ECOVE

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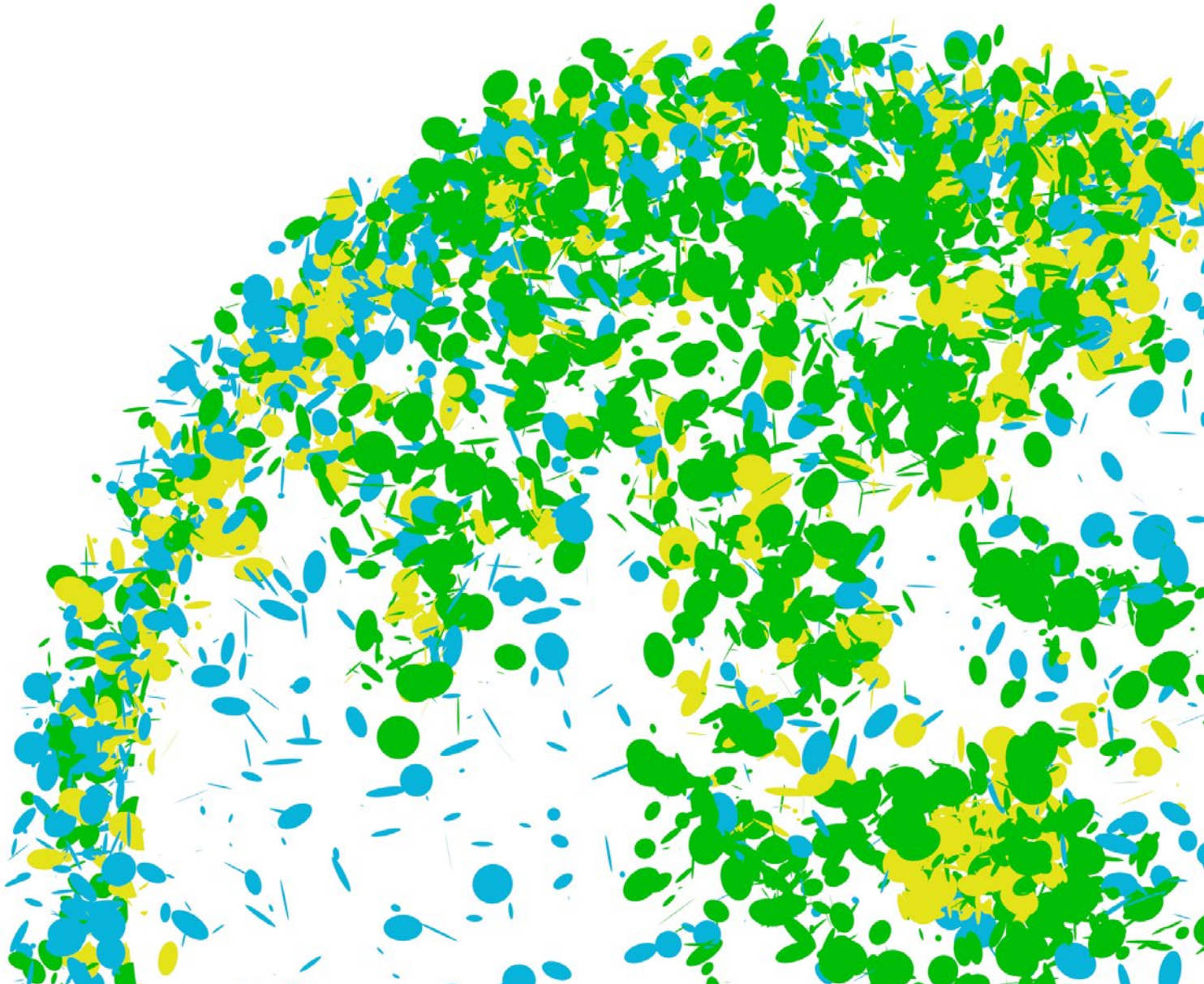
Energy-from-Waste:

A Practical and Efficient Solution to the Global Waste Crisis

A Case Study from Taiwan



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Executive Summary

The United Nations predicts the global population will increase by over two billion people by 2050,[1] while the urban population is predicted to increase by a third by 2025.[2] The majority of this population growth is expected to be concentrated in developing countries, where dramatic increases in population will put further strain on governments' ability to deal with municipal waste. Developing countries allot less than five percent of the waste management budget for waste treatment and disposal, resulting in an overwhelming majority of waste disposed of without treatment, threatening water and air quality, exacerbating the risk of flooding, increasing the spread of disease, and degrading ecosystems.

Using the waste management transformation in Taiwan as a case study, this white paper recommends energy-from-waste (EfW) technology to solve the waste management crisis in developing countries. Critics of EfW claim it undermines recycling programs and emits dangerous pollutants into the atmosphere; however, there is little tangible evidence to support this claim as, 1) the countries with the highest rates of recycling also utilize EfW technology for nearly 100 percent of non-recyclable waste, and 2) negative effect of emissions from EfW facilities are negligible, as advanced pollution control technologies keep emissions as much as 100 percent below emissions standards.[3]

Waste incineration offers the following benefits:

1. An effective solution to waste management, as it is able to safely and responsibly treat waste regardless of the degree of separation.
2. Increased land availability, by opening up land that would have otherwise been designated for use as an open dumpsite or landfill.
3. Reliable renewable energy through waste combustion, providing a continuous supply of baseload electricity.
4. Reduction in global greenhouse gas emissions by preventing methane and carbon dioxide emissions from landfills, and by offsetting carbon emissions from conventional power plants that use fossil fuel combustion to generate electricity.
5. Material recovery and bottom ash recycling, creating additional revenue base from the collection and resale of metals and recycling bottom ash for aggregate materials.

According to these benefits and to the Taiwanese case, we offer the following recommendations for governments in the process of improving waste management programs:

1. Seek an effective solution to waste management

EfW efficiently recovers energy from waste, regardless of a population's ability to properly separate out compost and recyclables. EfW is a mature technology used by industrialized countries across the world, and can easily be replicated in nations in the beginning stages of effective waste management. We recommend nations avoid diverting valuable resources towards less established waste treatment programs (such as gasification and pyrolysis), instead adopting mature technologies that have already proven to be effective waste management solutions.

