From Farm to Table to Energy:

Co-digesting China's Urban Food Waste in Wastewater Treatment Plants

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Introduction

In 2016, the Wilson Center's China Environment Forum (CEF) produced a scoping paper for the Global Methane Initiative (GMI) entitled *Scaling China's Sludge Mountains: Challenges and Opportunities to Improve Sludge Treatment and Disposal in China's Tier-2 Cities*. In the report, we highlighted the potential of sludge-to-energy (StE) technologies for methane capture and utilization in China as a solution to address water-energy choke points. With our extensive research and reporting experience on water-energy, sludge, and wastewater issues in China, CEF then conducted out additional research and meetings to help GMI identify potential tier-2 cities and partners in China to help catalyze 1 to 2 StE pilots in China at either wastewater treatment or stand-alone sludge treatment plants.

Our *Sludge Mountains* report highlighted that while China has 50+ StE plants, most are not in use or are underutilized. One of the biggest obstacles is the problem of excessive stormwater runoff diluting the urban wastewater and the resulting sludge lacks sufficient organic material to produce methane. Many Chinese cities are working to address the stormwater runoff under the central government's "sponge city" campaign, which is promoting green urban infrastructure such as green rooftops, porous pavements, and rainwater harvesting. Another solution to this problem, which supports the government's goals for low-carbon cities, is co-digestion of food waste and sludge to generate and use the waste methane. Co-digestion of these two wastes would increase organic matter in wastewater and further low-carbon goals by generating more methane that could be sold as CNG for vehicles or used to generate electricity for the treatment plant and/or grid. Additionally the sanitized biosolids could be sold as compost or used in building materials.

U.S. and European municipal wastewater treatment plants are increasingly tapping this profitable use of food waste and sludge and offer good models for Chinese cities. Co-digestion of food and sludge could help Chinese cities simultaneously address multiple major environmental problems--decrease landfilled waste and soil pollution, clean water more cheaply, and lessen dependence on polluting coal-fired power by producing a sustainable low carbon energy.

Few Chinese cities sort their waste, which makes up one-quarter of the world's municipal solid waste. Food waste makes up 50-70 percent of China's MSW and most is landfilled or incinerated with all other municipal solid waste. Many restaurants in China sell food waste to pig farms or to illegal gutter oil processors, both of which pose potential food safety problems. The Chinese leadership has begun to expand its war on pollution to the country's mounting solid waste and wastewater crises and new policies and pilots are rapidly emerging.

- In March 2017, the National Development and Reform Commission (NDRC) and the Ministry of Urban and Rural Development (MOHURD) selected 46 cities for mandatory garbage sorting.
- In January 2018, the Chinese government banned of imported plastics-- a potential catalyst for more formalized municipal recycling to make up some of the losses of imported recyclable plastics.
- In May 2018, MOHURD and the newly expanded environmental watchdog Ministry of Ecological Environment (MEE) initiated national investigations of illegal hazardous waste and wastewater dumping. This is a more focused campaign that builds on 5 major inspections MEE's predecessor agency did in 2016-2017.
- Since 2016, MOHURD and MEP (now MEE) partnered with China's leading open information NGO the Institute of Public and Environmental Affairs to create the Foul and Filthy that encourages citizens to photograph and geolocate particularly dirty water. IPE and other NGOs in the network have been making maps of these sites, helping to inform MEE and MOHURD inspectors.

- Over the past several years a number of Chinese cities have made voluntarily efforts or started plans on how to divert organic waste (principally food waste) to other beneficial purposes such as biogas and compost.
- Paralleling the local government initiatives, in some cities Chinese grassroots NGOs have created community-level pilots on waste sorting and recycling, often linked with strong anti-incineration grassroots movements.

These moves towards improved waste sorting and recycling could help cities create a sustainable food waste stream to feed waste methane co-digestion facilities. With solid waste management both directly and indirectly becoming a higher policy priority it is an opportune time for GMI to engage with China to highlight the environmental and economic benefits of co-digestion.

To help GMI navigate co-digestion potential in China, the Energy Resources Group and CEF were contracted by EPA to develop a scoping report to highlight the food waste trends in Chinese cities and assess the possibilities of redirecting food waste to municipal wastewater (MWW) and StE plants. The report also highlights some specific gaps that GMI and other organizations could help fill and potential Chinese partners to engage.

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Scale of the Problem: Food Waste Generation in China

Every year roughly one-third (1.179 billion metric tons) of the food produced for human consumption globally is lost or wasted.[1] Not surprisingly, China is a large contributor to this growing issue.[2] Food waste comprises between 50 and 70 percent of municipal solid waste (MSW) in Chinese cities,[3] three to four times the average in U.S. cities (14.9 percent)[4] and twice the average of European cities (35 percent). Nearly 60% of this food waste in China is generated by consumers.[5] There is a broad range of estimates on China's annual rate of food waste or loss or both - from a low of 15.4-16.33 million metric tons[6] to a considerably higher 97 million metric tons, as shown in Table 1. For more information about food loss and waste in China, see Appendix A.

Table 1. Estimates of Food Loss and Waste in China

Source	Year	Food Loss and/or Waste (Loss = pre-consumer; waste = post-consumer)	Amount (million metric tons)
Chinese Academy of Sciences[7]	2016	Food waste	15.4-16.33
Chinese Academy of Agricultural Sciences[8]	2015	Food loss	35
News Articles (SCMP, Daily Mail)[9]	2017	Food loss & waste	40
World Wildlife Fund[10]	2015	Food loss & waste	60
Qianzhan Industrial Research Institute[11]	2016	Food waste	97

[1] Gustavsson, Jenny, Christel Cederberg, Ulf Sonesson, Robert van Otterdijk, and Alexandre Meybeck. 2011. "Global Food Losses and Food Waste." Swedish Institute for Food and Biotechnology; FAO. http://www.fao.org/docrep/014/mb060e/mb060e.pdf.
[2] "Urban Population (% of Total)." n.d. United Nations Population Division. Accessed May 10, 2018. http://data.worldbank.org/indicator/SP.URB.TOTL.IN.ZS.
[3] Jun Tai, Weiqian Zhang, Yue Che, and Di Feng, "Municipal Solid Waste Source-Separated Collection in China: A Comparative Analysis," *Waste Management* 31, no. 8 (2011): 1673-1682.
[4] "Advancing Sustainable Materials Management: 2014 Fact Sheet." 2016. U.S. EPA. https://www.epa.gov/sites/production/files/2016-11/documents/2014_smmfactsheet_508.pdf.
[5] "CPPCC Standing Committee: The Food That Is Wasted Each Year Can Feed 300 Million People." 2010, March. http://www.chinanews.com/gn/news/2010/03-10/2161052.shtml.
[6] Zhang, Rui. 2016. "Research Shows Huge Food Waste in China." http://china.org.cn/china/2016-12/09/content_39882640.htm.
[7] "Food Wasted in China Could Feed 30-50 Million: Report." 2018. Chinese Academy of Sciences. http://english.cas.cn/newsroom/news/201803/t20180327_191074.shtml.
[8] Jaing, Heping, and Hui Jiang. 2015. "Reduction of Food Loss and Waste Urgent in China." Institute of Agricultural Economics Research, Chinese Academy of Agricultural Sciences. http://www.fao.org/save-food/news-and-multimedia/news/news-details/en/c/350718/.
[9] "In China, Maggots Finish Plates, and Food Waste." 2017. May 28, 2017. http://www.dailymail.co.uk/wires/afp/article-4551248/In-China-maggots-finish-plates-food-waste.html.
[10] "Climate Solver: Kitchen Waste Recycling and Treatment." *WWF*. http://www.climatesolver.org/innovations/eating/kitchen-waste-recycling-and-treatment.
[11] Zhu, Qian. n.d. "Analysis of the Status Quo of Chinese Kitchen Garbage Disposal Market in 2016." Qianzhan Industry Research Institute. https://www.qianzhan.com/analyst/detail/220/170918-bb7af665.html.

Food Waste Footprint

As China struggles to treat and reuse food waste, the environmental and economic costs cannot be overlooked. Economically, it equates to a wasted investment that reduces the economic well-being of stakeholders in the food value chain. Annually, about 200 billion RMB (US$32 billion) worth of food is thrown away in China even though 128 million Chinese still live below the poverty line and lack sufficient food.[12]

Environmentally, food waste accounts for unnecessary GHG emissions and wasted water and land. The FAO reported that food waste in industrialized Asia (China, Japan, South Korea) as of 2011 was responsible for roughly 1,100-1,300 million metric tons of carbon dioxide equivalent (CO_2e) of GHG emissions.[13] While there has been no national carbon footprint analysis of food waste, a household-level survey found that the average person wastes 16 kg of food at home annually, which equates to 40 kg CO_2e.[14] Improper food waste disposal has further damaging effects on the climate. Every kilogram of MSW can release 1.16 kg of CO_2e through sanitary landfill treatment, 0.79 kg under simple landfill treatment, and 0.51 kg when incinerated.[15] The catering industry in Beijing alone releases 1,925-2085 kg of CO_2e, 14% of which occurs during the treatment/disposal stage.[16]

In addition to the climate implications, the water and cropland wasted through food waste in China is immense. China's food waste in 2010 represented a loss of 135 billion m^3 of water used to produce it (equal to the entire water footprint of Canada) and 26 million hectares of cropland (an area about the size of total arable land in Mexico).[17] This does not take into account the 25.4 million metric tons of fertilizer used to grow this wasted food each year.[18]

Overview of Food Waste Management Practices

Anecdotal evidence indicates that all tier-1 and most tier-2 cities in China have set up or planned systems for food waste processing for energy and material recovery. Most cities require that larger food service operations sort their food scraps for licensed garbage trucks to pick up and deliver to composting facilities, biodiesel conversion companies, or AD plants. This often excludes residential buildings, grocery stores, and small workplace canteens. However, the existing sorting and recycling capacity in both large and small cities can hardly match the vast quantity of food waste generated and collected every day, and majority of Chinese cities still depend on landfilling and incineration for food waste disposal.[19] From source separation to collection,

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[12] Zhou, Wanqing. n.d. "Food Waste and Recycling in China: A Growing Trend?" *Worldwatch Institute* (blog). http://www.worldwatch.org/food-waste-and-recycling-china-growing-trend-1.

[13] "Food Wastage Footprint & Climate Change." 2011. Food and Agriculture Organization of the United Nations. http://www.fao.org/3/a-bb144e.pdf.

[14] Guobao Song, Mingjing Li, Henry Musoke Semakula, Shushen Zhang, "Food consumption and waste and the embedded carbon, water and ecological footprints of households in China," *Science of The Total Environment*, Volume 529, 2015, Pages 191-197, ISSN 0048-9697, https://doi.org/10.1016/j.scitotenv.2015.05.068.

[15] Wang, Z., Geng, L., 2015. Carbon emissions calculation from municipal solid waste and the influencing factors analysis in China. *Journal of Cleaner Production* 104, 177-184.

[16] Zhang D, Cheng SK, Gao LW, Liu XJ, Cao XC, Liu Y, Bai JF, Xu SW, Yu W, Qin Q, "The carbon footprint of catering industry food waste: a Beijing case study," *Acta Ecologica Sinica*, 2016, 36 (18): 5937-48.

