Scaling Sludge Mountains

Breaking Down Barriers for Chinese Cities to Turn Sludge Waste into Energy

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COVER PHOTO CREDIT: *TOVEN Company, Xiangyang sludge-to-energy plant*

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Abbreviations

AD	anaerobic digestion
BOT	build operate transfer
CEF	China Environment Forum
CNG	compressed natural gas
CNSF	China's National Science Foundation
EPA	Environmental Protection Agency
ERG	Eastern Research Group
FYP	Five-Year Plan
MEP	Ministry of Environmental Protection
MOA	Ministry of Agriculture
MOHURD	Ministry of Housing and Urban-Rural Development
MOST	Ministry of Science and Technology
MWW	municipal wastewater
NDRC	National Development and Resource Commission
NGO	Nongovernmental organization

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China's 'sludge-gates' were opened in 2013 when 30 sludge mountains resulting from illegal dumping were discovered surrounding Beijing, bringing light to the magnitude of the country's sludge problem. Caixin journalists had followed trucks from a Beijing wastewater treatment plant to the city's outskirts, only to discover the drivers were illegally dumping untreated sludge into farmers' fields. This sludge has been a silent killer--contaminating China's soil, groundwater, air, and croplands, and the problem is only growing as urbanization throughout the country rapidly increases. Beyond serious pollution problems, untreated sludge that is landfilled can create considerable methane emissions, a short-lived climate forcing gas.

China produces 40 million tonnes of sludge annually, enough to fill more than five great pyramids of Giza, of which only one pyramid is treated properly. Most of these mountains of sludge have been shipped to landfills and incinerators, or, as found outside of Beijing, illegally dumped into farmland and waterways.

The Wilson Center's China Environment Forum (CEF) produced this sludge scoping report for the U.S. EPA and the Global Methane Initiative. CEF delves into the obstacles and opportunities Chinese cities face in dealing with these sludge mountains, evaluating advanced sludge treatment and use strategies, particularly sludge-to-energy technologies and practices. In this report, we:

1. Describe drivers that created mountains of municipal sludge waste that pollute the environment, endanger public health and increase greenhouse gas emissions in China.
2. Introduce the key political and research entities involved in sludge regulation and research in China and discuss the policy and regulatory trends and gaps.
3. Review obstacles to adoption of anaerobic digestion, which is a crucial technology for sludge-to-energy development.
4. Provide a short case study of the challenges facing a pioneering sludge-to-energy project in one Chinese city.
5. Highlight opportunities for U.S. government, cities, and companies to engage with Chinese government agencies such as the Ministry of Housing and Urban and Rural Development (MOHURD), nongovernmental organizations (NGOs), and other stakeholders to support cities in China to create and sustain sludge-to-energy projects.

1 China’s Sludge Mountain Challenge

As only 20% of the 40 million tons of sludge China produces annually is treated properly, this leaves mountains of sludge that contribute to larger issues of environmental pollution--spanning from soil to water to air. Sludge also has significant impacts on climate through methane gas that is emitted when sludge is landfilled, dumped in a waterway or on farmland, or burned in an incinerator without efficient methane capture technology. Incorrect sludge treatment and disposal poses challenges to China’s ultimate goals to reduce pollution and greenhouse gas emissions, while proper treatment and disposal can produce considerable co-benefits.

1.1 Recognition of China’s Sludge Problem

While smog blanketing Chinese cities has been a major target of public complaints on environmental quality and at the heart of the Chinese leadership’s “war on pollution,” the poor quality of surface water and groundwater rose to higher prominence when the State Council, China’s Cabinet, released the *Water Pollution Prevention and Control Action Plan* (or *Water Action Plan*) in early 2015. The *Water Action Plan* lays out the Chinese government’s actions to improve the water environment by 2020 and “restore positive ecosystem cycles” by mid-century. This will be achieved through tackling excessive agricultural runoff from crops and animals, raising levels of municipal wastewater and sludge treatment, and reducing untreated water emissions from industries.

Encouragingly, the *Water Action Plan* highlights China’s long-overlooked wastewater sludge problem. Sludge treatment policies, orders, pilots, and targets have been released by MOHURD, Ministry of Environmental Protection (MEP) and the State Council since 1985, but they have done little to slow the growing production of sludge that is often landfilled or dumped with limited or no treatment. Among the 76 mandates for wastewater treatment, the *Water Action Plan* requires urban areas in central government-controlled municipalities (Beijing, Chongqing, Shanghai, and Tianjin), provincial capitals (27 cities), and several other key cities to “mostly collect and treat” municipal wastewater by 2017, while other prefecture-level city urban areas must meet the same requirements by 2020.[1]

[1] *People’s Daily*. (2015, April 16). Water Pollution Prevention and Control Action Plan (in Chinese). http://env.people.com.cn/n/2015/0416/c1010-26854928.html.

Such an ambitious expansion of wastewater treatment puts significant pressure on cities to improve their underdeveloped sludge treatment capacity. Since *Caixin* broke the Beijing sludge mountain story in 2013, the central government has raised the importance of sludge in wastewater treatment policies, emphasizing how municipal governments and industries must treat wastewater and sludge as critical urban pollution problem. The *Water Action Plan* mandates an ambitious target to "increase the rate of toxic-free sludge treatment and disposal in prefecture-level cities to over 90 percent by 2020."

Previous sludge regulations only led to a small number of successful, sustainable sludge treatment and disposal projects, but the ambitious sludge treatment goals in the plan could catalyze the necessary large-scale implementation and improvement in sludge management in Chinese cities.

1.2 China's Struggle with Sludge Emissions and Treatment Solutions

Like most of China's energy and environmental statistics, sludge statistics are not immune to the government's poor data collecting and reporting capacity. To date, there are no official data on any stage of sludge's life cycle in China, making it difficult to assess how much sludge is inadequately treated. Estimates vary significantly by source; our research showed that sludge output ranges between 28 and 38 million tonnes per year. (See Table 1). The highest estimate is by Dai Xiaohu, dean of Tongji University School of Environmental Sciences and Engineering and one of the foremost Chinese experts on sludge, who calculated China's sludge output in 2014 to be between 78,500 and 125,600 tonnes daily (see Figure 1), which translates to 28.6–37.3 million tonnes annually.[2] While the estimates presented in Table 1 vary, researchers all report a similar fast growth trend in China's sludge volume as the country pushes for near 100% wastewater treatment. Dai estimated that by 2020, the country's annual municipal sludge output could reach 60–90 million tonnes,[3] which is nearly triple the amount of today's sludge output.

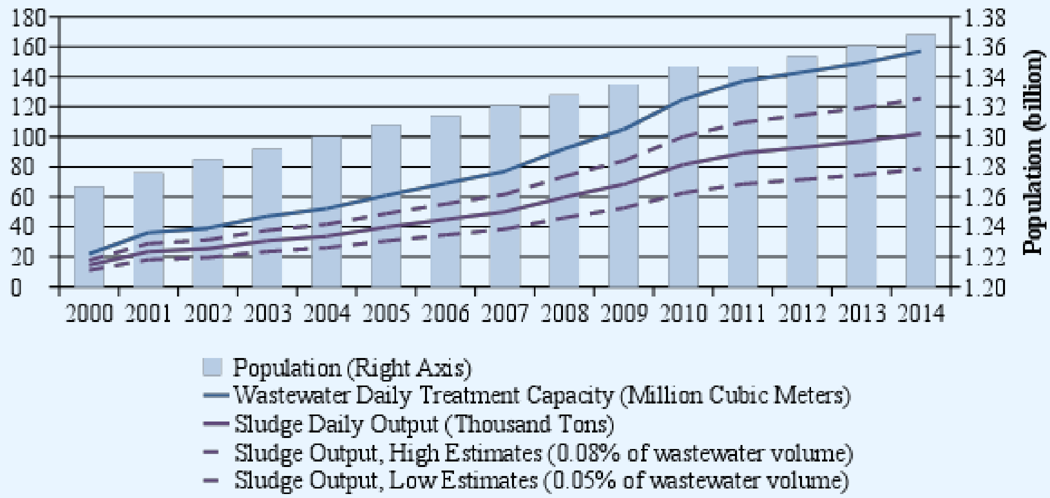
[2] Dai X. (2016). Sludge Safe Disposal and "Resource-lization": Status Quo, Bottlenecks, and Solutions. Bjx.com.cn. http://huanbao.bjx.com.cn/news/20160418/725595.shtml.
[3] Ibid.

Table 1. China Sludge Production, Estimates from Various Sources

Source	Year	Daily Output (tonnes)	Annual Output (million tonnes)
Fu Tao, Tsinghua University	2013	76,600	28
Zhao Yingmin, MEP[4]	2010	82,200	30
Dai Xiaohu, Tongji University[5]	2014	78,500–125,600	28.6–37.3*
U.S Department of Commerce[6]	2015	60,300-82,200	22-30
Essence Securities[7]	2015	95,900	35

* Calculated from wastewater daily treatment capacity (see Figure 1 for detail).

Figure 1. China's Population, Wastewater Treatment Capacity, and Sludge Output (2000–2014)



Source: Dai X., bjx.com.cn

1.2.1 The ABC's of Sludge Treatment and Disposal

Processing sludge normally involves two primary steps: treatment and disposal. Treatment techniques—including **compression and dehydration, thermal drying, hygienization** (usually with lime) —all work to decrease the volume of sludge by reducing its water content. The dehydration process can also use **aerobic or anaerobic digestion** (AD) to further stabilize and dry sludge. The AD process also produces methane, which can be recovered and used as biogas for energy, reducing the plant's energy consumption and greenhouse gas emissions.

Treated sludge can be disposed of in various ways. MOHURD's 2011 *National Technical Guidelines for Sludge Treatment from Urban Waste Water Treatment Plants (Trial)* established a preferred "loading

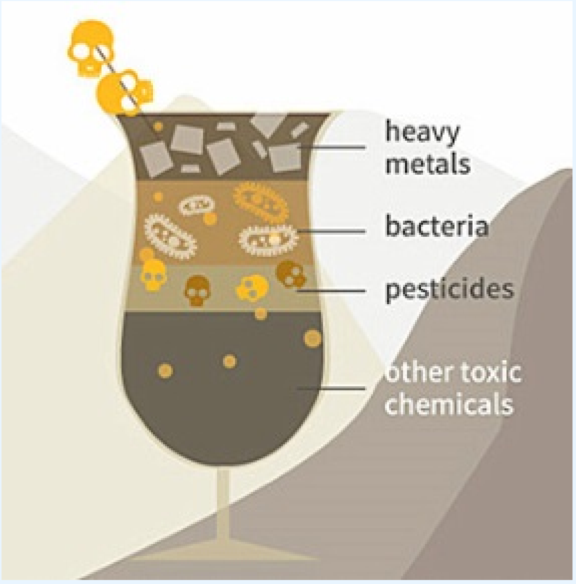
[4] Cui, Z. & Liu, Z. (2013). China's Urban Sludge Dilemma: Sinking in Stink. Caixin Online. http://english.caixin.com/2013-08-08/100566999.html?p3.
[5] Dai X. (2016). Sludge Safe Disposal and "Resource-lization": Status Quo, Bottlenecks, and Solutions. Bjx.com.cn. http://huanbao.bjx.com.cn/news/20160418/725595.shtml.
[6] Joint Department of Commerce and Department of Energy Smart Cities-Smart Growth Business Development Mission to China; April 12-17, 2015. http://energy.gov/sites/prod/files/2014/12/f19/Dept%20of%20Commerce%20and%20Dept%20of%20Energy%20Joint%20China%20Mission%20Statement.pdf.
[7] Zhu H. (2016). Sludge Market Boasts Billions of Wealth. Bjx.com.cn. http://huanbao.bjx.com.cn/news/20160426/727929.shtml.

order" for sludge disposal. In principle, sludge management entities should first consider **land use** as the preferred way of sludge disposal, after using anaerobic or aerobic digestion as the main treatment technique (choosing the former when possible to recover energy). Because sometimes as much as 35% of the water treated at municipal wastewater treatment plants is industrial wastewater, Chinese sludge usually is high in heavy metal content (see Table 2).[8] This has led China's Ministry of Agriculture (MOA) to ban sludge from farmland application. Permissible land use options for municipal sludge are limited mainly to **soil enhancement** (for kaline or desertified soils, abandoned mining sites, or forests) and **urban greening.** In Xiangyang City (Hebei Province), a sludge treatment plant uses digested soil to grow camphor, crape myrtle, and cherry trees, and other plants, in order to increase the economic value of its treated sludge.[9] See a more detailed case study of this Xiangyang plant in Section 4.

