INSIGHT OUT
Expert Voices on China's Energy and Environmental Challenges

Wilson Center

Closing the Loop on Wastewater in China

By Danielle Neighbour

China Environment Forum

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China Environment Forum's Role as Convener and Catalyst for Action

For 23 years the Wilson Center's China Environment Forum has carried out research and exchange projects on a broad range of energy and environmental issues in China—from U.S.-China clean energy cooperation and water-energy choke points in China to food safety and the ecological impact of China's overseas investment.

INSIGHTOUT is a China Environment Forum publication series that began in 2014. This sixth issue features research by Danielle Neighbour who was a Schwarzman Associate at the Wilson Center's Kissinger Institute and China Environment Forum in 2018-2019. We were proud to partner with the Stephen A. Schwarzman Education Foundation in sponsoring Danielle Neighbour's work on this policy brief during her tenure at the Wilson Center. This publication was also made possible with support from the Henry Luce Foundation and the U.S. Environmental Protection Agency through the Global Methane Initiative.

About the China Environment Forum

For 23 years, the Woodrow Wilson Center's China Environment Forum (CEF) has created projects, workshops, and exchanges that bring together U.S., Chinese, and other Asian environmental policy experts to explore the most imperative environmental and sustainable development issues in China and to examine opportunities for business, governmental, and nongovernmental communities to collaboratively address these issues.

The networks built and knowledge gathered through meetings, publications, and research activities have established CEF as one of the most reliable sources for China environment information and given CEF the capacity to undertake long-term and specialized projects on topics such as energy development in China, environmental justice, Japan-China-U.S. clean water networks, municipal financing for environmental infrastructure, river basin governance, environmental health, water conflict resolution mechanisms, food safety, and environmental activism and green journalism. Our current initiatives are:

- **Global Choke Point:** a multimedia and convening initiative created in partnership with Circle of Blue examining the water-energy-food confrontations in China, India, the United States and other countries around the world.
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- **Complex Connections**—meetings and research examining environmental impact of Chinese investment overseas.

The China Environment Forum meetings, publications, and research exchanges as well as Global Choke Point activities in India over the past two years have been supported by generous grants from Henry Luce Foundation, Energy Foundation China, Ford Foundation, ClimateWorks Foundation, the U.S. Embassy in India and the Walt Disney Company.

Dr. Jennifer L. Turner has directed the China Environment Forum since 1999. The China Environment Forum is a project under the Wilson Center's Global Sustainability and Resilience Program.

Chapters

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Abbreviations

AD	Anaerobic Digestion
CSOs	Combined Sewer Overflows
ETS	Emissions Trading Scheme
FYP	Five-Year Plan
MEE	Ministry of Ecology and Environment (name since 2018)
MEP	Ministry of Environmental Protection (name 2008-2017)
MoHURD	Ministry of Housing and Urban-Rural Development
MOST	Ministry of Science and Technology
MS4s	Municipal Separate Storm Sewer Systems
NDRC	National Development and Resource Commission
NEPA	National Environmental Protection Administration (name 1983-1988)
NGO	Nongovernmental Organization
NYC DEP	New York City Department of Environmental Protection
PPA	Power Purchase Agreement
RFS	Renewable Fuel Standard
RO	Reverse Osmosis
RINs	Renewable Identification Numbers
RNG	Renewable Natural Gas
SEPA	State Environmental Protection Administration (name 1988-2007)
WWTP	Wastewater Treatment Plant

AUTHOR'S NOTE

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Executive Summary

The expression "Nine Dragons Rule the Waters" has long been used to describe the contentious and fragmented roles and responsibilities of government agencies managing water in China. In the 1980s economic reform era, these competing and overlapping "dragons" often produced poor and contradictory policies that failed to reign in water pollution from China's rapid urbanization and industrialization. In 2001, when Beijing was chosen to host the 2008 Summer Olympics, untreated wastewater and agricultural runoff had turned many of China's rivers black and numerous large lakes were green with toxic algae blooms. At that time, despite wastewater treatment regulations, nearly 80 percent of China's sludge went untreated, making it a growing source of methane emissions—a potent greenhouse gas.[1]

China's mountains of municipal and industrial sludge and lack of rural wastewater treatment sparked Xi Jinping to declare wastewater a major part of his "war on pollution" in 2018. However, treating wastewater and sludge can be an expensive battle to wage. To advance its wastewater and carbon reduction targets, China can learn from cities such as New York, Washington DC, and Singapore to tap three marketable resources from sludge to close the loop on wastewater. Specifically, Chinese wastewater plants can: (1) capture methane to generate low-carbon power, (2) treat sludge digestate to make compost, and (3) recycle the wastewater to meet multiple municipal and industrial water needs. All three bring down the costs of wastewater and sludge treatment as methane can power wastewater treatment plants and the digestate and recycled water can be sold.

Methane: Turning Wastewater Gas into Power. Methane, a greenhouse gas produced when sludge decomposes, has an environmental impact 84 times greater than carbon dioxide.[2] The wastewater sector accounts for 10 percent of global methane emissions;[3] China is responsible for one-quarter of these emissions. Wastewater treatment plants (WWTPs) can capture methane through anaerobic digestion (AD)—a process in which microorganisms break down organic material in the wastewater in a digester tank.[4] The captured methane gas can be converted into electricity or vehicle fuel.[5]

Digestate: Utilizing Brown "Gold." Digestate (a.k.a. biosolids) produced in the AD process can be further dried and treated to be sold as organic compost, preventing the potentially toxic solids from being dumped into landfills and waterways. This compost can be used on urban rainwater gardens and green spaces to help reduce stormwater flood risks in China's megacities.

Recycled Wastewater: Quenching Thirsty Cities. Recycled wastewater provides an alternative tap for the water-scarce nation. Recycled wastewater can recharge aquifers, irrigate landscapes and agriculture, and supply water to local industries. China's available per capita water supply is one-fourth the world's average[6] and China only reclaims approximately 4 percent of its wastewater.[7]

Productively using methane, digestate and recycled water could help China's wastewater plants become more financially resilient, but they face challenges implementing measures to increase their climate resiliency. Like many cities in the United States, during extreme rain and hurricane events many of China's combined sewer systems and wastewater treatment infrastructure release sewage, flooding streets and contaminating drinking water sources. To increase the resiliency of wastewater systems, Chinese cities can follow New York City's lead by implementing green infrastructure, such as permeable pavement and catchment areas, and controlling public water usage to reduce the volume of stormwater entering drains.

A CLOSED-LOOP FUTURE

While Chinese cities can profit from methane capture, digestate use, water recycling, and measures to increase climate resiliency, economic challenges make implementation difficult. China's treatment plants often operate at a loss and managers are hesitant to invest in long return-on-investment projects. Additionally, finding customers for wastewater byproducts is difficult in China's state-driven economic model. Beijing policymakers could set higher water prices and increase subsidies to raise capital for water utilities looking to implement methane capture. Cities can also leverage existing policies to create demand for wastewater methane, digestate, and recycled water, enabling China's wastewater sector to reduce greenhouse gas emissions, remediate soil, and increase water security.

Chapter 1: Understanding China's Wastewater Crisis

Wastewater is often out of sight and out of mind, disappearing from our lives via pipes and underground sewers for treatment in plants often situated on a city's fringe. But how well are wastewater systems truly managed? Inadequate wastewater systems can cripple cities, leaving them vulnerable to flooding, surface water pollution, and aquifer contamination. Today, inefficiently managed wastewater systems can drain more than a third of municipal electricity. Managing wastewater has been a challenge since people began living in cities. Thousands of years ago, most metropolises dealt with their wastewater by putting it directly in rivers. With some notable exceptions, such as Ancient Rome's drainage channel, the Cloaca Maxima ("greatest sewage"), this method of management persisted into the late 19th century. Washington DC, for example, constructed its combined sewer system in the 1890s. However, the system did not include treating wastewater, which was discharged directly into the Potomac River. Like its western counterparts, wastewater treatment in China during the late 1800s and early 1900s was also rudimentary, with cities releasing it into rivers. Capitalizing on poor urban sewer management, rural farmers often carried wastewater sludge, dubbed "night soil," from the cities back to their village to fertilize crops. Sludge not used as night soil went into local rivers. By the 1970s, this sludge dumping, combined with China's rapid industrial urbanization and diversifying agricultural development, began taking a severe toll on the country's waterways.

An archive photo shows people tilling a field in Xiaogang. Courtesy of Yan Hongchang

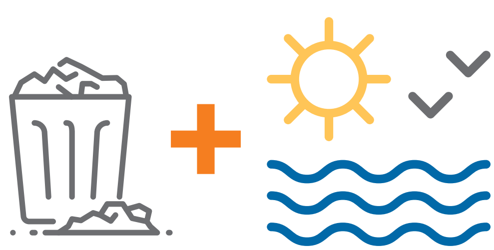
A HISTORY OF NEGLECTED WASTEWATER TREATMENT

By the beginning of the 1980s, many farmers had replaced night soil (human waste) with chemical fertilizers. These chemical fertilizers, in addition to waste from the nation's growing industrial sector and untreated city wastewater, left 80 percent of the country's rivers polluted.[8] In the 1980s and 1990s, most factories did not have (or did not turn on) wastewater treatment equipment, and three-quarters of all municipal wastewater in China was directly discharged into rivers without treatment.[9] Dams and land reclamation for crops caused lakes to shrink, exacerbating the water pollution crisis. Hunan Province's Dongting, at one time the largest freshwater lake in China, shrunk by almost two-thirds.[10]

In response to increasing health and environmental threats from wastewater, Chinese policymakers formulated more stringent and proper treatment practices and policies. China created its National Environmental Protection Agency (NEPA) in 1982, which quickly passed the *Water Pollution Prevention and Control Law* in 1984. While weaker than its U.S. counterpart, the 1972 *Clean Water Act*, the legislation was the first to prioritize wastewater treatment in China. Unfortunately, NEPA was an underfunded sub-ministerial agency that lacked strong enforcement capacity.

From 1982 to the early 2000s, most wastewater regulation in China focused only on pollution cleanup, targeting three lakes (Taihu, Chaohu, and Dianchi) and three rivers (Huaihe, Haihe, and Liaohe).[11] Cleaning up these heavily polluted waterbodies was a major policy and target under several five-year plans, yet it registered little impact. Officials overseeing the clean up of Lake Dianchi in 1997 reported that "no matter how much dredging we do, there will still be pollutants in the water. Because of years of abuse, the ecosystem is very fragile. Blue algae blooms are common."[12] In the Tenth Five-Year Plan (FYP, 2001-2005), China's leadership began pushing for more holistic water pollution prevention laws, moving beyond clean-up strategies to improving wastewater treatment standards.

1982 - 2000



AN OLYMPIC WATERSHED MOMENT FOR WATER POLLUTION CONTROL

When Beijing was announced as the host of the 2008 Summer Olympics in July 2001, the city's water management system could not support the influx of athletes and spectators.[13] In 2002, Beijing was treating only half of its municipal wastewater and insufficiently regulating industrial polluters, leaving the city's canals black and smelly.[14] In preparation for a global audience, the capital embarked on an effort to increase wastewater treatment, reuse water, and protect reservoirs.[15] In total, the Chinese government invested 111 billion yuan in environmental protection as part of the Tenth FYP.[16] Even before the Olympics bid, China's central government welcomed loans and aid from the World Bank, OECD, and Japan for wastewater treatment and sewage infrastructure construction.

By 2005, the central government had made two rounds of significant amendments to the *Water Pollution Prevention and Control Law*.[17] The corresponding oversight agencies also evolved. NEPA became the State Environmental Protection Administration (SEPA), then the Ministry of Environmental Protection (MEP), gaining authority with each name change. The Ministry of Housing and Urban-Rural Development (MoHURD) now regulates wastewater by issuing national standards and technical guidance for the operation and monitoring of treatment plants. At the provincial and municipal levels, MoHURD's departments wield the most authority in overseeing city performance of wastewater and sludge treatment plants. The

Ministry of Water Resources oversees water management issues from hydropower and water withdrawals to flood control and water quality monitoring. Other government agencies also control the tap of water regulation in China, with overlapping and unclear responsibilities.[18]

In China, the phrase "nine dragons rule the waters" is used to describe the bureaucratic competition around water management. In March 2018 the government attempted to finally behead the dragons by splitting MEP into the Ministry of Ecology and Environment (MEE) and Ministry of Natural Resources (MNR), with nearly all responsibility for water pollution delegated to MEE.[19]

BOX 1. CHINA'S WATER TEN PLAN

Comprised of 238 specific measures, the Water Ten Plan is China's most sweeping water policy. Coordinated by 12 ministries and government agencies, the plan focuses on four broad actions to strengthen water security:

- Drive pollution control, water conservation and recycling by transforming economic and industrial incentives.
- Promote science and technology and market mechanisms to improve regulatory enforcement.
- Strengthen management to ensure safe drinking water.
- Encourage public participation and clarify government responsibilities in protecting water.

Source: China Water Risk, New Water Ten Plan to Safeguard China's Waters. http://www.chinawaterrisk.org/notices/new-water-ten-plan-to-safeguard-chinas-waters/

WIELDING REGULATORY REFORM IN CHINA'S WAR ON WATER POLLUTION

The convergence of noncompliance, poor enforcement, lightning-speed urbanization, and industrial development generated the wastewater crisis in China today.[20] Yet, the country has begun to heavily invest in wastewater infrastructure and significantly reform environmental governance.[21] In the 1980s and 1990s, China urbanized at a rate faster than water pollution regulations could control. Now agencies are working to remedy this issue by uniting under a well-planned wastewater policy and treatment system.

China passed some 800 water policies, regulations and standards in the early 2000s and many have now been integrated into the 2015 *Water Ten Plan* (see Box 1), the most robust series of anti-water pollution actions passed in China.[22] However, many industrial and agricultural polluters do not yet comply with the *Water Ten Plan*, and provincial-level enforcement is still lacking.

China's leadership hopes to exert power over provincial delinquents by increasing accountability and oversight as well as centralizing water governance power in MEE. In an effort to rein in water pollution, MEE created the River Chiefs program in 2018 to make officials responsible for monitoring and protecting sections of river basins, holding them accountable for the rest of their career.[22] The central government keeps local governments in check by cutting economic development funds and demoting officials who do not keep water clean.

MEE is also strengthening local oversight, by creating provincial-level branches that report directly to authorities in Beijing. These offices oversee local compliance and are designed to be immune from bribery. MEE's multiple waves of surprise inspections to jolt better local enforcement of pollution control regulations[24] interweave with the Xi administration's anti-corruption campaign, increasing the government's environmental vertical management.[25]

Despite Xi's corruption crackdown, there are still cases where provincial leaders accept bribes from polluters in exchange for favorable environmental inspection results.[26] These quid pro quo local management situations continue to allow untreated wastewater into China's waterways.[27] Prior to the *Water Ten Plan* some 80 percent of China's wastewater sludge went untreated.[28] This compounds with the nation's overall water scarcity: China is home to 20 percent of the world's population, yet just 7 percent of its freshwater.[29] Limited freshwater threatens China's water security.

