# VALORISATION OF SOLID WASTE

FACULTY OF GRADUATE STUDIES
UNIVERSITY OF JAFFNA

Erasmus+ CBHE Capacity Building in Higher Education
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# WORKSHOP PUBLICATION

## ON

# VALORIZATION OF SOLID WASTE

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## CONTACT US

Editor/THE NAIL
Department of Civil Engineering
University of Jaffna
Ariviyal Nagar
Kilinochchi - 44000
Sri Lanka

**Email** cees@eng.jfn.ac.lk
**Mob** +94765246560

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## From the Editors

### Solid waste management, a priority, not an option!

Solid waste continues to mound in cities and urban environments and expected to exacerbate in the near future predominantly due to population growth, unhealthy consumerism, population mobilization and more importantly and gravely due to waste mismanagement and humans turning insensitive to the environment. Sri Lanka, including the Northern province have already started to bear the brunt of the consequences of waste mismanagement, specifically owing to spread of disease vectors and unhealthy environmental conditions. While the population at large need to peremptorily change their attitude towards a sustainable development, professionals should strive to incessantly educate the public of potential harm and the advantages of a healthy environment.

The contribution of professionals in such effort is not only crucial but also largely inevitable. From developing and implementing policies and devising innovative strategies to effecting congruent technological advancements and disseminating techniques and motivate entrepreneurial ventures could be the contribution of professionals. In addition, emerging contaminants and identifying consequential impacts of waste mismanagement, such as the impact of micro- and nano-plastics on the health of humans and other species could also be considered the role of professionals. Technological advancements on the other hand, could be pertaining to efficient and modern processes relating to material recovery and valorization of waste materials. For example, the dawn of electric vehicles is often seen as the solution to global carbon emission reduction, where the production of battery is expected to rise many thousand-folds in the span of a decade. This would in turn need retrieval of lithium and cobalt which again would be required to be mined affecting the natural environment. The elemental recovery from used batteries could partially substantiate the demand, reducing the stress on the environment and the need for virgin materials. Recovery of material from waste needs to be considered as two parallel process; 1. improving the technology of material recovery to be more efficient and economically feasible compared to the acquisition process of virgin material and 2. redesigning products contemplating the material recovery processes at the end-of-life of that product.

It is therefore apparent that the contribution of the scientific community and professional in the policy making to collaboratively strive to devise strategies and processes to enhance the sustainability quotient of our very living, without compromising the potential of the environment for our future generations to make a decent living. We need to manage our waste, without leaving it for our future generations to scavenge on them to make a living.

.

- D N Subramaniam

**Writers**

**Dr D N Subramaniam**
Senior Lecturer
Department of Civil Engineering
University of Jaffna

**Mr S Mathushan**
Department of Chemistry
University of Jaffna

**Workshop Organizing**

**Dr D N Subramaniam**
Senior Lecturer
Department of Civil Engineering
University of Jaffna

**Prof P Iyngaran**
Department of Chemistry
University of Jaffna

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ZERO WASTE


ENVIRONMENTAL EMERGENCY
Plastic waste generation per person, 2010
Daily plastic waste generation per person, measured in kilograms per person per day. This measures the overall per capita plastic waste generation rate prior to waste management, recycling or incineration. It does not therefore directly indicate the risk of pollution to waterways or marine environments.
Our World in Data
SRI LANKA
No data
0 kg
0.1 kg
0.2 kg
0.3 kg
0.4 kg
Source: Jambeck et al. (2015)
OurWorldInData.org/plastic-pollution • CC BY
Plastic waste generation by industrial sector, 2015
Global plastic waste generation by industrial sector, measured in tonnes per year.
Packaging
Textiles
Other sectors
Consumer & Institutional Products
Transportation
Building and Construction
Electrical/Electronic
Industrial Machinery
141 million tonnes
42 million tonnes
38 million tonnes
37 million tonnes
17 million tonnes
13 million tonnes
13 million tonnes
1 million tonnes
0 tonnes
40 million tonnes
80 million tonnes
120 million tonnes
Source: Geyer et al. (2017)
OurWorldInData.org/plastic-pollution • CC BY
Source: https://dailynews.lk/2021/08/21/
Source: blogs.ntu.edu.sg

**PERSPECTIVE**

# The real reason your don't get a charger anymore

## Based on the youtube clip (Channel: Mrwhosetheboss)

Dr D N Subramaniam

*The article analyses the claims of the electronic companies in ditching the chargers for an environmental cause, and a perspective on what may have been included in an environmental audit.*

The youtube clip is based on analysing the claim made by the mobile companies in ditching the power adapter in the box of new items. Major companies such as Apple and Samsung have all included a power adapter with the mobile items they sell, which are more or less customized for their respective productions, for a very long time. However, the new trend is to ditch supplying the adapters with the item, as an effort by the company to reduce the environmental damage they impart through these consumer products. This clip analyses how acceptable the claim can be in terms of environmental damage.

Environmental damage can be caused due to the carbon emissions these institution can release into the atmosphere in producing these items, which is measured by the carbon footprint of the product of the institution. In addition, the environmental damage can also include other dimensions of damage, that shall not be limited to water footprint, energy wastages and more importantly the solid waste generated (more specifically, electronic waste in this case). While water footprint is rarely spoken of, the environmental damage it causes through over exploitation and pollution are in the exponential increase, rarifying water accessibility, and is predicted to potentially cause a world war. These institutions at the moment are concerned about the carbon footprint and volume of solid waste generated through the process of production and consumption of the products released from their businesses. In this clip, the youtuber specifically discusses the aspects of both carbon footprint and solid waste generation, fraught with the reduction in power adapters.

The institutions claim that the power adapters are already included in the packages the consumers bought previously, and that providing them a new set of material for the same usage can unnecessarily generate waste, which have not reached the end of life as yet. In addition, cutting down on the number of entities produced may also lead to curbing emission of carbon dioxide that can improve environmental credibility of the business entity. The companies would have to release statements on these so as to validate the claims, based on their products and sales.

Is, not giving a charge actually better for the environment?

Yes, if everything else remained the same, not giving a charger may reduce the package size, the amount of packaging materials used and also the number of chargers produced, sold and wasted. The youtuber compares the packaging of mobile phones and packaging of entities with and without a charges, and claims the reduction is significant, and hence could be seen as a great environmental initiative by the business institution.

But, not everything does stay the same! The clip talks about the knock-on effects.

### People Will Buy

Most people will end up buying a new charger in addition to the mobile phone they purchased. There could be many reasons for this. The first one is that, the reason for most people buying a new phone may not indicate their earlier phone reached end of life. Most of the time, a software update or a better performance make people crave for a new one, (where the demand itself created by these business institution, for example, a software update may not be installed in several previous editions, leading to scrapping before the phone is actually unusable). When a person opts to update a mobile phone, the earlier possession is mostly sent to a second hand store, which requires submission of charger and cables attached to it. This will leave the consumer without a charger, and that he/she will have to inevitably purchase a charger, should that not be included in the supply of the mobile phone. In addition, most of the chargers loose the capacity of charging as they age, and within a 2 – 3 year period, they may have been substantially compromised on the charging performance, again leading to purchasing of a new charger. Third reason could be that when these business institu-

## The real reason your don't get a charger anymore... >

tions produce a new consumer product, due to the update intentionally or otherwise, the cables may not support earlier chargers. Due to these several reasons, the consumer may be necessitated to purchase a new charger, on procuring a new consumer product, such as mobile phone. Analysis on how many new chargers were purchased by consumers in a given period with respect to number of new products sold will shed on the significance of the claim by the institutions on reducing solid waste generation due to chargers.

### Packaging Material

Another important aspect that may not be included in the analyses of the business entities is that, should a consumer opt to buy a new charger together with a new mobile phone, how much an additional packaging that may have to be wasted. Including a charger in the mobile phone packaging shall be substantially less compared to having another individual packaging, solely for a charger, that includes the box and padding material. This has been illustrated in the clip, with actual packaging when bought for a specific product. In addition to the packaging of the charger, it would require an outer box and more padding for the transport and delivery. It is very rare that the outer box packaging is optimized for the size of the product that encapsulates. The packaging material will have to be anyways thrown immediately after purchasing, as they could not be used for anything else. The packaging and padding materials are primarily made of plastic and synthetic material and cardboard. None of which are easily decomposable and that have served a short-term purpose (shelving time and delivery time of the product). In other words, the packaging material will linger in the environment for many hundreds of times of their usable time, in the environment, damaging irrecoverably. A complete analyses may have to be done to verify, how much of additional packaging material is generated due to this purchasing as an individual item.

### Other Omissions

The youtuber also discusses that with the loss of charger in the product supply, earphones are also dropped in the supply of mobile phones. Again, the institutions claim that the consumer could potentially use the earphones previously bought, yet, have these business entities really considered this, is the question the youtuber puts forth. For example, the iphones do not have an earphone jack in the later versions. The consumer will never be able to use the old earphones in this case, and will have to buy either a new earphone or an adapter to support the old earphone in the new mobile phone. This increases purchasing another product, that include packaging and padding both in the product box and also in the out box for delivery.

### Transportation of Supplies

The youtuber has pointed a very important aspect, which is very often neglected even by professionals, during assaying materials in process and wastages. Should a person buy the phone and realizes that he/she would have to purchase another charger, he/she would immediately order a new charger and get it delivered. Now this increases the carbon footprint of the original product, as the de-

## SCIENCE NEWS

### Scientists suggest keeping some poo for a rainy day

A research study in the United States of America found out that maintaining a bank of faeces of healthy people can yield medical benefit. When a person develop diseases later in life, their stored faeces could be used to restore the intestinal bacterial flora, through the supply from the bank. Scott Weiss, a medical researcher at the Harvard Medical School in Boston said, faeces transplants hold the potential to counteract autoimmune diseases such as asthma, multiple sclerosis, inflammatory intestinal disease, diabetes, obesity, cardiac diseases and ageing.

The concept of using gut microorganisms (faecal microorganisms) dates back to 4th century BC, in China, reinstating a long history, while the efficacy of the method in treating diseases

Source: sacbee.com

remains limited, as found by a study in 2020 by Queen Elizabeth Hospital in Adelaide. The gur microorganisms are found to be surprisingly resistant to changes as said in the article. The US scientists however, believe that using the faeces of the same person for the treatment of diseases may be more effective and yield higher acceptance contributing to a higher treatment efficiency. The concept of poo bank however is declared to be a costly venture, as it will need to be frozen using liquid nitrogen, indicating that the facility will remain accessible for only wealthy clients until the technology is advanced to make it more economically feasible to maintain.

**Original article: Science Illustrated, Issue 96 (2023): page 17**

## The real reason your don't get a charger anymore... >

livery would emit carbon dioxide. Had the consumer been given the charger with the product, this extra delivery travel wouldn't have transpired, significantly reducing the carbon footprint of the product. Should the consumer also buy another set of earphones that are compatible with the new mobile phone, that adds another process of delivery, consuming more energy and releasing more carbon dioxide.

The last point the youtuber speaks about is the concept of wireless charging. It is more often seen as modern, comfortable and eco-friendly, that ditches the wires and plastics fraught with it. However, what is needed to be analysed is the efficiency of charging. The clip reveals that the wireless charging comes with many layers in between, wastes energy in the process of transferring (mostly as heat), reduces the efficiency of the charging process to less than half compared to wired charging. Although it may sound and look as environmental friendly, yet, the amount of energy wasted (where bigger fraction of energy comes from unsustainable sources), wasting a little amount of plastic instead may be more eco-friendly.

There are couple of ideas that the youtuber puts forth in actually walking the talk of becoming environmental friendly. The silicon based battery does waste more energy compared to the GaN batteries (recently adopted by Xiomi). Perhaps, using GaN based batteries may help more efficient charge and hence reduce energy wastages and also claimed to have a better and longer life span compared to the conventional batteries. In addition, as the old conventional R referring to reduction in waste, these companies may adopt policies to reduce advertising small improvements and updates and urge people to purchase new products. For example, not many people would even realize the difference between an old and new version of a mobile phone, where the consumer barely uses it for anything other than just making calls. A phone that was released several years ago would be more than satisfactory for his/her purpose of usage, while a new product may not add or even enhance his life significantly. More consumers are lured into purchasing new products by extensive advertising and moral sabotaging, which run businesses to profitable equity. These institutions can offer software updates for older versions to extend their life span in the market, so that consumers may still feel relevant to the modernity and trends. The businesses may collaborate to merge systems to use accessories across different brands consequently reducing the consumption of accessories and related packaging material.

Environmental audit of a product or a process or even an institution has to be comprehensive. Auditing the environmental damage of a product may have to inevitably include processes of production, supplies, consumer usage and waste management. Analysing a particular fraction of the processes to state and environmental credential may take the product to be more damaging to the environment than it serves the intended purpose.

## SCIENCE NEWS

### A plastic-eating superworm might help the waste crisis

While managing plastic waste continues to pose a challenge and researchers are tirelessly working on devising strategies and technologies to handle them, perhaps it is time to get some help from the larvae of Zophobas darkling beetles. These larvae are usually used as a food source for pet reptiles, amphibians, fish and birds, the scientists attached to University of Queensland, Australia have found that they (larvae) can themselves consume a diet of only polystyrene for survival. Compared to the other types of plastics, polystyrene are relatively hard to break down, rather, it disintegrates into smaller and smaller fragments and continue to accumulate in the environment, specifically oceans. While the Australian government adopted strategies to phase out usage of polystyrene in takeaway foods, it continues to remain widely used

Source: www.scientificamerican.com

and account for approximately 1% of all landfill in the country. The percentage computed based on the weight, and that the density of polystyrene is low, the volume that it accounts for in the environment is more pronounced than many other types of municipal solid waste.

The Zophobas larva, also known as 'superworm', adopts only one goal in its life span, which is to gain as much weight as possible on its projectile to develop into a beetle. The worms are found by the scientists of the University of Queensland (Dr Chris Rinke, a member of the research team

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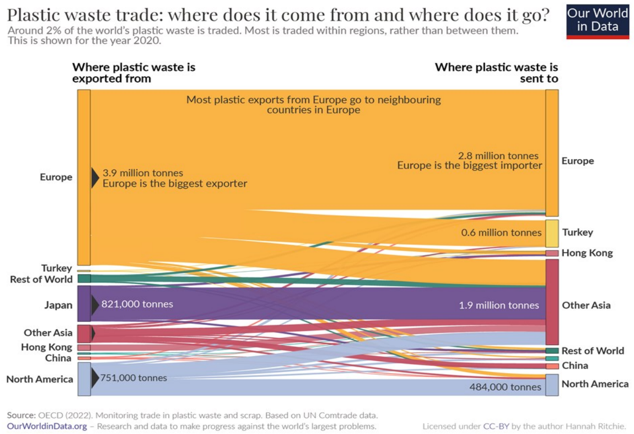
## MEETHOTTUMULLA — SCAVENGING

Sri Lanka produces approximately 700 tonnes of waste every day, of which 65% is produced in the western province alone. This translates to approximately 0.4 kg of waste generated per person (national average). Waste from the western province is scantily managed in the past, piling in dump yards of which Meethottumulla is one. Awareness of solid waste management in Sri Lanka rose to predominance when the nation learnt that communities scavenge dump yards to make a living, even in our own country, following major disaster at the site in 2017. It was appalling to learn how vulnerable these communities are, due to the unhealthy practices of another fraction of the same community. Discussions and debates were kindled to find a sustainable solution to manage our own solid waste, that even led to the inclusion of solid waste management in the curriculum of several streams of study. Yet, are we doing enough to find an ultimate and equitable solution to all fractions of the community?

Source: https://www.theguardian.com/global-development/2018/apr/19/scavenging-grime-sewage-gold-mumbai-streets-india

## WASTE OR RESOURCE?




## GOLD MINING — SCAVENGING

Gold is a precious metal, mainly due to the properties it possess and not because of rarity. However, the gold supply is manipulated so as to keep the demand in the market to make the businesses sustainable and profitable. Gold stores would have the material emerging as waste, which more often is recovered in the store itself. Yet, an insignificant amount (as seen by the store owner), mainly in dust form would end up in the wastewater stream and get deposited in the drains.

A community in India (Mumbai), recover gold dust particles that were deposited in the drain sediments, literally scavenging, and return them to the store for a very low price, just enough to make the ends meet. Their families live off the income solely received through this business venture.

## IS THIS MODEL SUSTAINABLE?

Having a stratified community has been the norm of Sri Lankan (South Asian) communities, that was once reeling in caste system. Although modern human civilizations speak of democracy and equal rights, and the United Nations developed goals (SDGs) to propel governing bodies to provide equality across country borders, the model of having a particular fraction of the community scavenge to make a living is not acceptable , if not sustainable. The waste of a person may be a resource to another, however dignity and sanity should prevail in the process that valorize the waste component that recirculates that into the market.

**ARTICLE**

# Plastic Waste – A global perspective

**Dr D N Subramaniam**

**Based on plastic as a persistent marine pollutant (Annu. Rev. Environ. Resour. 2017. 42:1-26) and data and plots from Our World in Data**

*The article illustrates the plastic production, waste generation and consequences in a global perspective.*

Plastics are synthetic organic polymers that can easily be molded into required shapes and products that can be used for a wide range of applications, invented approximately a century ago and is currently the most used man-made material which is almost omnipresent and causing detrimental effects on the total environment. The annual production of total plastic material was approximately 500 million tonnes per year (3 years back, 2019) while it accumulatively amounts to more than almost 10 billion tonnes as of 2019 (Figure 01 and Figure 02). The trends for both annual production rate and accumulation rate are on an exponential increase, being mindful that only a fraction would have been reported and these are extrapolated computations.

## Plastic production

Natural polymers such as cellulose and DNA were known for sometime, it was hard to decipher their structure and properties, until the invention of celluloid in 1879, produced by chemically modified cellulose. The first synthetic polymer Bakelite was invented in 1907 by Leo Baekeland who named it plastic from the Greek word, 'plastikos' which meant, 'moldable'. With the improved properties such as transparency or the ability to hold different colours, dramatic increase in production of plastics were observed between 1930 – 1950s. Specifically, during WW II, production of polyamide (nylon) was produced in extensive amounts for parachutes and then eventually introduced in clothing industry. The author of the article on Annual Reviews claims three phases in global plastic production, 1) 1910 – 1950: slow initial growth as new forms of plastics were invented, tested and marketed, 2) 1950 – 2000: rapid exponential growth as plastic use expanded across various applications and global zones and 3) 2000 – 2015: more linear growth in lockstep with economic growth. The author further reinstates an observation that, even though consumption and waste generation are to wealth and economic growth, he observed both decoupled beyond a deflection point in plastic production around 2015. This he calls the beginning of the 4th phase, which could saturate or start to decline, the prediction would not be possible as it depends on sever-

**Figure 01**

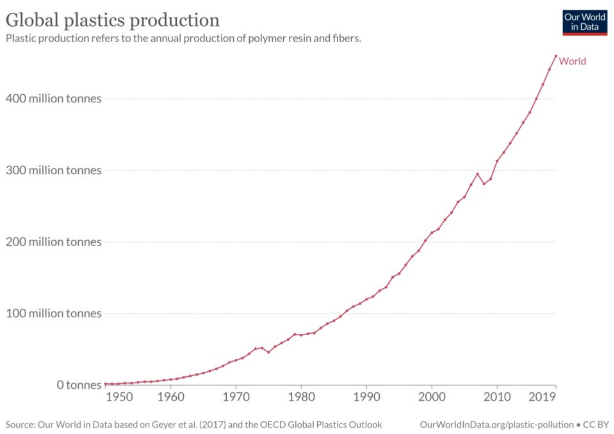
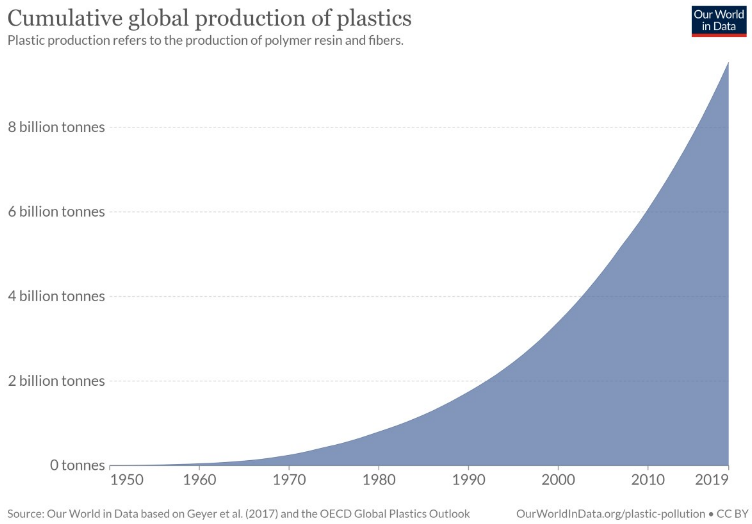



**Figure 02**

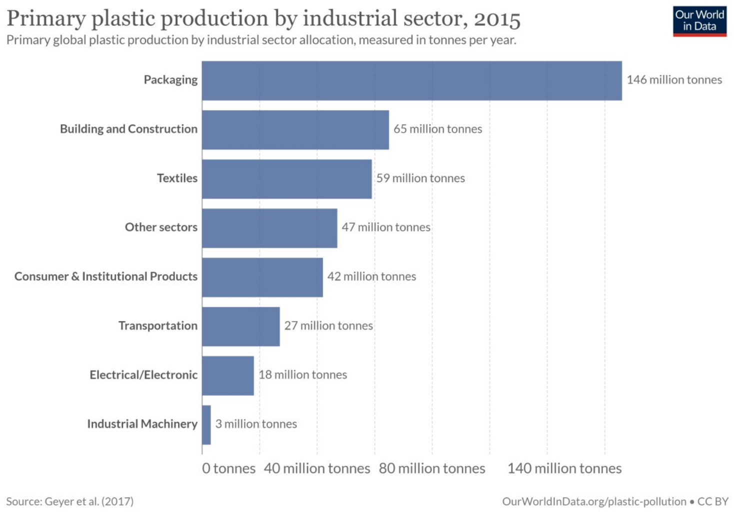


## Plastic Waste — A global perspective ... >

ral factors, including demand and policies.

It is widely used for various appli-

**Figure 03**

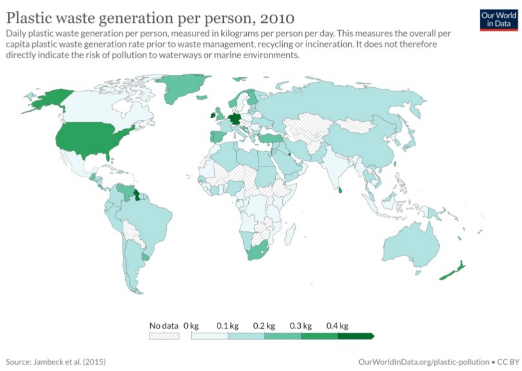



cations including medical supplies, packaging, bottles, clothing and construction materials. The largest sector for which plastics are produced is single-use packaging (36% of total production) while building and construction (approximately 16%) and textiles (15%), Figure 03. While this is the global trend according to the figure, the article records similar figure in the Europe, that has more developed countries in the region. Looking at the total production of plastics by country, China produces 28% of the total plastics, while Asia produces 49% followed by Europe and North America each producing approximately 19% each.

### Plastic waste generation

Production of plastics may not correlate to plastic waste generation (could be manufacturing plastics and exporting, while another country may not produce, but import and generate waste). In addition, waste generation depends on other factors, specifically the characteristics and consumer attitudes. It is important also look at the plastics waste generation based on per capita (although large density countries would produce more in total). From the Figure 04, it is apparent that both China and India (largest populations) have rather lower per capita plastics waste generation, where North America (US) and Europe have higher productions. Interestingly, Sri Lanka produces 0.3 – 0.4 kg per capita which is way higher in the region, specifically compared to India which produces approximately 0.1

**Figure 04**




## SCIENCE NEWS

### Plastic eating superworm

*... continued from page 07*

attached to School of Chemistry and Molecular Biosciences) that they can derive the energy required for their development from polystyrene, probably with the help of the microorganisms in their gut. As with other types of break downs, this break down by the superworm also results in broken down products, which can subsequently used by other microorganisms to create high-value compounds such as bioplastics. While the research team made the observation that the larvae can survive on a diet of only polystyrene, a sole diet as such may hamper minimum weight gain when directly used in larger farms and the team suggested that supplementing the substrate for the larvae with food waste in addition to Styrofoam may solve the problem.

Further studies on isolating the microorganisms in the guts of the superworm larvae and delving into identifying the enzymes that break down


Source: hight3ch.com

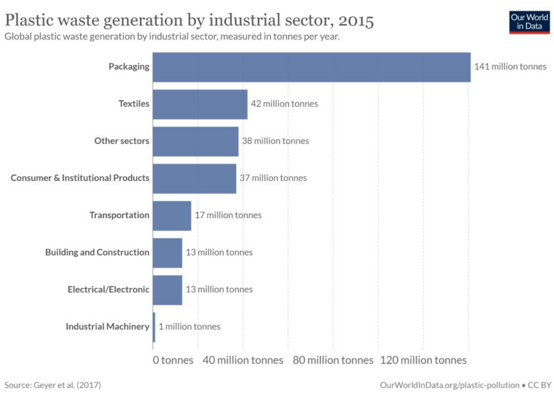
polystyrene may potentially give a more efficient solution for the management of the same. Although the solution proposed through this research may only be relevant to a particular type of plastic, and that enzyme engineering could enhance a large scale management facility for this type of plastic, it is considered to significantly contribute to the management of plastic waste at large. Articles on plastic eating worms have been published on many scientific journals and magazines, and are seen as a potential solution, while commercial scale implementation is awaited.

**Original article: Science Illustrated, Issue 96 (2023): page 16**

kg per person.

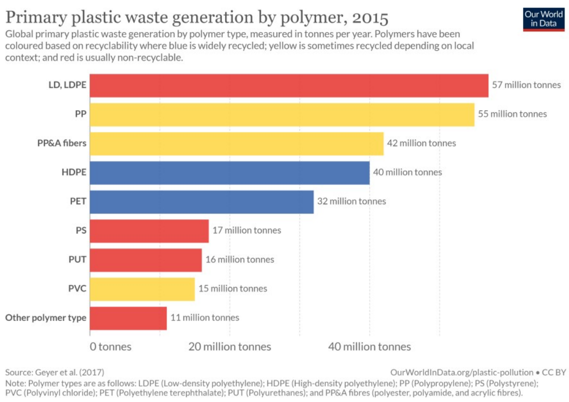
Looking closely into the sectors that generate plastic waste, the largest contributor remains the packaging industry, for which almost 40% of plastics are produced (Figure 05). While textiles, which recorded third highest sector that demands plastics, is observed to produce the second largest amount of plastic waste, construction and building industry, relatively generates less plastics while being the second largest consumer of plastics. This could mean, that the building sector that incorporated plastics in productions are relatively young, and upon the aging of building and at the disposal at the end of life of building (expected to start generating later this decade), this could amount to unprecedented levels of plastic waste generation. Looking further into the type of plastic generated, it could be observed from Figure 06 that low density plastics and polypropylene plastics have almost equal fraction of total plastic waste produced, while high density plastics and PET plastics are closely behind. The data shown in the plots correspond to 2015 statistics, where the current status may be very different (8 years since then) looking at the rapid changes in trends and waste generation.

**Figure 05**



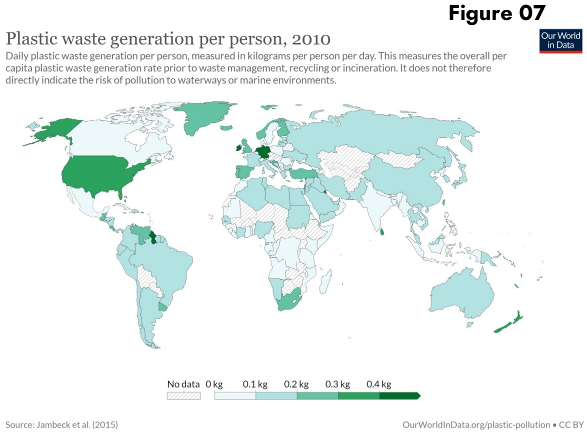

Looking at generation of plastic waste per capita, Figure 07 shows the distribution corresponding to

**Figure 06**




the GDP, which indicates the economic status of a country. Generally, higher economic countries (developed countries) would be expected to consume higher fraction of plastics globally, hence expecting to generate higher amount of plastic waste. This would be represented by a linear or non-linear increasing trend with GDP. Although lower GDP countries exhibit lower amount of plastic waste generation, higher GDP countries widely vary in plastic waste generation. For example, Sweden, which is a very high GDP country produces some of the lowest plastic waste generation while Kuwait which is similar in GDP to Sweden produces more than 20 folds of plastic waste generated in Sweden. In the same figure, countries that are larger in populations (indicated by the size of the circle) generate lower plastics waste, however, the total generation and hence contributing to environmental deterioration is immense. Perhaps, the better indication would be to analyse with the population density, as the land area that a country covers together with population could give rather a better indicator for waste generation analyses.

**Figure 07**




### Plastic waste management

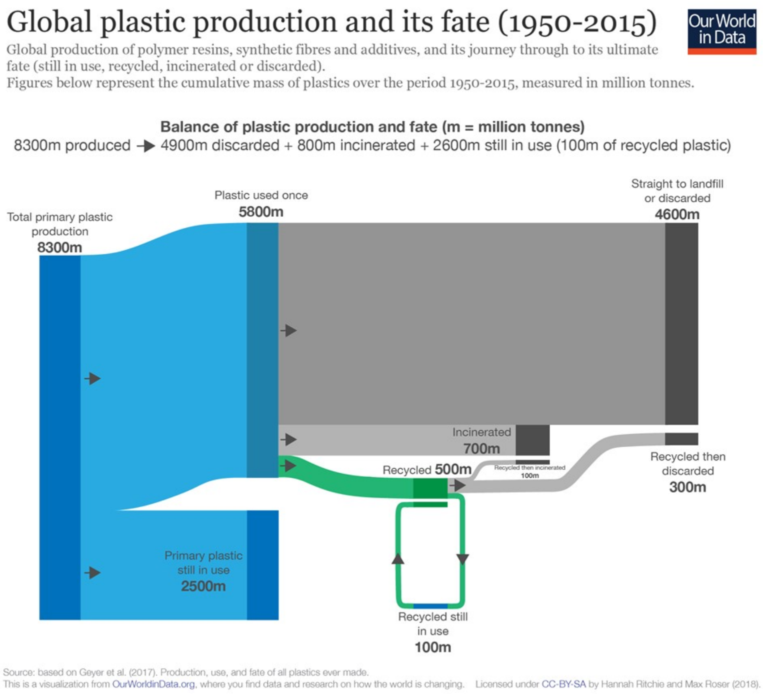
Management of solid waste is seen as a huge challenge on administrative bodies both in the developed and developing fractions of the world, each resorting mostly to get rid of the waste from the territory at present. Plastic waste, owing to its persistence in the environment, continues to accumulate and is

## Plastic Waste — A global perspective ...

seen as the biggest culprit and needs imperative attention. Although plastics are produced and consumed globally, consumption amount per capita would largely vary depending on habits, seasons, geological locations, economic stability and consumerism

Figure 8 shows the primary waste management practices through which plastic waste generated are currently managed across the globe (as of 2015). Out of 8300 million tonnes of plastic produced

**Figure 08**




as with all types of solid waste. Generally it is expected that a higher economic wealth would tend to increase consumption of material including plastics and hence tend to waste more, compared to those who have limited resources and finances. The environmental burden induced by plastic waste would have to be studied in the context of mismanaged waste rather than the total waste produced or materials consumed. The magnitude of mismanagement of waste and subsequent environmental pollution vary across regions depending on many factors. Before analysing the mismanaged waste, it is pertinent to view the waste management practices related to plastics.

in the period 1950 – 2015, approximately 30% are still being used while the rest 70% have already been generated as waste. Of the fraction generated as waste (5800 million tonnes) almost 80% are sent to landfill as shown in the diagram. The next largest fraction of 700 million tonnes (12%) ended up in the incinerator with or without energy produced for power and heat generation. Only 500 million tonnes (8%) ended recycling of which again 400 million tonnes have either been already discarded or ended up in the incinerator. Only 100 million tonnes 1.5% of the total waste generated are still successfully being recycled. An ideal waste management hierarchy would have Reduce,

## SCIENCE NEWS

### Human waste could help deal with global fertilizer shortage

A research study conducted on cabbage plants using recycled human urine and faeces have proven to be just as safe and effective as conventional fertilisers. Given, the amount of waste that could potentially be harvested and recycled, and that being sustainable in supply, the study provides assurance on finding a solution to the fertilizer shortage that contribute to rising food prices, yet, people should be convinced on its application according to the article. Conventional fertilisers based on nitrogen are energy intensive to make and their production accounts for 1.4% of global carbon dioxide emissions, according to the article.

The essential nutrients that are required for plant growth such as nitrogen and phosphorus are ample in human waste derived fertilizer, while there is a potential that they carry disease-causing pathogens and parasites. This requires prior treatment before applications, to consider it safe to be used in food production. However, the article reveals that in some low-income countries, the human waste is currently being used, without prior treatment, which is not an option in high-income countries.

Source: www.urbanorganicgardener.com

A study was conducted by Frabzuska Hafner at Agrsoscope in Zurich, Switzerland where cabbages grown in Germany using organic fertilisers derived from vinasse, a byproduct of ethanol production with fertilisers made from treated human urine and faeces. The yield from experiment

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## Plastic Waste — A global perspective …

Reuse, Recycle and Recover as the first option followed by elemental recovery, composting, incineration and finally landfilling. It is clear that both landfilling and incinerations are considered the least preferred categorized as mismanaged waste according to sustainable standards where litter strewn across land area would be considered the ultimate mismanagement of waste. This picture shows a dire situation of the plastic waste management, that clearly shows almost 90% of the waste produced are mostly mismanaged.

**Figure 09**

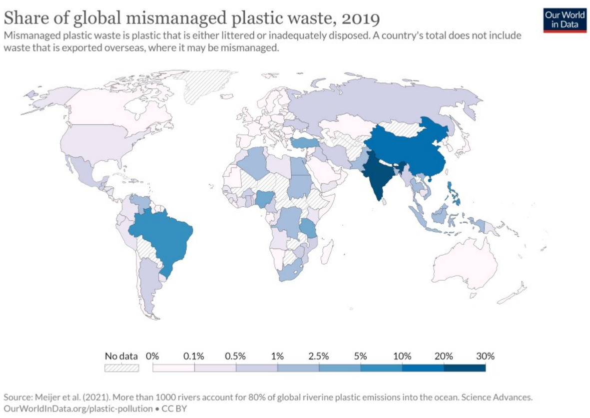
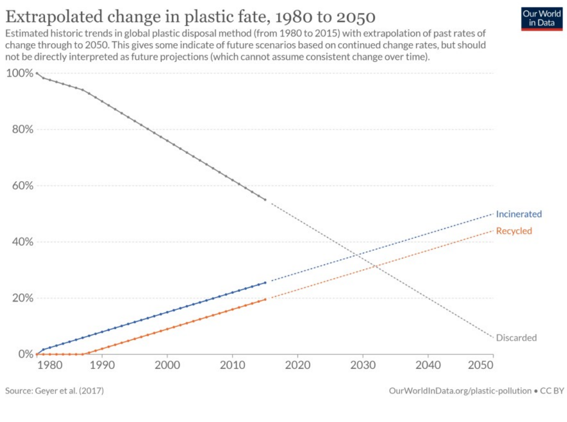



Figure 9 shows the mismanagement of plastic waste per capita, distributed country-wise. While many countries have not recorded plastic waste mismanagement, it is not clear if other countries have impeccably accounted for the mismanagement of plastic waste. However, of the mismanagement accounted for, India recorded highest mismanagement percentage as high as 30% followed by China and Brazil. Most of the developed countries including European and North American countries have recorded less than 1%. This figure actually considered waste not collected and littered across regions and not the landfilled and incinerated fractions. Sri Lanka has although reported as the highest plastic producing nation per capita, and not necessarily meaning what was produced was consumed in the country itself, the fraction of mismanaged plastic waste is approximately 1%.

Figure 10 shows the current trend in the amount of plastic waste managed through recycling and incineration till 2016, and upon extrapolating the prediction indicates that by the year 2050, both incineration and recycling would capture 90% of the plastic waste generated. This trend indicates that only less than 10% of the plastic waste would end up in the environment. However, this is with respect to yearly generation and management, where as the waste accumulated through the years would continue pose threat to the environment at large. In addition, the assumption is that the trend continues unwavering and that all waste generated are accounted for in the assays. However, it is obvious that most plastic waste is unaccounted for, more in the lower income countries, that also happen to be highly populated. Hence, the total amount of plastic waste ending up in the environment mismanaged would still be hard to be accounted for in the projections, and more stringent and well implemented collection and accounting systems are placed to avoid an environmental catastrophe. In addition, more sustainable ways of managing plastic waste must be devised to address a reduced impact on the environment.

