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Technologies of *Swachh Bharat*
Machines and Methods for Cleaning India

Under the categories of Earth, Fire and Water, this paper reviews some of the technologies being deployed in the Swachh Bharat *or Clean India* campaign. *Humans have buried, burned or washed away unwanted materials since pre-historic times, but modern population densities and production capacities pose unprecedented problems. The paper examines "scientific landfills,"* incineration *methods and toilet and waste-water innovations. Although superior technologies are essential for the success of the Clean India initiative, they must be accompanied by superior training and conditions for existing low-status workers and widespread change in attitudes towards public sanitation. Achievement of these latter ends calls for further urgent research.*

Robin Jeffrey and Assa Doron[1]

The Clean India! or *Swachh Bharat!* campaign launched by Prime Minister Narendra Modi on Mahatma Gandhi's birthday on 2 October 2014 aims to tame India's mountains and rivers of solid and liquid waste by 2019. To succeed, the program requires investment of funds,

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behavioural change, administrative perseverance and appropriate technologies. For officials responsible for achieving *Swachh Bharat!* targets, there is a temptation to adopt uniform methods that appear to offer single, comprehensive answers to truly "wicked problems."[2] This essay reviews technical options in the management of liquid and solid waste and alludes only in passing to the immense economic, administrative and cultural aspects of the Clean India! initiative.

In understanding the ways in which the modern urban world has tried to deal with "waste," two broad categories are in common usage. "Solid waste" (SW) includes the things that households throw away – from food scraps and garden waste to pots and pans and mattresses and electrical goods. Within SW are sub-categories such as construction and demolition waste (C&D) from building projects and hazardous waste (HW), the by-products of industry and machinery. The other broad category is "liquid waste" (LW) – human excreta, used water and rain run-off, sometimes contaminated with hazardous waste, and often dumped into convenient water bodies by irresponsible industries.

In the past, when societies were overwhelmingly rural and relatively poor, most discarded things were dealt with through natural processes. There were places – usually barren land or declivities – where unwanted things could be discarded; the middens of pre-historic times provide evidence that ancient peoples also had things they wanted to be rid of. Nevertheless, until the industrial age, not much was thrown away. Pots were mended and charpoys restrung; domestic animals ate kitchen waste; and the fields were broad enough and the rains heavy enough to absorb animal waste and human defecation. Such conditions were common throughout the world in pre-industrial, rural times.

India has urbanized steadily but not spectacularly. In sixty years from 1951 to 2011, urban population less than doubled – from 17 per cent of the population to 31 per cent.[3] What is unprecedented, however, are the sheer numbers. They lend urgency to India's need to tame growing volumes of waste generated by an increasingly prosperous population eager for the throwaway comforts of middle-class life enjoyed elsewhere. In 1951, there were 62 million urban Indians, and they had few things to throw away. By 2011, there were 377 million – more

2 For a quick view of the "wicked problem" as a concept in public policy, see Angi English, "Ten Properties of Wicked Problems," https://goo.gl/9egxOF (accessed 21 July 2016).

3 *Statistical Outline of India* (Mumbai: Tata Services, for relevant years).

than six times as many; they had much more to throw away; and because the total population had more than trebled to 1.2 billion in the same period, space to dispose of unwanted things shrank constantly. As one example, 27,000 motorbikes navigated India's roads and byways in 1951; in 2011, there were more than 100 million.[4]

Earth

Dumps are as old as human settlement. Even in the distant past, people found isolated places to discard unsavoury and unwanted things. Town and city life, however, makes it more difficult to find such spaces, and by the second half of the nineteenth century, rulers and officials of expanding cities in Europe and North America had to make arrangements to deal with the thrown-away things of their residents.

In 1914 J. C. Molony, the Indian Civil Servant (ICS) who was commissioner of the city of Madras, reckoned that the municipal servants collected about 300 tons (about 270 metric tonnes) of almost entirely biodegradable waste each day. A hundred years later, the Chennai Municipal Corporation reckoned the city's employees collected 4,500 tonnes a day, more than 400 tonnes of which was plastic, a non-degradable material unknown in Molony's time.[5] Taking these crude estimates, Chennai's waste collection had increased about 17 times in a hundred years. This was about double the rate of its population growth – from something like 500,000 to 4.7 million or about nine times.[6] Most of the waste collected in Chennai went to two large dumps, one at Kodungaiyur to the north of the city and Perungudi. Each site was said to receive more than 2,000 tonnes of garbage a day.[7]

India's best-known dump is probably Deonar which occupies 130 hectares of eastern Mumbai. It gained international attention early in 2016 when its smouldering fires burned with greater intensity than usual and shrouded portions of the city in smoke and haze for a few weeks.

4 "Total Number of Registered Motor Vehicles in India during 1951-2012," https://data.gov.in/catalog/total-number-registered-motor-vehicles-india (accessed 6 May 2016).

