Municipal Solid Waste Management in Taiwan: From Solid Waste to Sustainable Material Management

Harvey Houng, Shu-Hung Shen and Hsiao-Kang Ma

1 Introduction

Ever since the "Solid Waste Disposal Act" was established in 1974, Taiwan has been developing waste management for nearly four decades. Over the years, the substantial increase in the amount of solid waste and the indiscriminate disposal of waste had caused serious environmental pollution problems. In 1984, the "Municipal Solid Waste (MSW) Disposal Plan" set landfill as the initial goal and incineration as the long-term policy. The "MSW Disposal Plan" was promulgated in 1991, empowering the Government to construct 21 incineration plants to relieve from the burdens of MSW pollution.

To promote the reduction, reuse, and recycling 3R principles, the Taiwan government established the Recycling Fund Management Board and launched a series of practices including: pay-by-bag collection fee system, mandatory MSW sorting, keep trash off the ground, plastic bag limitation, package reduction, one-time-use product reduction and hazardous substance prevention. As a result, Taiwan has had outstanding performance in resource recycling promotion plan for general waste. In 2012, the daily amount of MSW collected per person for disposal was 0.397 kg, which was over 60 % less than the highest record in history (1998). Resource recovery rate was 54 %, proper trash treatment rate was 99 %, and initial MSW disposal problems in the early days had been rectified (EPA, Executive Yuan 2012b).

H. Houng (✉) · S.-H. Shen
Environmental Protection Administration, Taipei, Taiwan, ROC
e-mail: harvey@epa.gov.tw

H.-K. Ma
National Taiwan University, Taipei, Taiwan, ROC

A. Pariatamby and M. Tanaka (eds.), *Municipal Solid Waste Management in Asia and the Pacific Islands*, Environmental Science and Engineering,
DOI: 10.1007/978-981-4451-73-4_16,

2 Legal Structure of Waste Management

2.1 Solid Waste Disposal Act

The "Solid Waste Disposal Act", was promulgated in 1974 and has been amended several times, including the period from 1980 to 1987 when Taiwan's economy began to rise and industry as well as commerce gradually developed. At the same time, environmental pollution also grew to severe levels. The construction of sanitary landfills and incineration plants did not seem to resolve problems as expected. In 2001, the "Solid Waste Disposal Act" was amended in compliance with the promotion of the "Zero Waste" policy and addressed problems of preventing arbitrary disposal of waste. Major Policies and Regulations relevant to MSW Management in Taiwan are illustrated in Fig. 1.

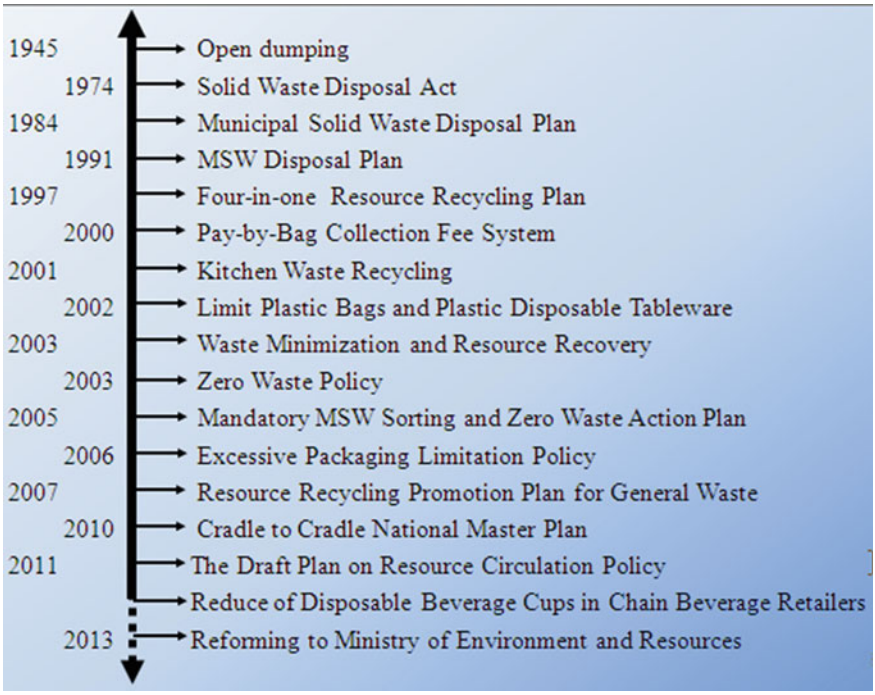

Fig. 1 Major policies and regulations relevant to MSW management in Taiwan (EPA, Executive Yuan 2012b)

2.2 Resource Recycling Act

The regulations of the initial Solid Waste Disposal Act were end-of-pipe control and never provided overall governing from the entire process of product life cycle. Thus, it was necessary for legislation to guide enterprises in designing and producing easy to recycle products, as well as using renewable resources as materials. The "Resource Recycling Act" became effective in 2002, comprising 6 chapters and 31 articles. Keypoints included practicing resource recycling, expanding diversified recycling approaches, and varying recycling methods for different products. All citizens were encouraged to participate to further achieve the goal of "comprehensive resource recycling, zero wasting". Principle rules were established for use of substances and sequence of waste management; the prerequisite of suitability of the principle was "based on feasible technology and economy".

3 Generation and Composition of MSW

3.1 Quantities of MSW

The "Mandatory MSW Sorting and Zero Waste Action Plan" promoted in 2005 started with reducing and recycling by sorting MSW at households. In 2007, MSW was banned from being taken to landfills except in the remote areas. The daily MSW generation per capita per day in Taiwan had decreased from 1.143 to 0.397 kg in 2012, which was 60 % less than the highest MSW generation in history (EPA, Executive Yuan 2012a).