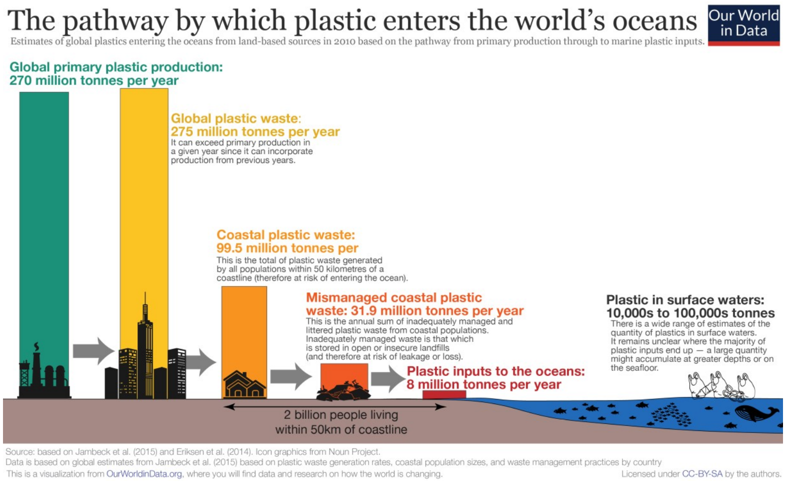
**Figure 10**




### Plastic in Oceans

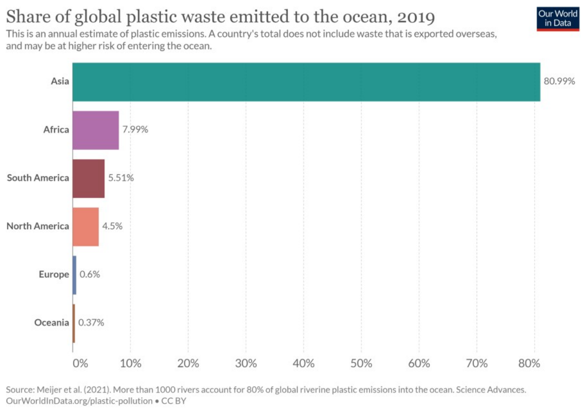
Plastic waste (mostly mismanaged) enter the oceans predominantly via rivers, wastewater outflows and transport by wind which contrives varied loading across regions depending mostly on coastal population density, plastic consumption and waste management practices. The article claims a total of 4.8 – 12.7 Mt has been released in 2010 which is equal to dumping a garbage truck every minute. The article further claims that between 2 – 90% of the total waste is mismanaged (not controlled at least in a managed landfill) of which 2 – 25% is plastic waste. For example, both US and India have a coastal population of 113 and 188 millions respectively and a US citizens generate 2.58 kg of solid waste (of which 13% is plastic) while an Indian citizen generate only 0.34 kg (of which 3% is plastic). However, while 2% of the waste stream is mismanaged in US coastal zone, 88% is mismanaged in India. Figure 11 shows the results of an analysis (prone to uncertainties and missing data) the typical values of plastic waste generated and discarded into the ocean as of 2014. It is evident from the figure that almost equal amount of plastic that is produced is wasted and waste generation could be expected to surpass production rate when production of yesteryears reach life span after cycles of reuse. Almost one third of the plastic generated is observed to be generated in the coastal zones

**Figure 11**




(probably owing to higher population densities in the coastal areas) wile a third of that is mismanaged. Although only a fraction, yet significant, ends up in the ocean, the data as mentioned above, has many uncertainties, specifically to that of data collection from records. An estimated 10000 to 100000 tonnes of plastic is believed to be in surface of the oceans as of now.

**Figure 12**




According to the article, the top contributors to plastic waste in ocean are China, Indonesia and Philippines, mainly due to large coastal populations, increased consumption of plastics and poor waste management practices. According to Figure 12, Asia contributes almost 90% of plastic waste in the ocean followed by Africa (8%), predominantly due to the population, and coastal developments. It is worthy to analyse the shoreline length and the population density dynamics to understand enormous contribution of Asia in plastic waste emission to the oceans. From Figure 13, it is apparent that Asia has the highest share of land area (approximately 30%), followed by Africa (20%) and North America (16%). However, North America has the highest length of coastline (35%) followed by Asia (24%) and Europe (15%). The length of North America and Europe is extraordinarily high due to the small islands and the geographical morphology of the coastline. Considering the length of coastline per square kilometer of land, Europe has the highest length (38 m) followed by North America (36 m) and Oceania (23 m). Observation on the population distribution, Asia has the highest (60%) followed by Africa (17%) and Europe (10%). It is clear

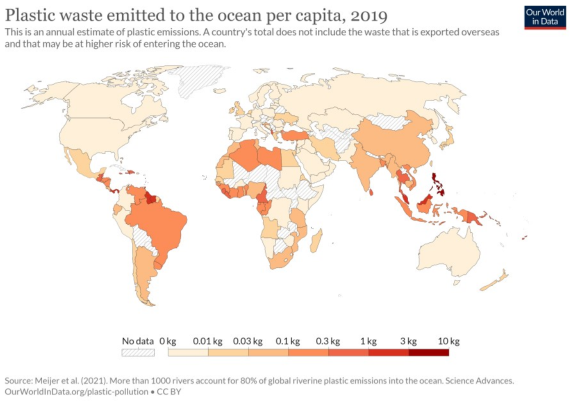
**Figure 13**

| Continent | Population | Area | Percentage in global land (%) | Shorline length (km) | Percentage in global shorline (%) | Shoreline length per $km^2$ of land ($m/km^2$) |
|---|---|---|---|---|---|---|
| Asia | 4,641,054,775 | 44,127,508.85 | 29.91 | 587,803.99 | 23.51 | 13.32 |
| Africa | 1,340,598,147 | 29,834,614.26 | 20.23 | 121,545.74 | 4.86 | 4.07 |
| North Amer | 592,072,212 | 24,243,886.75 | 16.44 | 875,242.66 | 34.99 | 36.1 |
| South Amer | 430,759,766 | 17,741,013.97 | 12.03 | 250,230.74 | 10.01 | 14.1 |
| Antarctica | 0 | 12,610,490.93 | 8.55 | 82,305.88 | 3.29 | 6.53 |
| Europe | 747,636,026 | 9,996,090.89 | 6.78 | 382,001.76 | 15.28 | 38.22 |
| Oceania | 43,111,704 | 8,939,857.13 | 6.06 | 201,622.08 | 8.06 | 22.55 |
| Total | 7,795,232,630 | 147,793,462.77 | 100 | 2,500,752.85 | 100 | 16.96 |

## Plastic Waste — A global perspective ... >

although Asia has the highest population distributed along the land area, the coastline is substantially smaller indicated by the shoreline per square kilometer of land compared to North America and Eu-

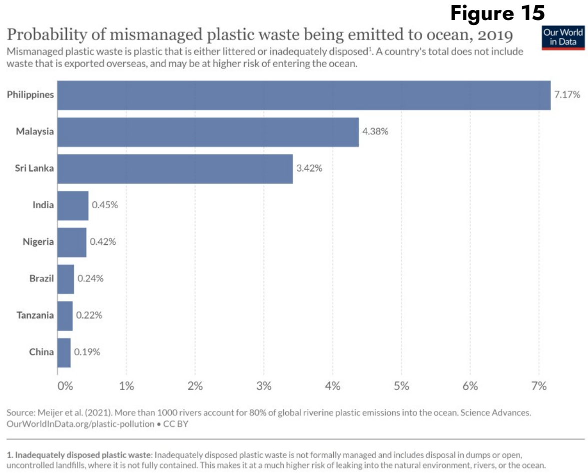
**Figure 14**




rope. Simultaneously, Africa has the second highest population with a very low coastline length per square kilometer. However, these two continents contribute the largest in ocean plastic debris, as shown in Figure 12. Although it could be argued that most of the Asian largest cities are in the coastal zone while the same could also be observed in Europe. On the contrary, most of the largest cities of Africa are in the land area away from coastal zones. The contribution of plastic waste ending up in the ocean is clearly indicative of mis-management rather than accidental discharges.

From Figure 14 it is evident the highest plastic waste is generated in Asian countries based on per capita figures, where Sri Lanka is one of the top polluter. Sri Lanka has a moderate population density (per area) compared to other South Asian nations such as India and Bangladesh. Being an Island, Sri Lanka may have larger coastline length per square kilometer of land area compared to the other South Asian nations mentioned above. In addition, Sri Lanka may also have a higher population distributed along the coastline as highly populated cities in the nations are comparatively located in the coastal zone. This may contribute to a higher plastic waste emission into the ocean compared to other nations in South Asia region, as shown in Figure 14. Considering the region around the Indian Ocean, Sri Lanka is comparable to other nations of similar character such as Indonesia, Thailand and Malaysia, all contributing similar per capita loading of plastic waste to the oceans. However, compared to Island nations in the Eu-

**Figure 15**




## SCIENCE NEWS

### Human waste fertilizer

*... continued from page 12*

that used nitrified urine fertilisers (NUFs) was comparable to those grown with vinasse while the cabbages grown with faecal compost had a significantly lower yield. The experiment that had both NUFs and faecal derived compost together also had a lower yield, while it is also believed to enhance soil carbon in the long term. The research of the study also tested for more than 300 chemicals in the faecal compost, including pharmaceuticals, flame retardants and insect repellents, which are commonly found in human waste. The study found that only 6.5% of these chemicals were detected, and again at lower concentrations. Further analyses on the contents (the chemicals), out of 11 pharmaceuticals found in the compost, only two were detected in the edible parts of the cabbage, which were painkiller ibuprofen and the anticonvulsant and mood-stabilising drug carbamazepine. The concentration of the latter was found to be extremely low in the study, that one would have to consume half a million cabbages to get a single dose of the medication.

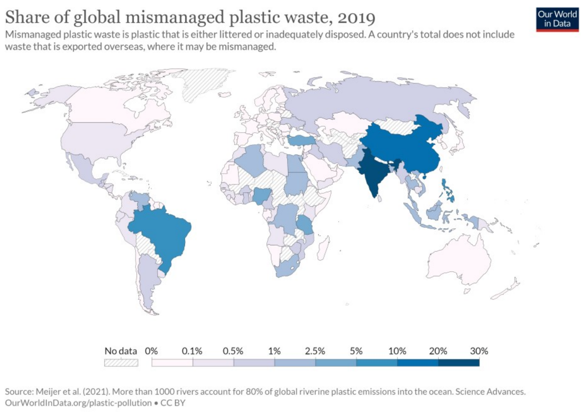
The researchers suggest from their study that if correctly prepared and quality controlled, up to 25% of conventional synthetic mineral fertilisers in Germany could be replaced by the recycled urine and faeces from human waste. While this being studied, the article claims that some countries have already started using NUFs, for example, an NUF called Aurin is already approved and applied for agricultural use in Austria, Switzerland and Liechtenstein. Another study by Benjamin Wilde at ETH Zurich discussed in the article reveals that it obtained similar results in yield and safety when the NUFs they used was tested in field trials in South Africa. The farmers would need to be convinced through long discussions.

**Original article: New Scientist, 28th January, 2023: page 17**

## Plastic Waste — A global perspective ... >

rope and North America, Sri Lankan per capita loading of plastic waste is extremely high, specifically owing to mismanagement of plastic waste in the costal zone. This could be read from Figure 15, where Sri Lanka ranks the third highest in probability of mismanaged plastic waste reaching the oceans in a global context where Philippines and Malaysia rank first and second, respectively. India and China (two highly populated countries in the Earth) could be observed to be much lower (many folds) compared to Sri Lanka, probably due to the lower coastline length per square kilometer metric. Looking at Figure 16, it is apparent that much larger fraction of plastic waste generated in India is mismanaged compared to that of Sri Lanka. In addition however, a lower fraction of plastic waste is mismanaged in China and Brazil (the other two populous countries) compared to that of India (where China has a similar population). Brazil on the other hand, having larger area and less population, still has a comparable fraction of plastic waste that is mismanaged, compared to China. This indicate that mismanagement of plastic waste is an attribute relating to policies and consumer habits.

**Figure 16**




Speaking of plastics in the ocean, and that it is a global phenomenon, why would Sri Lanka need to worry about our loading of plastic waste to the oceans? Sri Lanka is surrounded by Indian Ocean, and it is a dominant economic resource specifically for tourism and ocean resources. Polluting our own water could be detrimental to our very existence. For example, plastic waste in specific, has a high persistence in the environment that does not degrade or decompose, and continue to linger in the environment much longer than human life span. In addition, consumption of plastics by marine organisms may eventually be injected to humans upon consumption. The plastic debris discharged to the oceans may eventually return and pollute the coastal waters, affecting tourism and recreational activities that solely depend on the oceans surrounding us.

### Loading of plastic in the oceans

Having understood the dynamics and future projections of plastic production, plastic waste generation and mismanagement, and that having observed substantial damage caused by plastics getting loaded to the oceans it is imperative to understand the primary pathways plastics ending up in the oceans, before any management protocols and policies could be designed and implemented. Plastics are loaded onto the oceans

## SCIENCE NEWS

### The UK's plastic problem

The articles starts discussing with an event observed in Turkish province of Adana, where plastics have been accumulated along roadsides and riverside and some which burning, while Greenpeace UK in March of 2021 found that several plastic items such as carrier bags, yogurt pots and milk bottles found involved in that incident bore UK labels, that ended up in illegal dump sites. This raises concern of how the solid waste is transported across boundaries causing mismanagement, while the countries where it was transported out from portrayed as less in mismanaging waste. This had led to the Turkish government to impose a ban on importation of key types of plastic waste that was imposed almost immediately. After China, who used to be the largest importer of plastic waste closed its doors in 2018, ban of importation in Turkey inched closer on making UK and other high-income countries manage their own waste rather than export it to other nations. Nina Fasciaux from UK's Greenpeace questioned if UK would continue on the parcel passing mechanism to dispose of their waste, while the article claims that the Netherlands and Malaysia could be seen as viable option for UK to transport plastic waste once Turkish borders are closed.


Source: www.bbc.com

Greenpeace UK is determined to pressure the UK government to ban plastic waste exportation by 2025 (on the contrary to other countries imposing importation ban). The article suggest two ways to solve for the rich countries to manage their own waste inland. The first option relates to the very first R in the waste management

*Continued on page 18 ...*

primarily in three ways; 1. Mismanaged waste in the coastal zone getting washed off the shores into the oceans due to wave action (particularly tidal waves and rogue waves that reach higher up the coastal shores), 2. Waste discharges in the rivers inland, that get transported with the river flow and end up in the oceans and 3. Intentional dumping of waste in the oceans by nations (which used to happen until international waters were regulated).

**Figure 17**

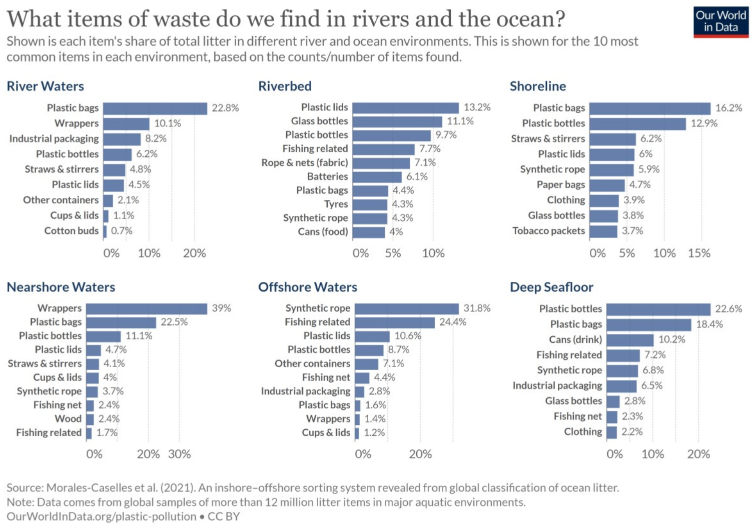



Figure 17 shows the top ten items found in different zones of water resources. It could be observed that the primary culprit of plastic waste in water resources are the plastic bags (or wrappers) followed by plastic bottles and containers. Interestingly, industrial packaging material is third in river waters indicating unregulated discharges from industrial zones into the adjoining rivers. Absence of Industrial packaging in the shoreline or coastal zone and presence of the same in offshore waters and deep seafloor indicate the impact of river discharges on distributing the plastic waste. Another important aspect is that the batteries in riverbeds, and that it was not observed in other water resources. This also further reinstates the state of waste discharges into the river, and batteries being heavy, they sink and remain at the river bed rather than being transported to the ocean waters. Otherwise, most of the items observed in the waters are daily consumer items such as bags, stirrers and straws indicating the result of consumer habits in polluting the waters.

**Figure 18**

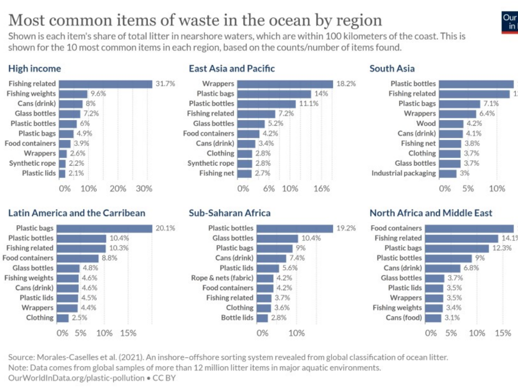
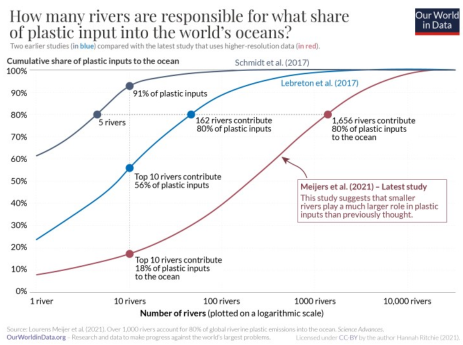



Figure 18 shows the variation in distribution of different types of plastic debris in the ocean zones. Consumer waste such as plastic bags, wrappers and plastic bottles are predominant in the oceans adjoining low- or middle-income nations as shown in the figure (all zones other than High income zone), where as the same was observed to be a much lower contributor in the high income zone. High income zone however has a significantly high loading of fishing related plastics (as percentage) compared to the other zones which was also observed to be significant in South Asia and North Africa and Middle East. These comparisons are however, analysed as the percentage of the total loading in the particular zone, where the total mass or number of loading in the zones may vary extensively as seen earlier. The percentages however, indicate that the economic prosperity does play a role in management of general consumer waste where the discharge industry related waste remain largely unregulated (specifically, fishing industry related).

**Figure 19**




Having learnt that the river transport significant amount of

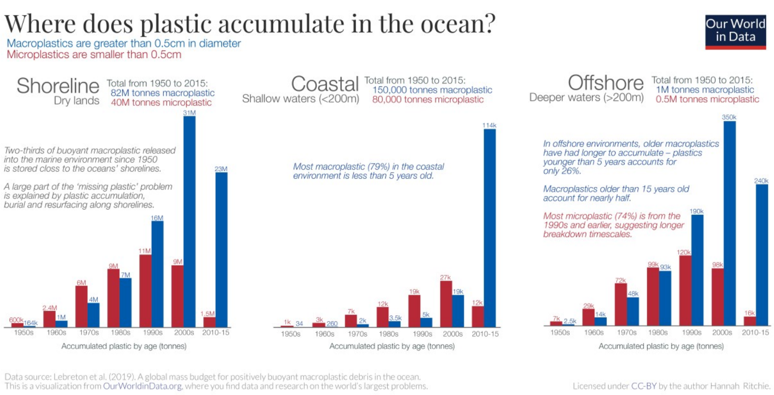
## Plastic Waste — A global perspective …

plastic waste to the oceans, Figure 19 further illustrates the potential of rivers in contributing to ocean plastic waste. Three different studies have been analysed in this plot where the first study (Schmidt et al. 2017) has analyse the input of lower number of rivers (approximately 100) where 5 major rivers have been observed to contribute to 80% of the ocean plastic waste. On the other hand, the second study (Lebreton et al. 2017) did a similar analysis with approximately 1000 rivers and observed around 162 rivers contributed to 80% of the total loading. In contrast, the third study (Meijers et al. 2021) did the analysis with approximately 10000 rivers and found 1656 rivers contributed 80% of the total plastic waste to the ocean. Each of these studies had different total mass/volume of plastic loading. In the third study, only 18% of contribution of plastic loading to oceans could be attributed to top 10 rivers in comparison to 80% contribution from five rivers in the first study. According to the third study however, more than 80% of the plastic waste loading is attributed to smaller rivers. It is therefore apparent that consideration given to small rivers in management of plastic waste is crucial in total environmental restoration rather than the major rivers alone.

### Accumulation of plastic in oceans

While plastic waste is transported to the oceans, it is essential to learn where all that plastic would accumulate, should any efforts to restore be effectively implemented. Figure 20 shows the general distribution of plastic waste in three coastal zones varying with time (in years) from 1950. A large amount of plastic waste rests on the shoreline (approximately 122M tonnes, as of 2015) of which a highly significant amount (40M tonnes) is micro plastics (smaller than 0.5 cm in diameter). An interesting trend to note is that the accumulation peaked in the period 2000s and then significantly reduced in 2015. The reduction is more pronounced in microplastics than that in macroplastics. Simultaneously, around 1.5M tonnes of plastic waste has accumulated offshore (more than 200 m away from the shoreline) of which approximately 1/3 is microplastics. A similar trend in dynamics of accumulation as observed in shoreline accumulation could also be observed in offshore accumulation. While total accumulation of plastic waste in the coastal zone (within 200 m from the shoreline) was observed to be much lower com-

**Figure 20**




## SCIENCE NEWS

### UK's plastic problem

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hierarchy, Reduce production (in this case to reduce production of plastic in UK) that can lead to less consumption in the country itself. WRAP, a waste charity in UK computed that only 61% of the waste generated in UK in 2019 (2.3 million tonnes) was recycled, while half that through exportation. The UK had a capacity to recycle 1.3 million tonnes of plastic a year. The second way suggested in the article is to boost this recycling capacity in the country itself. The article cites anther study where it was concluded that the best way to manage plastic waste is to curb the demand rather than boosting recycling capacities, that in turn depends on many other logistical challenges. This means, 'ultimately, the problem of plastics is not so much one of waste, but one of production'. In other words, measures need to be taken to question the need for plastics in each application and hence reducing their manufacturing in the first place, says Nick Voulvoulis at Imperial College London.

A suggestion for a quick fix for the UK, was to ditch the usage of plastic packaging on fresh fruit and vegetables, claims the article. However, the consumer preference on packaged good compared to loose package still remains at large, further induced by the Covid 19 spread. The article points out an important aspect in assessing the plastic waste, which is conventionally assayed by weight, where the plastic waste if a problem due to its volume rather than weight. Furthermore, WRAP conducted a study and found out that people who consume plastic-wrapped produce unintentionally buy more that they consume compared to a scenario where they could have bought loose produce, where they would have bought only the amount of produce they would have consumed. This in turn, in addition to causing plastic

***Continued on page 22 ...***

pared to offshore, the trend shows exponentially higher loading occurring in 2010-2015 in contrast to coastal and offshore zones. Coastal zone is where most of the wave action occur and that the material would tend not to accumulate and any occurrence would be transient, which in longer period it would either be transported and sedimented in the coastal zone or transported inward to the offshore zone. The amount of plastic shown in this plot merely refers to transient plastic waste, that has been discharged from rivers and coastal sediment transport.

Plastics particles are widely categorized by the size of particles as microplastics (particles that are less than 1 mm in diameter) and macroplastics (particles that are larger than 200 mm in diameter), in plots from Our World in Data, whereas actual categorization differs (which will be discussed later). Considering the categorical analysis accordingly, Figure 21 shows the variation of the distribution of particles in different oceans. While smaller particles may be very high in number, the total weight may be significantly less (e.g. 1 mm and 10 mm particles of same density will have a weight ratio of 1:1000 approximately; in other words, 1000 number of 1 mm particles would be equal in weight to that of one 10 mm diameter particle, which is only 10 times larger in particle size). While the number of microplastics (0.33 – 1 mm) are approximately a third of total number of plastic particles, the figure shows the weight fraction of the same is less than 5% of the total weight of plastics. Simultaneously, macroplastics (larger than 200 mm) constitute more than 60% of the total weight of plastics in oceans, they are less than 1% of the total number of plastic particles. Analysis will need to take both number and weight distribution of particles into consideration as the smaller particles will be widely distributed causing environmental damage while macro particles will continue to damage aquatic ecosystems. In addition, macroparticle when degrade naturally, will result in formation of microparticles, increasing the presence of microplastics in oceans.

Figures 22 and 23 show the future projections of presence of macroplastics and microplastics, respectively. The projects have three scenarios, where the first scenario is to expect the current trend of emissions (continuing to increase in rate of emissions), the second

**Figure 22**

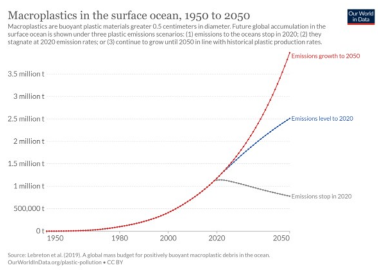
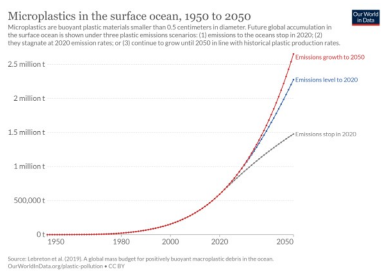
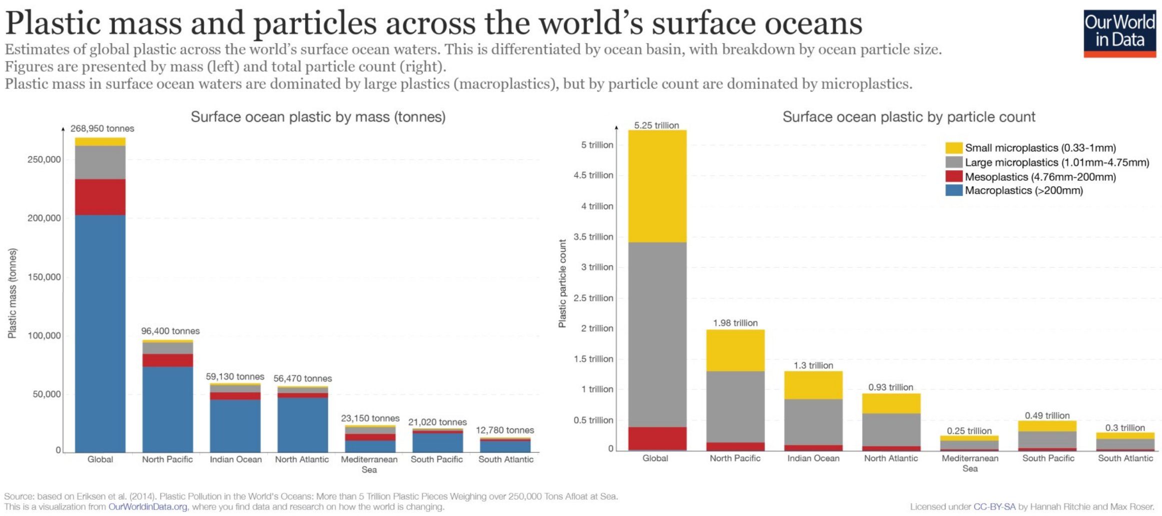



**Figure 23**

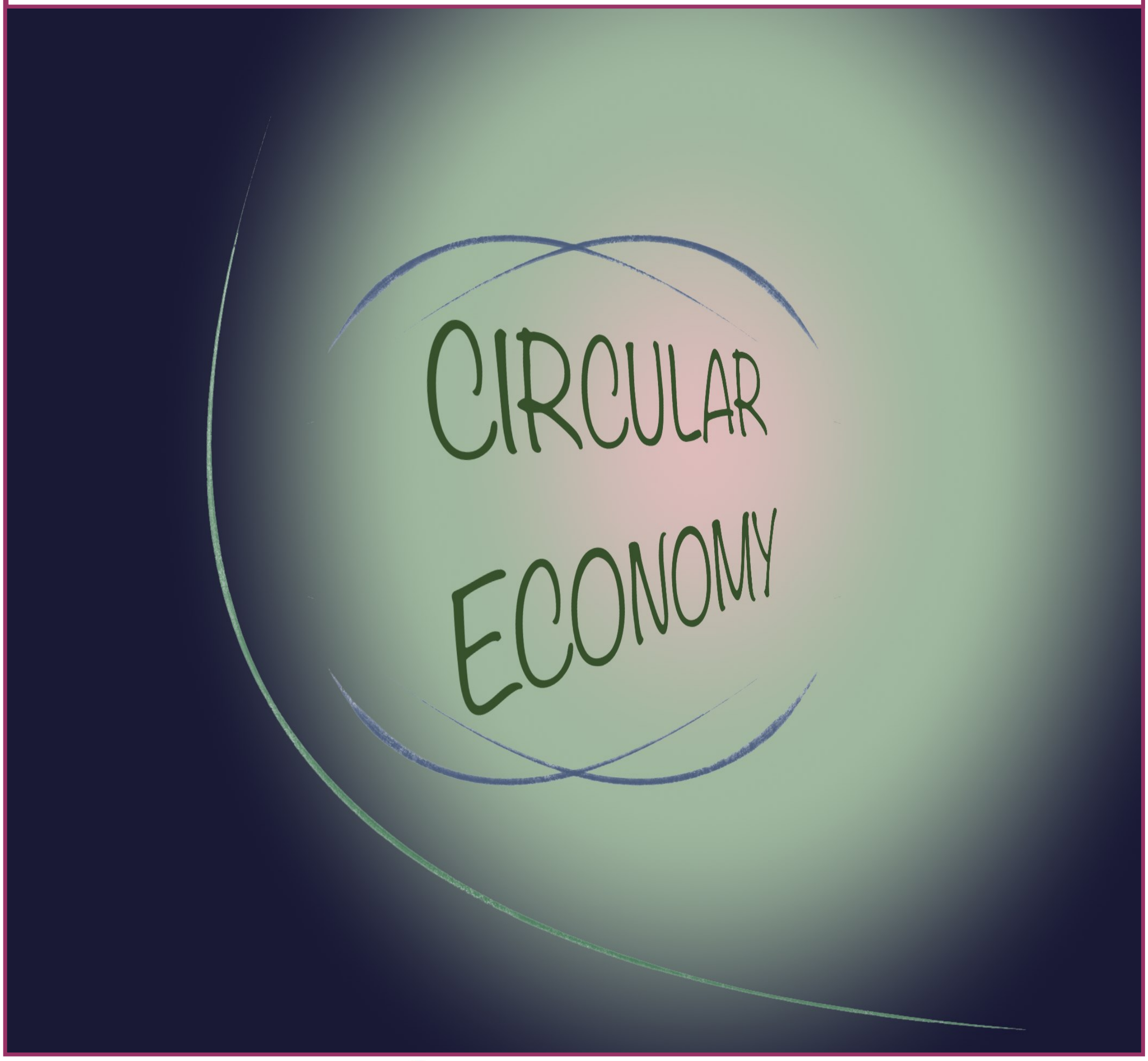



scenario is were the current rate of emission is maintained (the rate of emission doesn't continue to increase) and the third scenario is where the emissions are immediately curbed (rate of emissions are brought to zero). While the trends are modeled from 1950 till 2020, the future trends are considered

**Figure 21**




ZERO WASTE


CIRCULAR
ECONOMY

from 2020 till 2050. First scenarios would contribute to increase in the presence of macro- and microplastics as both scenarios are based on continued emissions, although the rate at which the presence increase would shift according to the change in rate of emissions. The most important point is the third scenario where the presence of macroplastics almost immediately decline once the emissions have been curbed. The microplastics however, continues to increase in presence (not exponentially though) even after immediate curbing of emissions. This is due to the degradation macroplastics that have already been emitted that continues to generate (and hence emit) microplastics to the ocean waters. It is therefore important to note, that not just curbing emissions, but removing already emitted plastics in the ocean is critical in restoring the ocean environment.

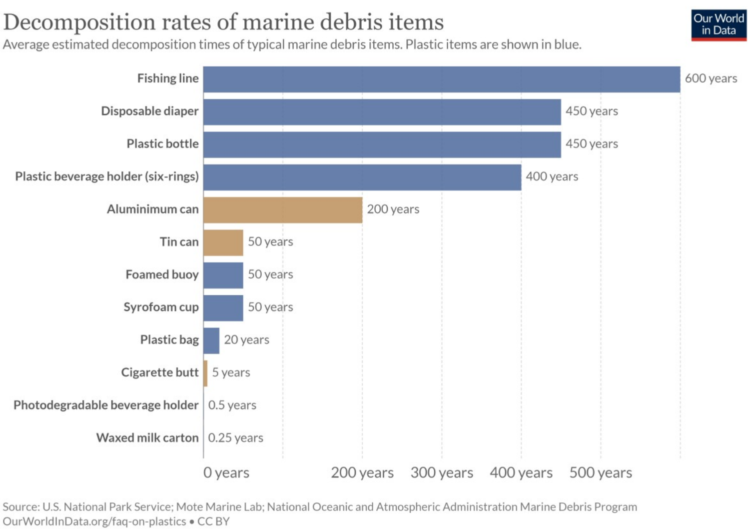
### Persistence of plastic in the oceans

Figure 24 shows the most common debris found in the oceans and the average time it takes for each of them to disintegrate (in other words, the life of the product debris in the oceans). Decomposing time as reported in the figure is not the total time it takes to disintegrate into elemental forms, rather, it is the time taken to break into micro-scale fragments. The actual time it takes for the articles to completely disintegrate may be many folds the time reported in the figure. It could be observed that most plastic particles take much longer time to disintegrate compared to other non-plastic particles and some forms of plastic material, while the fishing lines taking the longest (approximately 600 years). Disposable diapers and bottles take the second longest (approximately 450 years) followed by plastic beverage holder taking approximately 400 years. In comparison aluminium cans take 200 years while tin cans take approximately 50 years which similar to foamed buoy and syrofoam cups. Plastic bag is the shortest in the plastic category that takes nearly 20 years to disintegrate. It is understandable that the time each material takes to disintegrate is much longer than the actual lifespan (usable period) of the material, for example, a plastic bag may be used for hours while it takes 20 years to disintegrate. This indicates that the debris would continue to accumulate exponentially if end-of-life product is not managed sensibly.

The environmental impacts of different types of plastics varies with the chemical composition of plastics. The most commonly produced, used and wasted plastics are polypropylene (PP) and polyethylene (PE), which is mostly used to produce pliable films and materials for packaging while the same are also used for automotive parts, pipes and houseware. Polyvinyl chloride (PVC) and polyurethane (PU) on the other hand as mostly used for the production of materials related to construction and automotive industries. Furthermore, polyethylene terephthalate (PET) is used for textile fibres and drink containers (bottles) while polystyrene (PS) widely varies on applications such as packaging (StyrofoamTM) and building insulation. Polycarbonate (PC) is used in applications where hard and transparent material is required such as eyeglasses and clear roofing sheets. All these varieties of plastics together constitute more than 80% of plastics in use in Europe (as of 2016) in addition, contribute to large fraction of global plastic production.

Because of the fact that most plastic polymers are insoluble in water and that they are biochemically inert (due to large molecular weight), they are inherently low toxic. Yet, the monomers (that are then combined into synthetic polymers) such as styrene or vinyl chlo-

**Figure 24**



## Plastic Waste — A global perspective ...

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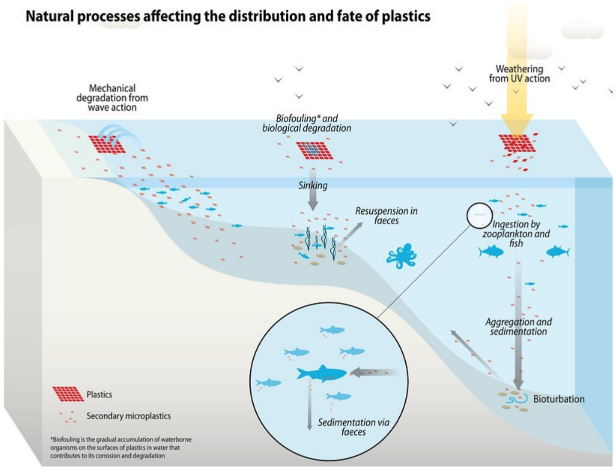
ride, are toxic and carcinogenic hence the residues in plastic products can be hazardous. In addition, plastic production from monomers also extensively use additives, which are highly hazardous to the environment, for example that used in PVC, PU, PS and PC. These additives include fillers and plasticizers that are used to modulate texture, or colouring agents, antimicrobials, flame retardants and other substances that change material properties to produce materials with desirable properties. While these additives can be toxic to humans and other species, they also limit the potential of recycling of plastic products. For example, Bisphenol A (BPA) which is widely used in the production of PC plastic water bottles and other resins used in food containers, is found to be estrogen-mimicking, hormone-like properties and are also found to accumulate in humans, causing hormone imbalance. Several other additives such as adipates and phthalates have been observed to mimic different hormones and hence are considered to be highly toxic to living organisms, yet, they are widely used to make pliable plastics for food packaging, toys and many other daily-use items.

**Figure 25**

Source: gittakeinanen.kscopen.org




### Size classes: Micro- versus macro-plastics

Other than plastics being classified to analyse the risk it poses, they are also classified according to its particle sizes, where the size does play an important role in the risk it poses to the environment in addition to its chemical and physical properties. The article proposes a specific classification as follows:

- Small nanoplastic (< 1µm in diameter)
- Microplastic particles (1µm – 5mm)
- Mesoplastic particles (5 – 200mm)
- Microplastic items (> 200mm)

Microplastics can emerge from two ways: 1. Directly from production (e.g. plastic pellets that are used as the raw material for fabricating larger items) and 2. Indirectly from disintegration of larger items (e.g. a plastic rope disintegrates into finer filaments). A large fraction of microplastics also emerge directly from cleaning products and cosmetic products (e.g. toothpaste and facewash),

## SCIENCE NEWS

### UK's plastic problem

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waste problem, generates another type of waste, food waste that leads to carbon emissions. Several manufacturers are observed by Fasciauz to have tried to ditch single-use plastic packaging, for example, solid bars of shampoo rather than liquid bottles and toothpaste tablets rather than a paste in tubes. Helen Bird at UK Waste charity WRAP says, this trend should be the future, where single-use plastic are substituted for a more sustainable and environmental friendly options. Another observation discussed in the article is that some firms adopting biodegradable and compostable plastic, while the article claims that the infrastructure to recycle them have not been implemented to support this trend, which will result in waste piling. Furthermore, such biodegradable and compostable alternatives often do not end up in the right bins, which would be taken to the right place to be composted, rather, ending up in the wrong bin may not served the intended purpose of degradation. For applications where single-use plastic does not have an alternative, it is suggested that the manufacturers could use just one type of plastics instead of bonding different types together, which would make the recycling process more accessible.

The other option to curb consumption of plastic (mostly as packaging and container applications) is to move towards reuse and refill culture, which requires a shift in consumer behaviour. This move has been started in many chains of companies around the world, including Sri Lanka, where bags are often reused instead of purchasing a new one, and refilling shampoo and shower gel bottles, without buying a newly packaged item for the same purpose. Yet, this remains in a smaller scale, contributing very little to the management of plastic waste. While it can be

*Continued on page 29 ...*

while usage of plastics in such products are currently being phased out in the developed countries. Small microplastics (typically less than 1mm) have drawn concerns due to their abundance in water, air, sediments and organisms and that they can potentially bioaccumulate being transferred through the food chains and infiltrate living tissues. Very small nanoplastics (< 1µm) have only been recently studied typically directly emerging from processes like 3D printing in addition to disintegration of microplastics. These particles can be transferred through cell membranes in living organisms, accumulating in blood streams, affecting the bodily functions. They are so small, that even the studies on them remains highly challenging.