5 J. C. Molony, *A Book of South India* (London: Methuen, 1926), p. 144. Greater Chennai Corporation, "Solid Waste Management," http://goo.gl/PIoXYf (accessed 12 May 2016).

6 Or to 7.1 million and 14 times, if one goes by the Greater Chennai Corporation's website. Greater Chennai Corporation, "Area & Population," http://goo.gl/MaQNNx (accessed 12 May 2016). Underlining the inexactness of waste-science, *Outlook* magazine put Chennai's daily waste total in 2014 at 6,400 tonnes.

7 http://www.chennaicorporation.gov.in/departments/solid-waste-management/index.htm#solid (accessed 22 July 2016).

Deonar and dumps like it often have walls and guards to control the entry of garbage trucks and thousands of waste-pickers who tear a living from the things they find on the dump.

Municipal councils and corporations, which became a requirement after constitutional amendments in 1993, inherited unregulated dumps. Part of the mandate of local governments is to provide public sanitation, and existing dumps have been the place to which a town's waste has been sent. Today, as local governments struggle to meet the expectations of the *Swachh Bharat!* program, they are faced with decades accumulation of compacted waste. Deonar rise to more than 45 metres and has thousands of waste-pickers working its heights each week. Deonar has a (broken) wall around it, and there is an attempt to control access, but it is not difficult to find a way inside and to climb the heights.

Unregulated dumps violate the Solid Waste Management Rules (SWMR) of 2000, which carry the authority of a directive of the Supreme Court. The Rules state that "existing landfill sites … shall be improved in accordance of the specifications given in this Schedule." Schedule III runs to 33 paragraphs and 1,900 words of excellent direction on how to construct a "scientific land fill" and dismantle an existing dump. In 2016, the SWM Rules were updated with detailed regulations for different categories, including plastic, construction and demolition, medical and hazardous waste.[8]

The operation of an old-fashioned "dump" is straightforward. At a remote ravine or gully, unwanted material is brought and "dumped" – flung into the pit or strewn about the ground. Birds, animals and very poor people may come to pick through it. Edible and biodegradable materials will disappear; durable items will eventually be covered by new layers of waste. Growing towns and cities reach a point where the production of waste each day exceeds the capacity of the dump to accommodate it, so the hole in the ground becomes a mound, then a hill and eventually, like Deonar and Kolkata's Dhapa, a small mountain. Citizens' complaints about vermin and odour force local governments to act. The SWM Rules make it mandatory to do so.

[8] http://envfor.nic.in/sites/default/files/Waste%20Management%20Rules,%202016.pdf (accessed 25 July 2016).

The technologies for renovating existing dumps and building “scientific landfills” are well known and widely implemented in various parts of the world. Such landfills begin from the same principle as a dump: they are located at sites as remote as possible from habitations yet as close as possible to the sources from which waste comes. Such sites are excavated, surveyed and divided into cells that are intended to be filled one by one. A cell is lined with a layer of hard clay over which is laid a blanket of tough plastic (HDPE) to contain the polluting liquid that leach out of suppurating material.[9] Pipes are installed to capture this leachate and pour it back over the contents of the cell so that constant evaporation prevents leachate from escaping to contaminate ground water. Additional piping draws off the methane gas that decomposition produces, and this methane is burned off, often to create electric power. Filters capture toxic emissions from the burning. In the ideal type, the cell into which material is dumped, is covered each night to minimize access to birds and rodents and annoyance to neighbours from odours and wind-blown rubbish.

Though the technology is straightforward, implementation is complex and costly, and maintenance requires relentless daily attention. To establish a new land fill requires painstaking discussion with people living nearby. Recent examples of failed waste-management projects reinforce suspicion that proximity to waste will make nearby life unpleasant, degrading and dangerous.[10] The cost of a preparing a sanitary landfill in the USA was roughly calculated in 2005 at USD 1.5 million a hectare. In India, more recently, estimates suggested that building a scientific landfill of unspecified size needed about Rs 15 crores (USD 3 million).[11] Where these have been created, the contract for ownership, operation and maintenance is a complicated document usually negotiated between a local government and a private corporation but with scrutiny by a state government, NGOs, unions of sanitation employees and wary citizens.

A properly functioning scientific landfill should be more than a carefully tended hole where things are dumped. The precinct should provide space for separation of biodegradable material for compost and enable segregation of recyclable materials like plastic, paper and glass.– if this

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9 HDPE – high density polyethylene, the same material that drink bottles bearing the code number 2 are made from.

10 The failed waste site at Vilappilsala on the outskirts of Thiruvananthapuram is a striking example.

11 Koride Mahesh, “Waste management project: Greater Hyderabad civic body in dilemma as workers oppose move,” *Times of India*, 13 February 2014 (1 March 2015). Daniel P. Duffy, “Landfill Economics: Getting Down to Business – Part 2,” *Foresterdailynews*, 16 March 2016, first published in 2005, http://goo.gl/t8anvh (accessed 27 July 2016).

has not already been done closer to the initial collection points. The philosophy of a scientific landfill is based on the premise that burying is a last resort.