Table 2. Comparing Heavy Metal Content in Chinese and German Sludge (mg/kg of Dry Sludge)

Country		Cd	Cu	Pb	Zn	Cr	Ni	Hg
China	***Low***	0.04	51	3.6	217	20	16.4	0.04
	High	999	9592	1022	30098	6365	6206	17.5
	Average	2.01	219	72.3	1058	93.1	48.7	2.13
Germany		1.0	300	37	714	37	25	0.6

Source: Dai X., bjx.com.cn



MOHURD mandates that in places where municipal sludge cannot be used as urban soil enhancer, wastewater utilities may consider **incineration** (sometimes considered a treatment technique when residual ash is utilized afterwards). In some Chinese cities, sludge is incinerated with trash or used in cement kilns or power stations; the remaining ash is then sometimes collected and used in building materials. MOHURD encourages adding ash from incinerated sludge to cement, ceramsite, or foundational material for roadbeds. **Landfills** should be considered the last resort for disposal of sludge ash or partially dried sludge.[10] As many experts emphasized during our interviews, how the "toxic cocktail" of sludge is disposed of depends on what treatment it received. MOHURD guidelines for pairing treatment and disposal techniques are laid out in Table 3.

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[8] Feng, L., Luo, J., & Chen, Y. (2015). Dilemma of sewage sludge treatment and disposal in China. *Environmental Science & Technology, 49*(8), 4781-4782. Retrieved from http://pubs.acs.org/doi/abs/10.1021/acs.est.5b01455.

[9] Fu, X. & Zhong, L. (2015). "Environmental-Energy-Economic Benefit Assessment for Sludge-to-Energy: A Case Study of Capturing Methane from Sludge in Xiangyang, Hubei Province." World Resources Institute.

[10] Ministry of Housing and Urban-Rural Development of the People's Republic of China, & National Development of the People's Republic of China Reform Commission. *Municipal Wastewater Treatment Plant Sludge Treatment and Disposal Technical Guide (Trial)* (in Chinese).

Table 3. Typical Pairing of Sludge Treatment and Disposal Options

Treatment	Disposal Options
Anaerobic digestion > drying (or aerobic digestion)	Land use
Dehydration > aerobic digestion	Land use
Dehydration > hygienization	Co-processing in cement kiln
Dehydration	Co-processing in cement kiln, power station, or waste co-burning
Dehydration > thermal drying > incineration	Ash used in building material or landfill
Dehydration > hygienization	Landfill
Enhanced dehydration	Landfill

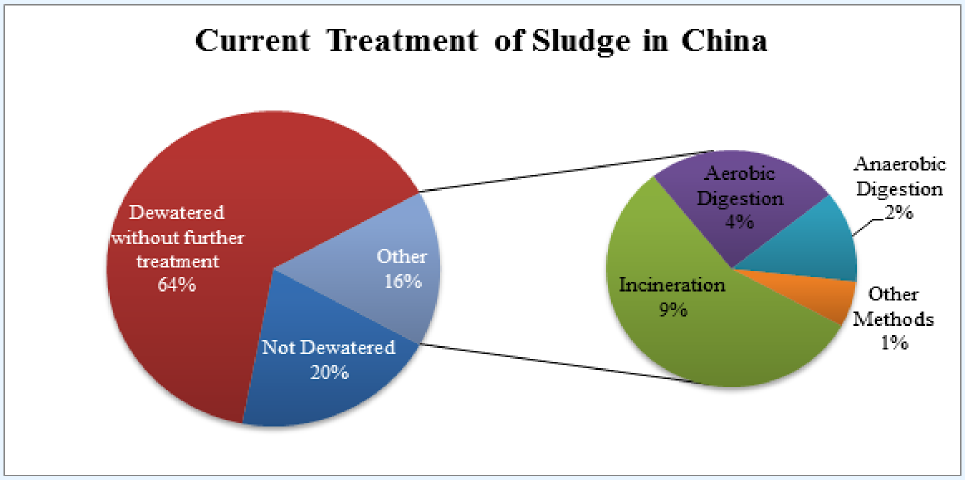
Source: MOHURD, *National Technical Guidelines for Sludge Treatment from Urban Waste Water Treatment Plants (Trial)*

1.2.2 Low Sludge Treatment and Disposal Rates

There is no single research center or database that provides comprehensive information on how much sludge is treated and how it is disposed of in China. To assemble a picture of the overall trends, we conducted many interviews and examined papers, yearbooks, and databases from research institutes across various government ministries and universities.

Chinese research and government documents estimate that **slightly over 80% of sludge in China currently receives primary dewatering** in wastewater treatment plants, i.e., thickening that separates and removes some of the liquid from raw sludge. At least 75 percent of the dewatered sludge does not undergo any further treatment, and is simply landfilled or dumped on the land. Sixteen percent of the dewatered sludge is dried, incinerated, or used in building materials. The remaining 10 percent is stabilized (e.g., through a chemical treatment to break down chemicals and minimize odor and/or harmful bacteria) and land applied. (See Figure 2).

Figure 2. Current Sludge Dewatering Rate and Disposal of Dewatered Sludge in China



Source: Modified figure from Dai X., bjx.com.cn, author interviews and calculations

Sludge treatment rates vary significantly by city, but few cities are close to the *Water Plan* treatment goals. Even the capital city of Beijing is reportedly only treating 23% of its sludge to a degree that its disposal is not harmful to environmental or human health in 2015, but the city has recently installed the first of four new sludge-to-energy plants so this rate should rise in the near future.[11] Only a small number of wastewater treatment plants in the country are capable of enhanced sludge treatment (see Table 4).

Chinese cities leading in sludge management are promoting different disposal techniques: Beijing is encouraging city-wide AD adoption, Changsha and Xiangyang have AD projects, Guangzhou is focused on thermal drying then co-processing (in building materials), while Shanghai prefers incineration.[12]

Table 4. Sludge Treatment Capacity in China

Treatment Technique	Capacity
Dewatering	~80% of all sludge produced by wastewater treatment
Enhanced dewatering	>100 plants
Anaerobic digestion	60 plants, 15-30 plants in operation
Aerobic digestion	~35 plants
Drying + incineration/co-processing	~15 plants

Source: Modified from Dai X., bjx.com.cn

1.2.3 On-the-Ground Sludge Treatment Performance in Chinese Cities

Every day, each of China's first-tier megacities processes a huge amount of wastewater, generating around 3,000 tonnes of sludge requiring treatment. Most cities cannot meet the large demand for sludge treatment and did not meet their sludge treatment targets in the 12th Five-Year Plan (FYP) and have fallen behind the new targets in 13th FYP (see Table 7 and Appendix 1). Existing sludge treatment plants face financing issues and are running below capacity.

北京

For example, as many of **Beijing**'s wastewater treatment plants lacked adequate equipment to store and treat sludge, the city had commissioned private companies to "export" and dump often minimally treated sludge into landfills in surrounding cities or rural areas. In 2015, after some bad media reports about this practice, the Beijing city government announced a policy banning the transport of sludge to other cities; it is now focusing on increasing investments to raise its sludge treatment capacity.

深圳

Similarly, until the practice was halted in July 2015, more than half of **Shenzhen**'s untreated sludge was transported outside the city for treatment or simple disposal in landfills. Even though Shenzhen is a provincial-level city and invests heavily in clean energy technologies, it has not been able to tap the energy potential of sludge—sludge in Shenzhen contains low organic matter and consequently produces a limited amount of methane, thereby making biogas production infeasible. In the past, the Shenzhen Water Resources Office expressed safety concerns over the proximity of residential buildings to methane storage sites. Shenzhen has recently revived its interest in sludge-to-energy, but it is unclear what energy use technology the city may choose.[13]

While Beijing and Shenzhen have struggled with sludge problems, some other first-tier cities have seen greater successes in addressing the policy gaps and capacity issues around sludge treatment. In an

[11] Zhu H. (2016). Sludge Market Boasts Billions of Wealth.
[12] Dai X. (2016). Sludge Safe Disposal and "Resource-lization."
[13] Interview of Shenzhen Water Resource Bureau by Coco Liu and Jennifer Turner June 2, 2015.

attempt to meet the 12th FYP targets, Guangzhou and Shanghai sought technological solutions to address their sludge treatment capacity shortcomings.

广州

- The **Guangzhou** municipal government invested 917 million RMB ($138 million) to update the sludge treatment facilities in five wastewater treatment plants. The updated facilities are projected to reduce the water content of sludge from 80% to 30–40%, a decrease that could enable the city to consider more advanced sludge treatment options like AD.
- **Shanghai**'s 14 wastewater treatment plants can dewater 2,882 tonnes of wet sludge each day, lowering sludge volume to 576 tonnes after the drying process. However, sludge utilization in Shanghai remains low due to low organic content; therefore, most of the partially treated sludge is landfilled. The Shanghai government plans to import advanced sludge drying systems to improve the city's sludge quality and open up more income-generating disposal options. By 2020, Shanghai aims to manage more than 1,000 tonnes of dry sludge per day.

上海

Despite the ambitious sludge treatment goals, financing challenges still face Shanghai's wastewater treatment plants. For example, China's *Sina Blog* reported that Shanghai's Shidongkou Sludge Treatment plant ran at half its capacity in 2006. Experts attributed this to deliberate attempts to cut operational costs and prevent economic loss. Designers also did not take into account the high sand content in the city's sludge, which creates additional maintenance costs.[14] In 2009, Shanghai released a strategic plan to address sludge management. However, despite such policy efforts, there are major gaps in and concerns over the feasibility of the financing targets and the low sludge utilization.[15]

广东

Although central government investments and policy pressure are starting to increase, sludge management is still highly dependent on whether provincial and municipal governments prioritize sludge and create policies and financial incentives. **Beijing**, for example, was reported in 2015 to have only 23% of its 1.02 million tonnes of sludge annually treated and safely disposed of. In contrast, **Guangdong** has made steady progress to meet its 12th FYP targets. 22 sludge treatment plants were processing 72.8% of the province's sludge in early 2015. The provincial government fell short of its 100% treatment goal by the end of 2015,[16] but ultimately achieved a rate of 86%, making it one of the few cities to nearly reach the 13th FYP targeted sludge treatment goal.[17]

杭州

In addition to providing subsidies to cover treatment costs and water rates to promote sludge treatment, in 2015, the Zhejiang provincial government approved investment in a sludge treatment project in **Hangzhou** with the capacity of 4,000 tonnes of sludge per day.[18] By the end of 2017, the project was in operation, and at full capacity it will be able to manage the entire city's sludge. Currently, Hangzhou produces 3,639 tonnes of sludge every day, most of which is given basic dewatering and then

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[14] China Greentech Initiative. (2011).
[15] China Greentech Initiative. (2011).
[16] Guangdong Association of Sludge Industry. (2015, April 23). 100% safe disposal of sludge in Guangdong in 2015 (in Chinese). http://www.gdsludge.com/bencandy.php?fid=47&id=15421.
[17]Cui Hailiang. (2017, June). The management characteristics and its management guidance of harmless disposal of sewage sludge in Guangdong province https://www.google.com/url?q=http://www.doc88.com/p-5159647490870.html&sa=D&ust=1518716098829000&usg=AFQjCNEmmGmkU0UiUvrGqTEYvDLEQ03ObQ
[18] Zhejiang Provincial Development and Reform Commission. (2015, June 9). Notice by the Provincial Development and Reform Commission on the approval of Xiaoshan District 4000 tons / day of sludge treatment project. http://www.zjdpc.gov.cn/art/2015/6/9/art_808_1281436.html.

sent to landfill or land reclamation. The sludge processed by this new project will be of higher quality and able to be used as construction material, for power generation, and as organic fertilizer.[19]

武汉

The city of **Wuhan** has 12 wastewater treatment plants processing 2 million tonnes of wastewater per day. The treatment process generates 1,000 to 2,000 tonnes of sludge per day according to estimates made by MOHURD. However, in 2014 Wuhan could only treat 600 tonnes of sludge per day.[20] The city government planned to build one sludge treatment plant and equip three wastewater treatment plants with sludge treatment facilities for a total capacity of 2,000 tonnes of sludge per day by the end of 2016. As of 2017, the HanXi sludge treatment plant[21] and two wastewater treatment plants (Sanjin Tan and Huajia Hu) equipped with sludge treatment capacity were functioning and bringing treatment capacity to a total of 1,400 tonnes per day.[22]

成都

Four major plants process most of **Chengdu**'s wastewater; collectively, their capacity is 750,000 tonnes of wastewater per day and they generate 375–750 tonnes of sludge per day.[23] In 2013, Chengdu Drainage Company invested in the city's first sludge treatment plant, which can treat 400 tonnes of sludge per day. Following a strategy to meet the growing demand of sludge treatment, this plant in Chengdu has advanced beyond simply landfilling dewatered sludge and has added incineration to lower sludge volumes and to prepare sludge ash for further reuse as construction material.