Conventional plastics (plastics that are produced using synthetic monomers) do not readily biodegrade (decomposed by microorganisms) in the marine or terrestrial environments, yet, they do disintegrate physically (into micro- and nanoplastics or even further small particles). Physical disintegration of plastic particles occur mainly due to mechanical forces such as waves or abrasive forces of sediment grains and are broken into smaller pieces. Since they do not decompose and just disintegrate to smaller pieces, although the particles become smaller and possibly not visible after sometimes, the cumulative weight of plastics in the environment does not change, only the distribution of its size that is changed. When plastics are exposed to UC radiation in sunlight and oxygen, the plastic material can be oxidized forming hydroperoxides that lead to polymer chain scission, which may take decades to centuries in natural soils. In the oceans however, these processes can be much slower due to diminished mechanical and photolytic forces, more specific in deeper waters. Furthermore, in the oceans, the plastic materials are fouled by microorganism (attached growth) that in turn reduce the surface area of plastic particles exposed to UV radiation. This causes accumulation and persistence of plastic material in oceans that may span centuries.

### Microbial decomposition of plastics

Microorganisms can consume carbon-based substrate, and as such, plastics materials could in principle be a substrate for microorganisms such as bacteria, algae or fungi that manage to break down polymer chains. Microorganisms being a living organisms, need a long time to get evolved to consume substrate for their growth and cell functions. Plastics, specifically synthetic plastics being a new material to the environment, microorganisms have not evolved to consume them as yet (it may do so, given enough time for the evolution of microorganisms to prey on plastics). The study on the ability to microorganisms in consuming plastic also remain scarce in current literature, more specially in ocean environments. Microorganisms will prey on smaller substrate that can be taken into the cell structure, and the particles that are bigger will not be able to penetrate into the cell. In such cases, the microorganisms grow on the surface of bigger substrate, and excrete enzymes to break bigger particles into fragments, which can be subsequently consumed by microorganisms. This process needs a concert of microorganisms and not just one species. Should there be microorganisms that can consume plastics, the plastic particles would have to be fragmented by another set of microorganisms for effective consumption. Polymers being long and that the binding between monomers have high energy stored, microorganisms need to develop specific skills and expertise to fragment these chains. There are several experiments documenting microbial degradation, focusing on more easily degradable polymers. For example, *streptomyzes* species increased decomposition of degradable polyethylene films when compared to uninoculated samples. Similarly, *Amycolatopsis* species, which are sparsely distributed in natural soils, effectively degrade polyactide (PLA) polymer samples. However, these microorganisms need very specific characteristics of environmental conditions, for examples, PLA decomposition needs very high temperatures, which are currently employed in industrial facilities, and cannot take place in natural environments. N another occasion, in a recycling plant of PET, a bacteria was identified to have degraded PET that use it as an energy and carbon source, while their decomposing capacity in natural environments still need to be studied.

It is understandable that the plastics do persist in the environment while also accumulating, if it is not managed in production, usage and disposal. The natural process of decomposition wouldn't assist us in phasing out or removing plastics as of now. Management of plastics is therefore critical and inevitable.

## TOOL

# Waste auditing tool

### Construction & demolition waste auditing tool for a construction company

*A tool that audits the C&D waste from a project and compares different waste management techniques.*

Construction and demolition (C&D) waste refers to the waste generated during construction, renovation, and demolition activities. It encompasses a wide range of materials, including concrete, masonry, timber, metals, plastics, and other construction-related debris. C&D waste is generated throughout the different stages of the life cycle of buildings, including construction, rehabilitation or renovation, and demolition.

### Waste auditing tool

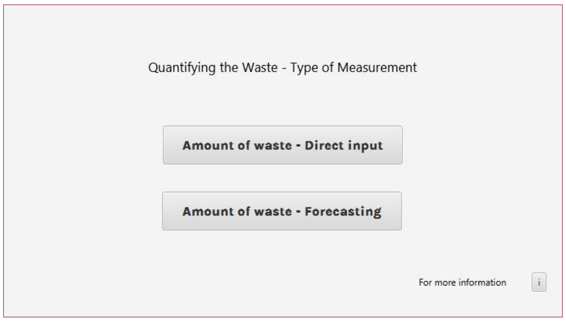
The developed tool encompasses a comprehensive scope, aiming to assess and manage waste generation in a construction company. It performs a thorough waste audit, collecting data on various waste streams like packaging waste (paper, cardboard, plastic, wooden, metallic, mixed) and construction and demolition (C&D) waste (concrete, ceramics-bricks, mixed concrete ceramics, drywalls, mixed C&D waste).

**Figure 01**


The tool analyses the waste composition, evaluates its environmental impact, and conducts an economic analysis (considering costs, fines, and potential savings). It generates a detailed report with findings and recommendations, covering waste generation rates, disposal methods, compliance with regulations, and recycling practices. The report includes an implementation plan, empowering the construction company to proactively pursue waste reduction strategies, material reuse, and recycling initiatives, thereby fostering economical and efficient operations.

Figure 01 shows the initial interface of the tool, by clicking the "Open" icon tool can be launched. Upon launching the tool, the next step involves gathering data to quantify the amount of C&D waste. There will be two options to choose between: "Amount of Waste - Direct Input" or "Amount of Waste - Forecasting Method" as shown in figure 02. If the user already knows the waste amount, they can input the information directly into the tool. This allows for a more accurate assessment and management of waste generation in the construction company. By having access to specific waste composition data, the tool can provide tailored recommendations and strategies for waste reduction and recycling efforts. This targeted approach ensures that the company can prioritize and address the most significant waste streams effectively.

**Figure 02**



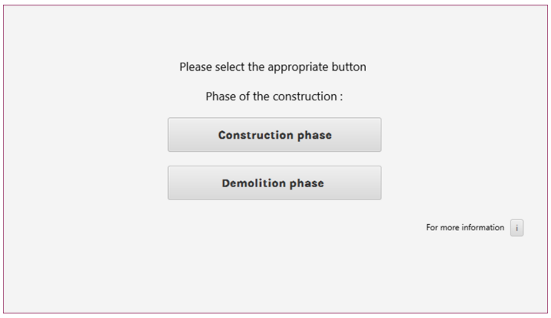

However, in cases where the user doesn't possess the precise waste composition data or where the amount of waste needs to be forecasted before the start of the project, the tool incorporates a quantification procedure to estimate the approximate amounts of waste generated. This is achieved using waste quantization tables, which are based on classification characteristics and construction techniques employed in each building.

By utilizing these tables, the tool can provide reasonable estimates of the types and quantities of waste generated during the construction, and demolition phases. While the quantification procedure may not yield precise figures, it still enables the construction company to have a general understanding of the waste generated and allows for the implementation of waste management strategies that can mitigate the environmental impact and optimize resource utilization.

## Waste auditing tool ...

If the user chooses the "Direct Input" option, that will open the interface to choose the phase of the project, whether the known amount of waste produced during the construction phase or demolition phase. The user needs to select the correct phase from the interface shown in figure 03 in order to get the appropriate types of waste based on the period that the waste was produced.

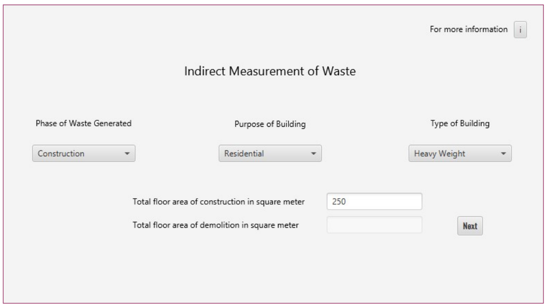
**Figure 03**




The figure 04 shows the corresponding window if the chosen phase is construction and the figure 05 shows the corresponding window if the chosen phase is demolition. Here user can enter the known values of available waste in kg. After entering the amount of waste, the user can go to the waste report page by clicking the "next" option. Here some conversion factors are used to covert the weight of each waste into volume, to find the waste composition, and the required number of trucks to transport the waste from the site.

But if the user chooses the "Forecasting ( Indirect measurement)" option to find the amount of waste, that will open another window where the user needs to choose the type of building and enter the total floor area instead of entering the amount of waste directly. This window is shown in the figure 06.

**Figure 06**




As mentioned earlier, the tool will estimate the waste data at the end of a project, for that, the user should choose the right combination of purpose, and type of building that is going to be constructed or to be demolished. Estimation rates found from past data will be used by the tool based on this information. Then the tool will quantify each waste using these estimation rates and total floor area.

In the construction phase, the waste originates from the specifications of dimensions, building materials, and construction procedures required for the project. Construction waste consists of packaging wastes such as paper, cardboard, plastic, wooden, metallic, and mixed and excess wastes such as concrete, ceramics-bricks, mixed concrete ceramics, drywalls, and mixed C&D waste.

**Figure 04**

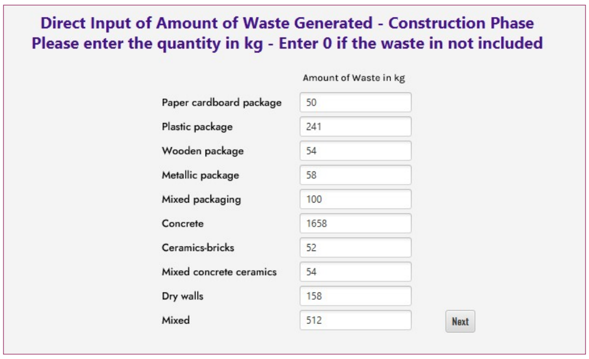
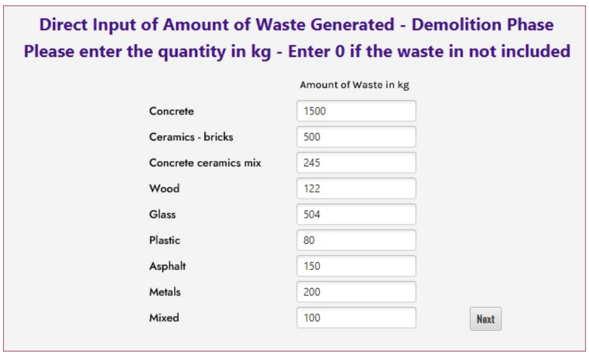



**Figure 05**




In partial or total demolition, waste is generated as the building or its components reach the end of their life cycle and are demolished. Demolition waste consists of concrete, ceramics-bricks, mixed concrete ceramics, wood, glass, plastic, asphalt, metals, and mixed C&D waste. These two stages serve as selection criteria for C&D waste, enabling the tool to effectively quantify and manage waste arising from each specific phase of the building's life cycle.

The type of building needs to be chosen between lightweight and heavy weight to forecast construction waste. If the waste comes from

## Waste auditing tool ...

demolition then the user should define the type whether it's concrete or masonry building. Before that user should select the usage from residential and non-residential options. This selection of options to forecast the waste can be illustrated as in the figure 07.

After obtaining specific quantities of waste, the next step is to rely on a tool to determine the optimal waste management option. This process involves conducting a cost-benefit analysis for three main methods: landfilling, recycling, and incineration. Each method is evaluated based on its associated costs and benefits, resulting in a numerical value that represents the overall benefit derived from it. By clicking the "Compare Waste Management Techniques" button in the waste report window user can view the waste management comparison. Figure 09 shows the sample waste management comparison produced by the tool. Here user have to enter the distance to the landfill for each type of waste.

Figure 08

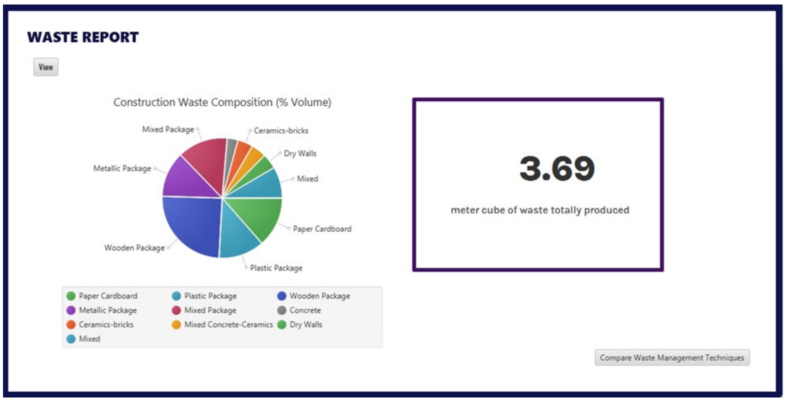
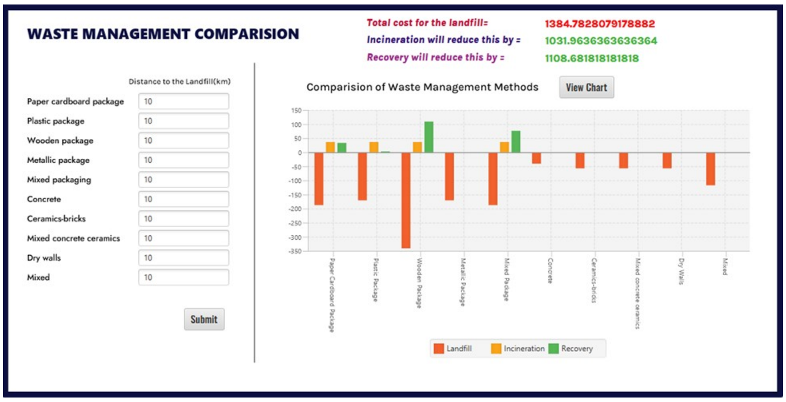


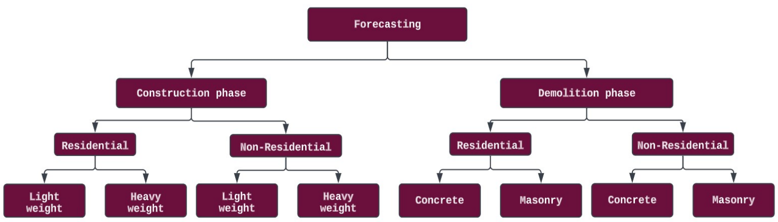

Figure 09




The cost analysis of each waste management method took into account various parameters, such as the distance between the waste production point and the intended site, the number of trips required for transportation, and the labor force involved. These factors were considered to provide a comprehensive evaluation of the financial implications associated with each method. Similarly, when calculating the benefits of incineration, the focus was on determining the amount of waste suitable for incineration and estimating the energy produced per cubic meter of waste. This allowed for an assessment of the energy recovery potential associated with incineration.

For recycling, the analysis considered the effectiveness of the recycling process in terms of how much waste could be successfully recycled. Additionally, the portion of the recycled waste that could be sold on the secondary market was also taken into account. This approach helped quantify the economic benefits derived from recycling. By quantifying the costs and benefits of each approach, the tool facilitates decision-making and allows for the selection of the most advantageous waste management method.

Figure 07




By:


RINDUJA R
University of Jaffna


VINOJAN P
University of Jaffna


SARANKAN S
University of Jaffna


SAMHAN M A
University of Jaffna


VITHUSHAN A
University of Jaffna

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BRIEF

## Recycling RARE EARTH Elements

The applications where rare earth elements are used, seldom can we find alternatives. In addition, most applications, specifically in the electronics domain, the demand continues to exponentially increase, increasing the demand on rare earth elements. Two aspects are spoken of in the article; 1. Assist diversify the control of supply of rare earth elements, and 2. Make the process of acquiring the elements more greener (environmental friendly). While research studies are exploring extracting the elements from coal waste to mining from other celestial bodies, the immediate solution in part could be to recycle them from wasted application equipment – recycling. Ikenna Nlebedim, a materials scientist at Ames National laboratory in Iowa claims that recycling is going to play a very important and central role, yet, not to say we're going to recycle our way out of the critical materials challenge. It is expected rather, by about 10 years from now, that we could satisfy a quarter of the demand through recycling rare earth elements. With the exponential increase in demand, supplying a quarter of the demand in a decade would be a huge accomplishment. However, recycling rare earth elements from an old laptop like recycling an alumunium can, technological, economical and logistical challenges are needed to be overcome.

### Extraction challenge

While 15 – 70% of elements such as iron, copper, aluminium, nickel and tin are recycled specifically in US and Europe, less than 1% of rare earth elements are currently being recycled says Simon Jowitt, an economic geologist at the University of Nevada, Las Vegas. Recycling capacity would not the same for all elements. For example, copper wire can be recycled into copper wiring and steel can be recycled into more steel, yet, rare earth elements cannot be recycled in simple capacity as such, because they are more often blended with other metals to produce applications such as touch screens, which inherently makes the processes more of elemental recovery and reapplications rather than recycling. The process of elemental recovery and using into application is similar to extracting from ore itself, let alone the latter can be more economically feasible. Conventional elemental recovery processes of rare earth elements require hazardous chemicals such as hydrochloric acid in addition to large demand of energy (heat). These processes and demand of resources make the process of elemental recovery of rare earth elements more costly, often more than obtaining virgin elements, specifically due to the amount of elements that can be extracted from used products. For example, a hard disk drive may contain just a few grams of rare earth elements, while many products yield only milligrams. Chemists and material scientists are researching on more advanced methods to make extraction of rare earth elements more economically feasible, such as using microbes to extract, ditch acids of conventional methods or attempt to bypass extraction and separation.

### Microbial miners

Microorganisms are believed to contribute to the extraction of rare earth elements from used products, for example, Gluconobacter bacteria naturally produce organic acids can extract rare earth elements such as lanthanum and cerium from spent catalysts used in petroleum refining or from fluorescent phosphors used in lighting. These bacterial acids, that originate from microorganisms are more environmental friendly than the conventional acids such as hydrochloric acid (or other metal leaching acids), says Yoshiko Fujita, a biogeochemist at Idaho National laboratory in Idaho Falls. However, it has been observed that these bacteria derived acids can only recover approximately quarter to half from spent catalysts and phosphors, while hydrochloric acid can perform much better (almost 99% recovery).

Although a reduced amount of elements could be recovered using bacteria derived acids, it is still expected to be economically feasible, for example, the article says that a hypothetical plant recycling 19000 metric tons of used catalysts a year may produce revenues of approximately $1.75 million. However, the process of feeding the bacteria that produce the acid for leaching the metal, for example refined sugar, can cost as high as $1.6 million a year, with only $150000 in profits for that hypothetical plant. Simultaneously, the study says that using other forms of substrates for the bacteria can significantly reduce the feeding cost, for example, using corn stalks can reduce the cost of feeding by $500000 .

Another study is discussed in the article, where some bacteria are observed to metabolize rare earth

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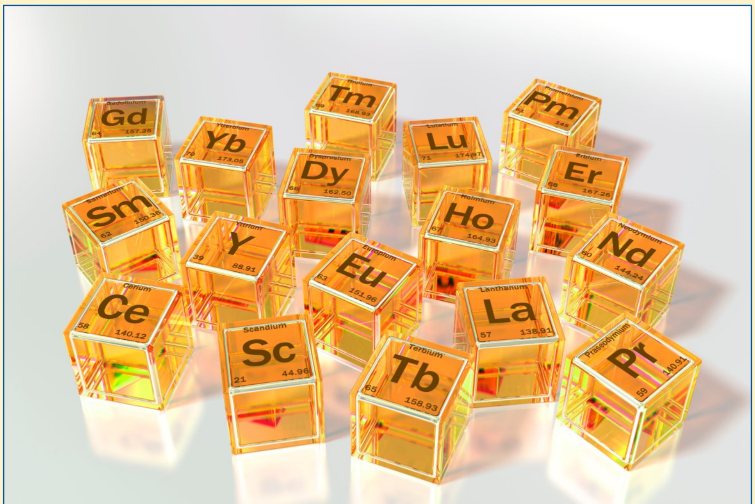
## Rare earth elements ...

elements produce protein that preferentially attaches to these metals. The protein is known as lanmodulin can therefore be used to extract rare earth elements, such as neodymium from dysprosium, two components usually found in rare earth magnets. While this process makes several chemical obsolete in the process of recovery of these elements, the waste that is left behind in this case (a protein) is biodegradable and hence more environmental friendly. Yet, upscaling to commercial plants that could use microorganisms to do rare earth recovery still far from industrial implementation.

### Electronic waste

While microbes based technology Is far from commercialization, a method using copper salt to extract rare earth elements from discarded magnets is already adopted in commercial scale plant. Neodymium-iron-boron magnets constitute approximately 30% by weight (of rare earth elements). The article states that recovery of neodymium from magnets from US hard disk drives would meet almost 5% of the world's demand outside of China, by the end of this decade.

Nlebedim eld team shredded electronic waste containing magnets and dunk them in a copper salt solution at room temperature to dissolve rare earth elements. While other metals can be scooped out (and perhaps recycled for respective applications), copper itself can be used to make more salt solution. The rare earth elements are then solidified with additional chemicals and heating and subsequently transformed into powdered minerals called rare earth oxides. This process is proven in the experiments to yield 90 – 98% of recovery of rare earth elements, and are pure enough to make new magnets. An economic analysis on this experimental recovery study found that of 100 tons of leftover magnet material would yield 32 tons of rare earth oxides to harbour approximately $1 million in profit. The study simultaneously analysed the environmental impacts compared to producing rare earth oxides from conventional mining processes (used in China) and found that the copper salt method had only half the carbon footprint compared to the conventional mining. Yet it could not be considered greener than all forms of mining as this method employs ammonium hydroxide and roasting, that consumes large amounts of energy, leaving significant carbon footprint. The article speaks about a few industrial companies that have already commissioned pilot scale plants and are currently aiming to produce smaller amounts of recovered rare earth elements.



Source: www.thoughtco.com

### Overcoming logistics

Although several research studies are aimed at and also succeed in clearing the technological hurdles in making these novel processes for commercial applications, logistical barriers are often observed to impede the efforts on recycling rare earth elements. "we don't have the systems for collecting end-of-life products that have rare earth in them" says Fujita, "and there's the cost of dismantling those products". This quote speaks the logistical issues in two aspects. The first is to implement a system to collect the items that are used and have rare earth elements in them, which relies on the local government policies and collection strategies. The second is to dismantle the items to get the magnets or relevant items with rare earth elements, so as to reduce the solutions needed to dissolve rare earth elements. The second struggle would need designers of the items to design it in such a way to easily dismantle the items upon reaching end-of-life. The article discusses how Apple trying to use an automated recycling process using the company's Daisy robot, that dismantle iPhones. In addition, the article further states that Apple announced pair of robots called Taz and Dave that can facilitate recovering rare earth elements.

**Original article: Science News, Issue January 14, 2023: page 20**

PERSPECTIVE

# Biogas as an alternative cooking fuel

*The article discusses the potential usage of biogas as an alternative cooing fuel.*

Prof G L S Arachchige
University of South-Eastern Norway

Prof V Sivalingam
University of South-Eastern Norway

Sri Lanka has been experiencing a severe economic crisis for the last few years, which has resulted in soaring fuel prices and an inadequate supply to meet the growing demand. Not only transport fuel but also cooking fuel, such as Liquefied petroleum gas (LPG) prices, became incredibly expensive to the level that local working-class people could not afford. This write-up briefly explains the potential of replacing LPG with biogas, an alternative fuel. Importantly, it can be produced and utilized at local induvial houses.

Biogas is a gas mixture of methane and carbon dioxide, produced by degrading organic waste, anaerobically. Anaerobic condition refers to the absence of oxygen. Organic wastes such as food, manure, sewage, and kitchen waste are potential raw materials for biogas production. The produced biogas can be directly used as cooking fuel and fuel for combined heat and power plants. Also upgraded into biomethane thus replacing the transport fuel and natural gas grids. The digested sludge is utilized as fertilizer. All these contemporary benefits lead to a circular economy model (Figure 1). However, using biogas as cooking fuel is the interest of this article.

The production of biogas from organic waste involves a biochemical process that is complex. However, individuals interested in producing and using biogas as a cooking fuel do not need to master the scientific details. A basic understanding of the process is sufficient, as the process flow and reactor setup can be simple.

**Figure 01**

Source: World biogas association. (2022). Why biogas. https://www.worldbiogasassociation.org/why-biogas/


To establish biogas production at the household level, individuals can set up small-scale biogas digesters (e.g., gas-tight vessels). These digesters can be designed to accommodate the organic waste generated within the household or obtained from nearby sources. Proper maintenance and regular feeding of organic waste into the digester will ensure a

## SCIENCE NEWS

### UK's plastic problem

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cumbersome for consumers to move around with spent containers to refill throughout the week, the article suggests that the manufacturers do the collection (from collection points) of spent containers and refill them in their facility and shelve in the stores. This method is also practiced in several countries and the article reveals such an effort be Tesco, a UK supermarket chain, to implement it that year. While all experts agree, instantaneously curbing plastic production to zero may not be practical, UK Greenpeace believes that cutting down plastic production in UK by 50% can immediately stop exporting the same, reaching the target at least by 2025 (with the current recycling capacity in the country). It is also observed by the author of the article that several plastic items such as milk bottles and soft drink bottles have high value and that they are mostly recycled in the country itself, while thin film plastics used in packaging fruits and vegetables are exported that bear low value. This may mean that new ways of recycling (chemical recycling) of these thin film plastics may offer a solution, where it would be broken down to their constituent parts. Jacob Hayler at the Environmental Services Association says, even the technology for this process is about 5 years from now. The article believes that the UK is in the right track.

**Original article: New Scientist, 5th June, 2021: page 18**

steady supply of biogas for cooking and other energy needs. The wastes should be homogenized in a way that can facilitate efficient digestion. Then it needs to be fed into the digester. To start the digestion process, the reactor should be seeded by manure or sludge from an existing biogas plant. The presence of active microorganisms in the seed material aids in the decomposition of waste and the production of biogas. The fed waste will produce biogas for a month. However, the volume of produced biogas becomes gradually decreases with time. Therefore, the reactor needs to be fed regularly; simultaneously, the digested sludge should also be removed. The sludge can be used as organic fertilizer or soil conditioners depending on the waste source. This is an extra benefit of producing biogas at home. The produced gas can be directly used as cooking fuel without any pre-treatment. Also, it can be stored in a gas cylinder or gas bags placed outdoors that enhance the biogas availability. However, it is crucial to follow certain safety measures when handling biogas due to its flammable nature, and as it could potentially cause explosions.

A brief scientific insight into the biogas production process is given below for interested candidates.

1. Overview of waste digestion process or metabolic pathways during anaerobic digestion, organic matter is broken down in a series of steps:
   a. Hydrolysis: Complex compounds are broken down into simpler molecules like sugars, amino acids, and fatty acids. This breakdown is facilitated by hydrolytic bacteria that secrete enzymes.
   b. Acidogenesis: Simple molecules (the products of hydrolysis) are converted into volatile fatty acids (VFAs) and other compounds.
   c. Acetogenesis: VFAs and other intermediates are further metabolized to produce acetic acid, hydrogen, and carbon dioxide.
   d. Methanogenesis: Methanogenic archaea convert the products of acetogenesis into methane and carbon dioxide.
2. Key parameters of the process: The anaerobic digestion process is influenced by several key parameters that affect its efficiency and performance. These parameters include:
   a. Temperature: Temperature plays a crucial role in anaerobic digestion as it affects the activity and growth of microorganisms. The optimal temperature range for mesophilic anaerobic digestion is typically around 35-40°C.
   b. pH Level: The pH level of the digestion system is another critical parameter. The optimal pH range for anaerobic digestion is generally between 6.5 and 8.0.
   c. The organic waste fed into the digester should have a balanced mixture of carbon-rich and nitrogen-rich materials. Diverse types of waste have varying nutrient contents and biodegradability. Finding the right combination is important for optimal microbial activity and biogas production.
   d. Retention Time: The retention time, or hydraulic residence time, refers to the duration that the organic material remains in the digester. It determines the contact time between microorganisms and the substrate, allowing for sufficient digestion.
   e. Some substances found in organic waste, such as heavy metals, certain chemicals, or elevated levels of ammonia, can inhibit the anaerobic digestion process. It is important to monitor and control the concentration of these inhibitory substances.

## SCIENCE NEWS

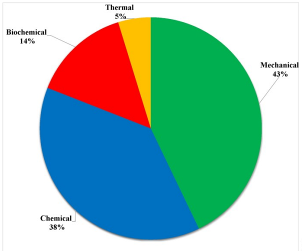
### UK's plastic problem

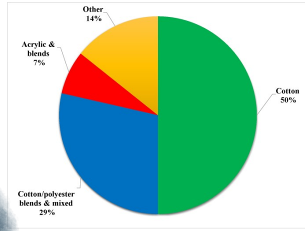
Under the Basel Convention, UK has tightened regulations on plastic waste exports in January, 2022. In April, introduction of plastic packaging tax will further improve recycling efforts. Furthermore, 'polluter pays' concept will assist reduction in plastic waste production and improve end of life management of the same, which may come into effect in 2024, report says.

## SUMMARY

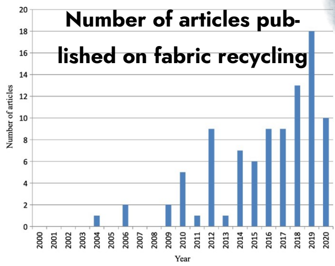
# Textile Waste

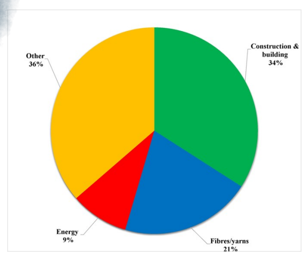
*The article illustrates the environmental issues and the challenges faced in implementing textile waste management and research and developments, in the current context.*








Source: https://link.springer.com/article/10.1007/s42824-021-00042-2

## TEXTILE WASTE

Conventionally, specially in Sri Lanka and in neighbouring countries, textile did not end in the bins.

Used clothes and fabrics have traditionally been upcycled or recycled within families without trading or binning.

Consumerism has changed a lot in the past decade, increasing purchases of textiles and hence wasting or binning of textiles.

Second-hand stores for clothes have opened up (e.g. Oxfam) where used and washed clothes were sold at a lower price. Yet the market remains highly restricted.

Exportation of textile waste (used clothes) to countries reeling in poverty (e.g. African nations) have become common, where the second-hand market for used clothes are still in vogue.

Reports claim that more than 80% of the used clothes sent to such countries are so unusable that they directly end up in dump yards

Source: deskrush.com

Fashion industry is claimed to have been environmentally unsustainable, both in consumption and end of life management

### Sustainability in Textile Industry

Although synthetic textiles are becoming more common, reducing consumption of virgin finite resources, further research and development could be observed going into biodegradable textiles

Plastics fibres turned into yarn (e.g. Eco Spindles in Sri Lanka) and incorporating plastic waste into production of textile material. Further research is also gone into development of bioplastics (those that use natural monomers and/or biologically degradable), which can also be incorporated into yarn production

Brands, including luxury brands sourcing from sustainable sources for textile production, considerate about their carbon foot print and environmental foot print, contributing towards a safer and sustainable environment.

Fibres sourced from natural wastes such as banana fibres and coir, that are used for the production of textile materials that are subsequently used for various types of consumer products

A modern trend is turning into using textile wastes (cut pieces) to create unique clothing pieces, revolutionizing the fashion industry in a more sustainable way. Used clothe wastes are also used in custom products catered for the consumer, contributing to averting textile wastes going into landfills.

Source: bloelizabethgalloway.co.za

3862 kg of textile waste upcycled

# HOUSE OF LONALI

## FOUNDER : LONALI RODRIGO

706.1 kg of $CO_2$ emissions curbed

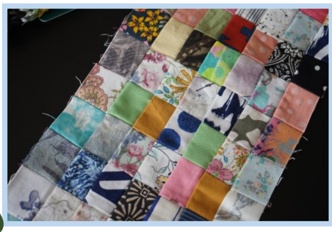
**WEBSITE: https://www.lonali.com/**

**'conscious lifestyle brand that creates uncompromising fashion and style keeping both people and the planet at heart '**

Source: fashioninsiders.co


Source: www.pixelpool.com

CIRCULAR ECONOMY



ZERO WASTE

**"We believe there is unique beauty in every flaw and little choices we make over time have potential to change the future for the better."**

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INTERVIEW

# FASHION

## WITH SUSTAINABILITY

*Circular economy through innovative approach in fashion*

**LONALI RODRIGO**

**Founder/Head Designer** House of Lonali

**Q1 Please tell us about yourself and how did you become a fashion designer.**

From my childhood, I had a penchant for fashion and creativity, evident in my habit of cutting my grandmother's saree into fashion clothes for my dolls. However, after completing my higher studies, it took me two years to truly understand what I wanted to pursue in life. I explored various avenues in the creative industry and eventually found my way into the apparel industry. Recognizing my passion, I decided to enroll in a degree program for fashion design and successfully graduated. Throughout my college years, I realized that sustainability was a recurring theme in the projects I undertook. Incorporating sustainability into my college projects deepened my understanding of its importance.

**Q2 How did you come up with the idea to use waste materials in your design? Is there any specific incident that inspired you to do this?**

The source of my passion and inspiration stems from my dedicated practice and love for fashion. While I was in college, I became increasingly aware of the booming nature of the fashion industry and its significant contribution to the economy. However, I also noticed the considerable amount of waste generated by the industry. Recognizing this as an opportunity, I realized I could make a meaningful impact by creating something valuable from waste materials. By embracing waste as an opportunity rather than a problem, I sought to revolutionize the way we approach fashion design.

**Q3 What type of waste materials do you use in your designs? Are there any specific characteristics or criteria which is suitable for your design?**

Initially, our focus was primarily on utilizing pre-consumer waste from the apparel industry. Unlike in the Western world, where fast fashion dominates and post-consumer waste is more readily available, earlier our cultural practices traditionally discourage throwing away clothes. However, in 2020, we observed significant changes in our culture, influenced by various factors such as influencers, lockdowns, and shifting consumer behaviors. These changes resulted in the rise of fast fashion consumption patterns, making post-consumer waste more accessible than before.

As a result, we now actively work with both pre- and post-consumer waste, enabling us to create sustainable and innovative fashion products. Furthermore, we remain open to exploring various opportunities beyond apparel waste. For instance, we have ventured into transforming discarded bags into shoes and repurposing airplane seat covers into unique products.

**Lonali Rodrigo**

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## INTERVIEWS

### Q4 If you are using post-consuming waste materials, how do process the materials for your usage?

We encourage people to bring us their waste materials, assuring them that we will create something valuable in return. This way, nothing is taken from them without giving something back in return. This principle reinforces the idea of a mutually beneficial relationship, where waste is transformed into meaningful products. To streamline the process and minimize excessive efforts in cleaning and reworking, we prioritize upcycling as our primary method of transforming waste materials. By focusing on upcycling, we minimize the need for complex cleaning processes and reduce energy consumption, aligning with our commitment to sustainability.

### Q5 Some others use plastic materials to prepare fabric, how do you see it?

I understand the challenges posed by the demand for mixed fabric and the difficulties in recycling such materials. Mixed textiles, especially those containing polyester, present unique obstacles when it comes to recycling. Additionally, lightweight materials like lycra can be particularly challenging to upcycle due to their specific properties. In situations where we receive mixed fabric waste, we strive to find the most sustainable and efficient solutions. While it may not always be possible to recycle or upcycle every component of the mixed material, we focus on maximizing the use of the available resources.

> **"RECOGNIZING THIS AS AN OPPORTUNITY, I REALIZED I COULD MAKE A MEANINGFUL IMPACT BY CREATING SOMETHING VALUABLE FROM WASTE MATERIALS"**

### Q6 In your opinion, what impacts does your fashion design using waste materials have on society, and how do they contribute to a broader approach?

In our production process, we prioritize working with cottage industry artisans who operate from their homes. By collaborating with these artisans, we not only create unique and handcrafted products but also contribute to their livelihoods by providing an additional source of income. As a smaller brand, we have developed close relationships with around 10-15 individuals whom we collaborate with regularly.

Overall, our partnership with cottage industry artisans not only enhances the quality and authenticity of our products but also reflects our commitment to social responsibility and sustainable practices within the fashion industry.

### Q7 How do you address the issue of textile waste within your design purpose?

Textile waste is the primary resource we work with, and we have made it a central focus of our process to achieve zero waste. We are dedicated to ensuring that every scrap of material is utilized and given new life. This approach allows us to create a range of products, including the main garment as well as accessories and patchwork materials, using the various remnants and leftovers from the waste. By adopting this mindset, we greatly reduce the amount of waste generated throughout our production process. We view textile waste as a valuable resource, and we find immense joy and inspiration in working with it. As a designer, the process of purchasing fabric and creating designs may become monotonous over time. However, with textile waste, every piece carries a unique story and presents exciting challenges in creating innovative materials. with scrap materials. Over time, as the brand establishes its name, vision, and focused approach, buyers should come to appreciate and seek out these variations in the products. Building a strong brand reputation and emphasizing the unique qualities of the products can attract buyers who value sustainability.

## Q8 If a person wanted to enter this fashion design industry based on textile waste, what would be your opinion on it?

I consider why someone must choose to start a new brand, particularly in a saturated market like fashion, there can be several motivations. While established brands already exist, why should one go to a new brand whether they bring something unique and innovative to the industry?

In the context of sustainability, launching a new brand can be driven by a desire to address the environmental and social challenges prevalent in the fashion industry. By starting a new brand, individuals can create products that align with their values and contribute to paving the path for sustainability.

## Q9 Does using scrap material instead of scrap material limit your creativity?

Using scrap materials instead of virgin materials can indeed present certain limitations in terms of creativity, as the available materials may vary depending on the type and quantity of waste obtained. Additionally, the number of units produced can be directly influenced by the amount of waste materials acquired. However, these challenges do not detract from the value and uniqueness of the process. While scalability can be a consideration, buyers need to understand and appreciate the individuality that comes with working

## Q10 Tell us about other challenges and obstacles in using waste textiles and how did they nurture you?

Sourcing waste materials from industrial sources can indeed present certain challenges due to regulations and restrictions. It may be necessary to adhere to specific guidelines regarding the types of materials that can be used, particularly when it comes to avoiding branded materials. However, these limitations can also lead to unique opportunities for creativity, as working with smaller and diverse pieces of waste material can result in more interesting and innovative products. Manufacturing is another aspect that can pose challenges when working with waste materials. Mass-cutting conditions in conventional factory settings may not be suitable for the nature of the materials. However, in the initial years, it can be difficult to shift the mindset of individuals to embrace the use of waste materials and adapt their manufacturing processes accordingly. Insufficient machinery can also be a hurdle in effectively processing waste textiles. Marketing can be a challenge as well, particularly when introducing the concept of upcycling and using waste materials to consumers who may not be familiar with these practices. Overcoming the perception that using waste materials diminishes the value of the products requires educating and raising awareness among potential customers.