[17] Junguo Liu, Jan Lundqvist, Josh Weinberg, and Josephine Gustafsson, "Food Losses and Waste in China and Their Implication for Water and Land," *Environmental Science & Technology* 2013 *47* (18), 10137-10144, DOI: 10.1021/es401426b

[18] Lipinski, Brian, Craig Hanson, James Lomax, Lisa Kitinoja, Richard Waite, and Tim Searchinger. 2013. "Reducing Food Loss and Waste." Creating a Sustainable Food Future. WRI, UNEP. http://www.wri.org/sites/default/files/reducing_food_loss_and_waste.pdf.

[19] Song, Guojun. 2015. "Evaluation of Urban Domestic Waste Management in China." Renmin University of China National Development and Strategy Research Institute. http://www.3edata.com/uploadfiles/ckeditor/files/household%20garbage.pdf.

beneficial use practices, resource recovery, and disposal, food waste management in China could be significantly more efficient along the entire chain. The following section highlights food waste management practices in China.

Source Separation

Source separation assists in the material and energy recovery of generated waste—by preventing food from entering MSW streams, waste treatment facilities can significantly lower disposal costs and generate income by channeling the food scraps into profitable recycling or reuse streams. Shenzhen, a booming southern Chinese city next to Hong Kong, has been a waste sorting pilot city for 17 years, yet less than 20 percent of the residents effectively sort their household waste.[20] In March 2017, NDRC and MoHURD selected 46 cities for mandatory garbage sorting, with a goal to achieve a minimum recycling rate of 35% by 2020.[21] According to its classification standards, "wet" garbage (food waste) must be separated from the "dry" garbage (other types of waste) in order to reach the recycling threshold.[22] The standards allow cities to create waste sorting systems that fit their local context, but each city must create detailed classification principles, as well as collection, transportation, treatment, and disposal plans. In short, these new NDRC and MOHURD standards are pushing local authorities to promote reutilizing and repurposing of organic waste and expedite the construction of food waste treatment infrastructure. Chinese cities are interested in learning about new technologies and management strategies so they can meet the central government's stringent targets on waste separation and utilization.

The Chinese government, tech entrepreneurs, and civil society groups have been exploring a variety of ways to curb food loss and waste. Some are targeted at individual consumers, ranging from campaigns and initiatives that encourage changing behaviors and culture around food[23] to online platforms advertising and selling unused fresh food.[24] Others put emphasis on preventing unnecessarily discarded food at schools, universities, restaurants, and grocery stores through information technology that estimates customer base and optimizes food inventory.[25]

Another example is lowering food waste for disposal through commercial waste disposers that can grind food scraps into residue suitable for compost or wastewater/sludge flows. These approaches, to a large extent, count on public engagement and education rather than Chinese government and private sector players, who strikingly have rarely embraced the business opportunities of reducing food loss and waste, but this is likely to change as there are a handful of private companies who are beginning to invest and in food co-digestion facilities.

In a study of more than 700 food service companies across 17 countries, analysts from World Resources Institute and WRAP concluded that food related-businesses earn a median $14 return for every $1 invested in waste mitigation. Cities and countries can also benefit significantly. For instance, the UK and six West London boroughs have saved £250 and £8, respectively for every £1 invested in food waste reduction.[26] China could similarly cash

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[20] Wang, Yiwei. 2017. "China's Latest Trash-Sorting Push Not Good Enough, Experts Say." *Sixth Tone* (blog). June 6, 2017. http://www.sixthtone.com/news/1000294/chinas-latest-trash-sorting-push-not-good-enough%2C-experts-say.

[21] Hong, Zhao. 2017. "China Enforces Garbage Sorting in 46 Cities." *CGTN*. May 4, 2017. https://news.cgtn.com/news/3d67544e7a637a4d/share_p.html.

[22] "Domestic Garbage Classification System Implementation Plan." n.d. National Development and Reform Commission; Ministry of Housing and Urban-Rural Development. http://hzs.ndrc.gov.cn/newzwxx/201703/W020170331321268083586.pdf.

[23] Zhou, Wanqing. 2013. "From Famine to Food Waste: Time to Reflect." *Chinadialogue* (blog). December 2, 2013. https://www.chinadialogue.net/blog/5697-From-famine-to-food-waste-time-to-reflect/en.

[24] "Hong Kong Food Waste: How It's Being Reduced by Restaurants, Charities and Perishable-Food Portal." 2017. April 26, 2017. http://www.scmp.com/lifestyle/food-drink/article/2090420/hong-kong-food-waste-how-its-being-reduced-restaurants.

[25] "China Takes on New Strategy on Reducing Food Waste." 2017. January 16, 2017. http://www.foodingredientsfirst.com/news/China-Takes-on-New-Strategy-on-Reducing-Food-Waste.html.

[26] Hanson, Craig, and Peter Mitchell. 2017. "The Business Case for Reducing Food Loss and Waste." Champions 12.3. https://champions123.org/wp-content/uploads/2017/03/report_-business-case-for-reducing-food-loss-and-waste.pdf.

in if their cities and food businesses took these steps--in this current "war on pollution" movement in the government could start encouraging such moves.

Animal Feed

The use of food residue as direct feed for livestock, poultry, or other animals was a prevailing practice across China for many years. In 2010, it was estimated that four-fifths of collected food waste was used as feed on pig farms.[27] However, as food scraps in urban areas often contain metals, hard objects like toothpicks and plastic, as well as potentially pathogenic microorganisms, parasites, and bacteria, feeding discarded food can damage animals' digestive systems and cause zoonotic diseases that can pose health hazards to consumers.[28] In 2003, the MoA issued "Measures for the Administration of Safety and Hygiene of Animal-derived Feed Products" prohibiting the use of animal-derived feed for ruminants.[29] The State Council released "Opinions on Strengthening the Remediation of Waste Oil and Management of Kitchen Waste" in 2010, forbidding companies and individuals from collecting, disposing of, and treating food waste without government permission, and banning the use of kitchen waste as animal feed without prior "harmless treatment" (refers to thermal treatment used to kill pathogens).[30] Some cities, such as Shanghai Minhang District, Tianjin, Hohhot, Urumqi, and Xining are permitted to send treated kitchen and restaurant waste for use as animal feed. Enforcement of these practices remains uneven, but with the central government expanding its war on pollution to waste, these practices should diminish.

Rendering

Rendering refers to the treatment of animal byproducts from slaughter operations or meat-processing activities where the food waste is processed and converted into marketable products like lard, tallow, or grease that can serve as low-cost raw materials for producing soap, cosmetics, explosives, pharmaceuticals, lubricants, and biofuels. The magnitude of the rendering industry in China is hard to quantify as most rendering facilities are integrated plants that operate in conjunction with animal slaughterhouses or poultry processing plants.

Another significant segment of the rendering business is converting used cooking oil from restaurants and fast food chains into yellow grease to manufacture biofuels and biodiesel.[31] In China, the urban catering industry generates more than 4.53 million metric tons of used cooking oil each year, of which more than 181.4 metric tons are converted into biodiesel. Unfortunately, 40 to 60 percent of this biodiesel ends up being reused for cooking through underground sales—at certain points it was being used to prepare up to 1 in 10 meals in China.[32] The revelation of this practice created a food scandal in 2010 and catalyzed the government to crack down on the production and sales of gutter oil,[33] forcing restaurant owners to seek safe and profitable alternatives. This includes producing biofuel derived from waste oil, which has a potential to cover 43.5% of China's 2010 aviation

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[27] Yangyang Li, Yiying Jin, Jinhui Li, Yixing Chen, Yingyi Gong, Yuezhong Li, Jinfeng Zhang, "Current Situation and Development of Kitchen Waste Treatment in China," *Procedia Environmental Sciences*, Volume 31, 2016, Pages 40-49, ISSN 1878-0296, https://www.sciencedirect.com/science/article/pii/S1878029616000074.

[28] Ting Chen, Yiying Jin, Dongsheng Shen, "A safety analysis of food waste-derived animal feeds from three typical conversion techniques in China," *Waste Management*, Volume 45, 2015, Pages 42-50, ISSN 0956-053X, https://www.researchgate.net/publication/280135474_A_safety_analysis_of_food_waste-derived_animal_feeds_from_three_typical_conversion_techniques_in_China

[29] "Measures for the Safety and Sanitization of Animal-Derived Feed Products." 2003. Ministry of Agriculture of the People's Republic of China. http://jiuban.moa.gov.cn/zwllm/zcfg/qtbmgz/200601/t20060123_541383.htm.

[30] "The General Office of the State Council on Improving the Treatment of Waste Oil and Food Waste Management." 2010. Central People's Government of the People's Republic of China. http://www.gov.cn/zwgk/2010-07/19/content_1658092.htm.

[31] "Used Cooking Oil Theft." n.d. *Render Magazine* (blog). http://www.rendermagazine.com/industry/used-cooking-oil-theft/.

[32] "Food Waste Recycling: Jinhua Waste Collection and Transportation Leads the Country." 2015. December 2, 2015. https://zj.zjol.com.cn/news/218901.html.

[33] Barboza, David. 2010. "Recycled Cooking Oil Found to Be Latest Hazard in China." *New York Times*. March 31, 2010. https://www.nytimes.com/2010/04/01/world/asia/01shanghai.html?_r=1.

fuel demand (equivalent to 6.5 million metric tons of aviation bio-kerosene and 3 million metric tons of co-produced biodiesel).[34]

Composting

Every year, around 2 percent of China's food waste is directed to fewer than 10 composting plants throughout the country, a steep drop from 2000 levels (at 20 percent, 134 plants).[35] Funded by government bonds, most plants are constructed and operated by Goldenway Biology Tech Co., Ltd which owns several patents for thermophilic composting (type of dry aerobic fermentation).[36] A major bottleneck obstructing the scaling of compost treatment is the incomplete separation of food waste from the MSW stream.[37] Sorting non-biodegradable materials and removing toxic substances in the composting plant is extremely costly. Consequently, the organic fraction of final products is usually less than 20%, much lower than the standard for organic fertilizers (>45 percent), which limits the use of compost generated in Chinese cities as a soil amendment or for land reclamation and desertification control. Low profit margins, limited market demand, poor processing technology and equipment, and political barriers are putting Chinese composting plants out of business—several composters in Sichuan, Yangzhou, Daqing, and Hefei have suspended their production or are on the brink of bankruptcy.

Meanwhile, small-scale composting is on the rise, circumventing safety and environmental restrictions imposed on large-scale composting. This regulatory vacuum enables individuals to build compost piles at home, while schools and communities create education and engagement programs. Some of these household and community-level projects have been started by Chinese grassroots NGOs, some of which are working on anti-incineration campaigns.