乌鲁木齐

On the other hand, Veolia, contracted by the government of Xinjiang to operate a sludge-to-energy plant in **Urumqi**, has expressed greater ease in implementing this technology due to its global experience in the field. (Veolia does cite capacity building—e.g., training staff operators—as a major challenge.) Veolia only treats sludge and captures methane; the other products of the process go to a third party, which processes them into compost that it sells to local fruit growers.

Some cities and municipal governments are beginning to take measures to manage their sludge instead of landfilling or dumping it untreated in agricultural fields. Sludge treatment capacity has been expanding in order for municipal wastewater treatment plants to meet wastewater targets laid out in the 12th FYP. Since there is a large gap between the status quo and outlined targets, more incentives and action plans are required to integrate the efforts of local governments and their affiliates, including the Water Affairs Bureaus and Municipal Commissions of MOHURD. See Table 5 for a sample of current technologies that are being tried by cities in China for sludge treatment, reuse, and disposal.

Table 5. Current Technical Routes of Sludge Treatment, Reuse, and Disposal in China*

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[19] Hangzhou Daily Press Group. (2010, July 22). Hangzhou offers incentive for sludge treatment businesses to find most effective and environmentally-friendly sludge treatment options. http://hzdaily.hangzhou.com.cn/hzrb/html/2010-07/22/content_907360.htm.
[20] Xinmin. (2014, June 5). Wuhan treats daily sludge disposal rate of 600 tons to reach 100% by 2020. http://biz.xinmin.cn/2014/06/05/24479533.html.
[21] Wuhan Water. (2017, August). The completion of the Hanxi Sludge Treatment Plant Rectification (in Chinese). https://www.google.com/url?q=http://www.whwater.gov.cn/water/tzgg/9435.jhtml&sa=D&ust=1518716098846000&usg=AFQjCNEMnaizvbQKbuvYskDg59IHH2VCDg
[22] 1400 Tons of Sludge Turning Waste into Treasure in Wuhan, Turning the Streets Green through Nurturing (in Chinese). https://www.google.com/url?q=http://news.cnhan.com/html/minsheng/20170913/870257.htm&sa=D&ust=1518719115119000&usg=AFQjCNEVIy-LBaoIoMKAIoiVgdidsbMDVg
[23] Sichuan Provincial People's Government. (2016, June 22). Downtown Chengdu to increase daily sludge treatment capacity by several tons. http://www.sc.gov.cn/10462/10464/10465/10595/2016/4/22/10377384.shtml.

Technical Route			Equipment	Projects in Cities
Treatment	**Typically used**	Dewatering	Belt filter press, sludge cake water content at ~80–85% (Dry Solids = 15–20%)	
			Centrifugal decanter, sludge cake water content at ~75–80% (Dry Solids = 20–25%)	
			Frame filter press, sludge cake water content at ~60–70% (Dry Solids = 30–40%)	Kunming (Yunnan) Zhangjiagang (Jiangsu)
		Thickening		
		Composting		Guilin and Nanning (Guangxi)
		Incineration (co-processing)		Liuzhou (Guangxi) Zunyi (Guizhou)
		Combustion		Zhuyuan WWTP (Shanghai)
		Anaerobic digestion		Xiangyang (Hubei)
		Aerobic digestion		
		Biogas utilization		Xiangyang (Hubei)
	Newly used	Solar sludge drying		Yucheng and Linyi (Shandong)
		Thermal hydrolysis		Tianjin Xiangyang (Hubei)
Disposal/ Reuse		Land application (fertilizer)		Nanning and Guilin (Guangxi) Tianjin
		Incineration (co-processing cement)		Tianjin and Chongqing Liuzhou (Guangxi) Zunyi (Guizhou)
		Incineration (supplementary fuel resources)		Kunming (Yunnan) Zhangjiagang (Jiangsu) Linyi (Shandong)
		Landfill		Most Chinese cities
		Incineration (sludge only)		Zhuyuan WWTP (Shanghai) Nanjing (Jiangsu) Hong Kong Many cities in Zhejiang

Sources: World Bank Report and data gathered by authors

*List of cities by technical route is preliminary and only meant to illustrate certain examples.

1.2.4 Environmental Threats

Some of the environmental threats from untreated sludge are exacerbating existing water quality problems in China, including:

- Impaired waterways with high levels of fecal coliform and other harmful bacteria can breed various **water-borne diseases.**[24]
- Reduction of oxygen levels in water threaten **aquatic life ecosystems**—a growing concern in China, where all major lakes suffer from eutrophication and frequent toxic algae blooms.[25]
- A study done by the Chinese Academy of Meteorological Services found that over 6,500 metric tonnes of sludge dumped by Beijing Huanxingyuan Environmental Protection Technology Company near the source of Beijing's groundwater over a year caused significant local air pollution (including **severe odor**) and contaminated the surrounding area's groundwater (from excessive levels of **heavy metals, chemical oxygen demand, biochemical oxygen demand, NH_4, coliform bacteria, and *Shigella***).[26] The Chinese news media reported that treatment could initially cost over 80 million RMB ($12 million).[27]
- The exposure of heavy metals, pathogens, nanomaterials, and hormones from land application of sludge fertilizer can bio-accumulate through, if not directly harm, the **food chain**. While levels and sources of soil pollution are treated as state secrets, Chinese researchers have estimated that approximately 20% of China's soil is contaminated with heavy metals. [28] The potential linkages of sludge to soil pollution have accelerated concerns by the public and policymakers about landfills and illegal dumping.

The environmental footprint of sludge goes beyond water and soil: the drying and landfill disposal of sludge also can become a significant source of greenhouse gas emissions. Table 6 presents data from the Asian Development Bank on the carbon footprint of various disposal options for sludge. Landfilling sludge without gas management has the largest carbon footprint; followed closely by land application.

Modern urban wastewater treatment plant Source: hxdyl on Shutterstock (#166378049)

[24] Maine Department of Marine Resources. (2012). The public health risks associated with fecal pollution keeping sewage out of Maine waters. https://www1.maine.gov/dmr/rm/public_health/sewagefacts2012.pdf.
[25] Maine Department of Marine Resources. (2012).
[26] 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.
[27] Yu, D. (2012, March 26). As number of sewage plants soars, nation's sludge problem mounts. *Caixin.* http://english.caixin.com/2012-03-26/100373136.html?p0.
[28] Duggan, J. (2014, April 18). One fifth of China's farmland polluted. *The Guardian.* http://www.theguardian.com/environment/chinas-choice/2014/apr/18/china-one-fifth-farmland-soil-pollution.

Table 6. Carbon Footprint of Sludge Treatment and Disposal Options

Reference Number	Technical Route	Carbon Footprint[a]
1	Thermal hydrolysis, anaerobic digestion, biogas utilization, heat drying (10% moisture content), coal substitution (e.g., in a power plant or cement kiln)	(500)
2	Anaerobic digestion, biogas utilization, landfill with landfill gas utilization	0
3	Thermal hydrolysis, anaerobic digestion, biogas utilization, land application	200
4	Anaerobic digestion, biogas utilization, compost, land application	450
5	Anaerobic digestion, biogas utilization, land application	950
6	Heat drying(10% moisture content), coal substitution	1,300
7	Composting, land application	2,400
8	Heat drying, gasification, energy recovery	4,750
9	Lime stabilization, land application	4,900
10	Heat drying, incineration, heat recovery	5,900
11	Landfill with landfill gas utilization	6,200
12	Anaerobic digestion, biogas utilization, landfill without landfill gas management	6,300
13	Heat drying (65% moisture content), land application	7,600
14	Heat drying (40% moisture content), land application	10,000
15	Landfill without landfill gas management	30,000

( ) = negative.

[a] Based on a typical urban wastewater treatment plant treating 100,000 cubic meters/day, producing 80 tons/day of dewatered sludge with 80% moisture content; carbon footprint indicated as tons of carbon dioxide equivalent/year.

Source: East Asia Department, ADB.

Illegal municipal and industrial sludge dumping remains a prevalent issue and a major threat to the environment. While some enforcement is occurring, the frequency is minimal and insufficient to deter the practice:

- In the 2013 Beijing sludge dumping case, the main offender was sentenced to nearly 4 years in prison and fined 30,000 RMB ($4,500).
- In June 2010, five offenders dumped over 2,700 tonnes of sludge into the Yangtze River near Wuxi city. The sludge contaminated water irrigating nearby rice fields. They were sentenced 3 years' imprisonment and fined 90,000 RMB ($14,000).
- In March 2013, Nanjing Environmental Protection Bureau discovered that Changhua Recycling Company and Jiangxinzhou wastewater treatment plant had been illegally landfilling over 33,000 tonnes of sludge.
- Between April and June 2012, two leather manufacturing plants and four dyeing plants hired Xincheng Resource Reuse Company to transport and dump over 2,000 tonnes of chemical-rich sludge at a port, which contaminated a nearby river.
- In September 2011, over 60,000 tonnes of sludge produced from dyeing processes were dumped onto an empty field stretching over 9,200 square meters. The sludge also entered a nearby water body.

2 State of Sludge Management Policy in China

2.1 Government Agencies, Regulators, & Research Institutes on the Frontlines of Municipal Sludge

Four national-level agencies are leading planning, policymaking, and standard-setting for sludge treatment and development in China—the State Council, the National Development and Reform Commission, the Ministry of Environmental Protection, and the Ministry of Housing and Urban-Rural Development.

- The country's top leadership cabinet—**the State Council** and **NDRC**—formulate broad plans with targets and investment goals for sludge treatment that provide direction to other government agencies and cities.
- Following the goals and directives by the State Council and the NDRC, **MOHURD** issues national standards and technical manuals to offer operational guidance for sludge treatment plants and for municipal governments to monitor the process and results. MOHURD leads national research programs to improve sludge treatment. Its lower-level departments at the provincial and city levels wield considerably more power than the Ministry of Environmental Protection in overseeing city performance on sludge issues.
- The **MEP** also follows State Council and NDRC plans as it develops pollution emission control regulations and standards. MEP's Water Office sets monitoring and emission standards for wastewater and sludge emissions (into water and air) and disposal, but MEP depends on its lower-level bureaus to enforce the standards and ensure sludge disposal methods meet the national standards. MEP and its Environmental Protection Bureaus have low levels of funding and political authority, limiting their effectiveness.