3.2 Composition of MSW

The chemical and physical composition of solid waste in 2012 was analyzed (Table 1, 2), where the results revealed that paper, food waste, and plastic accounted for 92.79 % of the total physical composition, among which food waste had the highest content with 38.33 %, followed by paper with 38.85 %, plastic with 15.61 %, and metal and glass with 0.28 and 1.26 %, respectively. The total contents of leather and rubber, fiber and cloth, and wood and leaf accounted for 4.18 % of the physical composition of solid waste (EPA, Executive Yuan 2013a).

Table 1 Typical physical composition of MSW in Taiwan, 2012 (EPA, Executive Yuan 2013a)

Physical composition (wet basis)	Combustible	Paper (%)	38.85
		Textile (%)	2.52
		Wood, trees, etc. (%)	1.46
		Food waste (%)	38.33
		Plastics (%)	15.61
		Leather, rubber (%)	0.20
		Other metal (including debris below 5 mm) (%)	0.49
		Sub-total (%)	97.46
	Non-combustible	Ferrous-metal (%)	0.28
		Non-ferrous metal (%)	0.22
		Glass (%)	1.26
		Other non-combustible material (Ceramics, sand) (%)	0.78
		Sub-total (%)	2.54

Table 2 Typical chemical composition and energy content of MSW in Taiwan, 2012 (EPA, Executive Yuan 2013a)

Chemical analysis	Moisture content by wt. (%)	53.97
	Ash content by wt. (%)	4.96
	Carbon (%)	22.36
	Hydrogen (%)	3.46
	Oxygen (%)	14.62
	Nitrogen (%)	0.38
	Sulfur (%)	0.15
	Chloride (%)	0.11
Energy content	Dry kcal/kg	5,322.44
	Wet (high value) kcal/kg	2,451.31
	Wet (low value) kcal/kg	1,940.74

4 Collection and Transportation

4.1 MSW Removal Policies

Before 1968, MSW was stored in outdoor trash boxes, and cleaning personnel would collect the MSW from these boxes by man-hauled carts or tricycles and transport the MSW directly to disposal sites or transfer posts. This further evolved into transporting the MSW to transfer posts with tricycles or directly to waste disposal sites with small trucks. Until the 1970s, solid waste transportation still adopted the same method from the 1960s, which was using sealed MSW trucks to collect household wastes. Public trash containers were abolished in 1971. Up until

now, MSW collection methods included collection by households (placed at the door or a collection point), collection by stations (MSW trucks or dumpcarts), or collection along streets at fixed locations and times (keeping trash off the ground).

The "Keep Trash off the Ground Policy" is currently implemented in Taiwan, except for specific remote areas. Thus, MSW collection is mostly done by a street collection fleet at fixed locations and times. Where the fixed location collection is not feasible in the remote areas, collection service provided to each household is practiced. The frequency of collection is generally five days per week and once per day. Time of collection mainly depended on the schedule of local habitants; night collection is mostly carried out in urban areas, though there is also morning or daytime collection. Transportation equipment and labor are distributed based on the population and local budget of the area served.

When people discharge MSW, waste recycling and disposal regulations should be followed. Sorting rules established classify MSW into general solid waste, resources, food waste and others as regulated by local governments before handing MSW over to the cleaning squad. As for large MSW such as furniture, the local cleaning squad must be contacted in advance to schedule timely collection.

4.2 Replacement of Old MSW Collection Equipment

Taiwan promotes the "Keep Trash off the Ground Policy", where the MSW collection method involves frequent driving and stopping of trucks. This repetitive acceleration and deceleration cycle during the process of MSW collection consumes a substantial amount of fuel. Fuel consumption of MSW collecting trucks is significantly higher compared to other trucks of similar grade, leading to an increase in the emission of air pollutants, such as NOx and particulate. To enhance cleaning efficiency and reduce vehicle maintenance fees, hybrid hydraulic tanks for MSW collecting trucks were brought in from Germany. The hybrid hydraulic tanks transfer braking energy into hydraulic power using a hydraulic system. The energy is stored and then released through a precise computer control system at the next acceleration. Therefore, the truck can reduce fuel consumption, assist acceleration, decrease brake abrasion and prolong engine life. Other cleaner fuels such liquefied natural gas (LNG), compressed natural gas (CNG), hybrid fuels, and electric engine are under investigation or field test driving for practical utilization on MSW collecting trucks.

As for beneficial assistance to environmental protection, new vehicle NOx exhaustion was reduced by 50 %, and smoke exhaustion (degree of pollution %) also decreased from 35 to 25 %. Furthermore, the EPA implemented environmental driving education and consultation for drivers so that 7 % of fuel consumption are saved through adjusting driving behavior, equivalent to 274 l a year per truck, reducing 740 kg of carbon dioxide exhaustion and saving NTD 8,768 per year (EPA, Executive Yuan 2013b).

5 Treatment and Disposal

5.1 Sanitary Landfills

There were 296 solid waste disposal sites in Taiwan in 1984, among which 147 sites were expected to have less than 1 year of service time. The sanitary landfills used by various townships only accounted for 65.5 % and dumping in low-lying lands accounted for 19.6 % (EPA, Executive Yuan 2013b). The "Comprehensive Regional Waste Disposal Plan" was established on September 21, 1984, which proposed 14 important construction plans for demonstrative waste disposal. The plan involved establishing correct public views towards MSW treatment. Future promotion and establishment of standard waste sanitary landfills would be implemented successfully to prevent illegal dump yards or landfills and improve environmental sanitation.

