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Waste Management for a Sustainable Future

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ABSTRACT
Waste management has become an important aspect of today's life as the collection, transportation and disposable of municipal solid waste are unscientific and chaotic. Uncontrolled dumping of wastes on outskirts of towns and cities has created overflowing landfills, which are not only impossible to reclaim because of the haphazard manner of dumping, but also have serious environmental implications. This paper is an attempt to understand the regulations, initiatives and the role of technology in the domain of waste management towards achieving sustainability. The study sources it's information from the various available secondary data such as literature from academic research, industry reports and case studies. The study tries to find out the role of entrepreneurship, technology in the domain of waste management.

Key words: Waste management, regulatory policy, sustainability, entrepreneurship, technology.

1. Introduction:

The rapid growth of global population, coupled with urbanization and economic progress, has led to an exponential surge in waste generation. As cities expand, so do consumption rates, resulting in significant challenges and mounting costs associated with waste management. Unfortunately, many urban centres, particularly in underserved regions, lack effective strategies to handle this escalating volume of waste. Moreover, the dynamic nature of waste— its composition and characteristics—compounds the issue.

Even economically prosperous nations struggle with the overwhelming demands in waste management. Factors such as overpopulation and increased affluence contribute to the complexity of the problem. As cities advance economically, the types of waste too evolve driven by heightened consumption of paper, plastics, packaging, and multi-material items.
In this paper, we delve into the regulations, initiatives, and technological solutions that can pave the way towards sustainable waste management. By examining entrepreneurship, technology, and regulatory policies, we aim to showcase innovative solutions for a cleaner, more environmentally conscious future.

Objectives:

1. To understand the initiatives and regulations taken in waste management.
2. To understand the role of entrepreneurship in waste management.
3. To understand the application of technology in waste management.
4. To showcase innovative solutions.

2. Research methodology:

This study tries to understand waste management practices, regulations and technology in the Indian Context and best practices from other parts of the world. Drawing insights from secondary data sources such as academic literature, industry reports and case studies we aim to contribute to sustainable waste solutions. By analysing existing information, we explore the role of entrepreneurship, technology and regulatory policy in achieving effective waste management. The research objectives include identifying challenges, understanding initiatives and showcasing innovative solutions.

2. Literature Review:

The study by Bingbing Fang (2023) and others review examines the application of artificial intelligence in waste-to-energy, smart bins, waste-sorting robots, waste generation models, waste monitoring and tracking, plastic pyrolysis, distinguishing fossil and modern materials, logistics, disposal, illegal dumping, resource recovery, smart cities, process efficiency, cost savings, and improving public health. Using artificial intelligence in waste logistics can reduce transportation distance by up to 36.8%, cost savings by up to 13.35%, and time savings by up

to 28.22%. Artificial intelligence allows for identifying and sorting waste with an accuracy ranging from 72.8 to 99.95%. Artificial intelligence combined with chemical analysis improves waste pyrolysis, carbon emission estimation, and energy conversion. We also explain how efficiency can be increased and costs can be reduced by artificial intelligence in waste management systems for smart cities.

The study by Raveesh Agarwal and others (2015) researched the current practices related to the various waste management initiatives taken in India for human wellbeing. The other purpose is to provide some suggestions and recommendations to improve the waste management practices in Indian towns. This paper is based on secondary research. Existing reports related to waste management and recommendations of planners/NGOs/consultants/government accountability agencies/key industry experts/ for improving the system are studied. It offers deep knowledge about the various waste management initiatives in India and find out the scope for improvement in the management of waste for the welfare of the society. The paper attempts to understand the important role played by the formal sector engaged in waste management in our country.

MyGate's blog post on the "Challenges of Solid Waste Management in Housing Societies and Tips for Improvement". The article discusses common issues faced by housing communities regarding waste management and provides practical tips to address these challenges effectively.

Raveesh Sharma's article on "Waste Management in India: Status, Challenges, and Solutions" published on ForumIAS (2022) delves into the current state of waste management in India, highlighting existing challenges and proposing potential solutions. Published in December 2022, the piece offers insights into the complexities of waste management practices in the country and explores avenues for improvement.

Manoj Kumar Sharma's work on "Environmental Laws and Policies", authored by Manoj Kumar Sharma in 2016, includes a chapter on Solid Waste Management Rules. This resource provides valuable information on the legal framework surrounding solid waste management in India, offering guidance on compliance and implementation.