While these agencies issue regulatory frameworks for sludge development, other central-level agencies determine the technical routes for sludge utilization and disposal, from which issues of overlapping jurisdiction and lacking coordination emerge. For example, the **MOA** prohibits treated sludge to be reused in agriculture, despite existing MEP national standards for sludge application since the 1980s. MOA's decision discourages high-cost sludge treatment and underscores an ongoing confrontation between national ministries due to a lack of communication and coordination.

State-owned research institutes are taking the lead on sludge technology innovation, acquisition, and evaluation, providing professional directives on science and technology for executive departments. Two institutes are focusing specifically on sludge: the **State Environmental Protection Engineering Center for Sludge Disposal and Resource** (founded in 2010, the first engineering research center under the MEP) and the **National Strategic Alliance for Technological Innovation of Sludge Treatment and Disposal Industry**.

Other research centers on wastewater treatment and environment science, such as the **China Urban Water Association** and the **Chinese Society for Environmental Sciences**, are increasingly focused on sludge issues. Furthermore, several associations bring together scholars, engineers, and entrepreneurs from the sludge field to promote the communication and development of sludge management, including:

- National Association for the Promotion of Sludge Treatment and Disposal
- Strategic Alliance for Technological Innovation of Sludge Treatment Industry

Beginning in 2009, MOHURD began gathering representatives from these research and industry institutions to attend an annual national seminar focused on urban sludge technology application. Also represented at these gatherings are research centers, schools, and departments within various universities that have been key in providing research to inform national-level policies, strategies, guidelines, and action plans, as well as offering consultation for the aforementioned state-owned research institutes. The following have been major sludge research hubs:

- School of Environment and Natural Resources, Renmin University of China
- Institute of Urban Environment, Chinese Academy of Sciences
- College of Environmental Science and Engineering, Tongji University
- School of Environment, Tsinghua University
- School of Earth Sciences, Zhejiang University
- Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences

Some of these institutes were contracted by either MOHURD, MEP, or state-owned research institutes to conduct studies and/or tapped for input on regulations/technologies related to sludge treatment. We have not determined if the Ministry of Science and Technology (MOST) or China's National Science Foundation (CNSF) have awarded any of them research grants related to sludge treatment. As the sludge problem is gaining higher recognition as a national problem, it is likely there soon will be funding programs from MOST/CNSF for research into wastewater and sludge treatment technologies.

2.2 Regulations and Targets for Sludge Treatment

National policies on sludge treatment had an early start in 1984, but they have developed slowly. (See Table 7 for a summary of key national policies and targets, and Appendix 2 for an in depth list of regulations and laws since 1984.) From 1984 to 2008, MOHURD and MEP developed four national standards on sludge quality for wastewater and sludge treatment plants in different disposal routes: agriculture, gardens or parks, co-landfills, and land improvement. MOHURD amended three of the four standards and issued a fifth on forestry application. All five standards went into effect on June 1, 2011.

Table 7. Key National Policies and Targets for Sludge Management

Year	Governing Agency	Policy/Institution	Developments
2006	MEP	*Guiding Rules for the Release of Environmental Information on Solid Waste in Medium- and Large-Sized Cities*	Requires medium- and large-sized cities to publish information on solid waste treatment each year
2009	MEP	*Policy on Sludge Treatment and Pollution Prevention Technology in Urban Wastewater Treatment Plant (Trial)*	Offers a comprehensive regulatory framework on sludge management
			Offers mechanisms to ensure national standards are met
			Offers guidance on financial and operational management options
			Recommends local governments adjust wastewater rates to include the cost of sludge treatment
2010	MEP	*State Environmental Protection Engineering Center for Sludge Disposal and Resource*	Creates a national-level research center responsible for technology advancement, project evaluation, and personnel training in sludge treatment
2011	MOHURD	*National Technical Guidelines for Sludge Treatment from Urban Waste Water Treatment Plants (Trial)*	Provides a comprehensive guide on international practice, comparative analysis of sludge technologies, assessment of treatment and disposal methods, and risk management
			Offers technical guidance to wastewater treatment on sludge technology application
			Establishes a "loading order" for sludge treatment and disposal*
2011–2015	State Council	*China's 12th Five-Year Plan*	Provides clear targets for sludge treatment rates for each province in wastewater plants
2012	State Council	*Plan for the Construction of Urban Wastewater Treatment and Reuse Facilities (2011–2015)*	Sets up clear targets for each province to process their urban sludge treatment during the 12th FYP
2013	State Council	*Urban Drainage and Wastewater Treatment Directive*	Recommends local governments allot part of wastewater revenue to cover sludge treatment fees and significantly raises fines for cities that violate existing sludge emission standards
2015	NDRC	*Notice on Adjusting Rates for Wastewater Treatment Service*	Central government affirms subsidies will be given to cover sludge treatment costs
2015	State Council	*Water Pollution Action Plan*	Existing sludge treatment and disposal facilities should be retrofitted to meet compliance requirements by 2017; prefecture-level and above cities should increase the rate of toxic-free sludge treatment and disposal to over 90% by 2020
2017	NDRC	*13th Five-Year Plan on Urban Wastewater Treatment*	Sets goals that by 2020, wastewater treatment facilities should cover all urban area, urban wastewater treatment rate should be 95%, and urban harmless treatment rate of sludge should reach 90%

* "Loading order" prioritizes land use employing anaerobic digestion and aerobic fermentation treatment techniques (choosing the former first). If land requirements do not permit land use, then co-processing incineration follows. Landfilling should be the last resort.

In China, current regulations require that before landfilling sludge must be pretreated so water content drops to 45–60 percent (municipal waste sludge must be at the lower end of this range).[29] As Chinese wastewater treatment plants usually only dewater sludge down to 78–80 percent water content, most municipal wastewater treatment plants have had to dump their sludge illegally. Incineration also requires enhanced dewatering, which explains why incineration has been slow to develop in many cities. Treatment processes also significantly increase the cost of sludge management (see Table 8). Lack of public awareness of sludge's environmental threats, combined with weak capacity and incentives for the government to hold illegal dumpers accountable, have further discouraged wastewater treatment facilities from spending limited finances on infrastructure and operations to seek further sludge stabilization and treatment.

Table 8. Capital and Operational Expenditure Estimates of Various Sludge Treatment Technologies

Technology	CAPEX (Thousand RMB ($)/Tonnes of Wet Sludge*)	OPEX (Thousand RMB ($)/Tonnes of Wet Sludge*)
Anaerobic digestion	200–400 RMB ($30,000-$60,000)	60–120 RMB ($9,000-$18,000)
Aerobic fermentation	250-450 RMB ($37,500-$67,500)	120–160 RMB ($18,000-$24,000)
Thermal drying	Chinese technology: 100–200 RMB($15,000-$30,000) Imported technology: 300–400 RMB ($45,000-$60,000)	N/A
Hygienization with lime	20–40 RMB($3,000-$6,000)	50–150 RMB ($7,500-$22,500)

Source: MOHURD, *Municipal Wastewater Treatment Plant Sludge Treatment and Disposal Technical Guide (Trial)*

* Wet sludge defined as 80 percent water content.

China's 12th FYP laid out an ambitious target to increase the country's sludge treatment capacity by 5.18 million tonnes per year. The 12th FYP also pushed for an increase in the rate of safely disposed sludge by expanding its use in building materials, incineration, fertilizer production, and safe landfills. See Table 9 for sludge safe disposal goals according to city type. Specific targets for regions throughout China can be found in Appendix 1.

[29] Ministry of Housing and Urban-Rural Development of the People's Republic of China. (2009). Disposal of sludge from municipal wastewater treatment plant—Quality of sludge used in land improvement (in Chinese).

Table 9. Sludge Safe Disposal Targets for Urban Areas in China's 12th FYP

Sludge Safe Disposal Targets	2010	2015
36 major cities*	<25%	80%
Municipalities		70%
Counties		30%
Designated towns		30%

Source: MOHURD: *Plan for the Construction of Urban Wastewater Treatment and Reuse Facilities, 2011–2015*

* The 36 major cities include four central-government-controlled municipalities, five designated municipalities, and 27 provincial capitals.

Of the 430 billion RMB ($65 billion) allocated for the wastewater treatment sector in China's 12th FYP, only 34.7 billion RMB ($5 billion) was allocated to improve the capacity of sludge treatment and disposal. Despite sludge treatment receiving a small part of the investment in wastewater treatment, the increase in funding for it indicates the leadership is beginning to recognize the importance of sludge management.

Despite these ambitious goals, the actual implementation of sludge investment and achievement of safe disposal targets has proven to be difficult.

- In June 2013, the NDRC conducted a mid-term evaluation of the sludge treatment plan and found only 8 billion RMB ($1.2 billion) had actually been invested.
- In late 2013, MOHURD reported only 43.4 percent of the sludge treatment capacity target was achieved.[30]
- By the end of 2014, about 60 percent of the provinces were behind targets in sludge treatment infrastructure investments.
- By early 2015, MOHURD announced that only 56 percent of municipal sludge was being disposed of safely. Another one-third is stored temporarily, while the remaining approximately 10 percent of the country's sludge cannot be traced.[31] The rate of increase of safe disposal from 2012 remained significantly behind what had been targeted in the 12th FYP.

These results are perhaps not as dismal as they appear on the surface: the fact MOHURD and NDRC are publicizing the poor results indicates that more "sticks and carrots" will likely be employed over the next few years. For example, in 2013 the State Council's *Urban Drainage and Wastewater Treatment Directive* raised fines for cities and utilities in violation of sludge emission standards. Two years later, NDRC issued a notice adjusting rates for wastewater treatment and affirming that subsidies will be given to cover sludge treatment costs. MOHURD has been steadily increasing its actions in the area of sludge, from ramping up its investments in research to creating a clear "loading order" for sludge treatment and disposal. MEP is using the *Water Action Plan* to ramp up its monitoring of water pollution from wastewater treatment plants, which is yet another source of pressure on cities. The 13th FYP on Urban

[30] Ministry of Housing and Urban-Rural Development of the People's Republic of China (2014, January 28). Bulletin of the Ministry of Housing and Urban-Rural Development on urban sewage treatment facilities in the fourth quarter of 2013 the construction and operation of communications (in Chinese). http://www.mohurd.gov.cn/zcfg/jsbwj_0/jsbwjcsjs/201403/t20140320_217412.html.

[31] Caixin. (2015, July 11). Nearly half of China's sludge is not safely disposed (in Chinese). http://china.caixin.com/2015-07-11/100828106.html.

Wastewater Treatment sets clear goals for local governments by the end of 2020, helping to reinforce the recent MOHURD, State Council, and NRDC priorities around sludge. This plan increases ambitions from the 2015 targets in both wastewater treatment and safe sludge disposal, including a goal for the rate of urban wastewater treatment to reach 95% amongst others, as shown in Tables 10 and 11.

Table 10. Sludge Safe Disposal Targets for Urban Areas in China's 13th FYP

Sludge Safe Disposal Targets	2020
Prefecture-level cities	90%
All other cities	75%
Counties	60%

Source: China's 13th FYP on Urban Wastewater Treatment

Table 11: Wastewater Treatment Targets for China's 13th FYP

Wastewater Collection and Treatment Target	2020
Prefecture-level cities	100%
Counties	85%
Eastern Regions	70%
Western Regions	50%

*the Beijing-Tianjin-Hebei, Yangtze River Delta, and Pearl River Delta should realize the goal one year early
Source: China's 13th FYP on Urban Wastewater Treatment

3 Key Barriers for Advanced Sludge Treatment

3.1 Financing Policy Obstacles

Landfilling and water prices are major barriers for any meaningful sludge treatment or safe disposal of sludge in China. Landfills have become the most popular disposal solution because of low tipping fees. Cities in China pay between 30 and 50 RMB (around $5–8) per metric tonne for landfilling, considerably less than in other countries. The EU, for example, charges between 70 and 100 euros ($79 and $112) per tonne of sludge landfilled,[32] about 14 times more than China charges. Even with these low fee rates for landfilling, illegal dumping of sludge appears to be fairly common in China.

