscribed in 2008. Often referred to as the Prince of Tulou for its architectural sophistication, it is a major cultural landmark that attracts global attention for preserving Hakka heritage.



Figure 7: Front view of Zhengchenglou

Constructed over 5 years between 1912 and 1917 during the early Republic of China era, it is a masterpiece of Hakka tulou architecture. Its construction coincided with a period of cultural openness, allowing the incorporation of western architectural elements.

Designed and funded by the Lin Family leader, Lin Hongxian, the structure embodies the Bagua or Eight Trigrams (Taoism) philosophy; the building is divided into eight sections with fireproof walls in between. Each section corresponds to a trigram, promoting harmony and order.

The Zhengchenglou follows the typical circular design of many Yongding tulou, symbolising the concept of a unified and harmonious family. Its thick earthen walls offer superior defence against attacks. The interior layout is meticulously planned to maximise space and promote communal living. Multiple families live within the structure, sharing common spaces

while maintaining individual living quarters. There are courtyards, wells, and storage areas. The external building is 15m in height and 57m in diameter with a wall measuring 1.5m-thick at the base.

The layout consists of a two-ring circular design. The outer ring is a four-storey building. The ground floor is for the kitchens and dining while the first floor is for storage. The two upper floors are for dwelling and have small windows to prevent enemies entering. The circular shape means the structure can withstand strong wind blowing from any direction.

The inner ring has a two-storey central hall with 12 rooms on each floor for ancestral worship, meetings, and a theater stage. The design blends traditional Chinese elements (e.g., grey-tiled roofs, ancestral hall) with western influences such as Greek-style columns and arched doorways.