2. Choose a responsible EfW company to aid in transition

We recommend governments judge EfW companies based on their financial stability and their reputation in the EfW industry, in terms of years of experience, technology, and ability to cooperate with governments and communities. Additionally, governments seek an EfW company that has experience operating under conditions similar to the host country, both in terms of climactic/geographic conditions and also waste composition types, to ensure waste is properly treated in case of extreme climactic conditions or natural disasters.

3. Create the conditions for technology transfer

Governments should make an effort to import technology from abroad while also supporting nascent EfW industry. Ensure locals are employed

at the original facilities established by international companies. Allow the chance for local companies to develop by opening a national tender, encouraging joint ventures with foreign companies that excel in operations and maintenance to allow for technology transfer.

4. Implement effective education programs

Work closely with the community to explain the positive benefits of incineration technology, including sponsoring tours to international EfW plants, implementing rebate packages for communities that agree to host an EfW plant, and equipping all EfW plants with a viewing platform and visiting facilities. Arrange tours to local EfW plants for elementary school children and government officials to create awareness about EfW technology.

5. Focus on long-term savings

Despite the high installation cost, waste incineration results in long-term net savings. Waste incineration can generate revenue by generating electricity, recovering sellable materials, recycling bottom ash, and diverting land from use as sanitary landfills. One study estimates that a waste management policy dominated by waste incineration could generate an additional €2 million (USD 2.3 million) in revenue over a duration of 20 years.[4]

1 United Nations Department of Economic and Social Affairs. (2015) World Population Prospects: The 2015 Revision.

2 World Bank. 2012. “What a Waste”

3 At ECOVE’s Zhunan EfW plant in Taiwan, NOx, SO_2, CO and HCl emissions were recorded at 54 percent, 0.04 percent, 8.3 percent, and 34 percent of regulated emissions levels, respectively.

4 Tang. 2012.

Introduction

The United Nations predicts the global population will increase by over two billion people by 2050,[1] while the urban population is predicted to increase by a third by 2025.[2] The majority of this population growth is expected to be concentrated in developing countries, where dramatic increases in population will put further strain on governments' ability to deal with municipal waste.

A large fraction of waste in developing countries is not collected from populated areas, leaving the task of handling waste to individuals through uncontrolled open burning or dumping in water bodies such as rivers, streams, or drainpipes. In the case that waste is collected, the overwhelming majority is disposed of at uncontrolled dumpsites without treatment. Mismanaged waste has created a public health crisis—as the urban population and their incomes continue to expand, waste generation will continue to increase, further exacerbating an already serious issue.

As Taiwan's economy sky-rocketed in the 1970s and 1980s, the dregs of development silently amassed into massive "garbage mountains" decorating the sides of highways, mountain valleys, and riverbanks and thickening the Tamsui River into a black sludge, earning it the nickname "Black Dragon River". Taiwan's garbage crisis reached such massive proportions as to earn it an international reputation as a "Garbage Island". In just 30 years, Taiwan not only toppled its garbage mountains and removed the festering waste from the Black Dragon River, it has also become one of the world's leaders in recycling and recycling technology. Taiwan boasts a 58 percent recycling rate,[3] including compost and bulk waste, and deposits a mere 1.4 percent of its waste in sanitary landfills.[4]

Through the lens of the global waste crisis, this white paper will explore the success of Taiwan's waste management program, intended for governments seeking a practical, effective and responsible solution to waste management.

1 United Nations Department of Economic and Social Affairs. (2015) World Population Prospects: The 2015 Revision.

2 World Bank. 2012. "What a Waste"

3 Taiwan Environmental Protection Agency (TEPA). Linian gonggao ying huishou feqiwupin ji rongjiliang tongji 歷年公告應回收廢棄物品及容器回收量統計 [National Report on Statistics on Recycled Products and the Recycling System]. Taipei, Taiwan, 2016.

4 Taiwan Environmental Protection Agency (TEPA). Lese chansheng liangan fangshi fen 垃圾產生量按處理方式 [Waste Management Methods]. Taipei, Taiwan, 2015.

The Global Waste Crisis

The consequences of mismanaged waste

The Global Outlook

Waste Collection

Waste management represents the largest cost for municipalities in developing countries. The majority of the budget is spent on waste collection and street sweeping, with just a fraction allotted for final disposal.[1] Despite this, waste collection rates range from below 50 percent to no more than 80 percent.[2] Inefficient waste collection negatively impacts local living conditions, causing public health and environmental problems.

Designated Waste Collection Sites

Due to the relatively low implementation cost, many municipal governments implement a "curbside pick-up system", appropriating certain streets and street corners to act as waste collection sites for local residents. In this approach, residents deposit their waste directly on the street at designated locations. Waste trucks are scheduled to collect the waste with varying frequency; however, waste collection frequency is not consistent, causing waste to accumulate at the designated waste sites for extended periods of time. While the monetary cost is low compared to other systems, the environmental and health costs are comparably high.

Water pollution and flooding

One of the biggest concerns for mismanaged waste is water pollution. When rainwater percolates through the waste, it creates an output liquid referred to as "leachate". The composition of leachate, and the corresponding negative and health effects, varies based on the content of the waste. Unsorted waste containing hazardous municipal waste such as batteries, lightbulbs, and, increasingly, e-waste, can result in leachate containing traces of mercury and lead.[3] If this dangerous form of leachate invades groundwater or aquifers used for drinking water or irrigation, it can inflict major harm on the population.[4]

In case of heavy rainfall, excess waste can be pushed into storm drains, causing blockages and exacerbating the risk of flooding in already flood-prone areas. Clogged drains also cause long expanses of water to remain stagnant, creating breeding grounds for mosquitoes and increasing the risk of mosquito-borne diseases such as malaria and dengue fever.[5]

Increased risk of disease

Large piles of unattended garbage attract vermin such as rats and flies, increasing the risk of spreading bacterial, viral and parasitic diseases.[6] Indeed, according to surveys conducted by UN-Habitat, the incidence of diarrhea is twice as high and acute respiratory infections six times higher in areas with large masses of accumulated waste, compared to areas where waste collection is frequent.[7] This problem is exacerbated in areas with high temperatures, as the breeding rate of flies is exacerbated by high temperatures.[8]

Container System

In this system, waste containers are placed at designated locations. Residents can dump their waste in these containers at their own convenience, and waste collection trucks will empty the waste containers with varying frequency. If implemented correctly, container systems can alleviate many of the aforementioned negative effects of dumping waste at designated waste collection sites—by reducing the amount of litter discarded directly on the street, it will lower the risk of drinking and irrigation water being contaminated by leachate, the spread of disease, and the risk of flooding due to blocked drains. The containers also reduce odor and unsightliness.