In an interview with China Water Risk, Professor Ma Zhong, dean of Renmin University's School of Environment, offered insights into the water pricing gaps facing industrial and municipal water use and treatment that is hindering the expansion of sludge treatment.[33] Water resources fees are determined by local governments and vary greatly across cities. However, a national wastewater discharge fee is supposed to be consistently applied across the country. Currently, China's water price policy is divided into four components:

- Water resource fee
- Tap water fee
- Wastewater treatment fee
- Wastewater discharge fee

水费

Challenges with current water pricing policies are traced back to government incentives to spur economic growth, as evidenced by low discharge standards and low water prices. Many industries enjoy subsidized water prices and, when possible, tap even cheaper residential water sources. Low water fees have not created incentives for conservation or sufficient treatment of water. Statistics on the severity of water pollution vary and can be (perhaps intentionally) vague. In 2015, MEP reported that only 3.4 percent of 968 water monitors ranked surface water at the top grade, while its survey of 5,000 groundwater monitors found 60 percent of groundwater at a level that should not come in contact with humans.[34] Somewhere around 35–40 percent of China's surface water is categorized in the Chinese pollution level scale as IV, V, and V+.[35]

Municipal governments—wishing to protect both industry and poorer segments of the population—have been hesitant to increase water fees too much. Gaps between water fees and treatment costs reveal major financing challenges for sustainable sludge development. In 2011, the average industrial water resource fee was RMB .013/tonne, about one-twelfth to one-third of water withdrawal costs

[32] Yu, D. (2012, March 16). As number of sewage plants soar, nation's sludge problem mounts. *Caixin.* http://english.caixin.com/2012-03-26/100373136.html?p0.

[33] China Water Risk Interview with Professor Ma Zhong

[34] https://www.rt.com/news/265186-china-water-air-pollution/

[35] Water at level IV may be used for industrial and recreational activities but not with direct human contact; V's only acceptable use is agriculture and landscaping. V+ is not suitable for any use.

(RMB 0.4–1.6/ton). The average industrial wastewater treatment fee was RMB 1.28/tonne, about one-eighth to one-quarter of the actual treatment costs (RMB 5–10/tonne).

Instead of wastewater plants internalizing these costs, major plants operate at an economic loss and cannot afford proper treatment. With major financing gaps, plant operators often seek the cheapest treatment and disposal options, which are often inadequate, energy-inefficient, and harmful to the environment. By cutting corners on treatment practices and operations, wastewater treatment plants are not investing in methane capture or energy recovery technologies which they view as another cost and operations issue.

Table 12. Current Subsidies Available to Sludge Plants in Various Provinces/Cities

Plant Location	Treatment/Disposal Solution	Subsidy (RMB ($)/metric tonne)
Xiangyang	Anaerobic digestion	254 RMB ($38)
Dalian	Anaerobic digestion	135 RMB ($20)
Ninghai	Anaerobic digestion	200 RMB ($30)
Baotou	Aerobic digestion	90 RMB ($14)
Beijing	Drying + cement co-processing	315 RMB ($47)
Xiamen	Landfill, brickmaking, urban greening	130 RMB ($20)
Guangzhou	Drying + brickmaking	195 RMB ($29)
Qinhuangdao	Compost	130 RMB ($20)
Shandong	Compost	180 RMB ($27)
Jiangsu	Enhanced dewatering + incineration	258 RMB ($39)
Jiangsu	Incineration	95 RMB ($14)
HK	Incineration	HK$ 1,000 ($130)
Jiangsu	Incineration	180–200 RMB ($27-30)
Nanjing	Incineration	86 RMB ($13)
Shanghai	Incineration	280 RMB ($42)
Zhejiang	Incineration	100 RMB ($15)

Source: World Resources Institute. (2015). *Environmental-Energy-Economic Benefit Assessment for Sludge-to-Energy: A Case Study of Capturing Methane from Sludge in Xiangyang, Hubei Province*

In 2014, a group of researchers at Tsinghua University estimated that treating all the sludge in China would require around one trillion RMB ($150 billion) of new investment.[36] To put that number into perspective, China's total sludge treatment and disposal investment budget between 2010 and 2015 was only 34.7 billion RMB ($5.2 billion).

The central government has made policy pledges to increase wastewater treatment fees. The *Water Action Plan*, for example, states "municipal wastewater treatment fee standards should not be below the combined cost of wastewater treatment and sludge treatment and disposal." Pricing standards from Ministry of Finance are still being developed, though, without a concrete timetable for completion. In the meantime, several local governments that recognize the importance of sludge treatment are currently giving sludge-specific subsidies (based on tonnage of sludge treated/safely disposed of; see

[36] Sina. (2014, January 8). 12th Five-Year Plan's 34.7 billion RMB investment for sludge development is not enough (in Chinese). http://finance.sina.com.cn/chanjing/cyxw/20140108/132317883604.shtml.

Table 10). Table 13 in Section 4 discusses the types of subsidies the Xiangyang project secured to completely cover costs.

3.2 Roadblock to Adoption of Anaerobic Digestion

Chinese policymakers realize that simply landfilling or incinerating sludge not only produces additional damage to the environment—in the form of soil contamination, odor, or poor air quality—but also sidesteps tremendous opportunities to capitalize on the resource potential found in sludge.

A number of reasons have slowed China's adoption of AD technologies:

- In 2009, MEP wrote its own technical guideline that "when a wastewater treatment plant is over 5,000 m^3/day in wastewater treatment capacity, AD becomes the most economical technique to process its sludge."[37] However, in practice, AD adoption has been slow and hindered by actual or perceptions about low organic content in Chinese sludge (see next).
- Chinese sludge typically exhibits lower organic content than sludge in other countries because it is typically composed of industrial and municipal wastewater and urban runoff (see Table 11). Because industrial and municipal sewage collection systems are often combined, higher concentrations of macro-nutrients, including potassium, nitrogen, phosphorus, persistent organic pollutants, and grit from industrial and storm water runoff are introduced into the sludge mix.[38] Grit in Chinese sludge is usually smaller in diameter (averaging 50 µm) than in developed countries with better drainage systems (above 200 µm).[39] Low organic content prevents AD from functioning at a high load, and the grit from rainwater wears away facilities faster. Compounding matters, opportunities for increasing organic content through co-digestion of food waste with sludge has an even lower adoption rate by wastewater treatment plant operators.

Table 13. Comparing Organic Content in Chinese and German Sludge (% in Dry Sludge)

Country	Organic Matter	Total Nitrogen	Total Phosphorus	Potassium
China	30–60%	1.3–4.1%	0.2–2.6%	0.4–1.0%
Germany	50–75%	4–5%	2–3.5%	0.2–0.3%

Source: Dai X., bjx.com.cn

- Many Chinese wastewater treatment plant operators do not fully understand the quality of their sludge and the incompatibility between their sludge and the AD technologies (some imported from abroad). The mismatch between foreign technology and Chinese sludge, along with higher maintenance costs, often leads to operational shutdowns. Very few operators have the technical knowhow and capacity to adopt measures to increase sludge's organic content—for example, blending with food waste—or increase methane production while reducing CO_2 (current average

[37] Ministry of Environmental Protection of the People's Republic of China. (2009). Best available techniques directive for treatment and disposal of sludge from wastewater treatment plant (in Chinese). http://www.mep.gov.cn/gkml/hbb/bgth/200910/W020081128537317891756.pdf.
[38] Feng, L., Luo, J., & Chen, Y. (2015). Dilemma of sewage sludge treatment and disposal in China. *Environmental Science & Technology, 49*(8), 4781-4782. Retrieved from http://pubs.acs.org/doi/abs/10.1021/acs.est.5b01455.
[39] Interview with Xue Chonghua

methane content in biogas produced from sludge is around 65 percent, but researchers believe pretreatment and better management can increase methane content to 80–90 percent).[40]

- As discussed previously, government subsidies and market investment have failed to meet the high capital and operation costs of AD projects. These projects normally expect a lower methane production rate in early stages; this lower early return makes it difficult for them to last beyond infancy.
- There are several barriers to building sustainable, profitable business models around sludge. While MOHURD has approved the use of bio char from sludge AD for tree planting in urban areas, the central government banned agricultural irrigation with wastewater and land application of sludge in January 2013, due to reports of municipal wastewater being contaminated with industrial waste.[41] This is an understandable precaution, but it makes land application of treated sludge—such as composting—illegal, and has thus eliminated a revenue source that could support a promising business model. Furthermore, most local governments have yet to create sustainable and dependable channels to use biogas produced by AD projects. Incentives for using biogas in various sectors are scarce. When biogas is not properly consumed, it becomes a safety hazard to surrounding communities.

According to Zeneca Research Institute, China has some 50 AD facilities. All are in medium or large wastewater treatment plants, in cities such as Beijing, Shanghai, Tianjin, Chongqing, Qingdao, Shijiazhuang, Zhengzhou, Shenyang, Nanjing, Jinan, and Xiangyang; only about 20 are still operating (see Table 14).[42]

Table 14. Selected Anaerobic Digestion Projects in China

Location	Temperature	Sludge Volume	Methane Use
Beijing Gaobeidian	33–35°C	800 tonnes/day	Power generation
Tianjin Jizhuangzi	33–35°C	1620 tonnes/day	Power generation
Hangzhou Sibao	35–40°C	—	Power generation
Zhengzhou Wangxinzhuang	35 ± 1°C	500 tonnes/day	Heating boiler
Dalian Xiajiahe	35–40°C	600 tonnes/day	Natural gas purification
Qingdao Maidao	35 ± 2°C	109 tonnes/day	Power generation
Beijing Xiaohongmen	35°C	800 tonnes/day	Power generation
Shanghai Bailonggang	35–40°C	1,020 tonnes/day	Heating boiler
Xiangyang	40°C	300 tonnes/day	Heating + CNG

Source: Zoneco

[40] Dai X. (2016). Sludge Safe Disposal and "Resource-lization."

[41] Yu, J. (2011). The foreground analysis of sewage sludge agriculture application in China. *Advanced Materials Research*, *335-336,* 1316-1320. Retrieved from http://www.scientific.net/AMR.335-336.1316.

[42] Zoneco. Study and analysis on anaerobic digestion technology of sludge in typical cities in China. http://www.zonesi.com/news_.php?newsI=59.

4 Yuliangzhou Sludge-to-Energy Plant in Xiangyang City

The Yuliangzhou sludge-to-energy project in central China's Xiangyang City is the first Chinese project using high-temperature thermal hydrolysis, highly concentrated AD, and methane capture and utilization technology. The project not only has solved Xiangyang's air pollution problem associated with inadequate sludge disposal practices, but also is protecting the water quality of Xiangyang's Han River, an important river in China's South-North Water Transfer project. Important to the project's long-term sustainability is how it developed a business model and achieved profitability by selling various byproducts generated from the AD process. This example is now being replicated in other Chinese cities such like Hefei and Beijing.

Not far from downtown Xiangyang, Yuliangzhou is a 6,424-acre island surrounded by the Han River. The island has no industrial development and residential buildings are scarce. It is home to the city's largest wastewater treatment plant (300,000 m^3 wastewater/day), which generates 270 tonnes of sludge daily.

Like many other cities in China, Xiangyang—a prefecture-level city in northwestern Hubei Province with a relatively small population of 5,591,000—used to dump sludge in landfills.[43] In recent years, growing land shortage forced the Xiangyang wastewater utility to seek alternatives. It first tried to use sludge as an alternative fuel for cement kilns. However, the local government called off the incineration project when its production process resulted in the emission of hydrogen sulfide, sparking protests.