Policy initiatives like the *Water Ten Plan* and strengthened MEE oversight underscore how wastewater is an important long-term issue to China's central government. Encouragingly, MoHURD also published new rural wastewater treatment discharge limits in September 2018.[30] President Xi also included water and wastewater in his 2018 war on pollution declaration.[31]

1900

Farmers gather night soil from cities to apply on crops

No national environmental watchdog agency exists

1984

First Water Pollution Prevention and Control Law (WPPCL)

Water Pollution Prevention and Control Law (WPPCL) is first legislative action by newly created NEPA

90

Agriculture shifts away from night soil to chemical fertilizers

First Chinese NGOs register under new Social Organization Law. Many early green groups focus on water protection

96

Cities construct centralized wastewater treatment plants

First WPPCL amendments spark more holistic river basin planning and standardized total pollutant discharges

01

Municipal wastewater treatment rate only 20%

Announcement of Olympics sparks wastewater reform in Beijing

South-North Water Transfer Project construction begins, aiming to move water from Yangtze to dry northern cities

03

Beijing mandates water recycling for large buildings

Ministry of Construction publishes Urban Wastewater Reuse Water Quality Standards

06

The NGO IPE creates China's first online searchable water pollution database

SEPA reports nearly 60% of environmental emergency accidents are water pollution related

07

Wuxi river chief system created after massive toxic algae bloom on Lake Tai

SEPA releases WPPCL draft amendments for public comment

08

Second amendments to WPPCL

amendments require standardized release of pollution data, tougher penalties, pollutant discharge permit system, and include an opening for public interest lawsuits

12

Total annual urban wastewater discharge rose 65% since 2000

Urban wastewater treatment reaches 77%

14

Xi Jinping declares a war on pollution

Amendments to Environmental Protection Law pass with stricter penalties for local government violators

16

Environment and Housing ministries launch "black and smelly" river crowdsourcing campaign

State Council requires all stationary polluters (including WWTPs) to be covered by pollutant emissions permit system by 2020

17

Water Ten Plan enacted; third amendments to WPPCL

Municipal wastewater treatment rates hit 80%

18

Ministry of Ecology and Environment formed and National River Chief Program launched

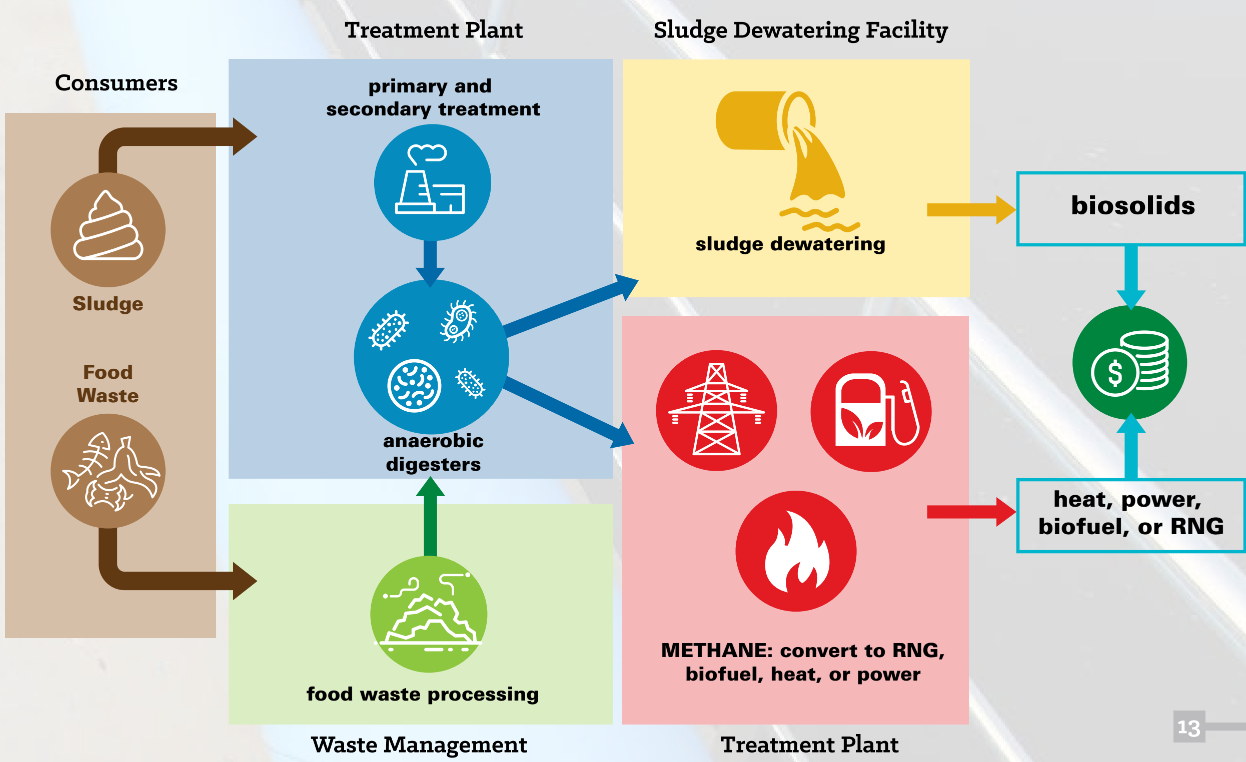
MEE requires environmental health risk monitoring and public health water quality standards pollutant emissions permit system by 2020

A NEW PATH FOR CHINA'S WASTEWATER

When wastewater breaks down, it produces methane, a potent greenhouse gas that exacerbates climate change. But when managed efficiently, this "waste" can become a cost-saving renewable resource. In comparison to methane emissions from wastewater in the United States and Europe, China's wastewater sector "has the most to gain in terms of both investment returns and emissions abatement," according to a report by Xylem, Inc.[32] The water technology company estimates that China's wastewater sector has the potential to abate almost 13 Mt of carbon dioxide equivalent each year (almost total the annual electricity emissions used to power all the U.S. wastewater treatment plants) at zero to negative cost.

Recent improvements in China's water governance (see Timeline) have laid the foundation for policymakers and city water managers to tackle wastewater holistically. China is primed to adopt three resource recovery solutions—methane capture, digestate reuse, and wastewater recycling—that can make the country's wastewater systems more efficient and divert it from the current energy-intensive pathway. (See Figure 1). Separately, each solution generates byproducts that save energy and water and reduce pollution and greenhouse gas emissions. When implemented collectively, they can change the paradigm of wastewater treatment in China, closing the loop on waste and turning it into profit. This report will cover use opportunities, case studies, and recommendations for policies that would enable the uptake of technologies to reuse methane, digestate and wastewater in China.

Figure 1: The Loop of Waste Resource Recovery



Source: Created by Danielle Neighbour and Kathy Butterfield

Byproduct 1: Methane: Turning Wastewater Gas into Power. As an extremely potent greenhouse gas, methane (CH_4) has an environmental impact 84 times more severe than carbon dioxide.[33] The gas is produced when organic biosolids, commonly called sludge, in wastewater break down.[34] If landfilled or dumped into rivers, the sludge decomposes and directly releases methane into the atmosphere. The wastewater sector accounts for 10 percent of global methane production; China is responsible for one-quarter of these emissions.[35] However, wastewater plants can mitigate methane's migration into the atmosphere by capturing it in an anaerobic digester (AD). Methane captured and refined via AD can be converted into electricity sold to power utilities, provide fuel for municipal vehicle fleets, or power portions of the wastewater treatment process, closing the loop of wastewater methane pollution.

Byproduct 2: Digestate: Utilizing Brown "Gold" for China's Soil. "Biosolids" or "digestate" from AD treatment can be dried and further treated for use as organic fertilizer. Using biosolids as fertilizer can prevent waste from entering China's overflowing landfills and end sludge dumping

into water bodies, 29 percent of which are not suitable for human contact.[36] Finally, selling fertilizer adds revenue to China's wastewater plants. Treated digestate can sold as compost for rainwater gardens and greenspaces as a part of China's "sponge city" initiative that aims to reduce storm water runoff floods in China's megacities.[37] Diverting sludge from landfills and recovering it as fertilizer allows wastewater plants to close the loop on their solid waste.

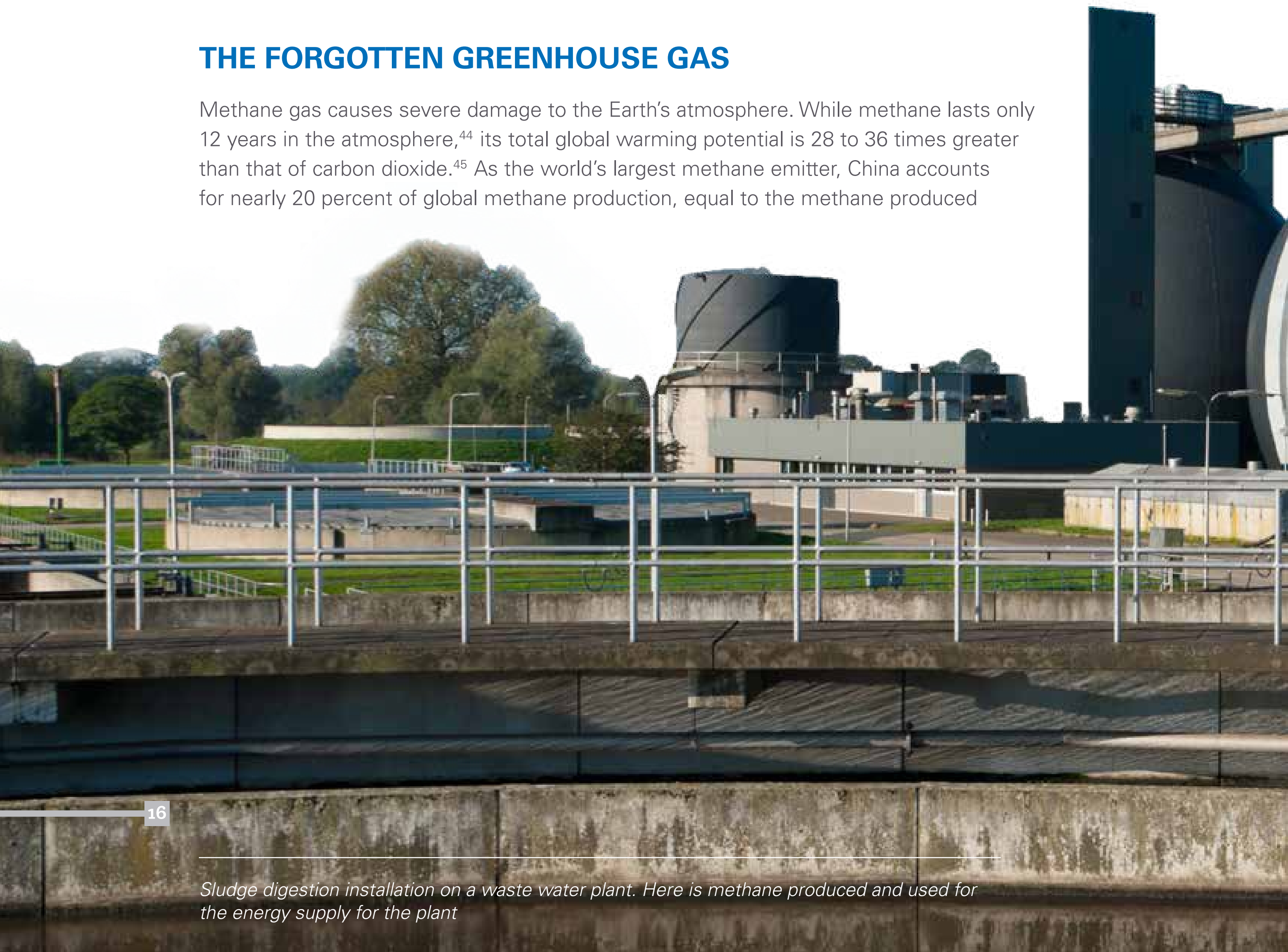
Byproduct 3: Treated Effluent: Quenching the Thirst of Chinese Cities. China's available per capita water supply is one-fourth of the world's average.[38] Wastewater may provide an alternative water source for the thirsty nation. Once properly treated, consumers can immediately reuse wastewater. However, China only reclaims approximately 4 percent of its wastewater.[39] Recycled wastewater can recharge aquifers, irrigate landscapes and agriculture, and streamline industrial processes, including those on-site at the WTTP. Though China has policies to encourage water recycling, their implementation and enforcement are neither robust nor consistent.[40] By recycling treated wastewater, cities can close the loop of their water supply systems, increasing future water security.

Chapter 2: Capturing the Power of Wastewater Methane

Wastewater treatment plants account for an average of 30 to 40 percent of a city's total electricity use.[41] Generating power from methane for on-site use provides advantages to energy-intensive wastewater treatment plants. Captured methane gas powers one-third of Washington DC's Blue Plains Treatment Plant, the largest advanced wastewater treatment system in the world.[42] The use of methane decreases Blue Plain's energy bill and lowers the total electricity demand on the city. Methane reuse makes wastewater plants, considered by the U.S. Department of Homeland Security as "critical infrastructure," more resilient to shocks and stresses by diversifying power sources and allowing them to function partially off-grid.[43] Wastewater treatment plants in China can follow the lead of Blue Plains by capturing methane produced during wastewater treatment and using it for productive purposes, such as electricity, heat, and vehicle fuel.

THE FORGOTTEN GREENHOUSE GAS

Methane gas causes severe damage to the Earth's atmosphere. While methane lasts only 12 years in the atmosphere,[44] its total global warming potential is 28 to 36 times greater than that of carbon dioxide.[45] As the world's largest methane emitter, China accounts for nearly 20 percent of global methane production, equal to the methane produced



Sludge digestion installation on a waste water plant. Here is methane produced and used for the energy supply for the plant annually by India, France, Germany, and Russia combined.[46] Alarmingly, China's methane production has increased 49 percent from 2000 to 2017. By contrast, the United States and the EU's methane production levels have remained unchanged over the same time period.[47]

Methane is produced from anaerobic digestion (AD), a natural process in which microorganisms break down organic materials, such as waste from livestock, humans, or discarded food. It occurs naturally in landfills and wetlands. Methane is also produced during rice paddy cultivation,[48] released when biomasses are incinerated, and leaked from oil and gas pipelines.[49]

Methane produced by human waste (sludge) from the wastewater sector, often released in landfills, accounts for 10 percent of global methane emissions.[50] The EPA's Global Methane Initiative estimates that methane emissions from the wastewater sector will increase 20 percent globally by 2030. Unless action is taken, as China continues to expand its wastewater sector, the nation's wastewater-derived methane production will increase.[51]

Thankfully, captured methane can revolutionize the wastewater sector. Instead of landfilling sludge and allowing methane to be produced and released, sewage sludge can be fed into an enclosed tank called an anaerobic digester. Inside digesters, sludge is broken down or "digested" by microorganisms living in the heated environment of the AD

unit. The methane gas can then be captured and converted into heat, power, or biofuel, which can be used on-site at the plant or sold to the power utilities or municipalities. For example, Los Angeles County Sanitation Districts' Joint Water Pollution Control Plant is now 100 percent self-powered from its captured waste methane and continues to process sludge from 11 wastewater treatment plants serving 5.5 million people in Los Angeles County.

Anaerobic digesters offer wastewater treatment plants numerous benefits. Digesters mitigate greenhouse gases while creating new power sources or revenue streams for utilities. (See Box 2). Yet anaerobic digestion is underutilized; in the United States, the biogas market to digest farm, water, food, and landfill wastes could support 14,000 operational systems compared to the current 2,200, according to Patrick Serfass, executive director of the American Biogas Council.[52]

Treatment plants around the world stand to benefit from anaerobic digestion, and China's wastewater sector presents a unique opportunity for uptake. While incorporating AD in the United States and Europe requires retrofitting existing wastewater infrastructure, China is in the midst of building up its wastewater sector[53] with renewed investment from the government in wastewater innovations.[54] "Currently, around 70 AD plants have been installed in China, but only around ten are fully operational capturing and using methane," says the Wilson Center's China Environment Forum Director, Jennifer Turner. In order to curb wastewater methane, Chinese cities must bring existing plants online and construct new AD units. The inclusion of AD systems in wastewater treatment plants will allow China to leapfrog the wastewater development path and reduce greenhouse gas emissions.

Methane gas molecule

BOX 2. SPOTLIGHT ON NYC'S SUCCESS IN WASTEWATER METHANE CAPTURE

All 14 wastewater treatment plants in New York City capture wastewater methane using anaerobic digestion. 1,269 wastewater plants currently use the process in the United States, and 860 effectively use or sell the methane biogas byproduct. However, three quarters of U.S. wastewater treatment plants capable of supporting a digester system do not currently have one, exposing a significant gap as well as a missed market opportunity for AD technology.

At four plants in New York—Red Hook, Oakwood Beach, Hunts Point, and 26th Ward—the Department of Environmental Protection and New York Power Authority have partnered to install fuel cells to convert methane into combined heat and power (CHP).[55] At Newton Creek, the largest treatment facility in New York, methane is captured in giant digester eggs, which are so striking they have been featured in movies.[56] The gas at Newtown Creek will soon be converted into pipeline-quality renewable natural gas (RNG) to be purchased and processed by National Grid. In late 2019, the power utility was finalizing construction of a large methane scrubbing and processing facility on-site. The project will eventually produce enough RNG to heat 5,200 homes and reduce greenhouse gas emissions by 90,000 MtCO2 equivalent (akin to removing 19,000 cars from the road).[57]

Newtown Creek elected to convert methane to RNG (as opposed to CHP) because the production allows the plant to qualify for renewable identification numbers (RIN) under the U.S. EPA's Renewable Fuel Standard Program.[58] This program allows producers of renewable fuel to earn identification numbers for each gallon of fuel produced. The producers then sell or trade RINs through an EPA-moderated transaction system. This system allows Newtown Creek and other producers of renewable fuel to earn significant profits from their recycled byproducts.

RAMPING UP METHANE PRODUCTION WITH CODIGESTION

The more methane the AD process produces, the more power benefits wastewater plants gain. AD systems generate more biogas when the organic content of the feedstock (the material loaded into the digester) is high. At most AD plants, liquids and solids are separated, and the solid sludge is piped into the digester. However, digesters can also be loaded with other organic materials via codigestion, the simultaneous digestion of food waste (or other organic waste) and sewage sludge.

Codigestion significantly increases methane production. One study found that methane production increases 5.7 times when digesters add animal byproducts from slaughterhouses to sewage sludge.[59] Studies on codigestion with dairy manure[60] and food waste [61] also reported relatively higher levels of methane production when compared to digesting sludge alone. In addition to increasing biogas production, codigestion with food waste was found to reduce volatile solids, ammonia content and sodium.[62] Reducing volatile solids, or organic solids with a calorific value, means wastewater plants have less biosolids to dispose of or disinfect after AD.[63] Decreasing ammonia and sodium allows for cleaner methane, which reduces the purification needed before conversion into a final product. Too much free ammonia also prevents a stable AD process, threatening the profitability of the treatment.[64]

Codigestion is not the only parameter of digester productivity. The organic loading rate, retention time, and fatty acids content also have an impact.[65] But focusing on codigestion allows processing of multiple forms of waste together, keeping them out of landfills and turning them into a revenue stream.