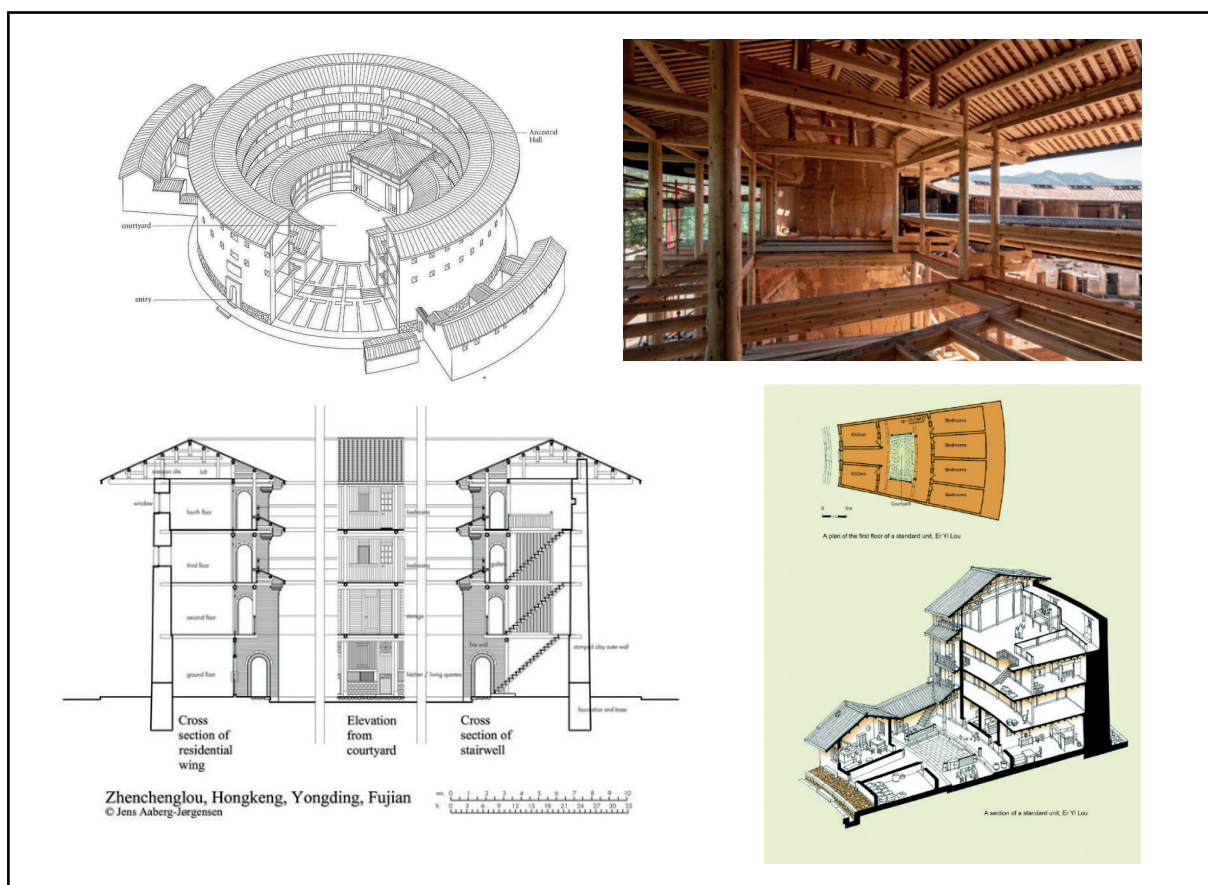


Figure 8: Details of the Zhengchenglou structure

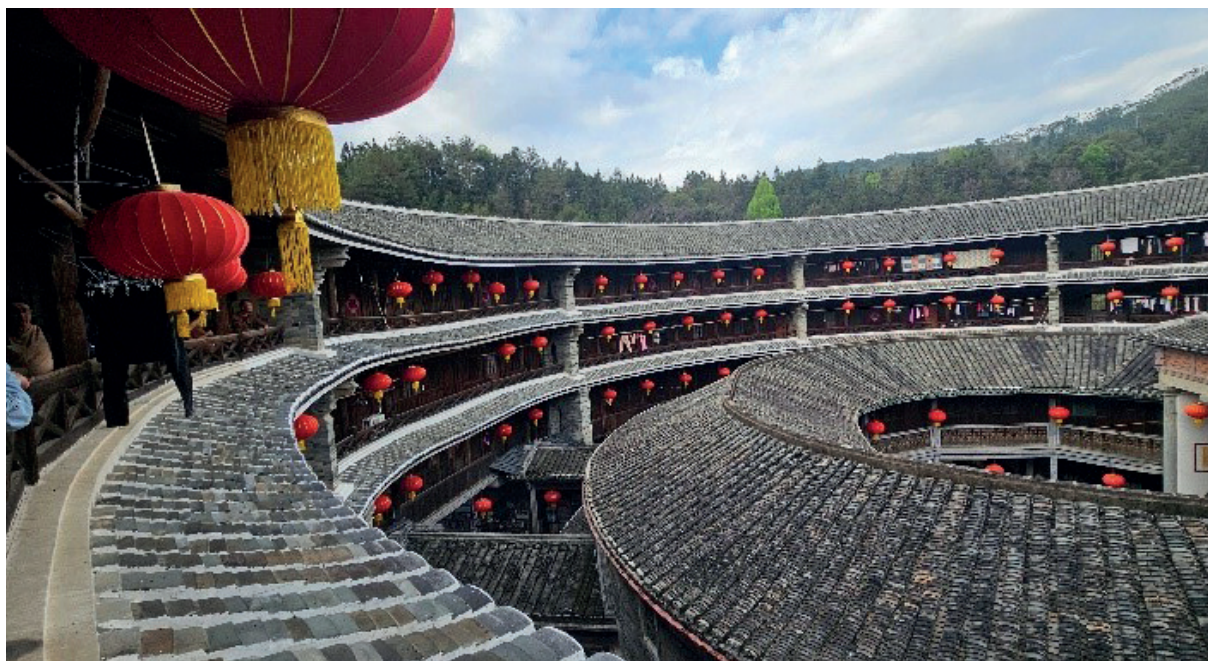


Figure 9: From the 4th level, one could view the inner circular three-storey building and the ancestral hall