Clean India Journal Editor's article (2015) on "Waste Management in Smart Cities", discusses waste management in the context of smart cities. It explores innovative approaches and technologies aimed at optimizing waste management practices in urban environments, contributing to cleaner and more sustainable cities.

Stephen Beacham's article (2021) on CNET titled "Mr. Trash Wheel" is gobbling up millions of pounds of trash showcases a local innovation in Baltimore aimed at mitigating water pollution through the use of trash-intercepting technology. This example demonstrates the potential of technological solutions in addressing waste management challenges.

Andrew Moore's work (2023) at NC State University, further explores waste management innovations, particularly focusing on AI-powered systems for. The research highlights the potential of advanced technology in revolutionizing waste management practices for improved environmental outcomes.

4. Results and discussion

4.1 Regulations

Challenges in Urban Solid Waste Management:

Effective solid waste management (SWM) is a major challenge in cities with high population density. Achieving sustainable development within a country experiencing rapid population growth and improvements in living standards is more difficult.

According to the Central Pollution Control Board (CPCB) the total quantity of Solid waste generated in the country is ~160,000 metric tonnes per day (TPD). ~153,000 TPD of waste is collected at a collection efficiency of ~96%. 80,000 TPD (50 %) of waste is treated and~30,000 (18.4%) TPD is landfilled. ~50,000 TPD (31.2 %) of the total waste generated remains un-accounted.

However, the predominant challenge in waste management lies in the inadequate waste collection infrastructure and the absence of efficient sorting and recycling systems. These deficiencies lead to valuable materials ending up in landfills instead of undergoing proper recycling processes. Addressing these issues is crucial for enhancing the sustainability and effectiveness of waste management practices in the country.

The waste collection process in housing societies is predominantly managed by local government entities or their authorized vendors. Across numerous cities, the absence of segregation at the individual household level gives rise to significant challenges:

The government faces difficulties in achieving 100% segregation and processing of the collected waste.
Segregation activities are conducted under unsafe and hazardous conditions, leading to health risks and injuries for waste collectors.

Mixed waste is indiscriminately dumped in landfills.
Due to insufficient infrastructure and inadequate law enforcement, waste accumulates on streets, vacant sites, and drains.

Solid Waste Management Policy: Guidelines from the Ministry of Environment, Forest and Climate Change
The SWM Rules, 2016, extend their applicability to various urban entities, including local bodies, industrial townships, and special economic zones. Additionally, they outline the duties and responsibilities of stakeholders, encompassing waste generators, event organizers, street vendors, and government agencies. These provisions emphasize waste segregation, proper disposal, and the establishment of necessary infrastructure within specified timeframes.

Duties and Responsibilities under SWM Rules, 2016
SWM Rules, 2016 have obligated various stakeholders regarding sustainable disposal of solid waste in India. Duties have not only been cast upon Urban Local bodies, various central and State ministries but also on the street vendors, event organizers, producers, brand owners, commercial and domestic waste generators. The duties of various stakeholders are discussed hereinafter.

Duties of Waste Generators – Rule 4
Rule 4 of SWM cast duties on every waste generator, including domestic and institutional waste generator. Duties of waste generator are detailed hereunder:

- Segregation and storage of waste in three separate bins
  - Bio-degradable – any organic material which can be degraded by micro- organisms into
  - simpler stable compounds
  - Non bio-degradable – to contain dry waste including recyclable and non- recyclable waste, combustible waste, sanitary napkins and diapers etc.
  - Domestic Hazardous waste – CFL bulbs, expired medicines, broken mercury thermometers, pesticide cans, discarded paint drums, used needles and syringes, contaminated gauge, used batteries etc
- Segregated waste to be handed over to authorised waste collectors/waste pickers
- Used sanitary napkins, diapers etc. to be packed/wrapped safely either in the pouches provided by manufacturers or in other prescribed suitable material
- Construction and demolition waste to be separately stored and disposed off as per Construction and Demolition Waste Management Rules, 2016
- Horticulture and garden waste to be separately stored in the premises
- No littering of solid waste on streets, public spaces roads etc
- Solid Waste not to be burnt/buried in streets or open public spaces
- Solid Waste not to be thrown in drains or water bodies