In addition, in order to provide the concept of sustainable land use, saturated waste yards were to be recovered and transformed into sports and recreational facilities as a feedback to local people. Up until now, there were 110 landfills in operation in 2011, with a total volume of approximately 18,250 million m^3.

5.2 Incinerators

The waste disposal policies in Taiwan shifted from "focus on sanitary landfill" in 1981 to "incinerate aided by landfill" in 1991, with a focus on solving waste disposal problems properly as the primary task. The contents of the "Municipal Solid Waste Disposal Plan" promoted in 1984 included establishing waste management policies, increasing active MSW cleaning machinery, strengthening personnel education and training, building waste disposal plants, and creating basic properties data on municipal solid wastes to increase the proper waste disposal rate from 2.4 % in 1984 to 62.0 % in 1990.

The "Construction Plan for Solid Waste Resource Recycling (Incineration) Plant" established in 1991 handled the construction of 21 incineration plants. The Department of Solid Waste Resource Recycling Plant Construction was setup to be in charge of handling construction related matters. The Plants in Taiwan have a cogeneration system designed for waste heat recycling. Such system uses the heat generated by incinerating solid wastes as the energy source for a heat recovery steam generator (HRSG). The water in the generator is heated into steam that is 400 °C and 40 Bar, to drive the steam turbine to transform heat into electricity. Each incineration plant can generate at least 5,200 kW of power. The electricity generated can be used within the plant; the heat remaining after generation can be reused for a warm water swimming pool, and the remaining electricity can be transformed into 69 kV with a transformer and transmitted back to Taiwan Power Company for use by the general public. As of 2013, 24 large scale incinerator

Fig. 2 Taipei Mu-Zha incinerator and its surrounding areas (EPA, Executive Yuan 2012b)

plants are in operation with more than 95 % waste treated by incineration. The built-in co-generation facilities contribute more than 8 million kWh of electricity per day. The most stringent air emission standards are also applied to all incinerators to safe guard the environment. Part of revenue received by the Incinerator Plant is used for community services such as warm water swimming pool, fitness center, gardens, environmental education centers, etc. (Fig. 2).

6 Reduce, Reuse, Recycle, and Recovery

6.1 Source Reduction

The progression of the view of solid waste disposal focuses first on waste disposal technology and then on resource recycling. However, the focus today is on "pre-generation of MSW," i.e. "source reduction," which stresses recycling and encourages enterprises to engage in ecological design in the hope of achieving the prospects of resource reuse maximization and waste minimization ("zero waste"), as well as transforming managerial thinking to developing towards sustainable substance circulation. Source reduction is something that everyone can do. For example, drinking less bottled and canned beverages will generate less waste containers.

6.1.1 Policy Promotion

Promotion of source reduction brings multiple benefits such as lowering operational cost, enhancing corporate image and decreasing MSW generation. In the initial period of various source reduction promotions, the EPA was committed to combining environmental groups, enterprises and local governments in resource guidance to create a trend of source reduction among industries in society. For example, the "Environmental Tableware Package Design Contest" in 1996 encouraged people to prepare their own environment friendly tableware; the "Use Less Plastic Bags" activity was promoted since March of 2001; restaurants began

to switch to using washable tableware in June of 2001, and the "Environmental Protection Convention on Use of Shopping Bags Instead of Plastic Bags" activity was executed in September of 2001. These events received enthusiastic response and support from industries, and became the important foundation stone for EPA's promotion in "Limitation on Use of Plastic Shopping Bags and Disposable Plastic (Including Styrofoam) Tableware".

6.1.2 Changing Life Styles

Plastic bags became indispensable in people's lives because of their cheap cost and convenience. Based on statistics taken by the EPA before implementing plastic limitation policies, the annual plastic bag usage amount in Taiwan was 105 thousand tons, among which plastic shopping bags accounted for 65 thousand tons per year. Large amounts of discarded plastic bags appeared in the environment, often leading to clogged drainage ditches, which further caused floods; some piled up at river coasts, sea coasts and mangrove forest at tidal beach, also damaging the eco-environment. Therefore, to change the habit of disposable consumption in people's daily life, the EPA began to promote the "Plastic Shopping Bags and Disposable Plastics (Styrofoam Included) Tableware Limitation Policy" in public departments in July of 2002 to limit the usage of plastic shopping bags and disposable plastic tableware. In January of 2003, the policy expanded to include malls, shopping centers, hypermarkets, supermarkets, chain convenience stores, chain fast foods stores, and restaurants and cafeterias.

Government agencies and schools had the responsibility of setting good examples and educating of the new generation by promotion of source reduction in Taiwan. After the plastic limitation policy achieved its initial success, the EPA promoted the policy of not providing any disposable tableware (including cups, bowls, dishes, plates, boxes, chopsticks, spoons, knives, forks, stirring sticks, etc.) when dining in restaurants at government departments and schools on July 1 and September 1, 2006. In addition to regulating caterers working for government agencies and schools to reduce MSW generation by switching to using washable tableware, promotion of reducing use of disposable tableware also expanded to restaurants and cafeterias in malls to achieve source reduction. The policies guided people to change disposable living habits and performed indicative demonstration effects. Since the use of plastic shopping bags and disposable plastic tableware was limited in 2002, the annual amount of plastic bags used was reduced by 2 billion bags, a reduction rate of 58 %; the annual amount of disposable tableware used was also reduced by 2 billion bags, a reduction rate of 85 % (EPA, Executive Yuan 2012a).

6.1.3 Product Design

To follow the trend of international source reduction development, product design was taken into account when considering source reduction. The results of "Excessive Packaging Limitation", "Limitation on Manufacture, Import and Sale of Mercury Containing Dry Cells", and "Limitation on Import and Sale of Mercury Thermometers" demonstrated the EPA's efforts in reducing MSW generation, creating a quality living environment for the public, and guiding industries in sustainable development.