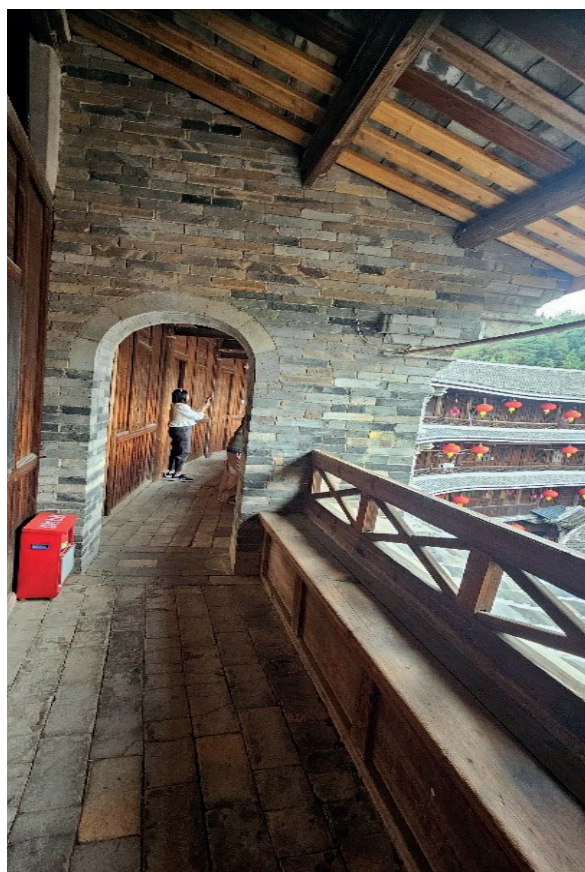


Figure 10: View of a firewall made of bricks. The timber floor is also tiled for sound insulation as well to protect the floor boards in case of fire



Figure 11: Left: The 120mm thick hardwood timber door with a 10mm thick steel plate. Right: The 200mm timber bolt that can be slid from one side of the wall to a hole on the opposite side to prevent forced entries.



Figure 12: The space between the outer and inner buildings

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UNESCO quote:

They are exceptional examples of a building of tradition and function, exemplifying a particular type of communal living and defensive organisation, and, in terms of their harmonious relationship with their environment, an outstanding example of human settlement.

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Zhengchenglou has a total of 208 rooms, enough to house 60 families. There are a few wells and enclosures for livestock such as pigs, chicken and ducks. The toilets are sited at the two external wings.

The entrance door is made of 120mm thick hardwood with the front face reinforced by a 10mm thick steel plate. There is a 200mm timber bolt installed at the side of the wall. Once the door is closed, the timber bolt can be slid sideways as an added barrier to prevent the door from being forced open from the outside.

Family privacy

The circular space between the outer and inner buildings has eight partition doors resembling the Bagua or Eight Trigram. If a family requires privacy, they just need to close the doors on both sides.



Figure 13: The toilets are sited at the two external wings.

Common toilet

There are no private toilets inside the tulou. Common toilets are sited outside the buildings at both wings of the tulou. Farmers use the sewerage to fertilise their crops.

Conclusion

The tulou of Yongding stands as a symbol of resilience, innovation, and cultural heritage. These structures not only provide security but also foster a strong sense of community among the Hakka people. Their architectural brilliance, combining sustainability with practicality, continues to inspire modern architectural designs that emphasise eco-friendly and durable construction techniques. Today, many tulou are UNESCO World Heritage sites, ensuring their preservation for future generations.

In an era where sustainable architecture is gaining prominence, tulou serves as a reminder that traditional building methods can offer valuable insights into modern-day construction challenges. The fusion of natural materials, structural efficiency, and communal living found within a tulou is a good example of a sustainable and harmonious approach to human habitation. 🏡

Engineering Marvel: Taroko Gorge Highway, Taiwan

by
Mary Foo Mee Sim



Picture 1: Narrow part of the Taroko Gorge Highway

Nestled in the eastern part of Taiwan, Taroko Gorge is one of the most breathtaking natural wonders in Asia. Known for its towering marble cliffs, cascading waterfalls, and winding river valleys, the gorge is a masterpiece of geological forces.

Now, its beauty is matched by the incredible engineering feats in constructing the roads and tunnels that make it accessible. The Taroko

Gorge Highway (part of the Central Cross-Island Highway), carved into its sheer cliffs, stands as a testament to human ingenuity and determination.

Taroko Gorge was formed over millions of years by the relentless erosive power of the Liwu River which cuts through solid marble and metamorphic rock. The result is a dramatic canyon with sheer vertical cliffs rising over 1,000m above the river and



Picture 2: Steep cliffs and deep ravines are a common sight along the highway

Picture 3: The narrow road is often barely wide enough for buses to pass through



narrow passageways, some of which are only a few metres wide. These create a sense of awe over natural wonders with stunning views, including the Eternal Spring Shrine, Swallow Grotto, and the Tunnel of Nine Turns. The gorge is part of Taroko National Park, established in 1986, and remains one of Taiwan's most visited natural attractions.