Duties of Event organizers

- All events/gatherings of more than 100 persons on unlicensed places should be held after prior advance intimation to local bodies. The intimation to be sent atleast three days in advance.
- Organiser of the event to ensure that waste generated in such gatherings to be segregated at source and handed over as per the Rules

Duties of Street Vendors

Street Vendor includes persons selling goods, food items or merchandise or offering services in streets, lanes, side walk and it includes persons selling/providing services in public parks, footpaths, public place, private area from a temporary built up structure on by moving from place to place. It also includes hawker, peddler etc

To keep containers/bins for storage of waste
To deposit waste at waste storage depot or container or vehicle as may be notified by local authority

Duties of Ministry of New and Renewable Energy Sources – Rule 10

- To provide subsidy/incentives to Waste to Energy Plants based on solid waste

- To facilitate creation of infrastructure for Waste to Energy Plants

Solid Waste Management in Hilly Areas – Rule 20

- In addition to duties imposed upon urban local bodies, additional provisions have been made for hilly areas. Rules contemplate avoiding construction of landfill on the hills, instead, it is provided that a suitable landfill may be set up within 25 kms in the plains. Local bodies in hilly areas have been directed to issue instructions to tourists so as to prevent littering of water bottles, soft drink/liquor bottles, tetra packs etc on the hills. Local bodies in hilly areas have been authorised to levy charges on the tourists so that the revenues generated can be utilized for effective implementation of SWM rules. SWM Rules have also promoted setting up of step gardens in hills.

Duties outlined for the Central Ministry of Urban Development:

Duties for the central ministry **as per Rule 6**, encompass a wide array of responsibilities aimed at enhancing solid waste management (SWM) practices nationwide. These include the formulation of a comprehensive national policy on SWM and 'Waste to Energy' initiatives within a stipulated timeframe. The timeline for these policy formulations was extended by the Almitra H. Patel v. Union of India case, with the revised period commencing from January 1, 2017. Additionally, the Ministry is tasked with conducting regular reviews of SWM measures and projects funded by various agencies, facilitating the development of state-level policies, and promoting research and development in SWM. Moreover, it is mandated to disseminate information, organize training programs, and provide technical guidance and financial support to states, union territories, and local bodies to bolster SWM efforts at all levels."

4.2 Cases

"Smart Solutions for Urban Waste Management: A Case Study of Agra Smart City"

In current scenario with respect to Solid Waste Management, there is a large scope for the engagement of Technology Partners and System Integrators (SI) to engage with Solid Waste Department of Municipal Corporation to setup right systems in place which help corporation with proper planning, monitoring, controlling and measure through a survey of hygiene, cleanliness and liveability index.

The Agra Smart City got selected in the second round Cities Mission in September 2016.The tender document published for Master System Integrator concentrates on ICT Enablers for PAN City. A city has a vision to bring awareness among citizens of Agra and with stringent monitoring systems on cleanliness and Hygiene factor across all the wards in the city, Special Purpose Vehicle (SPV) formed for Agra Smart City emphasized to provide a more robust, transparent and comprehensive mechanism with a lot more IT and ICT enablers.

The proposed solution intends to implement a RFID / QR Code based and GPS enabled Solid Waste Management System practices within the existing landscape. The existing vehicles deployed for collection of solid waste will be fitted with GPS devices for vehicle tracking. RFID readers/Smart Phones to read the RFID/ QR Code installed on community bins. RFID tags / QR Code will be installed at each house and commercial establishment in the city and all the field staff collecting the solid waste will be provided with GPRS Based RFID readers/Smart phones. Handheld devices like GPRS based RFID Reader/Smart Phones or POS Device will be deployed to manage the workforce deployed for solid waste collection.

The field staff collecting the solid waste should capture evidence of pickup and notify the user on Mobile App/SMS and the end customer should be able to track daily/monthly collection status/ report thorough Mobile App. It should also be possible for the end customer to request for the collection report though a missed call or SMS on a predefined number.
Furthermore, waste management systems are crucial not only for cleanliness but also for public health and sanitation. Initiatives such as the Swachh Bharat Mission have played a pivotal role in raising awareness about the health hazards associated with improper waste disposal. Additionally, the deployment of IoT components and feedback sensors further enhances governance at the city level, allowing for timely responses to citizen feedback and issues.