Not only do we work

## INTERVIEWS

with individuals, but we also provide business-to-business (B2B) solutions. Our services extend beyond creating products for individual consumers; we offer comprehensive solutions to meet the needs of other businesses in the industry.

Obtaining ISO certifications and setting sustainable Key Performance Indicators (KPIs) demonstrate **our commitment to transparency, accountability, and environmental responsibility**. We are building a sustainable lifestyle that involves more than just offering eco-friendly products.

### Q11 When you pick workers, how do you do it do you give additional training?

I engage directly with our B2B partners, working closely with them to develop samples and prototypes. By being present during the development process, I ensure that their unique needs and requirements are met. Throughout the collaboration, **I gradually introduce more challenging products, pushing the boundaries of creativity and sustainability**. To ensure continuous improvement, we have a dedicated person who monitors the progress of each project and provides valuable feedback. This feedback loop is essential in refining our designs, optimizing production processes, and enhancing the overall quality of the products we create together.

### Q12 How long will it take for a person to train for this process?

Indeed, the **development timeline for unique pieces can vary significantly** depending on the complexity and nature of the product. Some intricate and innovative designs may require months of dedicated effort to bring to fruition.

### Q13 In the usual design you provide the layout for workers, in this how will it work?

We value the importance of bridging the gap between the buyer and the wearer by keeping the initial sketches as a reference throughout the development process. This ensures that the vision and intent behind the design are effectively translated into the final product.

Initially, some workers may have questioned the use of waste materials in our production process. However, over time, we have been able to shift their mindset and empower them to actively participate in the enhancement of our products.

**"WE ARE COMMITTED TO TRANSPARENCY, ACCOUNTABILITY AND ENVIRONMENTAL RESPONSIBILITY"**

### Q14 How do you plan for the future of your sustainability of design concept?

Ensuring that **nothing goes to landfill and promoting a circular approach are essential pillars of our brand's commitment to sustainability**. We are dedicated to minimizing waste and embracing a circular economy mindset that maximizes the lifecycle of materials. We actively work to divert materials from landfills, reducing environmental impact and conserving valuable resources.

**Interview:**
**Sajeevan M**
**Dept. Civil Engineering,**
**University of Jaffna**

**Transcript:**
**Rinduja R**
**Dept. Civil Engineering**
**University of Jaffna**

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**PERSPECTIVE**

# Microplastics

*While plastic pollution is extensively studied and the management including recycling of plastics waste are well discussed, this article discusses the emerging toxic side ot microplastics.*

**Dr D N Subramaniam**

Source: www.thesourcemagazine.org

## What is micro-plastics

"It is not another type of plastic, but the micro-size particles of macro plastics"

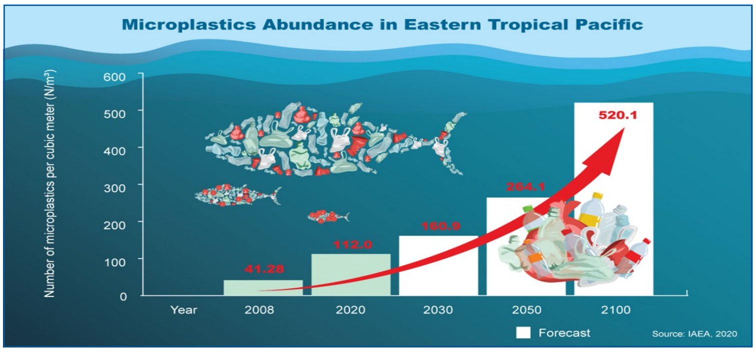
The particles are in the range of micro-meters. However, plastic particles are also found in much smaller scales, e.g. nano-plastics. It certain that plastic particles would be in existence in sizes smaller than nano metres, while locating them would need more sophisticated instruments.

Particles in the size range of micro metres are particularly dangerous to animals and humans, as they could penetrate the organs and deposit, while not being able to degrade will further lead to accumulation. Along the food chain in the animal kingdom, the predators would consume accumulated plastic when they prey on species that had microplastics deposited in them. This process is called bioaccumulation, and is a threat to all living organisms.

Compared to micro size particles, nano size particles can further penetrate cells in living organisms and reach blood streams, significantly reducing its functions.

Source: www.firstpost.com

Analysis of nanoplastics hence becomes important and imminent.

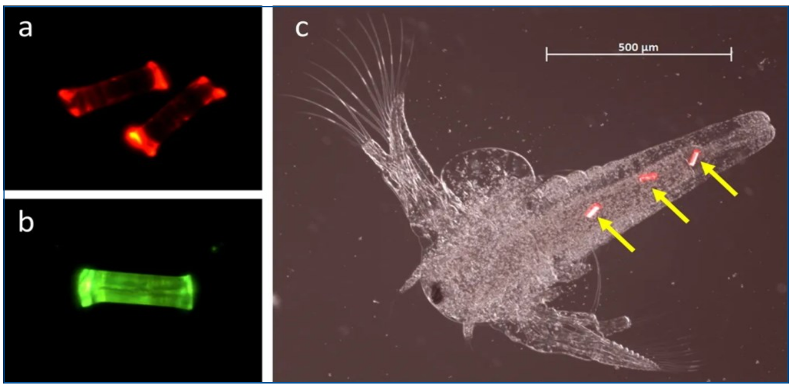



Source: www.iaea.org

Both micro— and nano-plastics can be either water-borne or air-borne. Macro-plastics when exposed to heat and UV, can disintegrate and decay in to micro-size plastic particles. Further process of decay reduces the particle size reaching nano and even smaller scales. Micro— and nano-plastic particles, when lighter than air and water can be airborne or waterborne.

Biodegradable plastics are believed to be environmental friendly, yet, disintegration of bioplastics also result in micro— and nano-plastics. Control of all types of plastics is therefore essential.

Source: desdemonadespair.net

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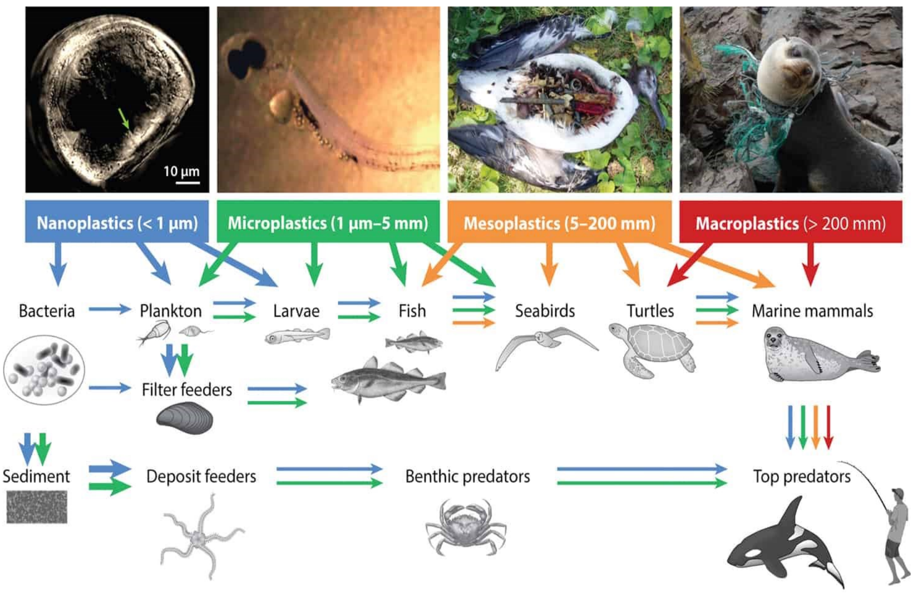
## Micro-plastics in terrestrial systems

Research on microplastics were more focused on aquatic environment and life forms until about a decade ago, mainly ecotoxicological. It included laboraotyr tests on indiividal living organisms and also focused on selected soil samples. Most effects microplastic have on the environment are mediated by physical parameters such as particle shape and size, rather than overt chemically mediated toxicity (plastics were originally believed to be inert in chemical toxicity). The first step in modern conceptualization of research on microplastic arises from the adoption of analyses on, 'plastic cycle', where macro plastics can get fragmented and become micro plastics, while they can also be transported across air, terrestrial habitats, rivers and other aquatic systems, including sediments. The focus of research is how microplastic flows affect such pools and fluxes in terrestrial ecosystems. While plastics are believed to be chemically inert, the behaviour and residence time of microplastics in soil are currently unknown. In addition, the current input rate of microplastic into the ecosystem is also not known. The origin of most carbon in microplastics are fossil based. Because of the resistance of microplastics to decomposition, it would continue to accumulate in ecosystems, including soil and this needs to be accounted for in assessment of soil caron storage related studies. The article says, the other effects of microplastics will be indirect owing to the particle shape and size distribution. Studies have established on the impact microplastics have on soil aggregation, that governs soil structure. Soil aggregates are the crumbs that contribute to soil structure and play a vital role in shaping the habitat of soil organisms. Furthermore, carbon compounds are stored within aggregates, where they are physically protected from being rapidly decomposed. Soil aggregate also determine the pore spaces available in the soil strata, that will in turn influence movement of fluids (gases and liquids) that will affect activities involving microbial activities. Another aspect would be because of plastic fibres where they will reduce the soil density, that can facilitate more plant growth, as the roots will have less resistant to penetrate. However, microplastics can also adversely affect plant growth, specifically by affecting growth of microorganisms, which need to be included in future studies.

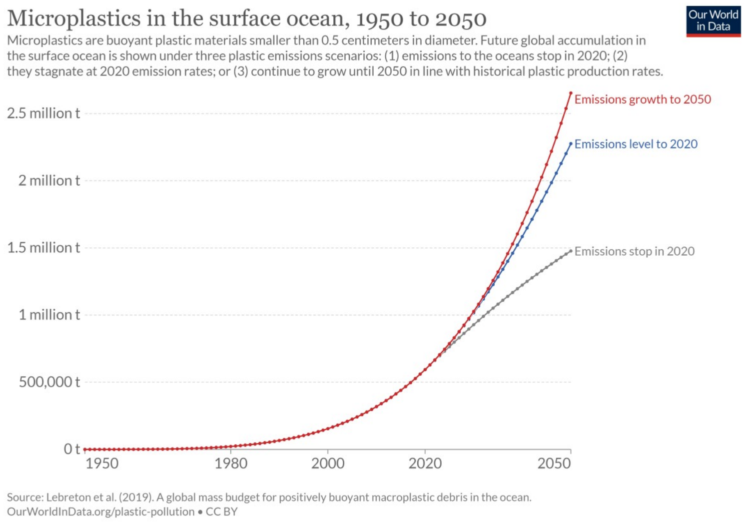
Since microplastics have less content of nitrogen and phosphorus, the impact microplastic may have on their cycle would be comparatively less to that they have on the carbon cycle. However, alternations effected by microplastics in the soil structure and microorganism populations, that may have an impact on the cycles of other elements too. For example, process of denitrification depends on specific anoxic condition and the presence of particular species of microorganisms, which may be affected by the presence of microplastics, that may in turn affect the process of denitrification. Another example discussed in the article is that the observation of increased population of arbuscular mychorrhizal fungi, that affects phosphorus cycling. Plastic films and fibres affect the flow of water in soils, including evaporation which eventually affect water dynamics and energy balance of the ecosystem. Another impact presence of microplastics and the changes in soil aggregation is that the impact it will have on erosion,

Source: thediscourse.ca




Worm B, et al. 2017.
Annu. Rev. Environ. Resour. 42:1–26

that depends on soil stability and structure. The article claims that the testing methods need to improve (accurate, sensitive, low-cost and harmonized detection) in order to facilitate studies to analyse the impact of microplastics on the terrestrial ecosystems.




### Microplastics may increase how much fat the body adsorbs

Microplastics can bioaccumulate, and the observations that they are already in the cells of aquatic living organisms such as fish and prawns, we are sure to get injected doses of microplastic in our daily diet. In addition, presence of microplastics in the water we consume and air we breathe, the dosage of microplastic to humans could be much higher than once thought. These traces of plastic in our food and water may increase how much fat we digest and absorb, a study finds according to the article, which will lead to the risk of obesity, heart disease and other conditions associated with consuming too much fat. The smaller the plastic particles become (micro, nano, pico....), the easier it is for them to leach into food and water. Demokritou and his colleagues looked at how nanoplastics affect digestion using a model of the small intestine made from these different types of human epithelial cell, which line membranes. In this study, the researchers added a nanoplastics to a slurry of protein, fat, carbohydrates, sugar and fibre, comparable to the average US diet. The researchers then added heavy cream to boost the fat content. In order simulate the process of digestion, the passed this solution through three other liquids containing enzymes and molecules present in mouth, stomach and small intestine. The final product contained about 100 micrograms of nanoplastics per millilitre, which is again comparable to the average concentration of nanoplastics in food and water consumed (although it varies widely). The researchers coated the solution onto the small intestine model and measure the concentration and breakdown of fat after 2 hours later. Compared to the control in the study, the observed that the presence of nanoplastics boosted the breakdown of fat, increasing digestion by 33%. In addition, nanplastic mixture also increased the amount of fat the tissue absorbed by approximately 145%. On the other hand, they found that nanoplastics was not toxic to epithelial cells or even decreased gut permeability. The researcher claimed, that as of now, although nanoplastics was not toxic, they interfere with other processes at an alarming rate, which makes them toxic.

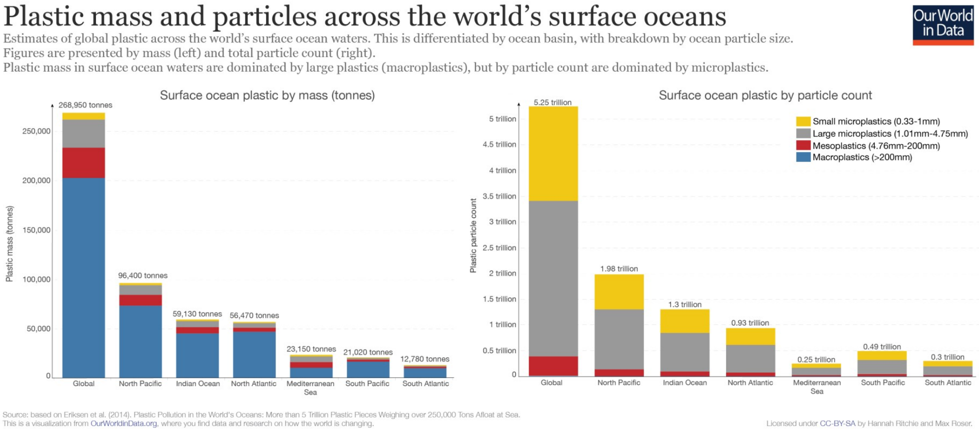
**Source: www.umsicht.fraunhofer.de**

## Microplastics alert

We have discussed above that the loading of microplastics into the ecosystem is yet hard to monitor and assay. This article claims studies that try to track the presence of microplastics in seaborne flecks from more than 300 miles (from space).

A report on Scientific Reports have outlined how microplastics appear to flow alongside floating patches of oily and soapy substances called surfactants, which create distinct footprints in ocean currents. These footprints are believed to be detectable by NASA'a Cyclone Global Navigation Satellite System (CYGNSS), a network of eight hurricane-monitoring satellites. Tracking the presence of microplastics in oceans will assist manage them and also to clean them up from the oceans. Yulin Pan, a researcher at University of Michigan claims that using remote sensing technique could find a solution for this challenge. The CYGNSS satellite radar measure the ocean surface's roughness caused by wind-generated waves. In 2021, the researchers observed that the radar picked up peculiar areas of smoothness that had fewer and smaller waves. Later they found out that the anomalies coincided with Great Pacific Garbage Patch, which also correlated to the amount of microplastics in the water. This technique was then used to monitor to track microplastics in other hotspots to affirm the observations. While the researchers have not still found out the reason for the smoothness, they even still haven't identified if it was mainly due to microplastics or other factors such as marine life, other debris or chemical reactions. They claim it is hard to isolate microplastic in such studies in the wide ocean to confirm if microplastics were the sole reason for the anomaly.

Pan and his CYGNSS colleagues then used 750000 gallon indoor wave tank to simulate real-world currents. They found that microplastics alone, at their reported ocean concentration, did not generate the smoothness, but the smoothness came when the researchers added surfactants. These surfactants influence wave activity by decreasing the water's surface tension, often accompany microplastics as a by-product of plastic production and breakdown and are carried on the same ocean currents. From this observation, surfactants can be used as tracer or surrogate parameter to identify the microplastics in the ocean.




## Consumption of microplastics

Plastics in the environment, such as roofing, water bottles and other consumer items, even while in use can disintegrate and release micro and nano particles. For example, roofing tiles may disintegrate and release micro— nano-plastics into the indoor air, which would be inhaled during beathing by inmates. Furthermore, plastic bottles that are used to bottle water and other consumer drinks, may disintegrate and release micro— and nano-particles of plastics in the drink that it contains, which upon consumption may enter the consumer. Plastic in this range can interfere cell functionalities and are potentially seen as carcinogenic.

Source: www.impaxhealth.com

**Original article: Science, 26th June, 2020: page 1430**

**Original article: New Scientist, 8th April, 2023: page 12**

**Original article: Scientific American, May 2023: page 17**

ARTICLE

# The Need of Managing Municipal Solid Waste to Preserve Intergenerational Equity: What could we do?

Prof Chamara Kuruppu

*The article discusses implementation of concepts of circular economy for management of municipal solid waste.*

## Introduction

Individuals and organisations, along with the population and economic growth, tend to increase the consumption of renewable and non-renewable resources, and the generation of waste. As such, waste is part of our day-to-day life. In general, waste refers to any substance or object that its owner would like to dispose, as it has reached the end of its useful life or lifespan. Normally, waste could contribute to generating a twofold challenge namely, negative impacts on human health and the environment, and loss of finite and valuable resources (Van Ewijk and Stegemann, 2020). As any other country, local governments in Sri Lanka are officially responsible for managing solid waste within its administrative area.

As envisaged in the literature, manging municipal solid waste is a challenging task even in the developed countries (Alwood et al., 2011; Minelgatie and Liobikiene, 2019). For example, the European Union is likely to dispose more than 50% of municipal solid waste generated by its member countries through landfill (see Pires and Martinho, 2019; Tomic and Schneider, 2020). Therefore, there is increasing pressure to adopt environment friendly waste management practices, as unsustainable waste disposal practices contribute to endangering biodiversity, quality of air and water, degrading soil, and depleting resources amongst others (see Geissdoerfer et al., 2017). Any harmful waste disposal practice – used by the present generation – could negatively influence not only its well-being, but also the well-being of future generations. Such a scenario is unfair, as they cannot oppose any decision made by the former group. This means that it is necessary to preserve the future generation's equity in our planet.

In 1987, the United Nations' World Commission on Environment and Development (WCED) underscored the responsibility of the present generations to future generations through its reports, namely "Our Common Future". As emphasised by this commission, it is the obligation of the present generation to minimise or avoid the waste of resources, and negative environmental and societal consequences of human activities. We are urged not attain our well-being at the cost of future generations' well-being and existence. This means that resources at our disposal belong to future generations and we are the custodians of their resources. As such, we should make our authentic endeavours and commitment to be accountable for intergenerational equity concerned with the right of future generations to reap the benefits of natural resources without a substantial deduction of their availability (Lamberton, 2000).

The publication of the 2030 Agenda and the 17 sustainable Development Goals (SDGs) in September 2015 echoes the need of assuring sustainable development in its three dimensions, namely economic, social and environment, in a balanced and integrated manner, and conserving intergenerational equity. Therefore, this agenda urges us to assure that our production and consumption patterns and use of all natural resources should not undermine the human beings' sustainable existence on the earth. Nevertheless, solid waste – harmful residue of our production and consumption efforts – is inevitable (see for example, Van Ewijk and Stegemann, 2020). While such waste could negatively affect the three dimensions of sustainable development, a crisis dealing with waste management is very attractive to media outlets. In Sri Lanka, Meethotamulla tragedy in April 2017 being a typical example. As a nation, we should avoid such incidents. This essay aims at pinpointing circular economy as a way forward to preserve intergenerational equity, whilst assuring the well-being of our generation.

## A Perspective on Circular Economy

The SDGs in the 2030 Agenda emphasise the need of assuring the well-being of the present generation and future generations. In contrast to the UN's expectation, contemporary entrepreneurs often adopt a linear economic approach



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(Neumeyer et al., 2020) – promoting the behaviour of producing, consuming and disposing – that increases the volume of waste. The inability of manging disposing products – solid waste – could certainly generate adverse consequences to human health and biodiversity. Based on the Word Bank's estimation in 2018, the global community produces nearly 2 billion tonnes of solid waste annually, whereas the annual solid waste generation is approximately 2.50 million tonnes in Sri Lanka. While the global unsafe waste disposal rate is 33%, the island's rate could be 85%. Such a waste management practice impedes our ability to attain the SDGs and to conserve intergenerational equity. As a member of the UN, if waste is unavoidable, Sri Lanka should minimise its negative consequences.

To address the challenge of managing solid waste, Some of the European countries have relied upon a waste hierarchy principal since the late 1970s (Geissdoerfer et al., 2017). In 2008, the European Union forced its member states to introduce national laws on waste hierarchy by endorsing the Waste Framework Directive (WFD) 2008/98/EC that outlines the EU's waste hierarchy principal (Gharfalkar et al., 2015). Its waste management hierarchy propagates five approaches – prevention, preparing for reuse, recycling, other recovery and disposal. Because of the WFD, all the member states are obliged to lay foundation for a circular economy in contrast to the existing linear economy approach.

Scholars have envisaged the earth as a closed and circular system. Similarly, its assimilative capacity is limited. Therefore, the environment and the economy should maintain their coexistence in a balanced manner, as demonstrated by Geissdoerfer et al. (2017). In other words, the CE is promoted as the pathway to sustainable development (Corona et al., 2019). Based on such discussions, we could argue that the CE enables enterprises to operate their business activities as per the UN's SDGs. Accordingly, the need of minimising waste and its negative consequences amongst others are discussed in the political, social and economic forums. In addition, the importance of using waste as a resource to refrain from landfilling are underscored (Van Ewijk and Stegemann, 2020). In other words, such discussions request to adopt a new business model while underscoring that the environment is not a waste reservoir (Urbinati et al., 2017).

By reviewing the literature on the CE, Kirchherr et al. (2017, pp. 224 - 225) elaborate the CE as "an economic system that is based on business models which replaces the end -of-life concept with reducing, alternative reusing, recycling and recovering materials in production/distribution and consumption processes, thus operating at the micro level (products, companies, customers), meso level (eco-industrial parks) and macro level (city, region, national and beyond), with the aim to accomplish sustainable development, which implies creating environmental quality, economic prosperity and social equity, to the benefits of current and future generations". Akin to the EU's waste hierarchy principal, their definition demands us to change our production and

## SCIENCE NEWS

### Space junk satellite to launch

We have been discussing waste material in land and ocean most of the time and also refer to pollutants and contaminants that are airborne. We have not moved past out near atmosphere, as the out space may not be of much problem to us in the near future. However, we have often failed to realise how much of material we have sent to space, and perhaps, a lot of it are actually orbiting around the earth at a distance in the distant atmosphere. All of the equipment we have sent have a finite lifespan and that they too become waste, probably quite too soon. These junk material, already started to accrue in the out atmosphere, may have to be removed. The Finnish company, Aurora Propulsion Technologies, is preparing to launch a satellite to test space junk removal technologies using Rocket Lab, a launch provider and space systems company. Aurora is planning to deploy AuroraSat-1 to low-Earth orbit in a demonstration of its proprietary propulsion devices and plasma brakes that have been designed to provide enough propulsion and deorbiting capabilities for small satellites.

Source: spacengineer.com

**Original article: New Electronics, 24th August, 2021: page 07**

consumption behaviour.

### What should we do to preserve intergenerational equity?

A country's waste generation particularly depends on its economic development (Minelgaite and Liobikiene, 2019). In line with the economic growth, the volume of waste is climbing. In other words, the present generation will exploit more of virgin resources — renewable and non-renewable. Such a trend could adversely impact on intergenerational equity, as there is possibility to extract natural resources beyond their regeneration rate. Similarly, the opportunity for future generations to enjoy the benefits of non-renewable resources may decline, whilst waste could end up in open dumps. As exhibited in the literature, unsafe disposal of waste could contaminate water sources, pollute soils, spread disease and increase the risk of flooding (Bekchanov and Mirzabaev, 2018). To avoid such consequences, the present generation should alter its production, consumption and waste disposal practices (For example, see Gharfalkar, 2015; Urbinati et al., 2017; Corona, 2019; Minelgaite and Liobikiene, 2019). Otherwise, we particularly act in contrast to most of the SDGs.

Source: lens.monash.edu


While being a problem, solid waste generates opportunities to answer some of the previously unresolved issues (Tomic and Schneider, 2020). Nevertheless, a country's inability to manage solid waste effectively, both its citizens and the global community are likely to lose alternative uses of such waste. In other words, it could be a lost opportunity. To address this problem, the EU has adopted its WFD to facilitate and nurture the alternative use of solid waste (see for example, Pires and Martinho, 2019). Albeit this WFD has been criticised for the confusing nature of the waste hierarchy (see Gharfalkar et al., 2015), the prevention of waste behaviour is in the highest level of the waste hierarchy, whereas the disposal of the waste is placed in the lowest level. When the scenario of waste prevention is unattainable, the present generation should explore other alternative behaviours.

To instigate the CE as the optimal pathway to sustainable development, scholars have discussed to refine the EU's waste hierarchy (see Gharfalkar et al., 2015). Such discussions particularly aim at widening the scope of the five lawyers — prevention, reuse, recycling, recovery and disposal — in its waste hierarchy to accomplish a full or broader circular economy (Urbinati et al., 2017). One of the arguments is to prevent the possibility of occurring waste (Pires and Matinho, 2019). Such a behaviour can be materialised with the help of qualitative and quantitative measures (Gharfalkar et al., 2015). The former measures encourage to design products to last longer or to keep them longer (reduce). Similarly, the process of buying and selling used goods — owners have not intention to keep them — is also a qualitative measure (reuse). In addition, using biodegradable parts instead of hazardous substance (Pires and Matinho, 2019) is another qualitative measure (replacing). Moreover, consumers could refrain from purchasing (refuse) products made of non-degradable materials (Kirchherr et al., 2017). As a quantitative measure, our desire to purchase a smaller number of products or items and use fewer amount of material per unit (reduce) is important (Gharfalkar et al., 2015).

Reuse is given the second top priority in the EU's waste hierarchy. Reusing a discarded product by another individual, as it is in proper condition and useable for its original purpose (Kirchherr et al., 2017). Similarly, a technically malfunction or defect product could be repaired and reused without reprocessing (Gharfalkar et al., 2015). Recycling is the third rung of the waste hierarchy. It implies that materials are processed to derive a high quality, same quality or less quality product (Kirchherr et al., 2017). As demonstrated by Pires and Martinho (2019), both up-cycling and down-cycling are part of recycling initiatives. Because of the recycling measures, waste materials will be subject to some types of biological, chemical or physical treatment enabling it\them to be used in producing a similar product or another product (Gharfalkar et al., 2015).

The fourth stage of the waste hierarchy represents recovery of materials from waste. Recovery refers to measures that enable to avoid using virgin natural resources (Gharfalkar et al., 2015). It could be divided into two sub-categories – non-energy recovery and energy recovery (Van Ewijk and Stegemann, 2020). The measure of incinerating material for deriving energy is a good example (Kirchherr et al., 2017). Nevertheless, the latter alternative should be considered as the last resort. The fifth level of the waste hierarchy is disposal or return. It means any initiative through which a product – useless for any operation – is disposed to the environment (Gharfalkar et al., 2015). It is necessary to assure that our waste disposal practices would not contribute to degrading biodiversity and ecosystem services.

## Concluding Remarks

Manging solid waste is a challenging and difficult problem to the municipalities in the developed and developing countries. Some of the European countries have attempted to recycle waste with a view to preventing or delaying the occurrence of waste since the 1970s. Albeit the Sri Lankan ancestors have historically practiced a sustainable way of living (see Pemananda and Kuruppu, 2022), the country's contemporary way of managing waste contradicts with the UN's SDGs. For example, Sri Lanka annually collects around 3 500 tonnes organic waste per day and recycle around 20% of such waste (Bekchanov and Mirzabaev, 2018). Such a trend envisages that most of the island's waste could often end up in landfills, causing environmental, health and social issues. To address the challenge of managing waste, this essay envisages the CE as a way forward. However, this essay does not claim that there are no good examples of wate prevention, reusing, recycling, recovering and disposing initiatives in Sri Lanka. Instead, this essay underscores the need of formally promoting a waste management hierarchy that will transpire the island-wide CE initiatives. Such a move will help us avoid the occurrence of disaster like Meethotamulla. Otherwise, our descendants will criticise us for being ignorance of possible waste-related crisis.

It is not possible to establish the CE without altering our prevailing way of producing, consuming and disposing practices. We are being influenced by the advertising campaigns – instigating consumerism. It is our obligation as the academics to take initiatives in educating the citizens the negative consequences of unsustainable way of consuming both renewable and non-renewable resources, and disposing waste, while the government adopts a suitable waste hierarchy – promoting waste prevention, reuse, recycle, recover and disposal – to preserve intergenerational equity of future generations. It will certainly be costly to propagate the CE. At present, the country may not be able to bear the cost of fostering the environment friendly waste management practices due to the economic crisis. The Techno-Economic-Societal Sustainable Development Training in Sri Lanka (TESS) project – funded by the European Union under its Erasmus+ CBHE programme – could play a leading role in educating both municipal officials and citizens how to segregate and recycle waste to conserve the environment and its biodiversity.

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**BRIEF**

## Global implications of the EU battery regulation

Predominantly, electrification of urban transportation modes are considered a solution for decarbonation of the industry, provided the electrical energy is sourced from renewable technologies. This makes the design, production, manufacture, use and disposal of lithium ion batteries (LIBs) drawing more consideration. Owing to ensuring environmental, economical and social consequences of the battery cycle is sustainable, exponential growth in metal extraction, impact of battery production on climate change and uncertainties in battery end-of-life (EOL) safety and recyclability are becoming important in policies and studies.


Source: www.edfenergy.com

The European Union (EU) has initiated and drafted a Battery Regulation, which aims to ensure sustainability for batteries placed in the EU market, developing a robust European battery industry and value chain. The article discusses on the implications on the global scale of this regulation, where certain aspects are unintended consequences and it is observed that if left unaddressed, may hamper global scale efforts on combating climate change revival measures and fall short of promoting circular economy.

A current regulation (2006 EU Battery Directive) is amended in this proposal to address modern challenges, primarily stipulating labeling and information provisions, setting out supply chain due to diligence requirements and enforcing the use of recycled materials for batteries over 2 kWh (most of which are used in electric vehicles). The trend is observed to have increased the demand for LIBs by ten folds in the last decade, and is expected to continue in the current decade, necessitating regulating production, usage and disposal of LIBs. Although EU is the second largest market for EVs, specifically due to the regulations imposing restriction on sales of conventional vehicles in the EU, LIB supply chains remain out of EU, and hence relying outside EU for metal extraction, refining and battery manufacturing. These global manufacturers of LIBs would have to comply with the EU regulation which is to be implemented, indicating a global scale repercussions. The article assesses four key elements of the regulation that are core to improving sustainability of LIBs.

1. The proposed regulation intends to increase transparency and traceability across the battery life cycle, mandating third party due diligence of the supply and value chains for batteries greater than 2kWh.

2. It addresses climate impact throughout the battery life cycle by mandating carbon footprint declaration and later establishing maximum thresholds.

3. The regulation emphasizes on certain action to promote circularity of critical materials, targeting increased collection and recycling efficiency, improving recover rates for metals such as lithium, cobalt and nickel and mandating the use of recycled materials in new batteries.

4. The regulation also proposes requirements for longevity and performance management, including assessment for waste processors to the battery management system (BMS), that in turn verifies the state of health of the battery in realtime and can determine the potential for the battery to be reused or repurposed before being recycled.

The first two elements discussed in the article seek to ensure the quality and availability of underlying data needed to guide environmental responsibility and track compliance by industrial player, while the last two elements provide a foundation for EU efforts to establish circularity as an economic opportunity aligned with its long-term sustainability objectives.

The EU in addition to the regulation proposed, also intends to support battery developments through various initiatives including creating an alliance called European Battery Alliance and financial aid packages to churn research and innovation all along the entire battery value chain. Contemporarily, the LIB market is dominated by companies from China that holds more than 65% of the supply chain. Although companies like Tesla in the US have their own battery development facilities, like

*Continued on page 46 ...*

## EU battery regulation ...

EU, they rely on supply chains outside the country. The EU also aims to provide subsidies related to battery production given certain requirement are met specifically meeting minimum standards for the reclassification of batteries for reuse applications, recycling efficiency of plants treating batteries at the EOI and product labeling. Meanwhile, China's State Council issued a blueprint for energy sector that included guidance on the development of battery supply chains, recycling to support energy efficiency and provisions for reducing the carbon intensity of electricity production used to power EVs. The United Stats also has considered supply of critical materials for electrification of transportation with the Biden's administration a priority with an investment of $174 billion in EV programs. The effort focuses on reestablishing primary metals refining and manufacturing in the US and creating new recycling capabilities as part of materials criticality efforts. The article however claims that the US lags behind China and EU in devising policies relating to EVs, specifically in mandating Extended Producer Responsibility (EPR) or promoting circular economy principles, while basic regulations regarding classifying batteries as hazardous waste and to keep them away from landfills and incinerators.

The LIB industry is currently experiencing rapid growth and innovation, where new technologies emerge very frequently. The dynamics in the demand and supply growth and technological advancements create an uncertain future on market development, which in turn restricts market investments. Introduction of regulations as the ones proposed by EU would contribute to make a firm footing on developments making the market more robust to change, availing market opportunities for a longer period. On the other hand, over-regulating the industry may also hinder competitiveness, leading to reduced innovation.

**Original article: Science, 23rd July, 2021: page 384**

## SCIENCE NEWS

### Termite bacteria could chomp wood waste into biofuel

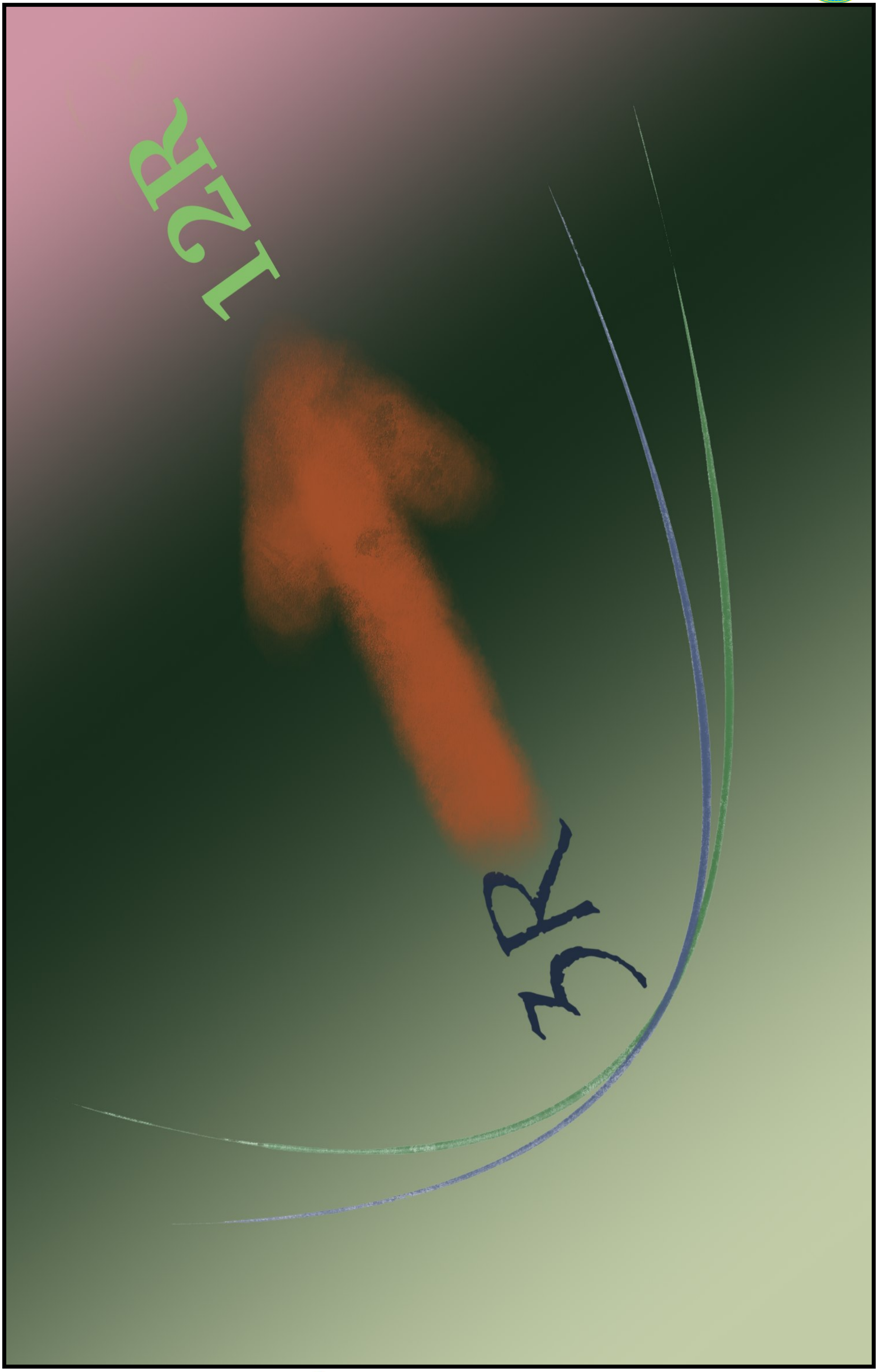
Bacteria found in the guts of a particular species of termite are observed to break down toxic creosote, a chemical that used to preserve wood. This finding is useful in turning otherwise harmful chemically treated wood waste into biofuels, that are environmental friendly and also help manage wood waste that would take longer to degrade as it was preserved using creosote. The guts of termites are observed to have concert of microorganisms that allow the insects to digest tough lignin and cellulose in wood as observed in previous studies. Lignocellulose has abundant sources of renewable carbon on the planet – into biofuels via anaerobic digestion. Anaerobic digester systems often use methane-producing microbes to convert food waste or sewage into biogas. However, as most microorganisms struggle to break lignocellulose, digestion of woody plants remains challenging. When wood preservatives are added, it becomes almost impossible to break down preserved wood in digesters.