During the Japanese colonial period (1895-1945), the Japanese attempted to build roads for resource extraction but faced extreme difficulties. The most significant transformation came in the 1950s-1960s under the Kuomintang (KMT) government, which sought to connect eastern and western Taiwan.

Eventually, the Central Cross-Island Highway was constructed between 1956 and 1960, involving thousands of workers, including

former soldiers and labourers. But progress was slow and perilous due to the dangerous conditions of frequent landslides and rockfalls, manual labour and limited machinery. The highway finally opened in 1960, revolutionising travel between Taiwan's east and west coasts.

Constructing a road through Taroko Gorge was one of the most difficult engineering projects in Taiwanese history. Key challenges included unstable terrain and frequent landslides as the cliffs were prone to erosion and collapsing rocks. To prevent disasters, engineers had to reinforce slopes with nets, bolts, and retaining walls.

To carve tunnels through the solid rock, workers used dynamite and hand drills; some tunnels were barely wide enough for motor vehicles to pass through. There are more than 30 tunnels.



Picture 4: Scenic suspension bridge linking two cliffs of the deep ravine

Many are short and follow the natural curve of the gorge. The famous Tunnel of Nine Turns had winding curves inside sheer cliffs that required precise blasting to avoid destabilising the cliffs. In places where tunnelling was impossible or too dangerous, cantilevered roads were built - horizontal platforms anchored to the cliff face, hanging above the river. Retaining walls and rock shelters were used extensively to prevent rockfalls. Modern upgrades include steel nets and mesh draping over cliff faces

A series of bridges, including suspension bridges (such as Lushui-Heliu Bridge), were constructed over deep canyons and these had to withstand earthquakes and typhoons. Some sections that were built hanging over the river, required innovative support structures.

Workers laboured under harsh working conditions and suffered from extreme heat, monsoon rain, and falling rocks. Over 200 workers died and memorials were built along

the highway to commemorate their sacrifice and dedication.

The Taroko Gorge is more than just a scenic wonder. It is a symbol of Taiwanese resilience and engineering brilliance. The construction of the Central Cross-Island Highway is a monumental achievement of overcoming deadly terrain to connect remote regions. Today, visitors marvel at not only the natural beauty of the gorge, but also at the daring human effort that has made it accessible. The road was constructed without overwhelming the gorge and yet, still preserved much of its natural beauty.

Taroko Gorge remains a must-visit destination, where every twist in the road tells a story of geological forces and human determination. Whether hiking its trails, driving through its cliffs, or standing underneath its waterfalls, one cannot help but feel humbled by the power of nature and the perseverance of those who dared to conquer it. 🏞️

Kunming-Montreal Global Biodiversity Framework: Opportunities for the Engineering Fraternity

by
Lee Soo Leng

The Malaysian government announced at end of 2024 that it was finalising the National Clean Air Action Plan 2025-2040 (NCAAP). The comprehensive plan, aimed at improving the country's air quality, will serve as a guiding document for a unified and comprehensive effort to address air quality challenges. It augurs well for the global effort in environment sustainability under various platforms.

Kunming-Montreal Global Biodiversity Framework

The engineering fraternity has a role to play as well as opportunities in the various global action plans on environment sustainability. The recent landmark Kunming-Montreal Global Biodiversity Framework (GBF) is one that engineers should be interested in. Adopted in December 2022 at COP15 to the Convention on Biological Diversity (CBD), the GBF is a landmark global agreement aimed at halting and reversing biodiversity loss by 2030. This framework sets 23 targets under four overarching goals, emphasising conservation, sustainable use of biodiversity, and equitable benefit-sharing.

For the engineering community, the GBF presents unprecedented opportunities to contribute to biodiversity protection through innovative technologies, sustainable infrastructure, and nature-based solutions. Engineers play a crucial role in designing systems that minimise ecological harm while supporting economic and social development.