Even when street containers are installed in place of open dumping at designated sites, if the street containers are deemed inconvenient or difficult to use, locals often dispose of their trash adjacent to street containers rather than inside. Piles of trash surrounding street containers give users who come later an added disincentive to deposit their waste inside of the container. This negative feedback loop can result in a large mass of garbage surrounding

the containers, causing the same negative health and environmental effects as are mentioned in the previous section.

Waste Disposal

After waste is collected from the city, it is transported for final treatment and disposal. Over 90 percent of the waste management budget in developing countries is allotted for waste collection; as a result, the overwhelming majority of waste in developing countries is disposed of at open dumpsites located within and in close proximity to municipalities, receiving zero to minimal treatment.[9] Open dumpsites put soil and water at greater risk for contamination and are also responsible for aggravating respiratory problems due to toxic air emissions released during uncontrolled burnings. Allocating land for use as open dumpsites diminishes the value of land and surrounding environment, reducing economic and agricultural development opportunities, and destroying the natural ecosystems.

Water Pollution and Land Degradation

Hazardous municipal waste, including lightbulbs, batteries, and e-waste, is rarely removed from the solid municipal waste stream in developing countries, usually disposed of at open dumpsites without treatment. Leachate generated from waste containing these toxic materials can contaminate groundwater and aquifers. If leachate containing heavy metals such as lead or mercury intrudes on drinking water or irrigation sources, it can cause a number of public health problems including cancer, kidney and liver diseases, or neurological damage.[10] For example, an open dumpsite in Guanghan, China caused skin diseases in farmers working in the field and contaminated the soil to a degree that rendered the harvest completely inedible.[11]

Leachate containing a high concentration of nitrogen, as is the case of a high concentration of organic waste, causes an acidifying or eutrophying effect on soils and water bodies, respectively.[12] The resulting nutrient-poor soils and oxygen-depleted water bodies can be devastating for those whose livelihoods rely on farming or fishing. Contaminated soil and water poisons agricultural land and natural ecosystems, requiring decades to be restored to their original states.

Air Pollution

Waste disposed of at landfills and open dumpsites account for almost five percent of total greenhouse gas emissions.[13] Furthermore, excess methane emitted at open dumpsites can result in spontaneous fires at the dumpsite, emitting toxic fumes into the air. Individuals may also purposely set fires in order to increase available space to dump garbage or to more easily find non-combustable materials such as glass and metal to collect for sale. Open burning both at open dumpsites and also within municipal areas is responsible for high levels of dioxins and furans, carbon monoxide (CO), particulate matter (PM) and hydrocarbons (HC). In Mumbai, open burning contributes to 20 percent of air pollution due to PM, CO, and HC.[14]

Taiwan's Dirty Past

Waste Collection

Before Taiwan began to think seriously about its waste management system, Taiwan's Sanitary Department appropriated certain streets as waste deposit sites. Taiwanese would throw their waste directly onto the street at these designated locations, where waste collection trucks would routinely collect the waste. In order to improve sanitation and reduce the risk of flooding, Taiwan set up waste containers to replace open dumping on the street; however, this did very little to improve the sanitation level.

Attributing the problem to a lack of monitoring, government officials changed the system to one that ensured waste professionals were present to ensure proper waste disposal etiquette, introducing a fleet of musical garbage trucks to its streets. These trucks follow designated schedules and routes, serenading residents with classics such as Badarzewska's "A Maiden's Prayer" to notify them it is time to bring out the trash. This new system significantly reduced the amount of litter in public areas.

Waste Disposal

After Taiwan's economic boom in the 1970s and 1980s, the government began to find it difficult to safely manage the huge mass of waste that had accumulated alongside GDP. At that point in time, the majority of waste was haphazardly collected and

dumped on public lands, including on river banks, alongside highways, at national cemeteries or in mountain valleys. At the time of the first official waste policy in 1984, only 2.4 percent of total waste was treated before disposal.[15] Open dumping caused major health and environmental problems across Taiwan. The methane releases from open dumpsites both increased global GHG emissions, intensifying the effects of climate change, and also caused open dumpsites to spontaneously combust, releasing dangerous pollutants into the atmosphere. The fumes from open burning contained high amounts of particulate matter (PM), carbon monoxide (CO), hydrocarbons (HC) and PCBs (dioxins/furans), aggravating already serious public health outcomes of poor air quality.

As Taiwan's economy improved, the Taiwanese environmental movement also began to strengthen in response to the negative environmental effects spawned in the wake of development. This new wave of environmentally-concerned citizens demanded regulations to improve sanitary conditions and air and water quality. Partly in response to this pressure, the government passed the Municipal Solid Waste (MSW) Disposal Plan in 1984. In designing this plan, the government set its short-term goals on solving the immediate negative consequences of open dumping, namely poor sanitary conditions and high level of air and water pollution. Accordingly, the six year plan lay an immediate focus on sanitary landfills, and a long-term focus on thermal waste treatment plants.