Co-digestion

In several cities, waste disposal companies haul the food waste to a wastewater treatment plant and charge a tipping fee for taking the waste. The food waste contributes to increasing biogas (methane) generation that can be collected and used for beneficial purposes (e.g., produce electricity, vehicle fuel). In the city of Xiangyang, where the TOVEN StE plant is located, the operator company has been generating methane from food waste co-digestion for over five years. Food waste is collected from dozens of trucks sent out daily to collect food waste from 5,000 restaurants around the city. The Xiangyang government mandated restaurants provide the waste to TOVEN to help with increasing methane generation. The restaurants do not pay a disposal fee nor do they earn any money. Restaurants in the city were initially opposed to this scheme because they used to make money selling the food waste to local pig farms but this practice has been discouraged.[38]

Anaerobic Digestion

Over the past 20 years, China has promoted anaerobic digestion (AD) to manage organic waste and generate biogas as a sustainable energy source, albeit with different purposes in the rural and urban areas. AD has also become a mainstay technology for treating food waste in urban areas: 13 of the 19 food waste treatment plants that have started since 2014 use AD with an average capacity of 90-180 metric tons/day. According to a 2016 report by the Xi'an Environmental Industry Association, 80 out of the 111 planned urban food waste treatment

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[34] Liang, Sai, Zhu Liu, Ming Xu, and Tianzhu Zhang. 2013. "Waste Oil Derived Biofuels in China Bring Brightness for Global GHG Mitigation." *Bioresource Technology* 131 (March): 139–45.

[35] Wei, Yuansong & Fan, Yao & Wang, Min-Jian & Wang, Ju-Si, "Composting and Compost Application in China," *Resources, Conservation and Recycling*, 30 (2000): 277-300, 10.1016/S0921-3449(00)00066-5.

[36] "Company Profile." n.d. http://www.jiabowen.com/english/index.html.

[37] Yan, L., Wu, Y., 2003. Secondary pollution problem caused by urban domestic refuse. *Zhongguo Huanbao Chanye* 4, 16–17.

[38] Interview with Dou Wenlong, General Manager at TOVEN plant. May 8, 2018

plants will use AD.[39] Companies undertaking AD projects include domestic industrial leaders like Sound Group, Qinghai Jieshen, and Qingdao Shifang Bio-Energy, as well as international corporations like Sweden's Purac.

Incineration

NDRC reported that the number of incinerators across China nearly doubled from 238 in 2010 to 514 in 2015, with a total capacity of 42 million metric tons a year.[40] The number rose to 898 in the end of 2018[41]. Chinese policymakers desire to treat MSW and generate power from resource recovery is fueling an incineration boom, particularly Waste-to-energy (WtE). By 2015, China had 223 WtE plants generating 18.7 billion KWh of electricity, or 1.2 percent of China's renewable energy generation.[42] The central government expects the number of WtE plants to double again by 2020,[43] with a capacity to burn 54 percent of its garbage, up from 31 percent in 2015.[44]

In order to induce investment, Beijing has fostered a regulatory environment in favor of WtE through prioritized commercial bank loans, provincial level subsidies for loan interest, guaranteed subsidized prices for purchase of electricity, and carbon financing benefits as renewable energy.[45] The profit margin of incineration is sizable, far surpassing that of recycling, leading well-off cities to expand incineration for MSW treatment.

> Chinese incinerators often operate at such low energy efficiency that about 30 percent of the generated heat is lost, and dioxin emissions increase when the furnace temperature is below 850 degrees Celsius. By diverting food waste for other types of treatment, the remaining waste feeding incinerators will be greatly improved in terms of energy content and air pollution reduction. In addition, leachate generation requiring treatment will also be reduced (reducing the moisture content of the incoming waste).

Cities in Japan and Europe divert a high proportion (up to 70%) of their trash for combustion, and the remainder for recycling. However, the model is hard to mimic in China since MSW contains 50-70 organics and around 50 percent moisture content, thus lowering its average heating value to 3-6.7 MJ/kg, much lower than the 8.4–17 MJ/kg in other developed countries.

Landfill

More than two-thirds of urban waste in China still goes into landfills (comprised of 50-70 percent organics). Therefore, the majority of food waste in China ends up in landfills which contributes to landfill gas (LFG) generation (i.e., increasing GHG emissions from methane emissions). A 2014 survey estimated that 2,107 landfills were operating in China, including 630 sanitary landfills and 1,477 simple landfills (open dumps) accepting over 152 metric megatons of waste.[46] (The number of landfills and the amount waste disposed in this

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[39] Annual Report No. 7 Progress of Food Waste Treatment in 2014." 2014. Xi'an Environmental Protection Industry Association. http://www.xahbcy.com/show.asp?id=47

[40] Li, Rongde. 2017. "Shenzhen Becomes First Chinese City to Raise Stink over Unsorted Garbage." *Caixin*. June 5, 2017. https://www.caixinglobal.com/2017-06-05/101098363.html.

[41] QianZhan Industry Research Center. 2019. Report of Market Demand and Investment Planning Analysis on China Refuse Incinerator Industry(2019-2024) https://www.qianzhan.com/analyst/detail/220/190102-78a0231d.html

[42] Stanway, David. 2016. "China to Burn, Not Bury, as It Tackles Trash Challenge." *Reuters*. November 13, 2016. https://www.reuters.com/article/us-china-power-waste/china-to-burn-not-bury-as-it-tackles-trash-challenge-idUSKBN1390B7.

[43] For locations of the incinerators, see an interactive map at http://www.waste-cwin.org/map/node.

[44] Yuan, Suwen, and Rongde Li. 2017. "Burning Unsorted Garbage Could Cost Beijing Billions in Health Care Costs." *Caixin* (blog). March 23, 2017. https://www.caixinglobal.com/2017-03-24/101069583.html.

[45] Dong, Yani. 2011. "Development of Waste-To-Energy in China; and Case Study of the Guangzhou Likeng WTE Plant." *Columbia University*, December. http://www.seas.columbia.edu/earth/wtert/sofos/Dong_thesis.pdf.

[46] Cai Bo-Feng, Liu Jian-Guo, Gao Qing-Xian, Nie Xiao-Qin, Cao Dong, Liu Lan-Cui, Zhou Ying, Zhang Zhan-Sheng, "Estimation of Methane Emissions from Municipal Solid Waste Landfills in China Based on Point Emission Sources," *Advances in Climate Change Research*, Volume 5, Issue 2, 2014, Pages 81-91, ISSN 1674-9278, https://www.sciencedirect.com/science/article/pii/S1674927814500147

report are roughly 5 and 2 times greater, respectively, than China National Bureau of Statistics data—a discrepancy caused by exclusion of simple landfills in national statistics. Built in the 2000s, most municipal landfills are not engineered properly and do not meet China's national standards for liners, drainage, LFG control, leachate treatment, and environmental monitoring. Only newly developed landfills in a few cities like Shenzhen and Guangzhou are able to meet national standards for landfills. In fact, more than 80 percent of the landfills have not incorporated methane capture and 47 percent have no precautions that prevent leachate from polluting groundwater. Methane emissions are estimated to contribute 1.9 metric megatons in 2013, and less than one-fifth of the resulting LFG was captured and processed into biogas—which is not only contributing to GHG emissions but losing out on a potential source of energy.[47]

Sewage Sludge Management and Treatment

Anaerobic Digestion

China has adopted AD for treatment of agricultural waste, food waste, and sewage sludge, recognizing it as a key technology to manage these wastes. Chinese municipal WWTPs generated more than 27.2 million metric tons of dewatered sludge containing 80% moisture content in 2011, four-fifths of which was insufficiently stabilized, meaning pathogens and strong odor was present in the sludge.[48]

China's National Bureau of Statistics states that one quarter of the 792 municipal WWTPs from the southwestern city of Kunming to the eastern port city of Ningbo installed AD units to stabilize sewage sludge by 2010.[49] However, empirical evidence implies the actual number is much less—Shanghai Municipal Engineering Design Institute reported as of 2015 only 46 WWTPs had installed AD for sludge treatment, of which only 25 facilities were running. Researchers from Tongji University determined that currently only 60 AD sludge facilities have been built, and only about 15 among them are in operation.[50] Table 2 shows a partial list of existing AD plants.

Struggling with a growing sludge crisis, the Chinese government has drawn a blueprint for constructing medium-to-large scale AD facilities in order to achieve the triple benefits of reducing the amount of sludge, restraining dewatered sludge from landfills, and utilizing the bioenergy, looking to American and European experience where 40-50% of urban sludge is treated through AD.

A series of policies will gradually be mapped out to stimulate AD application, ranging from technical guidelines (e.g., Guideline on Best Available Technologies of Pollution Prevention and Control for Treatment and Disposal of Sludge from Municipal Wastewater Treatment Plant by MEP in 2010[51]) to financial incentives (e.g., subsidizing electricity generated from waste, offering tax reduction or exemptions for StE). The attractiveness of AD for co-digestion is also being encouraged by the Ten-Year Medium to Long Term Energy Plan for Renewables that sets targets for renewables to reach 15% of primary energy by 2020.

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[47] Du, Mingxi, Changhui Peng, Xiaoge Wang, Huai Chen, Meng Wang, and Qiuan Zhu. 2017. "Quantification of Methane Emissions from Municipal Solid Waste Landfills in China during the Past Decade." *Renewable and Sustainable Energy Reviews* 78 (October): 272–79.

[48] Meng, Xiang Zhou, Arjun Venkatesan, Yi Lin Ni, Joshua Steele, Ling Ling Wu, Anders Bigner, Ake Bergman, and Rolf Halden. 2016. "Organic Contaminants in Chinese Sewage Sludge: A Meta-Analysis of the Literature of the Past 30 Years." *Environmental Science and Technology* 50 (11): 5454–66.

[49] He, Pin Jing. "Anaerobic Digestion: An Intriguing Long History in China." *Waste Management* 30, no. 4 (2010): 549-550.

[50] Dai, X, and X Zhou. n.d. "High-Solids Anaerobic Digestion of Sewage Sludge in China." https://www.aquaenviro.co.uk/proceedings/high-solids-anaerobic-digestionof-sewage-sludge-in-china/.

[51] "Guideline on Best Available Technologies of Pollution Prevention and Control for Treatment and Disposal of Sludge from Municipal Wastewater Treatment Plant（on Trial）." 2010. Ministry of Environmental Protection. http://www.mep.gov.cn/gkml/hbb/bgg/201003/W020100310402829058583.pdf?COLLCC=1566219628&.

Table 2: Existing AD Plants

Name of WWTP	Location	Processing Capacity[52]
Bailonggang	Shanghai	1,020 metric tons/day
Jiguanshi	Chongqing	—
Dongjiao	Tianjin	—
Jizhuangzi	Tianjin	1,620 metric tons/day
Sanjintan	Wuhan	—
Wangxinzhuang	Zhengzhou	500 metric tons/day
Gaobeidian	Beijing	800 metric tons/day
Xiaohongmen	Beijing	800 metric tons/day
Sibao	Hangzhou	—
Baishamen	Haikou	—

Through the successful Zhenjiang plant example, co-digestion of food waste and sludge is attracting other Chinese cities looking for waste diversion opportunities and climate change mitigation coupled with economic benefits. Cities often build co-digestion plants at WWTPs or inside local industrial parks to leverage existing logistic networks and MWW treatment facilities. Examples include Tai'an and Qingdao City (Shandong Province), and Hohhot City (Xinjiang Autonomous Region). Table 3 is a partial list of ongoing food waste co-digestion projects in China.

Table 3: Ongoing co-digestion projects in China

Factory name	Location	Current status
Heishizi Food Waste Treatment Plant (Phase 2)	Chongqing	Under construction
Yangli WWTP	Fuzhou, Fujian	Under construction

[52] "Analysis of Anaerobic Digestion Technology Process for Urban Sludge in China." n.d. http://www.zonesi.com/news_.php?newsI=59.