For a start, the engineering fraternity can play a big role in green infrastructure, renewable energy, pollution control, and smart conservation technologies. Environmentalists worldwide are concerned that biodiversity is declining at an alarming rate due to the destruction of habitat (deforestation and urbanisation), pollution (plastics, chemicals, industrial waste), climate change and overexploitation of species.

The 2019 IPBES Global Assessment Report warned that 1 million species face extinction, threatening ecosystems that support human life. The GBF was developed to replace the Aichi Biodiversity Targets (2011-2020), which saw limited success due to weak implementation and funding gaps. The GBF has 4 long-term goals (2050) and 23 action targets (2030) which include:

Targets 1-8: Reducing Threats to Biodiversity

- 30x30 Target: Protect 30% of land and oceans by 2030.
- Restore 30% of degraded ecosystems (forests, wetlands, marine areas).
- Reduce pollution (plastics, pesticides, nutrient runoff).
- Control invasive species and promote sustainable land use.

Targets 9-13: Sustainable Use of Biodiversity

- Ensure sustainable agriculture, fisheries, and forestry.
- Increase urban green spaces and ecological connectivity.

Targets 14-23: Implementation & Finance

- Mobilise US\$200 billion/year for biodiversity (including US\$20b from developed to developing nations).
- Reform harmful subsidies (fossil fuels, overfishing, deforestation).
- Integrate biodiversity into business and policy decisions.
- Strengthen indigenous and local community rights in conservation

Opportunities for Engineers

Engineers can drive technological and infrastructural innovations to support the implementation of GBF. Below are key areas where engineering expertise is crucial:

1. Targets 8, 12: Sustainable Infrastructure & Urban Planning.

- Green Building Design:
 - Biophilic architecture integrating natural elements.
 - Permeable pavements to reduce urban flooding.
 - Vertical gardens and green roofs to enhance urban biodiversity.
- Ecological Corridors:
 - Designing wildlife overpasses and underpasses to prevent habitat fragmentation.

- Smart city planning with biodiversity-friendly zoning.

2. Targets 6, 7, 18: Renewable Energy & Low-Impact Development.

- Solar/Wind Energy Innovations:
 - Floating solar panels on water bodies to reduce land-use conflicts.
 - Bird-friendly wind turbines with AI-based monitoring.
- Hydropower & Ecosystem Protection:
 - Fish-friendly turbines to prevent aquatic biodiversity loss.
 - Sediment management systems to maintain river health.

3. Target 4, 14, 16: Pollution Control & Waste Management

- Plastic Waste Solutions:
 - Biodegradable materials and circular economy models.
 - AI-powered waste sorting for better recycling.
- Water & Air Pollution Mitigation:
 - Constructed wetlands for wastewater treatment.
 - Nanofiltration systems to remove microplastics and chemicals.

4. Targets 1, 3, 5, 21: Conservation Technologies

- AI & Remote Sensing for Biodiversity Monitoring:
 - Drones and satellite imaging to track deforestation and species movements.
 - Acoustic sensors for monitoring endangered wildlife.
- Genetic Engineering for Conservation:
 - Biobanking and cryopreservation of endangered species.
 - Gene editing to combat invasive species (e.g., sterile insect techniques).

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5. Targets 6, 11: Climate Resilience & Nature-Based Solutions

- Coastal & Wetland Restoration:
 - Mangrove replanting using drone-seeding technology.
 - Living shorelines to prevent erosion and support marine life.
- Carbon Capture Systems:
 - Bioenergy with carbon capture and storage (BECCS).
 - Afforestation drones for large-scale tree planting.

6. Target 21, 22: Indigenous & Community-Led Engineering Solutions

- Collaborating with Indigenous knowledge systems for sustainable land management.
- Developing low-cost, locally adaptable conservation tools (e.g., rainwater harvesting in arid regions).

The Challenges

There are challenges facing the engineering fraternity in meeting the GBF goal as well as the way forward. The main barriers are:

- Funding constraints for green tech R&D.
- Policy gaps in enforcing biodiversity-friendly engineering standards.

- Conflicts between development and conservation (e.g., dams vs. river ecosystems).

The engineering fraternity can overcome such barriers by acting as an advocate for biodiversity-inclusive engineering codes (e.g., LEED certification for ecosystems). They should partner with ecologists and policymakers to come up with integrated solutions. Practising smarter conservation through AI and big data is the way forward to achieving the goals.