In 2014, India had 94 sites that aspired to be sanitary landfills, according to returns received by the Central Pollution Control Board.[12] The best of these resembled the model that sanitation specialists expect to see elsewhere in the world. The site at Jawahar Nagar, operated by Ramky Enviro Engineers on the outskirts of Hyderabad, for example, in 2015 had the required attributes – clay bedding, plastic liner, leachate catchment, methane capture and composting facility. The centre also aimed to mine the pre-existing dump and render it benign before the whole site was closed when it reached capacity, estimated about 2035. But the Jawahar Nagar site, which could be presented as a model scientific landfill on a good day, was bitterly criticized by nearby residents. "The filthy tale of Jawahar Nagar," the *Times of India* headlined a story in September 2015, and nine months later, there were accusations that leachate at the site was out of control.[13]

The difficulty of running an effective sanitary landfill underlines the need to reduce centralization and minimize reliance on burying waste, even "scientifically." A principle of the Solid Waste Management Rules is "segregation at source." The 2016 version of the Rules dictates that "Every waste generator shall - (a) segregate and store the waste generated by them in three separate streams namely bio-degradable, non biodegradable and domestic hazardous wastes."[14] As household and commercial waste is collected, it should be sorted into various categories for recycling and composting, and this should be done as close to the place of origin as possible. Carrying waste long distances to central landfills, burns diesel, costs money, pollutes the air and annoys citizens. The requirement to maintain separate streams of waste to enable recycling is repeated continually throughout the SWM Rules of the year 2000 and their new incarnation in 2016.

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12 *Consolidated Annual Review Report on Implementation of Municipal Solid Wastes (Management and Handling) Rules, 2000. Annual Review Report: 2013-14* (Delhi: Central Pollution Control Board, 6 February 2015), Annexure III, pp. 51-2.

13 When Jeffrey visited the Jawahar Nagar site in May 2015, it had characteristics of a model landfill. But the *Times of India* reporter saw a different side in September. *Times of India*, 1 October 2015. *Deccan Chronicle*, 18 May 2016.

14 Ministry of Environment, Forest and Climate Change Notification**,** New Delhi, 8 April 2016, Solid Waste Management Rules, 2016, p. 55.

The Rules also require all local governments to "arrange for door to door collection of segregated solid waste from all households including slums and informal settlements, commercial, institutional and other non residential premises."[15] Such collection is intended to enable local sorting and processing of waste, and the Rules insist that local governments establish places where segregated waste can be organized and passed onto dealers in paper, plastic, glass and metal. Ideally, biodegradable waste can be composted at such sites or fed into a biodigester to produce methane gas to generate electricity. The residue becomes acceptable compost.

These technologies are simple. The people who do the door-to-door collection need sensible protective clothing and vehicles suitable to the areas they work in. In parts of Andhra Pradesh, Telengana and Karnataka, towns use a rugged three-wheeled cart, designed and built locally, intended to be pulled by hand, and rolling on polyurethane wheels, the same material used to make roller skates roll. The carts have room for four 60-litre bins that allow separation of waste into biodegradable, paper, plastic and miscellaneous.[16] The carts cope with uneven surfaces, manoeuvre in narrow lanes and turn tight corners. There is little to break, and repairs can be done locally and quickly. Cycle rickshaw frames, which are used elsewhere, have been adapted for similar work, but the bicycle frame is more fragile, the adapted vehicle is imperfectly balanced and pneumatic tyres puncture under the weight of daily collections.

A biodigesting plant to turn wet waste into electricity-generating gas and compost uses well-known technology and requires relatively little space. A unit that digests three tonnes of wet waste a day can fit into the area of a couple of shop fronts and produce 265 kilowatt hours of electricity a day, enough to power more than 300 100-watt bulbs for eight hours, a significant contribution to neighbourhood street lighting or households.[17] Vegetable waste from markets and households, carefully segregated, is brought to the location and chewed up by machine into a pulp and fed into a pit where it is stirred and agitated to accelerate its gas-making properties. The gas is captured and used to fire a turbine that powers a generator to make electricity. The problem in crowded cities is to find space for such plants and to convince neighbours that their lives are not going to be made miserable by refuse, odour and disease. In the suburb of

[15] Ibid., p. 58.

[16] Interview, Khader Sahib, former joint director Andhra Pradesh Administrative Service, with R. Jeffrey, Hyderabad, 10 March 2015.

[17] Jeffrey visited the plant at Arcot in Tamil Nadu on 14 November 2013 and walked round the site with **S.** Parijatham, the municipal commissioner.