From Trash to Treasure: Surat's Cutting-Edge Waste Management Technology

The Smart City Mission launched by Prime Minister Narendra Modi on 25 June.The Silk city generates about 2,100 tonnes of garbage per day, of which 800 tonnes is processed and treated (. The civic body has deployed 425 vehicles on 900 routes for door-to-door collection of waste, each of which is equipped with Radio-frequency identification (RFID) tags and GPS for real- time tracking and to prevent leakage of waste. [1]

[1] Clean India Journal, 2015

For the waste generated through sweeping, night brushing activities and some commercial areas there are about 1100 containers throughout the city. Everyday filled containers are replaced by empty containers.

Unlike many leading metros that continue to grapple with issues of overflowing public dump yards, exhausted landfills and foul air, the diamond city has installed 43 underground garbage bins to manage its waste. Surat Municipal Corporation has installed theses bins under Smart City Mission.
The bins are also equipped with sensors to alert the control room as soon as 70% of the container is full and have been installed on footpaths. Each of them has two openings or inlets. One is for individuals to throw waste, another is for the municipal carts that bring collected waste. These humongous metal bins are being lifted with the assistance of cranes, thus emptying the entire waste mechanically, without any direct human involvement. All the bins are equipped with two compartments – one for the general public to discard their litter and the other one for municipal workers who collect waste from that area. To ensure efficient waste segregation, the bins are further divided into dry and wet waste. The size of the underground dustbin is 3 cubic meters and each bin can hold up to 1.5 tonnes of garbage . Cities like Mumbai and Chennai are currently in their respective planning stages. Other small cities which have a similar technology include Dharamshala, Panchkula and Dehradun.

Besides the monetary benefits, the bins are also solving other issues related to cleanliness. The automatic bin lifting, emptying and washing of underground dustbins ensures that no garbage is spills out while transferring the waste and the bins can be reused. The problem of overflowing is also resolved in the areas where these bins have been kept.

Moreover, the bins are helping to put an end to bad odour from dirty smelly bins and stray animals feeding on waste. As there is minimal human effort required, the workers don’t come in contact with the garbage thus giving them a clean working environment.

"Transforming Temple Waste into Sustainable Innovations: The Phool.co Journey" In 2015, Ankit Agarwal, an automation scientist, observed devotees bathing in the polluted Ganga River during Makar Sankranti in Kanpur. His curiosity was piqued when he noticed discarded temple flowers fading in the water. Research revealed that over 8.4 tonnes of flowers, cultivated with pesticides, entered the Ganga daily. Inspired to address this issue, Agarwal founded Phool.co in 2017, a social enterprise revolutionizing the treatment of temple flowers and farm waste. Employing a groundbreaking process called "flowercycling," Phool transforms these flowers into therapeutic incense sticks, handcrafted by marginalized women. The initiative not only provides them with a sustainable livelihood but also empowers them socially. The flowercycling process involves collecting waste from various temples, turning it into powder, and crafting incense sticks and cones. Phool.co's impact extends beyond environmental sustainability; it has led to economic empowerment and social change. Anita Devi, once considered 'untouchable,' opened the first Dalit beauty parlour in her village. Others engaged in fish farming, significantly increasing their income. Notably, three temples in Kanpur have banned flower offerings in support. Recognized by the Tata Social Enterprise Challenge in 2016, Phool.co has continued to innovate. "Fleather," a bio-alternative to animal leather, made from temple flowers and farm waste, won the BIRAC Innovator Award 2021. Additionally, 'Florafoam,' a 100% biodegradable alternative to thermocol, and skin-safe gulaal for Holi, showcase Phool.co's commitment to sustainable solutions. With backing from IIT- Kanpur, the company has demonstrated how waste can be transformed into valuable biomaterials, addressing environmental, social, and economic challenges. As the journey continues, Phool.co remains committed to launching new, first-of-its-kind collections, building on its success in creating innovative and sustainable products.