Policy and financial incentives alone cannot spur the type of growth of AD needed unless several technical barriers underpinning China's sludge treatment and disposal are resolved. Some of the main barriers include:

Low Organic Content: lower organic content in China's sludge (47-50%) compared to other nations (>70%) results in less decomposition and methane production. This low organic content is attributed to combined municipal wastewater network composed of wastewater, industrial discharge, and urban runoff (i.e., dilution). Recently, some plant operators began introducing food waste as a supplemental feedstock, especially when the facility has a surplus of capacity. Co-digestion can benefit existing infrastructure by not only diverting organic materials from the waste stream (incineration, disposal) but also improves the mixing ratio for optimal digestion conditions and maximizes biogas production.

Mismanagement: WWTP operators often import inappropriate technologies or close down systems when the maintenance and operation of AD becomes uneconomical or they lack engineers with the appropriate technical skills and expertise to maintain the plant.

Low Profits: because of mismanagement and low organic levels in the sludge, profits from sale of high-quality products (biogas and fertilizer) cannot overcome high capital and operation costs, even with government subsidies and market investments.[53]

These hurdles will be covered in greater detail later in the report.

Landfilling

More than 75 percent of dewatered sludge is landfilled in China. Although policies such as the *National Technical Guidelines for Sludge Treatment from Urban Waste Water Treatment Plants* state that landfilling should be the last resort for dewatered sludge, it is still a predominant practice. On the financial end, landfilling is highly favored, as tipping fees per metric ton of sludge are between $5 and $8, significantly lower than the $79-$112 charged per metric ton in the EU. Current regulations require that sludge must be dewatered to 45-60 percent before being landfilled, but most WWTP dewater to 80 percent making it hard to legally landfill their sludge, leading to illegal dumping.

Water bodies discharge

The largest problem with discharging untreated sludge into waterways is the significant impact that it has on water quality throughout China. In 2015, 3.78 billion cubic meters of untreated wastewater was discharged in China—this wastewater is technically unfit for use in agriculture and industry, and is dumped into rivers and lakes.[54] In Beijing alone, over 6,500 metric tons of sludge were dumped near Beijing's groundwater source for over a year, contaminating the water with excessive levels of heavy metals, chemical oxygen demand, biochemical oxygen demand, NH4, coliform bacteria, and Shigella.[55] Greenpeace Asia estimates that the treatment of this water is likely to cost over $12 million. Cases like this are common across the country—from Beijing to Qilin, where chromium-contaminated waste was discharged into waterways, and industries were charged for this pollution.

Incineration

Incineration in China is a controversial method of dealing with waste. Incineration of sludge is a method to reduce the environmental impact that other disposal methods cause—from reduced methane emissions to reduced pollution of soil, water, and air (with proper pollution monitoring control technologies and monitoring

[53] From sludge report.
[54] Deng, Tingting. 2017. "In China, the Water You Drink Is as Dangerous as the Air You Breathe." *The Guardian*. June 2, 2017. https://www.theguardian.com/global-development-professionals-network/2017/jun/02/china-water-dangerous-pollution-greenpeace.
[55] Sina. (2010, November 18). Beijing sludge dumping case: who to hold accountable for pollution damages. http://gongyi.sina.com.cn/greenlife/2010-11-18/113921742_2.html.

are in place). These incinerators tend to be attached to WWTP. Currently, there are more than 50 StE pilots throughout China that are working to overcome policy, governance, and financing obstacles in order to succeed. These barriers include the water content of Chinese sludge, which is often too high to immediately be incinerated and requires enhanced dewatering. Increasingly, however, provinces and cities including Jiangsu, Hong Kong, Nanjing, Shanghai and Zhejiang, have provided subsidies to incineration as a solution for sludge treatment.[56]

Policies and Regulations Impacting Co-digestion

The Administrative Players

Food waste management is considered a municipal responsibility in China. Ideally, China would have national legislation to establish an overarching framework for food waste management, identifying and delegating the respective roles and responsibilities at each government level. In the absence of a well-planned institutional and legislative framework that addresses food waste management, treatment, and disposal, China currently manages its food scraps under a fragmented regulatory structure with limited private sector participation. The departmental responsibilities covering food waste until March of 2018 were:

- State Council: Financial guidance for public-private partnership projects;
- NDRC: Investment and budget;
- MoHURD: Project plan, design and construction; technical standards of MSW treatment and disposal; target setting for emissions through MSW disposal and wastewater treatment; sewage plant management and sludge disposal
- MEP: Environmental standards and pollution control; utilization methods of waste products (with MIIT);
- MoA: Livestock and crop-related waste; feedstock utilization;
- AQSIQ: Products and residues of food waste processing and management;
- CFDA: Food safety and public health related issues;
- MOFCOM: Procedure design and management of PPP in public services; market planning and management.

As governance reforms in 2018 transformed MEP to the Ministry of Ecology and Environment (MEE), the ministry was given some of the waste responsibilities that previously fell under NDRC. Thus MEE will be playing a bigger role in food waste reduction. However, subnational government responsibilities will take longer to shift.

National Level Turns up the Regulatory Heat on Food Waste

Following the issuance of the "*Law of the People's Republic of China on the Prevention and Control of Environmental Pollution by Solid Waste* (2005)," the Chinese central government mandated that food waste be treated as a type of urban garbage and solid waste. Thereafter, MoHURD defined regulations, stakeholders, and responsibilities in "*Measures for the Management of Municipal Solid Waste* (2007)," assigning food service

[56] Fu, Xiaotian, Lijin Zhong, Vijay Jagannathan, and Wanli Fang. 2017. "Sludge to Energy: An Environment-Energy-Economic Assessment of Methane Capture from Sludge in Xiangyang City, Hubei Province." World Resources Institute. https://www.wri.org/sites/default/files/Sludge_to_Energy_An_Environment-Energy-Economic_Assessment_of_Methane_Capture_from_Sludge_in_Xiangyang_City_Hubei_Province_0.pdf.

operations to collect waste and authorizing companies for waste transport, treatment, and disposal. Combining the "*Code for the Operation of Catering Businesses* (2007)," the "*Circular Economy Promotion Law of the People's Republic of China* (2009)," and "*Opinions of Further Strengthening the Work of MSW Disposal* (2011)," four basic principles of policy priorities can be summarized as follows:

- Food waste management is centered on reduction, resource recovery, and harmless treatment, following the polluter-pays principle.
- Companies undertaking food waste collection, transport, and disposal must obtain appropriate administrative licenses for business operation.
- Food waste must go to treatment facilities designated by the government.
- National and local governments have the right to penalize business operators involved in illegal activities.

Directive Policies on Food Waste Management

Catalyzed by the gutter oil scandal in 2010,[57] the Chinese government started formalizing food waste management and adding "harmless treatment," resource utilization, and food waste recovery into legislation. In addition, the State issued policies and regulations to specify the technical and operational details necessary to assist the public and regulated entities in implementing the laws (Table 4). Most existing policies are designed to tackle a specific facet of the food waste problem, such as the impact of wasted oil on food safety and public health, environmental hazards caused by unregulated waste disposal, and loss of energy due to insufficient repurposing infrastructure.

Although the key principles of reduction, resource recovery, and "harmless treatment" are widely recognized and prioritized, no hierarchy of food waste or solid waste management has been formulated. Existing policies and regulations emphasize one or two particular stages of the waste management system, such as collection, transport, treatment or disposal instead of devising a holistic, integrated solid waste management system.

[57] Barboza, David. 2010.

Table 4: Food Waste Management Policies

Year	Issuing Agency	Law/Regulation	Description
2010	State Council	Opinions on Strengthening Gutter Oil Remediation and Food Waste Management	Specifies the technical and operational details necessary to assist the public and regulated entities in implementing the laws
2012	MoHURD	Technical Requirements of Food Waste Resource Utilization	Streamlines each step in the food waste management process, from collection and transport, to operation of treatment plants, to the employment of treatment and axillary technologies.
Policies Under Formation	National product standards: "Technical Requirements of Food Waste Utilization," "Technical standards of Resource Recovery and Refinery of Used Cooking Oil," and "Safety Standards for Products from Food Waste Reutilization"		
	Infrastructure design and construction standards: "Technical Code for Food Waste Treatment," and "Technical Procedure for the Operation and Maintenance of Food Waste Treatment Plants"		
	Industrial standards: "Food Waste Dewatering Machine," and "Technical Code for Food Waste Treatment Plants"		

Food Waste Collection and Transportation: Policies and Implementation

The catering and food processing industries (commercial food waste) have a highly centralized treatment and disposal system, and because of this China has been pushing for a commercial waste recycling rate of 100 percent while attempting to reach zero emissions and zero net energy consumption. Similarly, in cities where waste is being sorted food waste will be routed to treatment or disposal facilities through a centralized system in which discarded food is collected and transported by a contracted service company or municipal sanitation department (Table 5). In contrast, rural households and businesses tend to sanitize and dispose of food scraps *in situ*, in a decentralized system.

Table 5: Food Collection and Transportation Policies

Year	Issuing Agency	Law/Regulation	Description	Implementation
2016	MoHURD	Compulsory Waste Classification System	By the end of 2020, the key cities should achieve an effective separation of MSW. MSW separation rates should reach more than 90 %, and the recycling and utilization rate should reach more than 35 % (including renewable resources recycling, with biodegradable waste separated from MSW).	
2014	The Central Committee and State Council	Practicing Strict Reduction of Waste	Targets the catering and food processing industries (commercial food waste) for source reduction.	Since 2011, China has experimented with commercial food waste treatment and recycling pilot projects in 100 cities. Such projects are mainly supported by local municipal governments with subsidies for waste transportation and treatment.
2014	SAG, MIIT, and AQSIQ	Saving Food and Reducing Food Losses among Foodstuffs and Oil-processing Industries		
2010	State Council	Opinions on Strengthening Gutter Oil Remediation and Food Waste Management	Specify the technical and operational details necessary to assist the public and regulated entities in implementing the laws.	

Food Waste Treatment and Disposal: Policies and Implementation

The state has prioritized "harmless treatment" of food waste among all waste management practices for the dual purpose of mitigating cities' dependence on landfills and maximizing the safe utilization of the waste. MoHURD has highlighted solid waste "harmless treatment" in each of its Five-Year-Plans since 2007, urging cities to increase their waste treatment capacity by constructing, retrofitting, and upgrading more WtE plants. As the national government focuses on technical support and resource allocation, financing the construction of treatment facilities mainly depends on the local government, and policies pushing for increased waste treatment capacity lead cities to increase investment and establish stable funding sources. Notably, the central government is promoting a significant green finance initiative in economically developed areas, and cities short on landfills, incineration is regarded as the priority technology.

Under mounting pressure over environmental pollution, Beijing recently promulgated the "*Law of the People's Republic of China on Environmental Protection Tax* (2016)" and the "*Program to Implement Producer Responsibility Extension System* (2017)." While the food waste treatment sector is not their focal point, both

regulations encompass all enterprises and institutions that discharge pollutants directly into the environment, with an extension to upstream actors responsible for inducing pollutants into the supply chain. Therefore, food waste treatment and disposal facilities are included in these laws and are expected to pay environmental protection taxes for emitting air pollutants and wastewater unless they can run waste control systems round-the-clock. Such "hammers" offer potentially strong incentives for food waste to be directed to more productive and less polluting channels, such as co-digestion with sludge to enhance StE (Table 6).