Yeshwanthpur in Bengaluru in 2015, however, such a plant operated opposite an Ayyappa temple with what was said to be relatively good will on both sides.[18]

Well-designed spaces are also necessary to separate and organize recyclable waste. The people who collect from households and shops need places to sort their collections and to accumulate quantities large enough to attract the next level in the recycling chain – collectors who will come with trucks to pay cash for large quantities of sorted materials and carry them away. As Bengaluru wrestled with multiple waste problems in 2015, it attempted to set up such local centres – a large purpose-built shed with a concrete floor, showers, scales and the opportunity for waste-collectors to be paid in cash with rates of payment posted regularly depending on market prices. Such arrangements minimize the need to cart waste to distant landfills and improve the chances of comprehensive clean-ups because waste-collectors get paid regularly and predictably.

The scientific or sanitary landfill is one of the most expensive and technically sophisticated methods of dealing with waste. It should be a place of last resort, especially in India where more than half of household and commercial waste is wet (biodegradable) waste. Wet waste can be cooked and composted, used to make electric power and turned into acceptable fertiliser. It does not need to go to a centralized landfill. Landfills, however, have attractions because they appear to provide solutions that take waste far away from householders and business premises and make it the problem of distant places and people. Such single solutions are attractive to policy makers, politicians and urban citizens because they seem to provide a complete fix to a complex problem.

Fire

Fire is a time-honoured way of getting rid of waste, as the charred bones in pre-historic middens indicate. As towns and cities grew in Europe and North America in the nineteenth century, the industrial expansion that produced greater quantities of waste also generated industrial-style solutions. Nottingham in England introduced “the first systematic cremation of refuse at the municipal level” in 1874, and “large-scale implementation of incinerating devices” spread

[18] Jeffrey visited the plant on 26 November 2015 accompanied by Dr B. Veerabhadrappa, Joint Commissioner, Raha Rajeshwarrinagar.

throughout Europe and the United States thereafter.[19] In the US, the story of burning waste has played out in "three major waves." There have been similar trends and discoveries in India since the 1990s.[20]

The first wave in the United States introduced European-style incinerators in the 1880s, but by 1910, these had lost their attraction because American waste, like Indian waste today, was often too wet to burn effectively. Operators needed to add fuel – and therefore cost – to make things burn. If they didn't, smoke and ash annoyed citizens, and many US towns and cities, unlike those in India today, had vast empty spaces where waste could be dumped. The second period in the US, according to Walsh and Warland, ran from the 1930s to the 1960s with more effective incinerators and growing volumes of waste. By 1967, the environmental movement had provoked legislation that forced these second-generation incinerators to install "scrubbers" to try to control smoke and toxic gases. These were "expensive enough to put most of the second wave of incinerators out of operation."[21] The third wave of incineration has been founded on expensive high-combustion furnaces that generate modest amounts of electricity, reduce the volume of waste by 90 per cent and leave an ash suitable for building purposes. They are designed, their supporters argue, to ensure that poisonous gases are not released into the air. They provide a standard method of waste management in Japan, Singapore, Germany and the Nordic countries of Europe. Since the mid-1970s, more than 230 Mitsubishi-Martin incinerators have been installed throughout Japan, China, South Korea and Singapore.[22]

In India, the first plant on this scale opened at Okhla in the southern part of Delhi at the end of 2011. Built and operated by a company of the Jindal group, one of India's largest conglomerates, the Timarpur-Okhla plant is a public-private partnership with the Delhi government, located within the boundaries of the South Delhi Municipal Corporation.[23] Dogged by controversy, the plant provided a focus for questions about high-combustion incineration and its suitability for India. Construction began in 2010, and the plant was accepting garbage and generating electric power by early in 2012. In 2016, it was said to use

19 Martin V. Melosi, *Garbage in the cities. Refuse, reform and the Environment*, rev. edition (Pittsburgh: University of Pittsburgh Press, 2005), p. 39.
20 Edward J. Walsh and Rex Warland, *Don't Burn It Here. Grassroots Challenges to Trash Incinerators* (University Park, PA: Penn State Press, 1997), p. 2.
21 Walsh and Warland, *Don't Burn It Here*, pp. 3-4.
22 Phoenix Energy, "Kwinana Waste to Energy Project. Public Environmental Review. MHIEC Global WtE Plant Delivery Record," [2013], http://goo.gl/ES0JbU (accessed 28 February 2016).
23 http://towmcl.com/content.aspx?MKey=43 (accessed 29 February 2016).

2,300,000 tonnes of waste a day to generate 16 megawatts of electricity. One megawatt is estimated to be sufficient to power more than 500 American homes for a day, so Okhla's 16 megawatts would be capable of providing power to at least 8,000 Delhi households.[24]

High-combustion incineration attracts politicians and policy-makers because it also appears to provide a single solution to a wicked problem. An efficient plant reduces the volume of waste by 90 per cent, which means a landfill, though still necessary, has a substantially longer life. High-combustion incinerators can produce heat and electricity, though in many countries these are subsidiary benefits, because volume reduction may be the most important aspect. High-combustion incineration, as described by advocates and manufacturers, offers desperate governments a seemingly magical solution to a compounding nightmare: growing volumes of waste and shrinking areas of land to accommodate it. A well-run plant will reduce the volume, leave a useful ash and provide significant amounts of heat and electricity. This is a recipe followed in Germany, the Nordic countries, East Asia and Singapore.