Currently, codigestion is not the norm for wastewater treatment in China. Management of municipal solid waste (MSW) has long been inefficient and siloed from the wastewater treatment sector.[66] About 50 to 70 percent of MSW in China could be used for codigestion;[67] yet currently, nearly all of this urban waste goes to landfills[68] or to incinerators.[69] However, China's "war on pollution" may provide the solution; new central government regulations and campaigns mandating waste sorting and reduction are sparking local governments to take action. In summer 2019, the Shanghai municipal government mandated all city restaurants and households to sort waste, creating a steady supply of food waste that could be redirected to wastewater plants for codigestion. See Boxes 3, 4 and 5 for U.S. and Chinese codigestion initiatives.

BOX 3. DIGESTING KITCHEN WASTE IN NINGBO

Thanks to a 15 billion yuan investment from the World Bank, the city of Ningbo, China has embarked on a closed-loop integrated waste management system. The World Bank-Ningbo Municipal Solid Waste Collection and Recycling Demonstration Project collects domestic kitchen waste, sorts it, then anaerobically digests it at the Ningbo Kitchen Waste Treatment Plant. The plant captures the methane, reusing it for power in Ningbo. As one of the first plants of its kind in China, Ningbo has embarked on a robust public education campaign. Increasing awareness of proper in-home sorting has been one of the most significant challenges, with many plastic utensils and cups being sent to the plant. To combat this, each home is given a kitchen waste garbage bag equipped with a QR code to be deposited in new neighborhood waste bins. If the waste in a bag is not properly sorted, a training crew can come to the resident's home and teach them proper sorting techniques.

Source: World Bank (March 2019). Ningbo Municipal Solid Waste Minimization and Recycling Project.

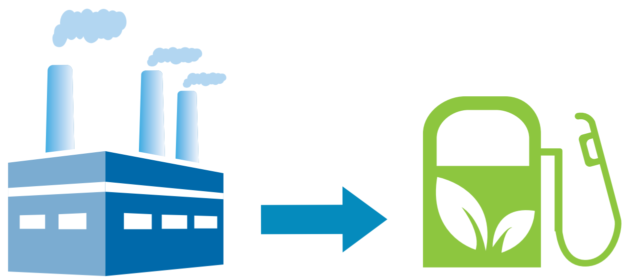
BOX 4. CODIGESTION COLLABORATION IN LOS ANGELES

35.8 percent of LA's 21 million tons of annual food waste is organic. In 2014, Los Angeles County Sanitation Districts decided to stop letting these organics go to waste in landfills. The Districts collaborated with Waste Management, a private company specializing in waste collection, to develop a pilot project from 2015-2018 at the Joint Water Pollution Control Plant (JWPCP). The project received 65-85 tons of food waste slurry per day, which was pre-processed at a materials recovery facility and then injected into digesters at JWPCP. During the pilot, methane production of the test digester increased by 112 percent with the codigestion of food waste, according to Districts' Supervising Engineer, William Chen. After the success of the pilot project, the Sanitation Districts are now seeking to solidify their partnerships with multiple waste haulers and develop a "comprehensive solution" including in-house pre-processing food waste and biogas conditioning of the digester gas to produce renewable natural gas for vehicle fuel.

OPPORTUNITIES FOR LOW-CARBON PROFIT

Vehicle Biofuel: Turning Wastewater Treatment Plants into Gas Stations

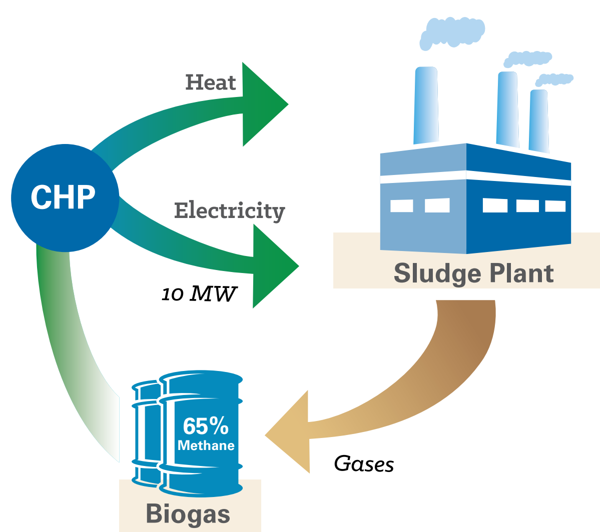
Following capture in digesters, methane purified of carbon dioxide, water vapor, and trace gases can be used as vehicle biofuel.[70] This renewable natural gas (RNG) is chemically equivalent to conventional natural gas, useful for any vehicle that runs on liquefied natural gas.[71] Methane biogas reduces the greenhouse gas emissions of gas-fueled cars by 91 percent compared to traditional gasoline.[72]



In the United States, the EPA's Renewable Fuel Standard (RFS) program offers an incentive for transportation consumers to use biofuels over traditional petroleum. Producers of waste biofuel, such as Los Angeles Sanitation, receive credits in the form of renewable identification numbers (RINs). Each gallon of renewable fuel is assigned a number.[73] Gasoline refiners and importers must offset non-renewable fuels by purchasing RINs from renewable fuel producers.[74] These producers keep the profits from the sale of RINs. The RFS system financially benefits wastewater treatment plants that generate RNG from sludge.

Notably, EPA experts with the RFS system have remarked that China's recent tariffs on U.S. soybeans create an opening for more soy to be converted to biofuel.[75] Fuel from soy, corn, wastewater sludge, and agricultural waste—together representing all biofuel feedstocks—made up approximately 7 percent of U.S. transport fuel consumption in 2012.[76] The vast majority of this fuel is comprised of corn-based biofuel (ethanol). The EPA has set the goal for biofuel production in the U.S. wastewater sector to reach 16 billion gallons by 2022. However, as of 2014, only 25,000 gallons of cellulosic biofuel were produced annually.[77]

In China, the wastewater methane biofuel sector likewise has room to grow. Like the United States, China has set a national biofuel target—3 billion liters of biodiesel annually by 2020—yet is unlikely to reach the goal without robust government support. Currently, China produces 1.14 billion liters of biodiesel annually. The city of Xiangyang, Hubei, serves as a biofuel success story where the Yuliangzhou



wastewater plant uses AD to codigest sludge with kitchen waste from local restaurants. The project was made possible by a local government mandate requiring restaurant food waste collection.The plant converts its methane to biofuel, which it sells to fuel the fleet of taxis in the city. The system produces enough biofuel to support 400 vehicles per day.[80] While the Xiangyang government partially subsidized the codigestion at Yuliangzhou, the Chinese central government does not have an RFS-equivalent national incentive scheme.

On-site Combined Heat and Power: Maximum Energy from Waste Methane

In order to use methane as power, wastewater treatment plants may use it to run combined heat and power infrastructure (CHP). CHP can be used to run pumps, turbines, and blowers at wastewater plants, while the heat can keep the anaerobic digester at its ideal temperature of 40 degrees Celsius (104 Fahrenheit). (See Figure 2)

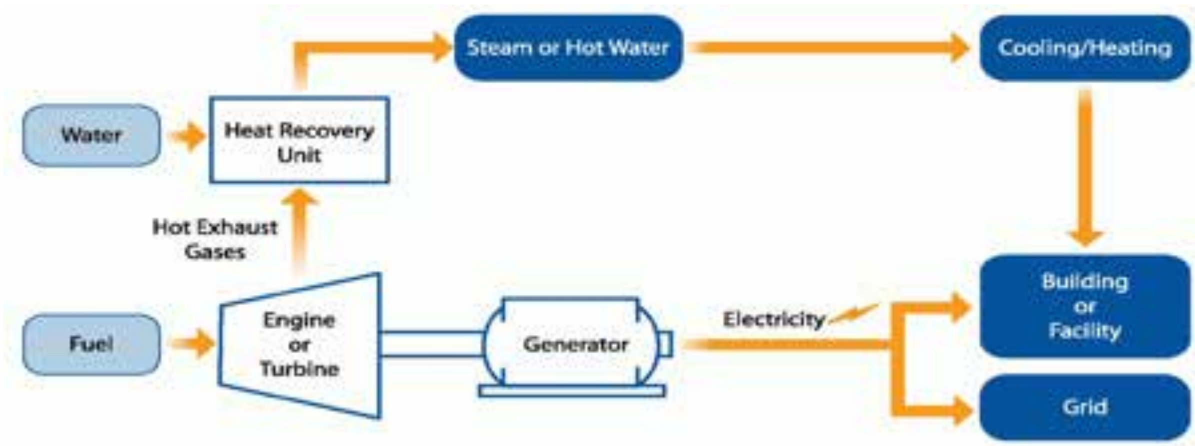
Heat from CHP can also be used to support thermal hydrolysis, an optional process that makes sludge more biodegradable and increases production of methane biogas by 50 percent.[81] The Washington, DC Blue Plains treatment plant's thermal hydrolysis system is heated solely by the plant's on-site CHP system. Blue Plains is the first plant in North America to use this technology.[82] If widely implemented in China, the combination of thermal hydrolysis and AD may turn wastewater treatment into an effective carbon sink with a potential 500 ton carbon-negative footprint.

CHP converts 90 percent of primary energy (in this case, methane) to power and heat; traditional thermal power generation is capable of converting only 36 percent of the fossil fuel energy to useful power.[83] CHP's extremely high efficiency makes the process cheaper than buying coal-fired power from utilities.[84] Moreover, it is more reliable than traditional power, produces fewer GHG emissions and reduces transmission and distribution leakage.[85]

DC Blue Plains treatment plant's thermal hydrolysis system is heated solely by the plant's on-site CHP system.

Figure 2. Mapping Out CHP Generation

(Source: U.S. EPA)



Selling Electricity to the Grid: Wastewater Treatment Plants as Power Plants
Wastewater treatment plants can also sell the energy they produce to the electricity grid. CHP provides the best option for generating heat and power simultaneously, but plants that opt to generate only electricity from methane can use a plethora of technologies, including turbines, fuel cells, and reciprocating internal combustion engines.[86] Such engines are most common due to their low cost and high efficiency. Plants intending to sell pipeline-quality natural gas may use pressure swing adsorption, a purification process that separates methane and carbon dioxide. Pressure swing adsorption is capable of recovering 75 percent of methane, rendering a 96 percent pure final product.[87]

ROADBLOCKS TO DEPLOYMENT OF WASTE METHANE TECHNOLOGY IN CHINA

Feedstock quality. In many Chinese cities, treatment plants use wastewater collected from both industrial and municipal customers through combined sewers. These sewers also collect large amounts of stormwater runoff, diluting wastewater. This results in wastewater with high levels of grit and heavy metals and low levels of organics—the opposite of the ideal anaerobic digestion (AD) feedstock.[88] Implementing AD to process diluted wastewater will likely require codigestion, or adding organics such as food waste to gritty wastewater. In general, this especially watery wastewater also makes application of Western wastewater technologies, which generally process wastewater with more organics and less grit, more difficult in China. Although it is expensive, Chinese cities should invest in separated sewer infrastructure to prevent flooding and facilitate proper wastewater treatment.[89]

BOX 5. TAKING A BITE OUT OF FOOD WASTE IN THE BIG APPLE

To incorporate codigestion into New York City's wastewater treatment systems, then-Mayor Michael Bloomberg passed codigestion and composting bills in 2013.[90] One law mandates residential and commercial food waste collection.[91] The second requires large food waste producers, like stadiums or large hotels, to either compost or send food waste to wastewater plants. Together, these laws have increased the amount of organic food waste for codigestion at wastewater plants, thereby improving the amount of methane produced and used for energy.

Currently, only the Newtown Creek Wastewater Resource Recovery Facility codigests sludge and food waste. At Newtown Creek, a pilot project with Waste Management (WM), a private waste disposal company, has cleared one of the tallest hurdles in the codigestion process: pre-processing.[92] Pre-processing removes contaminating materials like plastics and glass in organic waste before codigestion. In 2012, WM built its Varick I solid waste station, which screens and processes food waste collected from NYC customers (using WM's proprietary Centralized Organix Recycling equipment).[93] The final, entirely organic product, dubbed Engineered BioSlurry, is delivered to Newtown Creek where it is codigested in three of the facility's eight digesters.

No monetary gain motivates this symbiotic public-private partnership. While Newtown Creek does not pay WM for the slurry it benefits because codigestion produces better quality methane gas. The plant also does not need to pre-process food waste, unlike other plants around the United States.[94] The partnership also is beneficial for WM, as giving the waste to Newtown Creek is a free alternative to costly landfilling. Newtown Creek does not receive any NYC funding for the project, but the New York State Energy Research and Development Authority is funding a study to determine benefits—like efficiency increases—of the partnership.

Return on investment. Costs for AD implementation vary significantly depending on the size, scale, and application of the digestion project. Small digesters for single farms or wastewater plants range in cost from 5,000 to one million USD.[95] Large-scale digesters for municipal wastewater plants can cost many millions to purchase and hundreds of thousands of dollars to operate. Return on investment for these digesters depends on feedstock, digester size, and power purchase agreement (or CHP system, if using power on-site).

In the United States a small 100 kW AD plant requires an annual operating cost of nearly $800,000 in addition to an $8,000 initial investment.[96] With feed-in tariffs, the plant's return on investment is nine years. For larger plants (500 kW to 1000 kW) capitalizing on economies of scale, payback periods are four to five years. This return on investment timeline can prove difficult for cash-strapped or smaller wastewater treatment plants. In China, many wastewater treatment plants already operate at an economic loss.[97] While AD systems offer long-term profit sources, the five+ year payback period can make initial investment difficult.

Non-market based economy. Without a market economy, finding demand for methane in China is more difficult than in the United States. However, China's newly launched national carbon emissions trading scheme presents an opportunity for inclusion of wastewater treatment plants.[98] To make their caps, fossil fuel utilities and energy-intensive manufacturers could purchase low-carbon power generated by wastewater treatment plants. This is more of a long-term goal, as the national ETS has been rolling out slowly China.[99]

Financial mechanisms. In the United States, the most common financial mechanism used by wastewater treatment plants to capitalize on their generated power is a power purchase agreement (PPA) between power utilities and wastewater treatment plants. In some cases—such as Newtown Creek (see Boxes 2 & 5)—power utilities planning to purchase renewable electricity will construct a methane-to-power conversion system on-site at the wastewater plant. In these cases, a build-operate-transfer agreement allows the utility to recoup construction costs. PPAs that do not include such an agreement usually stipulate a required baseline amount of energy to be produced, coverage of fixed and variable costs for the power generator, and penalties for underperformance.

In China, PPAs for renewable energy have historically included heavy subsidies from the National Development and Reform Commission (NDRC) supporting energy producers. While well intended, these heavy subsidies have the potential to create a mismatch between energy production and transmission capacity. For example, heavy subsidies for solar PV production led to an overproduction of solar infrastructure, which outpaced demand.[100] China soon found itself with more solar power generation than the grid could distribute, leading to high rates of curtailment.[101] Today, China is moving to subsidy-free solar and wind.[102] If NDRC does opt to subsidize wastewater methane production it must be carefully monitored to prevent a similar over-production and curtailment cycle.

POLICY RECOMMENDATIONS: REMOVING THE ROADBLOCKS

Counting on Codigestion. Collecting municipal food waste at scale—as accomplished in New York, Ningbo, and Los Angeles—and processing it in anaerobic digesters with wastewater significantly increases methane production. Digesting organic waste at wastewater plants also keeps food waste out of landfills, curbing another source of methane leakage.

To make national codigestion possible, large Chinese cities should adopt the model of New York and Los Angeles. In those two cities, the garbage collection company Waste Management collects, sorts, and screens waste for non-organics. In China's smaller towns, following the lead of Ningbo (see Box 3), incentivizing residents to pre-sort and screen kitchen waste reduces overhead costs borne by utilities. As in the case in Xiangyang, Chinese cities can supplement domestic kitchen waste with waste from restaurants and other major food producers.

Importance of Infrastructure (separated sewer systems, urban greening & holding tanks). In addition to codigestion, which adds much-needed organics, China should expand its efforts to lower stormwater in sewers. Moving to a municipal separate storm sewer system (MS4s) to transport sewage and stormwater separately, may prevent flooding and facilitate proper wastewater treatment. But a complete overhaul of sewage systems takes years.[103] In the meantime, China can emulate NYC by expanding retention facilities in its combined sewer system and engaging communities to create urban green spaces. (See Chapter 5).[104] Such a model fits well into China's sponge city initiative. An example of a useful non-infrastructure solution for Chinese cities is NYC's pilot SMS text program called "Wait…," which asks New Yorkers to delay using water until after a heavy rainfall event ends. Such small actions can reduce the strain on wastewater treatment plants. By addressing this issue from multiple points in the wastewater collection and treatment process, Chinese wastewater treatment plants can mitigate the problem of gritty, low-organic wastewater and produce substantial and sustainable amounts of methane.