Conclusion

The Kunming-Montreal GBF provides a global blueprint for biodiversity conservation, and engineers are essential to its success. By integrating sustainable design, pollution control, smart monitoring, and nature-based solutions, the engineering community can help reverse biodiversity loss while supporting economic growth.

The future of biodiversity depends on cross-disciplinary collaboration, and engineers must take a leadership role in developing innovative, scalable, and equitable solutions to achieve the GBF 2030 vision. 🌱

The Slim River Deviation Project - PWD Fleet of Scrapers at Work, 1962

by
Cheo Hong Keyong

The Slim River Deviation Project in 1962 was part of the infrastructure development in Malaysia aimed at improving transportation routes. Specifically, it was a major road project designed to create a diversion for the Federal Route 1, which passes through Slim River in Perak, Malaysia. The deviation was necessary due to the frequent flooding and congestion along the original route, which caused delays and posed challenges to transportation.

The project was a key part of the government's efforts to enhance the nation's road network during the post-Independence period and to improve access between the southern and northern regions of Malaysia. It involved the

construction of a new road alignment that bypassed the Slim River town centre, reducing traffic bottlenecks and improving overall safety and travel time.

On this 13 mile deviation stretch, some self-propelled scrapers seen in the 1962 photos were used as fast earth moving plants wherein the earthworks for the whole project were nearing completion. The scrapers were maintained by PWD workshop. 🇲🇾

Reference

1. Annual Report of PWD 1962



KYODO PIPE STANDARD GALVANISED STEEL CONDUIT



BS 31 CLASS B (SCREWED) / MANUFACTURER'S STANDARD

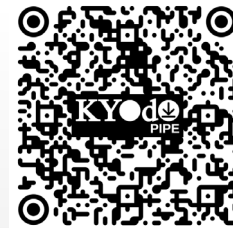
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	MINIMUM		MAXIMUM		MINIMUM		MAXIMUM						MINIMUM		MAXIMUM	
in	mm	in	mm	in	mm	in	mm	in	kg/m	kg/ft	lb/ft	PER INCH	mm	in	mm	in
¾	18.76	0.7387	19.05	0.7500	1.52	0.060	1.63	0.064	0.713	0.217	0.479	16	12.70	0.5000	14.29	0.5625
1	25.11	0.9887	25.40	1.0000	1.52	0.060	1.63	0.064	0.972	0.296	0.653	16	15.88	0.6259	17.46	0.6875
1¼	31.46	1.2387	31.75	1.2500	1.52	0.060	1.63	0.064	1.240	0.376	0.830	16	17.46	0.6875	19.05	0.7500
1½	37.80	1.4880	38.10	1.5000	1.73	0.068	1.83	0.072	1.680	0.511	1.130	14	19.05	0.7500	20.64	0.8125
2	50.50	1.9880	50.80	2.0000	1.93	0.076	2.03	0.080	2.510	0.765	1.690	14	22.23	0.8750	23.81	0.9375

MS 275 / BS 4568 CLASS 3 (SCREWED) / MANUFACTURER'S STANDARD

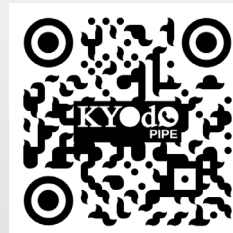
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	MINIMUM	MAXIMUM		MINIMUM	MAXIMUM		MINIMUM	MAXIMUM
mm	mm	mm	mm	kg/m	kg/m	mm	mm	mm
20	19.7	20.0	1.6 ± 0.15	0.643	0.783	1.5	13	15
25	24.6	25.0	1.6 ± 0.15	0.811	0.995	1.5	16	18
32	31.6	32.0	1.6 ± 0.15	1.069	1.301	1.5	18	20

MS IEC 61386-1 / MS 61386-21 CONDUIT SYSTEM FOR CABLE MANAGEMENT

NOMINAL SIZE	OUTSIDE DIAMETER		INSIDE DIAMETER	EXTERNAL THREAD LENGTHS
	MINIMUM	MAXIMUM	MINIMUM	MINIMUM
mm	mm	mm	mm	mm
20	19.7	20.0	1.6 ± 0.15	13
25	24.6	25.0	1.6 ± 0.15	16
32	31.6	32.0	1.6 ± 0.15	18



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