But high-combustion incineration has drawbacks. First, it is expensive. A new plant near the prosperous city of Toronto in Canada, built to deal with only 400 tonnes of waste a day, cost USD 215 million when it was completed in 2016.[25] (Delhi and Mumbai collect more than 8,000 tonnes of waste a day). The first plant on these lines in Australia was budgeted to cost US 285 million and would handle 1,100 tonnes of waste a day for the southern suburbs of the city of Perth.[26] The large plant at Tuas South in Singapore handles 3,000 tonnes of waste a day and cost more than USD 600 million when it was opened in 2000.[27]

A second limitation lies in the conditions such plants require. They need constant supplies of dry, high-calorie waste. Ideally, an incinerator burns 24 hours a day. If it gets wet waste, fuel must be burned to dry the waste before it can be burned. If an incinerator shuts down for a period, it needs external energy to restart it and heat it up for action. An incinerator must be shut down for maintenance every 8,000 hours or about once a year. Multiple incinerators are necessary to keep a plant running constantly. As these numerous conditions suggest, such incinerators need constant, close supervision.

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[24] *Indian Express*, 30 May 2016.
[25] *The Star*, Toronto, 5 January 2016, http://goo.gl/tHKEST (accessed 1 March 2016).
[26] ABC News, "Contract inked for $400m Kwinana thermal waste facility in WA," 16 February 2016, http://goo.gl/qBXQZA (accessed 1 March 2016). AUD 400 million/USD 285 million.
[27] *Tuas South Incineration Plant*, brochure, 2014. Cost of construction was SGD 890 million in the year 2000.

"High combustion" is essential to minimize harm to environment and health. Highly toxic substances known collectively as dioxins are formed when materials containing atoms of carbon and chlorine are burned. Thus PVC plastic (polyvinyl chloride), benign in itself and widely used in industry (e.g., PVC pipes in plumbing), produces dioxins when burned under uncontrolled conditions. Tobacco smoke, smoke from forest fires and smoke from peat bogs also release dioxins into the atmosphere.

Burning wastes at high temperatures above 800C reduces formation of dioxins, but there is a catch. In such a process, the materials are splintered into their constituent atoms, and unless the combustion gases are cooled rapidly, carbon and chlorine recombine to form dioxins. (Think of making jelly: if you don't pour the mix into moulds when it's hot, it takes its own shape when it cools). Special equipment is used to minimize the re-forming of dioxin molecules (though it is never entirely prevented) and mop up other chemical fragments resulting from combustion. In countries like Japan, Singapore, Sweden and Germany, the latest generation of incinerators appears to emit only tiny amounts of dioxin, especially when compared with emissions from forest fires or illicit burning.[28] Nevertheless, a number of environmental groups oppose incineration of any kind, because of atmospheric pollution and the belief that incineration discourages frugality and recycling.[29]

Though high-combustion incineration is often described as a Waste to Energy process that produces electricity, the amount of power generated is secondary to the reduction in the volume of waste that goes to landfill. In Singapore, where the large Tuas South plant deals with 3,000 tonnes of waste a day, the plant produces 65 megawatts of electricity, 20 per cent of which is used to run the plant itself; the remainder is sold into the Singapore electricity system.[30] Such an addition would cover the needs of fewer than 3 per cent of Singapore's family households and represents only a small contribution towards its overall electricity needs.

[28] Henri Dwyer and Nickolas J. Themelis, "Inventory of U.S. 2012 dioxin emissions to atmosphere," *Waste Management*, vol. 46 (December 2015), pp. 242-46. We are grateful to Professor Ian Rae of the University of Melbourne for help with this paragraph.

[29] See "Global Alliance for Incinerator Alternatives/Global Anti-Incinerator Alliance," http://www.no-burn.org/ (accessed 2 August 2016).

[30] Chong Kuek On, General Manager (Tuas South Incineration), National Environment Agency, Singapore, interview with R. Jeffrey, Singapore, 14 August 2014. The plant has a theoretical capacity to generate 80 megawatts of electricity. http://www.nea.gov.sg/docs/default-source/energy-waste/waste-management/tsip-brochure.pdf (accessed 2 August 2016). Singapore in 2014 had electricity consumption of more than 12,000 megawatts.