Table 6: Harmless Treatment and Energy Recovery Policy and Implementation

Year	Issuing Agency	Law/ Regulation	Description	Implementation
2010	NDRC, MoF, and MoHURD	Notice on Organizing the Pilot Projects of the Utilization and Harmless Treatment of Urban Food Waste	Announces a total of 100 food waste treatment pilot cities in 32 provinces and municipalities between 2011 and 2015 granting them half the necessary startup capital.	By May 2016, only 6 of the 32 pilot cities/provinces in the first batch passed the midterm examination for meeting criteria for treating urban food waste. Indicating that the overall progress is lagging severely.
2011	NDRC	12th FYP of MSW Harmless Treatment Facilities Construction	Between 2011-2015, a total of 242 new food waste treatment facilities to be built with an increased processing capacity of 30,000 metric tons per day Special project investments to amount to 10.9 billion RMB in order to cover half the designated cities with basic food waste sorting and treatment facilities	By the end of 2015, 119 disposal projects were put into operation, under construction or in the planning stage, with a total processing capacity of 21,500 metric tons/day. The actual processing capacity of China's food waste treatment is no more than 14,000 metric tons/day, whereas the daily processing rate is only 5.5%, far less than the anticipated 30,000 metric tons/day under the 12th-Five-Year Plan.[58]
2016	NDRC	13th FYP Targets for 2020[59]	The decontamination rate of urban refuse must reach 100% in tier-1 and tier-2 cities, 95% in tier-3 cities, 80% in towns and villages	The targets aimed for an additional 104 waste treatment facilities to be established across 100 pilot cities.

[58] Zhu, Qian.

[59] "National Development and Reform Commission, Ministry of Housing and Urban-Rural Development: '13th Five-Year Plan' National Urban Domestic Waste Harmless Treatment Facilities Construction Plan." 2016. National Development and Reform Commission; Ministry of Housing and Urban-Rural Development. http://www.ndrc.gov.cn/fzgggz/hjbh/huanjing/201701/t20170122_836131.html.

			Designated tier-1 and tier-2 cities must realize zero landfilled MSW and a full coverage of harmless treatment facilities	Around 50 have already been put into use as of September, 2016. Among the 90 facilities the distribution of the processing technologies are AD (79%); aerobic digestion (7%); composting (4.5%), and mixed technology plants (5.5%) and other (4%). Of the 84 treatment plants with specific financing forms, 38.4% chose a build-operate-transfer (BOT) or build-own-operate (BOO) model and included industrial leaders such as Tus-Sound Environmental Resources, NETZSCH, SinoRehoo, and Qinghai Jieshen.[60]
			Incineration should account for at least half of the total harmless treatment capacity (and 60% in eastern provinces)	
			The average processing capacity of MSW must increase by 509,700 metric tons per day	
			The average processing capacity of food scraps must increase by 34,400 metric tons per day	
			The total investments will amount to 251.84 billion RMB, of which 169.93 billion is used for harmless treatment, and 18.35 billion is for food waste treatment	

Slippage at the Local Level: Challenges for Legislation and Policy Implementation

Unlike the national government which stresses overarching objectives, strategic planning, legal obligations, nationwide standards, and supervision, China's provincial governments bear the responsibility of creating, planning, and enforcing local policies and regulation. Essentially, local authorities are the key providers of public services to all urban and semi-urban communities within their jurisdiction, either directly or through public-private partnerships (PPP). By 2015, a total of 9 provinces and municipalities (Beijing, Shanghai, Chongqing, Hebei, Jiangsu, Fujian, Shandong, and Gansu); 101 prefecture-level cities; and 6 county-level cities had put food waste management regulations in place. Since 2010, 68 of the 100 pilot cities have enacted municipal food waste management measures.

Many cities are leveraging economic incentives to drive behavioral changes toward voluntary waste sorting and source reduction. This includes provisions for infrastructure, subsidies on electricity production through WtE, and income tax and VAT (value-added tax) exemptions. Subsidies and tax relief for companies and households that show food waste reduction and diversion for treatment or fines for those that fail to fulfill their sorting/recycling obligations.

[60] "Latest: China Sanitary Industry (2015-2016): Analysis and Prospect of Food Waste Disposal Policy." 2017. May 14, 2017. http://www.sohu.com/a/140444935_357509.

Shanghai's municipal government has incorporated a variety of financial measures to induce change in the food waste stream from purchasing new recycling bins, bags, and garbage trucks for communities to offering subsidies for community campaigners, social workers, and volunteers. Sanitation workers in charge of waste classification get a monthly allowance from the district's Bureau of Environmental Health in addition to their earnings by selling certain types of trash (e.g., plastics). Combusting the remaining garbage is rewarded by a stipend of 0.25 RMB (0.10 from provincial government, 0.15 from China's Ministry of Finance) for each kWh of electricity it generates.

Challenges for Legislation

Despite increasing attempts to incorporate better waste management practices, barriers to municipal food waste legislation and their effective implementation still remain:

- Only Xining City (Qinghai Province) and Yinchuan (Ningxia Province) have codified the administration of food waste. All other cities merely have recommended measures that lack legal obligations.
- Providing incentives may exacerbate government financial burdens, and overcompensation for WtE incineration may push less competitive (and likely more sustainable) technologies out of the market.
- Most local governments have yet to specify rules that help regulated entities comply with national, provincial, and municipal requirements or hold entities legally accountable for violations. Few local governments have binding laws and guidelines on penalties, fines, and their uses.
- Lack of technical and industrial standards for factors such as food waste collection containers, collection transport job specifications, and food waste-to-resource processing technologies.

Challenges for Policy Implementation

The implementation of a food waste management practices depends on several important factors, such as the city's statutes, environmental requirements, strategies in environmental management, energy policies, economic standing, technological capabilities, education and environmental awareness of its citizens. Different cities prioritize waste reduction, treatment, or final disposal based on local needs. Overall, throughout China the lack of data collection and transparency on food waste flow undermines good governance and practices. This allows food waste to easily be unreported at any stage of the food supply chain and routed from treatment facilities to cheaper options such as illegal landfills.[61] As stated previously, the expanding war on pollution could soon lead to stricter food waste reporting requirements, as has been the case with air emissions.

Because most policies and regulations on China's food waste management have been in effect for less than five years, only prominent outcomes and primary challenges are discussed below.

[61] "Food Waste Management: A MASSIVE Growth Opportunity in China." 2016. June 15, 2016. http://www.coresponsibility.com/china-food-waste-management-opportunity/.

Laggards on Sorting, Recycling, and Reducing

As food waste continues to grow, local governments are lagging on sorting, recycling, and reducing food waste:

- Food waste separation, transportation, and disposal companies are numerous and not well regulated. Thus, businesses and individuals who voluntarily sort their garbage face difficulties when they attempt to find certificated companies to collect, treat and haul for collection and treatment.
- There are few economic incentives to sort and reduce waste. Businesses often have to pay for the delivery and disposal of collected recyclable materials out of their own pockets, and the cost is even higher to compost or sustainably treat food waste. Waste management companies charge for the collected trash by weight regardless of the type of garbage or the cost of clearance.
- The informal MSW management sector still plays a significant role in waste separation in Chinese cities. Scrap trading black markets, run by residents and waste service managers, operate in warehouses filled with waste that is collected from small-scale scrap buyers who get their scrap from garbage pickers who search for discarded objects of value in public spaces and waste bins.[62] There are three actors in the informal sector—waste pickers, waste merchants, and middlemen (who collect an average of 16,311kg of waste per day in Beijing alone). Average monthly income is lowest for the waste pickers (1200 RMB) and merchants (2500 RMB) and highest for the middlemen (5250 RMB).[63] Local governments have failed to organize and manage the informal system or integrate the relevant stakeholders into formal waste management so that the municipal institutions can better regulate waste sorting and transportation.

Inadequate Support for Proper Treatment and Resource Recovery

Although the central and local governments have introduced a series of policies to bolster development of harmless treatment and resource recovery in the food waste industry, the implementation of such practices is still slow, even in tier-1 cities.[64] The state pledged to expand treatment capacity by building new facilities or upgrading existing plants, most of which are funded by private investment through PPPs. Source reduction, treatment, and resource recovery are inextricably linked. The effect of upstream garbage sorting proves to be the bottleneck of food waste treatment and disposal. Efforts to classify different waste streams may help break the cycle—poor separation has driven up investment and operations costs of treatment projects, and weak implementation leads to more unsanitary waste disposal. The challenges facing existing food waste treatment plants include:

- Large inputs of low quality waste due to insufficient source-separation or mixing of source- and non-source separated trash during collection, transportation, or storage.
- Low technical expertise, low processing efficiency, poor operating environments, and incomplete processing.

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[62] "Informal Waste Management in China." 2017. July 2017. http://www.eco-business.com/research/informal-waste-management-in-china/.

[63] Benjamin Steuer, Roland Ramusch, Florian Part, Stefan Salhofer, "Analysis of the value chain and network structure of informal waste recycling in Beijing, China," *Resources, Conservation and Recycling* 117, Part B (2017): 137-150, https://www-sciencedirect-com.libezproxy2.syr.edu/science/article/pii/S0921344916303238

[64] "2014 Analysis of the Investment Prospects and Industry Operation Environment of China's Kitchen Waste Processing (Original)." 2017. July 17, 2017. http://www.fei123.com/2060000/2055296.shtml.

Food Waste Co-digestion as a Technical Solution

Because the majority of Chinese MSW is food waste, opportunities for co-digestion at WWTPs are ripe for integrating these systems. While not yet common practice in China, many countries divert food waste to WWTPs to boost methane production as food waste has up to three times more biogas generation potential compared to sludge treated alone.[65]

The co-digestion process is a multi-step integrated system from source to product, starting with source separation, collection, pre-processing, treatment, and post-processing. Aside from source separation and collection challenges discussed above, food waste pre-processing, treatment, and post-processing are all technologies that exist, but are only being applied in a few Chinese cities and will need to be adapted to the Chinese context.

Pre-treatment is necessary for the Chinese context due to the large amounts of debris, water, and oil that would otherwise limit biogas generation, machine performance, and product quality. Immediate anaerobic treatment of food waste would cause the accumulation of lactic acid at early stages of the digestion process, leading to sudden drops in pH and inhibitory levels of ammonia, sulfide, and long-chain fatty acids, impeding the process of AD. This type of technology is available, and despite being a larger up-front cost, can reduce yearly costs of operating co-digestion plants, increase biogas production, and create conditions under which products are suitable for being sold in the market by eliminating contaminants. Mechanical (e.g., sonication), chemical (e.g., alkali or acid), osmotic (e.g. NaCl treatment, freezing), oxidative (e.g., ozone), thermal, and biological (e.g., enzymes) pre-treatment methods are all available and improve the quality of inputs. For example, a Beijing WWTP utilizes pre-treatment that consists of influent pumping, bar screening, and an aerated grit chamber. However, this is a relatively energy intensive process, requiring nearly 32 percent of the total energy of this plant,[66] but from increasing biogas generation, more can be used to generate electricity for onsite use by the plant (reducing the amount purchased from the grid) ot to produce vehicle fuel (reducing oil imports). And by reducing contaminants, beneficial products such as organic fertilizers, soil amendments or biochar can be produced and sold to market.