Source: www.oist.jp

Researchers Sameh Ali and Jianzhong Sun at Jiangsu University in China have found that the bacteria in the guts of Coptotermes formosanus termites can decontaminate wood containing creosote, in addition to breaking down lignocellulose. Broken lignocellulose can then be easily digested in anaerobic digesters to produce bio fuels. The researchers isolated bacteria from the guts of the termite and selected four that could decompose creosote. Thereafter they grew them in liquid cultures. Creosote-soaked saw dust was treated with the bacterial mix for 12 days and observed that they removed toxic naphthalene and phenol. The main findings from the study was that the bacterial pretreatment boosted biogas production and methane yields by approximately 58% and 83% respectively.

Source: www.enviroshield-usa.com

**Original article: New Scientist, 31st July, 2021: page 12**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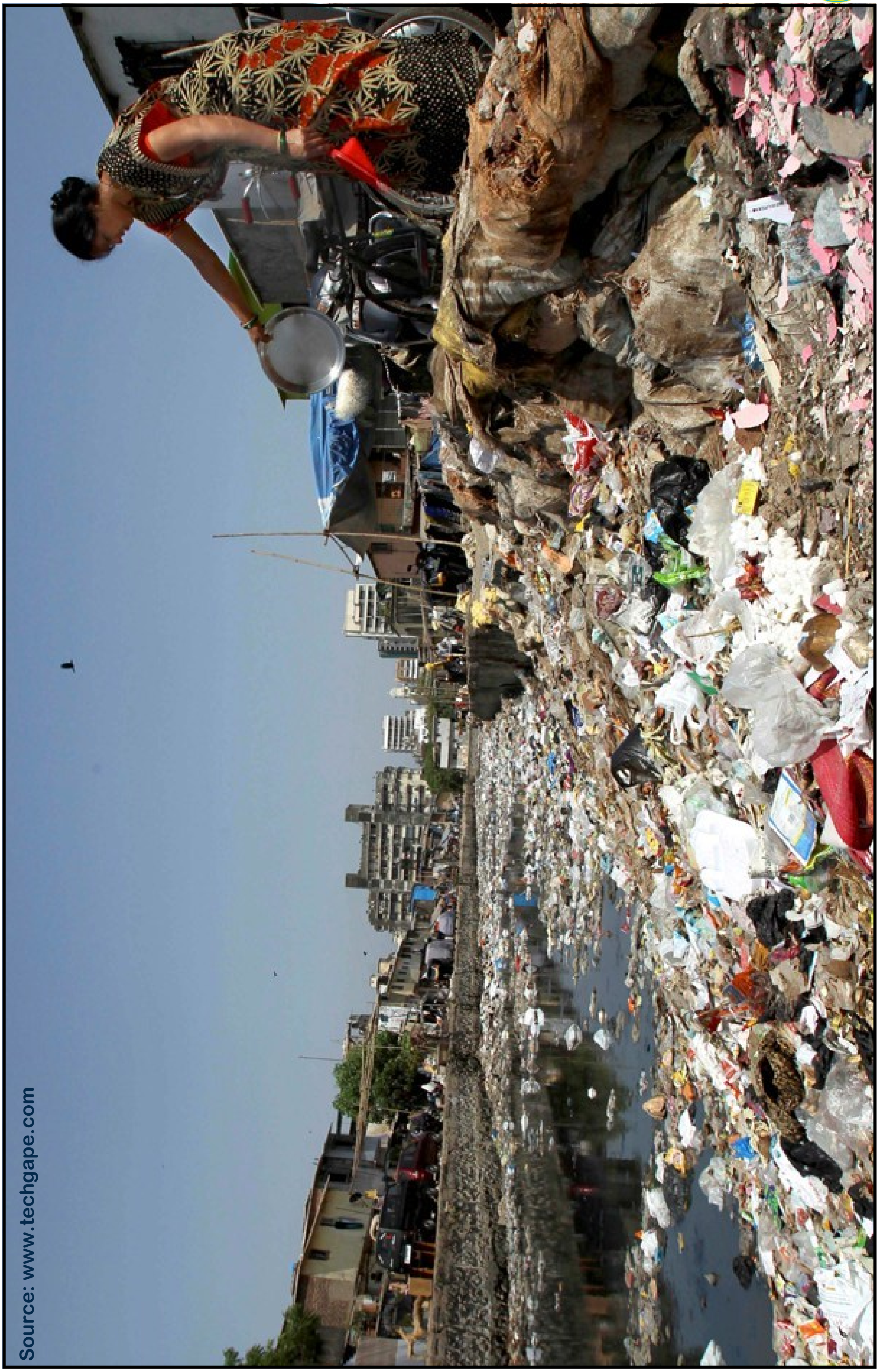
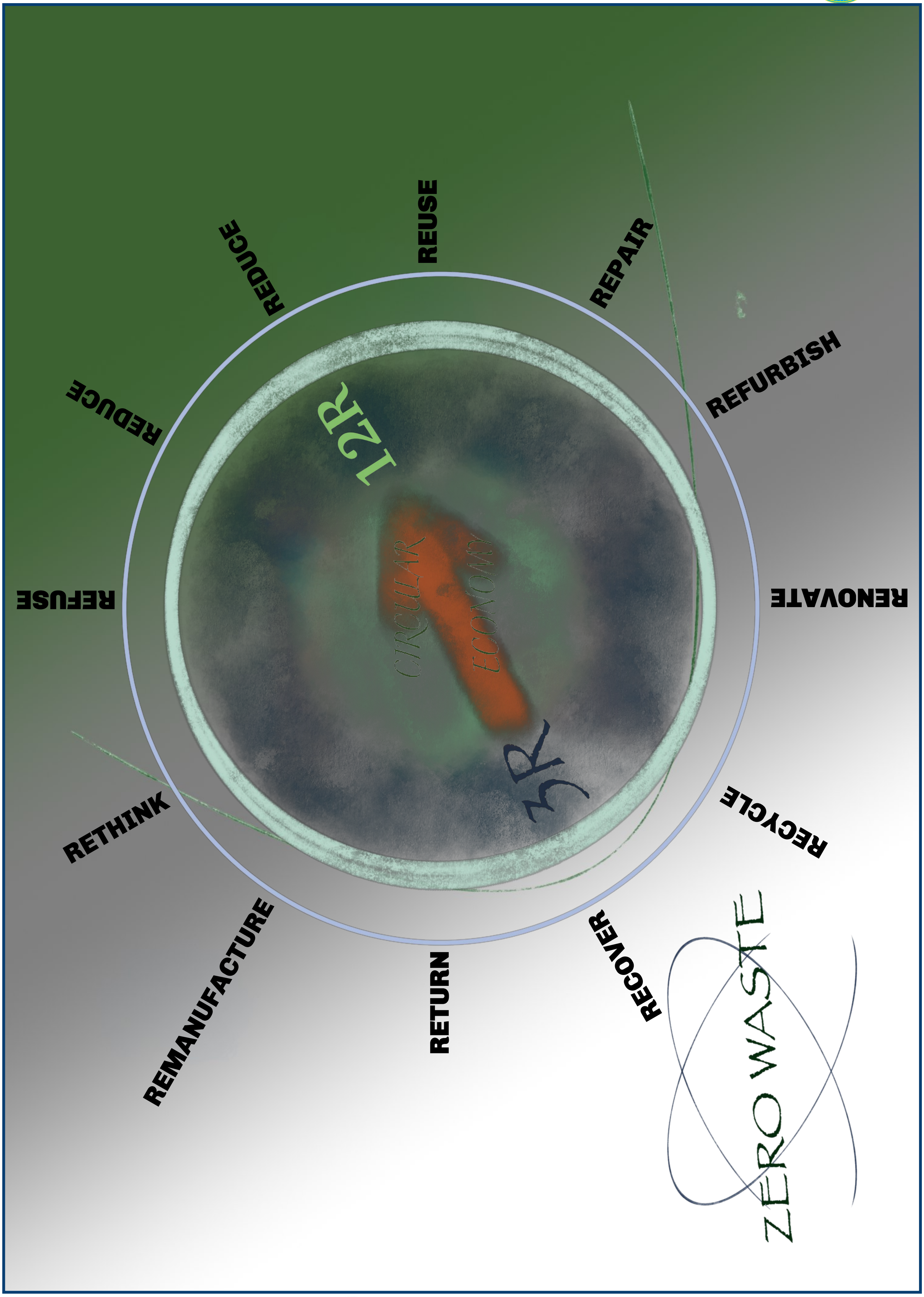


Source: www.techgape.com


REDUCE
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ECONOMY
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ZERO WASTE


Source: www.averda.com

**NOVEL CONCEPT**

# Green Life Generation

**Ms Savandie Abeyratna**

*An institution, 'Green Life Generation', explaining about the initiative, concepts and challenges in running the business sustainably, and the novel concepts implemented through this project.*

What we tried to represent here is that planet earth is our home. It's a finite place, not infinite. And our development trajectory industrialization has driven us in that path. It is not far away, but we are there. What we as green life generation try to do is how we can look at this global perspective of think globally and act locally to make this shift towards the greener world. We use the framework of sustainable development goals to which the world has come into a consensus that we should abide by. Se specifically look at Goal 12, responsible consumption and production, which foundational and a great starting point to make massive changes towards the greener initiatives.

One of the biggest issues with the industrial development trajectory is the linear economic model. Wee take to change that to a circular model, based on circular economic principles. As Green Life Generation, we are trying to do this on the ground. What prompted us to start this Green Life Generation, which started in 2017, was the Meethotumulla garbage disaster happened in April/2017. While we respect those who lost their life in the incident, we do not want a tragic incident as such to take place again in this country. You may have heard about the 3R concept, whereas we have adopted a 16R concept in our operations. We start here by recovering waste from the community, to implement it in our bin-coin system. We have implemented a membership concept, where members of the community can obtain a membership to the program. The members can bring in all their waste (including plastics) where we separate them based on the market value. What is novel here is that, instead of integrating to the already existing market recycling, we have created our own currency called BinCoin, which is based on a value determined by the organization (this may also partially reflect market value, but not completely). Our approach is ecosystem based eccentric approach. For example, even a toffee wrapper has a value

**Figure 02**

**Figure 01**

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a week, to clear the backlog as well.

The second R that we adopted here is RECORD. Once we collect all the waste from the previous location, it comes here where we do a brand audit. We record everything we had collected by brand and at the moment everything is in paper form (not IT based) where we lack technology at the moment. We have got brand audit record since 2021 when we started the BinCoin system. The purpose of us doing this is because several items such as low value plastics does not bear any incentives for collection to happen. In the meantime, there is no solution for those waste either. At the moment, most of this goes to Puttalam cement incineration plant, and people keep sending it there as there are no alternatives. We believe that scientists will come up with better solution and what we could do at the moment is to not send it into a pathway where there's leakage, we should just keep hold of it. Our belief of a solution now is space and time. If we can creatively use space to buy time, solutions will emerge. At that moment, this waste collected will be sent for processing. Until then we do not want to pollute the environment. The other aspect of our brand audit is about the responsibility of the waste. While the local government has a responsibility, it is often transferred to the consumers. We however believe, that the producer is also responsible. Most European countries have regulations on Extended Producer Responsibility, while in Sri Lanka it is emerging, yet restricted to PET bottles ad yoghurt cups at the moment. It will take a long time to get there, but we are pushing for that. It's an uphill battle, and will need a lot of advocacy to push towards implementation. Our vision is principally to establish a model, something like our BinCoin (among many other models currently in research) where a customer would know the path of managing their waste while the producer also tracks their product end of life. Another purpose of the brand audit is to change the measure of waste (other than weight base measure). This is also a cutting edge in research, where we are still uncertain of where we will be led to. We believe that we should implement a system like a square area, where our BinCoin is also measured in size as a metaphor. For example, 5 BinCoins for a toffee wrapper and 10 BinCoins for a larger wrapper, where according to weight measure, the wrapper may not have any significant value. Yet, the wrapper can cause an extensive environmental damage. We aspire to develop a more representable measuring system, having collected the data as we do in brand audits. After collection, the waste materials (e.g. beer cans, PET bottles, yoghurt cups etc) are washed by ladies who are employed in the institution. Waste materials like toothbrush and razors, we collect but do neither wash no process, due to the hazards fraught with it. The materials we consider washing are subsequently used for upcycling in our institution.

Figure 03

Figure 04

This is our cleaning location, which corresponds to the R of REGENRATE. This is where we start to delve into the circular economy. This is where we take a material and start to regenerate into a new generation of production and process and take into the cycle. We haven't started cleaning in this new location as yet, as we believe that the water used for cleaning will need to be treated. Sending the cleaning water into a water resource, no matter how less polluted it can be, it can set a bad reputation and an image on our wholistic approach on zero impact on the environment. We are in the process of designing a filter (perhaps, natural filter) to remove any pollutants that may come with washing of waste material. Typical pollutants could be food waste, mostly oil, and cosmetics items that will need specific treatment objectives. The gap we have is the investment and also technology that is required for water treatment.

We learnt in 2019 and thereafter with the turn of events in the nation, that production system alone cannot sustain an initiative as such. Prior to 2019, we focused more on the production line. For example, we opened our upcycling institution with cement paper and cardboard upcycling. With the cement and milk powder crisis, we ran out of supply of cement paper that strained our activities, that led to layoff of staff and also finding it challenging to even stay afloat. That is when we introduced a system where the members of the community could bring in their waste and earn BinCoins to shop in the secondhand shop we had. Initially we got donation of secondhand materials, mostly clothes which were used for upcycling. In addition, during the national crisis, we realized, some people did not need clothes, but needed more basic like food. This led to

**Figure 06**


the establishment of a café, where people could use their BinCoins to buy food in the café. We have gone wider with our initial focus on the 12th goal of Sustainable Development, and now we have adopted the 2nd goal which is to go for zero hunger. We hope to develop this place more of other services, particularly educational services of tuition classes. This way, members would be able to get much more valuable services through the BinCoin system. We believe that strengthening the relationship with the members is cru-

**Figure 07**


cial in this type of initiatives, and more valuable services would be a better option for that motive. Cafes are considered a luxury in an average Sri Lankan village, and access to a café is not freely available for such members of the society. Getting access to such a shop through tendering in their waste material (otherwise bear them no value) is expected to give them an incentive to take part in the larger goal of our institution (waste reduction in the community). Another R we focus on is REGULATE. Regulation is inevitable for models as these to successfully function in a community, that requires laws and policies to be implemented. This requires a lot of RESEARCH (another R) and development. This is important for a financial success of such an initiative. We have to look at things from different perspectives and angles to bring a comprehensive solution and make it more sustainable. This will also lead to innovation that can greatly improve the

**Figure 05**

efficacy of this model. I, the Founder, is the main analyst who collect data analyse, conduct literature reviews and develop concepts. However, I hope to involve more

Figure 08

people to join, to make it more innovative and wider collection of ideas. It is apparent that a polluter will know they are polluting. However, when the producers want to greenwash, they put out some products that can pollute, and they collect some waste from the environment and balance it by weight. However, what the producer put out to pollute may not necessarily have been collected by them. For example, a produces releasing plastic bags, may collect few plastic bottles (equivalent by weight), while their products are still polluting the environment by a large volume. This type of issues need to be sorted through research and development in policies and regulations. Policies should necessitate collection of the waste produced by the polluter instead. We believe that the innovation should also encompass policies and regulations in addition to the conventional focus on technological advancement.

Figure 09

In our secondhand shop, members can bring in their used products and exchange for a product or BinCoins. We started off with cement paper, carboard and wood. This focusses on REUSE and REDUCE in this section of our institutions. At the moment we are not upcyclig plastics or even selling it in the secondhand shop. We do not believe in promoting reusing plastic and release it back into the society. For example, the toys are not sold in the secondhand shop. Instead, we have them in the paly area, where children of members could come and play, but that cannot be purchased. We want to give a message to the community, that plastic needs to be contained and not upcycled. When it comes to upcycling of fabric and cosmetic packaging, we are still working on our way to check for testing protocols for reuse and recycle. They

Figure 10


can have pathogens and dust material, which may have to be treated prior to upcycling.

We are also trying to develop another concept called 'My EcoBond', a financing strategy to keep this initiative going. We do also take into account of material assay in our upcycling. For example, if we are producing a cushion using waste material, we do keep a record of what material, which brand of material and in what quantity has it gone into the cushion. When a more affordable and sustainable solution comes, we have the record of which products need to be considered. Several upcycling items are a temporary solution, awaiting a more sustainable solution is developed. We also give a notion to the customer that it is not a product that they are buy-

**Figure 11**


ing to keep it to themselves, but it is that they are becoming part of the temporary solution providers to a bigger environmental issues, and that they are championing their social responsibility towards the community by diverting some waste ending up in a landfill and pollute the environment. This is one way we use space and time, as I explained earlier, our concept. For example, if you open this chair, you may find waste materials that are temporarily stored, for a bigger cause. When a customer buys a product, they do not just buy a visual product, but they are becoming part of a movement for environmental change. Extending further on the concept, a person may realize that if a plastic bag is left in the environment, it may end up damaging life forms both on land and sea. By getting involved in this initiative, they are averting a larger danger. These cushions are mostly filled with polyester fibres anyways, and we are filling them with plastic waste instead. All our products have a BinCoin value and a LKR value. By purchasing the items, consumers also become part of the project and concept. This can therefore be considered as a partnership of public and private entities.

People are highly skilled and talented, where most are not even realized by themselves. There is lot of creativity, and projects and initiatives like this would bring out the potential in them, benefitting monetarily and environmentally. I really hope, we can expand this models or any other sustainable model to be implemented widely, and becomes part of the ecosystem and change the consumerism more environmental friendly and sustainable. While I understand, this is only the start, I expect more research and studies go into several aspects of waste management challenges and more innovative solutions are brought into this sphere of business and entrepreneurial opportunities.

**Figure 13**


**Figure 12**


**Figure 14**


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**BRIEF**

## Making everything smarter

Internet of things (IoT) has become the norm and also focal point in research studies and innovation. Yet, the common consensus is that it is mostly attached to smart appliances in home and connected to vehicles and perhaps for engineers it may mean Industry 4.0. IoT is highly beneficial in the domain it is currently employed, yet, it has the potential to contribute to a larger cause, according to this article. For example, incorporating smart systems in day to day products like plastic bottles, test tubes or milk cartons may not have been even remotely considered as yet. Cambridge based company known as PragmatIC founded in 2010, produces low-cost ultra-thin flexible electronics and it believes that it could help connect 1 trillion objects to the internet in the next decade, according to the article. In


Source: www.printedelectronicsworld.com

the early stages, the company focused on research and development establishing design parameters for flexible integrated circuits (LexICs) while at present the facility in Sedgefield Durham is ramped to produce 1 billion units per year, equipping things like consumer goods and packaging with radio-frequency identification (RFID), alongside with other advanced features. The article believes that these types of products has the capability to turn any product from dumb to smart.

In recent developments, the company (PragmatIC) has developed PlasticARM, an advanced flexible circuit in collaboration with Arm (another Cambridge based company involved in semiconductors). They have produced in collaboration product featuring 128 bytes of RAM and 456 bytes of ROM, which is the largest integrated circuit designed with PragmatIC's FlexIC Foundry service as yet. This may be insignificant compared to silicon chips, yet, this is considered in the article as a huge enhancement from earlier versions of flexible chips. The company declares that it does not intend to compete with the silicon chip technology, but make chips that are more affordable and push electronics in domains where they previously couldn't reach. In other words, the aim is to stretch the technology and see if we could do something more complex in new domains on more common products. In their business goal, according to their objectives, they aim to apply electronics and technology in objects that conventionally did not use electronic circuits (typically day to day products, that are otherwise dumb), and hence this technology would not be designed to substitute silicon based technology.

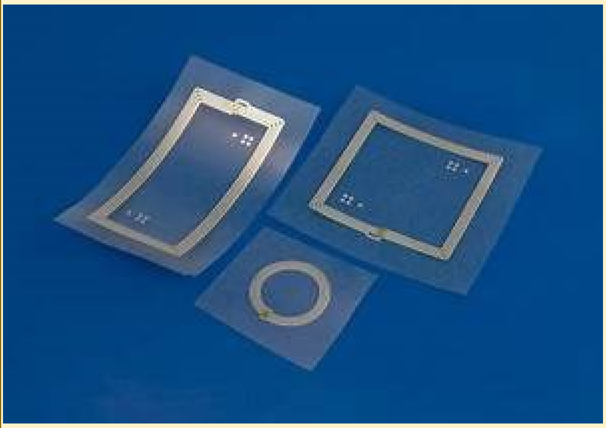
Although PlasticARM features are impressive, the article claims, not many objects require that level of sophistication. Rather, a simple RFID would be sufficient for mere identification and tracking, which is the objective of making day to day products smart. RFID along with NFC (Near Field Communications) are more than sufficient to revolutionize supply chains for all types of consumer goods. Furthermore, sensors and rudimentary edge processing will add features that can make packaging material more smart for example to sense if the food it contained was spoiled. A UK consortium known as SecQuAL (Secure Quality Assured Logistics for Digital Food Ecosystems) intends on a concept not only to trace the food items but also to sense freshness of its constituents and communicate it to consumer. The concept is called farm to fork traceability and it uses PragmatIC chips for this purpose). The result of such an initiative would that, it will lead to reduction in food waste, and the consumer would be satisfied with the purchase they make.

The main purpose the big brands would want to employ this technology is to manage the supply chain effectively in the retail environment and track items for anti-counterfeit and anti-grey-market in addition to communicating useful information to the consumer. However, the other benefits of such a system would be that it will facilitate implementation of circular economy on most products, effectively reducing waste generation and pollution. Better visibility and tracking bring advantages to retailers and suppliers while smart packaging would be able to convey information regarding recyclability and potential rewards associated with return/ deposit scheme related to the product. Major recycling projects that PragmatIC is already involved with include SPRITE (Sustainable Plastics Recycling Innovation by Tagging Electronically), which uses NFC to reward consumers for recycling and SORT-IT, which aids

*Continued on page 52 ...*

## Making everything smarter ...

the tracking and separation of various material streams at recycling facilities. The product manufacturer may be able to find answer for questions such as, How do you reduce waste within the supply chain?, How do you improve recycling outcomes?, How do you influence consumer behaviour to make recycling or reuse of packaging more effective?, through a smart technology as PragmatIC.



Source: www.pragmatic.tech

Another field that would prove beneficial implementation of such a smart system is the healthcare. The article discusses about a case where a partnership with NHS South Tyneside and Sunderland Trust resulted in producing SamplePod that embeds flexible circuits that handle medical sample tubes, allowing pathology samples to be traced securely on their journey to and from laboratories. This is believed to reduce wastages related to pathology testing in addition to the facility of being able to trace the samples. In addition, such a smart system may reduce erroneous processing of sample collection, testing and reporting with the use of traceability and smart features thereof, which is currently absent in the manual operation. "being able to add RFID at the samples we get much traceability, fewer lost samples, better visibility of where they are and better planning around the lab infrastructure, which has huge operational efficiency benefits for the NHS", claims the article.

At present PragmatIC is manufacturing and transferring using thin plastics substrate, yet, they are cautious on how it is used at the end of life (making sure it doesn't end up littering the environment). However, the company looks for ways to integrate flexible circuits into packaging without the need for these substrates. While these plastic substrates do not contribute any thing electronically to the items, the company believes that they should be able to reduce the use of plastic in manufacturing and transferring. In addition, the article claims that PragmatIC chips are 10o to 1000 times better in environmental performance metric (such as carbon footprint) compared to that of silicon chip.

**Original article: Eureka, September 2021: page 10**

## SCIENCE NEWS

## A plastic revolution

"All Things Bakelite" is a documentary by John Maher on history of Bakelite, the first fully synthetic plastic, and its inventor, Leo Baekeland. Bakelite's breakthrough properties, including electrical nonconductivity and heat resistance, made it popular in various industries. It offered designers and manufacturers the opportunity to create appliances like radios and rotary dial telephones in a range of vibrant colors. Baekeland, revisited photography, inventing a water-based process for developing photographic plates. In 1899, he created Velox photographic paper, which could develop prints under artificial light. George Eastman, the owner of Kodak, purchased Velox, providing Baekeland financial stability and space for further innovation. The documentary showcases the versatility of Bakelite through stock footage and close-ups, highlighting its applications in automation and consumer goods. Interviews with experts from chemistry, Bakelite jewelry designers, and Baekeland's descendants provide valuable insights into its significance. Hugh Karraker, Baekeland's great-grandson and producer of the documentary, that celebrates plastic's importance and impact. Patent issues and business-related stress affected him negatively, leading to eccentric behavior and eventual seclusion after retiring from the Bakelite Corporation. Overall, "All Things Bakelite" celebrates revolutionary nature of plastic despite the hope offered by the recyclability of modern polymers, the documentary reminds audiences of the environmental consequences associated with Baekeland's invention. While focusing on Bakelite, the documentary also acknowledges the environmental impact of plastic. .

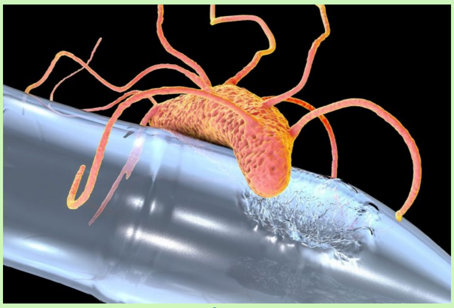
**Original article: New Scientist, 3rd July 2021: page 31**

Source: www.recyclereminders.com

**RESEARCH**

## The plastic eaters

The quest to find treasures in waste plastic continues in research studies around the world. Muhammad Reza Cordova, a marine biologist tried to find a microorganism that could digest plastic, specifically in the slime coating ocean plastic debris, near Jakarta, Indonesia. The researcher harvests the microorganisms in the slime and cultures them in the laboratory on a plastic only substrate, to see which of the survives. Several other researchers are also on the same quest for example, hot springs in Yellowstone National Park, remote island beaches in the pacific Ocean and also a plastic recycling factory in Japan are to name a few among them. Some studies have found microbes that can eat plastic derived from bottles and clothing, one of which is discussed in anoth-



Source: www.salon.com

er article in this publication as well. A company in France is spoken of in the article to have already built a demonstration facility that will use enzymes to turn plastic trash into raw material for new bottles. After finding an enzyme that could digest plastic waste is the first step in the quest while several technological, logistical and economical challenges would have to be faced and overcome in scaling up the laboratory model to an industrial plant.

The low value of plastics retard any efforts towards innovative ways to recycle them, says Susannah Scott, a chemical engineer art the University of California, Santa Barbara, who develops metal-based catalysts, synthesized in the laboratory to recycle plastic. She claims, it is a tall order to ask biology to do that well, in the scale we expect it to perform. Plastics are purposefully built to last longer, that is to say, to restrain natural degradation processes. The molecules therein therefore, resist breaking apart, while each molecule have distinct chemical properties that must be tackled differently. The article speaks of an example, where an ordinary potato chip bag has many types of molecules fused together, confounding the goal of easily extracting pure materials to develop a new product. The current recycle processes predominantly sort usable types of plastic, melt them and eventually solidify them again into pellets to be later converted into lower grade plastics such as bags and artificial lumber. A study in 2017 revealed that only 19% of all plastic was being recycled in 2014 although plastic production is expected to grow 70% by 2050, to almost 600 million tons per year, according to an estimate. Though some fraction of plastic that goes into the bin is used for recycling, much of them is either incinerated or buried in landfills or dumped in the environment uncontrollably. Another study revealed that almost half of the plastic waste in US in 2020 was exported while a quarter of that was too contaminated to be used in recycling at all. When China banned importation of plastic waste in 2020, much of US plastic waste is turned to landfills instead according to the article.

Unlike chemicals, enzymes are advantages in some ways such as, they can function in low temperatures and can choose a particular type of plastic in a pool of different types of polymers. In 2016, when Japanese researchers found a microorganism that could feast on plastic, studies have been stirred all around the globe in the quest to find more species to solve the problem of plastic waste. The Japan study found two enzymes that together enabled digestion of polyethylene terephthalate (PET), a common form of plastic such as single-use drink bottles and fibres in polyester clothing, by breaking them into its building blocks, terephthalic acid and ethylene glycol. Most plastics, specifically those used in fabrics are hard to recycle as they are often mixed with other materials, such as additives. Cordova, scientist working in Indonesia while collecting samples from ocean debris, also obtain sample of microorganisms from the roots of mangroves, where those organisms would have been exposed to plastic that clung to the roots and may have developed an appetite for plastic. Once microorganisms are found, and the enzymes are identified, x-ray crystallography is used to peer into their structures, deciphering how they bind to polymers and help break their chemical links. PET breaking enzymes were observed to have a valley in their surface into which the plastic molecule nestles, where a distinctive trio of amino acids attacks the molecular bond joining units of the polymer. By matching the DNA sequences, studies are attempting to find which other enzymes would possibly have the capability to digest plastic.

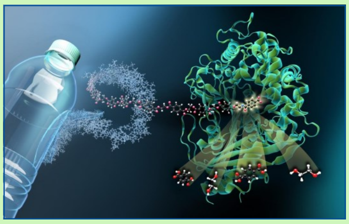
Another consortium of European

*Continued on page 60 ...*

## RESEARCH

### The plastic eaters …

and Chinese laboratories working to find and cultivate bacteria whose enzymes could break down plastic and other enzymes that can turn those broken down products into valuable chemicals. A group of researchers from Germany, Ireland and France also recycled PET using a modified version of an enzyme found in a compost pile that takes apart the waxy layer on leaves. A strain of bacteria evolved in the laboratory was then used to



Source: medium.com

build two new kinds of plastic from the broken products. This technology of using enzymes is not new, the article discusses, for example, enzyme-based detergents are already used to break down food stains in dirty clothes. Gregg Beckham, a chemical engineer at the US Department of Energy's National Renewable Energy Laboratory (NREL) working on a DOE worth $32 million, to develop new plastic recycling methods collaborating with enzyme researchers. The vision of them is to create a box, where plastic could be fed to get an output something like food or gun oil. Another study in NREL lab in Golden, Colorado, used cut sheets of PET plastic into small squares and dunk them in a brew of warm water, salt and a version of the leaf-digesting enzyme found in compost, altered by French researchers. After 24 hours, they observed 64% of the plastic has been dissolved, which indicated that the enzyme had broken the plastic down into smaller molecules. Beckham's target is to break down 95% of 5kg of plastic in 1 month. These types of studies would have to also take into consideration, the reaction kinetics to understand the parameters that influence the efficiency of the processes involved and also to understand the factors that contribute and inhibit the processes. Another French company that developed the enzyme called Carbios, plans to build the world's first enzyme-based plastic recycling facility with the aim to break down plastic into their building blocks to produce new PET plastic.

These enzymes may work best on plastics that have molecules constituting of carbon atoms joined by an oxygen atom, such as polyesters, which are also found in plant fibres. The bacteria have been exposed to these for millions of years and have evolved to feed on them. On the other hand, plastics with bonds linking carbon atoms directly are tougher to crack, such as polyethylene and polypropylene, which have applications from syrup bottles to car dashboards. While enzymes can work only in particular temperatures, and they fail in higher temperatures, and since they are very slow in processes compared to industrial chemicals, they are considered to be inefficient in commercial scale operations. The biggest economic challenge that awaits implementation of such technology is that the virgin materials are very cheap and that the commercial entities that could recycle plastics would need a large cost in terms of infrastructure to meet the demand of plastics.

**Original article: Science, 2nd July, 2021: page 37**

## SCIENCE NEWS

### Turning coal waste into precious metals

The researchers envision turning toxic waste from coal mining into treasure. The polluted mines that are left behind after mining coal are found to be an untapped source of rare earth elements. As we discussed in another article in this publication, China dominating mining and processing of rare earth elements and supplying to electronic equipment manufacturing and that other countries are looking for ways to distribute their dependency so as to break a monopoly while the demand a exponentially growing, the interest in finding alternative sources for rare earth elements is growing consistently. Pulling rare earth metals from coal waste serves two purposes simultaneously, by retrieving the metals, we assist in cleaning up the mining industry's dirt and pollution When some of the rock left over from mining is exposed to air and water, sulfuric acid forms and pulls heavy metals out of the rock. Paul Ziemkiewicz, director of the West Virginia Water Research Institute in Morgantown pointed out the benefits of recovering metals from this acid soup. Unlike the ore that is mined from the earth, where the metal could be scarce (but can be economic), the acid soup is highly rich in rare earth metals In addition, extraction from acid mine drainage does not generate the radioactive waste, which is typically generated in mining of rare earth metals. Furthermore, there are facilities to treat this acid mine drainage, which can be used or enhance and used for metal recovery, which can be cost effective and financially feasible compared to developing a new mine. The article say, 'theoretically, you could start producing tomorrow'. An estimation in the article reveals that from a few hundred sites already treating acid mine drainage, nearly 600 metric tons of rare earth elements and cobalt, could be produced annually.

**Original article: Science News, 14th January, 2021: page 22**

**ARTICLE**

# Plastic waste valorization

**Based on Innovations toward valorization of plastic s waste (Annu. Rev. Mater. Res. 2022. 52: 249-80) and data and plots from Our World in Data**

**Dr D N Subramaniam**

*The article illustrates the demand for plastic waste and innovations in the valorization of plastic waste.*

Plastics are one of the most important innovations of the post-industrial revolution in the world, that significantly contributed to improving human quality of life and reduction in energy consumption and environmental harm associated with other similar materials. For example, Figure 1 shows the number of times a simple bag needs to be reused to have similar contribution to greenhouse gas emissions. According to the figure, organic cotton bag may have to be used the highest number of times (150) to have a similar carbon footprint of a conventional bag that would be reused 50 times (approximately). This indicates that each use of a conventional cotton bag would need the organic cotton substitution to be reused three times. According to the figure, bags made of plastics (recycled PET, being the most environmental unfriendly among plastics) needs to be reused only approximately 10 times to equal the impact a cotton bag reused 150 times. In other words, for every organic cotton bag, we could use 15 recycled PET bag to have the same impact on the global carbon emissions. Paper based bags have the lowest environmental carbon footprint according to the figure, which is one tenth of recycled plastic and 1/150 of the organic cotton bags.

This is one of the important reasons why plastic material recycling is mostly spoken of and are also widely exported and imported by countries all around the world.

**Figure 01**

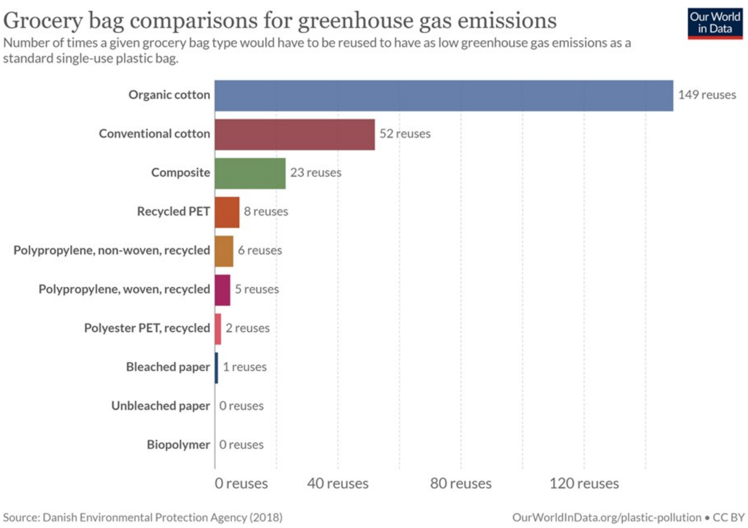
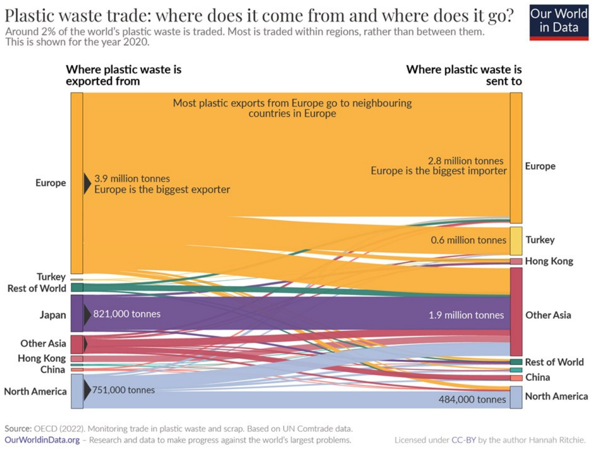



Figure 02 shows the export market of plastic waste. According to the figure, 3.9 million tonnes of plastic waste produced and exported from

**Figure 02**



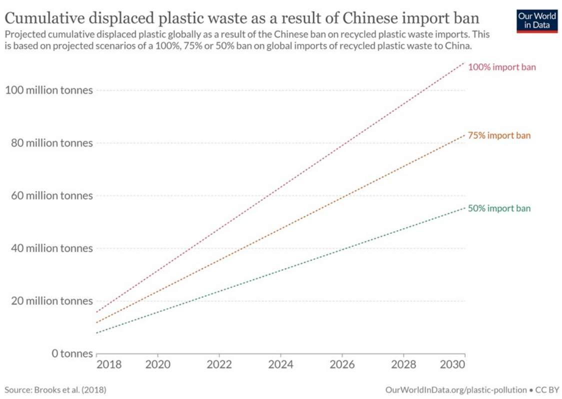

Europe (the biggest exporter of plastic waste) is typically imported mostly (70%) by other European countries (amounting to 2.8 million tonnes) while the rest (other than a little that is sent to North America) is sent to Asia (if Turkey is taken as Asian nation). Turkey is importing 0.6 million tonnes from Europe (15%), being the biggest importer of European plastic waste. While Japan exports approximately 0.8 million tonnes, all of that is imported by Asian countries, other than China. North America, that exports approximately 0.75 million tonnes of plastic waste is distributed mostly among North America and Asian nations other than China. While Turkey is the biggest importer of plastic waste as a single nation importing almost 0.6 million tonnes of plastic waste, China also

## Plastic Waste valorization ...

remains a significant importer of plastic waste as a single nation, according to the figure.