Sanitary landfills mitigated the negative environmental consequences of open dumping. In order to reduce the risk of ground water contamination, a plastic sheet is placed at the bottom of the landfill. Leachate is then collected and treated. After each deposit of waste, the site is covered with a layer of dirt to reduce the propagation of the vermin population and the subsequent spread of disease. Increased regulations also prevented purposeful burning of waste, thereby reducing the release of dangerous toxins. In order to encourage municipalities and provinces to replace open dumping with sanitary landfills, the central government provided generous subsidies—between one and two thirds of the total cost. By 2007, 100 percent of waste in Taiwan was treated in either sanitary landfills or energy-from-waste facilities, compared to just 2.4 percent of waste in 1984.[16]

While the proliferation of sanitary landfills offered a definite improvement to open dumping, it did not provide an absolute solution to waste management in Taiwan. First, there was still a chance that the protective layer at the bottom of the landfill would rupture, allowing leachate to flow into the soil. Additionally, landfills represent the third largest anthropogenic source of methane, a a greenhouse gas 34 times more potent than CO_2 as a driver of climate change over a 100-year period.[17] Most importantly, especially for Taiwan, a comprehensive sanitary landfill policy is intrinsically unsustainable, as it requires an unlimited supply of land. The limits to land are acutely felt in Taiwan—a nation with a central mountain range covering two thirds of the total area, restricting 23 million Taiwanese to an area about the size of Qatar.

> ***"If solving a problem creates another problem, that's not a real solution. Sanitary landfills moved the "garbage mountains" underground, sacrificing arable land. In Taiwan, the limited nature of land was very potent—if we continued to fill our land with garbage, we wouldn't have any land left to live on."***
>
> — 夏家承，*Former National Development Committee Member*

1 World Bank. 2012. “What a Waste”

2 World Bank. 2012. “What a Waste”

3 Mor, Suman, Khaiwal Ravindra, R. P. Dahiya, and A. Chandra. “Leachate Characterization and Assessment of Groundwater Pollution near Municipal Solid Waste Landfill Site.” Environmental Monitoring and Assessment 118, no. 1–3 (2006): 435–56.; Chonattu, Jaseela, Kavya Prabhakar, and Harikumar Puthenveedu Sadasivan Pillai. “Geospatial and Statistical Assessment of Groundwater Contamination Due to Landfill Leachate—A Case Study.” Journal of Water Resource and Protection 8 (2016): 121–34.

4 Tang, Jiao.“A Cost-Benefit Analysis of Waste Incineration with Advanced Bottom Ash Separation Technology for a Chinese Municipality- Guanghan.” Master’s thesis, University of Vienna, 2012.

5 World Bank. 2012. “What a Waste”

6 For example, plague, murine typhus, diarrhea, dysentery, rabies, typhoid fever, salmonellosis, cholera, malaria, yellow fever, dengue fever, among others (UN Habitat. 2010. “Solid Waste Management in the World’s Cities.”)

7 UN Habitat. 2010. “Solid Waste Management in the World’s Cities.”

8 UN Habitat. 2011. “Collection of Municipal Solid Waste, Key Issues for Decision-Makers in Developing Countries.”

9 World Bank. 2012. “What a Waste”

10 Collin, Robert William. Trash Talk: An Encyclopedia of Garbage and Recycling around the World. Santa Barbara, California: ABC-CLIO, 2015.

11 Tang, Jiao.“A Cost-Benefit Analysis of Waste Incineration with Advanced Bottom Ash Separation Technology for a Chinese Municipality- Guanghan.” Master’s thesis, University of Vienna, 2012.

12 United Nations Environment Program. 2013. “Guidelines for National Waste Management Strategies”.

13 World Bank. 2012. “What a Waste”

14 Annepu, Ranjith Kharvel. “Sustainable Solid Waste Management in India.” Master’s thesis, Columbia University, 2012.

15 Taiwan Environmental Protection Agency (TEPA). “Lese Fenhuachang Xingjian yingjun jishi” 垃圾焚化廠興建營運紀實 [A Record of Waste Incineration Plant Construction and Operation]. Taipei, Taiwan, 2003.

16 Taiwan Environmental Protection Agency (TEPA). “Daxing lese fenhuachang caozuo yingyun qingxing” 大型垃圾焚化廠操作營運情形. [The Situation of Large-scale Waste Incineration Plant Operation and Maintenance]. Taipei, Taiwan, 2017.

17 IPCC 5th Assessment Report. 2013.

A Comprehensive Waste Treatment Solution

Energy-from-Waste

What is Energy-from-Waste (EfW)?

In this paper, EfW refers to the thermal waste treatment process that recovers energy from waste products.[1] Unlike conventional power plants that burn fossil fuels such as coal or natural gas to generate electricity, EfW facilities serve the dual purpose of treating waste and generating electricity. Waste is continuously fed onto a moving grate in a furnace where it is burned at temperatures over 850 °C, directing generated heat through boilers to create steam that drives a turbine and produces electricity. Extensive air pollution control systems ensure the exhaust emitted from EfW facilities comply with regulatory emission limits before being released into the atmosphere.

Misconceptions about EfW

Waste incineration causes dangerous levels of air pollution

Many people associate waste combustion with open burning that emits thick plumes of toxic smoke. While burning waste in an uncontrolled setting at low temperatures does cause serious air pollution, modern waste incineration technology employs advanced pollution control methods to safely and responsibly treat waste. Waste is continuously burned at extremely high temperatures, allowing no more than two seconds of burning below 850 °C, to ensure continuous combustion and reduce dioxin emissions. The flue gases (the term for exhaust emitted by incineration facilities) are treated to remove oxides of nitrogen and sulfur, mercury, dioxins and furans, and acid gases. The air stream is further passed through a filter to remove particulate matter. Each EfW plant closely monitors emissions to ensure air quality standards are maintained.[2] In 2012, dioxin emissions from all Energy-from-Waste plants in the United States totaled around 3 grams for the entire year, compared to landfill fires which released a total of 1,300 grams, representing a respective 0.09 percent and 36.78 percent of total[3] national dioxin emissions.[4] Indeed, in the United States more dioxins are released from home fireplaces and backyard barbecues than from waste incineration.[5]

> ***"Sanitary landfills occupied a large area of space, making it difficult to control. Incineration was much easier to control—we just had to focus on different "points", if we had the technology to treat air emissions and treat the ash, we didn't have much else we needed to worry about. It was much easier to control"***
>
> — 鄭顯榮，*Former Director of the Waste Management Division, Taiwan Environmental Protection Agency*