Chapter 3: Digging into Digestate

Every day, Washington DC's Blue Plains Advanced Wastewater Treatment Plant receives 300 million gallons of wastewater from the nation's capital.[105] Little of this wastewater is wasted. The plant, situated on the shores of the Potomac, uses gas byproducts such as methane from AD for heat and power. The Blue Plains plant also notably disinfects biosolids—called digestate—for use as fertilizer. Blue Plains produces high-quality fertilizer from its sludge labeled by the U.S. EPA as a Class A EQ biosolid, a designation that allows for commercial sale. DC Water now sells its fertilizer in DC, Pennsylvania, Maryland and Virginia as Bloom. Its customers include landscapers, farmers, homeowners, and even the National Park Service uses Bloom as fertilizer on the National Mall.[106] DC Water sells Bloom in bulk and in stores and generates a source of profit from D.C.'s wastewater. Chinese wastewater treatment plants have not yet begun to tap the market of producing and selling digestate.

SHIFTING PRIORITIES ON SLUDGE DISPOSAL

Instead of treating sludge and greywater from wastewater treatment plants as waste, these resources should be treated and reused to create economically and environmentally profitable products. This chapter dives into the "gold" found in sludge.

During the wastewater treatment process, most suspended solid organic material is separated from water in sedimentation tanks as primary treatment.[107] About 90 percent of China's municipal plants then treat the remaining sludge through secondary treatment.[108] During this phase, sludge undergoes aeration, and bacteria from the "activated" sludge eats away pathogens. The activated sludge used in secondary treatment can go through further aeration. However, in China the sludge settled out from primary and secondary treatment is usually landfilled or incinerated, methods that often pollute air, water and soil.[109]

Landfills are currently the most popular method of waste, including sludge, disposal in China. Unfortunately, official landfills are running out of capacity, leading to the creation of nearly 10,000 unofficial landfills, many of which contain over 200 tons of waste.[110] In 2013, journalists discovered 30 "mountains" of illegally dumped sludge in the outskirts of Beijing.[111] In total, Beijing properly treated and sanitized only 23 percent of its sludge in 2015. In most other Chinese megacities, treatment rates are even lower.[112]

Chinese cities are turning increasingly to incineration to manage mountains of sludge, part of a broader waste management trend. Xi Jinping's administration set the goal to incinerate nearly 50 percent of the country's approximately 500 million tons of municipal waste by 2020.[113] Since sludge must dry completely before incineration, it is energy intensive and financially expensive to burn.[114] Transparency regarding the environmental impacts of China's new incineration plants has been limited, sparking public outcry in many cities.[115] Case in point, when Shenzhen announced its plans to construct the world's largest incinerator in 2015, over 5,000 residents protested in front of the mayor's office. The city subsequently increased public access to information on incinerator emissions and operations.[116]

Land application offers a compelling alternative to landfilling or incinerating sludge. An insightful U.S. example is the Forest County Potawatomi Community Biodigester Facility in Wisconsin, which processes 132,000 gallons of food waste and wastewater daily from restaurants and a neighboring casino, producing digestate for land application. The land application process differs from using sludge as fertilizer because it does not require the same amount of treatment.

While sanitized digestate cannot be used for agriculture in China, it could help revitalize pasture land and increase tree growth in urban parks. However, China has yet to surmount the logistical challenges of transporting sludge to large areas of forested or unfarmed land. China needs a solution for its sludge that keeps it out of landfills, minimizes incineration, and out of the nation's waterways and soil. Even New York City faces challenges in exporting its digestate to rural areas. (See Box 6.)

BOX 6. NEW YORK CITY PUTTING THE BRAKES ON EXPORTING BIOSOLIDS

Three wastewater treatment plants in New York City (NYC)—Red Hook, North River, and Newtown Creek—do not have on-site capacity to dewater their own biosolids. In these cases, sludge vessels or force mains (pipelines that convey wastewater under pressure) transport liquid sludge to other treatment plants with dewatering capabilities. This practice is both energy intensive and expensive, highlighting an area for improvement in the plants.

Once dewatered, the material is classified as a biosolid, or a nutrient rich soil conditioner.[117] NYC alone produces over 1,000 tons of biosolids each day—about the weight of four Statues of Liberty.[118] Until the late 1980s, the city disposed of its biosolids into the ocean. The federal government prohibited this practice with the *Ocean Dumping Ban Act*, prompting NYC's Department of Environmental Protection to implement its current biosolids management program.[119] Under today's system, private contractors either dispose of digestate in landfills in New York, Pennsylvania, and Virginia, or lime stabilize the material in Pennsylvania and Colorado facilities. Landfilling partially sanitized biosolids can pollute water and soil and daily transport of 300+ tons by truck increases the air pollution and carbon footprint of disposal.[120] The trucks and landfilling have angered residents in some states receiving NYC's biosolids.[121]

In 2015, 68 percent of New York State's biosolids were landfilled, but only 16 percent were beneficially used through land application, composting, or mine reclamation.[122] To remediate these issues, NYC has announced the laudable goal of zero-landfilling of biosolids by 2030[123] as a part of the Mayor's Office of Sustainability's OneNYC Plan (detailed in Chapter 5).[124] NYC plans to strengthen the sludge treatment capacity at its Hunts Point plant with a $67 million installation of centrifuges to dewater digestate.[125] In the long term, the city also needs to increase capacity to convert its own digestate to Class A biosolids to use as agricultural fertilizers.[126]

SLUDGE AS A RESOURCE

In anaerobic digestion (AD), 40 to 60 percent of the organic solids are converted to methane and carbon dioxide. The remaining biosolids—now referred to as digestate—are stable, odorless, and free of most pathogens. In order to increase the solids content, digestate must be dewatered and thickened. The most common dewatering methods include centrifuges, belt filter presses,[127] and direct and indirect heat dyers.[128] The solids can be further disinfected and stabilized with lime after dewatering.[129] The lime-stabilized biosolids can be reused as livestock bedding,[130] biochar,[131] or fertilizer. In addition, liquids removed from sludge called "liquor" have many uses. Nutrients such as phosphorus in the liquor can be recovered and sold.[132] Liquor can also be purified and recycled with effluent.[133]

ECOLOGICALLY AND ECONOMICALLY VALUABLE FERTILIZER

Rich in nitrogen and phosphorus, digestate provides nutrients for soil.[134] The fertilizer also mitigates greenhouse gas emissions. After two years of biosolids application, digestate-applied soil absorbs carbon at a rate between 37 and 84 percent more than degraded urban soils, according to a Virginia Tech study.[135] Finally, by treating the biosolids via AD, dewatering, and disinfection, wastewater treatment plants can sell the product. In the United States, the EPA regulates digestate treatment by various "classes" of biosolids. (See Box 6).

BOX 7. CLASSIFYING BIOSOLIDS IN THE UNITED STATES

The 1987 amendments to the Clean Water Act included new Standards for the Use or Disposal of Sewage Sludge (40 CFR Part 503). The standards also delineated a classification system for treated biosolids, with categories Class A, Class A EQ, and Class B.

Class A biosolids must be completely free of pathogens and comply with stringent standards on odor and heavy metals. Class A biosolids also must have "reduced attractiveness" to organisms that can carry disease, like flies, mosquitoes, or rodents (usually achieved via lime stabilization). If Class A biosolids successfully exceed the requirements, they are labeled as Class A EQ (exceptional quality). Such biosolids can be used on food crops and sold as fertilizer or compost to farms and homeowners.

Class B biosolids have less stringent requirements, which allows for some detectable pathogens. Class B biosolids cannot be used on foods, but qualify for land application and soil remediation. Some states, like Virginia, require permits before Class B biosolids can be applied to land.

Sampling of biosolids is the responsibility of the wastewater treatment plant. The National Biosolids Management Program provides support to wastewater plants to ensure standards are met; it also certifies biosolid products.

Sources: Water Environment Federation: www.wef.org & Clean Water Act: https://www.epa.gov/laws-regulations/summary-clean-water-act

WHAT'S DAMMING UP DIGESTATE USE IN CHINA?

Investment gaps. China's investment in sludge disposal pales in comparison to national investment in wastewater treatment as a whole. While wastewater treatment investment is equal to $68.8 billion (USD) per year in China, annual national investment in sludge disposal is only $5.6 billion.[136] In most developed nations, these investment rates are approximately equal.[137] Recently, China's central government sought to increase sludge initiatives by requiring municipalities to construct sludge treatment facilities. The effort is to be funded by another $9.6 billion capital investment from the central government.[138] While a step in the right direction, total investment in sludge in China is still remarkably low.

Heavy metals. Currently, about 16 percent of the soil in China is polluted by heavy metals such as cadmium, mercury, lead, arsenic, copper, zinc and chromium.[139] In China, heavy metal contamination of sludge occurs where plants treat industrial wastewater together with municipal wastewater, and where combined sewers transport stormwater and wastewater together.[140] These metals are difficult to remove from sludge and can remain in the solids through the AD and dewatering processes. If incoming wastewater has high levels of heavy metals, the final digestate will also likely contain heavy metals. Soil and crops can absorb metals from contaminated digestate used as fertilizer, which harms humans who consume the agricultural products.[141]

In the 1990s, China's lead environmental agency sought to mitigate heavy metal pollution by establishing discharge limits for both wastewater and sludge. But the limits on 14 heavy metals outlined in the *Integrated Wastewater Discharge Standard*[142] did not include discharge data from industrial wastewater users.[143] The ineffectual standards failed to solve the issue of heavy metal pollution in soil and water. Now, China's environmental agencies have ratcheted up efforts to control soil pollution through the *Soil Pollution Prevention Action Plan*, announced in 2016. The effort aims to remediate 90 percent of polluted soil by 2020, with a specific focus on ending heavy metal pollution. While the action plan is making headway in combating toxic soils and slowing new contamination, China is unlikely to reach the 90 percent goal in 2020.[144]

Land application laws. Land applying biosolids with a heavy metal content would further damage soil. As part of its soil cleanup effort, China's Ministry of Agriculture has outlawed the practice of applying treated digestate to crops.[145] Unfortunately, this ban has led to more illegal sludge dumping, exacerbating heavy metal leakage into the environment.[146]

While sludge containing heavy metals should not be applied on land, metal-free sludge could play a key role in helping China meet its 2020 soil remediation goal. Such digestate can be applied to land to remove soil pollutants.[147] Processing industrial wastewater separately from municipal and commercial wastewater allows for significantly lower metal content in the final digestate product and would generate a higher methane production from AD plants.

If such wastewater cannot be separated, industrial users should be required to remove heavy metals from wastewater before sending them to a treatment plant. DC Water, the producer of Bloom biosolids, requires heavy metals to be removed during pretreatment to keep its digestate at the EPA's Class A EQ level.[148]

POLICY RECOMMENDATIONS: REMOVING THE ROADBLOCKS

Establish a national classification system for sludge. As the main regulating agency of wastewater treatment plants, the Ministry of Housing and Urban-Rural Development (MoHURD), should establish a national sludge rating system, akin to the EPA's classification system. MoHURD could offer a multi-level classification system in which only fertilizer with minimal heavy metals (Class A equivalent) would be applied to crops; alternatively, fertilizer with trace amounts (Class B equivalent) could be used for land application.

Increase funding for sludge treatment. The NDRC should appropriate more funding channels for sludge treatment, recycling, and disposal in China's 14th Five-Year Plan (2021-2025). Funding mechanisms should include subsidies for constructing sludge pre-processing and dewatering infrastructure to provide the necessary treatment for turning sludge into fertilizer. Funds could also help establish the classification system.

Retrofit infrastructure and classify solids. Sewers that separate stormwater runoff (a major source of heavy metals) from sewage can reduce the amount of heavy metals mixing with sludge before treatment.[149] Treatment plants do have strategies for removing metals that still enter sewers. Lime stabilization, for example, can immobilize metals and prevent them from seeping into soil or crops.[150] Reverse osmosis through membranes has also been proven to remove metals from wastewater, with an especially high removal rate of 98 and 99 percent for copper and cadmium, respectively.[151] The MoHURD classification system could cover metals not removed through combined sewers or wastewater treatment.

Adopting and financing the classification system would help close the loop on sludge, generating a marketable product that brings considerable environmental benefit a fertilizer for crops and urban landscaping.

Chapter 4: Recycling Wastewater for Water Security

El Paso, Texas is running out of water. In 2000, a study by the Border Information Institute estimates the aquifer supporting the city and its neighboring border town of Ciudad Juarez would go dry by 2025.152 In response to the pressure, the city began bolstering its water reclamation program. El Paso has been recycling wastewater from its four treatment plants since 1963. The water can be used for a range of non- potable uses, from watering city parks and street sweeping to industrial processes.[153] Now, El Paso hopes to also recycle its wastewater effluent as drinking water.

Treating wastewater for immediate use as drinking water, called direct potable reuse, is completely safe. However, public skepticism of "toilet-to-tap" systems has been strong. In order to educate El Pasoans on the safety of the proposed system, El Paso Water embarked on a public relations campaign. It even created a plush mascot who makes visits to local schools.[154] The proposed direct potable reuse system has now completed the pilot-testing phase garnered public buy in, which prompted the Texas Commission on Environmental Quality to certify it for full-scale design and construction.[155] The plant uses four processes to treat wastewater effluent: membranes, reverse osmosis, ultraviolet disinfection, and granular activated carbon.

El Paso's long-lasting water recycling program—growing from indirect reuse to direct—can serve as a model example for China's thirsty cities.[156] Beijing, with a population of 31 times the size of El Paso, has dried up many of its reservoirs.[157] The city now relies increasingly on the South-North Water Transfer Project, a controversial, multibillion-dollar system that pumps water from the Yangtze River in the south into the capital and other dry northern areas. Water recycling offers Beijing and other Chinese cities a more sustainable solution.[158]

Photo Credit: El Paso Water

THE IMPERATIVE FOR WASTEWATER RECYCLING

Around the world, most cities discharge treated water into nearby water bodies. However, in water-scarce regions, to release treated wastewater or effluent into rivers or oceans is to discard a precious resource. As the climate continues to change and rainfall patterns become increasingly unpredictable, recycling provides a reliable water source. Such water can be utilized for indirect potable reuse, such as injection into aquifers.[59] Or it can be used for direct potable reuse, where water is treated and piped back to consumers as drinking water.[160]

Recycled water is most commonly used for non-potable applications in the United States. Designated by purple pipes, non-potable recycled water is primarily used for industrial processing and cooling, landscaping, and public parks. In some states, recycled water can also be used in agriculture to irrigate crops. The United States has been slow to embrace indirect and direct potable reuse technologies. However, over the past five years with growing droughts in some regions interest in recycled water has grown, as have pilot projects.[161] Because each state has jurisdiction over water recycling regulation within its borders, no national laws outside of the EPA's Safe Drinking Water Act regulate water reuse. Currently, 94 percent of all reuse efforts occur in nine states, with California in the lead. Los Angeles Mayor Eric Garcetti recently announced a campaign to recycle all the city's wastewater by 2035.[162] However, direct potable reuse is still illegal in California.[163]

In China, implementation of water recycling has been fractured; like the United States, uptake of recycling varies across China's provinces. China does have national standards governing water recycling. In 1985, in dry northern Tianjin, Xi'an, and Taiyuan the city governments implemented regional pilot recycling projects. Data from these projects was used to inform MoHURD's development of the national *Urban Wastewater Reuse Water Quality Standards*, published from 2002 to 2005.[164] These standards exclude direct potable reuse but allow indirect and non-potable use.

In water-scarce Beijing, the city government implemented a water recycling law in 2003—as part of the city's Olympic preparations. The new law subsidized the price of recycled water and mandated all buildings larger than 30,000 m^2 to construct and employ an on-site, decentralized recycling system, unconnected to citywide sewers.[165] Unfortunately, implementation of this law is fraught and only about half of the constructed systems remain in use.[166] Decentralized recycling cannot capitalize on economies of scale, especially with little government support. Centralized recycling plants would be a better strategy for a megacity like Beijing.

In fact, Beijing's largest wastewater treatment plant, Gaobeidian Wastewater Treatment Plant, has a full centralized water recycling plant on-site.[167] While much of Gaobeidian's daily 4.1 million cubic meters of intake water is fully treated to potable quality, most of it is discharged into rivers. Gaobeidian operators blame this on compounding issues. Reclaimed water can only be used for non-potable applications in China, making the market for reused water small.[168] Currently, both national and local laws prevent Gaobeidian from using its recycled water for indirect or direct potable applications, even though the water is safe for consumption.[169]

SUCCESSFUL STRATEGIES

With the right policies to create markets for recycled water and successful public outreach, cities like El Paso have taken full advantage of recycling technologies to reuse water.

El Paso's Strategy: The water recycling methods employed by El Paso represent common treatment techniques used to treat water after the wastewater treatment process. One common process, reverse osmosis (RO), purifies water by pushing it through semi-permeable membranes. When water is forced through membranes at a rate higher than osmotic pressure, the water is both demineralized and deionized.[170] Filtration with micrometer-size membranes is also used to remove bacteria.[171] Another process, ultraviolet (UV) disinfection, inactivates harmful bacteria in water.[172] Often, recycling plants use a combination of RO, UV, and microfiltration treatment to purify water before reuse.