Packaging management illustrates one of the ways of source reduction. From the viewpoint of package design, the eco-friendly green concept should be included at the design phase, also known as green package design. From the angle of consumers, choosing a green product is choosing to be eco-friendly. If more people chose green purchasing, it will help to promote more firms to join in on green products, further attracting green consumption. Thus, solid waste may be reduced from the source and allow resources to enter a more sustainable circulation. Surveys taken by the EPA in 2000 and 2003 showed that over 60 % of the public thought gifts were excessively packaged, including too many layers of wrapping, excessive packaging space, excessively high packaging cost, and too many types of packaging materials; over 70 % of the public expressed an unwillingness to purchasing excessively packaged products or those with exquisite packaging for higher prices. In a 2000 survey, 82.4 % of the public supported the government in establishing packaging reduction control policies, and the number increased to 91.4 % in 2003 (EPA, Executive Yuan 2012a). The survey indicated that a majority thought excessive packaging was a serious problem and supported the government in taking control measures.

Therefore, the EPA established the "Excessive Packaging Limitation Policy" in compliance with the Resource Recycling Act on July 1, 2005. The policy included two phases for controlling the packaging volume ratio (<1) and layers (less than two; less than three for pastry box and computer program disc) of gift boxes. The Policy became effective in 2006, and regulated the packaging volume and layers of pastry, cosmetics, processed foods, wine and disc, as well as guided packaging toward reduction and easy to recycle green design, which had reduced 7,300 tons of packaging waste in the first year (EPA, Executive Yuan 2012b).

As for source reduction of toxic substances, the demand for dry cell batteries had increased with the development in electronic instruments and consumption of electronic products. However, there are numerous types of dry cells battery on the market due to differences in manufacturing principles, technology and functional requirements, and some products still contained mercury, a toxic substance harmful to the human health and the environment. If the mercury batteries are not properly recycled and disposed of, their distribution in the environment may cause mercury to accumulate in organisms and environmental pollution, eventually harming the human body. Under the international trend of "Limit Hg Gradually, Ban Hg Ultimately," governments around the world are limiting the use of mercury in certain products, and taking strict control measures toward the final

disposition of Hg-containing products. The EPA also referred to the cell directives of the E.U., to establish the "Limitation on Manufacture, Import and Sale of Dry Cell Batteries" to limit the manufacture, import and sale of dry cell batteries containing over 5 ppm of mercury. In 2006, Taiwan began to prohibit the manufacture, import and sale of manganese–zinc cells and non-button type alkaline manganese cells that contained over 5 ppm of mercury.

In addition, Hg-containing thermometers were also an important source of mercury distribution in the environment. Since households and medical facilities used mercury thermometers, they were commonly found throughout the environment. Furthermore, the product shattered easily during use. The spilt mercury is extremely difficult to be collected or recovered for proper disposal. At the same time, production technology for electronic Hg-free thermometers was quite sophisticated with growing adoption rates, and inspection technology regulations had been established. Thus, the EPA announced the "Limitation on Import and Sale of Mercury Thermometer" to restrict the import and sale of Hg thermometers through various phases. Since 2008, the "Limitation on Import and Sale of Hg Thermometer Policy" was implemented and resulted in a reduction of 850 kg mercury each year (EPA, Executive Yuan 2012c).

6.1.4 Voluntary Cooperation

In 2007, the EPA promoted the "Paper Cup Reduction Plan in Government Agencies and Schools" and encouraged restaurants to use washable tableware, people to prepare their own tableware, and hotels to reduce their usage of disposable tableware. The EPA also asked four major chain convenience stores "not to provide disposable chopsticks unless necessary" in July of 2008, in the hope that the public would practice the habit of not using disposable chopsticks. The EPA negotiated with the restaurants and cafeterias in malls and hypermarkets to promote the "Disposable Chopsticks Reduction Activity" in January of 2010. The activity required that stores change to washable chopsticks instead of disposable chopsticks. The EPA hoped to achieve "resource circulation, energy conservation and carbon reduction" society through multiple aspects of movements and collective efforts.

At the same time, in order to reduce packaging waste, the EPA not only restricted the volume and layers of packaging of products through the Excessive Packaging Limitation Law, but also promoted voluntary reductions by industries in 2010. By signing agreements with brand enterprises regarding reduction of waste volume and weight, the EPA and enterprises continued to promote spontaneous lightweight packaging. By engaging in the voluntary reduction agreement, an enterprise could not only express its support for sustainable development of the earth's resources and increase attraction by enhancing brand image, it could also reduce packaging materials, further lowering costs. Fifteen products from 11 enterprises signed the agreement in 2011, eliminating 1,720 tons of packaging

materials. This was expanded to 15 products from 12 enterprises in 2012, and it is expected to reduce even further by 965 tons (EPA, Executive Yuan 2012a).

6.1.5 Economic Incentives

Food and beverage stores have been providing take-out drinks in the recent years, forming a consumption habit of disposable cups. Chain beverage stores, convenience stores and fast food stores use around 1.5 billion cups per year. In addition to consuming a large amount of natural resources, cups are often discarded arbitrarily, causing pollution and damage to the eco-environment. It is necessary to enforce source reduction and strengthen the collection of disposable take-out cups.