4.3 Technology Trash wheel:
Mr. Trash Wheel, the brainchild of John Kellet, founder of Clearwater Mills is a local logistics company in Baltimore established in 2014. Mr. Trash Wheel is a massive garbage interceptor stationed in the Jones Falls stream of Baltimore's Inner Harbor. By stopping trash before it can empty into the Chesapeake Bay and the Atlantic Ocean, he's making a difference far from the city limits. Kellet was inspired to create Mr. Trash Wheel after witnessing the alarming amount of rubbish flowing into the harbor during rainstorms. Determined to find a solution, he founded Clearwater Mills and embarked on the mission to build a trash-intercepting mechanism. Since its installation Mr. Trash Wheel has intercepted over 3 million pounds of trash, making the harbor not only cleaner and more beautiful, but also a nicer home for local wildlife as well as waterfront businesses. Four different wheels now sit in Baltimore's rivers, and soon more will be helping clean other cities across the globe.

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(Stephen Beacham, June 14, 2021, CNET, "Mr. Trash Wheel is gobbling up millions of pounds of trash")

A simple technology

The Trash Wheels employ a straightforward technology: A large water mill is turned by the flowing river which powers a system of pulleys that turn a large conveyor belt and an array of rakes which help scoop floating debris onto the conveyor belt as trash floats downstream. The trash wheel has 2 long floating buoys which trap garbage that's floating on the surface and funnels it into the mouth of Mr. Trash Wheel. From there it gets carried up the conveyor belt and emptied into a large dumpster. A small crew easily removes and empties the floating dumpsters as they get full.

Power for the belt comes from river currents that turn the water mill, but the Trash Wheels are also outfitted with solar panels and batteries for times when the river isn't flowing fast enough to turn the wheel. Kellet is able to switch on pumps remotely from his smartphone so it never stops turning and gobbling garbage. Mr. Trash Wheel also has an internet connection so Kellet can see what's happening on the vessel via webcam and take action if needed.

After designing his concept, Kellet contacted the city, which was open to new ideas for combating the trash flowing into the harbor. He eventually partnered with a nonprofit called the Abell Foundation, which put up money to develop and refine the Trash Wheel concept.

After much trial and error and months of testing and building Mr. Trash Wheel was installed in Baltimore's Harbor.

Once Mr. Trash Wheel was operational, business and community leaders noticed the immediate improvement in the harbor's pollution levels and lobbied to make the wheel a permanent fixture. The Waterfront Partnership of Baltimore, a nonprofit funded by a coalition of local businesses, then got involved and began a campaign to produce more Trash Wheels and install them in other areas of Baltimore.

Ai powered waste management system to revolutionize recycling:

Americans generate more than 290 million tons of municipal solid waste each year — that's all the packaging, clothing, bottles, food scraps, newspapers, batteries and other everyday items that are thrown into garbage cans.

Some of that waste is recycled, composted or burned for energy, but nearly 50% of it is sent to a landfill where it slowly decomposes and emits greenhouse gases that account for about 25% of today's global warming.[2]

With support from the U.S. Department of Energy, NC State researcher Lokendra Pal has partnered with the National Renewable Energy Laboratory, IBM and the Town of Cary to solve that problem. Pal, the EJ Woody Rice Professor in the Department of Forest Biomaterials, is working with his collaborators to develop a "smart waste management system" for the collection, identification and characterization of organic materials in non-recyclable waste.

Non-recyclable waste includes items that are too contaminated for recycling, often because they contain organic materials

such as oil, grease and dirt. The researchers want to convert these materials into renewable products, energy and fuel. In developing the "smart waste management system," Pal and his collaborators are integrating smart sensors, visual cameras and hyperspectral cameras with an automated waste sorting machine to examine non-recyclable waste items.The visual and hyperspectral cameras will capture images of the items as they move along a conveyor belt, while the sensors will help to monitor and control the waste management process.

[2] as per Andrew Moore, November 9, 2023, NC STATE UNIVERSITY

Most objects absorb and reflect light. Digital cameras can only visualize three colour bands of light — red, green and blue. Hyperspectral cameras, however, can visualize many more bands from across the electromagnetic spectrum, resulting in images that showcase chemical characteristics that would otherwise be invisible.By combining hyperspectral imaging with visual cameras and smart sensors, we can collect data in real-time to improve the process of characterizing and separating waste so that it doesn't end up in landfills.

Pal and his collaborators are also analysing non-recyclable waste items to determine their physical, chemical, thermal and biological properties, including moisture, density, particle size and distribution, surface area, crystallinity, calorific value and more. This information will help the system to further differentiate items as they're scanned. The researchers plan to upload this metadata information, along with the images and descriptions of the items, to a cloud database to train and test machine learning models that can be integrated with the system's cameras to improve the recognition and classification of non-recyclable waste.