Environmental Benefits

By incorporating food waste co-digestion in WWTPs, less waste is going to incinerators or landfills or illegally dumped where it emits pollutants into the air, soil, and water. Currently, WWTPs utilize around 25 percent of China's electricity generation, and by adding food waste co-digestion, biogas generation increases and more onsite electricity (power the plant) and heat (for the digester) generation result (i.e., reduces grid energy demands of WWTPs). And having WWTPs possibly contribute excess energy back to the grid or producing vehicle fuel or pipeline quality gas, further reduces the need to use fossil-based resources low-carbon energy. This would contribute to China's goals to transition from coal to natural gas with aims to increase its share to 10 percent by 2020, while providing reliable, baseload renewable energy.

Economic Benefits

The economic benefits of co-digestion are intricately tied to the environmental benefits. From potential reduced energy costs for WWTPs that adopt co-digestion, to the potential income from beneficial products, and charging for collecting food waste. Typical WWTPs in China used an average of 0.254 kWh/m^3 of energy in 2009, higher

[65] Hagey, Paul. 2011. "Utility District Ramps Up Food Waste To Energy Program." November 2011. https://scenicviewdairy.com/news/utility-district-ramps-up-food-waste-to-energy-program/.

[66] Smith, Kate, Shuming Liu, Ying Liu, and Shengjie Guo. 2018. "Can China Reduce Energy for Water? A Review of Energy for Urban Water Supply and Wastewater Treatment and Suggestions for Change." *Renewable and Sustainable Energy Reviews* 91 (August): 41–58.

than the average in the United States which was 0.20 kWh/m^3.[67] As the average electricity price in China ranges between 0.4 and 0.7 yuan ($0.063 to $0.11), the costs to WWTPs could average $0.016/$m^3$ to $0.0279/$m^3$. With 3,500 plants operating by the end of 2013 processing an average of 149 million cubic meters of wastewater each day, equates to total energy usage of 37.85 million kWh per day, or a cost of $2.38 million to $4.16 million per day. This is a huge cost to the Chinese WWTP industry, averaging approximately 25-40 percent of their operating costs.[68] With co-digestion, these costs can be mitigated if not avoided as WWTP can rely on their own energy production rather than setting aside such a large portion of their budget for energy demands. Further economic benefits come from the fees that can be charged for food processing. For example, the Xiangyang StE plant benefits from a fee of 254 RMB ($38) paid by the local government to treat every metric ton of sludge and 59 RMB ($9) to treat every metric ton of kitchen waste.

These plants can also create end products such as construction materials, fertilizers, biofuels, or energy to sell back to the grid, again, increasing revenues or generating savings, and reducing their reliance on government funds and subsidies. Landfilling and brick manufacturing are the two least energy intensive sludge disposal methods, followed by disposal as fertilizer, incineration, and cement manufacturing at 70, 120, 200, and 250 kWh/metric ton on average, respectively.[69] The products created can be specific to the location of the plant--as Chinese urban areas transition to reliance on natural gas rather than coal, production of CNG or LNG from biogas will be beneficial.

Finally, by combining two processes in one plant, co-digestion reduces construction and operation costs, as sewage and solid waste are transferred and handled in the one location rather than many, and having one location makes monitoring and avoiding pollution leaks easier.

Development of Co-digestion Projects in China

Stakeholders

The development of co-digestion projects in China requires the cooperation of multiple stakeholders, which in many ways is one of the barriers to its widespread use. These stakeholders include:[70]

- **Government ministries and agencies:** Including, but not limited to MoHURD, MEP, NDRC, MoF, and MoA. These government agencies are responsible for policy coordination, guidance, and oversight of the projects as well as ensuring resource availability to achieve the project objectives and sustaining services at the central, provincial, municipal levels. They are stakeholders with high levels of influence, that with President Xi Jinping's emphasis on ecological civilization and green development, have a strong interest in improving treatment and resource recovery of urban food waste in the country.
- **Provincial and municipal organizations:** Including, but not limited to, Provincial (Municipal) Development and Reform Commissions (DRCs), Provincial Department (Municipal Bureau) of Finance, Provincial Department (Municipal Commission) of Housing and Urban-Rural Development, Provincial Department (Municipal Bureau) of Environmental Protection, Provincial Department (Municipal Commission) of Agriculture, Municipal Administration of City Appearance and Environmental Sanitation, Municipal Administration of Gardening and Urban Greening, Municipal Water Authority, as well as local utilities like gas companies. Among them, sanitation and housing and urban-rural development

[67]Tao, Xie, and Chengwen Wang. 2012. "Energy Consumption in Wastewater Treatment Plants in China." *World Congress on Water, Climate and Energy*, May. https://www.researchgate.net/publication/266146909_Energy_Consumption_in_Wastewater_Treatment_Plants_in_China.
[68]Smith, Kate, and Shuming Liu. 2017.
[69]Smith, Kate, and Shuming Liu. 2017.
[70] Primary stakeholders are those groups, people and institutions who will be affected either positively (direct beneficiaries) or negatively (those involuntarily resettled). Secondary stakeholders are defined as the important intermediaries involved in project delivery.

departments are primary stakeholders and have very strong interest in beautifying the city (President Xi just made this a pivot in his vision of a "beautiful China"[71]) and improving sanitation services to their residents. The remainders are secondary stakeholders and executing agencies in charge of certain aspects of project implementation.

- **City- and district-level administrations:** City- and district-level administrations have high interest in receiving investments from the central or provincial governments to achieve waste recycling and reduction targets. They are also the primary stakeholders responsible for ensuring sustainable management and operation of completed projects and leading consultation and monitoring work.
- **Catering enterprises, canteens of schools, hospitals, factories, and institutions**: They have very high interest in complying with food waste collection and disposal standards and avoiding the likelihood of revoking hygiene or business licenses; and can have medium influence on the project if they work collectively.
- **Construction contractors, building/designing companies:** Construction contractors and building/design companies have very high interest in bidding for work and participating in constructing and upgrading facilities and networks of WWTPs. Most are subsidiaries of SOEs or utility companies. Increasingly, more are private firms. They have low influence on the project.
- **Chinese banks:** Chinese banks are coming under pressure to finance green infrastructure. One of the newest tools is green bonds. In 2015, the People's Bank of China, NDRC and China Securities Regulatory Commission released guidance on green bond standards. Over the past two years China has developed a green bond system that generates "green credits" and other financial tools to spur greater private investments in pollution control infrastructure and green technologies that can be marketed in and outside China.
- **Technology companies:** Technology companies have high interest in contracting with food waste service companies to provide real-time monitoring, automatic metering systems, GPS positioning systems, and surveillance cameras that allow governments and service providers to oversee the entire food waste-to-resource process.
- **Urban residents:** In light of growing public anger over pollution from incinerators and landfills, StE plants could be seen as yet another health threat. Urbanites are very concerned about receiving high quality sanitation services for basic living needs and improving waste management for food safety and security.
- **International organizations and agencies:** They have a strong interest in assisting city governments with sustainable waste management practices and climate change mitigation. Responsible for offering financial support (e.g., low-interest loans, investments), technical expertise, and managerial and operational experience in bettering project implementation. Examples include the World Bank, investment banks in European nations, the majority of projects are funded by PPPs (combination of private investments, loans, and government subsidies).

Challenges in Developing Co-digestion Projects in China

The food waste treatment industry is still in its infancy, characterized by inadequate regulations and policies, oversimplified techniques, immature and unprofitable business models, lack of mechanisms to hold waste producers accountable, and unstandardized industrial development. The biggest challenges can be characterized into the following:

[71] "Press Conference Held on Pursuing Green Development and Building Beautiful China." 2017. *Xinhua*. October 23, 2017. http://www.xinhuanet.com/english/2017-10/23/c_136699906.htm.

Feedstock: The quality of China's food waste is relatively poor as it consists of plastic bags, napkins, and paper, which lowers the proportion of organic content and introduces potential contaminants detrimental to the AD process. Moreover, the composition of China's food scraps has a wide mix of components as food is often not processed before entering the market. This inconsistency of waste composition decreases systematic efficiency. Data available on feedstock is available from a variety of sources—general feedstock information can be obtained from the Municipal Statistics Bureaus or the Municipal Housing and Urban-Rural Development Bureaus, and laboratory data of feedstock, end products, and byproducts can be acquired from the testing department owned by the contractor.

Logistics: Directing food waste to StE at WWTPs requires transport networks with trucks to carry food waste or large pretreatment trucks capable of grinding the food waste in-situ. As of now, food waste collection in large metropolises is compatible with the wastewater treatment system, but smaller cities may not have the network set up, relying on smaller vehicles to carry food scraps and MSW.

Processing technology: Few studies have been conducted on AD co-digestion of sewage sludge and food waste both domestically and internationally. Existing research focuses on the sludge and MSW components, temperature, mixing ratio, hydraulic retention time (HRT), and the effects of the parameters on co-digestion. Technological problems when incorporating food waste are the optimal parameters (e.g. temperature, mixing ratio, pH, stirring strength) for co-digestion and the design of sludge digesters. The variation of food waste quality across Chinese cities further complicates WWTPs operations when trying to mix the waste from different sources and adjusting the operational parameters to a suitable range.[72]

In order to maximize efficiency, product yield, and to reduce operations costs, Chinese cities also need to incorporate pretreatment to remove non-biodegradable materials and homogenize the feedstock. Effective food waste separation and on-site pretreatment at restaurants or carriers can be a vital step to guarantee the feedstock compatibility in Chinese WWTPs. Existing treatment facilities often collect data on their operations, and this can be used to optimize their procedures.

Outputs: Starting in 1994, the Chinese government identified biogas as a major product to develop from AD (rural areas) and WtE in order to alleviate reliance on imports of fuels for transportation, industry, and commerce.[73] However, challenges remain in technology, grid connection, and market creation for biogas products. StE is highly reliant on subsidies and tariffs from the government, which focus on the construction of treatment facilities rather than on the products that the treatment produces. Sludge-derived digestate is banned as compost and from use on farmlands, and bio fertilizers are limited to urban greening or soil amendments. These regulations limit the market for these products, and therefore have an impact on the long-term economic viability of these plants.

Personnel and Operations: Large-scale plants struggle with recruiting qualified site managers, operators to load waste, maintenance staff, and wastewater/sludge engineers. The wages and welfare packages for jobs at Chinese WWTPs are often low for their required responsibilities. Existing WWTP operators lack the technical knowledge and practical experience with co-digestion, and seldom engage with research institutions capable of training and capacity building.

Affordability: Few co-digestion projects are in operation in China and the developing world, so cost and revenue predictions are often inaccurate. The capital investment for energy production systems can be higher for AD systems than typical WtE incineration plants, but the development of AD technologies bears greater potential if incorporated with existing waste management facilities (e.g., co-located at a WWTP). The costs of AD systems

[72] Li Lei, "Advances in Anaerobic Co-Digestion of Sewage Sludge Mixed with Kitchen Waste," *Sichuan Environment* 30, no. 2 (2011): 93-96.
[73] Jiang, Jianguo, Jichao Sui, Shiyao Wu, Ying Yang, and Liming Wang. 2007. "Prospects of Anaerobic Digestion Technology in China." *Tsinghua Science and Technology* 12 (4): 435–40.

depend on local circumstances, including construction and labor costs, treatment capacity, the possibility of energy recovery, energy price, output markets, taxes, tariffs, land prices, and the value of the digested material. Although the equipment for AD plants is expensive, the operating costs are relatively low considering their small size, high efficiency, and water savings.