Waste incineration undermines recycling efforts

Many recycling advocates are opposed to EfW technology, assuming that EfW counters efforts to increase recycling by rendering recyclable materials useless through high temperature combustion. This assumption is incorrect for a number of reasons. First, any materials burned during waste combustion are not wasted; rather, their caloric content is recovered to generate heat and electricity. Second, EfW does not work against recycling efforts; on the contrary, EfW and recycling work hand-in-hand to improve a country's waste management policy. As waste separation becomes more advanced, waste moisture content decreases and electricity generation at EfW facilities becomes more efficient. In Taiwan, from 1992 to 2016, per capita waste generation decreased to under 0.5 kg per person and the recycling rate increased to nearly 70 percent (including bulk waste recycling and composting). During the same period, electricity generation became 30 percent more efficient. Indeed, countries with the most advanced waste recycling programs (i.e. Taiwan, Germany, Japan,

South Korea, Austria, and Sweden) also use EfW thermal combustion to treat nearly 100 percent of non-recyclable waste. The United States, on the other hand, has a recycling rate that has hovered a bit above 30 percent—one of the lowest rates among industrialized countries—since the early 2000s and relies on sanitary landfills to dispose of over half its waste.[6] Energy was recovered from only 12.8 percent of total waste using waste incineration.[7] This is not to suggest that EfW causes increased recycling rates; instead, this demonstrates that recycling and EfW facilities work together to responsibly manage waste.

Benefits

1. Offers an effective solution to waste management

Many governments prefer to manage waste using sanitary landfills or open dumpsites, partly because waste can be disposed of without undergoing extensive waste separation. Similarly, EfW plants can process all types of municipal solid waste, offering an effective solution to waste treatment. As waste management infrastructure improves, recycling and composting programs can develop alongside an already mature EfW system, allowing developing countries to increasingly recover value from disposed resources.

2. Increases land availability

Sanitary landfills require extensive land to operate. In just twenty years, Taiwan allotted 732 hectares of land to be used for waste disposal, enough land to grow 4,596,960 kg of rice.[8] Land used as sanitary landfills requires hundreds of years to completely recover. Recent efforts to convert former landfills into parks and recreation centers are admirable, but are also expensive. For example, the Taiwanese government spent TWD 220 million (USD 7.3 million) to transform the Shanzhuku Sanitary Landfill—an area of just 65 hectares—into an ecological park.[9] EfW facilities are able to reduce waste volume by over 90 percent, significantly reducing the demand for landfills, and opening up land for more productive uses.

3. Provides reliable renewable energy

Renewable energy such as wind and solar depend on fluctuations in natural flows of energy in order to generate electricity. WtE technology, on the other hand, provides a non-intermittent electricity source, continuously combusting waste products to generate electricity and supplementing renewable energies with base load electricity. As such, EfW technology also reduces dependence on imported fossil fuels. In 2016, Taiwanese EfW facilities generated over 250,000 MWh of electricity[10], enough to offset the combustion of 85,040 metric tons of coal[11] and supply nearly 70,000 households with renewable energy.[12]

4. Reduces global greenhouse gas emissions

Sanitary landfills aggravate the already serious effects of climate change, releasing an approximately equal amount of carbon dioxide and methane. Indeed, the decomposition of municipal waste in landfills is recognized as one of the largest sources of global anthropogenic methane emissions, a greenhouse gas 34 times more potent than CO_2 as a driver of climate change over a 100-year period.[13] Treating waste in EfW facilities rather than sanitary landfills can offset the carbon dioxide and methane emissions that result from sanitary landfills, even when technologies to capture landfill gas are installed.[14]

Furthermore, the electricity produced by an EfW plant displaces electricity that would otherwise be provided by nuclear or fossil fuel powered power plant. Because most utility power plants burn fossil fuels and emit CO_2, the electricity produced by an EfW plant reduces CO_2 emissions. Additionally, EfW facilities recover materials such as iron and glass. Processes that use recycled inputs require less energy than processes using virgin inputs, resulting in further reduction of greenhouse gas emissions.[15]

5. Allows for bottom and fly ash recycling and material recovery

After waste has been completely combusted, 10 percent of the original volume is retained in the form of fly and bottom ash, which can be recycled to create aggregate material. In Taiwan, incinerators produce a yearly average of 8 to 10 million tons of sludge, which can be used to pave roads—road repair and construction demands an estimated 10 to 43.8 million tons of sludge annually.[16] As such, incinerators can provide anywhere from 20 to 100

percent of the yearly demand for road building and repair material, saving an estimated 10 percent of total construction cost.[17]

Bottom ash also contains metals—including iron, aluminum, copper, zinc, lead, gold and silver—that can be recovered for additional income. In a study performed at the KEZO plant in Switzerland, it was discovered that an additional €38.55 (USD 45.49) of revenue could be generated per ton of waste processed. At a large-scale facility with a capacity to process 900 tons of waste per day, this totals an additional daily revenue of €34,651 (USD 40,892). While waste composition in developing countries contains relatively small amounts of metal compared to Switzerland, a study conducted on material recovery potential in China finds the potential to generate over €2 million (USD 2.3 million) from recovered aluminum, copper, and iron over a 20-year period, using 2012 waste composition data and price.[18]

1 Energy can be recovered from waste from various different technologies, including combustion, pyrolysis/gasification, and anaerobic digestion. When this paper refers to "EfW", it is referring only to energy recovered from waste through combustion.

2 At ECOVE's Zhunan EfW plant in Taiwan, NOx, SO_2, CO and HCl emissions were recorded at 54 percent, 0.04 percent, 8.3 percent, and 34 percent of regulated emissions levels, respectively.

3 Total dioxin emissions in the United States from controlled and uncontrolled sources was 3,535 g TEQ in 2012. Landfill fires emitted 1,300 g TEQ; EfW facilities emitted 3 g TEQ. (Dwyer, Henri, and Themelis, Nickolas J. "Inventory of U.S. 2012 Dioxin Emissions to Atmosphere." Waste Management 46 (2015): 242–46.)

4 Dwyer, Henri, and Themelis, Nickolas J. "Inventory of U.S. 2012 Dioxin Emissions to Atmosphere." Waste Management 46 (2015): 242–46.

5 Dwyer, Henri, and Themelis, Nickolas J. "Inventory of U.S. 2012 Dioxin Emissions to Atmosphere." Waste Management 46 (2015): 242–46.