Considering the international trend of waste management, the EPA pronounced "Regulations on Rewards for Disposable Take-Out Cup Source Reduction and Collection" in 2011. It regulated chain fast food stores, chain convenience stores, chain coffee shops and chain beverage shops submit discount plans for self-prepared cups to reduce use of disposable cups; in the case a store from the above-mentioned industries did not implement resource reduction, it should recycle the disposable take-out cups from its own chain system. When a customer brought a used cup of the brand to one of its chain stores, the store should offer a reward of NTD 1 for every 2 cups. This was to encourage the public to strengthen recycling, prevent pollution and damage to the eco-environment due to arbitrary disposal, and to achieve the goal to resource circulation and reuse. Since 2011, 388 brands and over 17,000 stores in the chain beverage industry offer discounts for people who bring their own cups. After 1 year of implementation, the ratio of people bring their own cups increased 9.6 % (EPA, Executive Yuan 2012b).

6.2 Reuse

In Taiwan, any old furniture worth fixing was recovered and reused, while those not worth fixing were smashed, and the wood, plastics and metal were separated and recycled for reuse. Because the policies for waste reduction and sustainable resource reuse promoted in Taiwan were accepted by the public, the generation of bulk waste in the nation had decreased from 235,554 tons in 2005 to 140,882 tons in 2011, a reduction rate of 40.2 %. The bulk waste recycling rate in the nation had increased from 12.6 % in 2005 to 57 % in 2011, and the incineration and landfill rate had decreased from 87.4 to 43 %. Statistics from 2007 to 2012 showed that counties and cities in Taiwan have sold 165,000 pcs of renewable furniture and bicycles, amounting to NTD 127.97 million. During the recent three years, over 210,000 persons from agencies, groups and schools visited recycling plants and participated in auctions every year. The "Website for Bulk Waste Recycling" was also established for providing relevant information on bulk waste recycling and

links to auction websites of counties and cities, allowing people to acquire the data they required.

6.3 Recycle

The EPA began to implement mandatory MSW sorting in 2006, required people to sort their wastes into three categories: resource, food waste and MSW. When collecting MSW, the crews of sanitation fleets inspect MSW for compliance. After the implementation of this policy, the recycling rates of resource and food waste had increased significantly, reducing the amount of MSW disposal. Survey results showed that the recognition and support of the people toward mandatory MSW sorting measures were 90 %, indicating most people could comply with resource recycling policies.

In order to practice the principles of "users pay" and "polluters pay", the "Regulations for Collection of Solid Waste Clearance and Disposal Fees" was established in 1991, by which local governments collected clearance and disposal fees from the people according to standards stipulated by the central government. The regulations were amended and implemented in 2002, requiring that each local government should calculate fees to be collected based on actual cost of waste collection and treatment. According to Article 3 of the regulations, municipal and county (city) governments should calculate fees by one of the three methods: amount of water usage, quota per household, or amount of MSW (pay-by-bag collection fee).

Taipei City Government began to promote pay-by-bag collection fees in 2000 to encourage people to practice MSW and resource sorting by using the economic incentive of controlling quantity with price. New Taipei City also began promotion in 2008 and full implementation in 2010. Shigang District in Taichung City is also enforcing the regulations. The EPA started to promote mandatory MSW sorting in 2005, stipulating that people should sort their solid waste by resource, food waste and MSW, and then hand them over to be collected or cleared by sanitation fleets. They should also comply with the Keep Trash off the Ground Policy to reduce MSW and increase resource recycling.

During the promotion, households were reached by applying various channels for the public to understand the policies. For example, education bureaus focused on school teachers, market management focused on vendors, environmental protection bureaus focused on various propagandas and media reports, labor departments held events for strengthening propagandas of foreigners, while information service departments made propagandas on public communication media such as newspapers, broadcasting, television, outdoors e-boards, public bus and MRT car. Ever since implementation of the pay-by-bag collection fee, the amount of MSW in Taipei City had decreased 21.3 % from 1999 to 2000 and it continued to lower yearly; the resource recycling rate also increased 113.5 % (Ma et al. 2009).

The above indicates that outcomes of MSW reduction and resource recycling can be enhanced effectively. The MSW clearance and disposal fees in other counties and cities are currently collected by being added to water fees. However, MSW fees and water usage have no direct relationship, thus implementation of pay-by-bag collection fee system can meet the fair principle of "polluters pay," as well as guide people in the behavior of "less trash, less payment" through economic incentive, to achieve the goals of MSW reduction and resource recycling.

6.4 Methane Gas Recovery

In order to solve the gap in greenhouse gas exhaustion reduction, Taiwan considers energy conservation and carbon reduction as important goals to enhance energy use efficiency.

In general, a sanitary landfill with over 1 million tons of raw MSW is feasible for methane recovery for power generation of one to two MW. Although 400 thousand tons of raw MSW can support a small methane power generator up to 230 KW, it is only sufficient for self contained electricity within the plant. It offers no economic benefits and the cost is relatively high. Since 1996, the Taiwan Government has used the "Air Pollution Prevention and Control Fund" for executing recovery of methane at closed sanitary landfills. Most of these landfills have established methane gas recovery facilities. It was estimated that between 1999 and 2006, landfill methane gas was recovered to generate 5.16 million kWh of electricity, that is equivalent to 114 thousand tons methane gas recovery or 3 million metric tons of carbon dioxide equivalent (MTCO2E). In 2011, Taiwan also pushed for an annual methane generation of 553 million m^3 (5 years service life) at 110 operating landfills. The greenhouse effect is approximately 8.94 MTCO2E per year (EPA, Executive Yuan 2012a).