In 2018, Chinese government imposed a ban on importation of plastic waste into the country, which put the exporters of plastic waste in jeopardy. Figure 03 shows the impact that imposition of importation ban in China on the global trade of plastic waste. With a 100% ban by the Chinese government, little less than 20 million tonnes of plastic waste needs to be diverted as of 2018. Furthermore, tendering in the projection of plastic waste trade, by 2030, approximately 100 million tonnes of plastic waste will need to bediverted, should the Chinese government impose 100% ban, while even a 50% ban would require diversion of approximately 50 million tonnes of plastic waste. It is apparent that the plastic waste trade is soaring, which is not observed for any other material. There could be several reasons, where predominantly, it could be due to possible valorization of the waste to subsequent applications. Current state-of-the-art approaches in valorisation of plastic waste focuses more on utilization of polymers as feedstock for a wide variety of products via chemical recycling, that use industrial chemicals.

**Figure 03**



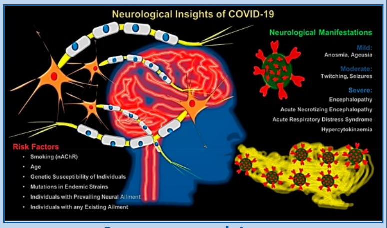

### From polymers to molecules

The first method of valorisation of plastic waste discussed in the article was the method that deconstructs polymers into smaller molecules. The process deconstruction of polymers refers to any means of converting polymers into smaller constituents, ranging from chemicals and monomers to oligomers, which is obtained by chemical processes or biological processes (that employ microorganisms or enzymes). The most important factor that defines the efficiency of the process in commercialization is the energy consumption to deconstruct polymers. Heteroatoms in polymer (e.g. PET, PU, PA) backbones allow energetically favourable deconstruction at uniformly spaced bonds to yield homogenous products (e.g. monomers, chemical building blocks), whereas carbon-carbon bonds, found in other polymers (e.g. PE, PP, PS, require more energy to break and more often leads to wider assortment of products from a single feedstock. In addition, the variety of polymer types, macromolecular architectures and processing histories found in plastic waste necessitates the development of new approaches to effectively target high-value products and minimize energy and environmental costs. Presently, chemical method of deconstruction of plastic waste is observed to be less compared to mechani-

## SCIENCE NEWS

## The neurological impact of covid-19

COVID-19 has the potential to impact the brain, affecting our thoughts and behaviors. While most people with COVID-19 do not experience brain-related issues, a notable number do. These can include blood clots, confusion, inflammation, nerve damage, and mental health problems like depression and anxiety. Younger individuals may be more susceptible to brain problems caused by the virus. It's important to note that COVID-19 doesn't directly attack the brain itself, but it can cause inflammation in the blood vessels that supply the brain, potentially leading to complications like strokes. Paul Harrison and colleagues from the University of Oxford studied 236,000 COVID-19 patients and found that 34% of them were diagnosed with neurological or psychiatric conditions in the six months after the infection. For 13% of these patients, it was their first-ever diagnosis of such conditions. The virus can lead to changes in genes and molecules, which may contribute to symptoms like memory problems and fatigue. This raises concerns about possible long-term consequences, including an increased risk of developing Alzheimer's disease. In a study called the UK Biobank, the brains of 40,000 individuals were initially scanned before the pandemic.




Source: www.mdpi.com

The findings indicate that individuals who were infected with the virus experienced a reduction in grey matter in specific areas of their brains. This effect was observed in both younger individuals and those with mild cases of the disease. Recently, 800 of these

*Continued on page 63 ...*



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## Plastic Waste valorization ...

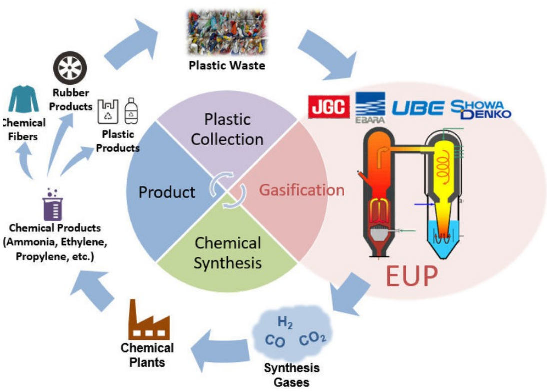
cal methods of deconstructing them (almost by an order of magnitude). Several research studies are proven at the laboratory scale and pilot scales on deconstruction of plastic waste, that await overcoming logistics challenges for commercialization.

### Chemical deconstruction

For a particular feedstock of plastic waste (particular type) and when a desirable products is envisaged that is also of a particular type of product, unique mechanism can be more useful. These unique mechanisms include, thermochemical deconstruction, including gasification and pyrolysis, which operated at a very high temperature to induce chain scission. This method converts polymers to gaseous (e.g. syngas and methane) or liquid (e.g. short aliphatic and aromatic hydrocarbons) chemicals. Solvolysis on the other hand involves solvents (e.g. alcohols, glycols, water or amines) to break down bonds between backbone heteroatoms to obtain building blocks or oligomers from the feedstock. Several challenges include, high energy demand, poor product selectivity and value or inadequate applicability to certain polymer types restrict the implementation potential of pyrolysis, gasification and solvolysis technologies, while catalysts are used to enhance efficiency and control in these processes. Additional catalytic strategies (e.g. hydrogenolysis, hydrocracking) also provide unique deconstruction mechanism to convert particular types of plastics waste into a variety of high-value chemicals (e.g. fuels, waxes, lubricants) and monomers with moderate energy consumption and improved product selectivity. Several factors such as polymer chemistry and heteroatoms in polymer backbones are considered in material criterion for application of chemical deconstruction. Feedstock of plastic waste such as Pus, Pas or polyesters may lead to generation of a plethora of smaller molecules upon deconstruction, that will require separation processes to separate the produced molecules for subsequent applications. Advanced catalytic approaches can provide additional options for processing conditions and potential products for heteroatom-containing polymers. For example, melt-phase pyrolysis, hydrogenolysis or depolymerization can facilitate deconstruction of PET into monomers, fuel and aromatic chemicals.

**Figure 04**

**Source: www.process-worldwide.com**




Polymers with only carbon-carbon bonds will require higher energy for deconstruction (breaking the bonds), and can possibly lead to different types of products depending on the catalyst chosen. Introduction of heterogeneous and homogeneous cata-

## SCIENCE NEWS

### The neurological impact ...

*... continued from page 62*

individuals were rescanned, including 400 who tested positive for the virus.US Food and Drug Administration, told CBS News. "It suggests corvid's a disease that could create "persistent symptoms. "The virus may also harm the olfactory nerve, responsible for our sense of smell, and this damage could extend to other parts of the brain. Ongoing research aims to understand the lasting effects of COVID-19 on the brain and its potential connection to conditions like dementia.

**Original article: New Scientist, 3rd July, 2021: page 12**

## SCIENCE NEWS

### A paradigm shift to combat indoor respiratory infection

There is a significant disparity in how we address different sources of environmental infection. While governments have invested heavily in legislation and measures to ensure food safety, sanitation, and clean drinking


water, the regulation and standards regarding airborne pathogens and respiratory infections, such as seasonal influenza or COVID-19, are relatively weak or nonexistent. This disparity should prompt a paradigm shift in how we view and address the transmission of respiratory infections to minimize suffering and economic losses. Recognizing that preventing respiratory infections is a solvable problem, similar to reducing

*Continued on page 80 ...*



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lysts for pyrolysis processes has significantly reduced energy demand and increased product selectivity for the process of deconstruction, yet, the end product value is highly compromised. For example, many common catalysts (e.g. zeolites, amorphous silica-alumina, mesoporous acids such as MCM-41) produce only light alkanes of marginal value but still require substantial amounts of energy input. Several studies have tried to incorporate methods such as hydrocracking and hydrogenolysis from refining industry to deconstruct polymers with factors such as material chemistries, surface morphologies and geometric structures to enhance the efficiency of the catalytic processes. A correct selection of catalyst support material, parameters such as product molecular weight or chemical structure can be targeted that in turn increase the end product value. For example, hydrocracking of PE and PP to lubricants and heavy waxes can occur at mild temperatures with high selectivity of products on the basis of catalyst properties (e.g. site types, site balance, geometry), leading to products that do not require additional chemical modifications (e.g. chemical conversion, polymerization) to increase the product value. Commercialization of these deconstruction methods depend on improving scalability, selectivity and profitability. Macromolecular characteristics, such as chain architecture and molecular weight, lead to high variability in deconstruction producs for a given process due to polymer dynamics (e.g. rheology, transport, adsorption and kinetics). Catalyst design may improve processes despite unfavourable macromolecular phenomena by introducing novel structures to orchestrate desired deconstruction activity.

## Biological deconstruction

Unlike chemical deconstruction processes, biological deconstruction is done by microorganisms or components of living things such as enzymes. Almost all synthetic plastics would not decompose in natural environments within relevant timescales, unless a microorganisms evolve to decompose them, given sufficient time. However, enzymes and microorganisms can be engineers to valorize plastic waste in controlled system, which is contemporarily studied around the world. Engineering enzymes or microorganisms refer to metabolic engineering and synthetic biology, that have enabled rapid modification of a variety of microbes to perform well controlled chemistries, including those that are uncommon or are not known to exist in nature. The research at present and in the past decade have focused on identifying or conceiving or microorganisms that deconstruct other recalcitrant materials, such as lignocellulose. In most of these occasions, the microorganisms act as catalysts, by their enzymatic activity. While enzymes function are near ambient temperature, atmospheric pressure and neutral pH, some of them can function under process conditions required for polymer dissolution or monomer stabilization. They require low energy and have high selectivity toward valuable products, yet, they can be vulnerable to environmental conditions.

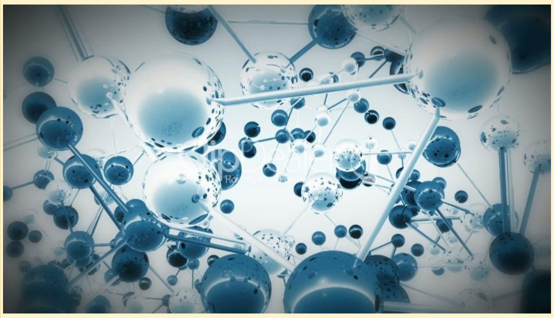
Just like the chemical methods depend on the input material chemistry, biological approaches are dependent upon substrate chemistry. Polymers with heteroatoms in their backbones (e.g. PET and PA) have energetically favourable bonds for facile biological deconstruction while carbon-carbon bonds are tough to break down. Natural hydrolase enzymes are mostly successful when applied to polymers with structure that are similar to the natural macromolecules that organisms utilize for nutrient storage. Identification of such enzymes are observed to be industrially competitive for deconstruction of PET plastics. Microorganisms are designed to perform multiple process stages (e.g. deconstruction, bioconversion) to yield new aromatic hydrocarbons from waste PET that are useful as cosmetic, pharmaceutical and agricultural feedstocks, increasing the value of deconstructed products. The efficacy of these processes can be further improved by combining other processes such as thermochemical deconstruction. A distinctive difference between the chemistries of carbon only polymer backbones (e.g. PE, PP, PS, PVC) compared to those that are based on natural molecules increases the limitations of microorganism based deconstruction. Material properties of plastic waste predominantly affect efficacy of biological valorization compared to that in chemical deconstruction processes. A careful design of process and control factors can lead to successful commercialization of biological deconstruction and can be more economically feasible and environmentally friendly and sustainable compared to chemical processes.

BRIEF

## Freaky bonding

Chemists are continuously making groundbreaking discoveries in the realm of chemical bonding, uncovering new ways in which atoms can stick together and form unique materials. Despite the central role of chemical bonds in understanding material properties, our comprehension of bond formation remains incomplete. Recent findings have demonstrated the existence of additional bond types beyond the traditional classifications of covalent, ionic, and metallic bonds, shaking the foundations of our understanding. These novel insights have the potential to revolutionize various fields, including technology, medicine, and energy.

In the conventional framework, chemical bonds are categorized into covalent, ionic, and metallic types. Covalent bonds involve the sharing of electrons between atoms, while ionic bonds arise from the attraction between positive and negative ions. Metallic bonds result from the detachment of electrons from atoms, forming a fluid "electron sea" that holds positively charged ions together. However, this classification falls short of capturing the full spectrum of bonding phenomena. One bond type challenging the established understanding is the van der Waals force. This weak force arises from fluctuations in electron clouds surrounding atomic nuclei and can cause atoms to adhere to each other without forming conventional chemical bonds. Van der Waals bonds possess unique properties and play a role in various phenomena, such as the liquefaction of inert gases and the formation of atomic clusters. Nevertheless, there is ongoing debate regarding the classification of van der Waals bonds as "real" bonds.



Source: wallpapercave.com

Another intriguing area of exploration focuses on materials that exhibit characteristics of both covalent and metallic bonding, known as "incipient metals." These materials consist of elements located between metals and non-metals on the periodic table, blurring the line between covalent and metallic bonds. Incipient metals offer distinct properties and potential applications in fields like thermoelectric materials and solar cells. Similarly, "strange metals" possess metallic properties but display unconventional behaviors, such as electrical resistance increasing linearly with temperature.

Hydrogen bonds present another type of bond challenging conventional understanding. These bonds form through the attraction between hydrogen atoms and regions of high electron density in other elements. While hydrogen bonds are crucial for various biological processes, their precise nature remains somewhat elusive. Recent studies have shed light on the complexities of hydrogen bonding, unveiling new insights into its structure and properties. Additionally, supercritical water has emerged as a promising alternative to solvents based on toxic organic compounds like benzene or toluene. It possesses the ability to dissolve compounds that normal water cannot, making it a valuable "green" substitute in various industries. Chemists have also explored unconventional bonding involving particles other than electrons. For instance, muons, which are heavier counterparts to electrons, can create stronger bonds between atomic nuclei by replacing electrons. This discovery has potential applications in muon-catalyzed fusion, a process that harnesses nuclear energy by temporarily bringing hydrogen atoms closer together.

Furthermore, researchers have discovered a fascinating phenomenon known as "entropic bonding," where particles organize into ordered structures solely due to the influence of entropy. In these cases, the ordering emerges from maximizing the overall entropy of the system, rather than traditional energetic considerations. Entropic bonding has yielded unique materials and holds implications for future technologies like molecular nanotechnology. To summarize, our understanding of chemical bonding is expanding, uncovering new and unexpected bonding mechanisms. These discoveries challenge existing knowledge and offer exciting possibilities for the development of novel materials and technologies. By exploring and harnessing these diverse bonding phenomena, scientists can unlock new frontiers in fields such as materials science, energy, medicine, and beyond.

**Original article: New Scientist, 22nd May, 2021: page 44**

## SUMMARY

# Construction and Demolition Waste

*Mostly inert construction and demolition waste remains unmanaged. It has a high potential of usage in both construction and other industries, provided it is efficiently separated and processed. This page summarizes the current state of management of construction and demolition waste.*

Solid waste is generated from all spheres of human existence, sources broadly classified as domestic (residential), commercial and industrial institutions. Of the three sources, domestic waste emerges from almost throughout civilisations, are varied in constituents and perhaps is very dynamic owing to factors such as human behaviour, seasons, geographical locations, economic status and standard of living. For example, a person in New York and a person in Kathmandu may neihther generate same amount of waste nor same type of waste, owing to different environmental conditions, while the same may also apply to a person in New York and another person in Houston. While such a variation may also be applicable to the other two sources, commercial and industrial, they may also be not as much varied as it would be for domestic sources, as the nature of business and consumer product manufacturing and retail may not vary to that extent. For example, solid waste emerging from a bank in New York may perhaps be similar in composition to that emerging from a bank in Kathmandu, while the amount of waste produced may significantly differ, for example due to the availability of online banking facilities. Yet, this can be debated.

Again, delving deeper into management of solid waste, the composition of industrial waste may differ distinctively depending on the type of industry considered. For example waste emerging from a poultry industry shall be significantly different to waste emerging from a steel manufacturing facility. This vouches for devising industry specific management practices for the management of solid waste, with respect to industries. A careful design of process and control factors can lead to successful commercialization of biological deconstruction of plastic waste. However, what still remains a larger fraction, yet inert in character is the construction and demolition waste. Construction demolition waste at the moment is a mixture of concrete, masonry, ceramics, glass, wood and plastic (all types of plastics, ranging from packaging polythene to hard plastics used in fixtures and pallets). Compared to waste emerging from the construction phase of a building, which can be separated at source itself, demolition waste leads to a mix of waste, often infused with toxic elements coming from additives including paints. The current practice of managing both construction and demolition waste is to use it as fillers (for land filling) while most of the waste is sent to landfills (often unsustainable landfills). Research studies are conducted in using the construction and demolition waste, mostly concrete waste for different types of applications where it substitutes natural virgin aggregates. However, the current practice of demolishing a building, generating a mix waste, separation of concrete waste for subsequent applications remain limited. Deconstruction of a building, a term evolving in the current context, refers to separating construction materials before demolishing the building, which can lead to efficient management of waste. The knowledge and technology in processing such waste remains at research stage still, and practicing professionals need to enhance their knowledge to use these waste in applications, which can be proven to be economically beneficial to an institution as well.

Source: www.rmit.edu.au

Source: www.machinexrecycling.com



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**ARTICLE**

# Construction and Demolition Waste Management for Sustainable Development

*The article is based on a survey conducted among practicing recent graduate engineers, discussing the current situation and a path forward.*


## Abstract

Construction and demolition (C&D) waste management is a critical aspect of sustainable development in the construction industry. This study examines the current stage of C&D waste management in Sri Lanka through surveys conducted among recent graduate engineers. Objectives include identifying waste management practices and challenges, evaluating awareness levels, understanding environmental and economic benefits, investigating waste reuse strategies, and assessing waste composition knowledge. Findings reveal gaps in practices, limited awareness of regulations, and a need for education on innovative strategies. Recommendations include stricter regulations, awareness programs, capacity-building, and promotion of reuse methods. This research contributes to enhancing C&D waste management, reducing environmental impact, and fostering sustainability in Sri Lanka's construction industry. Valuable insights, supported by data analysis and visualization, are provided for policymakers, practitioners, and stakeholders to improve waste management strategies and support sustainable development.



## Key words

***Construction and demolition waste, segregation, landfilling and disposal, questionnaire survey, recycling, sustainable development***


## Introduction

Sri Lanka is a developing country in the world and the construction sector contributes an average of 7% to the Gross Domestic Product (GDP) (Jayalath and Gunawardhana 2017). As a result of the massive development projects and global population growth, there is an increasing demand for construction activities, which raises the amount of C&D waste. C&D waste, commonly known as construction waste (Kofoworola and Gheewala, 2008), encompasses the solid waste generated from construction, renovation, and demolition activities (Townsend et al., 2019). It is a global concern, with significant amounts being generated annually. For instance, in the United States, approximately 136 million tons of building-related C&D debris is generated each year, with only 20-30% being recycled. Similarly, in the United Kingdom, around 70 million tons of C&D materials and soil are wasted annually, highlighting the high wastage rate in the construction industry (Yuan and Shen, 2011). China is the world's largest C&D waste producer, with around 2300 million tons in 2019 (Elshaboury et al., 2022).

Rock, masonry, asphalt, metals, sand, plastics, asbestos, plasterboard, and cardboard are among the most typical C&D waste material profiles. There are two main kinds of building construction waste, structure waste and finishing waste (Poon et al., 2001). Demolition waste usually consists of a high percentage of inert materials like bricks, sand, and concrete. The generation of C&D waste has adverse impacts on the environment, including the consumption of large land resources for waste landfilling and the pollution of surroundings through hazardous materials. Waste reduction offers significant benefits by minimizing the generation of C&D waste and reducing costs associated with waste transportation, disposal, and recycling (Poon, 2007). However, a substantial portion of the generated C&D waste, ranging from 10% to 30%, ends up in landfills, leading to environmental, social, and economic problems (Periathamby, 2009).

Understanding the types and origins of waste generation is crucial for effective C&D waste management. Errors in design, inadequate material handling knowledge, poor material planning decisions, and changes in building design contribute to the generation of C&D waste (Yeheyis et al., 2012). Procurement issues, transportation challenges, material storage, handling, site operation, residuals, weather, and vandalism also contribute to waste generation (Begum et al., 2006).

In the Sri Lankan construction industry, C&D waste management is classified under solid waste, lacking specific regulations

regulations (Karunasena et al., 2012). Landfilling has become the primary method for C&D waste management, despite it being the least preferred option in waste management processes. Several factors contribute to the generation of C&D waste in Sri Lanka, including cutting waste resulting from materials being cut into different sizes and uneconomical shapes, and management waste stemming from incorrect decision-making and inadequate supervision (Kulatunga et al., 2006).

By investigating the types and origins of waste generation in the Sri Lankan construction industry, this study tries to identify the current practices, challenges, and opportunities for improvement. The findings will contribute to developing effective strategies and policies for enhanced C&D waste management in Sri Lanka.

## Aim and objectives

This report aims to analyze C&D waste management in Sri Lanka, focusing on efficient segregation, recycling, and reuse. It identifies areas for improvement and recommends sustainable solutions. The report provides actionable recommendations to policymakers, industry stakeholders, and organizations, promoting an environmentally conscious and responsible approach to waste management. By evaluating current practices, challenges, and opportunities, the report aims to reduce environmental pollution and optimize resource utilization in the construction and demolition sector. Also, Recent graduates (up to 4 years of experience in the field) are the main target audience for this analysis. The selected objectives of this analysis can be described as follows.

**Evaluating the awareness level among recent graduates about the construction and demolition waste management concept and its regulations and guidelines:** This is requisite to assess the discernment of waste separation, recycling, and waste management regulations among new professionals in the construction industry. By identifying their level of awareness, suitable measures can be taken to raise their knowledge through educational programs, workshops, and curriculum integration. Also, this objective emphasizes the role of enhancing awareness among new graduates to foster a more sustainable and responsible construction industry in Sri Lanka.

**Identifying the current waste management practices and challenges used by construction and demolition sites and companies:** Inadequate waste allotment, limited recycling and reuse initiatives, and not enough worker awareness are key challenges interrupting effective waste management in the division. To solve these issues, it is crucial to implement proper waste segregation protocols, promote material recycling and reuse, raise awareness about sustainable waste management practices, and enforce stricter regulations. Accessional, this identification facilitates the development of good solutions and strategies to enhance waste management in the sector.

**Evaluating the knowledge about the composition and segregation of construction and demolition waste:** Proper waste composition and segregation are condemnatory for promoting efficient waste management practices. By assessing industry professionals' and stakeholders' understanding of waste materials and the momentousness of proper segregation, gaps, and misconceptions can be identified, allowing for targeted awareness programs and training initiatives to encourage effective waste segregation, resource preservation, proper disposal, and decrease of environmental impacts.

**Investigating the knowledge of potential construction and demolition waste reuse strategies and new waste management techniques:** By traveling over innovative approaches such as recycling, upcycling, and circular economy principles, the industry can decrease waste generation, conserve resources, and minimize environmental impact. This evaluation helps in developing targeted educational programs, capacity-building initiatives, and policy recommendations to encourage the adoption of efficacious waste reuse strategies and advanced waste management techniques in Sri Lanka.

**Determining the understanding of the environmental and economic benefits of effective construction and demolition waste management:** This objective aims to assess the industry's awareness of the positive impressions that proper waste management can bring. Understanding the environmental advantages, such as corruption reduction and resource conservation, as well as the economic advantages, such as cost savings and potential revenue from recycling, is crucial for making informed determinations in waste management practices.

## Methodology

This research survey methodology is a valuable approach employed to uncover critical insights and essential information regarding construction and demolition waste management and practices. Information gathered from the survey is mainly based on the five objectives mentioned above. The basic steps used for the identification of important factors about C&D waste management are, 1) selecting the effective objectives for C&D waste management, 2) conducting a survey to investigate the important details about C&D waste, and 3) calculating and analyzing the data obtained and drawing to full conclusions.

### 1) Selecting the effective objectives for C&D waste management.

Following an extensive literature review, the best objectives related to C&D waste management were selected for this research survey (Bao & Lu, 2020; Poon et al., 2001; Saez et al., 2013; Yuan & Shen, 2011). These objectives were chosen to cover many aspects and get the most important information about C&D waste management.

### 2) Conducting a survey to investigate the important details about C&D waste management.

Surveys are helpful as valuable scientific research tools that use well-designed questionnaires to gather reliable and specific information directly from the target audience (Appendix A). By using the questionnaire methodology, researchers can conduct a descriptive analysis of the gathered data, which can be statistically processed to increase the reliability of the survey analysis. Commonly, questionnaires are a well-accepted and widely used research method by researchers in the construction sector. Here also, online questionnaires have been used to collect information from the target audience. High accessibility, efficiency, confidentiality, increasing data accuracy, and providing data security are the main reasons for selecting this way to gather information. In addition to that, the questionnaire length is the other factor that should be considered more. If it is very long, no one prefers to fill this form because it is time-consuming. And also, maintaining a long telephone conversation or arranging an interview is difficult in some situations as they are too busy with their work. Therefore, online questionnaire surveys are the most appropriate modality to gather reliable information from the expected audience.

The gathered details are mainly under five objectives and the first part of the survey was designed to get information about the awareness level, regulations, and various challenges related to C&D waste. The second part focused on the segregation, composition, and management techniques of C&D waste. Finally, the third part paid attention to getting an idea about the benefits of effective C&D waste management. Unnecessary responses were removed from the analysis to maintain the validation of the results.

### 3) calculating and analyzing the data obtained and drawing to full conclusions.

When drawing to conclusions, the basic step is calculating and analyzing the data gained from the survey. Microsoft Office Excel 2021 and IBM SPSS Statistics 26 were the softawares used in this analysis. As the first step, all data were arranged properly and imported into the IBM SPSS software. Then the reliability of the surveying data was checked by measuring Cornbach's Alpha value and the significant value of P. Finally, the variation of the imported data was analyzed, and reached conclusions.

## Results and discussion

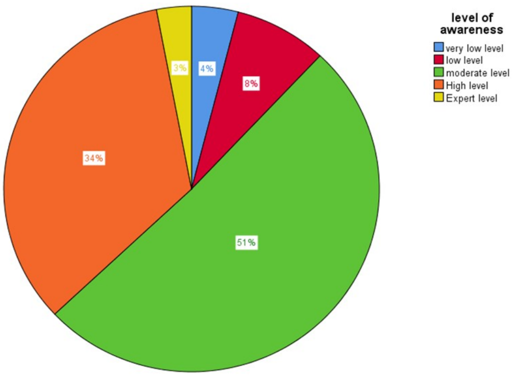
Nowadays, C&D waste is a main topic that everyone is talking about. If it is managed efficiently, construction companies can gain lots of economic and environmental benefits and also, if it is not considered much, they have to face many difficulties such as problems due to waste management, decreasing profit, and increasing the production cost. Sometimes, legal problems also can be occurred against the companies due to inefficient C&D waste management. Therefore, the main purpose of this research analysis is to see to what extent, the current existing companies in Sri Lanka are concerned about this problem.

Among the total 109 online questionnaire responses, 100 valid responses were received from the 03rd of June to the 24th of June 2023. The reliability statistic test was used to check the reliability of this study. For higher reliability, Cornbach's Alpha value should be greater than or equal to 0.7 and the significant value of P should be less than 0.005. For this analysis, Cornbach's Alpha was equal to 0.859 and significant P was equal to 0.000. So, the internal consistency was good and the research tool was reliable, and it will give credible results.

### Awareness, Guidelines, and Regulations

According to the survey analysis, 88% of recent graduate engineers in Sri Lanka have knowledge about C&D waste management to some extent too. It is shown in Figure 01 as Moderate level-51%, High level-34%, and Expert level-3%. So, only

**Figure 01: Awareness level of the recent graduate engineers in Sri Lanka (According to the survey analysis)**




a few engineers have little or no knowledge about C&D waste management. And also, the calculated mean value of the awareness level is equal to 3.24 and it has passed the moderate value of the awareness level. Finally, the results conclude that the recent graduate engineers have a good awareness level of C&D waste management.

Then the online questionnaire focused on how they got knowledge and awareness about C&D waste management. There, 39.7% of recent graduate engineers had got knowledge from academic courses, and 37.8% had gained knowledge from industrial experience. Apart from that, a significant amount like 22.5% had acquired knowledge through other methods such as professional training and online resources.

Knowledge from industrial experience is more important than other methods because, then they can gain practical knowledge also. Most engineers have got an awareness of C&D waste management through academic courses. But Table 01 shows that 13.2% of engineers who acquired knowledge from academic courses have low and very low levels of awareness about this topic. The main reason for this may be that knowledge through academic courses is forgotten over time. According to the results of the survey, 5.3% of recent graduate engineers have expert knowledge about C&D waste management through professional training. It is a higher value compared to the other percentage values. It further shows that if the company provides professional training to their staff, the awareness level can be raised a lot and the company can be reduced their production cost and increased profit. Nowadays, online resources are very famous, because most people used online resources to do their day-to-day activities in the pandemic situation. 14.8% of the engineers who gained knowledge using online resources have moder-

## SCIENCE NEWS

### Yeast turns corn leftovers into fuel

As we leave husks of rice grains out, the corn farmers leave stalk, leaves and spent cobs to rot in the field when they harvest the crops. These parts of the crop remain in the field or in unmanaged sites, yet it is hard to decompose. Engineers have found a new strain of yeast that can convert this inedible and hard to decompose parts of corn crop debris into ethanol, a biofuel. Several attempts to produce biofuel from fibrous material called corn stover revealed limited success, because, the stover needs to be broken down before yeast could produce biofuel and the breaking down process produces toxins that kill yeast. Researchers have engineers a strain of the yeast to defuse the toxins to produce biofuel. The article claims that the modified yeast can produce 100g of ethanol from a litre

Source: geneticliteracyproject.org

Source: www.manitobacooperator.ca

of corn stover., which is comparable to production of ethanol from corn kernels (that are easier to break down by common yeast). In the US, most ethanol is produced from corn kernels, the country's largest crop, and the ethanol derived is mixed with gasoline and sold at gas stations. This creates diverting corn production away from food supply, where this new invention is believed to solve that problem where the waste part of the

*Continued on page 72 ...*

BRIEF

## Production technology challenges

One of the biggest challenges in manufacturing technology is meeting the demands of end consumers. These challenges are now extending into production technology as well. In the realm of manufacturing technology, meeting the diverse preferences of end consumers presents a significant challenge, which is now extending into production processes. Industry 4.0 emphasizes the importance of individualized mass production, prompting the need for new production designs to prevent soaring costs.

Customization requires a delicate balance between standardization and automation, allowing for variations in customer-relevant product features. Modularization, offering tailored product configurations based on modular building blocks, emerges as a cost-effective approach to meet individual customer needs. Interfaces play a vital role in the growing automation and modularization processes, acting as the keystone that connects elements or modules and allows them to function as a whole.


Source: chipolaworkforce.com

As customer-oriented individualization gains traction in mechanical engineering, the advantages outweigh the disadvantages. Appropriate arrangements of sensors, actuators, and machine control components, along with their interconnection, are the sole domains of original equipment manufacturers (OEMs). These companies possess comprehensive system competence, a valuable asset to leverage in their favor.

Mechanical development's core has shifted to software departments or electrical design due to remarkable performance improvements. For OEMs to achieve the right level of individualization and align with automation and modularization requirements throughout a product's life cycle, they need to think in terms of different functional groups or clusters. The development of electronic components has led to a compression of functions, enabling higher energy efficiency and greater packing densities. This technological progress drives decentralization, modularization, and scalability of machines, using compact building blocks and elementary controls. The complex control of motion sequences and related processes becomes a central competence for machine manufacturers.

Manufacturing system manufacturers concentrate on a few technologies, while overall system suppliers excel in application and technology connection know-how. Specialized technology units deployed as finished aggregates with defined interfaces represent the central OEM know-how. Data transmission technologies, particularly industrial bus systems and Industrial Ethernet, are revolutionizing manufacturing systems. The potential for change lies in these data transmission aspects, even though they are not the core competence of OEMs. To ensure advanced and scalable machines and systems, OEMs are advised to follow the latest control technology standards for interfaces.

Manufacturers utilize customer-specific, tailored interfaces for various product individualization degrees in mechanical engineering. While standard solutions are common for data interfaces, trend-setting OEMs differentiate themselves by deploying specific, tailor-made interfaces. Customized interfaces offer advantages in service expansion, differentiation, and protection of proprietary know-how.

HARTING can customize electro-mechanical interfaces to meet unique OEM requests in mechanical engineering. They offer various options, like combining connector products with different housing types, configuring cable entries and imprints, and designing customer-specific contact inserts. They also provide coding pins and socket combinations for added customization. Additionally, they offer customer-specific design of data transmission interfaces, using standardized preLink contact blocks for tailored sub-routes as per end-user requirements.

As manufacturing technology faces the challenge of meeting individual consumer preferences, adopting individualization and customization becomes essential. Modularization, automation, and customer-specific interfaces play pivotal roles in this evolution. By embracing digitalization and following the latest standards, OEMs can create economically and technically optimized systems for current and future requirements while ensuring a competitive edge in the market.

**Original article: New Scientist, 22nd May, 2021: page 44**

ate, high, and very high awareness levels. According to that, it can be seen that there are recent graduate engineers who have studied this on their own and gained knowledge.

According to the results, 25.6% of companies have a waste management plan. A high percentage of companies like 20.4% use recycling and reuse strategies. In addition to that, 19.4% of companies use waste classification, 18.4% waste reduction strategies, and 16.2% training and awareness programs currently. According to that, these results say that many companies use specific regulations or guidelines in some way. 12% of recent graduate engineers have a low level of awareness of C&D waste management. Therefore, companies can conduct training and awareness programs and improve the knowledge of the workers. This fact is very clear from the results of Figure 02. Because everyone who has professional training is at a higher level of awareness. However, this helped reduce the problems on the waste management side and improve the progress of a company while increasing profits and reducing the production cost. Waste reduction is also very important than other specific regulations. The reason for that is that a company can manage the C&D waste without taking any other measures. And also, waste classification helps C&D waste management and on the simultaneously he recycling process too. The final decision that can be drawn from this is that a company can achieve its maximum profit by managing C&D waste by following specific regulations and guidelines.

**Figure 02: Level of awareness and How the knowledge enhancement on C&D waste cross-tabulation**

| | | | How the knowledge enhanced on C&D waste | | | |
|---|---|---|---|---|---|---|
| | | | Academic courses | Professional training | Industrial experience | Online resources |
| level of awareness | very low level | Count | 4 | 0 | 0 | 0 |
| | | % | 4.80% | 0.00% | 0.00% | 0.00% |
| | low level | Count | 7 | 0 | 6 | 1 |
| | | % | 0.084 | 0 | 0.076 | 0.036 |
| | moderate level | Count | 44 | 8 | 42 | 13 |
| | | % | 0.53 | 0.421 | 0.532 | 0.464 |
| | High level | Count | 26 | 10 | 28 | 13 |
| | | % | 0.313 | 0.526 | 0.354 | 0.464 |
| | Expert level | Count | 2 | 1 | 3 | 1 |
| | | % | 0.024 | 0.053 | 0.038 | 0.036 |

## Waste Generation, Handling, and Challenges

There are several methods to generate C&D waste in companies. The online survey has provided reliable data on how C&D waste is generated in companies or workplaces in Sri Lanka. Relative to the other activities, maintenance and repairs, and laboratory tests play a vital role to generate a higher amount of C&D waste in construction sites. When taking the sum of the percentages of these two activities only, the value is shown as 56.6% of the whole percentage.

Generated C&D waste from the above methods, is handled using different technical methods in Sri Lanka. According to the results of the survey, the majority of the companies have focused on waste reduction and reuse concepts to handle the generated waste and it can be shown as 21.3%, and

## SCIENCE NEWS

### Biofuel from corn stover ...

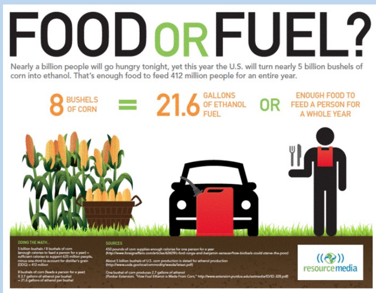
... continued from page 70

corn crop could be used to produce ethanol instead.

Felix Lam from MIT and colleagues started the experiment with Saccharomyces cerevisiae, the common baker's yeast, which can also be used to produce ethanol from corn kernels. Sugars of corn stover in contrast to corn kernels is covered with lignocel-

Source: www.ameslab.gov

lulose, a plant compound that is hard to break down, making the sugar part of stover inaccessible for digestion. Application of strong acids may solve this issue to free sugars from stover, however, the byproduct known as aldehydes can kill yeast consequently. The research team randomly generated 20000 variants of yeast gene called GRE2 and mixed them with the toxic aldehyde to observe which of them would survive. While several variants survived, one particular variant dominated, which was also found to produce ethanol from corn stover. Furthermore, that variant could successfully produce ethanol from other woody materials such as wheat straw and switchgrass. For commercial applications however, several challenges mostly logistics related need to be solved.




Source: soapboxie.com

**Original article: Science News, 31st July, 2021: page 12**



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18.7% respectively. C&D waste that can't be controlled by these methods is mostly handled by landfilling (22.2%) and waste separation and disposal (17.2%) methods. However, there have a small number of companies also that are used other methods to control this generated C&D waste.

According to the results, landfilling, waste separation and disposal are the main methods that are used by companies to handle C&D waste currently. Waste from laboratory tests is mainly handled by these two methods at 41.5%. And also, the respective values are 41% through maintenance and repairs and 39.1% through the lack of waste reduction planning (Figure 03). Waste reduction, reuse, and recycling are the other methods used by companies to handle C&D waste. But according to the results obtained, these existing values are in very low percentages. It is very important if the companies can get another usage without going to landfilling and disposal. For that, construction companies can refer to other alternative products. For example, the researchers' field investigations have focused on reusing C&D waste in the plant production of masonry bricks. From that, construction companies can manage their C&D waste efficiently while contributing to small enterprises like brick manufacturing. As the environmental pollution is minimal, this method is also environmentally friendly.

Waste management is not an easy task in companies or construction sites. Nowadays, there are several challenges faced in managing C&D waste in Sri Lanka. According to the result analysis, it has been shown that 25.6% of companies are struggling with limited space for waste storage and sorting issue in construction sites. In addition to that, inadequate infrastructure and the cost of waste reduction practices also come as the challenges during waste management process and they are significantly higher at 20.4% and 18.2% respectively.