One company's failure has become another company's opportunity. TOVEN, a Chinese private firm specializing in waste-to-energy, introduced high-temperature thermal hydrolysis with AD to Xiangyang, and the project went online in 2012. The plant received 180 million RMB ($27 million) of investment. The company provided 30 percent of the investment; 60 percent came from a low-interest loan from China Import-Export Bank and a German bank. China's Ministry of Finance coordinated the loan application with the banks and financed 10 percent in central government subsidies.

Along with wastewater sludge, the project was designed to treat kitchen waste. Handling kitchen waste properly is another challenge facing Chinese cities, as kitchen and restaurant food waste is rarely recycled, making solid waste very wet and difficult to incinerate. TOVEN was able to help solve this

[43] Official Website of Xiangyang Municipality. (2013). http://en.xf.cn/.

problem, having learned from foreign peers that adding kitchen waste to wastewater sludge can increase organic matter and boost methane production.

The company has some 40 trucks going to restaurants in the city three times a day to collect kitchen waste. In terms of sludge, 230 tonnes come from a nearby wastewater treatment plant via pipelines and 70 tonnes are delivered by truck from a small wastewater treatment plant 15 kilometers away.

The project's initial capacity was 300 tonnes/day. In 2013, the project expanded its capacity to 450 tonnes/day, including 300 tonnes/day of sludge and 150 tonnes/day of kitchen waste. At the end of 2015, the project not only completed the treatment of 150,000 tonnes of sludge left by the incineration project, but also managed to handle all the sludge and almost all the kitchen waste from Xiangyang City.

The project produces 12,000 to 16,000 cubic meters of biogas per day and half is used to run the facility. The rest is converted into 3,000 to 4,000 cubic meters of compressed natural gas (CNG). CNG is then sold at a gas station built by TOVEN outside the sludge facility. The generated gas is sufficient to serve 400 vehicles per day, and customers include local taxi drivers, bus companies, and a nearby driving school in Yuliangzhou Island. For now, Xiangyang does not have any policy favoring sludge-generated CNG, and the project operator sells its gas at the same price as conventional CNG.

TOVEN chose to produce CNG rather than combusting methane for power generation because it believes there is a growing demand for CNG in Chinese cities. In Xiangyang, for example, all the taxis and city buses in the city are now running on CNG, due to concerns over air pollution.

As well as CNG, TOVEN sells biochar produced from the AD process. Though MOA has banned the use of sludge in farmland, the company targets tree growers as key buyers of biochar soil. The company also sells "container" forests, or potted trees grown in biochar soil, which are sold to parks and gardens. Demand for these is expanding since the central government has begun pushing a "sponge city" policy for cities to create solutions to growing storm water runoff and water shortage problems. They can also be used to green wastelands that are otherwise unable to grow trees. By expanding to container forests, TOVEN has found a way to get around the limited market demand for fertilizers like biochar soil. It has also avoided competition with other companies that produce compost from sludge.

Sales of container forests, biochar soil, and CNG make up about 50 percent of the project's revenue. But payments from the local government for sludge treatment and kitchen waste treatment (254 RMB ($38) to treat every tonne of sludge; 59 RMB ($9) to treat every tonne of kitchen waste) are still the main source of revenue. The subsidies were decided during the project's bidding process and rates have stayed constant over the past three years. While the subsidies are large, contrary to what was reported by WRI (see Table 13), the subsidies from the city (and provincial) government do not cover all major parts of the treatment process, specifically the drying of sludge in the incineration process. The company is currently profitable, though a revenue/cost breakdown is not available.

Table 15. Xiangyang City's Yuliangzhou Project Annual Subsidies and Expenditures

Revenue(+) [RMB ($)/Year]		Cost (-) [RMB ($)/Year]	
Sludge treatment subsidy	18.288 million ($2.74 million)	Sludge disposal costs	15.84 million ($2.38 million)
Food waste treatment subsidy	2.592 million ($389,000)	Food waste treatment costs	2.7 million ($405,000)
CNG sales revenue	9.72 million ($1.46 million)	Clean energy adjustment fund	0.216 million ($32,400)
		Taxes	0.9 million ($135,000)
		Financial expenses	2.448 million ($367,000)
		Overhead	8.496 million ($1.27 million)
Total	30.6 million ($4.59 million)	**Total**	30.6 million ($4.59 million)

Source: WRI (2015)

Based on the success of the Xiangyang project, TOVEN won a contract in Hefei city to develop a sludge-to-energy project using the same technology. A project is currently under construction and designed to treat 600 tonnes of sludge per day and produce 18,000 cubic meters of biogas.

Figure 3 below summarizes the Xiangyang project and its lessons and limitations for being adopted in other second-tier cities in China.

The Xiangyang sludge-to-energy plant,
used with permission courtesy of TOVEN.

Figure 3. Overview of Xiangyang Sludge-to-Energy Project

Quick Facts

TOVEN is the project's technology provider and equipment supplier.

The project currently handles all the sludge (300 tons/day) from the city and almost all the kitchen waste (150 tons/day) from restaurants in Xiangyang.

The project produces 12,000 to 16,000 cubic meters of methane per day (50 percent used for running the operation; 50 percent used for producing compressed natural gas).

End products include compressed natural gas, or CNG (3,000 to 4,000 cubic meters/day), biochar soil, and container forests (potted trees grown in biochar soil). CNG is sold at the company's own fueling station to taxi drivers, bus companies, and a nearby driving school. Biochar soil and container forests are sold to local flower growers and for the city's forestry programs.

Achievements

Introduced a new technology through which co-digested sludge and kitchen waste have been rendered harmless to the local, regional, and global environment.

Made a business case for capturing and utilizing methane from sludge with low organic matter. (Sludge in the Xiangyang project contains 40 to 50 percent organic matter—similar to levels in many Chinese cities but much lower than the international level of 70 percent.)

Maximized the sludge utilization. The Yuliangzhou project only releases carbon dioxide and water vapor. The rest of the sludge is turned into commercial products. By contrast, incineration can't reduce sludge volume completely, as incineration ash still has to be landfilled.

Challenges to Wider Adoption

Sludge-to-energy is fairly new in China and there is no example to follow. International practices don't always apply in the case of China. For example, in Norway, companies can land apply treated sludge as compost; this is not allowed in China.

Low awareness of sludge. The central government requires that 70 percent of sludge be treated properly, but it is hard to enforce. Most Chinese cities, including Xiangyang, do not have their own sludge policies. Local authorities tend to hide the problem or dump sludge in less developed places rather than looking for a way to treat sludge.

5 Opportunities for International Engagement in China

Many countries around the world are working toward solving their municipal sludge problems through appropriate technologies, robust policies, and innovative finance mechanisms. But in China, sludge has long been overlooked and mismanaged. For many years the massive scale of sludge production, lack of correct pricing on water treatment, and insufficient awareness of best treatment practices for sludge created a Wild West of illegal dumping and serious pollution.

Since about 2011, the Chinese government has ramped up its regulatory and finance efforts to address the sludge problem. This top-down action and a handful of promising municipal pilots are opening up opportunities that can make sludge treatment more attractive for investment and international cooperation. Five key issues can help sludge become more attractive to investors.

5.1 Promoting Sludge Waste-to-Energy

Energy recovery from municipal sludge can produce power for the plant and generate revenue. This is a win-win solution for carbon reduction and water protection, but it needs to be better marketed in Chinese cities. It will be vital for Chinese cities and companies to be shown more advanced disposal and utilization techniques and ways to profit from sludge. Chinese cities and MOHURD/MEP could learn from models of mature disposal, treatment, and use options in the United States, and to the regulations and enforcement used in U.S. cities to ensure protection of public health and the environment. MOHURD and MEP are moving toward creating regulatory frameworks that connect incentives for sludge treatment, and U.S. cities can help provide models (e.g., the Los Angeles County Sanitation District's co-digestion project). See Appendix 4 for several international examples of sludge treatment and use. There will also be a need to engage with China's power grid and electricity regulators to help get "sludge power plants" on the grid (see next sections for more on this topic).

5.2 Getting Beyond the Pilot

Stories of successful and failed municipal sludge pilots need to be told to help other cities learn their lessons. Some cities in China have formed clusters (usually three) to develop economies of scale in energy, transport, and environmental infrastructure development and such cities need to add sludge treatment to their development.

The U.S. EPA Office of Air has worked successfully over many years to help MEP and the Chinese leadership embrace regional air quality monitoring and management. Under the new air pollution law and 13th FYP targets goals are set for regions to reach stricter air quality standards. As these cities look to regional clean energy solutions, sludge-to-energy should be an option they consider. Regional initiatives to scale up sludge-to-energy could turn it into a more marketable source of distributed power or vehicle fuel.

5.3 Sparking an AD Revolution

Chinese cities are coming under increasing pressure to meet tightening limits on coal-fired generation and air pollution reduction targets, but few look at wastewater and sludge treatment as solutions. Encouragingly, GHG emission reduction is also becoming a major criterion for evaluating the performance of sludge management in cities, which is creating greater interest on biogas production and electricity generation. As co-digestion of sewage sludge and kitchen waste is becoming the preferred strategy to create biogas, it will be helpful to help promote technologies and best practices in this technology.

Our research has identified AD as the most overlooked yet potentially very impactful low-carbon solution for Chinese cities. However, Chinese cities need to eliminate AD adoption barriers. A study conducted in China in 2006 found that the high water content and low organic content poses a large challenge to proper treatment and disposal and is a top obstacle for AD. Some possible topics for U.S. and Chinese cooperation to increase the feasibility of AD in China:

- As the Xiangyang case demonstrates, city waste management departments should coordinate waste-gathering systems and identify opportunities (for example by co-digesting food waste). This could significantly increase sludge's organic content while eliminating the need to build separate food waste processing facilities.
- To further address the combined sewage system issue, the central government is providing funding for some sponge city initiatives to better control storm water runoff and harvest rainwater. There are many good examples of green infrastructure from U.S. cities and Shenzhen in China is quickly becoming a storm water management model.
- MOA's ban on sludge application as a fertilizer prevents projects that could transform sludge into beneficial products for agricultural application (e.g., biochar or compost) and generation of an additional revenue stream. MOA might consider modifying the current law to a performance-based law that would allow cities or companies interested in sludge-to-compost projects to demonstrate they can adhere to pollution targets and let them apply for an exemption from the land application ban.

5.4 Getting the Price Right for Sludge

Raising wastewater treatment fees is on the current agenda in China; many international organizations as well as the U.S. EPA Water Office have long been engaged with MEP, sharing examples of U.S. tiered fee structures and revolving fund mechanisms. With the new Water Pollution Action Plan, such water financing conversations could be expanded to include MOHURD and link to sludge pilots.

The Chinese government should establish subsidy standards for sludge treatment and disposal. Current subsidy schemes are determined by local governments and range from 50 to 600 RMB/tonne ($7 to $90)—they vary significantly across locations and techniques. Private industry investors desperately need consistent signals from the central level to recognize and support best sludge management practices. Even though low water fees are still a barrier to sludge treatment projects, examples such as

Xiangyang highlight that there can be pilots that experiment with higher fees and creative revenue streams.

5.5 Promoting Sludge Management Planning and Networks

The need for comprehensive sludge management planning has been raised by a number of recent studies of sludge in China (ADB, World Bank, and WRI). Cross-ministry collaboration on water issues has been particularly challenging in China where upwards of seven ministries compete for overlapping responsibility in its management, use, and protection. There are new opportunities, however, for the U.S. EPA and other partners to help make this needed cross-ministry/sector planning a reality. First, the April 2015 *Water Pollution Prevention and Control Action Plan* is a major breakthrough: an umbrella plan that aims to coordinate water pollution prevention and control in agriculture, industrial and municipal, and rural water sectors. The plan was developed with input from over a dozen ministries and government departments and their think tanks. Secondly, regarding sludge directly, MOHURD is now the uncontested leader of municipal wastewater and sludge management, but its work is being done increasingly in coordination with MEP and the Ministry of Water Resources (the latter focuses mainly on water quality issues).