7 Extended Producer's Responsibility and 4-in-1 Program

7.1 Resource Recycling Fun Management Committee

In 1988, the EPA began to promote the "Extended Producer's Responsibility" system based on the Waste Disposal Act, requesting product producers (responsible enterprises) to be responsible for waste recycling and disposal, and announcing that responsible enterprises should handle recycling, clearing and disposal of containers, tires, lead-acid batteries, lubricant oils, cars and motorcycles, and certain recycling rates must be achieved. Since 1997, EPA began promoting the 4-in-1 Program. Responsible enterprises did not have to recycle the wastes on their own, but pay a recycling, clearance and disposal fee to the

Resource Recycling Management Fund. The Fund Management Committee would use the fund as incentive to combine local sanitation fleets, communities and recycling firms to promote resource recycling. The product list of recycling, clearing and disposal fees payable also included electronic appliances, data processing objects and lighting.

The 4-in-1 Program promoted by EPA combines communities, recycling firms, local governments and recycling fund in the implementation of resource recycling. The public or communities establish recycling organizations to sort resources and general MSW generated by households for separate collection at recycling points or by local sanitation fleets or private recycling firms. The fund is used to subsidize local sanitation fleets and supplement recycling firms for establishing complete resource recycling systems to recycle resources effectively.

As for the recycling fund, the fee rates of manufactures/importers of objects or containers shall be determined by the Committee and paid to a financial institute for establishing a Resource Recycling Management Fund, which will be used for supplementing recycling and disposal of objects or containers to increase the incentive for people to engage in resource recycling. The fees to be paid by manufacturers/importers shall be determined upon factors such as material, volume, weight, recycling value and the previous year's recycling rate. As for the subsidy for recycling and disposal, the Recycling Fund shall pay it after the group certified by EPA had confirmed the quantity of properly recycled and disposed resources. The mechanism of the 4 in 1 program is illustrated in Fig. 3.

There are currently 33 items announced of which the recycling, clearing and disposal are the responsibilities of manufacturers/importers. The Recycling Fund is over NTD 600 million per year and is divided into two parts: 70–80 % is trust fund, used as subsidy for recycling, clearing and disposal; 20–30 % is non-operational fund, used for subsidizing recycling machinery and storage sites for local

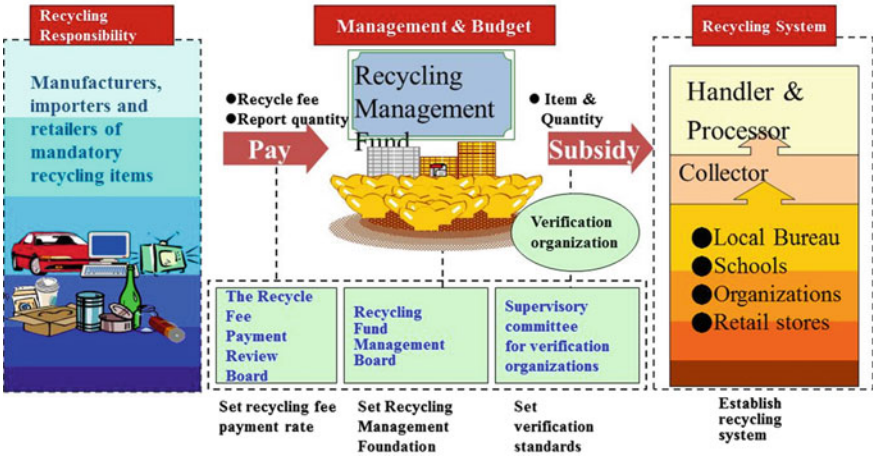

Fig. 3 Operation of resource recycling management fund (EPA, Executive Yuan 2012a)

sanitation fleets, supplementing or rewarding communities, agencies and schools for engaging in recycling and propaganda, auditing, inspections, executive administration and research development.

7.2 Recycling System

The resource recycling system in Taiwan has established diversified recycling channels that are based on two major systems. The civil resource recycling system of trash picking and returning old products that has operated for decades is still in operation through economic incentive of the recycling market and subsidy from the government. The other system is the local government recycling system, which uses recycling trucks for collecting resources sorted by people as a convenient recycling channel. The resource to be sorted can be divided into two categories. The first category is the waste or containers that are to be recycled, cleared and disposed of by manufacturers/importers. The other category includes waste that is worth recycling and can operate well without subsidy from recycling market and government interference. For the above two categories, people must sort the resources for collection by sanitation fleets on resource recycling day. After each local cleaning squad collects the abovementioned resources, it will classify the resources or entrust recycling firms based on materials or types into various resources, and send the resources to various materials renewal plants for reuse.

Taiwan has established a labeling system (Fig. 4) for people to distinguish recyclable items and general MSW. Manufacturers and importers are requested to label recycling marks on the recyclable products or containers they produce or import, as well as comply with the 4-in-1 Program. The recycling facilities, such as resource recycling trucks and bins, of each environmental protection unit, public location and vending points are currently required to print visible recycling marks for recognition by the public and strengthening the message of resource recycling. The resource recycling rate in Taiwan has increased from 5.88 % in 1998 to 53.94 % in 2012.

Fig. 4 Regulated resource recycling label (EPA, Executive Yuan 2012b)

7.3 Greenhouse Gas Reduction Benefits

When trash is delivered to a waste-to-energy plant, the energy content of the waste is retrieved, metals are recovered, and electricity is generated. However, waste-to-energy is the last resort for waste management. Through source reduction, reuse, and recycling, the energy and the resources taken to make the product can be tremendously reduced. The Taiwan EPA estimated that the reduction of annual waste from 9.43 million tons in 1998 to 7.35 million tons in 2012 prevented 2.08 million tons of waste from been disposed of in incinerator plants and as a result, reduced 2.25 million metric tons of carbon dioxide equivalent (MTCO2E) in 2012. This estimation let alone the additional carbon dioxide to be generated if coal is to be burnt in an ordinary power plant to generate the equivalent amount of electricity. In addition, through the 3R efforts, the recycled 3.1 million tons of recyclable material also contributed a reduction of 3.23 million MTCO2E in 2012 (EPA, Executive Yuan 2013a).