18.2% of companies are facing the higher cost of waste reduction practices. Therefore, most of them are not motivated to follow the C&D waste management strategies. But not getting involved in waste management can cause even more losses than this. As a solution for that, new technologies can be introduced and used for C&D waste management in companies. By increasing training programs, they can improve the knowledge of workers and it helps to find new solutions and technologies to waste management. And also, efficient C&D waste management causes the reduction of landfilling and protection of ecosystems. Apart from that, following reuse and recycling strategies, companies can earn maximum profit and reduce resource depletion also. If there has the strongest staff with knowledge about C&D waste management in a company, they can face the all challenges successfully.

## Segregation and Composition

In this online survey, data was collected under construction and demolition waste segregation too. In Sri Lanka, companies are currently using several segregation methods. According to the obtained data, those segregation methods can be classified as material-specific segregation (23.9%), hazardous waste segregation (5.8%), recyclable waste segregation (21.8%), non-recyclable waste segregation (10.2%), on-site segregation (21.8%), off-site segregation (11.6%), and salvaging and reusing materials (4.4%). Most of the companies have focused on material-specific segregation. It is easier than compared to other segregation methods and no special knowledge is required for that. 5.8% of companies are directed to hazardous waste segregation and it is a small percentage compared to others. It means that most hazardous materials are mixed with the surrounding environment without segregation.

**Figure 03: How C&D waste generated and How companies handle C&D waste cross-tabulation**

| | | | How companies handle C&D waste | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Waste Reduction | Reuse | Recycling | Waste separation and disposal | Collaboration with waste management companies | Landfills |
| How C&D waste generated | Laboratory tests | Count | 62 | 48 | 40 | 46 | 7 | 65 |
| | | % | 0.231 | 0.179 | 0.149 | 0.172 | 0.026 | 0.243 |
| | Maintenance and repairs | Count | 61 | 56 | 38 | 50 | 9 | 64 |
| | | % | 0.219 | 0.201 | 0.137 | 0.18 | 0.032 | 0.23 |
| | Lack of waste reduction planning | Count | 20 | 13 | 16 | 13 | 1 | 19 |
| | | % | 0.244 | 0.159 | 0.195 | 0.159 | 0.012 | 0.232 |

And also, this research has found several challenges during the segregation process. Those can be listed with their percentage values as follows. Lack of awareness and training (23.2%), limited space and infrastructure (28.2%), time and cost constraints (23.6%), inconsistent waste management policies (3.2%), limited recycling infrastructure (17.3%), supplier and subcontractor engagement (4.2%) are the main challenges facing by companies in Sri Lanka nowadays. Among these challenges, limited space and infrastructure is the main challenge during the segregation process. It has been shown as 28.2% of higher value. In addition to that, results show that 23.6% of companies lack awareness and proper training among workers on segregation. It can be caused a large loss to the construction companies.

Another problem that is faced by the companies is the existing impurities of C&D waste. Those impurities can be classified and expressed as the percentages below. Soil and dirt (27.5%), paint and coatings (16.5%), adhesives and sealants (5.7%), insulation materials (11.7%), asbestos-containing arterials (5.1%), plastics and packaging materials (18.0%), and miscellaneous debris (15.2%) are these impurities exists in the construction and demolition waste. Generally, soil and dirt are impurities contained in anything. Here also, it is the main impurity that exists in the C&D waste. In addition to that, plastics and packaging materials carry a higher percentage 18%. Everything is packed with materials like plastics and paper. Therefore these things can be mixed with C&D waste.

According to Figure 04, results show that Sri Lanka uses mostly onsite segregation and it is mainly focused on material-specific segregation and recyclable waste segregation. But there can be occurred lots of challenges during these segregation methods. When doing material-specific segregation, there can be occurred lack of awareness and training challenges at 25.9% and limited space and infrastructure at 31.2%. And also, when doing recyclable waste segregation, there can be happened lack of awareness and training challenges at 25.5% and limited space and infrastructure at 29.9%. These are the main challenges during the segregation process and they can be minimized by providing proper training and awareness programs in the companies. Apart from that, companies can introduce new technologies to address these challenges. By following these measures, companies can improve their progress effectively and they can get the maximum profit.

## Reuse Strategies and New Techniques

When looking at the reusability of C&D waste materials, familiarity with waste reuse strategies, and an awareness of modern waste reduction methods in the analysis of the survey outcomes. It can be started by focusing on the C&D waste materials that were recycled on Sri Lankan construction sites. With a reuse frequency of 25.7%, concrete is the material that is most frequently reused. Similar percentages of metals, wood, and bricks & masonry are reused, creating a total estimate of 51.7%. The materials for the lowest percentages of reuse, including plastics, glass, ceramics, and miscellaneous materials, account for only 20.7% of all reuse.

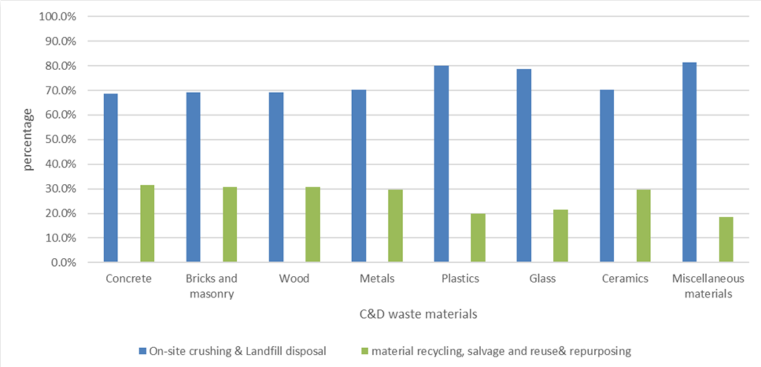
Then, this survey analysis looks at Sri Lanka's strategies for reusing C&D waste. Landfill disposal is the most common strategy, with 27.9% of respondents reporting that they are aware of it. Landfill disposal is the dumping of C&D waste in approved landfills. But this method is not good due to its negative impact on the ecosystem. Due to the potential for harmful pollution and the depletion of available land

**Figure 04: C&D waste segregation methods with segregation challenges**

| | | Segregation methods | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | On-site segregation | | | | Off-site segregation | | | |
| | | Material-specific segregation | | Recyclable waste segregation | | Material-specific segregation | | Recyclable waste segregation | |
| | | Count | % | Count | % | Count | % | Count | % |
| Challenges during the segregation | Lack of awareness and training | 44 | 25.90% | 35 | 25.50% | 17 | 28.80% | 12 | 25.00% |
| | Limited space and infrastructure | 53 | 31.20% | 41 | 29.90% | 21 | 35.60% | 17 | 35.40% |
| | Time and cost constraints | 38 | 22.40% | 31 | 22.60% | 8 | 13.60% | 8 | 16.70% |
| | Limited recycling infrastructure | 35 | 20.60% | 30 | 21.90% | 13 | 22.00% | 11 | 22.90% |

resources, landfill disposal is considered the least preferable option in waste management. On the other hand, On-site crushing and screening accounts for 24.8%. The combined percentage for on-site crushing and screening and landfill disposal is 52.7%.

**Figure 05: C&D waste material reuse strategies on sites**




This shows that more than half of the respondents use C&D waste management practices such as on-site crushing and landfill disposal for reuse. It is important to note, however, that alternative waste reuse techniques are also used on construction sites. A small percentage of the responders also mentioned material repurposing (10.6%), salvage and reuse (17.3%), and material recycling (19.5%).

These results express the need for more awareness-raising and promotion of more environmentally friendly methods of managing C&D waste. Development of waste management practices such as on-site processing, salvage and reuse, and material recycling will decrease dependency on landfill disposal and support a more environmentally friendly method of handling waste.

When regarding familiarity with different techniques and technology for reducing C&D waste, sustainable material alternatives obtained the highest proportion, at 25.1%, according to the analytical data. This shows an acceptable level of understanding and awareness of the worth of using sustainable and environmentally friendly materials in construction. Additionally, a significant percentage of 21.8% is assigned to waste tracking and analytics, indicating a growing awareness of the value of tracking and monitoring waste creation and management practices. This shows a proactive attitude to resource conservation and effective waste reduction.

The percentages for advanced sorting and recycling technologies (11.8%), waste-to-energy conversion (15.9%), and lean construction practices (17.0%), indicate that respondents exhibit different types of understanding and awareness of these waste reduction strategies. These strategies have a big impact on resource conservation and environmentally friendly construction methods. On the other side, there seems to be a lack of familiarity with certain strategies. Only 5.9% of respondents mentioned prefabrication or modular construction, indicating that they may not be familiar with these techniques, which have the potential to reduce waste through off-site production and efficient resource use. Similar to the previous point, only 2.6% of respondents suggest that they were familiar with 3D printing.

Therefore, the findings indicate the importance of focusing more attention on discovering alternative waste reuse methods beyond landfill disposal. A good trend towards improved waste management practices is presented by a growing familiarity with waste tracking and analytics.

## Economic and Environmental Benefits

The online survey data shows that construction and demolition waste management practices prioritize cost savings and profitability to a medium extent (47%), with a significant portion prioritizing Very much (23%). However, a minority of companies (7.0%) do not prioritize expense savings and profitability, indicating a potential lack of understanding of the economic advantages of productive waste management.

The economic advantage of productive construction and demolition waste management is evident in the creation of job opportunities, improved project efficiency, reduced construction costs, and improved public image. 13.7% of respondents believe that waste management can lead to employment progression and skill development in waste management-related work. 27.4% of respondents expect improved project efficiency, streamlined processes, and decreased project delays, resulting in cost savings and increased profitability. 29.5% of respondents recognize the potential for reduced construction prices, waste generation reduction, and improved public image. 14.4% of respondents believe that waste management strategies can improve a company's reputation, attract customers, and secure investment opportunities. 15.1% of respondents acknowledge the economic advantage of material recovery and recycling, highlighting cost savings and reduced resource procurement requirements.

Respondents identified environmental advantages of productive construction and demolition waste management. Landfill usage was emphasized as a significant concern, with 18.5% of respondents highlighting its importance in minimizing environmental shock. Conservation of natural resources was also emphasized, with 18.8% expressing a desire to minimize resource depletion through efficient waste management practices. Mitigating air, water, and soil pollution was noted by 15.3%, demonstrating an understanding of potential environmental mischief caused by proper waste management. Additionally, respondents recognized the advantages of decreased energy consumption, decreased greenhouse gas emissions, soil and water pollution interruption, and ecosystem protection (16.3%).

**Figure 06: Variation between up to what extent companies prioritize cost saving and profitability with economic benefits and environmental benefits**

| | Not at all | Somewhat | Moderately | Very much | Extremely |
|---|---|---|---|---|---|
| Economic benefits | 4.00% | 15.30% | 52.10% | 22.20% | 6.40% |
| Environmental benefits | 2.80% | 16.40% | 48.20% | 26.90% | 5.60% |

The data presented in the table above presents data regarding the economic and environmental benefits associated with construction and demolition waste management in Sri Lankan construction companies. The majority (52.1%) of the companies consider waste management practices to be moderate, while a significant percentage (22.2%) rate it as very high. On the other hand, 48.2% of the companies consider waste management practices as moderate and 26.9% as very high.

According to the online survey data, cost savings and profitability of the respective companies in the implementation of construction and demolition waste management practices in Sri Lankan companies are prioritized by 47% as moderate and 23% as very good. It is clear that many companies in Sri Lanka are thinking about economic benefits. Also, the measurement data confirms that most organizations in Sri Lanka are considering improving project efficiency and reducing construction costs. And the above data confirms that reducing land use and conservation of natural resources has been given priority when considering the maximum profit in terms of environmental benefits. It can be expected that the damage to the environment has also been minimized.

Finally, as shown in the pie chart above (Figure 01), Sri Lankan companies are 51% aware of construction and demolition waste management in Sri Lanka. If it is increased, the cost and profitability priority of the Sri Lankan companies can be brought to an excellent level and thereby saving their costs can further promote job creation and reduce unemployment. In terms of environmental benefits, the environment can also be protected by doing things that are beneficial to the environment, such as reducing landfilling.

## Conclusions

C&D waste management has been a worldwide concerned issue attracting increasing attention. This research study provides a clear idea about C&D waste management in Sri Lanka currently. From the analysis of the data obtained, the following conclusions can be drawn.

- Most recent graduate engineers have a moderate level of awareness about C&D waste management and they have gained knowledge mainly from academic courses and industrial experience. To improve this awareness level to the high, companies can conduct training programs for their workers. In addition to that, many companies use specific regulations and guidelines in some way.
- Maintenance, repairs, and laboratory tests are generated more C&D waste compared to the others. Generated C&D waste is mainly handled by using landfilling and disposal, but they are not efficient methods to control the waste. Reuse, recycling, and waste reduction are the most suitable methods that can be used to handle C&D waste. And also, most companies are facing the challenge of limited space for waste storage and sorting. Therefore, the companies can do the offsite activities except the onsite.

- Most of the companies have focused on material-specific segregation under on-site segregation. However, the limited space and infrastructure is the main challenge during the segregation process. Therefore, companies can use offsite segregation and they can provide their waste to another small enterprise as a solution for that issue. Apart from that, Soil and dirt are the main impurities that exist in the C&D waste.

- Concrete is a material that is highly reused in construction sites and landfill disposal is the most common strategy used in Sri Lanka. And also, using sustainable material alternatives is a new technology that Sri Lankan companies are familiar for reducing C&D waste. Reducing construction costs and conservation of natural resources are the main economic and environmental benefits that expect by construction companies.

This online survey is very important to know about lots of factors in C&D waste management and it helps to improve the efficiency of companies by managing C&D waste.

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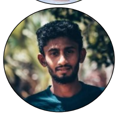
THEJAN W A Y
University of Jaffna

MADUSHANI P T W
University of Jaffna

BANDARA K M N P
University of Jaffna

BANDARA A M S
University of Jaffna

RATHNAYAKA M M M M M R
University of Jaffna



## SCIENCE NEWS

## The methane mystery

In a lab at the University of Colorado, scientists are investigating a puzzling rise in methane, a powerful greenhouse gas. They study air samples from around the world to determine if the methane comes from burning fossil fuels or from wetlands and livestock. Methane is a potent gas, with a warming effect 28 times stronger than carbon dioxide. Its levels have been increasing since 2007, defying predictions. Recent data shows the largest annual jump in methane levels since 1983, and the cause is still unknown. In 2020 the increase in methane is 14.7 parts per billion. Researchers analyze isotopes to identify the sources, pointing to both fossil fuels and wetlands.

A Canadian company called GHGSat launches satellites to track methane, revealing hidden sources.

Source: smartwatermagazine.com

The fossil fuel industry and agriculture contribute significantly to methane emissions. To combat the issue, covering landfills and sealing leaks in infrastructure are potential solutions. Reductions in methane emissions are crucial for addressing climate change and protecting against air pollution. According to a report by Shindell for the United Nations Environment Program (UNEP), reducing methane emissions by 45% by 2030 would prevent approximately 0.3°C of global warming by the 2040s.

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ARTICLE

# LCA comparison of roofing materials

*This case study presents a simple method of analysing alternative choices for a particular application (roofing), considering specific LCA indicators.*

## Introduction

Any building construction project requires roofing because it gives buildings a protection, insulation, and aesthetic appeal. Choosing the best material for roofing is very important. For roofing, the three materials of choice in this study are asphalt shingles as virgin materials, and rubber and metal as recycled materials.

Asphalt shingles are commonly used as a construction roofing material due to their durability, lower cost and ease of installation. Granules of asphalt, fiberglass, and minerals are used to create the asphalt shingles ((ARMA), 2016). Contents of asphalt shingle like fiberglass and asphalt provides strength, stability, and waterproofing properties to withstand weather elements (Inc., 2022).

Rubber roofs are often manufactured using recycled tires, have several benefits. Compared with traditional roofing materials, rubber roofs are more durable and require less maintenance. Compared to shingles or terra cotta roofing rubber roofs are light weight, low labor cost and easy to install (MaintenX, 2021).

Another choice is metal preferred for its longevity and sustainability. It often comes from recycled materials like steel or aluminum. Also, metal roofs can withstand severe climates and they are lightweight and fireproof. They last longer than many other roofing options with a lifespan of 40 to 70 years (Solutions, 2021).

Slate, wood shakes, clay or concrete tiles, composite shingles, and polymer-based products are some additional materials used for roofing. Each material has their own specific characteristics, advantages, and limitations. So, when selecting the appropriate roofing material, factors such as climate, budget, aesthetic preference, and local building code should be considered (Abraham and Allen, 2022). So for this study, we chose asphalt shingles, recycled metal, and recycled rubber for their durability, availability, accessibility, and sustainability.

## Scope of LCA

As civil engineers, we are responsible to select the most suitable materials for construction considering sustainability and environmental impacts. This life cycle study followed cradle-to-grave Life Cycle Assessment (LCA) of roofing materials that consists of raw material supply, transport of raw materials and manufacturing processes. As a result, we expected to find an optimum material for roofing purposes through comparisons of various indicators. Indicators are measurable aspects that reveal the potential role of the materials in having an environmental impact. We chose the indicators from recent concerns. For this analysis, we preferred more commonly used materials around the globe so, we opted for asphalt shingles as virgin material and metal & rubber as recycled materials. We collected all the potential emission data from various resources and compared all those numerical values to come to a conclusion for choosing the most suitable material.

Our main objectives of this study are to,

1. Identify the processes and raw materials.
2. Identify the common indicators to compare.
3. Compute the LCA elements and compare those products.

## Functional unit

The Evaluated functional unit is 1$m^2$ of the roof. All numerical values of emissions are taken per unit area of roofing.

## Life cycle stages assessed

The Life Cycle Assessment (LCA) is done for the three materials with chosen indicators. Out of phases such as production stage, construction stage, use stage and end-of-life stage, we only considered production stage that comprises of material extraction, manufacturing, and transportation processes.

## Assumptions

The available LCA data are only available for specific countries, but we assumed it is appropriate for our application.

All three materials compared assuming the LCA results of each of those materials are obtained under same environmental conditions.

### Inclusions

We included the following elements in our analysis,

- Data and numerical values from previous research reports.
- Indicators from recent implications or concerns.
- LCA analysis with raw material extraction, Manufacturing, and Transportation processes.
- Comparisons of those three roofing materials.

### Exclusions

We excluded the elements like installation, final product transport, deconstruction, waste transport, waste processing, and final disposal from our LCA comparison.

### Methodology

The analysis will involve the following steps:

- Understanding the aim of the study.
- Identifying the construction purpose and the raw materials to be analysed.
- Identifying the common indicators for the analysis.
- Collecting the necessary data from various resources.
- LCA analysis for each indicator and chosen roofing materials.
- Material comparisons and analysing the results.

### Limitations

This study fully relies on numerical values. Those values may have uncertainties because it differs for each country. For example, if a country depletes raw materials, and must import materials by cargo, the emission values in transportation increase more than we used in this analysis. And we can't select a construction material by only analysing LCA for environmental impacts but also, we have to analyse its economic and social factors.

### LCA indicators

For the LCA we have selected primary energy demand, material resource depletion, ozone depletion potential, waste generation, recyclability, water footprint, global warming potential, pollution level, acidification, eco-toxicity, and human toxicity potential as the important indicators to compare materials of our choice. Other impact categories such as eutrophication photochemical ozone formation, ionizing radiation were omitted since there are avoidable or no impacts based on the materials and processes of this study. Moreover, indicators that we considered cover vast range of environmental impact categories. Moreover, these indicators are more appropriate and significant to compare potential impacts according to the materials of our choice and processes.

### Primary energy demand

A measurement of the entire quantity of primary energy taken from the earth known as the cumulative energy demand or primary energy demand. This includes the energy demand met from nonrenewable resources (such as fossil, nuclear, etc.) and energy demand met from renewable resources (such as hydropower, wind energy, solar energy, etc.) are two ways that primary energy demand is defined (PE INTERNATIONAL, 2012).

The necessity of energy for maintaining human well-being and the global scarcity of energy supplies serve as the key reasons for the energy consumption as an indicator. Energy consumption is frequently evaluated with other impact categories, such as the potential for global warming, acidification, and toxicity, giving information on various environmental impacts (Arvidsson and Svanström, 2015).

### Material resource depletion

This is a measurement of the depletion of resources in the earth's crust based on the quantity of reserves and the potential applications for such reserves. Abiotic resources can be used by mankind for a range of beneficial purposes after undergoing one or more steps of industrial transformation (PE INTERNATIONAL, 2012). A resource's extraction from the Earth's crust implies a reduction in the associated geological stocks, which is considered to contribute to the resource's depletion (Beylot et al., 2020).

More pressure is being imposed on the environment by the always growing product demand. Extraction of virgin resources and production of goods can put the environment under potentially disastrous stress (Sackey, 2018). By considering on resource depletion potential, resource conservation and efficient material usage practices can be improved.

### Ozone Depletion Potential

Ozone Depletion Potential is a measure of the atmosphere's ozone layer's degradation. This

## LCA comparison of roofing materials ...

layer is reduced with the concentration of halocarbons in the atmosphere as these gases dissociate the ozone molecules presented, reducing this layer. A measure of air emissions that contribute to the depletion of the stratospheric ozone layer. Higher levels of UVB ultraviolet radiation are caused by the ozone layer being depleted. ODP is evaluated by a kilogram of CFC-11 (Trichlorofluoromethane) equivalent.

Asphalt shingles are typically constructed from petroleum-based materials, which can contain ozone-depleting substances such as volatile organic compounds (VOCs) and halogenated hydrocarbons. These chemicals can contribute to the depletion of the ozone layer and have a negative impact on human health and the environment. Because the recycling process avoids the need to extract and process virgin materials that might contain ozone-depleting substances, using recycled rubber and metal as roofing materials can aid in reducing the ozone depletion potential impact.

### Wastage

Considering the wastage as an indicator is important because it allows us to assess the environmental impact of waste generation throughout the life cycle of the product. The production, installation, and end-of-life stages generate considerable amount of wastes. Considering wastage enables the assessment of waste management practices and the potential for waste reduction. We can identify chances to lower the usage of virgin materials by evaluating the wastages. Utilizing recycled materials for roofing decreases the need for extracting the virgin materials, promoting resource conservation and circular economy principles.

### Recyclability

Increased recyclability paves the path to reduced environmental burdens. The ability of a material to be collected, processed, and reused in the production of the same or novel products rather than being discarded as waste (Keller et al., 2022). Recyclability is a key indicator that provides insights into the reduced use of raw materials and the associated environmental impacts. This indicator aligns with the circular economy where the resources are kept in use as long as possible and provides a comprehensive measure of environmental sustainability (Ramjeawon, 2020).

Generally, it takes asphalt shingles around 300 years to completely perish. Thus, recycling asphalt shingles and turning them into new asphalt shingles can create an iterative process that feeds itself without adding to landfills. Moreover, recycled metal roofing can save up to 4.9 billion liters of gasoline every year. Similarly, recycled rubber roofing also gives back to the environment. (AUCKLAND, 2020)

### Water Footprint

Water footprint includes the impacts associated with water usage and the availability of water as well as the particular influences on the water resources and its users from emissions to air, soil, and water. It is the total amount of water utilized in the production of a product

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### A paradigm shift to ...

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waterborne or foodborne diseases, is the first step.

Two factors contribute to the weaker approach to combating airborne transmission compared to waterborne and foodborne transmission. Firstly, tracing airborne infections is challenging because they are not tied to easily identifiable point sources like contaminated food or water. The impact of food and water contamination on human health is often immediate, allowing for easier tracking and identification of the source. This has led to well-established public health structures and standards for food and water processing. In contrast, airborne studies are more complex due to the nebulous and widespread nature of air as a contagion medium. Buildings and their airflow systems are intricate, and measurement methods for airborne studies are not standardized.

Secondly, there has been a longstanding misunderstanding and lack of research into airborne transmission, leading to a lack of recognition of its importance. Modern building

Source: www.elglaw.com

construction has neglected modifications to address airborne risks, focusing instead on thermal comfort and other performance factors. Respiratory outbreaks have been attributed to droplet transmission or inadequate hand hygiene, overlooking the role of airborne pathogens. Architects and building engineers have prioritized factors like energy efficiency and initial cost over infection control. However, evidence shows that healthy indoor environments with

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## LCA comparison of roofing materials ...

taking in to account all stages in its life cycle (Octavia et al., 2017). The water footprint is a vital indicator of the environmental impact which can possibly evaluate the water efficiency of different types of production systems and identify the opportunities for improvement in terms of water use and sustainability (Ramjeawon, 2020).

### Global Warming Potential

Global warming potential is a measure of greenhouse gas emissions, such as $CO_2$ and methane. Generally, all building materials are emitting Global Warming Potentials (GWP), The emission level varies from material to material, as roof materials asphalt, metals and rubber are taken for our analysis. Methane and $CO_2$ emissions cause an increase in the absorption of radiation emitted by the planet, thus increasing the natural greenhouse effect. It is generally considered to have adverse impacts on environmental health, human health and material well-being (TEGNOS Research, 2010).

### Pollution level

Roofing materials such as metals, plastics, and asphalt can release pollutants into the environment. The pollutants released can include polycyclic aromatic hydrocarbons (PAHs), phthalates, pesticides, nonylphenols, and carcinogenic compounds. One source suggests that asphalt shingles contain carcinogenic compounds that are considered environmentally toxic, the metals can release pollutants even after 60 years of time.

### Acidification

Acidification is one of the major issues to the environment. Anthropogenic air pollutants like $SO_2$, $NH_3$, and $NO_x$ are the first cause of the problem. Acidification leads to air pollution and carries those anthropogenic air pollutants to the soil and to the water resources by acidified rain, snow, and mist. As a result, rivers, groundwater streams, and soil become more acidic. Therefore, it damages aquatic life, plants, terrestrial animals, shelled animals, and food webs. Acidification also damages concrete structures and encourages the leaching of heavy metals into the soil So, it is one of the major issues to be analyzed before roofing (Kim and Chae, 2016).

### Eco-toxicity

Heavy metal contamination in water bodies has come to a major concern nowadays. Roofs taking a substantial part in this. Heavy metals from roofs enter the water resources and groundwater streams by stormwater runoff. Surplus consumption of these heavy metals is harmful to aquatic life. In 2011 an evaluation was conducted in the Puget Sound Basin to analyze the yearly accumulation of contaminants in the water. As a result, most of the contaminants were heavy metals such as copper, zinc, arsenic, phthalates, and PAHs. Therefore, they found out roof runoff was the substantial source of this contamination. Additionally, nitrogen release from roofs leads to the eutrophication issue and $O_3$ emission encourages smog creation or ozone formation. Thus, it is important to analyse the eco-toxicity while roofing (Winters et al., 2015).

## SCIENCE NEWS

### A paradigm shift to ...

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reduced pathogen counts are crucial for public health.

It is now known that respiratory infections are caused by pathogens emitted through the nose or mouth of an infected person and transported to susceptible individuals. These pathogens are enclosed in fluid-based particles released during respiratory activities like breathing, speaking, sneezing, and coughing. Airborne transmission, particularly in indoor spaces shared with infected individuals, is a dominant mode of transmission for numerous respiratory infections. The design, operation, and maintenance of buildings influence transmission, as evidenced by disease outbreaks in various settings. The estimated monthly global cost of COVID-19 is around $1 trillion, and there are also substantial costs associated with other common respiratory infections. In the United States, the annual cost of influenza, including both direct and indirect expenses, is estimated at $11.2 billion. For respiratory infections other than influenza, the yearly cost reaches $40 billion.

Despite the significant health burden and economic losses caused by respiratory infections, engineering-based measures to limit community transmission of respiratory infections have been rarely employed in public buildings or transport infrastructure worldwide. Ventilation, supported by air filtration and disinfection, is a key engineering measure to control airborne infection risk. However, existing guidelines, standards, and regulations primarily focus on addressing odor and occupant-generated bio effluents, neglecting the control of airborne pathogens. To address this issue, ventilation guidelines, standards, and regulations should be expanded to explicitly address airborne pathogens and the need for infection control. National comprehensive indoor air quality (IAQ) standards should be developed, promulgated,

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### Human-toxicity potential

Human toxicity potential (HTP) is a quantitative measure of how harmful people have been affected by the emissions of chemicals into the environment. HTP takes into account both general source-to-dose relationships for pollutant emissions and inherent toxicity. It is most likely to be inhaled, dermal contact, and consumption of contaminated foods (McKone and Hertwich, 2001). Young children have many characteristics which make them uniquely vulnerable to environmental exposures. Children have very low immunity systems; they breathe more air per pound of body weight than adults do in the same environment and their physical activity adds a factor to exposure through inhalation. Thus, it is necessary to analyze human toxicity potential indicators while roofing (Denly et al., 2008).

## Comparison and Discussion

### Primary energy demand

1. Asphalt (Virgin Material)

Asphalt shingles need significant amount of energy during production and construction stages. Energy is used to generate the various ingredients, which are then converted into roofing sheets (asphalt shingles). Primary energy demand for 1m$^2$ asphalt shingle shown below. During the production stage (Raw material extraction, transport, manufacturing) -177.5MJ ((ARMA), 2016).

Asphalt shingles slightly increase the % of energy savings since it doesn't allow dissipation of internal heat gains which increases the demand for cooling. But has little effect on energy consumption (ASSOCIATION, 2021).

2. Recycled Metal

The energy required to make a virgin material is significantly reduced when recycled metals like aluminum are used as roofing materials. Recycled aluminum only uses 5% of the original energy while recycled steel uses 26% of the original energy to produce a new sheet. Copper is another recyclable roofing material used in roofing and only 15% of the total energy is used (STEEL, 2021).

Renewable and non-renewable primary energy used for 1 m2 recycled metal (Steel) shown below. During the production stage (Raw material extraction, transport, manufacturing) - 44.9MJ (Institute, 2020)

3. Recycled Rubber

Rubber roofs have a little energy need for production and are effective insulators, which lowers the amount of energy needed for heating and cooling (Lugaria, 2020).

During the production stage (Raw material extraction, transport, manufacturing) -10.95MJ (Products, 2019). Comparatively, asphalt shingle, which is a virgin material contributes to the higher value of energy consumption than other two recycled materials.

### Material resource depletion

1. Asphalt (Virgin Material)

Asphalt shingles are one of the construction items with a high raw material input. Beginning with the extraction and transportation of the raw materials, the figure explains the phases in the production process for roofing sheets (asphalt shingles) (Sackey, 2018).

Primary input materials used to produce asphalt shingle roofs are fiberglass mat, asphalt, filler, ceramic granules, and sealants (OWENS CORING ROOFING AND ASPHALT, 2020). Resource depletion potential (Includes primary renewable and non-renewable resources used as material) for 1m$^2$ of Asphalt shingle roofs are shown below.

During the production stage (Raw material extraction, transport, manufacturing) - 44.3 [kg] ((ARMA), 2016)

2. Recycled Metal

Due to the substantial amount of recycled material in metal roofing, it helps protect the environment. Aluminum can be recycled multiple times without losing its quality, which avoids the need to extract materials from the natural world. Recycled content for various metal used in metal roofing shown below. Resource depletion potential (Includes primary renewable and non-renewable resources used as material) for 1m$^2$ of metal roofs are shown below.

During the production stage (Raw material extraction, transport, manufacturing) – 1.72 [kg] (Institute, 2020) .

3. Recycled Rubber

Ethylene propylene diene mono-

**Figure 01: Content of recycled material (STEEL, 2021)**

| Roof material (Type of metal) | Recycled material content (Weight %) |
|---|---|
| Steel | 25 |
| Copper roofing | 80-85 |
| Flat rolled aluminum | 75 |

mer (EPDM) known as rubber roofing material is a synthetic rubber made of a mixture of recycled rubber tires, slate, and sawdust (Lugaria, 2020). The use of recycled rubber in roofing applications removes the demand for new environmental resources and substitutes for virgin rubber (Battista et al., 2021). Used tires replace synthetic rubber in a variety of industrial applications at a weighted ratio of 1:1 (Merlin, 2020). Resource depletion potential (Non-renewable materials) for 1m$^2$ recycled rubber are shown below.

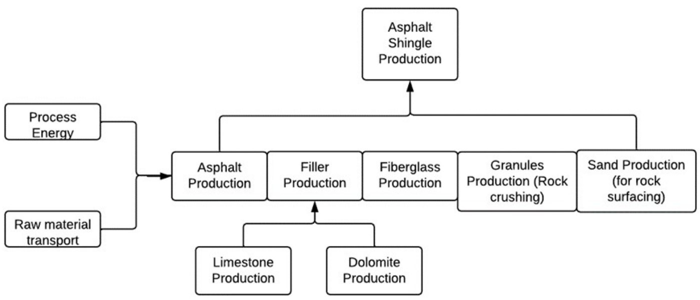
During the production stage (Raw material extraction, transport, manufacturing) -6.24[kg] (Products, 2019). Usage of recycled material from upstream significantly reduced the necessity of new material and contributed negative values for material depletion potential in usage of EPDM and Metal as the roofing material while Asphalt consumes material from environment during their production process.

## Ozone Depletion Potential

1. Asphalt shingles

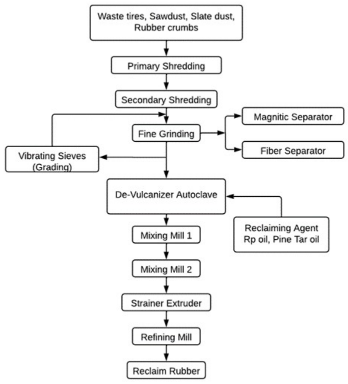
Asphalt shingles consist of fiberglass mat impregnated and coated on both side with filled asphalt. They are further surfaced with mineral granules on the side exposed

**Figure 02: Production process of asphalt shingles (Sackey, 2018)**




to weather. The ability of asphalt shingles to self-seal, acting as a primary barrier against weather elements, is one of their key features.

**Figure 03: Production process of recycled rubber (Group, 2021)**



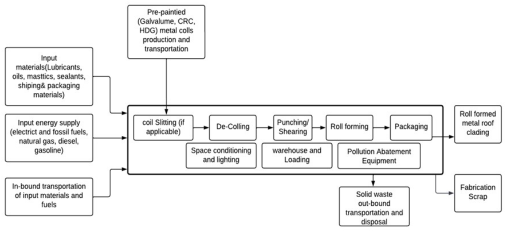

It has been determined that the ozone depletion potential of asphalt shingles at the product stage, which includes raw material supply, transport, and manufacturing, is about 4 x $10^{-10}$ kg CFC-11 eq per square meter. This impact arises primarily from the production of asphalt used in the shingle manufacturing process ((ARMA), 2016).

2. Recycled Rubber Roofing

The fire Firestone non-reinforced EPDM membrane is an extremely durable synthetic rubber single-ply roofing membrane used worldwide in low-slope roofs for commercial, industrial, and residential buildings. It has been recognized for its exceptional long-term performance, which includes great weather resistance, immunity to hail damage, and simplicity of repair.

When considering the production stage of non-reinforced EPDM membrane, which includes activities such as raw material supply, transport, and manufacturing, the impeach on ozone depletion potential can be assessed. The production of non-reinforced EPDM membrane estimated to have an ozone depletion potential of about 1.01 x $10^{-9}$ kg CFC-11 eq for every square meter of roofing (Products, 2019).

**Figure 04: Production process of recycled metal (Institute, 2020)**




3. Recycled Metal Roofing

Metal production begins with either primary or secondary resources. The decrease in energy required to produce a ton of metal is one of the productions of secondary metals' greatest environmental advantages. the reason for this is primarily because melting metal uses less energy than reducing naturally occurring oxides and sulfides.

The effect on ODP can be measured when analyzing the cradle-to-



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gate production stage of metal roof panels, which includes activities like extraction and upstream production, transport to the factory, and manufacturing. Total impact on ODP during the production stage is calculated to be 2.9 x $10^{-7}$ kg CFC-11 equivalent per 1 square meter (Institute, 2020).

## Wastage

1. Asphalt shingles

Considering the waste produced during the stages of production, which include raw material supply, transport, and manufacturing, can provide valuable information about the material's environmental impact. For an example an around 11 million tons of waste asphalt shingles roofing are produced annually in the US. 10 million tons of this total come from roofing projects.

We can categories the generated wastage in production stage into two types such as non-hazardous waste generated, and hazardous waste generated. The non- hazardous waste generated in the stage of production is estimated to 0.8 kg per square meter of asphalt shingle. Same time the hazardous waste is 0.001 kg per square meter of asphalt shingle ((ARMA), 2016).

Total waste (In Production stage) = Non-hazardous waste + hazardous waste = 0.801 kg ((ARMA), 2016)

2. Recycled Rubber Roofing

The huge number of unused wastes that ends up in landfills create environmental issues. So, finding new ways of utilizing these landfill wastes is vital. When considering the generation of non-hazardous waste and hazardous EPDM (Ethylene Propylene Diene Monomer) for roofing purposes in the production stage, EPDM generated 0.220 kg as non-hazardous waste per square meter, same time 1.86 x $10^{-5}$ kg as hazardous waste per square meter (Products, 2019).

3. Recycled Metal Roofing

Metals are the wastes produced from ferrous and non-ferrous materials, including pipes, reinforcing bars, steel, aluminum, copper, brass, and other materials. Metal generated some of the minimum waste out of four types (Concrete, Brick, wood) of construction waste.

In here wastage categories can be considered as hazardous waste disposed (HWD), non-hazardous waste disposed (NHWD), high-level radioactive waste (HLRW), and intermediate and low-level radioactive waste (ILLRW).

And the amount of the HWD is estimated as 0.00 kg per square meter, And NHWD is also estimated as 0.00 kg per square meter in production stage. Which means these wastes do not have the immediate risks to human and the environment.

On other hand considering about the radioactive waste, the amount of the HLRW is estimated as 6.4x$10^{-10}$ $m^3$ per square meter and the amount of the ILLRW is estimated as 1.2x$10^{-6}$ $m^3$ per square meter (Institute, 2020).

## Recyclability

1. Asphalt shingles

Recycling Asphalt shingles roofing is economically operable and convenient, preventing resourceful material from entering landfills. Generally, asphalt shingle materials are recycled into the pavement and compensate for the requirement of virgin asphalt material for pavements. Moreover, Asphalt shingle recycling creates jobs at recycling locations and the cost incurred in paving is lessened ((ARMA), 2016).

As Asphalt shingles contain inherent impurities, they cannot be combusted in standard incineration plants whereas the combustion is mostly incinerated at cement kilns.