While few U.S. organizations have engaged deeply on sludge issues in China, there are new opportunities. The Global Methane Initiative can leverage existing NGO, bilateral, or multilateral organizations and partnerships around not just water and wastewater, but also water-energy nexus issues, sustainable cities, and power grid reforms. (See Table 14 for a summary of potential sludge partners for U.S. organizations to work with in China)

Today there is a "perfect storm" for working on sludge in China—recognition of the sludge pollution crisis, increasing guidelines and policy prioritization, and a business sector hungry to invest. This scoping paper has endeavored to demonstrate how this is an optimal time for the EPA to be reaching out to MOHURD, MEP, and Chinese cities to start new conversations and partnerships to reduce China's sludge mountains.

Table 16. Potential Sludge Partners in China

Organization/Agreements	Activities Related to Sludge Development in China
Bilateral/Multilateral	
U.S.–China Water MOU (EPA-MEP)	Multiple issues areas around water pricing, standard setting, and most recently PPP.
U.S.–China Water Energy Technology Clean Energy Research Center (CERC) funded by U.S. Department of Energy and Ministry of Science and Technology	Newest CERC is led by UC Berkeley on the U.S. side. One of their key areas of work will focus on obtaining water and generating energy from untraditional sources, which includes wastewater.
GTZ	Long history of working on industrial biogas in China. In-country staff could have some valuable insights on progress and obstacles they have faced.
US–China Leaders' Summit	New city-to-city low carbon partnerships and Californian cities are particularly active in the wastewater/sludge-to-energy sphere.
U.S. DOE Eco-City Mayoral Exchange	From 2009 until 2015 the DOE ran a city-to-city exchange focused on promoting clean energy and other urban sustainability practices. Will be useful to learn what partnerships and connections this program created that could be tapped for sludge-to-energy engagement.
World Bank Water Partnership Program	Recent report on sludge management in China as well as water-energy nexus collaboration with National Energy Administration. World Bank is interested in more partners to help create enabling policies and research that encourages AD and other more advanced sludge treatment in China.
International NGOs, Think Tanks, NGOs, and Foundations	
World Resources Institute	Has been undertaking national- and city-level water-energy research and one component of which is examining sludge-to-energy obstacles and opportunities.
Regulatory Assistance Project	RAP is carrying out power grid and distributed renewable power research projects in China. They offer valuable insights into some of the obstacles faced when urban utilities/buildings try to generate distributed energy and sell it onto the grid. They could have insights on how to open up microgrids for methane power from sludge plants.
National Resources Defense Council	Their sustainable building program has predominantly focused on energy efficiency and building code issues, but they have touched on water and established good working relationships with various city governments and subnational housing and urban development agencies and think tanks.
Energy Foundation	Their sustainable city program has been helping to create low-carbon pilots that have given them good working relationships with numerous city governments and think tanks.
UC Green Building Council	Upcoming LEED City initiative includes some water components. Like the above two organizations, they have deep contacts within MOHURD and its affiliated think tanks.
Rockefeller Foundation	This foundation is currently scoping out potential impactful work they can do in China around water quality; it will be important to keep an eye on who they may support.
China-Based NGOs, Foundations, and Think Tanks	
National Strategic Alliance for Technological Innovation of Sludge Treatment and Disposal Industry & State Environmental Protection Engineering Center for Sludge Disposal and Resource	Key research institutes working with MEP and MOHURD on sludge treatment and disposal technologies and management.
Clean Air Asia (Beijing Office)	While focused on low-carbon issues that are not water related, this NGO has been doing extensive trainings of government and party staff in dozens of municipalities in China and could offer some valuable insights into creating such trainings around sludge. It would be interesting to see if sludge-to-energy/AD is both low-carbon and improves air quality.

Greenpeace China	Distributed solar panel campaign. Offers valuable insights into some of the obstacles faced when urban entities try to generate distributed energy and sell it onto the grid.
Alibaba Foundation	For the next three years, Alibaba Foundation is focusing on water quality issues. They have been funding testing kits and support for some Chinese NGOs to encourage citizens to test their water quality and post results online. Their CEO is very interested in pushing innovation in the clean energy sphere.
Private Companies	
TOVEN (China) Veolia (UK) ThermAer (U.S.) Energy from Waste (Germany) Envirowaste (Australia) CT Environmental Group (Hong Kong) China Water Environment Group Investment Limited (China) Sempcorp (Singapore)	All of these companies are involved in Build Operate Transfer (BOT) sludge treatment projects in Chinese cities.

Appendix 1. Sludge Treatment Targets for Urban Areas in 12th Five-Year Plan by Regions (Thousand Tonnes/Year)

Region	Municipalities		Counties		Towns		Total		Budget (Bln Yuan)
	2010	Targets	2010	Targets	2010*	Targets	2010	Targets	
Beijing	260	226	0	0	0	0	260	226	1.6
Tianjin	70	72	0	48	0	0	70	120	0.9
Hebei	140	205	25	114	0	28	165	347	2.3
Shanxi	50	81	10	25	0	2	60	108	0.6
Inner Mongolia	20	113	7	0	0	0	27	113	0.5
Liaoning Province	130	115	0	29	0	19	130	163	1.2
Jilin	50	52	0	18	0	14	50	84	0.6
Heilongjiang	70	130	0	14	0	0	70	144	1.2
Shanghai	60	81	0	59	0	0	60	140	1.6
Jiangsu Province	355	361	20	84	0	57	375	502	4.8
Zhejiang	180	217	27	73	0	99	207	389	2.4
Anhui	76	118	18	24	0	0	94	142	0.7
Fujian Province	50	109	20	23	0	12	70	144	0.6
Jiangxi Province	29	46	10	48	0	0	39	94	0.4
Shandong	240	158	35	56	0	18	275	232	1.3
Henan	140	185	20	64	0	12	160	261	1.8
Hubei	60	140	0	17	0	0	60	157	0.9
Hunan	40	173	10	76	0	0	50	249	1.6
Guangdong	200	502	8	14	0	50	208	566	3.8
Guangxi	40	74	0	8	0	1	40	83	0.6
Hainan	10	31	10	14	0	0	20	45	0.2
Chongqing	20	38	10	17	0	0	30	55	0.4
Sichuan Province	70	169	10	0	0	0	80	169	1.2
Guizhou	20	40	0	19	0	19	20	78	0.5
Yunnan	20	43	0	17	0	4	20	64	0.4
Tibet	0	6	0	3	0	0	0	9	0
Shanxi Province	90	123	10	52	0	23	100	198	1.1
Gansu Province	20	82	0	24	0	7	20	113	0.7
Qinghai	0	11	0	8	0	4	0	23	0.1
Ningxia	20	30	0	7	0	0	20	37	0.2
Xinjiang	10	89	0	25	0	1	10	115	0.5
XPCC**	0	10	0	0	0	0	0	10	0
Total	2540	3830	250	980	0	370	2790	5180	34.7

Source: MOHURD: *Plan for the Construction of Urban Wastewater Treatment and Reuse Facilities, 2011–2015*

* No statistics for towns in 2010.

** The capacity of sludge treatment of XPCC's municipalities was counted in Xinjiang.

Appendix 2. Sludge Regulations and Laws in China (1984–2015)

October 1, 1984	MEP announced the *Control Standards for Pollutants in Sludge from Agricultural Use* on October 1, 1984. These national standards apply to chemical pollutants in sludge for agricultural use from rivers, sewage plants, and wastewater treatment plants. The regulation identified monitoring requirements and specified the amount of content of each pollutant for safe sludge reuse in agriculture. It took effect on March 1, 1985.
July 2006	MEP published the *Guiding Rules for the Release of Environmental Information on Solid Waste in Medium- and Large-Sized Cities*. The rules require medium- and large-sized cities to publish their information from the prior year on solid waste treatment, with sludge data included, no later than June 5. Sludge is classified as industrial solid waste and defined as organic and inorganic sludge.
March 2007	MOHURD announced *The Disposal of Sludge from Municipal Wastewater Treatment Plant—The Quality of Sludge Used in Gardens or Parks*. This regulation was updated in April 2009 and took effect in December 2009.
2007	MOHURD announced *The Disposal of Sludge from Municipal Wastewater Treatment Plant—Quality of Sludge for Co-landfilling*. It was revised in April 2009 and took effect from December 2009.
2008	MOHURD announced *The Disposal of Sludge from Municipal Wastewater Treatment Plant—Quality of Sludge Used in Land Improvement*. It was updated in November 2009 and took effect on June 1, 2010.
February 2009	MEP announced *Policy on Sludge Treatment and Pollution Prevention Technology in Urban Wastewater Treatment Plant (Trial)*. This is the first general policy that is specifically targeted to monitor and management the process of sludge treatment. It defines sludge as semi-solid slurry generated from wastewater treatment processes. As specified, local governments are responsible for the design and implementation of their sludge treatment plants. The technology guidance from the policy covers the whole process of sludge treatment—production, storage, treatment, transportation, reuse, and disposal. Different ways to deal with or reuse sludge should be used depending on the chemical characteristics of various types of sludge and on other regional factors, with reference to the previous national standards. On the policy-making level, the national and local departments are required to improve the policy framework in sludge treatment by adding more detailed regulations and standards. The local governments should create incentives to support the development and operation of sludge treatment plants by offering subsidies or including the cost of sludge treatment into the pricing of waste water treatment rates.

October 2010	MEP decided to build the State Environmental Protection Engineering Center for Sludge Disposal and Resource with BMEI. The center focuses on exploring advanced sludge technology and engineering.
November 2010	MEP announced a *Notice on Reinforcing Municipal Wastewater Treatment Plant Sludge Pollution Prevention and Control*. The notice requires Environmental Protection Bureaus to present information on sludge treatment openly to the public. Local bureaus need to submit their annual reports on sludge treatment to the MEP by March 31 of each year.
January 2011	MOHURD announced it would conduct nation-wide research into China's current sludge treatment situation and technology as part of the Major Science and Technology Program for Water Pollution Control and Treatment for the 12th FYP. The research was aimed to map the general scope of sludge treatment in wastewater treatment plants in urban areas, including the amount generated, the quality after processing, the technology used, energy consumed, cost and benefit analysis, and domestic technical challenges compared to Western countries. MOHURD initiated an outline and a survey for each provincial bureau. MOHURD also planned to develop a sludge treatment committee under the major water program.
February 2011	MOHURD published *The Disposal of Sludge from Municipal Wastewater Treatment Plant: Quality of Sludge Used in Forestland*. The national standards took effect on June 1, 2011.
March 2011	MOHURD announced the *National Technical Guideline for Sludge Treatment from Urban Waste Water Treatment Plants (Trial)*. The guideline gives a general picture of the situation of this country's sludge properties and sludge treatment. Under the basic principles stated at the beginning, the guideline provides detailed explanation on sludge treatment technology and evaluation on several options for the reuse and disposal of sludge with the consideration of environment risks, recycling rate, energy consumption, cost and benefit analysis, and carbon emissions. Specifically, the carbon emissions are calculated with reference to IPCC's *Guidelines for National Greenhouse Gas Inventories*. In the last chapter, the guideline discusses the emergency and risk management in sludge treatment.
March 2011	MOHURD published the *Technical Specification for Operation, Maintenance and Safety of Municipal Wastewater Treatment Plant*. The national standards took effect on January 1, 2012. Chapter 5 details requirements and standards for the process of sludge treatment.
April 2012	The State Council published *Plan for the Construction of Urban Wastewater Treatment and Reuse Facilities, 2011–2015*. The plan set up clear targets for each province to process its urban sludge during the 12th FYP.

September 2013	The State Council passed the *Urban Drainage and Wastewater Treatment Directive*. Article 30 requires that all the agencies responsible for sludge treatment should follow the existing national standards and regulations, keep track of the treatment process, and report to the department in charge. Article 53 deals with the failure to follow Article 30. The punishment would be 100,000–500,000 yuan for violation by any agency and 20,000–100,000 yuan for an individual.
April 2015	The State Council issued *Action Plan for Preventing and Treatment of Water Pollution*. The action plan offers general recommendations and targets on sludge under its section on strengthening municipal wastewater treatment. All of the sludge treatment infrastructure should be updated by 2017 and 90% of the sludge should be treated.