8 Remarkable Outcomes

Taiwan has achieved remarkable success in reducing, reusing and recycling general household waste. Average daily waste collected for disposal was down from 1.143 kg per capita in 1997 to 0.397 kg per capita in 2012. Total waste volume was down by more than 60 % from the peak in 1997. Furthermore, total recycled materials collected amounted to 3.97 million tons representing a 54 % recycling rate. Over 99 % waste are properly processed, and the problems of waste management in the early days have been effectively addressed. Figure 5 illustrates the trends of waste generation and recycling since 1989.

9 Prospects and Challenges

9.1 State-of-the-Art Technology Application

By using the state-of-the-art technologies, Taiwan EPA initiated an Industrial Waste Control Center in 1997 (Fig. 6). The Center was originally established to manage infectious medical waste and hazardous waste but later expanded to cover non-hazardous industrial waste, agriculture waste, construction waste, commercial waste and part of general waste. Transboundary movement of E-waste is also tracked by the same system. Through internet reporting, government authorities have the instant access to the manifests. The Global Position System (GPS) provides the physical locations of the transporting trucks on real time bases. Online Analytical Process (OLAP), provides précised analytical data and operational

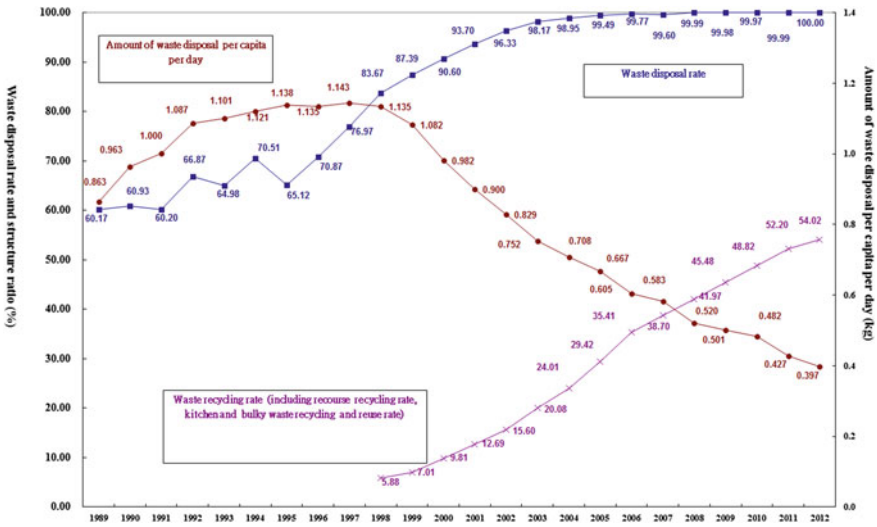

Fig. 5 Remarkable outcomes of waste generation and recycling. (EPA, Executive Yuan 2013b)

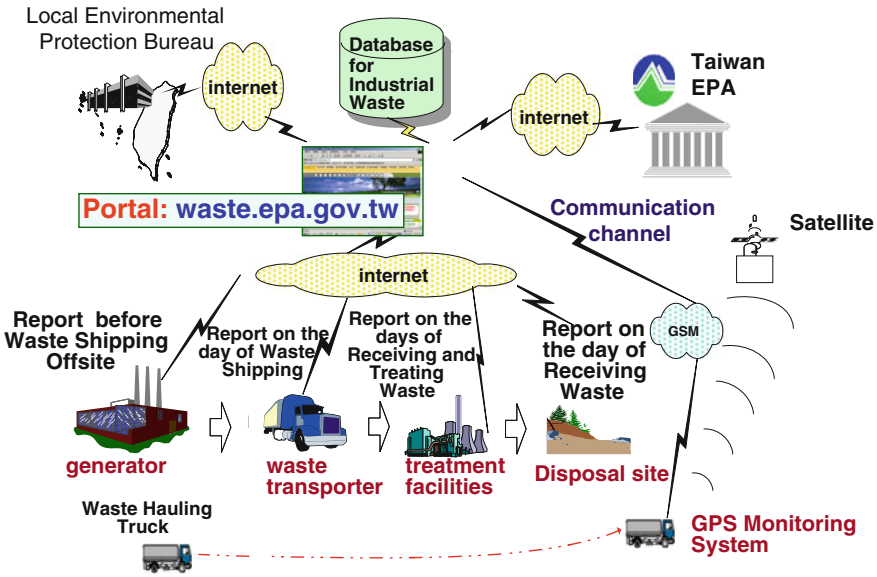

Fig. 6 Industrial waste control center (Houng et al. 2013)

patterns, easily pinpoints any illegal operations. The IWCC functions as an effective tool for compliance monitoring and tracking of wastes and provides a valuable database to assist in the development of effective policies on resource recycling and recovery (Houng et al. 2013).

9.2 Bio-Energy Center and Land Reclamation

To take advantages of the bio-energy in general solid waste, the EPA listed the "Transformation of Incinerators into Regional Bio-Energy Centers for Forestry and Agriculture" as one of the major works for "Zero Waste in a Resource Circulating Society". Retired incinerators will be transformed into regional bio-energy centers. General waste and agriculture leftover materials (such as straws, driftwood and branches not worth recycling) will be used to demonstrate and to verify emerging technologies such as torrefaction, bio-coal generation, high efficiency anaerobic digestion, etc.