The cost and rigorous technical requirements make complete-combustion incinerators unlikely to work effectively in India except under very special conditions. The large capital outlay means that authorities will look for cheaper versions of the technology. One of the criticisms of the Timarpur-Okhla plant in Delhi, which in 2016 was the only functioning example in India, was that it was a cheap and unsatisfactory Chinese design. The great cost also makes it difficult for India's under-powered local governments to raise the money to buy the best equipment. If such expensive units were built, waste would have to be accumulated in large volume from wide geographical areas to keep the furnaces burning and justify the expense. This puts large numbers of diesel-burning trucks on the road. A unit that deals with 3,000 tonnes a day, such as the one at Tuas South in Singapore, adds up to 300 journeys by 10-tonne trucks.[31]

The quality of the waste to be burned is also important. Waste in India usually contains more biodegradable material than in more industrialized and urbanized countries. To maintain the high temperatures necessary in an incinerator is likely to require additional fuel to dry incoming waste. If the temperature falls below 850C, toxic emissions are likely.

All these conditions require relentless supervision and maintenance. Dry, high-quality waste must flow steadily; temperatures and emissions must be relentlessly monitored; the plant was continue to operate even if a unit has to close down for maintenance or repair; and annual shutdowns for total overhaul of each furnace are essential. If things go wrong, the size of the operation means the consequences are wide.

In cities like Delhi (with its tightly confining borders) and Mumbai (with its island limitations), there may be a place for a Swedish or Singapore-style incineration plant. Space is scarce, current landfills are overflowing and the daily volume of waste continues to grow. But even in such circumstances, the costs and difficulties of directing hundreds of trucks a day to a single location are great.

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[31] There are lots of complications in any broad generalization, but the engine of a 10-tonne truck, making a 22-km journey at 80 kilometres an hours, uses about 7 litres of fuel. If there were 300 roundtrip journeys of that distance in a day, fuel consumption would be more than 4,000 litres. Department of Transport, UK, *The Fuel Efficient Truck Drivers' Handbook* (London: Her Majesty's Stationery Office, 2009), p. 9, https://goo.gl/Fsg1ai (accessed 3 March 2106).

There are other forms of incineration, and manufacturers eager to sell them to eager local governments, which lack sufficient funds, specialized staff and research capacity. Of government services, local government is the least glamourous, and public sanitation is the ugly duckling among ugly ducklings. Local governments have responsibilities that very often exceed their capacities. Both elected councillors and officials are desperate, however, to solve their waste problems, satisfy disgruntled citizens and meet the requirements of the Solid Waste Management Rules of 2016.

The plight of Thiruvananthapuram, the capital of Kerala, illustrates the temptation of incineration and its promises of a quick way to deal with urban garbage. Once a coconut-canopied, slow-paced tropical town, Thiruvananthapuram saw its population quadruple between 1971 and 2011 – from 400,000 to 1.7 million. More important, during those forty years Kerala's people flooded to the Gulf for work, came home relatively prosperous and turned one of the simplest lifestyles in India into one of the most consumer-conscious. Kerala, too, has always been densely packed – today, more than 800 people per square kilometre. (The UK rate is about 250; the Netherlands, 500).

In 2012, Thiruvananthapuram's municipal corporation, whose stalemate with villagers at its former dumpsite at Vilappilsala was notorious, bought a "mobile incinerator" from a company in Gujarat.[32] It arrived early in November 2012 in the form of a 42-metre green body towed by a Tata truck. "Mobile Stupidity," declared Shibhu Nair, one of Kerala's most committed and knowledgeable advocates of small-scale waste management. He posted a video on YouTube showing the agonies of a technician trying to make the incinerator work.[33] Expectations were unmet on all sides. The company that sold the incinerator complained that the Thiruvananthapuram authorities had not provided the diesel fuel needed to run the incinerator, had failed to collect the ash and waste water the incinerator produced and was not providing a regular flow of waste. They were owed, they claimed, for 10 days' worth of diesel that the company had bought. The Thiruvananthapuram authorities refused to pay for the incinerator until modifications were made in its design, including increasing the height of its chimney.[34]

[32] "Before the National Green Tribunal Southern Zonal Bench, Chennai, Application No. 247 of 2014," 30 September 2015, http://goo.gl/SoHwxc (accessed 28 July 2016).
[33] Shibhu Nair, "Mobile Stupidity," *YouTube*, 8 November 2012, https://www.youtube.com/watch?v=4fJ6QZ24lug (accessed 3 March 2016).
[34] *Hindu*, 10 December 2012, http://goo.gl/RHTyIe (accessed 3 March 2016).

The green incinerator became a white elephant. A year later authorities in Kerala were going to the courts to get the company to repay the Rs 1.5 crores (USD 160,000). It had operated for less than two weeks and had been moved out of the city to languish in a suburb in July 2013. "The incinerator did not function properly," a municipal official said, "mainly due to the technical faults, besides consuming a huge quantity of fuel. The operators went back to Gujarat after 15 days and they did not return. ... We could not operate it without expert operators ..."[35] In following years, the incinerator moved north up the Kerala coast, passed on to other local governments with waste problems. It was at the centre of dispute in the Kochi municipal corporation in 2016. A Kochi official said it was "a failure and the pollution caused by it was found to be high."[36]

The point of focusing on the green incinerator of Thiruvananthapuram is not to ridicule local authorities, but to highlight the dilemma of local governments. As their responsibilities and the anger of their voters increase, they search for rapid solution to problems that grow every day. In Thiruvananthapuram, residents often fall back on old-fashioned methods of incineration: they or their agents burn waste randomly at the side of the road.