A machine learning model is a type of artificial intelligence that analyses data to identify patterns, make decisions and improve themselves. In the case of Pal's research, the models will analyse the uploaded images and descriptions of non-recyclable waste — and the information about its physical, chemical and biological properties — to determine contaminants, energy density and organic content. According to Mr. Pal "If successful, this project will contribute significantly to the development of commercially viable, high-performance renewable carbon resources for conversion to biofuels and valued-added products," .

Pal and his collaborators are exploring the use of various processes and technologies to produce fuels such as bioethanol and aviation fuel, which can be blended and used as sustainable fuel in the transportation industry, and products such as biochar, which can be used in agriculture to enhance soil fertility and improve plant growth.

5. Conclusion:

Decoding India's Solid Waste Management Policy: Roles and Sustainability.

The policy delineates the specific duties and responsibilities assigned to different stakeholders, ranging from waste generators to government agencies. These duties encompass crucial aspects such as waste segregation, proper disposal methods, and the establishment of necessary infrastructure within defined timeframes. By detailing these responsibilities, the policy aims to ensure accountability and promote active participation in solid waste management efforts.

Smart cities - Surat and Agra:

Both approaches underscore the importance of technology and innovative infrastructure in addressing urban waste management challenges. While Agra emphasizes real-time tracking and citizen engagement, Surat's focus lies on efficient waste containment and mechanical handling to mitigate sanitation issues and improve overall cleanliness.

Transforming Temple Waste into Sustainable Innovations: The Phool.co Journey" highlights the innovative and impactful work of Phool.co, a social enterprise founded by Ankit Agarwal in 2017.

1. **Identification of a Social and Environmental Issue:** Ankit Agarwal identified a significant issue of a pollution in the Ganga River Caused by the disposal of temple flowers, which were cultivated with pesticides. This observation sparked the idea for Phool.co to address both environmental and social challenges.

2. **Innovative solution –** Flowercycling: Phool.co employs a groundbreaking process called "flowercycling" to transform discarded temple flowers into therapeutic incense sticks. This process not only helps in waste management but also provides a sustainable livelihood for marginalized women, empowering them socially and economically.

The case of Mr. Trash Wheel in Baltimore exemplifies a successful local initiative to address water pollution using a simple yet effective technology. Several key analyses can be drawn from this case:

1. **Local Innovation for Environmental Solutions**: Mr. Trash Wheel demonstrates the power of local innovation in tackling environmental challenges. John Kellet's initiative

to address the issue of trash pollution in Baltimore's Inner Harbor led to the development of an innovative solution that has had a significant impact on reducing water pollution.

2. **Community Engagement and Support**: The immediate improvement in pollution levels observed after the installation of Mr. Trash Wheel garnered support from both business and community leaders. This underscores the importance of community engagement and support in driving environmental initiatives forward.
3. **Scalability and Replicability:** The success of Mr. Trash Wheel has led to interest in replicating the technology in other cities facing similar water pollution challenges. This demonstrates the scalability and replicability of the solution, offering potential benefits beyond Baltimore's Inner Harbor.
4. **Integration of Technology for Monitoring and Management:** Mr. Trash Wheel's integration of technology, including remote monitoring via webcam and smartphone- controlled pumps, highlights the role of technology in optimizing environmental management practices.

The development of an AI – powered waste management system aimed at revolutionizing recycling efforts, particularly focusing on non-recyclable waste.

1. **Objective of the project**: The main goal of the project is to develop a "smart waste management system" capable of identifying and characterizing organic materials within non-recyclable waste. The intention is to convert these materials into renewable products, energy and fuel, thereby reducing their contribution to landfill waste and greenhouse gas emissions.

2. **Data Analysis and Machine Learning**: The project utilizes machine learning models to analyse data collected from the waste items, including images and descriptions to improve recognition and classification of non-recyclable waste. These models help identify contaminants, energy density and organic content, facilitating the conversion of waste into valuable resources.

3. **Future implications:** The success of the project is expected to have significant implications for waste management practices, potentially leading to commercially
viable renewable carbon resources and high-performance products. This highlights the border environmental and economic benefits of the proposed waste management solution.

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