Environmental issues: City legislation requires plant operators to conduct environmental impact assessments and food waste services companies to secure operational and environmental permits from relevant regulatory bodies. Ensuring that proper pollution standards are set and monitored, and that odors are controlled pose environmental challenges to co-digestion. The data to assess environmental impacts are available in annual and monthly monitoring reports provided by Municipal Environmental Protection Bureaus.

Regulations: In particular, the MoA has strongly opposed the standardization of food waste treatment for safety concerns. The potential health risks are hard to trace back to individual companies once the use of animal feed is scaled up, thus requiring food waste treatment companies to be responsible for the whole supply chain of animal feed, an unrealistic operational expectation.[74]

Opportunities for Developing New Co-digestion Projects

The main opportunities that may help spearhead the pilot projects are development of medium- and large-scale WWTPs through partnerships with relevant stakeholders, and incorporation of end-of-cycle products.

Scale: Medium- and large-scale WWTPs equipped with AD technologies have the greatest possibility to include co-digestion because they already have much of the technology, capabilities, and know-how for operation and maintenance. As MoHURD and MEP recommend, "AD becomes the most economical technique to process its sludge when a WWTP has a daily capacity of over 5,000 m^3." Notably, some Chinese cities are starting to build mega-incineration plants outside cities to deal with waste issues and similarly large AD plants could be a more cost-effective and environmentally safer option.

Partnerships and stakeholders: Developing an AD project in partnership with relevant stakeholders can help ensure the success of the project. The major stakeholders involved in food waste are similar across China, but the importance and influence of private and non-for-profit sectors may vary across cities.

Product creation: Continued efforts to support and develop markets for the fertilizer and biogas that WWTPs produce through co-digestion will help to push these plants into long-term economic viability. Learning from US or European examples or partnering with other plants that have successfully integrated their products into Chinese markets (such as the Xiangyang plant), would be helpful to advise and move these plants towards viability.

Help meet GHG Goals: The Chinese government's goals to transition away from coal use in urban areas and move towards natural gas is complementary for increasing the number of co-digestion projects. China Low-Carbon Cities would benefit from more co-digestion by helping cities manage two waste streams in a single-facility while producing GHG emission reductions and other environmental and economic benefits. This requires coordination between national level overarching policies and local level actions to implement co-digestion.

[74] "Why Does the Kitchen Waste Disposal Pilot Work?" 2015. February 3, 2015. http://scitech.people.com.cn/n/2015/0203/c1057-26494935.html.

Recommendations for GMI

During the 19th National People's Congress, China's President Xi Jinping emphasized an ecological society, promising a transition from economic growth at the cost of health and the environment. One of the critical components to achieving such a society is through proper management and treatment of urban waste and mitigation of pollution. President Xi pulled municipal waste to the highest level with the import ban on recyclables. Regulatory and financial support efforts at the national and provincial levels have improved significantly, with top-down action, and PPPs that support a number of promising municipal pilot projects. The benefits of implementing co-digestion are being slowly realized by public and private stakeholders. Given the rich experience and successes with co-digestion in the U.S., the U.S. EPA and GMI can play an important role in furthering the successes of co-digestion in China. The foundation for this engagement has rapidly improved with growing regulation and public pressure.

Given China's existing LCCs pilot program, food waste treatment in pilot cities, and city waste separation pilot cities, there are multiple tier-one and tier-two cities that intersect across these three areas that would benefit from exchanges with GMI. GMI efforts should focus on overcoming existing bottlenecks and taking advantage of opportunities outlined in the previous sections. In-depth recommendations are given to address each challenge.

Research

Adequate data collection and utilization is necessary for proper development and monitoring of co-digestion projects.

- A potentially important partnership would be with food waste and water-energy research hubs such as Tsinghua University headed by **Dr. Wen Zongguo** that works with MOST and several food/sludge co-digestion companies and the national standards bureau on the development of a National Biogas Roadmap initiative.
- Other possible research hubs: Tongji University; Harbin Institute of Technology; and the Research Center for Eco-Environmental Sciences at CAS.[75] This hub is mapping all urban and rural treatment plants (WWTPs, StE plants, stand-alone food waste plants, and co-digestion plants).
- Given the differences between each province, to ensure each location has the proper processing capabilities, local-level scoping and assessments are necessary. Such assessments should include: 1. Local wastewater treatment capacity, 2. Sludge treatment capacity, 3. Food waste production, 4. Penetration of natural gas in the market, 5. Regulations impacting the use of biosolids in products (construction, fertilizers, plastics), 6. Local market capacity to incorporate end-use products, 7. Variations in conditions (food waste, temperature, rainwater). GMI or other organizations could develop a template to allow cities to enter data and screen opportunities for food waste co-digestion.
- As programs are implemented, real-time data collection is needed on the collection of food waste, similar to studies that have been run by researchers at Tsinghua University.[76] As there are issues with illegal markets for food waste, such data collection and monitoring will be needed in order to ensure that co-digestion plants are getting adequate feedstock from food waste sources. GMI and other organizations provide information and examples of food waste or similar types of data collection and analysis from the US and Europe that can be applied to China's circumstances.

[75] For a list of experts, see http://ad15.medmeeting.org/Content/37991.
[76] Wen, Zongguo, Shuhan Hu, Djavan De Clercq, and Jianguo Liu. 2017. "Design, Implementation, and Evaluation of an Internet of Things (IoT) Network System for Restaurant Food Waste Management." *Waste Management* 73 (December). https://www.researchgate.net/publication/321740670_Design_implementation_and_evaluation_of_an_Internet_of_Things_IoT_network_system_for_restaurant_food_waste_management.

- Technology development, specifically focusing on pre-treatment, biomethane upgrading, and innovative new types of digesters. We have been told that Chinese companies in this space are very interested in learning about technology and management structures across these areas. GMI and other organizations could provide or develop resources and materials covering technologies

Creating Partnerships and Workshops

Chinese and U.S. NGOs/research centers involved in low-carbon city projects in China.

- Help LCCs learn about including food waste co-digestion as a valuable low-carbon strategy.
    - Action: Engage NGOs like the Paulson Institute or Energy Foundation to discuss how and why they could incorporate food waste and sludge related methane issues (e.g., diversion from landfills, methane capture) in their low carbon projects. Zero Emissions Alliance and other Chinese NGOs have been doing some community-level food waste sorting and it could be helpful to learn from them what cities are taking more action from the government side on co-digestion.

Business and Finance Sector Engagement to help share commercialization strategies for captured methane and sanitized biosolids.

- Many Chinese WWTPs currently use European technology so providing them access to US business and technology partners will help further their growth and expand the market.
    - Action: Explore existing partnerships such as LBNL, CitiBank and the Ma'anshan Rural Commercial Bank - partnering to advance energy-efficiency financing in China (a topic under which co-digestion can be introduced/included). Ma'anshan Rural Commercial Bank is interested in becoming China's first completely green bank and plans to focus on urban infrastructure.
- Opportunities for creating vehicle fuel from biogas are limited and not well understood. There is need to technology transfer and education to inform Chinese stakeholders about the many climate, environmental and economic benefits of biogas vehicle fuel.
    - Action: Engage with bus, natural gas, and car companies as well as the Ministry of Transportation to understand the policy priorities for developing waste biogas integration for CNG/LNG vehicles. This will work well in cities that are already transitioning to large fleets of natural gas public transportation or those that are utilizing natural gas to replace reliance on coal for heating. Ministry of Transportation also oversees China's Green Port initiative, which has switched most shoreside port vehicles and loading machines to natural gas. CEF knows the key researcher in this area and there is an opportunity to inform them on how StE and co-digestion could be a clean form of biogas for their vehicles and loading machines.

Technical Training

- There are a number of successful co-digestion plants throughout China, from Chongqing to Xiangyang to Haikou, all of which have slightly different approaches from the start to finish of the process. Researchers at Tsinghua have connections with these companies who would be interested to learn about technologies for pre- and post-consumer food co-digestion, etc. that are used in the United States.
    - Action: Develop case studies/project profile to share information about co-digestion project successes and lessons learned

- Develop training on “Assessing Waste Management Practices and Feedstock Considerations” Given Chinese cities are primarily (or only) focused on AD technologies without consideration of understanding their current waste management system and future feedstock considerations which must be analyzed first before deciding on a technological solution

Advise on Incentive Structures

- Engage with MEE on wastewater treatment policies in China, sharing examples of U.S. tiered fee structures and revolving fund mechanisms.
- Discuss subsidies and feed-in-tariffs on sludge and food waste with MoHURD in order to promote co-digestion rather than landfilling or illegal dumping.
- Integrate incentives for biogas projects to produce multiple outputs, and for food waste-based projects to co-digest food waste with other substrates as well as sludge-based projects to co-digest with food waste to have higher gas output.

By creating partnerships, hosting conversations, assisting in policy development, and promoting data collection and sharing, the Global Methane Initiative can bring together the U.S. and Chinese governments, nongovernmental organizations and the private sector to explore opportunities for co-digestion.

Appendix A: Food Waste and Loss

Main sources of food waste generation

Globally, food waste is prevalent from farm to fork, or in the case of China, chopsticks. Developing nations like China tend to experience severe loss in early stages of the food supply chain—from production to distribution to processing, where technology is critical to preserving fresh produce.