6 United States Environmental Protection Agency (US-EPA)."Advancing Sustainable Materials Management: 2014 Fact Sheet". 2016.

7 United States Environmental Protection Agency (US-EPA). "Advancing Sustainable Materials Management: 2014 Fact Sheet". 2016.

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9 Taiwan Environmental Protection Agency. "Shanshuilü shengtai gongyuan" 山水綠生態公園" [Shanshuilu Ecological Park]. 2013.

10 Taiwan Environmental Protection Agency (TEPA)."Daxing lese fenhuachang caozuo yingyun qingxing" 大型垃圾焚化廠操作營運情形. [The Situation of Large-scale Waste Incineration Plant Operation and Maintenance]. 2017.

11 United States Environmental Protection Agency. "Greenhouse Gas Equivalencies Calculator". 2016.

12 Taiwan Power Company. 2016. "Jingying shiji" 經營實績 [Record of Operations].

13 IPCC 5th Assessment Report. 2013.

14 United States Environmental Protection Agency."Solid Waste Management and Greenhouse Gases: A Life-Cycle Assessment of Emissions and Sinks." 2006.

15 United States Environmental Protection Agency. "Solid Waste Management and Greenhouse Gases: A Life-Cycle Assessment of Emissions and Sinks." 2006.

16 Taiwan EPA. "Zhuanlushi ji dizha xunhuan liyong guihua" 轉爐石及底渣循環利用規劃. [Slag and Bottom Ash Recycling and Reuse Plan]. 2017.

17 Taiwan EPA."Zhuanlushi ji dizha xunhuan liyong guihua" 轉爐石及底渣循環利用規劃. [Slag and Bottom Ash Recycling and Reuse Plan]. 2017.

18 Tang, Jiao. 2012. "A Cost-Benefit Analysis of Waste Incineration with Advanced Bottom Ash Separation Technology for a Chinese Municipality- Guanghan." Technical University of Vienna.

Key Recommendations for Governments

Seek an effective solution to waste management

Developing the infrastructure and bureaucracy of successful waste management programs is a highly monetary-intensive process. In order to reduce the risk of failed projects, we recommend developing countries adopt technologies that have been proven to successfully manage waste in industrialized countries and offer an effective solution to waste management.

As developing countries are largely agricultural-based and generate waste containing a relatively high amount of organic waste, technologies such as gasification and pyrolysis are touted as an ideal solution, as they simultaneously capture methane from decomposing organic waste and create fertile compost for use in agriculture. We suggest developing countries avoid these alternative waste treatment solutions for two main reasons. First, these technologies fail to offer a comprehensive solution to waste management, as they are only able to process organic waste, requiring alternative treatment facilities for other waste products such as glass, metal and plastic. Second, these technologies can only be successful serving a population with a strong ability to properly separate waste.

When Taiwan first implemented its EfW policy, the waste separation rate in Taiwan was dismally low, recycling under six percent of waste in 1998.[1] The overwhelming majority of waste consisted of organic waste, resulting in a high moisture content and low caloric value of waste. Failure to separate non-combustable waste such as metal and glass also decreased the caloric value of waste. At the time, Taiwan was under considerable pressure to establish recycling programs similar to those found in European countries (See: Alien Babies Crash in Taiwan). Indeed, many advocates promoted the idea of establishing comprehensive recycling programs to replace EfW facilities altogether. Instead, Taiwan developed recycling and EfW policies simultaneously. This approach was wildly successful—as Taiwanese began separating metal, glass, paper, plastic, and food waste from non-recyclable waste, Taiwan's daily waste generation dropped dramatically. At the same time, the caloric value of the remaining waste rose, allowing for more efficient electricity generation. As of 2017, Taiwan's nationwide recycling rate was nearly 58 percent, including composting and recycling bulk waste,[2] generating electricity as much as 30 percent more efficiently in 2017 as they did twenty years ago.[3]

EfW offers a waste management method that allows countries to safely and responsibly dispose all types of waste, while recycling and composting programs offer no solution to non-recyclable and non-compostable waste. As developing countries look to improve their waste management policies, we suggest recycling and composting technologies develop alongside EfW programs, rather than replace it.

> ***"We took a rational, professional point-of-view to solve the problem. We took technologies that were successful in other countries and adapted them to the Taiwanese condition, rather than testing out new technologies that hadn't been fully developed yet. Our priority was to find the most suitable way to solve the problem—and that's what we did."***
>
> — 夏家承, *Former National Development Committee Member*

Alien Babies Crash in Taiwan

Responding to increasing pressure to implement a recycling program of a similar caliber to those found in European companies, Taiwan imported a program from the Netherlands to encourage waste separation, locally referred to as wàixīngbǎobǎo, which translates as Alien Babies. The Alien Babies came in four different colors, each color representing a certain kind of waste—glass, aluminum/tin, plastic, and paper. However, Taiwan retracted this program not long after its introduction. It failed for three main reasons: 1) The Alien Babies were quite large and took up a lot of space, 2) The Alien Babies greatly strained the municipal budget, and 3) Neither the general population nor waste management employees had a good understanding of proper waste separation, resulting in a relatively low actual recycling rate.

Instead of developing a program around the needs of Taiwanese society, Taiwan imported technology from the Netherlands—a comparatively spacious country, populated by the environmentally-conscious and recycling-savvy Dutch—resulting in a program just as expensive as it was ineffective. Taiwan quickly dismantled the program, instead gradually developing a recycling system internally.

Taiwan's recycling program officially began in 1988, implementing a privatized system characterized by Extended Producer Responsibility, whereby manufacturers and importers formed associations to take further responsibility for their products by establishing and funding recycling programs.[1] Due to minimally enforced regulations and an over-abundance of organizations in operation, Taiwan nationalized the system, now referred to as the "4-in-1 Recycling Program". Based on the same concept of tying production to disposal, manufacturers and importers pay into the Recycling Fund, which subsidizes resource collection and recycling.