Water

Residents of Thiruvananthapuram also have recourse to the third time-honoured method of disposing of unwanted objects. They throw them into water bodies in the hope that they will be carried away. After spending a month clearing a waste-clogged canal near the centre of the city, "within a month the canal was partly blocked [again] because of the waste being dumped into it," a municipal councillor lamented. Water bodies throughout the country are one of the first places citizens turn to when they have things to throw away and nowhere else to throw them. Water pollution is acutely harmful because clean water is essential and scarce. No Indian summer has passed for sixty years without reports of water scarcity. Most waste water from the rains and from household and industrial use flows untreated into lakes, rivers and the sea.

About half of Indian households have no access to toilets or choose not to use them. Such open or random defecation leads to polluted water and the spread of water-borne disease. But the possibility of providing water-driven sewerage and sewage treatment plants (STPs) for India's

[35] *Times of India*, 9 October 2013, http://goo.gl/I4O8xq (accessed 3 March 2016).
[36] *Times of India*, 16 January 2016, http://goo.gl/wWY0fE (accessed 3 March 2016).

4,000 steadily expanding urban areas is remote. New technologies are needed to deal with human waste, both in urban and rural areas. The piped, underground, water-hungry sewerage systems built in Europe and North America a hundred years ago pose immense construction problems. Digging and pipe-laying disrupt towns and cities. Pipes and drains must be laid across jealously guarded municipal boundaries and must empty into sewage treatment plants. STPs themselves require large tracts of land, big investment, community acquiescence and relentless maintenance. More important still, sewerage systems require dependable supplies of water. It is only a small improvement to remove excreta from households only to consolidate it with others and dump it untreated into a water body. And even ageing purpose-built sewers in cities like Mumbai often mix their contents with drains that carry storm water, and the resulting mixture flows directly into tanks, rivers or the sea. A Mumbai engineer described some of the problems in 2016:

> We cannot put sewage pipes in the slum areas, with over 39 lakh population. This is because they are located on the hills, or near water bodies. It's also politically difficult, you cannot just raze the slums, and even if you try to put pipes it will be a zig-zag system, which makes it impossible to lay down 15 inch pipes for connections. This why about 40 per cent of Mumbai is not connected to sewage line, but we cannot do it – it is a hell of a job![37]

Another engineer pointed out that "harvesting of water should be the higher priority [than sewage systems] in a state like Maharashtra, and here in the city we hardly recycle 4 per cent of the water from the STPs."[38] Technology, imagination and cultural insight are needed to find better ways to husband water and tame human waste

In the countryside, there are plenty of models for self-composting toilets, but their acceptance has been reluctant and patchy. Such toilets too often fall into the condition that Vinay Srivastava described when he wrote of his family's latrine in old Delhi in the 1960s: "extremely small, just enough to accommodate one person, dingy, almost like a dungeon, and poorly-lit and ventilated, without any facility of water inside."[39] Can the internal design, even of rural

37 Interview with A. Doron, Mumbai, 24 March 2016.
38 Interview with A. Doron, Mumbai, 24 March 2016.
39 Vinay Kumar Srivastava, "On Sanitation: a Memory Ethnography," *Social Change*, vol. 44, no. 2 (2014), p. 277.

toilets, be transformed so that they are shiny, bright, and easy to use and keep clean? A New Model Toilet, achieved through clever design and suitable materials, would be cheap, durable, washable and attractive – and it would handle human waste in culturally acceptable ways.

The second part of the toilet equation requires disposal of urine and faeces. In the common two-pit design, when one pit is full, it is sealed, the other pit is used and later, after biodegradation has turned human waste into benign fertiliser, the first pit is emptied and rich manure is deposited on grateful fields. But who's to do the emptying? It is hard work, and it disrupts and dirties the neighbourhood of the toilet. Neater ways are needed to achieve the desired result of a clean, odour-free toilet room, self-contained, not needing connection to a sewer, and producing a manure that is easily removed. The specifications are simple, but the task is delicate and complex.[40]

In dealing with tainted water and human waste, space is essential. Community toilets need land to build them on; in the countryside, structures intended as toilets become storehouses; in towns, small flats skimp on plumbing to invest in the living areas. How do you provide satisfactory toilets in buildings thirty stories high and containing a hundred or more households? To be sure, Singapore and Hong Kong have built sewers, but these are city-states. It takes four Singapores to make a Mumbai or Delhi.

The ideal urban toilet would not need to be flushed with water and would not need to be connected to sewerage. Faeces would be contained within the toilet design, without giving off offensive odour, and would biodegrade into a bag that could be sealed and then easily removed once every week or two to be put out for collection like other waste. The collected bags could be processed at central locations, and the resulting manure put back into the land.