Designer Water in Los Angeles: Plants can also tailor their water treatment based on customers' needs. Even with strict water quality standards, there are wide opportunities for beneficial indirect potable reuse. For example, the West Basin Municipal Water District in Los Angeles produces five forms of "designer water" used for everything from industrial processing to groundwater replenishment.[173] The latter, a form of indirect potable reuse water, provides a seawater barrier to protect groundwater from saltwater intrusion. West Basin works directly with water customers to convert their facilities to accommodate recycled water.[174] The plant now treats 35 to 40 million gallons of water per day (MGD) and has plans to double its capacity to 70 MGD to supply new customers. While most wastewater treatment plants, such as Gaobeidian in Beijing, maintain their recycling infrastructure on-site, West Basin receives its water via a mile-long pipeline from the LA wastewater treatment plant, Hyperion.

By designing treatment according to end user needs, West Basin saves money and energy. Rather than treating all effluent to direct potable standards, the plant must only treat water to the level the customer requires. This is especially relevant for industrial applications that often only require ammonia removal. However, because California does not yet allow direct potable reuse, West Basin is not able to sell its product directly as drinking water.

Singapore's Successful NEWater Avoids the Toilet-to-Tap Trap: For a successful direct potable reuse story, Chinese wastewater treatment plants should look no further than Singapore. Singapore's Public Utilities Board (PUB), the national water utility, has branded its reuse water as NEWater, currently suppling 40 percent of Singapore's water needs.[175] Treated via microfiltration, RO, and UV disinfection, NEWater supplies direct and indirect potable and non-potable reuse.[176] In order to successfully incorporate NEWater as one of its "national taps," Singapore's PUB has conducted over 150,000 tests on NEWater, invited external auditors for semi-annual tests, and embarked on a large-scale public relations campaign.

The idea of drinking sewage is understandably unappetizing, however, properly recycled water is safe to drink. Incendiary headlines[177] proclaiming water reuse as "drinking toilet water" can incite public distrust.[178] Singapore's PUB has successfully avoided the "toilet to tap" trap through a multipronged educational approach.[179] First, Singaporean journalists were taken on study tours of other successful water recycling plants abroad, then invited to a press conference with recycling experts where they could ask questions about the safety and management of the water reuse project. Members of Parliament and public officials were similarly briefed. Second, PUB created a public visitor's center with interactive displays explaining the system's membrane treatment process, as well as free programs, like its NEWater Scientist and Ambassador programs.[180] Finally, PUB passed out free bottles of NEWater at public events and concerts. During engagement with the public, journalists, and elected officials, PUB stuck to its talking points, namely that recycling has been used for years around the world and the treatment process is proven and safe.[181] NEWater is expected to meet 55 percent of Singapore's water demand by 2060.[182]

ROADBLOCKS TO WATER RECYCLING IN CHINA

Establishing trust. Unfortunately, distrust of water recycling already exists in China, especially in the nation's capital. Because implementation of Beijing's decentralized water recycling law has been fraught, many of Beijing's residents are skeptical of recycled water quality. There is no required government monitoring of the recycling systems, which are often operated by a landlord with no water engineering experience.[183] Thus, concerned Beijing residents often opt out of their buildings' water recycling systems, even if the water is offered at a cheaper rate.[184]

Potable reuse policy. Both indirect and direct potable reuse face various restrictions or bans at the provincial and national level. Currently, China's water recycling laws are preventing centralized water reuse plants from being financially viable and environmentally sustainable. Chinese cities are thus missing an important opportunity to increase drinking water security.

POLICY RECOMMENDATIONS: REMOVING THE ROADBLOCKS

Increased monitoring and a large-scale, multi-level public education campaign. First and foremost, the Ministry of Ecology and Environment (MEE) and MoHURD must ensure recycled water is truly safe for use. City water authorities, must increase monitoring support for decentralized water reuse plants in order to guarantee the quality. Most critically, cities should capitalize on economies of scale and invest in centralized reuse plants where water quality is monitored by professional operators.

Once decentralized and centralized reuse water quality is guaranteed, MEE, in partnership with MoHURD, should conduct public education campaigns. Following the lead of El Paso and Singapore, the campaign should target stakeholders capable of shaping public opinion (e.g., policymakers, journalists, and community leaders). For direct public outreach, Chinese water reuse plants can establish free, interactive visitor centers and offer programs for children and adults highlighting the benefits recycled water. In addition, MEE and MoHURD should hold trainings for municipal leaders to ensure they understand the technology and can accurately communicate its importance. Finally, working with the media to ensure reporting accurately reflects the safety of water reuse, without incendiary language, is also critical.

Pass indirect, then direct, potable reuse laws. China should first pilot indirect potable reuse via aquifer recharge, with the long-term goal of direct potable reuse. Indirect potable reuse can replenish depleted aquifers and offer an environmental buffer. It is also the most common form of water reuse implemented by cities worldwide. As public opinion of direct reuse improves under a joint MEE and MoHURD public outreach campaign, the government could legalize direct reuse, a decision that would greatly increase water security in Chinese cities.

Chapter 5: New York's New Wastewater Ideas for Beijing and Beyond

Portions of this chapter were published in *China-US Focus*[186] *and Scientific American*[187] with contributions from Gillian Zwicker.

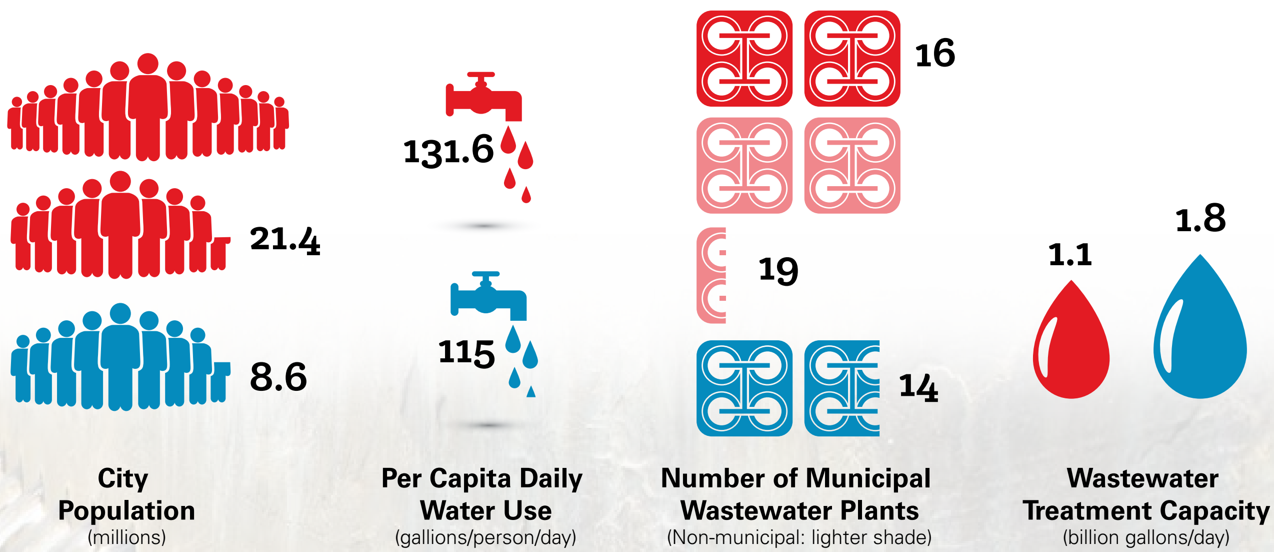
In 2018, floods resulted in over 20 casualties and billions of yuan in damage in China.[188] *The government issued 835 flood warnings nationwide.*[189] *As global temperatures rise, the combination of extreme weather events and sea-level rise threatens the basic infrastructure and water security of low-elevation Chinese cities. Coastal residents account for 43 percent of China's population, and approximately 170 million citizens live less than 10 meters above sea level.*[190] *In fact, 7 of China's 10 largest cities are on the coast, making it imperative for the government to address impending threats of flooding and sea-level rise.*[191] *Shanghai, China's largest city, is on the front lines of climate change*[192] *as one of the world's most flood vulnerable major cities.*[193] *Shanghai's government eagerly invested in China's sponge city initiative and expanded greenspace, rooftop gardens and porous pavements to control stormwater floods.*[194] *However, officials have been hesitant to invest in climate adaptation measures such as unglamorous networks of sewage and wastewater infrastructure that do not create a big splash.*[195]

In the United States, many wastewater treatment plants are tapping into opportunities to turn sludge, wastewater and methane into profit while mitigating risks of climate change. As Chinese cities continue to grow, municipalities can similarly manage unprecedented

amounts of wastewater. Currently, 80 percent of sludge in China is improperly dumped.[196] However, urban areas are rapidly developing wastewater treatment capacity to limit pollution from wastewater under the national Water Ten Plan passed in 2018. The Chinese government is also increasingly emphasizing a circular economy in its Five-Year Plans, promoting new methods to reuse waste as renewable energy. As China grapples with extreme water pollution and water shortage challenges, cities in the country—15 percent of which have a population of 10 million or higher—may follow the example of New York City in constructing wastewater management treatment systems to serve a large population.[197]

Holistically studying wastewater management in New York City—from sewer management to urban resilience—might enable Chinese cities to learn from NYC's successes and failures. Both countries have an opportunity to improve management of wastewater and infrastructural resilience to extreme climate events. (See Figure 3.)

Figure 3. Stacking Up: NYC vs. Beijing



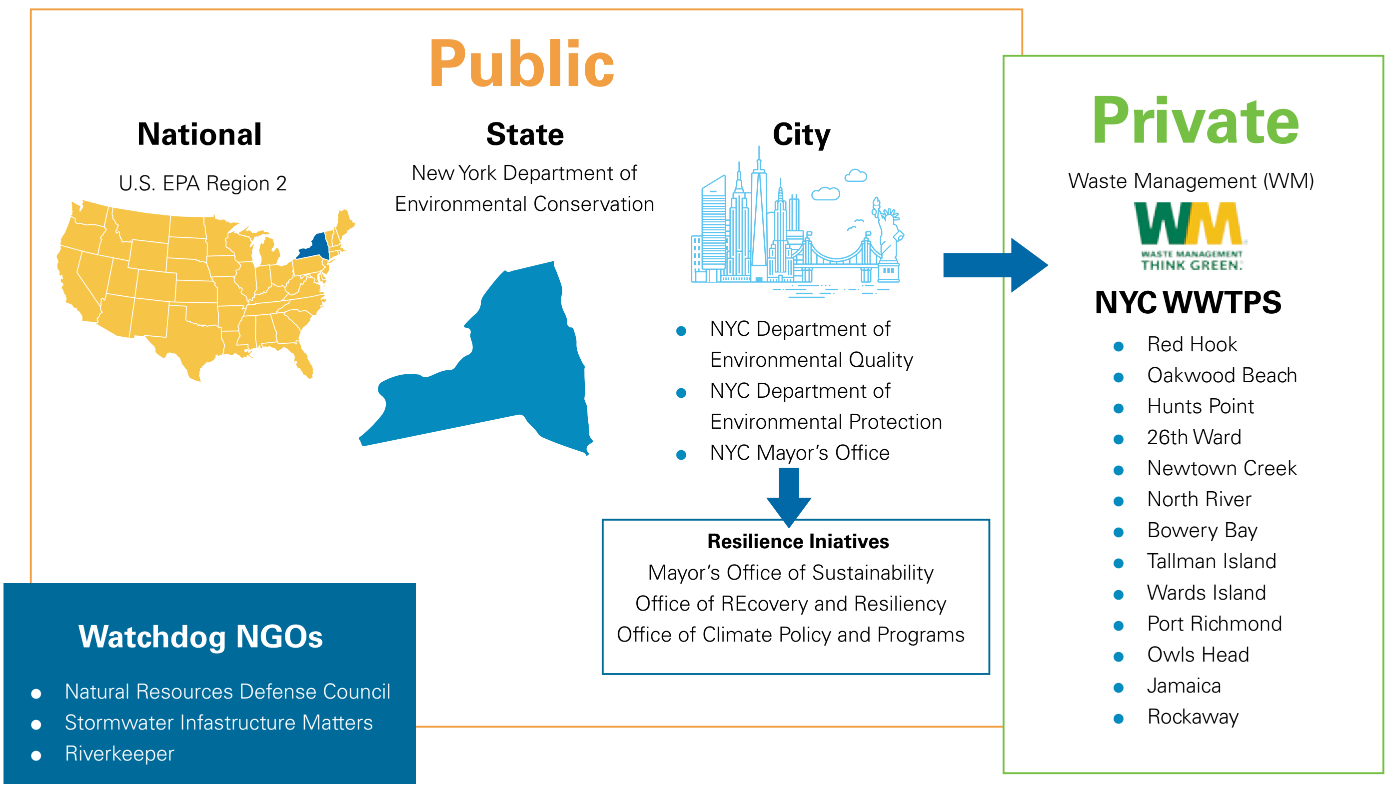
Beijing | New York City

Sources: Beijing Water Authority; NYC DEP; WWD; China Statistical Yearbook

THE FLOW OF AUTHORITY OVER WASTEWATER IN NYC

New York City's five boroughs must manage and treat the wastewater and waste generated by 8.6 million residents.[198] A cohort of private sector, federal, state and municipal stakeholders are responsible for treating the city's wastewater as well as regulating and enforcing treatment and discharge laws. These players sometimes have overlapping duties or conflicting incentives that threaten the system's efficacy. (See Figure 4). Several local and national watchdogs monitor the system and hold public and private players accountable.[199]

Figure 4. The Flow of Wastewater Authority in NYC



TACKLING COMBINED SEWER OVERFLOWS

Many older U.S. cities have combined sewers, which receive and transport both stormwater and sewage simultaneously. Combined sewers can create an abundance of problems as they are often centuries old and designed according to a city's original layout. During storms, combined sewer overflows (CSOs) will flood rivers and streams with raw sewage and rainwater.[200] Combined sewers also complicate the anaerobic digestion process by diluting organic matter, thereby reducing the methane captured for productive use.

As one of the oldest U.S. cities, New York City's combined sewers regularly overflow and discharge raw sewage with rainwater. On average, one discharge occurs every week, with the majority of severe CSOs occurring in Brooklyn, Queens, and the Bronx. Untreated wastewater discharges from CSOs have prevented New York Harbor from meeting the 1982 Clean Water Act requirements for waterways to be fishable and swimmable.[201]

In 2017, nine environmental organizations filed a lawsuit against the U.S. EPA for its failure to uphold the "fishable and swimmable" standard in New York City.[202] The organizations also maintained that New York State Department of Environmental Conservation's existing plans to address the combined sewer problem were subpar following outdated standards.[203] Short staffing and limited funds have hindered the EPA's enforcement ability in NYC and some commentators note that the agency is also reluctant to pressure the large city to change.[204]

To reduce its CSOs to comply with the Clean Water Act, New York City is turning to solutions beyond investing in an expensive municipal separate storm sewer system (MS4). The city has designed and constructed CSO retention facilities to collect and hold stormwater during heavy rain events. After storms, the facilities release the water back into sewer systems for treatment by wastewater plants. These expensive retention facilities cost nearly $300 million to construct, but they have helped prevent inundation of wastewater treatment plants.

Through recent sustainability and resiliency plans, NYC is utilizing more green infrastructure solutions, including natural catchment areas (like rain gardens), expanded park space and street trees, as well as permeable pavements to reduce the amount of storm water entering drains. Because over 70 percent of NYC's land area is covered by impervious surfaces, the DEP has sought to prevent paving natural drainage corridors through the Bluebelt program.[205] In place since the 1990s, the Bluebelt program maintains and expands natural storm water conveyors, like streams and wetlands, which can render construction of pricey stormwater tunnels unnecessary. These efforts are comparable to China's sponge city initiative that the central government launched in 2015 to reduce urban flood risks.[206] In addition to these physical infrastructure solutions, New York City's DEP has piloted an SMS text system that alerts citizens when to use less water after a heavy rainfall.[207] In total, NYC DEP has invested $10 billion in the last ten years on CSO prevention.

ONENYC AND WASTEWATER RESILIENCY

NYC is heralded as a strong model for cities looking to increase wastewater resilience.[208] After sustaining severe damage from Hurricane Sandy in 2012, mayoral efforts by Michael Bloomberg and his successor Bill de Blasio established a $20 billion resiliency investment fund for one of the only city-level wastewater resiliency plans in the world, as well as a city-level panel on climate change.[209]

NYC was primed to take this step, for in 2007, the city released its first plan to increase the climate resilience titled PlaNYC. In 2013, the same year New York City was selected as one of the Rockefeller Foundation's 100 Resilient Cities, the city passed a benchmarking law[210] requiring large buildings to collect energy and water data released every four years under the OneNYC city resiliency plan.[211] Initially released April 2015, OneNYC is now a robust project, with annual progress reports released each Earth Day. Implementation of the initiatives outlined in OneNYC falls under the purview of multiple offices. The Mayor's Office of Sustainability develops the content of OneNYC, and shares implementation responsibility with the Office of Recovery and Resiliency. Both offices, in addition the Office of Environmental Coordination, are housed in the Mayor's Office of Climate Policy and Programs.