Production Loss

The Chinese Academy of Agricultural Sciences (CAAS) concluded that the annual food loss before reaching consumers totaled 31.75 million metric tons--6% of China's total food production--which equals the total 2014 food output of the breadbasket province of Jilin.[77]

China's agriculture is fragmented and highly decentralized, with approximately 184 million small farms producing crops, meat, and milk. Despite efforts by the Ministry of Agriculture to modernize the agriculture system and alleviate poverty through larger state farms,[78] crops are mostly grown on small, individual household run farms with an average of 0.7 hectares of arable land, 145 times less than American farmers. Many farmers lack the financial resources and often the incentive (due in part to insecure land rights) to invest in the technology and infrastructure for disease and damage control. This lack of investment has contributed to China losing up to 9% of grains (mostly rice, wheat, and maize); 20-30% of fruits and vegetables; and 5-10% of meat because of pre-harvest infections and natural disasters.[79] China produces approximately 800 million metric tons of crop residues on a yearly basis.[80]

The fragmentation of the agricultural sector makes it difficult for the food industry and the government to monitor the food production process. From chemical inputs and veterinary medication during production to hygiene and temperature control during product storage and shipment, many food suppliers, processors, distributors, and retailers lack robust quality control and safe handling practices to reduce waste.[81] Poorly managed storage, processing, and distribution were estimated to contribute to losses of 8%, 2.6%, and 3% of China's grain output in 2013, respectively.[82] More than half of China's grains are stored at household farms in need of personnel trainings and technical upgrades. Losses of meat, fish, and aquatic products at the post-harvest stage ranges between 1 and 4 percent.[83]

Post-consumer Food Waste

A recent survey of 3,557 tables in 195 restaurants in Beijing, Shanghai, Chengdu, and Lhasa calculated that citizens in these four cities wasted 1.18 million metric tons of food in 2015 while eating out,[84] nearly as much as the total restaurant food waste of Germany (1.72 million tons) in 2013.[85] In medium- and high-income countries,

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[77] Jaing, Heping, and Hui Jiang. 2015.
[78] Mulholland, Jamie. 2018. "Xi Jinping's Rural Revitalization Strategy." *China's Poverty Reduction Online* (blog). March 15, 2018. http://p.china.org.cn/2018-03/15/content_50710642.htm.
[79] Liu, Gang. 2013. "Food Losses and Food Waste in China: A First Estimate." Industrial Ecology Programme and Department of Energy and Process Engineering, Norwegian University of Science and Technology. https://www.oecd.org/site/agrfcn/Food%20losses%20and%20waste%20in%20China_Gang%20Liu.pdf.
[80] Tong, Zhang, Liu Linlin, Song Zilin, Ren Guangxin, Feng Yongzhong, Han Xinhui, and Yang Gaihe. 2013. "Biogas Production by Co-Digestion of Goat Manure with Three Crop Residues." *Plos One*, June. http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0066845#pone.0066845-Jiang1.
[81] Lam, Hon-Ming, Justin Remais, Ming-Chiu Fung, Liqing Xu, and Samuel Sai-Ming Sun. 2014. "Food Supply and Food Safety Issues in China." *Lancet*, June. http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0066845#pone.0066845-Jiang1.
[82] Liu, G, X Liu, and S Cheng. 2013. "Food Security: Curb China's Rising Food Wastage." *Nature*, June. https://www.ncbi.nlm.nih.gov/pubmed/23765482.
[83] Liu Gang. 2013.
[84] Ling-en Wang, Gang Liu, Xiaojie Liu, Yao Liu, Jun Gao, Bin Zhou, Si Gao, Shengkui Cheng, "The weight of unfinished plate: A survey based characterization of restaurant food waste in Chinese cities," *Waste Management* 66 (2017): 3-12, https://doi.org/10.1016/j.wasman.2017.04.007.
[85] M. Blanke, "Challenges of reducing fresh produce waste in Europe: from farm to fork," *Agriculture* 5, no. 3 (2015): 389–399.

a large proportion of food is thrown away by consumers—42 percent in the European Union on average,[86] and nearly 30 percent in North America.[87] Mirroring trends in the western world, consumer food waste in China, while low per capita, has been rising along with urbanization and economic growth.[88]

A 2011 Chinese government report indicated that every year a total of 18.1 percent of grain is lost along the entire supply chain, of which 4.99 million metric tons was household food scraps.[89] It has been estimated that the average Chinese person throws away between 10 and 19 percent of meals ordered at restaurants, with total food scraps equivalent to the annual consumption of at least 200 million people. Food loss rates in canteens and homes have been estimated to be between 5 and 7 percent.[90]

In the spectrum of total food waste, first-tier metropolises like Beijing and Shanghai rank highest, producing 907.2-1814.4 metric tons per day, on par with rates in New York City and Los Angeles, albeit with much larger populations and lower per capita waste.[91] Second-tier cities such as Changsha and Nanjing generated 544.3-907.2 metric tons per day, followed by Fuzhou, Taiyuan, and Shenyang.[92]

To date, the research on food loss and waste in Chinese second-tier cities is far from conclusive due to a dearth of data, but the are trendlines are clear.. Food scraps continue to increase and dominate city waste composition as the economy soars and living standards improve. New strategies in the food recovery hierarchy, changes in social behavior, as well as better integration of new food preservation technologies will be the key to slowing down food waste in China. However, with a population of 1.3 billion there will always be considerable food waste in MSW and cities need to find ways to manage and use it.

[86] "Preparatory Study on Food Waste across EU 27." 2010. *European Commission*, October. https://doi.org/10.2779/85947.

[87] Gunders, Dana. 2012. "Wasted: How America Is Losing Up to 40 Percent of Its Food from Farm to Fork to Landfill." *Natural Resources Defense Council* . August 2012. https://www.nrdc.org/sites/default/files/wasted-food-IP.pdf.

[88] Parfitt, Julian, Mark Barthel, and Sarah Macnaughton. 2010. "Food Waste within Food Supply Chains: Quantification and Potential for Change to 2050." *Philosophical Transactions B*, September. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2935112/.

[89] Liu, G., X. Liu, and S. Cheng. 2013.

[90] J. Bai, T.I. Wahl, B.T. Lohmar, J. Huang, "Food away from home in Beijing: effects of wealth, time and 'free' meals," *China Econ. Rev.* 21 (2010): 432–441.

[91] Greer, Diane. 2012. "Commercial Food Waste Recovery in New York City." *Biocycle* (blog). December 2012. https://www.biocycle.net/2012/12/18/commercial-food-waste-recovery-in-new-york-city/.

[92] Gao Liwei, Cheng Shengkui, Cao Xiaochang, Zhang Dan, Liu Xiaojie, Qin Qi, and Liu Yao, "An Overview of the Resources and Environmental Issues from Wasted Food in Urban Catering Across China," *Journal of Resources and Ecology* 4, no. 4 (2013): 337-343.

Appendix B. Co-digestion Case Study

The First Case of MWW Co-digestion in China

The prefecture-level city of **Zhenjiang** in Jiangsu Province is the first Chinese city using anaerobic co-digestion of food waste and sludge at municipal WWTP. The project, started in June 2016, intends to not only improve harmless treatment of food scraps disposed from restaurants, schools, and canteens across the city but also to replace its current incineration plant with a new StE plant. Retrofitted onto the Jingkou WWTP, the co-digestion project pretreats food waste, followed by high temperature thermal hydrolysis, and highly concentrated AD. Moreover, it aims to have zero waste emissions throughout the procedure. Sludge is dewatered and dried for urban greening purposes, methane is captured and purified to power the plant and the city, wastewater is reprocessed at WWTPs before being discharged, and waste gas is confined to control odors.[93]

Zhenjiang is home to 3 million people, of which 1.2 million are urbanites. There are around 2,600 food service businesses that generate a total of 184.7 metric tons of food waste every day, 127.6 metric tons of which originates from urban areas.[94] But these food scraps are often delivered to livestock farms, and the gutter oil is processed and sold to manufacturers or even (illegally) back to restaurants.

Rising amounts of industrial and residential wastewater have posed another expensive challenge to urban development. The city's 8 WWTPs can handle 350,000 metric tons of wastewater per day and Zhenjiang is considering increasing their treatment capacity by building 2 extra plants. The 97.5 tons of sludge generated by the existing 8 plants is burned at Jianbi Incineration Plant but the moisture content in the sludge undermines its efficiency.

The city's co-digestion project presents a solution to difficulties around food waste, wastewater, and sludge. Zhenjiang Water Corporation, a state-owned enterprise in charge of municipal wastewater management, received 178 million RMB of investment from the government, 20 percent of which was subsidies from the central government. The project is devised to source food scraps from four central districts and retrieve sludge from three WWTPs (Zhengrunzhou, Jingkou, and Dantu), with a treatment capacity of 235.9 metric tons/day equaling 127 metric tons of food waste and 108.9 metric tons of sludge.[95]

Collecting adequate raw materials has been a bottleneck to the project's success, particularly in terms of food waste. Since 2014, the Zhenjiang Water Corporation has reached out to over 2000 agencies that produce food waste, negotiated with 500 to arrange services, and contracted with more than 100 to which trucks go and collect kitchen waste. Some restaurants withdrew their initial support for the project because of the lucrative illicit food waste trade. For instance, a restaurant that owns 50 tables produces around 400 kilograms of food residue daily, and can earn 70,000-100,000 RMB if giving it all as feedstock to a swine farm. Participation in the co-digestion project means a loss of this revenue, without even taking into consideration the labor cost of separating food waste.

When operating at a full capacity, the StE plant can produce 3,200 m^3 of methane per day at a cost of 304.15 RMB per ton of food waste/sludge mixture treated. Most of this is used to run the boilers for thermal hydrolysis; the rest is converted into CNG, which is then sold to municipal gas facilities. The project also generates 37.2 tons of biogas residue and 199.6 tons of biogas slurry for urban greening and soil enrichment. This slurry has become a helpful additive to Zhenjiang's recently initiated "sponge city" policy to expand parks and gardens in order to

[93] "Organic Matter Treatment." n.d. Zhenjiang Water Service Group. http://www.zhenjiangwater.com/list.asp?classid=17.
[94] "2010 Population Census." 2010. National Bureau of Statistics of China. http://www.stats.gov.cn/english/statisticaldata/censusdata/.
[95] "Commission of the First National Restaurant Kitchen Waste and Sludge Co-Digestion Project." 2016. http://www.cn-hw.net/html/china/201606/54004.html.

deal with growing storm water runoff and water scarcity problems. The city also partners with biodiesel companies to refine the 7.26 tons of primary oil created in the AD process.[96]

The company running this co-digestion plant has attached great importance to minimizing negative environmental impacts to the community. It has placed the project at Jingkou WWTP, 650 meters from the nearest residential area, to reduce the potential harms caused by waste gas, water, and solids. Through on-site investigation and expert reviews, Zhenjiang Water Corporation found that half of the odor was attributable to the pretreatment unit because the stench of food waste permeates during the fermentation, so pretreatment trucks now ferment the collected food waste into a slurry in situ and deliver it to sealed compartments. Deodorization equipment was also installed to be used after AD to maximize odor absorbance while dewatering and drying the sludge. Jiangsu Huanke Consulting, a subsidiary of Jiangsu Provincial Academy of Environmental Science, responsible for doing regular monitoring and environmental impact assessments of the project, publishes them online at jshbgz.cn, and solicits public feedback on the reports.[97]

Beyond the environmental and ecological gains, co-digesting food waste and sludge at municipal WWTPs creates employment opportunities for local communities and migrant workers. Employment at the Jingkou WWTP increased from 43 positions to 105.

As the first co-digestion project implemented in China, Zhenjiang represents a model of food waste and sludge management for other Chinese cities to mimic; however, challenges facing this model still remain:

- The collection of food waste relies on the voluntary participation and corporate social responsibility of businesses and organizations. The municipal government needs to tighten regulations over illegal food waste trading, incentivize restaurants to engage in innovative waste treatment projects, and monitor food waste disposal. Otherwise, co-digestion facilities will become “hungry” for input and unable to sustain profitability.
- The management of the final products from co-digestion is far from standardized. Most Chinese cities, including Zhenjiang, have neither formulated a sludge policy nor created a market for CNG or biochar soil generated through AD. Therefore, dumping sludge or incinerating sludge along with MSW is often seen as more favorable than seeking commercial possibilities.

[96] “Zhenjiang Develops Co-Digestion Project for Kitchen and Household Garbage.” 2015. June 24, 2015. http://news.inggreen.com/225.html.
[97] “Zhenjiang City Restaurant Kitchen Waste and Domestic Sludge Co-Processing Project Environmental Impact Report.” 2014. Zhenjiang City Water Corporation. http://www.jshbgz.cn/hpgs/201410/P020141016365705939220.pdf.

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