The Taipei and New Taipei municipal governments took these regulations one step further. Beginning in 2003 and 2005, respectively, all non-recyclable waste was required to be disposed of in relatively more expensive government-certified plastic bags. In accordance with article 50 of the Waste Disposal Act, anyone who attempts to circumvent the regulations can face fine ranging from NTD 1,200 to NTD 6,000 (USD 40-200), or are sometimes caught on surveillance camera and broadcast on local television. A high cost of the government-certified garbage bags, a hefty fine, and fear of public shaming work together to provide a strong incentive toward proper recycling and have contributed to Taipei and New Taipei's respective 68 percent and 65 percent recycling rate[2], compared to a nationwide recycling rate of nearly 58 percent (including composting and recycled bulk waste).

1 Recycling Fund Management Board (2017) Resource Recycling: Evolution of the System

2 Taiwan Environmental Protection Agency "Lese Qingyun Zhuangkuang" 垃圾清運狀況 [The Status of Waste Collection and Treatment]. 2016.

Implement effective education programs

Even though EfW plants offer a clean and efficient solution to waste management, especially when compared to sanitary landfills, many people equate "waste incineration" with open burning of waste. While open burning does give off dangerous emissions containing high levels of emissions (such as carbon monoxide, particulate matter, hydrocarbons, and dioxin and dioxin-like compounds), modern garbage incineration facilities are equipped with pollution control technologies that ensure air quality standards are well below regulated standards[4] (See section: 3.2: Misconceptions about EfW).

When the Taiwanese government began to actively promote its plan to transition to EfW technology, it received forceful pushback from Taiwanese citizens, who still associated waste incineration with landfill fires. Throughout the duration of construction and installation of EfW facilities, groups of concerned citizens across Taiwan actively protested the construction of incinerators in close proximity to their homes. The government dealt with this strong opposition in several ways.

First, the government arranged for influential members of opposition movements to visit the EfW plants in Japan. In doing so, these opposers were able to clearly understand the positive impact EfW plants could have on Taiwanese society, and transmit this knowledge back to their communities. Second, the government provided rebate packages to districts that agreed to construction of a EfW plant. The rebate packages varied by district, offering a set monetary amount per ton of garbage processed at the local incineration plant.[5] These packages are used to subsidize local infrastructure, including parks and recreation centers, exercise facilities and swimming pools, and can also be used to subsidize residents' utility bills. Finally, the government implemented a nation-wide educational program aimed at teaching elementary school students about EfW technology and proper waste habits. Incinerators in Taiwan are equipped with a viewing platform, allowing students and government officials to visit the facility. Environmental education facilities are staffed by professionals that teach students about the importance of waste reduction and waste separation, while also explaining the important service EfW technology provides to society, allowing for an influential platform for governments to relay important environmental information to the general public.

By implementing an effective environmental education system, resistance to waste incineration has greatly diminished. We suggest governments ensure each facility is equipped with a viewing platform, visiting facilities, and environmental education platforms in order to promote transparency and build awareness of the positive effects of energy-from-waste.

Encourage technology transfer and nascent industry

Unlike sanitary landfills, which can be constructed by local companies using relatively simple technologies, EfW facilities depend on patented technology and equipment imported from industrialized countries. In the 1970s, Taiwan had quickly entered a deal with a Japanese company to build an incinerator in Taiwan; however, due to poor technology and lack of capital, the project ended in failure and stained the concept of incineration in the minds of Taiwanese citizens (See: Ankang). As the Taiwanese government planned its first modern incinerator, it wanted to ensure it would be constructed up to international standards and equipped with all the necessary pollution control equipment and electricity generation technology. Additionally, Taiwan hoped to balance international technology with nascent EfW industry.

To gain access to international technology, Taiwan first opened an international tender, establishing a public-private partnership between two Japanese companies to construct Taiwan's first two modern incinerators. These Japanese companies were required to employ Taiwanese workers, giving Taiwanese an opportunity to work alongside skilled and experienced technicians and gain skills in proper operations and maintenance. To help further develop Taiwan's domestic EfW industry, Taiwan opened a national tender for the construction of its third EfW plant.

The Taiwanese workforce at Xindian, Taiwan's first modern waste incineration plant, established their own company—present-day CTCI[6]—to bid on the construction of new incinerator. In order to acquire foreign patented technology and gain credibility, CTCI formed a joint venture with a German company (MARTIN GmbH), eventually winning the bid to construct Taiwan's third EfW plant. Thereafter, Taiwanese companies were able to independently construct and operate EfW plants,[7] without relying on technology from their foreign counterparts.

Ankang

A lesson in proper planning

Ankang was Taiwan's first incinerator, built in the 1970s under the Taiwanese Provincial Government in an attempt to step into modernity. At the time, almost no garbage was treated before final disposal—most garbage was deposited along river beds, in mountain valleys, in public cemeteries, and on other public land. Despite good intentions, this incinerator proved to be disastrous in practice. However, Taiwan was able to learn some valuable lessons from the experience, and applied these lessons to future development of its waste management policy.

The Taiwanese government carelessly chose a foreign company to assist them in designing and constructing the Ankang incinerator. Instead of opening an international tender and choosing a company with extensive experience designing, constructing, and operating waste incineration facilities, Taiwan chose a Japanese company specializing in crematoriums.

As a result, the Ankang incinerator was poorly designed and implemented, operated by technicians with little background in large-scale waste incineration. The Ankang incinerator spewed black, toxic fumes into the air, leaving a negative impression of waste incineration in the minds of nearby residents. Unlike modern incineration facilities that continuously burn refuse at a temperature above 850 °C to ensure safe emissions, the Ankang facility only operated for eight hours per day—too little time for the incinerator to reach 850 °C.

When Taiwan began to re-assess its waste management policies, the government ensured the foreign companies responsible for handling design and construction were established waste incineration companies. These incineration companies employed

Taiwanese workers to help operate these facilities, allowing for incineration technology to transfer into Taiwan. Taiwanese companies are now some of the world's leaders in EfW technology.[1]

1 ECOVE, Taiwan's largest environmental services company, is responsible for operating and maintaining nearly a quarter of EfW facilities in Taiwan.