In addition to these mayoral offices, the NYC DEP has another resiliency initiative that grew significantly after power outages from Superstorm Sandy in 2012 led to serious treatment disruptions in eight of the city's wastewater plants.[212] A subsequent DEP study discovered the majority of the city's pumping stations and virtually all of its wastewater treatment plants are at risk of flood damage. The following year, DEP published a wastewater resiliency plan with new resilient design standards for 30 inches of flooding above the federal 100-year flood elevation estimates.[213] The plan also outlines an adaptation strategy that includes sealing wastewater treatment facilities, elevating and floodproofing equipment, and installing static barriers and backup power generators. These "hardening" upgrades will be installed at pumping stations and treatment plants by the engineering firm AECOM, which won a $41.5 million contract to implement the changes.[214] Albeit hefty, this price tag is far lower than the estimated $2 billion in damages from climate change that could occur over the next 50 years.[215]

The successes and lessons from New York City may provide a pathway to transforming China's wastewater sector, including improvements in infrastructure, technology, and management plans. Chinese urban areas currently facing significant wastewater treatment challenges can glean four major takeaways from New York City.

Takeaway 1: Widely implementing anaerobic codigestion, methane capture and productive use of digestate will allow Chinese cities to transform waste into energy and profit.

Without anaerobic digestion and methane capture, wastewater treatment plants must either incinerate sludge or put it in landfills. This leads to methane entering the atmosphere, as well as costly sludge transportation and disposal. In contrast, by using AD and, ideally, codigesting food waste and sludge together, WWTPs can decrease the amount of waste going to landfills and increase the quality of methane and digestate produced. The wastewater treatment plant can use the captured methane on-site, significantly reducing operational costs. Alternately, the plant can sell it to the local electricity grid or for vehicle fuel off-site. Meanwhile, leftover digestate can be dewatered and disinfected, then used for land application or as fertilizer.

Takeaway 2: CSOs are one of the most severe threats to water quality; they also reduce the effectiveness of AD. Investing in green infrastructure solutions to mitigate CSOs should be a priority for Chinese cities.

China's sewers have long been ignored by China's policymakers and city officials.[216] Data on the total amount of CSOs in the country is scarce, but combined sewers serve as the main drainage system in many of China's most populous cities, including Guangzhou[217] (which discharges 470,000 tons of sewage into the Liuxi River daily), Shenzhen,[218] and Shanghai.[219] As one of the largest contributors to urban water pollution, the Chinese government should make addressing CSOs a top priority.[220] This should be done via construction stormwater/CSO retention infrastructure as well as municipal separate storm sewer systems (MS4). Public engagement efforts similar to NYC's "Wait…" alert program could help reduce CSOs in the time period before such green infrastructure is installed.

Takeaway 3: Wastewater resiliency plans are necessary in the face of a changing climate.

As 12 percent of China's total population lives in low-elevation coastal zones,[221] excessive groundwater pumping and construction are exacerbating threats from sea level, causing megacities like Shanghai to sink.[222] These coastal cities face drainage challenges, saltwater intrusion into aquifers, and increased flooding. In order to ensure the resiliency of its wastewater infrastructure, China should follow the example of New York City and conduct a wastewater utility hardening campaign, including installation of backup power sources, elevation of critical equipment, and raising or sealing off areas of treatment plants. It should also continue to grow its sponge city program to reduce CSOs and increase climate resilience of cities.[223]

Takeaway 4: Too many cooks make an ineffective kitchen.

NYC's wastewater resiliency and wastewater management efforts are supported by multiple city, state, and federal government offices and private sector contracts resulting in a fragmented management structure. The crowded management of water increases bureaucratic infighting and redundancies, which may compromise overall effectiveness of policies and programs. For example, despite progressive proposals, the city continues to struggle with timely and effective implementation of measure to halt wastewater overflows.[224] As China begins to regulate its new wastewater industry, officials should seek to create streamlined regulatory organizations, whose capacities are not diluted by a plethora of similar organizations vying for influence.

Chapter 6: A Closed-Loop Future

By adopting all three of the solutions discussed in this report—methane capture, use of digestate, and water recycling—China's wastewater sector can transform its waste into profit. Doing so will mitigate greenhouse gas emissions, reduce waste entering landfills, save water, and create a revenue stream for utilities. Successful large-scale efforts to use the waste from wastewater could help mitigate China's extreme water pollution, water scarcity,[225] and enhance urban climate resilience,[226] and thereby improve the quality of life in Chinese cities.

To close the loop on wastewater in China, a multipronged approach of policy, public outreach, and infrastructure solutions is necessary. While previous chapters proposed some targeted solutions, this closing section outlines opportunities to lower the sector-wide barriers of implementation for wastewater methane capture, digestate use, and water recycling in China.

SECTOR-WIDE CHALLENGES

The Challenge: Return on Investment Timeline. Implementing the technologies required to close the loop—from new water recycling systems to anaerobic digesters—is a costly venture. If properly operated and regularly used, these technologies will eventually pay for themselves and generate income for the wastewater treatment plant. However, initial investments can be a major barrier to the majority of China's wastewater plants that generally operate at an economic loss.

Possible Solutions: Controlled Subsidies and an Accurate Water Price. As discussed in Chapter 2, while massive renewable energy subsidies from the National Development and Reform Commission (NDRC) rapidly increased wind and solar energy installations, power transmission infrastructure could not keep up. Thus, China faced high rates of "garbage" solar and wind farms that were not connected to the electricity grid. For lasting change, subsidies to construct new wastewater infrastructure should be combined with a long-term income source for wastewater utilities from water customers.

Currently, the cost of water in China does not cover supply and treatment costs.[227] Controlled by the state, China's residents pay the lowest price for water out of 19 major world economies.[228] Water for commercial and industrial users also is priced below the cost of treatment and delivery. Low costs can also incentivize users to waste water. China's government should continue their policies to slowly raise the price of water, ensuring the increase in tariffs is returned directly back to water utilities. As the overall price increases, subsidies for low-income residents should remain in place to ensure water remains accessible to all.

In conjunction with these tariffs, NDRC should offer financial support for initial construction of necessary infrastructure for water recycling, treatment of digestate, and anaerobic digestion—products that could help generate income for the utility. However, a robust application and vetting process for subsidy recipients should be implemented to prevent overcapacity. These two strategies will help reduce strain on cash-strapped utilities and shorten the time for return on investment into infrastructure that closes the loop on wastewater.

The Challenge: Non-market Based Economy. Without a market economy, finding demand for methane, digestate, and recycled water in China requires different approaches than in the United States.

Possible Solutions: Leverage Existing Policies and Systems. China can leverage existing policy programs to incentivize productive use of methane, digestate, and recycled water. In the case of methane, wastewater treatment plants should be included in China's national carbon emissions trading scheme (ETS). Currently, the recently launched national ETS is initially only including the power sector.[229] However, as the ETS expands it is imperative to include the wastewater sector. Cities and wastewater plants thus would be motivated to reduce methane emissions via AD and electricity utilities would be able to purchase power that does not contribute to their carbon cap. Chinese cities should look beyond small wind farms and rooftop solar to wastewater methane capture as they set targets and investments for distributed renewable energy infrastructure.

Using digestate as fertilizer can help meet the government's 2020 soil remediation target. Amending the *Soil Pollution Prevention Plan* to include digestate fertilizer as a bioremediation tool for croplands would create a policy-driven demand to use China's sludge for a productive purpose. A similar opportunity exists for recycled water: incentivizing centralized water recycling in an amendment to the *Water Ten Plan* would create a policy mechanism to encourage the reuse of recycled water in cities.

While wrapping these wastewater products into policy is not a catch-all solution—getting things on paper versus actual implementation are notoriously unequal feats in China—establishing political will for these solutions is a necessary first step.[230] A policy incentive provides local officials the wherewithal to begin investing in these technologies.

CONCLUSION

The recommendations throughout this report span a range of implementability and affordability. Retrofitting China's urban sewers, for example, would be a decades-long, expensive endeavor, while instituting a public outreach campaign for water recycling is more affordable shorter time frame endeavor. The economic and political challenges to make any of these changes are significant. However, China's imperative to wastewater reform is clear; landfills are overflowing, freshwater resources are being depleted, and air, soil and water pollution is worsening. While wastewater currently contributes to these challenges, it can also serve as the solution.

The policies put forward in this succinct wrap up chapter are meant to serve as only the beginning of the conversation for creating a more sustainable wastewater management system in China, one in which wastewater byproducts are no longer waste, but a source of profit. By learning from the successful closed-loop approaches in New York, Los Angeles, Singapore, and even within its own borders in Ningbo and Xiangyang, Chinese policymakers can establish a more robust wastewater infrastructure and increase the country's water security and climate resilience.

APPENDIX 1: CHINA'S WASTEWATER TREATMENT TRENDS AND POLICIES (SEE ENDNOTE 231 FOR SOURCES)[231]

Year	Watershed Moments/Trends	Policies/Governance
1900s	Farmers gather night soil from cities to apply on crops.	No national environmental watchdog agency exists.
1984	The 9th FYP introduces *Three Key Regions Policy* to clean up three major rivers and three lakes.	*Water Pollution Prevention and Control Law (WPPCL)* is first legislative action by newly created NEPA.
1990s	Farmers shift from night soil to chemical fertilizers. By 1995, fertilizer runoff contributes 2.87 tons of nitrogen pollution into Yangtze River annually.	First Chinese NGOs register under new *Social Organization Law*. Many early green groups focus on water protection.
1996	Cities are required to construct centralized wastewater treatment plants (WWTPs). 51% of rivers and lakes meet top three grades of water quality.	First *WPPCL* amendments spark more holistic river basin planning and standardized total pollutant discharges.
1998	*Three Key Regions Policy* removed after failing to improve water quality.	NEPA given ministerial rank and renamed State Environmental Protection Agency (SEPA).
2001	Announcement of Olympics sparks wastewater reform in Beijing. China only has 506 WWTPs and ~20% wastewater is treated.	South-North Water Transfer Project construction begins, aiming to move water from Yangtze to dry northern cities.
2003	Beijing municipality requires all buildings larger than 30,000m2 to recycle water on-site in decentralized plants.	Ministry of Construction publishes Urban Wastewater Reuse Water Quality Standards.
2005	Songhua chemical spill releases toxins that flow into Harbin and Russia, sparking first government admission of a major water pollution accident.	Songhua chemical spill leads Beijing to postpone and rework amendments to *WPPCL*.
2006	The NGO IPE creates China's first online searchable water pollution database. Only 46% of waterways meet top three grades of water quality.	SEPA reports nearly 60% of environmental emergency accidents are water pollution related.
2007	Lake Tai toxic algae blooms impacts drinking water for millions in Wuxi City, which creates river chief system to make officials accountable for protecting water quality.	SEPA releases *WPPCL* draft amendments for public comment. First time for citizen input on proposed environmental legislation, received to 1,400 comments.

2008	SEPA is renamed Ministry of Environmental Protection (MEP), expanding its regulatory mandate, but staff and budget remains low.	Second WPPCL amendments require standardized release of pollution data, tougher penalties, pollutant discharge permit system, and include an opening for public interest lawsuits.
2012	Total national wastewater discharged increases by 65% from 41.5 billion tons in 2000 to 68.5 billion tons. Urban wastewater treatment reaches 77%.	Government heavily subsidizes 25% of WWTPs as they operated at a financial loss.
2013	3508 WWTPs operate in 31 provinces, sludge treatment rates only reach 25%.	MEP issues *Guidelines on Construction and Investment for Rural Sewage Treatment.*
2014	Xi Jinping declares a "war on pollution" and announces *Water Ten Plan*	Amendments to *Environmental Protection Law* pass with stricter penalties for local government violators.
2015	Over 3.78 billion cubic meters of **untreated** wastewater is discharged into China's waterways. MEP orders provinces meet FYP water quality targets.	State Council passes *Water Ten Plan*, China's most comprehensive water policy to date.
2016	MoHURD and MEP launch "black and smelly" river crowdsourcing campaign, asking the public to share information on severely polluted waterways to help map out clean up priorities.	State Council requires all stationary polluters (including WWTPs) to be covered by pollutant emissions permit system by 2020.
2017	Municipal wastewater treatment rates in large cities hit 80 percent.	*Water Ten Plan* enacted. Third WPPCL amendments feature stringent water supply protection measures and mandates to build rural wastewater treatment facilities.
2018	Reforms give MEE nearly all power over water. MEE requires environmental health risk monitoring and public health water quality standards.	National River Chief program set up lifetime responsibility for officials to monitor and keep waterways clean.

ENDNOTES

1 Zwicker, Gillian & Turner, Jennifer. (2019, March 28). Tapping the power in China's municipal sludge. *New Security Beat*. https://www.newsecuritybeat.org/2019/03/tapping-power-chinas-municipal-sludge/

2 Environmental Defense Fund. (n.d.). Methane: the other important greenhouse gas. https://www.edf.org/climate/methane-other-important-greenhouse-gas

3 Du, Jillian et al. (2018, January). Waste power: Can wastewater revolutionize pollution control and clean energy in cities? *InsightOut, 4*. https://www.wilsoncenter.org/publication/insightout-issue-4-waste-power-can-wastewater-revolutionize-pollution-control-and-clean

4 Global Methane Initiative. (n.d.). Global methane emissions and mitigation opportunities. https://www.globalmethane.org/documents/analysis_fs_en.pdf

5 New York City Department of Environmental Protection. (n.d.). New York City's wastewater treatment system. http://www.nyc.gov/html/dep/pdf/wwsystem.pdf

6 Xie, Jian. (2009). *Addressing China's water scarcity*. Washington, DC: World Bank.

7 Yi, Lili; Jiao, Wentao; Chen, Xiaoning; & Chen, Weiping. (2011, October). An overview of reclaimed water reuse in China. *Journal of Environmental Sciences*. 23(10), 1585-1593.

8 Jusi, Wang. Water pollution and water shortage problems in China." *Journal of Applied Ecology 26, 3(1989): 851-57*.

9 Peter H, Gleick. "China and water." (2013, July). *World's Water*. http://worldwater.org/wp-content/uploads/2013/07/ch05.pdf

10 Du, Yun; Cai, Shuming; Zhang, Xiaoyang; & Zhao, Yan. (2001, November 15). "Interpretation of the environmental change of Dongting Lake, middle reach of Yangtze River, China, by Pb measurement and satellite image analysis." *Geomorphology*, 41(2-3), 171-181.

11 Liu, Muxing. (2010). Policy and advice for promoting pollution prevention and cure of water environment in China. *IEEE*.

12 Economy, Elizabeth C. (2010, July). *The river runs black: The environmental challenge to China's future*. Ithaca, NY: Cornell University Press. Page 129.

13 Wang, Jianhua; Shang, Yizi; Wang, Hao; Zhao, Yong; & Yin, Yin. (2015, June). "Beijing's water resources: Challenges and solutions." *Journal of the American Water Resources Association*. 51(3):614-623.

14 Beijing sewage resource allocation development status and public policy analysis: Rate of Urban Domestic Waste Recycling in China

15 United Nations. (n.d.). Beijing Olympics 2008: An urban transformation. https://sustainabledevelopment.un.org/partnership/?p=2203.

16 Lye, Liang Fook, & Chen, Gang. (2010, June 17). *Towards a livable and sustainable urban environment: Eco-cities in East Asia*. Singapore: World Scientific.

17 Li, Jingyun; & Liu, Jingjing. (2011, July 7). Quest for clean water: China's newly amended water pollution control law. *China Environment Forum*. https://www.wilsoncenter.org/publication/quest-for-clean-water-chinas-newly-amended-water-pollution-control-law

18 Hsu, Angel; Yan, Chendan; & Cheng, Yaping. (2017, January). Addressing gaps in China's environmental data: the existing landscape. *The Data-Driven EnviroPolicy Lab*. https://datadrivenlab.org

19 Xu, Yuanchao & Chan, Woody. (2018, April 18). Ministry reform: 9 dragons to 2. *China Water Risk*. http://www.chinawaterrisk.org/resources/analysis-reviews/ministry-reform-9-dragons-to-2/

20 Wen, Yi. China's rapid rise: from backward agrarian society to industrial powerhouse in just 35 years. The *Regional Economist*. https://www.stlouisfed.org/publications/regional-economist/april-2016/chinas-rapid-rise-from-backward-agrarian-society-to-industrial-powerhouse-in-just-35-years

21 Tortajada, Cecilia. (2016, October). "Policy dimensions of development and financing of water infrastructure: The cases of China and India." *Environmental Science & Policy*. 64, 177-187.

22 *China Water Risk*. (2015, April 16). New "Water Ten Plan" to safeguard China's waters.

23 Smith, Sam. (2018, August 30). China's river chiefs - An "ingenious" approach to water governance in China? International Rivers. https://www.internationalrivers.org/blogs/1126/china%E2%80%99s-river-chiefs-an-%E2%80%9Cingenious%E2%80%9D-approach-to-water-governance-in-china

24 Bowie, Julia. (2018, October 3). The anti-corruption campaign takes on the war on pollution. *ChinaFile*.

25 Ma, Yun. (2017, June 27). Vertical environmental management: A panacea to the environmental enforcement gap in China? *Chinese Journal of Environmental Law*, 1(1).