9.3 Zero Waste Policy

The waste management policy of Taiwan has advanced from the early "end-of-pipe management" to the modern "zero waste". The latter stresses "source reduction" and "resource recycling", which is consistent with the international trend of valuing sustainable use of substances. Taiwan government established the "Review and Prospects of Waste Disposal Programs" in December of 2003 for stipulating the goal of "zero waste" in the nation. The frame work for reaching "zero waste" including green products, procurement, and manufacturing, as well as mandatory policies is illustrated in Fig. 7 (Ma 2010). At the same time, due to the full promotion of total waste reduction and resource recycling of the "zero waste policy" and other regulations related to resource recycling, the goals of full waste recycling and zero waste were gradually accomplished. The goals of the "Zero Waste Policy" have been drawn to 2020 as shown in Table 3 (Houng 2008, Ma 2010) and the latest data showing that the goals have been accomplished as revealed in Table 4 (EPA, Executive Yuan 2013b).

9.4 Cradle to Cradle

Taiwan promoted the cradle-to-cradle principle in 2010, making it the first Asian country to apply C2C in the planning of resource circulation strategies. The nation entrusted professional agencies in 2011 to propagate and spread C2C prospects and resulted in products from two firms to receive the C2C's silver certification. In 2012, industrial, official, academic and research organizations combined and founded the "Taiwan C2C Association" as an important interflow channel for promotion of cradle-to-cradle.

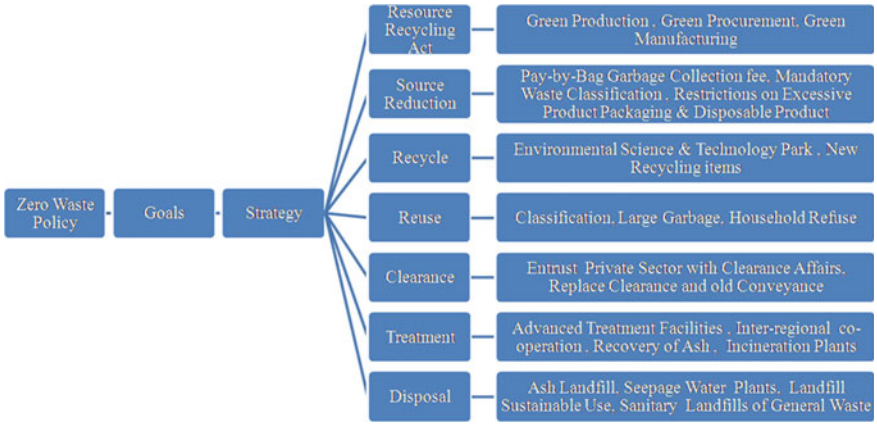

Fig. 7 Zero waste policy frameworkEPA, (Ma 2010)

Table 3 The goals of zero waste policy (Houng 2008)

Year	Reduction targets (%)	Resource recycling (%)	Food waste recycling (%)	Bulky item recycling (%)
2007	25	18.5	4	0.3
2011	40	24	7.5	1
2020	75	38	20	1.3

Table 4 The goals of zero waste policy accomplished in recent years (EPA, Executive Yuan 2013b)

Year	Reduction targets (%)	Resource recycling (%)	Food waste recycling (%)	Bulky item recycling (%)
2011	47.3	36.6	9.7	1.0
2012	48.3	37.2	10.0	1.1

9.5 Resource Productivity

"Reduce Waste Generation" and "Increase Waste Reuse" were adopted in the past, but the direction has shifted towards "sustainable substance/resource management" with the goal of reducing environmental impact and preserving natural resource. As for the increment of economic benefits from product/use/disposal of substance, decrements in resource input in the industries can lower the environmental impact of material extraction and the cost of waste treatment and disposal. It is a good example for substance used in product/use/disposal to achieve a win–win situation in resource sustainability management and economic growth.

9.6 Re-organization of Agency

Along with the idea of sustainable material management, the Taiwan government is establishing a new entity known as the Ministry of Environment and Natural Resources, expanding the scope of the EPA to encompass resources such as forests, agriculture, mining, hydraulics, etc. Taiwan EPA was established in 1987 as the first important milestone in protecting the nation's quality environment. Under the collective efforts of the public over the past 23 years, the environment in Taiwan has improved significantly. To cope with the new challenge in climatic changes brought on by global warming, the Solid Waste Department will be reorganized as the Department of Resource Management. This not only reflects to the prospect of a "proactive and right environmental policy" and responds to global climatic changes; it has also become the second important milestone in protecting the nation's quality environment. The Taiwan EPA has always been fine tuning its policies and keeping abreast with the trend of the global development of waste management. All efforts aim to promote a comprehensive circulating and sustainable society.

References

EPA, Executive Yuan (2012a), Records of waste management (1987–2012)
EPA, Executive Yuan (2012b) Review and prospect of 25 years of environmental protection
EPA, Executive Yuan (2012c) White paper on environment
EPA, Executive Yuan (2013a) Annual report on statistics of environmental protection
EPA, Executive Yuan (2013b) Environmental quality data storage system; global information network
Houng H (2008) Zero waste—waste management and regulations, sustainable development of resources and environment in Taiwan. Health, Welfare and Environment Foundation, pp 122–143. ISBN: 978-986-82147-5-0
Houng H et al (2013) Electronic tracking and management of industrial waste in Taiwan. J Mater Cycles Waste Manag 15(2):146–153
Ma HK (2010) A zero zaste policy for establishing a sound WEEE material-cycle society in Taiwan. In: 5th world recycling forum WRF 2010, international conference and exhibition on electronics, battery and car recycling, Hong Kong
Ma HK et al (2009) Evaluation o municipal solid waste reduction and recycle on pay-by-bag trash collection policy and pay-by-household water usage trash collection policy, EPA-97-H103-02-124, EPA, Executive Yuan