Choose a responsible EfW company to aid transition

Based on the Taiwanese government's considerations at the time of implementation, in addition to insights gained throughout the development of the program, we suggest governments focus on the following characteristics when considering companies to help establish a national EfW program:

Sound financial status and solid reputation

A government looking to expand its EfW program should avoid partnering with companies that lack sound financial backing, to avoid a project failing due to financial difficulties. Furthermore, extensive experience in the industry, measured not just in years but also technical know-how, is one of the most important factors to look for when deciding on an EfW company. Governments should ensure the company chosen has a deep understanding of proper operations, maintenance and pollution control. Failure to choose an EfW company that excels in operations and maintenance will likely poison the concept of waste incineration in the minds of locals (See: Ankang) and will complicate future waste incineration capacity expansion.

Experience cooperating with governments and communities

Oftentimes, residents' only experience with waste incineration is in the form of open burning, which emits thick, black fumes that negatively impact the respiratory health of those with extended exposure to it. When promoting waste incineration, it is important to differentiate modern waste incineration facilities with open burning—in order to do so effectively, we recommend governments employ EfW companies that have experience cooperating with governments to help improve local understanding of waste incineration technology and the impact it will have on their community. If governments are successful in choosing an EfW provider with extensive experience working with communities, it can help reduce the costs and delays of extended protests against waste incinerators.

Experience with local conditions

Taiwan chose Japanese companies to help establish Taiwan's EfW program partly because Japan and Taiwan have similar climactic and geographical conditions—both countries experience high levels of humidity and frequent typhoons and earthquakes. In doing so, Taiwanese facilities could be built better suited to their geographic condition by cooperating with Japanese companies.

Many developing countries are characterized by climates with high temperatures and high humidity, and regular periods of droughts or flooding. Different weather patterns affect waste management methods—finding a company that has experience safely and responsibly handling waste in climates and extreme weather patterns similar to a government's home country will help ensure a successful transition to EfW.

Additionally, many countries experience a similar trajectory of waste composition, whereby organic waste (such as kitchen scraps and agricultural waste) characterizes the majority of the waste toward the early stages of development, gradually transitioning to waste composition dominated by paper and plastic. An ability to safely handle varying waste compositions and moisture levels should be a key factor when choosing an EfW company to help transfer EfW technology into a country, ensuring waste will be handled responsibly at all stages of development.

Focus on the long-term savings of waste incineration

The cost of relevant equipment and technology are comparably higher for EfW plants than for sanitary landfills. As a result, many governments—including Taiwan—chose to focus on implementing a waste management policy focused on sanitary landfills before developing incineration capacity. Furthermore, an EfW plant can take years to become operational, while a sanitary landfill can be ready to safely dispose garbage in just a few months. Partly to avoid the large initial costs of EfW technology, Taiwan chose to solve its public health and sanitation problems associated with mismanaged waste by increasing sanitary landfill capacity. Thereafter, Taiwan gradually transitioned to a waste management dominated by waste incineration.

While Taiwan was able to save money in the short-term, the long-term financial burdens of sanitary landfills are still affecting Taiwan today. First, land that had been allocated for use as landfills are still affected by the tons of municipal waste buried beneath the soil, which is still not fit for agricultural use. Recently, the Taiwanese government has made impressive strides in transforming former landfills into parks and recreation areas. While these measures are laudable, they are also quite expensive—transforming a 68 hectare landfill into an ecological park cost the government over USD 7 million.[8]

While the initial costs of waste incineration are comparably higher, the long-term benefits outweigh the costs. A waste management program focused on waste incineration offers the following benefits: land diverted from use as sanitary landfills, electricity generation, material recovery, and bottom ash reuse. A study done at the Technical University in Vienna conducted a cost-benefit analysis of constructing a waste incineration plant versus a sanitary landfill found that the benefits of incineration outweigh the costs by nearly €2 million (USD 2.3 million).[9]

1 Taiwan EPA. Taiwan Environmental Protection Agency (TEPA). Linian gonggao ying huishou feqiwupin ji rongjiliang tongji 歷年公告應回收廢棄物品及容器回收量統計 [National Report on Statistics on Recycled Products and the Recycling System]. Taipei, Taiwan, 2016.

2 Taiwan EPA. “Ziyuan huishou” 資源回收 [Resource Recycling]. 2017.

3 Taiwan Environmental Protection Agency (TEPA). 2017. “Daxing lese fenhuachang caozuo yingyun qingxing” 大型垃圾焚化廠操作營運情形. [The Situation of Large-scale Waste Incineration Plant Operation and Maintenance].

4 Dwyer, Henri, and Nickolas J. Themelis. “Inventory of U.S. 2012 Dioxin Emissions to Atmosphere.” Waste Management 46 (2015): 242–46.

5 For example, if an incinerator has the capacity to process 900-tons of waste per day, the district may receive NTD 200 (USD 6.6) per ton of waste, amounting to a total of NTD 180,000 (USD 5,950) per year.

6 CTCI is now one of the world’s leading engineering procurement contractors. ECOVE, CTCI’s subsidiary, began delivering EfW plant operation and maintenance services in 1994—now it is one of the leading environmental services companies in Taiwan.

7 The Sino-Environmental Company—present-day ECOVE—was established to conduct Operations and Maintenance for Taiwan’s first domestically constructed and operated EfW plant, eventually becoming Taiwan’s largest environmental services provider.

8 Taiwan Environmental Protection Agency. “Shanshuilü shengtai gongyuan” 山水綠生態公園” [Shanshuilu Ecological Park]. 2013.

9 Tang, Jiao. “A Cost-Benefit Analysis of Waste Incineration with Advanced Bottom Ash Separation Technology for a Chinese Municipality-Guanghan.” Master’s thesis, Technical University of Vienna, 2012.

ECOVE (TPEx: 6803) — an affiliate of CTCI, a global engineering services provider — is an environmental services provider specializing in Energy-from-Waste (EfW), waste management, wastewater recycling, solar power and PET recycling. Founded in the midst of Taiwan's waste crisis in 1994, we quickly became a leader in effective waste management and resource recovery. With our main focus on recovering more value from otherwise wasted resources, we have continuously increased efficiency across our EfW, solar power, and recycling plants. Public and private entities in Taiwan, Macau, mainland China, Southeast Asia, India and the United States have trusted ECOVE for environmental services in operations and maintenance, consulting, and investment and development.

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