26 Li, Olivia. (2019, April 20). "Chinese authorities sack an entire environmental protection bureau for corruption misdeeds." *The Epoch Time*s.

27 Han, Dongmei; Currell, Matthew J; & Cao, Guoliang. (2016, November). "Deep challenges for China's war on water pollution." *Environmental Pollution*, 218, 1222-1233.

28 Zwicker, Gillian & Turner, Jennifer. (2019, March 28). Tapping the power in China's municipal sludge.

29 Larson, Christina. (2019, July 26). Growing shortages of water threaten China's development. Yale Environment 360, https://e360.yale.edu/features/growing_shortages_of_water_threaten_chinas_development

30 Wang, Meishu. & Gong, Hui. (2019, May 14). "Expected rural wastewater treatment promoted by provincial local discharge limit legislation in China." *Sustainability* 2019. 11(10), 2756.

31 Reuters. (May 20, 2018). China's president Xi Jinping calls for increased efforts to tackle pollution. *South China Morning Post*. https://www.scmp.com/news/china/policies-politics/article/2146945/chinas-president-xi-jinping-calls-increased-efforts

32 Powering the wastewater Renaissance: Energy efficiency and emissions reduction in wastewater management. (2015). *Xylem*, Inc. https://www.xylem.com/siteassets/support/case-studies/case-studies-pdf/xb040-xylem_abatement_opportunities_brochure.pdf

33 Environmental Defense Fund. (n.d.). Methane: the other important greenhouse gas.

34 Municipal wastewater methane: Reducing emissions, advancing recovery and use opportunities. (2013, January). *Global Methane Initiative*. https://www.globalmethane.org/documents/ww_fs_eng.pdf

35 Du, Jillian, et al. (2018, January).

36 *China Water Risk*. (2017, June 14). 2016 state of environment report review. http://www.chinawaterrisk.org/resources/analysis-reviews/2016-state-of-environment-report-review/

37 Sidner, Luaren. (2017, July 13). Sponge city: solutions for China's thirsty and flooded cities. *New Security Beat*. https://www.newsecuritybeat.org/2017/07/sponge-city-solutions-chinas-thirsty-flooded-cities/

38 Xie, Jian. (2009). *Addressing China's water scarcity*.

39 Yi, Lili; Jiao, Wentao; Chen, Xiaoning; & Chen, Weiping. (2011, October). An overview of reclaimed water reuse in China.

40 Neighbour, Danielle. (2018, November 19). Recycled water could solve Beijing's water woes, but implementation falls short. *New Security Beat*. https://www.newsecuritybeat.org/2018/11/recycled-water-solve-beijings-water-woes-implementation-falls-short-2/

41 Coperland, Claudia, & Carter, Nicole T. (2017, January 24). Energy-water nexus: The water sector's energy use. *Congressional Research Service*. https://fas.org/sgp/crs/misc/R43200.pdf

42 DC Water. (n.d.). DC Water's thermal hydrolysis and anaerobic digester project. https://www.dcwater.com/sites/default/files/documents/BioenergyFacility.pdf

43 U.S. Department of Homeland Security. (n.d.). Critical infrastructure sectors. https://www.dhs.gov/cisa/critical-infrastructure-sectors

44 Center for Climate and Energy Solutions. (n.d.). Short-lived climate pollutants. https://www.c2es.org/content/short-lived-climate-pollutants/

45 U.S. Environmental Protection Agency. (n.d.). Understanding global warming potentials. https://www.epa.gov/ghgemissions/understanding-global-warming-potentials

46 China Power Team. (2019, March). How is China managing its greenhouse gas emissions? *China Power*. https://chinapower.csis.org/china-greenhouse-gas-emissions/

47 Olivier, Jos G.J. & Peters, Jeroen A.H.W. (2018, December). Trends in global CO2 and total greenhouse gas emissions. *PBL Netherlands Environmental Assessment Agency*. https://www.pbl.nl/sites/default/files/cms/publicaties/pbl-2017-trends-in-global-co2-and-total-greenhouse-gas-emissons-2017-report_2674.pdf

48 Khalil, M.A.K; Rasmussen, R.A.; Ren, Lixin; Wang, M-X.; Shearer, M.J.; Dalluge, R.W.; & Duan, Chang-Lin. (1966). Methane emissions from rice cultivation: Flooded rice fields. *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*, 3, 4.53-4.75. https://www.ipcc-nggip.iges.or.jp/public/gl/guidelin/ch4ref5.pdf

49 Ramón A. Alvarez, Daniel Zavala-Araiza, David R. Lyon, David T. Allen, Zachary R. Barkley, Adam R. Brandt, Steven P. Hamburg. (2018, July 13). Assessment of methane emission from the U.S. oil and gas supply chains. *Science*. 361(6398), 186-188.

50 Global Methane Initiative. (n.d.). Global methane emissions and mitigation opportunities.

51 Zhao, X; Jin, X. K.; Guo, W; Zhang, C; Shang, Y. L.; Du, M. X.; Tillotson, M. R.; Yang, H.; Liao, X. W.; & Li, Y. P. (2019, April 15). China's urban methane emissions from municipal wastewater treatment plant. *Earth's Future*, 7(4), 339-502; 480-490.

52 Remarks from Wilson Center meeting *Closing the Loop on Wastewater* presentation, December 10, 2019. https://www.wilsoncenter.org/event/closing-the-loop-wastewater-china-and-the-united-states

53 China's Water & Wastewater Treatment Technology Market. 2019 - Usage in the Oil & Gas Sector Expected to Increase (2019, April 10). *AP News*. https://apnews.com/57983c1d8e3944f48aebb5a1686351e7

54 Soh, Tin Siao. China's 13th Five Year Plan: What Role Will Wastewater Play? (2018, January 30). *WaterWorld*.

55 New York City Department of Environmental Protection. (n.d.). New York City's wastewater treatment system.

56 Fractenberg, Ben & Hogan, Gwynne. (2016, January 25). Greenpoint wastewater plant now plays starring role in Hollywood. *DNAinfo*.

57 Giambusso, David. (2014, September 24). National grid begins work on Newtown Creek project. *Politico*.

58 U.S. Environmental Protection Agency. (n.d.). Renewable identification numbers (RINs) under the renewable fuel standard program. https://www.epa.gov/renewable-fuel-standard-program/renewable-identification-numbers-rins-under-renewable-fuel-standard

59 Pitk, Peek; Kaparaju, Prasad; Palatsi, Jordi; Affes, Rim; and Vilu, Raivo. (2013, February 29). Co-digestion of sewage sludge and sterilized solid slaughterhouse waste: Methane production efficiency and process limitations. *Bioresource Technology*. 134, 227-232.

60 El-Mashad, Hamade M., & Zhang, Ruihong. Biogas production from co-digestion of dairy manure and food waste. *Bioresource Technology*, 101(11), 4021-4028.

61 Lim, J.W.; Chen, Chialung; Ho, I.J.R; & Yang, Jingyuan. (2013, November). Study of microbial community and biodegradation efficiency for single- and two-phase anaerobic co-digestion of brown water and food waste. *Bioresource Technology*, 147, 193-201.

62 Dai, Xiaohua; Duan, Dina; Dong, Bin; & Dai, Lingling. (2013, February). High-solids anaerobic co-digestion of sewage sludge and food waste in comparison with mono digestions: Stability and performance. *Waste Management*, 33(2), 308-316.

63 U.S. Environmental Protection Agency (2001, January). Method 1684: total, fixed, and volatile solids in water, solids, and biosolids. https://www.epa.gov/sites/production/files/2015-10/documents/method_1684_draft_2001.pdf

64 Moestedt, Jan; Müller, Bettina; Westerholm, Maria; and Schnürer, Anna. (2016, March). Ammonia threshold for inhibition of anaerobic digestion of thin stillage and the importance of organic loading rate. *Microb Biotechnol*, 9(2): 180-194.

65 Labatut, Rodrigo A., & Pronto, Jennifer L. (2018). Chapter 4 - sustainable waste-to-energy technologies: anaerobic digestion. In Thomas A. Trabold, & Callie W. Babbitt (Eds), Sustainable food waste-to-energy systems (pp. 47-67). Cambridge, MA: Academic Press.

66 Yang, Qing; Fu, Lingmei; Liu, Xingxing; and Cheng, Mengying. Evaluating the efficiency of municipal solid waste management in China. (2018, November 2). *International Journal of Environmental Research and Public Health*. 15(2448).

67 Abbasi, S.A. (2018, November 19). The myth and the reality of energy recovery from municipal solid waste. *Energy, Sustainable Society*. https://energsustainsoc.biomedcentral.com/articles/10.1186/s13705-018-0175-y

68 Xiaofei, Mu. (2018). Analysis of the current situation of domestic waste treatment industry in 2018. *Forward-The Economist*. https://www.qianzhan.com/analyst/detail/220/180628-c69fe233.html

69 Chuanbin Zhou, Bin Lu, Lerong Shi, Zhuqi Chen, Yijie Liu & Lingyu Xu. (2018, March) Rate of Urban Domestic Waste Recycling in China. Statistical data collection countermeasures. *China Environmental Management Journal*. (In Chinese) http://zghjgl.ijournal.cn/ch/reader/create_pdf.aspx?file_no=20180315&flag=1&journal_id=zghjgl&year_id=2018

70 Fact-sheet - biogas: Coverting waste to energy. (2017, October 3). *Environmental and Energy Study Institute*. https://www.eesi.org/papers/view/fact-sheet-biogasconverting-waste-to-energy

71 U.S. Department of Energy. (n.d.). Renewable natural gas (biomethane) production. https://afdc.energy.gov/fuels/natural_gas_renewable.html

72 Fact-sheet - biogas: Converting waste to energy. (2017, October 3).

73 U.S. Department of Energy. (n.d.). Renewable identification numbers. https://afdc.energy.gov/laws/RIN.html

74 U.S. Environmental Protection Agency. (n.d.). Annual compliance data for obligated parties and renewable fuel exporters under the Renewable Fuel Standard program. https://www.epa.gov/fuels-registration-reporting-and-compliance-help/annual-compliance-data-obligated-parties-and

75 U.S. Environmental Protection Agency. (2018, December 11). Renewable fuel standard program: Standards for 2019 and biomass-based diesel volume for 2020. *Federal Register*. https://www.federalregister.gov

76 U.S. Department of Agriculture. (2019, July 8). U.S. Bioenergy statistics. https://www.ers.usda.gov/data-products/us-bioenergy-statistics/

77 Institute of Medicine. (2014). 5 water use, water pollution, and biofuels. *In The nexus of biofuels, climate change, and human health: workshop summary.* Washington, DC: The National Academies Press.

78 Van Dyka, J Susan; Lia, Ling; Leala, Deborah Barros; Hua, Jinguang; Zhang, Xu; Tan, Tianwei; & Saddler, Jack. (2016). The potential of biofuels in China. IDEA Bioenergy. http://task39.sites.olt.ubc.ca/files/2013/05/The-Potential-of-biofuels-in-China-IEA-Bioenergy-Task-39-September-2016.pdf

79 Liu, Coco. (2016, May 31). Innovative sludge-to-energy plant makes a breakthrough in China. *New Security Beat*. https://www.newsecuritybeat.org/2016/05/innovative-sludge-to-energy-plant-breakthrough-china/

80 China Environment Forum. (2018, November). Scaling sludge mountains: Breaking down barriers for Chinese cities to turn sludge waste into energy. https://www.scribd.com/document/393289300/Scaling-Sludge-Mountains-Breaking-Down-Barriers-for-Chinese-Cities-to-Turn-Sludge-Waste-Into-Energy#download&from_embed

81 Thermal hydrolysis. (n.d.). *Cambri*. https://www.cambi.com/what-we-do/thermal-hydrolysis/tion-recycling-project?lang=en

82 DC Water. (n.d.). DC Water's thermal hydrolysis and anaerobic digester project. https://www.dcwater.com/sites/default/files/documents/BioenergyFacility.pdf

83 Sterner, Michael. (2009). *Bioenergy and renewable power methane in integrated 100% renewable energy systems*. Kassel: Kassel University Press.

84 U.S. Environmental Protection Agency. (2011, October). Opportunities for combined heat and power at wastewater treatment facilities: Market analysis and lessons from the field. https://www.epa.gov/sites/production/files/2015-07/documents/opportunities_for_combined_heat_and_power_at_wastewater_treatment_facilities_market_analysis_and_lessons_from_the_field.pdf

85 Clarke Energy. (n.d.). Cogeneration / combined heat and power (CHP). https://www.clarke-energy.com/chp-cogeneration/

86 U.S. Environmental Protection Agency. (n.d.). Basic information about landfill gas. https://www.epa.gov/lmop/basic-information-about-landfill-gas

87 Cavenati, Simone; Grande, Carlos A.; & Rodrigues, Alírio E. (2005, August 25). Upgrade of methane from landfill gas by pressure swing adsorption. *Energy Fuels*, 19(6), 2545-2555.

88 Feng, Leiyu; Luo, Jingyang; & Chen, Yinguang. (2015, April 6). Dilemma of sewage sludge treatment and disposal in China. *Environmental Science & Technology*, 49(8), 4781-4782.

89 Neighbour, Danielle, & Zwicker, Gillian. (2019, May 31). Weathering the storm: wastewater resiliency in the US and China. *China-US Focus*. https://www.chinausfocus.com/energy-environment/weathering-the-storm-wastewater-resiliency-in-the-us-and-china

90 Taking a bite out of the big apple's food waste. (2017, February 16). *Natural Resources Defense Council*. https://www.nrdc.org/resources/taking-bite-out-big-apples-food-waste

91 Goldstein, Eric. (2013, June 17). A national model for sustainable food waste disposal is being created where? Right here in New York City. *The Natural Resources Defense Council*. https://www.nrdc.org/experts/eric-goldstein/national-model-sustainable-food-waste-disposal-being-created-where-right-here

92 NYC Water Staff. Closing the loop: when wastewater treatment becomes resource recovery. *Medium*. https://medium.com/nycwater/closing-the-loop-when-wastewater-treatment-becomes-resource-recovery-8266d1d576cc

93 WM Varick CORe, Newtown Creek Co-Digestion Project. (n.d.). *Waste Management*. https://www.wm.com/NYCMA/WMCORe%20varick-factsheet%20073114.pdf

94 East Bay Municipal Utility District. (n.d.). Food scraps recycling. https://www.ebmud.com/wastewater/recycling-water-and-energy/food-scraps-recycling/

95 U.S. Environmental Protection Agency. (n.d.). Preliminary project planning. https://www.epa.gov/agstar/preliminary-project-planning

96 Carlini, Maurizio; Mosconi, Enrico Maria; Castellucci, Sonia; Villarini, Mauro; & Colantoni, Andrea. (2017). An economical evaluation of anaerobic digestion plants fed with organic agro-industrial waste. *Energies,* 10, 1165.

97 China Environment Forum. (2018, November). Scaling sludge mountains.

98 Stoerk, Thomas; Dudek, Daniel J; Yang, Jia. (2019). China's national carbon emissions trading scheme: lessons from the pilot emission trading schemes, academic literature, and known policy details. *London School of Economics and Political Science*. *Climate Policy.* 19(4), 472-486.

99 Temple, James. (2018, June 18). China is creating a huge carbon market—but not a particularly aggressive one. *MIT Technology Review*. https://www.technologyreview.com/s/611372/china-is-creating-a-huge-carbon-market-but-not-a-particularly-aggressive-one/

100 Jackson, Margaret. (2017, March 7). Chinese solar shines at home and on the road. *New Security Beat*. https://www.newsecuritybeat.org/2019/03/chinese-solar-shines-home-road/

101 Li, Canbing; Shi, Haiqing; Cao, Yijia; Wang, Jianhui; Kuang, Yonghong; Tan, Yi; & Wei, Jing. (2015, January). Comprehensive review of renewable energy curtailment and avoidance: A specific example in China. *Renewable and Sustainable Energy Reviews*, 41, 1067-1079.

102 Sui, Jessica; Shen, Feifei; Yang, Jing; & Martin, Chris. China plans subsidy-free solar and wind projects. *Bloomberg News*. https://www.bloomberg.com/news/articles/2019-01-10/china-plans-subsidy-free-solar-wind-power-pilot-projects

103 Neighbour, Danielle, & Zwicker, Gillian. (2019, May 31). Weathering the storm

104 *Greenmarket*. (n.d.). GrowNYC's Garden Program. https://www.grownyc.org/gardens

105 The largest advanced wastewater treatment plant in the world. (2019). https://www.dcwater.com/blue-plains

106 DC Water. (2019). Good soil. Better earth. https://www.dcwater.com/biosolids

107 U.S. Environmental Protection Agency. Office of Water. (1998). *How wastewater treatment works… The basics*. https://www3.epa.gov/npdes/pubs/bastre.pdf

108 Chinese scientists find key factor to main wastewater treatment technology. (2018, March 27). *Xinhua News*. http://www.xinhuanet.com/english/2018-03/27/c_137069723.htm

109 Han, Zhiyong; Ma, Haining; Shi, Guozhong; He, Li; Wei, Luoyu; & Shi, Qingqing. (2016). A review of groundwater contamination near municipal solid waste landfill sites in China. *Science of the Total Environmen*t, 569-570, 1255-1264.