How achievable is such a picture? The Swachh Bharat (Clean India) campaign of Narendra Modi's government aims for 100 million toilets by 2019. The Sulabh Foundation, which has installed 1.2 million toilets since its founding in 1970, has experimented with various designs, none of which has proved so popular that it has become an item in demand in rural or urban

[40] See Coffey et al., 2015, "Understanding exceptionally poor sanitation in rural India: Purity, pollution, and untouchability," p.21, http://riceinstitute.org/research/culture-and-the-health-transition-understanding-sanitation-behavior-in-rural-north-india/. They argue that caste relations are critical to understanding the question of sanitation, especially given that, according to their findings on open defecation in north India, shame is not a consideration.

India. The Terra Preta system developed in Europe promises to make fine compost, but requires daily tending and the separation of urine from faeces.[41] A South African company, Ecosan based in Pretoria, has installed more than 9,000 self-contained moulded plastic units that appear to meet some of the requirements of Indian conditions. Faeces fall into a chamber that turns the contents every time the toilet seat is raised. The movement exposes the excrement to outside air from a vent, and over the course of a few weeks the contents of toilet decompose into a benign manure that is moved into a collection bag. The bag is removed about once a week, and a fresh bag installed, rather as the bag of vacuum cleaner is changed. The contents can be used by the household as fertiliser or put out to be collected and consolidated with bags from other households for agricultural use. The disadvantages are that a single unit is bulky (2.5 metres long, 65 cms wide), costs about US 750 and can accommodate the waste of only about eight people.[42] In India, too, there could be reluctance in many households to the idea of excrement remaining on the premises, even if there were no odour. [43]

An anaerobic bio-digesting toilet, developed by Indian Railways (IR) and the Defence Research and Development Organization (DRDO), was being widely installed in IR coaches in 2016. .[44] Indian Railways reported that 12,000 of its 55,000 passenger coaches had been fitted with bio-toilets by January 2016. The target for 2015-16 was to fit 17,000 bio-toilets which would equip about 7,000 more coaches.[45] The first "green corridor" – a section of railway line on which toilets would no longer drop excrement onto the tracks – was announced in July 2016 on the line between Rameswaram, the pilgrimage site at the tip of India, and Manamadurai, the junction 50 kilometres southeast of the great temple city of Madurai. The 280 coaches operating on the line were now equipped only with bio-toilets.

The chemistry of the biotoilet involves placing a cocktail of bacteria into the catchment tank under the toilets of each carriage. Sealed off from oxygen (thus "anaerobic"), the organisms reduce faeces and urine to methane gas and harmless water. The water is released into drains or used for irrigation, and methane is expelled into the air. Though methane is a powerful

[41] "Terra Preta Toilets," http://www.sswm.info/category/implementation-tools/water-use/hardware/toilet-systems/terra-preta-toilet (accessed 2 August 2016).
[42] Email, Ernest Tiedt, Ecosan, Pretoria, to R. Jeffrey, 1 February 2016 and see http://www.ecosan.co.za/contact.html (accessed 2 August 2016).
[43] Studies suggest such reluctance. See Jewitt, and Coffey et al. 2015, p.21.
[44] *New Indian Express*, 23 July 2016.
[45] Indian Railways, Centre for Advanced Maintenance Technology, "Presentation on IR-DRDO Bio-Toilet System," 3 May 2016, Slides 11 and 117. http://iced.cag.gov.in/wp-content/uploads/2016-17/NTP%2003/RK.pdf (accessed 2 August 2016).

greenhouse gas, the contribution of railway toilets to India's overall methane generation is thought to be minor. The bacteria in the catchments tank need renewing only about once a year, and the major maintenance problem is said to come from passengers blocking the toilet with plastic bottles and other foreign objects.[46]

This discussion of the technologies of toilets, sewers and water treatment emphasizes the need for a variety of methods appropriate for specific climates, geologies and cultures. Humans can travel to the moon and communicate globally at will, but have yet to devise effective, economical and popular ways of dealing with the daily production of human waste around the world. It is also clear that technology alone is not enough. Prejudices, cultural expectations and political rivalries have to be overcome, workers in existing unclean jobs need to be trained in new technologies, users must become supporters and new rules have to be enforced.

Conclusion

Since pre-historic times, humans have been burying, burning and washing away the things they don't want. Today, however, people have never had more things to throw away, and the planet carries, 7.4 billion people, 18 per cent of whom live in India. In future, India cannot afford to run uncontrolled dumps, burn waste randomly at the side of the road or send garbage, industrial effluent and human waste into lakes and rivers. This paper has aimed to scrutinize some of the technologies that officials, citizen groups, private industry and engineers are deploying across the country to meet the *Swachh Bharat* challenge set by the central government.

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[46] "Bio Toilets," CBS Technologies, www.cbsenergy.com/Bio-toilets.html (accessed 3 August 2016). Sushmita Sengupta, "On Green Track," *Down to Earth*, 15 November 2013,