Appendix 3. Sludge Policies in Select Second-Tier Cities

- **Hangzhou:** Temporary Act of Performance Management of Wastewater and Sludge Treatment, April 2, 2010: 杭州市□水□理□施□泥□理□置□目建□□效管理以□代□□行□法
    - Subsidies
        - City districts
            - For toxic-free treatment: city-level government covers 20 percent, district-level government covers 20 percent. The maximum reward by city-level government is 5 million RMB ($750,000).
            - For recycling projects: city-level government covers 30 percent, district-level government covers 30 percent. The maximum reward by city-level government is 8 million RMB ($1.2 million).
        - Suburban districts
            - For toxic-free treatment: city-level government covers 15 percent, district-level government covers more than 10 percent. The maximum reward by city-level government is 3 million RMB ($450,000).
            - For recycling projects: city-level government covers 20 percent, district-level government covers more than 10 percent. The maximum reward by city-level government is 5 million RMB ($750,000).
    - Rewards
        - In the first three years of operation, a sludge treatment plant in city districts can receive 20 yuan from the government for every tonne of sludge treated.
        - In the first three years of operation, a sludge treatment plant in suburban districts can get 10 yuan from the government for every tonne of sludge treated.
    - Results: 2010–2014 (lack of data in 2013)
        - By the end of 2014, the government has supported 27 projects in Hangzhou with 54.68 million RMB ($8.2 million).
- **Shenzhen**
    - Shenzhen Water Affairs Development, 12th FYP: 深圳市水务发展"十二五"规划
        - Three new sludge plants
        - Capacity will reach 35.9 million m^3/day
    - Shenzhen Sludge Treatment Plan, 2006–2020: 深圳市□泥□置布局□划 2006-2020
        - 11 sludge treatment plants are planned

        - Detailed information about each plant are analyzed
        - Clean river sludge
    - Shenzhen Annual Performance Report 2014: 深圳市 2014 年度绩效审计工作报告
        - Shenzhen Water Authority is responsible for the planning, development, and management of all the sludge treatment projects
        - In 2007–2011, 10 sludge treatment plants were built with a budget of 1.62 billion RMB ($243 million)
        - Capacity to deal with sludge is still lacking
            - Shenzhen produces 31 million m^3/day and can only treat 15.3 million m^3 sludge per day, not achieving the goal in Shenzhen's 12th FYP
            - The land expropriations for sludge treatment plants caused public protests, leading the delay of the projects
            - The charges for wastewater treatment don't include the costs for sludge treatment

- **Chengdu**
    - Chengdu Water Authority signed a contract with Chengdu Drainage Company in 2013
        - The company is authorized to be the only entity in charge of the sludge treatment in Chengdu city districts, with 400 million RMB ($60 million) invested
        - In 2013, the company planned to build Chengdu's first sludge treatment plant, called Chengdu First City Wastewater and Sludge Treatment Plane; with a capacity of 400 tonnes per day, it will deal with the sludge generated by nine wastewater treatment plants in Chengdu
    - Chengdu Wastewater Treatment Rates Regulations: 成都市□水□理□征收使用管理□□
        - Standards for wastewater treatment rates; considers the costs of wastewater and sludge treatment

- **Dalian**
    - Dalian Energy Conservation and Emission Reduction Plan 2007: 大□市人民政府关于印□大□市□能减排工作□施方案的通知
        - All the sludge generated from wastewater treatment should be sent to Dalian Xiajiahe Sludge Treatment Plant
    - Dalian Circular Economy Development 12th FYP: 大□市"十二五"循□□□□展□划
        - 98 percent rate of safe sludge (toxic free)
    - Dalian 12th FYP
        - 81 wastewater treatment plants and 2 sludge treatment plants

- Notice on Applying for Budget from the Central Government for Urban Wastewater and Solid Waste Treatment Projects: 关于□□□申□ 2015 年中央□算内投□城□□水垃圾□理□施建□□□□目的通知
    - Prioritizes the projects with high technology application
    - Prioritizes the projects with large capacity
- Xiajiahe Sludge Treatment Plant
    - Dealing with sludge by 17 wastewater treatment plants
    - Producing 10,000 m^3 biogas, serving 250,000 residents
    - Citizens can get free fertilizer from recycled sludge from the plant

- **Wuhan**
  - The first sludge treatment project, Longwangzui, was built in 2012, with a capacity of 300 tonnes per day (the average output was 730 tonnes per day)
  - Report on the Performance of Wuhan's Wastewater Treatment Plants on Sludge Treatment: 关于城□□水□理厂□泥□理□置情况的□告
    - Problems
      - Not enough investment in sludge treatment by wastewater treatment plants
      - Lack of sludge treatment facilities
      - Lack of relevant policies and plans (*The Plan for Sludge Treatment by Wastewater Treatment Plants* was initiated in 2011, but there have been no more updates)
    - Recommendations
      - Set up temporary storage places for the existing sludge
      - The municipal government provides more relevant and comprehensive policies
      - Increase the rates for wastewater treatment
      - Increase the investment in sludge treatment
  - Notice on Wuhan Prevention and Controlling Pollution from Solid Waste 2014: 武□市 2014 年固体□物□染□境防治信息公告
    - Longwangzui Sludge Treatment Plant has been updated to a capacity of 400 tonnes/day
    - Chenjiachong Sludge Storage has been operated
    - Three more sludge treatment plants have been under construction

Appendix 4. International Experience in Sludge Treatment

While the United States and Europe also face significant sludge management challenges, they are ahead of China in creating enabling a policy environment that creates incentives and penalties for cities to treat sludge more sustainably. With robust top-down clean water laws, regulations, and best practice guidelines for technologies—and bottom-up regulations that limit landfilling or incinerating sludge—U.S. and EU cities are expanding their use of more advanced sludge treatment technologies. As well as having stronger sludge control policies and financing, the U.S. and EU have been more successful than China because of better intergovernmental coordination and cooperation around sludge management.

In the United States, land application is the most common method for sludge disposal. The U.S. EPA produces a biennial *Sewage Sludge Annual Report Review Guide* with checklists of best practices and technologies for water utilities to use in planning sludge treatment options.

The U.K. offers a lesson of policy coordination among government agencies. Its Department for Environment, Food and Rural Affairs first produces a comprehensive guide on sludge treatment levels, monitoring requirements, and best practices on sludge used for land application. The Department of Agriculture and Rural Development then reviews these guidelines. This coordinated review of guidelines and laws has led to sludge regulation being integrated into other laws governing industrial waste, composting quality, and air emission standards.

In the EU, there will soon be more restrictions on land application of sludge that will decrease the practice. Directive 2000/76/EC on "incineration of waste" covers mono-incineration and co-incineration of all waste, including municipal wastewater plants.[44] With such comprehensive guidelines, incineration of sludge is expected to grow significantly in the future in the EU.

In contrast, recent rules passed by the U.S. EPA are creating more barriers to the growth of incinerating sludge. The U.S. EPA proposed that sewage sludge be included in the definition of solid waste under the 40 CFR Part 503 "Standards for the Use of Disposal of Sewage Sludge" in Subpart E, "Incineration." With this new definition, sludge incinerators are regulated under Clean Air Action Section 129, which sets emissions thresholds for incinerators.

In addition, the U.S. EPA's regulations for municipal solid waste landfills in 40 CFR Part 503 set guidelines for the design, monitoring, and operation options. They do not pose restrictions on land disposal. In contrast, the EU's current regulation on sludge disposal on landfills—1999/31/EC on the "Landfill of Waste"—recommends that each member state develop a national plan "for the reduction of biodegradable waste going to landfills."[45] Legally, this recommendation implies the phasing out of landfilling. As Table 14 shows, AD is the overwhelmingly favored treatment method for EU member states, and thus offers many lessons for China's adoption of such technologies.

[44] World Bank Report.
[45] Ibid.

Table 14. Sludge Treatment Techniques Used by Select EU Nations

Country	Treatment Techniques (%)			
	Anaerobic Digestion	Aerobic Digestion	Compost	Hygienization with Lime
Belgium	67	22	0	2
Denmark	50	40	1	5
UK	60	—	—	—
France	49	17	—	0
Germany	64	12	3	0
Greece	97	3	0	0
Ireland	19	8	0	0
Italy	56	44	0	0
Luxembourg	81	0	5	0
Netherlands	44	35	0	0
Spain	65	5	—	26

Source: Zoneco

A handful of U.S. cities have explored sludge-to-energy development. Los Angeles set a city-wide goal to reduce landfilling by 75 percent by 2020, with its *Cleaning Up Waste and Recycling Management and Securing the Benefits Plan,* compiled by the Los Angeles Alliance for New Economy.[46] This policy has spurred large food waste producers to seek ways to divert solid waste through recycling technologies, such as AD, in nearby cities like Compton.[47] Through public-private partnerships, some wastewater treatment plants have been able to upgrade their facilities to include AD technologies which have a low carbon footprint. (See Table 12.) Notable examples include:

- **Cleveland, Ohio.**[48] A start-up company, Quasar Energy Group, received federal and state subsidies to develop technology for bioenergy from sludge. By applying European technology which was later adapted by Ohio State University's Ohio Agricultural Research and Development Center, wastewater plants in Cleveland expanded their capacity in biogas production sufficient to power the plant and to sell surplus to local electric grid.
- **Rialto, California.**[49] Through a partnership with EnerTech, this city produced 60,000 tonnes of biogas from sludge each year, which helped to replace coal use in local industries, offered power to five municipalities in the Los Angeles region, and reduced over 80,000 tonnes of carbon emissions from fossil fuels annually.

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[46] Los Angeles Alliance for a New Economy. (2015). Cleaning up waste and recycling management and securing the benefits. https://drive.google.com/a/student.american.edu/file/d/0B2rKfsMZQPAgazJiT3RQak9NU2s/view.
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[48] Funk, J. (2014, July 16). Waste to energy power plants could generate an eighth of U.S. power says Cleveland's Quasar Energy (slideshow). *Cleveland.com.* http://www.cleveland.com/business/index.ssf/2014/07/waste_to_energy_power_plants_c.html.
[49] Climate Progress. (2011, July 11). The scoop on poop: Turning sewage sludge into energy and dollars. http://thinkprogress.org/climate/2011/07/11/264897/sewage-sludge-energy/.

- **Washington, D.C.** In the fall of 2015, D.C. Water became the first utility in the United States to use a Norwegian thermal hydrolysis system to convert the sludge left into electricity. The Blue Plains Advanced Wastewater Treatment Plant began producing electricity in September and is able to provide one-third of the plant's power, saving about $10 million annually. The *Washington Post* reported that the utility will save "$2 million or so annually on treatment chemicals and $11 million annually in trucking expenses."[50] Numbers like these could help make a very compelling case to Chinese water utilities.

- **Oakland, California.**[51] The East Bay Municipal Utility District's 64-year old regional wastewater treatment plant, located on Oakland's north side, has 11 megawatts of biogas-fueled electrical generating capacity, more than the plant's power demand. The excess power is sold to the Port of Oakland, which saves the District approximately $3 million in electric expenses a year. This Oakland plant (pictured below) is the first U.S. wastewater plant to sell extra electricity produced entirely from waste back to the power grid. The plant generates gas from digesting sewage, food waste, and other biodegradable byproducts, which is helping the city greatly reduce its solid waste production, a strong co-benefit from sludge and wastewater methane capture that many Chinese cities would be interested in.

[50] https://www.washingtonpost.com/local/trafficandcommuting/poop-flush-power/2015/10/07/d0c9c6de-6c3a-11e5-9bfe-e59f5e244f92_story.html
[51] https://www.newsecuritybeat.org/2015/07/oaklands-water-treatment-plant-generates-energy/