2. Recycled Rubber Roofing

Shingles that are made from recycled rubber are wholly recyclable. Discarded materials, like used vehicle tires and even rubber bottles, are cut, heated, and molded into shingles that resemble natural slate tiles. The environmental impact of manufacturing these recycled rubber shingles is not specified, however, repurposing an existing product that can be recycled again accompanies the basics of cradle-to-cradle principles. For instance, as they do not essentially require the inputs and landfilling associated with asphalt or the mining associated with other required raw materials, these recycled rubber shingles have a lower carbon footprint than traditional roofing shingles when looking at their complete product life cycle (Service, 2021).

3. Recycled Metal Roofing

Recycled metal roofing panels too offer the benefit of being completely recyclable at the end of their useful life. For instance, whereas conventional roofing materials are dumped as tons in landfills, the steel, aluminum, copper,

**Figure 02: Production process of asphalt shingles (Sackey, 2018)**

and zinc used in metal roofing panels are wholly recyclable, which confers to the emergence of sustainable products which eliminate the need to separate the old roofing material and helps preserve the landfill space.

In terms of recycled content, recycled metal has an advantage over many other construction materials in terms of LEED point calculations since metal can be re-used, while roofing materials such as asphalt or virgin rubber membranes end up in a landfill.

## Water footprint

1. Asphalt shingles

Asphalt shingle production typically requires a significant amount of water, fundamentally for cooling and cleaning processes. The water footprint of asphalt shingle production could be further risen by the energy which is required to heat the asphalt content and operate the machinery incorporated in production. In the production stage which includes raw material supply, transport, and manufacturing, per 1m$^2$ of individual components requires 24.3L of water ((ARMA), 2016).

2. Recycled Rubber

Recycled rubber production typically requires higher water than asphalt shingle production, as the processing of recycled rubber typically involves mechanical shredding and grinding. The water footprint of recycled rubber production is affected by the energy required to operate the machinery incorporated in the production and transportation of the material. In the production stage which includes raw material supply, transport, and manufacturing, per 1m$^2$ of individual components requires 12.4L of water (Products, 2019).

3. Recycled Metal

Recycled metal production typically requires less water than asphalt shingle production, as the processing of recycled metal significantly includes melting and casting, apart from the extensive washing or cooling processes. However, the water footprint of recycled metal production can be affected by the energy required to operate machinery incorporated in the production and transportation of the material to the site. In the production stage which includes raw material supply, transport, and manufacturing, per 1m$^2$ of individual components requires 23L of water (Institute, 2020).

## Global Warming Potential

1. Asphalt

Raw material extraction for asphalt involves mining and processing crude oil, a non-renewable resource that contributes to GHG emissions. The transportation of raw materials, such as crude oil and aggregates, also contributes to GHG emissions. Asphalt production involves the heating and mixing of these raw materials, which results in additional GWP emissions. The GWP emission for 1m$^2$ of the asphalt roof panel is 8.5 kg $CO_2$- eq during the production stage which includes raw material supply, transport, and manufacturing. So, for the asphalt roof, the production stage has significant GWP value ((ARMA), 2016).

2. Recycled rubber

By using GWP as an indicator, LCAs can evaluate the relative contribution of recycled rubber roofs to global warming compared to other roofing materials. This facilitates informed decision-making and allows stakeholders to select materials that minimize their climate impact. Literature review on the LCA of green roofs suggests that using recycled rubber in the drainage layer of an extensive green roof instead of pozzolana reduces environmental impacts and GWP emissions. 1m$^2$ of the recycled rubber roof panel has 69.9 kg $CO_2$ eq GWP during the production stage (Raw material supply, Transport, and Manufacturing) (Products, 2019).

As per the result, the (GWP) $CO_2$ emission is higher for recycled rubber compared to recycled metal and asphalt. And the recycled rubber from tires has the highest GWP emission (Cascone and Gagliano, 2022).

3. Recycled metal

Some of the results suggest that metal roofing systems have high recycled content, recyclability, durability, and longevity characteristics, which can reduce environmental impacts and low GWP emissions (Construction, 2021).

Recycled metal roofs have the advantage of reducing the demand for primary metal extraction and production. GWP analysis enables the evaluation of the emissions savings achieved through recycling compared to the extraction and production of virgin metals. The result for 1m$^2$ of the metal roof panel has GWP of 13.26Kg eq.

**Figure 02: Production process of asphalt shingles (Sackey, 2018)**

## LCA comparison of roofing materials ...

And a contribution analysis revealed that the manufacturing module generally accounted for 2% to 9% of the global warming potential (GWP) of the total cradle-to-gate product system (Institute, 2020).

### Pollution level

1. Asphalt

Asphalt involves the extraction and refining of crude oil. These processes can result in water, air and land pollution. Emissions of VOCs, particulate matter, and sulfur dioxide can occur during the production phase. In the use phase when the sun's heat is applied on the roof, the VOC emission will increase. And when the rainy season the heavy metals and chemicals are removed from the asphalt surface and will affect the groundwater quality and land pollution (Construction, 2021).

2. Recycled rubber

If rubber waste is not collected and stored properly, it can pose a risk of air and water pollution. However, when managed correctly, the collection and processing of rubber waste can minimize pollution levels. The production processes involve using chemicals, adhesives, or dyes, which can emit pollutants into the air and water if not properly managed. The lifecycle analysis of the impact on the climate, the air, water and toxicity of various synthetic membranes and asphalts. The environmental impact of EPDM membranes is less pronounced than other roofing systems (Products, 2019).

3. Recycled metal

Compare with other cladding materials metal wall panels and metal composite material (MCM) have higher ozone-depleting emission potential, when compared to the average statistical environmental burdens this concern is normalized. Because of made by recycled steel the metal buildings are good for the environment, its 100% recyclable and produce low carbon footprint.

### Acidification

1. Asphalt

$SO_2$ emission is one of the main reasons for acidification. Intentionally we don't use $SO_2$ in Asphalt production. Asphalt is derived from crude oil, which contains Sulphuric components. Due to Asphalt manufacturing at high temperatures, $SO_2$ emission increases with heat. When asphalt is used in roofing applications, it is exposed to moisture and sunlight so, it releases a significant amount of $SO_2$ to the environment. Acidification potential for $1m^2$ asphalt production is $0.42kgSO_2$ eq during the production process (Corporation, 2020).

2. Recycled Rubber

Polyvinyl Chloride (PVC), Modified Bitumen, and Ethylene Propylene Diene Monomer (EPDM) are the three main types of Rubber roofing. EPDM is the largely used roofing because of its lowest environmental impact, durability, long service life, and ability to be recycled and reused. From $1m^2$ of EPDM emits 0.05 kilograms of Nitric oxide (NOx), and the lowest rate of hydrogen ions (H+) at 8.8 moles, both contribute to the Acidification (ROOFING, 2022). Acidification potential for $1m^2$ asphalt

## SCIENCE NEWS

### A paradigm shift to ...

... continued from page 81

and enforced globally. Professional engineering bodies should improve ventilation standards to consider infection control explicitly. Mandating the use of monitors displaying IAQ parameters will increase public awareness and hold building operators accountable. The COVID-19 pandemic has exposed our lack of preparedness in responding to respiratory infections. A paradigm shift is necessary, similar to the establishment of clean water supplies and centralized sewage systems in the past. Ensuring clean air in our buildings, with reduced pathogen counts, should be a priority for the health of building occupants, just as we expect clean water from our taps.

**Original article: Science, 14th May, 2021: page 689**

## SCIENCE NEWS

### The methane mystery ...

... continued from page 77

Larger companies like BP, ExxonMobil, and others have set methane leak-reduction targets for 2025, indicating their increased seriousness about the issue compared to smaller companies. However, in 2019, these larger companies accounted for less than 2 million tonnes of the total 75 million tonnes of methane emitted by the industry. Stronger regulations are on the horizon, with the EU planning to develop its methane strategy later this year. The US Senate approved President Joe Biden's decision to reverse methane deregulation implemented by Donald Trump. Furthermore, advancements in technology are rapidly improving our ability to detect methane leaks from space. As we unveil the mysteries of methane, we strive for a brighter future, where harmony is restored to our delicate climate.

**Original article: New Scientist, 22nd May, 2021: page 16**

production is 1.18 kg SO2 eq during the production stage which includes raw material, transport, and manufacturing.

3. Recycled Metal

Typically, Aluminum and Steel are the two recycled materials that are used in roofing. Both contain a certain level of Sulphur components, which may result in acidification. Typically, metal emits 0.0454kg of SO2 eq from raw material extraction, transport, and manufacturing of 1 m2 of case steel roofing (Roy et al., 2022).

### Eco-toxicity

1. Asphalt

Asphalt emits several components that may become threats to the environment. Nitrogen emission is one of them, which encourages eutrophication. Eutrophication is the accumulation of excess nutrients in water bodies that damages the structural ecosystem, which encourages the production of Algae and aquatic plants, and depletes the fishes and other aquatic life. And also, Asphalt emits $O_3$, which leads to smog creation in the environment (Corporation, 2020).

2. Recycled Rubber

When the rubber roofing is exposed to heat, it releases volatile and semi-volatile organic compounds (VOC and SVOC), which directly contribute to material damage to the environment by ozone formation. Metals like Zinc, iron, manganese, Barium, and chromium are mostly detected in recycled rubber. 1kg of recycled rubber contains 11.4 mg of VOCs: methyl isobutyl ketone, 171 mg of Benzothiazole, 33,700 mg of Alkylphenols: 4-t-octyl phenol, and 203 mg of Bis(2-ethylhexyl) [DEHP] phthalate. All these are responsible for water pollution, soil pollution, air pollution, and climate change. Additionally, Alkylphenols: 4-t-octyl phenol and DEHP may lead to bioaccumulation and endocrine disruption (Denly et al., 2008).

**Figure 05: Eco-toxicity potential of Asphalt shingles**

| | Eutrophication (N) | Smog creation (O3) |
|---|---|---|
| | kg | kg |
| Raw materials (A1) | 0.048 | 1.027 |
| Raw material Transport (A2 | 0.035 | 0.284 |
| Manufacture (A3) | 0.062 | 0.357 |
| Total | 0.145 | 1.648 |

3. Recycled Metal

Steel roof emits PO4-, which is one of the reasons for eutrophication and it emits $C_2H_4$, which is the reason for ozone/ smog creation in the environment (Corporation, 2020).

**Figure 06: Eco-toxicity potential of recycled metal**

| | Eutrophication (N) | Smog creation/Ozone creation ($C_2H_4$) |
|---|---|---|
| | kg | kg |
| Raw materials (A1) + Manufacturing (A3) | 0.00285 | 0.00493 |
| Raw material Transport (A2) | 0.0024 | -0.00126 |
| Total | 0.00525 | 0.00367 |

### Human toxicity potential

1. Asphalt

Asphalt affects humans when breathed in, it causes nose irritation, throat, and lungs causing coughing, wheezing, and/or shortness of breath. Asphalt fumes on contact can cause eye irritation, severe skin burns, dermatitis, and acne-like lesions. Exposure to Asphalt fumes may result in headaches, dizziness, nausea, and vomiting. All these effects depend

## SCIENCE NEWS

## You can tell a city from its mix of microbial life

A survey conducted in 60 urban areas worldwide has found out that the cities have distinct microbiomes. Christopher Mason at Cornell University in New York with his team members conducted tests on swab samples taken in urban transport systems such as subways in the period 2015 till 2017, collecting 4728 samples from cities from major cities around the world.

The swab samples were then tested for presence of microorganisms such as bacteria and viruses and identifying their species, that indicated their presence in urban surfaces. From the data, each city was assigned an endemicity score: the number of species endemic to it that can define the microbial fingerprint of each city.

It was observed from the study that the larger the city, more complex and diverse microbial life in it. Furthermore, it was also observed that the microbial species were significantly different to distinguish cities from the others. Mason claimed that the accuracy was as high as 90% (distinguishability).

Source: okq.mx

The article draws conclusions that testing for a person to see if he/she has visited a particular city in the recent past, owing to the findings of this study. Surprisingly, Mason also found 10928 viruses and 748 bacteria, that were not in and reference databases.

**Original article: New Scientist, 5th June, 2021: page 21**

on consumption quantity and term. Even though Asphalt has not been identified as Carcinogen, it should be handled under necessary cautions. Health agencies recommend airborne exposure limit under 5 mg/m3, which should not be exceeded during any 15 minutes (Services, 2007).

2. Recycled Metal

While metal roofing some components may push us towards health risks. We mainly consume those by breathing or touching them. The risks of consumption depend on what we consumed-in or how much we've consumed. Commonly when it comes to metal roofing, most probably we consume components like Lead, Zinc, Copper, Arsenic, and Antimony. 1m2 of metal roof panel exposes 0.022 kg of Antimony in production (Institute, 2020). Zinc is another metal roofing component that can cause severe health problems (Mueller, 2022). Approximately it emits 0.0026 kg of Zn and 0.0014 kg of Cu from 1m2 of metal roofing (Galster and Helmreich, 2022). And, when we reach a critical level of Lead consumption, it may result in chronic complications like insomnia, Hallucinations, tremors, and cognitive deficits.

3. Recycled Rubber

Chemicals in crumb rubber are to be health concerns for humans such as Polycyclic Aromatic Hydrocarbons (PAHs), Volatile Organic Compounds (VOC), Semi volatile Compounds (SVOCs), Benzothiazole, and certain metals. We consume those chemicals by inhalation, ingestion, and dermal absorption. Consumption of those chemicals to the critical level leads us to physical effects such as Heat-related illness, Physical Injuries, and Bacterial Infections. 1kg of recycled rubber contains 1-20 mg of Lead, 0.12-2 mg of Cadmium, 4 -70mg of copper, 2-5200 mg of Chromium, 0.005-0.04 mg of Mercury, 174-18000 mg of zinc, 1120-33700 mg of Phenols, 0.12-3.1 mg of Benzopyrene, and 1- 76 mg of PAHs, which are highly toxic for humans on excessive consumption (Denly et al., 2008).

Below table consist of some important impact categories and the overall LCA results for 1 m2 roofing material such as Asphalt shingle, recycled rubber, and recycled rubber.

**Figure 07: Overall result of LCA**

| Production stage (Raw materials, Transport, Manufacturing) | | | | |
|---|---|---|---|---|
| **Indicator** | **Unit** | **Asphalt Shingles** | **Recycled Rubber** | **Recycled Metal** |
| Primary energy demand | MJ | 177.5 | 44.9 | 10.95 |
| Material resource depletion | kg | 44.3 | 1.72 | 6.24 |
| Ozone Depletion Potential | kg CFC-11 eq | $4 \times 10^{-10}$ | $1.01 \times 10^{-9}$ | $2.9 \times 10^{-7}$ |
| Wastage (Hazardous & Non-hazardous) | kg | 0.801 | 0.22 | 0 |
| Water footprint | L | 24.3 | 12.4 | 23 |
| GWP | kg $CO_2$ eq | 8.5 | 69.9 | 13.26 |
| Acidification | kg $SO_2$ eq | 0.42 | 1.18 | 0.0454 |

## Discussion

In this study, all measurements inherently constitute error. Uncertainty of measurements of values taken does not affect it only it affects the overall calculation because numerical values propagate as the values traverse through functional computations. Moreover, it is significant to note that the numerical data values presented in this study are specific to the United States which is not applicable to all countries. Environmental impacts vary based on regional factors too. These fluctuations may arise due to differences in production methods, resource availability, transportation distances, and other factors specific to each country or region.

## Conclusion

This LCA study examines the environmental impact of three roofing materials which are asphalt shingles (virgin material), recycled rubber roofing, and recycled metal roofing. It aids in sustainable decision-making upon evaluating several indicators.

Asphalt shingles have a higher energy requirement due to multiple production processes, while recycled rubber roofing requires less energy compared to asphalt shingles. Recycled metal roofing benefits from the energy efficiency of recycling metal scraps, resulting in lower energy demand. Recycled metal roofing demonstrates a lower resource depletion potential by utilising recycled materials. Recycled rubber roofing also reduces the demand for virgin rubber, potentially showing a lesser resource depletion potential.

In terms of ozone depletion potential, asphalt shingles have a relatively low impact, whereas recycled rubber roofing materials have a higher impact during production. Recycled metal roofing benefits from energy-efficient secondary metal production, resulting in a lower ozone depletion potential.

Waste generation is significant for

**Figure 02: Production process of asphalt shingles (Sackey, 2018)**



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asphalt shingles, while recycled rubber roofing produces smaller amounts of waste. Recycled metal roofing focuses on minimising hazardous waste. Effective waste management and recycling practices are vital for reducing environmental impacts. Recyclability plays a key role in sustainability. Asphalt shingles can be recycled for pavement use, while both recycled rubber and metal roofing materials are fully recyclable, contributing to waste reduction and resource conservation. Water footprint varies across materials, with asphalt shingle production consuming significant amounts of water. Recycled rubber processing requires more water, while recycled metal production generally demands comparatively lesser water.

Greenhouse gas emissions, measured by global warming potential (GWP), are moderate for asphalt shingles and higher for recycled rubber roofing compared to both asphalt and recycled metal. Recycled metal roofing offers environmental benefits due to high recycled content and recyclability.

Pollution and acidification potential must be considered. Asphalt emissions contribute to eutrophication and smog, recycled rubber releases VOCs, SVOCs, and metals causing pollution, while recycled metal emissions contribute to eutrophication and ozone/smog formation. In summary, this LCA study provides insights into the environmental impact of three different roofing materials, considering energy demand, resource depletion, ozone depletion potential, waste generation, recyclability, water footprint, greenhouse gas emissions, pollution, and ecotoxicity. By evaluating these factors, decisions can be made to select roofing materials that can potentially minimise the environmental impacts and promote sustainability.

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RINDUJA R
University of Jaffna


VINOJAN P
University of Jaffna


SARANKAN S
University of Jaffna


SAMHAN M A
University of Jaffna


VITHUSHAN A
University of Jaffna

# Waste Auditing Tool

## Construction & demolition waste auditing tool for a construction company

*A tool that track, analyze and manage construction & demolition waste in an economical manner*

Construction and demolition (C&D) waste management is a critical aspect of sustainable development in the construction industry. C&D waste includes materials such as concrete, wood, metal, plastics, and various other construction materials that result from building, renovation, and demolition activities. Improper management of C&D waste can have significant environmental and economic impacts, including resource depletion, pollution, and increased landfill usage.

To address these challenges, a Construction and Demolition Waste Auditing Tool has been developed to help construction companies, contractors, and waste management professionals effectively manage and reduce C&D waste. This tool provides a comprehensive framework for auditing and assessing C&D waste generated during construction projects.

### Scheme of the tool

In developing our Construction and Demolition Waste Auditing Tool, we have adhered to the following framework shown in figure 01.

De-

**Figure 02**

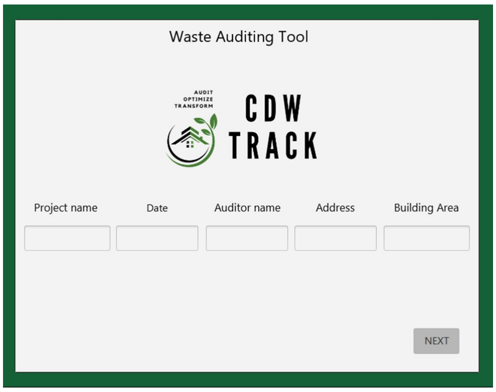
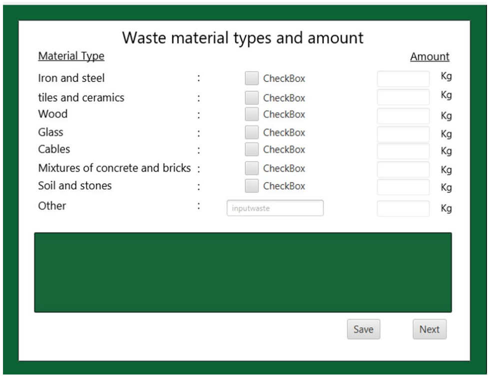
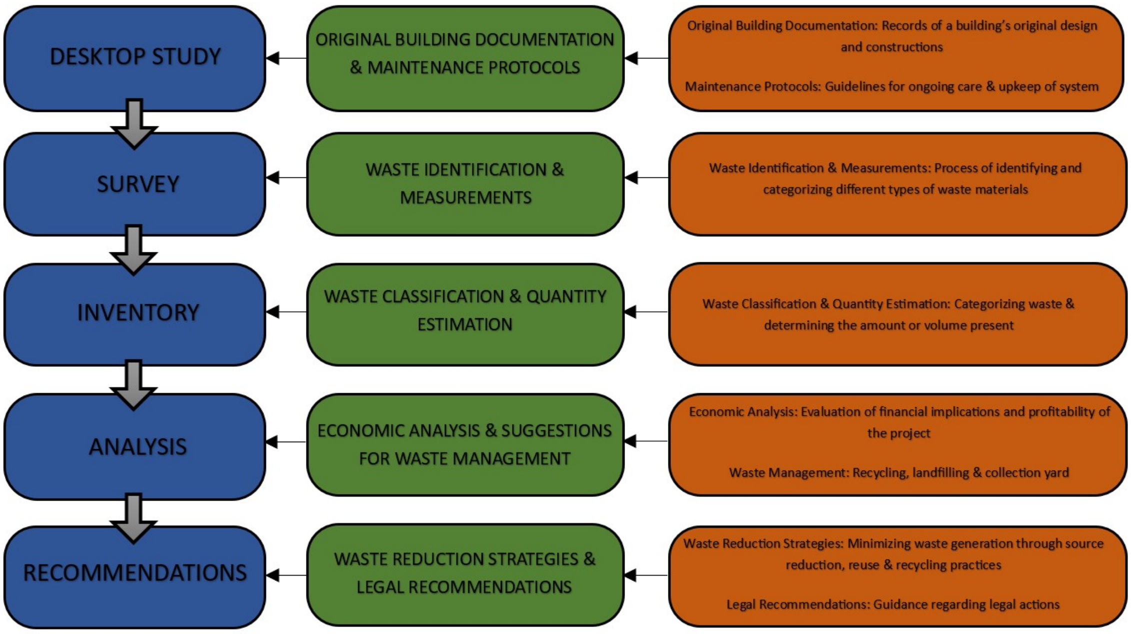



**Figure 03**



# Waste Auditing Tool

## Construction & demolition waste auditing tool for a construction company

*A tool that track, analyze and manage construction & demolition waste in an economical manner*

### Development of the tool

We have used JavaFX to develop our Construction and Demolition Waste Auditing Tool. It is designed to effectively track construction and demolition waste, and provide appropriate waste management methods and strategies. It boasts a user-friendly interface, as shown in figure 02. In that, user can input and save essential project details, including the project name, date, auditor name, location, and floor area. The floor area serves as a reference for estimating the amount of waste in cases where the user doesn't have precise measurements. We have incorporated various models to assist in determining the waste quantity accurately. Next, the interface will progress as in figure 03.

In that, the user can enter the types of wastes collected and their respective quantities. In case any material type is found that is not listed, the user can select the "Other" option from the dropdown menu. However, it's important to note that currently, the tool only supports a single material entry for the "Other" option. Further development can be made to accommodate multiple materials under the "Other" option.

Once all the details have been saved, the interface will transition to the view as shown in figure 04.

A sample set of values has already been entered in the previous interface. In that interface, the user can select the desired disposal method from the available options: recycling, landfilling, and collection yard. The choice of disposal method is left to the discretion of the user.

Additionally, there is a suggestion in the tool to input the distance between the disposal area and the construction site. This distance is required to calculate transportation fees. To streamline this process, further development is needed to implement an auto-suggestion feature for disposal area locations based on map data.

The user has the freedom to manually input the treatment fee amount. In cases where the amount is not provided, the tool will automatically retrieve the default treatment fee assigned for each treatment method. These default treatment fees have already been pre-entered in the tool.

**Figure 04**

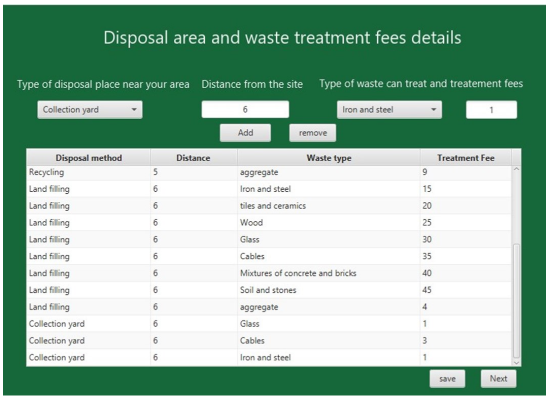
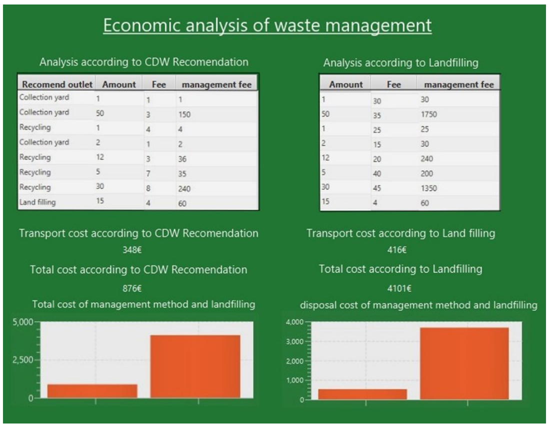



**Figure 05**


**Figure 06**



# Waste Auditing Tool

## Construction & demolition waste auditing tool for a construction company

*A tool that track, analyze and manage construction & demolition waste in an economical manner*

Subsequent interface is designed to recommend the most cost-effective treatment method for each material, based on a comparison of the treatment fees associated with the suggested methods. The tool evaluates the treatment fees and presents the comparison results using bar charts for visual clarity. The interface is as in figure 05.

We have now reached a crucial component of our tool, which is the economic analysis. This feature showcases the potential return on investment that can be attained by adopting specific treatment methods. The interface in figure 06 illustrates the comparison and analysis.

Finally, our tool offers waste management strategies tailored to each material type. These strategies aim to optimize waste management practices and promote sustainability.

### How the economic analysis has been done?

The economic potential of a sustainable approach to waste management is demonstrated through the calculation of costs for waste treatment and costs of waste transport for two variants.

One variant presents the waste management according to our tool recommendation and the other variant presents the least environment-friendly method of waste management, namely landfilling of the whole amount volume of waste.

Through the following step by step equations, we developed the cost analysis of our tool.

2. **Treatment costs depend on the user input and treatment method. They are expressed by the following equation.**

$$C_{wd} = \sum_{t=1}^{n} (Q_i \ x \ FD_{ij})$$

$C_{wd}$= costs for treatment

$Q_i$ = volume of i$^{th}$ waste type

$FD_{ij}$ = fee for j$^{th}$ waste disposal method of i$^{th}$ waste type

**i** = waste type

**j** = waste disposal method

2. **Transport costs depend on transport distance and transport fee. They are expressed by the following equation.**

$$C_t = \sum_{t=1}^{n} (n_{ij} \ x \ FT_{ij})$$

$C_t$ = transport costs

$n_{ij}$ = number of kilometers for the transport of the total amount of i$^{th}$ waste to the j$^{th}$ waste disposal site

$FT_{ij}$ = fee for transport i$^{th}$ waste type to j$^{th}$ waste disposal site

**i** = waste type

**j** = waste disposal method

$$n_{ij} = \sum_{t=1}^{n} (D_{ij} \ x \ nr_{ij} \ x \ 2)$$

$n_{ij}$ = number of kilometers for the transport of the total amount of i$^{th}$ waste to the j$^{th}$ waste disposal site

$D_{ij}$ = distance of the construction site for i$^{th}$ waste type to the j$^{th}$ waste disposal site

$nr_{ij}$ = number of rides from j$^{th}$ waste disposal site to the waste

$$nr_{ij} = \sum_{t=1}^{n} (Q_i \ / \ Q_v)$$

$$\text{Total cost} = C_{wd} + C_t$$


KESHIKAN B
University of Jaffna


KISHOTHARAN S
University of Jaffna


KUGALOJAN T
University of Jaffna


RISHIKEITHTHANAN H.
University of Jaffna


THILAKARATHNE E.M.M.M.K.
University of Jaffna

PERSPECTIVE

# Valorization technologies for waste management — The recycling of plastic packaging case

*This case study presents a simple method of analysing alternative choices for a particular application*

The widespread consumption of plastic and inadequate management of plastic waste causes pollution situations. Common pictures of the accumulation of plastic waste on beaches or in the oceans with direct consequences for marine animals and birds, raised public awareness of the uncontrolled consumption of plastic. Plastic packaging is part of this waste, along with fishing artifacts as nets and ropes, cotton swabs, etc.. Many products we consume daily are packaged in plastic, metal, glass or cardboard. Plastic is the most used material to pack the daily consumption products, namely drinking water, soft drinks, shampoos, detergents, other cleaning products, food, etc. And the plastic bags (namely as films) are commonly used for carrying these products. Organizing the disposal of packaging waste by providing appropriate bins for citizens to separate packaging from other waste, namely organic waste, allows for the collection and subsequent recovery of packaging materials. It is not enough to provide bins, it is also necessary to raise awareness and train the population on the separation of the various packaging materials. Figure 1 is an example of this type of bins which, in this case, is intended for waste-paper and cardboard packaging (blue bin), glass packaging (green bin) and plastic and metal packaging (yellow bin). The type of bin, size, color code, and the material aggregation model changes according to local options (as municipalities, countries), but it is important to standardize the options because it facilitates the population's understanding and adherence to separation.

**Figure 01**

**Bins for collection of packaging waste**

Plastic packaging is made of different polymers, such as PET, PVC, HDPE, LDPE, PS, PP, and others, which to be recycled must be separated by type of polymer. Thus, when these packages are placed in the correct bin (in figure 1, the yellow bin) they are collected by an appropriate truck and sent to a manufacturing facility, the Material Recovery Facility (MRF), for separation by type of polymer. Only then can the various polymers be used by the recycling industry to produce recycled plastic. The recycled plastic is used to produce new plastic. The separation by type of polymer is done in manual or automatic MRF. It is natural that when you start organizing this type of collection, you start with manual MRFs and that as the population's adherence to the separation of plastic packaging waste grows, these installations are converted into automatic installations. Figure 2 shows an example of a manual separation line for plastic packaging waste. It is a raised conveyor along which the operators who are responsible for separating a type of plastic packaging waste are placed. This packaging waste is accumulated in deposits placed on a lower level. Packaging waste is subsequently pressed and bales of different types of plastic packaging are produced, which are sent to the recycling industry.

The mechanical equipments foreseen in the manual MRF are: the scale for weighing the residues, the loader tractor to charge the line, the conveyor belt along which the operators are placed, the electromangnetic separator (to remove steel cans), the baler (usually two balers — one for polymers and another for steel and aluminum cans). In the example, figure 2, it is considered a deposit for storage paper and carboard because, although it is not the purpose of the yellow bin (figure 1) to separate these packages, sometimes the population puts these materials in this bin and the installation can decide for its separation and sending for recycling. In the example, the yellow bin also accepts metal packaging, which is why the MRF has an electromangnetic separator to sort out the steel cans. The aluminum cans are sorted manually. What is not separated by the operators is waste and is sent to landfill or incineration.

7-8 operators manage to sort 1 ton/h of packaging waste, with virtually no sorting errors. The amount of residue depends on the behavior of the population, which



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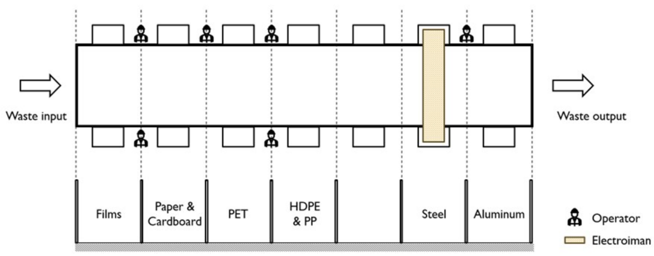
is intended to be as small as possible. The bales produced must comply with technical specifications. Normally, over 95% of the weight of the bale must consist of only one polymer, and less than 5% of weight can be other materials (contaminants). The bales of different polymers are sending to distinct recycling industries.

As adherence to selective collection of packaging increases, manual MRFs are transformed into automated MRFs capable of, through ballistic separators and optical separators, sorting 5-6 ton/h of packaging waste. Although the sorting capacity of these installations increases substantially in the automated MRF, the separation errors also increase, which makes it necessary to manually control the quality of the separated materials in order to comply with the quality requirements imposed by the technical specifications for packaging waste. These packaging materials are used for the production of recycled plastic incorporated in new products.

The organization of this value chain, namely the correct disposal of packaging waste, its separation in MRF and subsequent forwarding to the recycling industry and the production of new products, reduces the risk of pollution caused by plastic packaging waste. The replacement of these polymers of fossil fuel origin by other biobased and biodegradable ones has been studied during the last years.

**Figure 02**

**Scheme of a manual MRF**




One of the most biobased and biodegradable polymers studied are the polyhydroxyalkanoates (PHA). They are thermoplastic biodegradable and biocompatible polyesters produced intracellularly by microorganisms as reserve of carbon and energy and presented similar properties to the conventional plastics derived from fossil fuels. These characteristics makes them the next generation eco-friendly materials presenting as alternatives to petrochemical-based products. Nonetheless, the industrial production of PHA remains constrained due to its higher production costs in comparison to petrochemical-based products. One option to decrease the costs is the use of inexpensive feedstocks, such as industrial wastes, and mixed microbial cultures (MMC), since the use of open systems not required sterile conditions, making the process more economical. The production of PHA by MMC consists of a three-stage process: (1) acidogenic fermentation, where the organic matter is converted into volatile fatty acids (VFA), the precursors of PHA; (2) culture selection, where the MMC is enriched in PHA accumulating organisms; (3) PHA production, where the selected MMC is fed with the VFA produced in the first stage, aiming the culture's maximum PHA accumulation.

During the last years, the feasibility of PHA production using several industrial wastes, including cheese whey, fish silage, fruit waste, organic fraction of municipal solid waste, waste activated sludge, potato-starch factory wastewater, has been demonstrated. The feasibility of producing PHA from industrial wastes offers the opportunity to replace the conventional plastics with environmentally friendly products, as well as contribute for waste valorization and promotes a transition of the present linear economic model of "take-make-consume-dispose" by the circular economy approach.

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**Ana Silveira[a]**
**NOVA University, Lisbon**

**Mónica Carvalheira[b,c]**
**NOVA University, Lisbon**

**Maria Reis[b,c]**
**NOVA University, Lisbon**

[a] Department of Environmental Sciences and Engineering and MARE - Marine and Environmental Sciences Centre/ ARNET - Aquatic Research Network Associate Laboratory, NOVA School of Science and Technology, NOVA University Lisbon, 2819-516 Caparica, Portugal.

[b] Associate Laboratory i4HB - Institute for Health and Bioeconomy, NOVA School of Science and Technology, NOVA University Lisbon, 2819-516 Caparica, Portugal.

[c] UCIBIO – Applied Molecular Biosciences Unit, Department of Chemistry / Department of Life Sciences, NOVA School of Science and Technology, NOVA University Lisbon, 2819-516 Caparica, Portugal.

RESEARCH

## Enhanced mechanical energy conversion with selectively decayed wood

Other than the construction phase of the construction industry, building consume almost 40% of the total energy demand worldwide in addition to a quarter of the carbon emissions. Efficient management of energy in buildings would therefore greatly contribute to sustainability of the environment. Current trends in managing energy efficiency include insulation, sunshading and natural ventilation, so that indoor ventilation using electrical equipment are substantially reduced. In addition, other trends include integration of green energy sources into the building that make the building carbon neutral (also energy neutral) and at times produce more energy than they use. Energy productions from renewable energy sources such as Photo Voltics and wind energy depend extensively on the weather conditions, and can fluctuate significantly over a period of time. Therefore, it is highly desirable that raw construction materials such as wood, concrete or glass would be able to produce electricity from renewable sources without any weather restrictions.

Source: apples.extension.org

Wood, a conventional construction material, and still widely use in many countries as the dominant construction material, bears environmental benefits such as renewable and carbon dioxide storing resource. The research article speaks about the potential of using wood in addition, to generate electricity (power generation) in buildings. Wood construction material mainly composed of cellulose, hemicelluloses and lignin and the cellulose consists of amorphous crystalline regions. Piezoelectricity is induced in wood by the displacement of crystalline cellulose in response to applied mechanical stress which can result in generation of electrical charges. Although this was invented decades ago, further progress was hindered due to low piezoelectric modulii and the limited deformability of wood itself, resulting in an inefficient electrical output.

Several observations have been made on wood decay because of a fungi, that substantially compromised the durability of wood as a construction material. The study discussed in the article used what was considered to be detrimental as an advantage in power generation from wood. The study used white rot fungus *Ganoderma applanatum*, to partially remove lignin and hemicellulose from balsa wood (a part of the natural decay process). This modified wood is called biologically modified wood, in the article. The very property (poor deformability) that limited power generation in previous studies is enhanced using chemical delignification treatment in several other studies. This has resulted in higher gains in piezoelectric output. This study was done with the objective of employing biological processes to increase deformability of wood, taking advantage of a completely natural fungal decay process without the need of using chemicals. The study was able to fabricate an efficient wood energy convertor with a 55 times increments in piezoelectric effect.

In this study, Balsa (*Ochroma pyramidale* Cav. ex Lam.) wood that has high porosity and low density (approximately 94.8 kg/m$^3$) was incubated with the white rot fungus *G. applanatum* for 4—12 weeks. The fungal decay process has altered the structure of wood, improving the compressibility. Upon compression of the crystalline cellulose segments, centroids of positive charges and negative charges no longer coincide, inducing charges on the surfaces of wood for electrostatic equilibrium. Higher compressibility of wood (in this study effected by the natural fungal decay) resulted in a higher displacement (from higher compressibility) of cellulose crystals, which enhances the electrical output. The hyphae, that is the thread like cells of the fungus, grow within the wood cell lumen and secrete extracellular enzymes able to degrade lignin, resulting in changes of the wood structure. This specific fungus easily attack the Balsa wood compared to other wood significantly enhances compressibility and reducing weight by at least 15% in 4 weeks. Structural changes were evident upon a weight reduction of 25% and 35% after 6 and 8 weeks, respectively. After 10 weeks, the wood has decayed further with reduction of 45% of weight in 10 weeks.

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**Faculty of Graduate Studies, University of Jaffna**
**www.grad.jfn.ac.lk**
**+94 21 222 3608**
**fgs@univ.jfn.ac.lk**