110 *Caixin*. (2015, June 29). Land of 1,000 Landfills. https://slate.com/human-interest/2015/06/unregulated-landfill-epidemic-chinas-capital-is-cleaning-up-more-than-1000-unregulated-dumps.html

111 China Environment Forum. (2018, November). Scaling sludge mountains.

112 Wuni Shichang "Changxiang" Qianyi Caifu. (2019, April 26). SCL.BJX. http://huanbao.bjx.com.cn/news/20160426/727929.shtml

113 Leonte, Andreea. (2019, March 26). China is burning away its ecological future. *Foreign Policy*. https://foreignpolicy.com/2019/03/26/china-is-burning-away-its-ecological-future/

114 Twardowska, Irena, Schramm, Karl-Werner, & Berg, Karla. (2004). Sewage sludge. *Solid Waste: Assessment, Monitoring and Remediation*, 239-295. https://www.sciencedirect.com/science/article/pii/S0713274304800138

115 Xiang, Jiaqiao, Turner, Jennifer. (2019, April 18). From farm to table to landfills? Seeking solutions to China's food waste dilemma. *New Security Beat*. https://www.newsecuritybeat.org/2019/04/farm-table-landfills-seeking-solutions-chinas-food-waste-dilemma/

116 Ibid.

117 U.S. Environmental Protection Agency (n.d.). Frequent Questions about Biosolids. https://www.epa.gov/biosolids/frequent-questions-about-biosolids

118 McDonnell, J. & Elardo, P. (2018). Biosolids in the Urban Metropolis: Long-Term Planning for New York City. *Water Online*. https://www.wateronline.com/doc/biosolids-in-the-urban-metropolis-long-term-planning-for-new-york-city-0001

119 U.S. Environmental Protection Agency. (1988). *Ocean Dumping Ban Act of 1988* [Press release]. https://archive.epa.gov/epa/aboutepa/epa-history-ocean-dumping-ban-act-1988.html

120 New York City Department of Environmental Protection. (2016). *NYC DEP Biosolids Program: A Review and Update*.

121 Danner, C. (2018, March 11). Alabamians are sick of New York's crap. *New York Magazine*. http://nymag.com/intelligencer/2018/03/alabamians-are-sick-of-new-yorks-crap.html

122 New York State Department of Environmental Conservation. (2015). Biosolids management in New York State. https://www.dec.ny.gov/docs/materials_minerals_pdf/bsmgmt2015.pdf

123 McDonnell, J. & Elardo, P. (2018). Biosolids in the Urban Metropolis: Long-Term Planning for New York City.

124 City of New York. (n.d.). OneNYC 2050: Building a strong and fair city. https://onenyc.cityofnewyork.us

125 New York City Department of Environmental Protection, Public Affairs. (2018, June 12). $67 Million energy efficiency upgrade of the Hunts Point Wastewater Treatment Plant will improve air quality and reduce operating costs. https://www1.nyc.gov

126 North East Biosolids & Residuals Association. (n.d.). About biosolids. https://www.nebiosolids.org/about-biosolids/

127 *Sludge Dewatering*. (2014). SNF Floerger. https://www.snf.us/wp-content/uploads/2014/08/Sludge-Dewatering-E.pdf

128 Chen, G., Yue, P. L., & Mujumdar, A. S. (2002). Sludge dewatering and drying. *Drying Technology*, 20(4-5), 883-916.

129 Farzadkia, M., & Bazrafshan, E. (2014). Lime stabilization of waste activated sludge. *Health Scope*,3(3).

130 House, H. (2012, February). Bedding alternative. *Ontario Ministry of Agriculture, Food and Rural Affairs*.

131 Huang, Y., & Lo, S. (2019). Utilization of rice hull and straw. *Rice*, 4, 627-661.

132 Strileski, M. (2013). *Phosphorus Removal From EBPR Sludge Dewatering Liquors Using Lanthanum Chloride, Aluminum Sulfate and Ferric Chloride* (Unpublished master's thesis). University of Nevada, Las Vegas.

133 Pell Frischmann Consultants, Ltd. (2012). *Enhancement and treatment of digestates from anaerobic digestion* (Rep. No. OMK006 - 002). Banbury, UK: Waste and Resources Action Programme (WRAP).

134 Magrí, A. (2018). Research Trends on Nutrient Management From Digestates Assessed Using a Bibliometric Approach. *Frontiers in Sustainable Food Systems,* 2(40).

135 Bloom. Research on Bloom. https://bloomsoil.com/bloom-research-efficacy/

136 Zhang, X., Wang, X., & Wang, D. (2017). Immobilization of heavy metals in sewage sludge during land application process in China: A review. *Sustainability*, 9(11), 2020.

137 Jin, L.; Zhang, G.; & Tian, H. (2014). Current state of sewage treatment in China. *Water Research*, 66, 85-98.

138 Export.gov. (2019, July 30). China: environmental technology. https://www.export.gov/article?id=China-Environmental-Technology

139 Pong, J., Scarr, S., & Weber, M. (n.d.). Heavy Metal Pollution in China [Digital image]. http://graphics.thomsonreuters.com/14/soil/index.html

140 Ibid.

141 Zhang, X., Wang, X., & Wang, D. (2017). Immobilization of heavy metals in sewage sludge.

142 PRC, National Environmental Protection Bureau, State Technology Supervision Bureau. (1996). *Integrated Wastewater Discharge Standard GB 8978 - 1996*. Beijing, PRC.

143 Zhou, Y., Lei, J., Zhang, Y., Zhu, J., Lu, Y., Wu, X., & Fang, H. (2018). Determining discharge characteristics and limits of heavy metals and metalloids for wastewater treatment plants (WWTPs) in China based on statistical methods. *Water*, 10(9), 1248.

144 Zhang, J. & Lin, X. (2018, September 10). Cleaning up toxic soils in China: A trillion-dollar question. *International Institute for Sustainable Development.* https://www.iisd.org/blog/toxic-soil-china

145 Hooks, C. (2017, September 19). Managing China's sludge mountains. *chinadialogue*. https://www.chinadialogue.net/article/show/single/en/10080-Managing-China-s-sludge-mountains

146 Greenpeace, East Asia, Beijing. (2021, May 21). *With poor oversight, China's industrial parks no match for illegal wastewater dumping* https://www.greenpeace.org/eastasia/press/1333/with-poor-oversight-chinas-industrial-parks-no-match-for-illegal-wastewater-dumping-2/

147 Gielnik, A., Pechaud, Y., Huguenot, D., Cébron, A., Riom, J., Guibaud, G., . . . Hullebusch, E. D. (2019). Effect of digestate application on microbial respiration and bacterial communities diversity during bioremediation of weathered petroleum hydrocarbons contaminated soils. *Science of the Total Environment*, 670, 271-281. doi:10.1016/j.scitotenv.2019.03.176

148 Bloom. (2018). *Facts About Bloom* [Brochure]. https://bloomsoil.com/wp-content/uploads/2018/01/bloom_facts.pdf

149 Wang, J., Zhao, Y., Yang, L., Tu, N., Xi, G., & Fang, X. (2017). Removal of heavy metals from urban stormwater runoff using bioretention media mix. *Water*, 9(11), 854.

150 Zhang, X., Wang, X., & Wang, D. (2017). Immobilization of heavy metals in sewage sludge.

151 Qdais, H. A., & Moussa, H. (2004). Removal of heavy metals from wastewater by membrane processes: A comparative study. *Desalination*,164(2), 105-110.

152 Chavez, O. E. (2000). Mining of internationally shared aquifers: The El Paso-Juarez case. *Natural Resources Journal*, 40, 237-260. https://digitalrepository.unm.edu/nrj/vol40/iss2/5

153 El Paso Water. (n.d.). Reclaimed water. https://www.epwater.org/our_water/water_resources/reclaimed_water

154 El Paso Water. (2018, February 21). El Paso Water's Willie, the water drop. http://digie.org/media/5849

155 El Paso Water. (n.d.). Advanced purification. https://www.epwater.org/our_water/water_planning/advanced_purification

156 Schlanger, Z. (2018, August 23). A major US city will start drinking its own sewage. Others need to follow. Quartz. https://qz.com/1353825/a-major-us-city-will-start-drinking-its-own-sewage-others-need-to-follow/

157 Ritter, K. (2018, March 14). Water-Stressed Beijing Exhausts Its Options. *Circle of Blue*. https://www.circleofblue.org/2018/water-management/infrastructure/water-stressed-beijing-exhausts-its-options/

158 Wilson, M. C., Li, X., Ma, Y., Smith, A. T., & Wu, J. (2017). A review of the economic, social, and environmental impacts of China's south-north water transfer project: A sustainability perspective. *Sustainability*, 9, 1489. Doi:10.3390

159 Rodriguez, C., Van Buynder, P., Lugg, R., Blair, P., Devine, B., Cook, A., & Weinstein, P. (2009). Indirect Potable Reuse: A Sustainable Water Supply Alternative. *International Journal of Environmental Research and Public Health*,6(3), 1174–1203.

160 Leverenz, H. L.; Tchobanoglous, G.; & Asano, T. (2011). Direct potable reuse: A future imperative. *Journal of Water Reuse and Desalination*, 2-10.

161 U.S. Environmental Protection Agency, Office of Ground Water and Drinking Water, & CDM Smith. (n.d.). *2017 Potable Reuse Compendium* (Rep. No. EPA/810/R-17/002).

162 Boxall, B. (2019, February 22). L.A.'s ambitious goal: Recycle all of the city's sewage into drinkable water. *Los Angeles Times*. https://www.latimes.com

163 WateReuse. (n.d.). State Policy and Regulations. https://watereuse.org/advocacy/state-policy-and-regulations/

164 Yi, Lili; Jiao, Wentao; Chen, Xiaoning; & Chen, Weiping. (2011, October). An overview of reclaimed water reuse in China.

165 Ibid.

166 Neighbour, Danielle. (2018, November 19). Recycled water could solve Beijing's water woes.

167 China Development Gateway. (2015, March 22). Beijing Gaobeidian wastewater treatment plant. http://en.chinagate.cn

168 Zhu, Z., & Dou, J. (2018). Current status of reclaimed water in China: An overview. *Journal of Water Reuse and Desalination*, 8(3), 293-307.

169 Based on interviews conducted with Gaobeidian Wastewater Treatment Plant staff in March 2019.

170 Petrucci, R. H., Herring, F. G., Madura, J. D., & Bissonnette, C. (2017). Osmotic Pressure. In *General Chemistry: Principles and Modern Applications* (10th ed.). New York, NY: Pearson Education. https://chem.libretexts.org/Bookshelves/General_Chemistry/

171 Lenntech B.V. (n.d.). Micro filtration and ultra filtration. https://www.lenntech.com

172 Oram, B. (n.d.). UV Disinfection Drinking Water: Drinking Water Treatment with UV Irradiation. *Water Research Center*. https://www.water-research.net

173 West Basin Municipal Water District. (n.d.). Edward C. Little Water Recycling Facility. https://www.westbasin.org/water-supplies-recycled-water/facilities

174 West Basin Municipal Water District. (n.d.). Customer Development. https://www.westbasin.org/water-supplies-recycled-water/customer-development

175 Public Utilities Board (Singapore). (n.d.). NEWater. https://www.pub.gov.sg

176 Tan, T. P., & Rawat, S. (2018, January 15). NEWater in Singapore. *Global Water Forum*. http://www.globalwaterforum.org/2018/01/15/newater-in-singapore/

177 Wright, I. (2018, March 12). More of us are drinking recycled sewage water than most people realise. *The Conversation*. https://theconversation.com

178 Woo, M. (2016, January 6). Why we all need to start drinking toilet water. *BBC*. http://www.bbc.com

179 Soon, T. Y., Jean, L. T., & Tan, K. (2008). Clean, Green and Blue: Singapore's Journey Towards Environmental and Water Sustainability. Singapore: The Institute of Southeast Asian Studies, Yusuf Ishak Institute.

180 Public Utilities Board (Singapore). (n.d.). Programmes. https://www.pub.gov.sg/getinvolved/schools/programmes

181 Tan, T. P., & Rawat, S. (2018, January 15). NEWater in Singapore. *Global Water Forum*.

182 Public Utilities Board (Singapore). (n.d.). NEWater. https://www.pub.gov.sg

183 Mels, A.; Guo, S.; Zhang, C.; Wang, H.; Liu, S.; Li, X.; & Braadbaart, O. (2006). Decentralised wastewater reclamation systems in Beijing: Adoption and performance under field conditions. *SWITCH*. http://www.switchurbanwater.eu

184 van Dijk, M. P., & Liang, X. (2016). Evaluating the interests of different stakeholders in Beijing wastewater reuse systems for sustainable urban water management (M. A. Rosen, Ed.). *Sustainability*, 8, 1098.

185 Ritter, K. (2018, March 14). Water-Stressed Beijing Exhausts Its Options. *Circle of Blue*.

186 Neighbour, Danielle, & Zwicker, Gillian. (2019, May 31). Weathering the storm.

187 Neighbour, Danielle & Zwicker, Gillian. (2019, Mar. 8). What China Can Learn from New York City about Wastewater Management. *Scientific American*. Neighbour, Danielle, & Zwicker, Gillian. (2019, May 31). Weathering the storm: wastewater resiliency in the US and China. *China-US Focus*. https://www.chinausfocus.com/

188 ReliefWeb. (n.d.). China: Floods - Jul 2018. https://reliefweb.int

189 Eastern Weather Network. (2019, February 27). China issued a total of 835 flood warnings in 2018, with 120,000 flood checkpoints across the country. https://tianqi.eastday.com

190 Gass, H. (2014, August 8). More Chinese on the coast, less fish in the sea. *ClimateWire*. https://www.scientificamerican.com

191 Armbrecht, A. (2015). The 10 largest cities in China. *World Economic Forum*. https://www.weforum.org/agenda/2015/08/10-largest-cities-in-china/

192 Harvey, F. (2018). From London to Shanghai, world's sinking cities face devastating floods. *The Guardian*. https://www.theguardian.com/environment/2018/oct/05/from-london-to-shanghai-worlds-sinking-cities-face-devastating-floods

193 Kinver, M. (2012). Shanghai 'most vulnerable to flood risk'. *BBC News*. https://www.bbc.com/news/science-environment-19318973

194 Shepard, W. (2016). Can 'sponge cities' solve China's urban flooding problem? *100 Resilient Cities*. https://100resilientcities.org/can-sponge-cities-solve-chinas-urban-flooding-problem/

195 Kimmelman, M. (2017). Rising Waters Threaten China's Rising Cities. *The New York Times*. https://www.nytimes.com/interactive/2017/04/07/world/asia/climate-change-china.html

196 Zhang, X., Wang, X., & Wang, D. (2017). Immobilization of heavy metals in sewage.

197 OECD. (2015). *OECD Urban Policy Reviews: China 2015*. Paris: OECD Publishing.

198 Barron, J. (2018, March 22). New York City's Population Hits a Record 8.6 Million. *The New York Times*.

199 SWIM Coalition, NYC Soil & Water Conservation District and Riverkeeper, Inc. (n.d.). Stormwater Infrastructure Matters (SWIM). https://www.swimmablenyc.org

200 Riverkeeper, Inc. (n.d.). Combined Sewage Overflows (CSOs). https://www.riverkeeper.org/campaigns/stop-polluters/sewage-contamination/cso/

201 U.S. Environmental Protection Agency. (2019, March 11). Summary of the Clean Water Act: 33 U.S.C. §1251 et seq. (1972). https://www.epa.gov

202 Natural Resources Defense Council. (2017, June 29). Environmental groups sue over unsafe waters in New York City. *Natural Resources Defense Council*. https://www.nrdc.org/media/2017/170629-1

203 NYC Environmental Protection. (n.d.). NYC waterways. https://www1.nyc.gov/site/dep/water/nyc-waterways.page

204 Sanaker, A. (2017, September 7). EPA Reaching Lowest Staffing Levels Since Reagan. *Countable Corp*. https://www.countable.us

205 NYC Environmental Protection. (n.d.). The Bluebelt Program. https://www1.nyc.gov/site/dep/water/the-bluebelt-program.page

206 Chan, F. K.; Griffiths, J. A.; Higgit, D.; Xu, S., Zhu, F.; Tang, Y; Thorne, C. R. (2018). "Sponge City" in China: A breakthrough of planning and flood risk management in the urban context. *Land Use Policy*, 76, 772-778.

207 NYC Environmental Protection. (n.d.). Wait… https://www1.nyc.gov/site/dep/whats-new/wait.page

208 100 Resilient Cities. (2015, April 29). New York City announces new resilience plan, Champions City Resilience. http://www.100resilientcities.org

209 City of New York. (2017, April 28). Mayor announces new resiliency guidelines to prepare city's infrastructure and buildings for effects of climate change. https://www1.nyc.gov

210 City of New York, Mayor's Office of Sustainability. (n.d.). NYC benchmarking law. *NYC*. https://www1.nyc.gov

211 City of New York. (n.d.). OneNYC 2050: Building a strong and fair city.

212 NYC Water Staff. (2017, October 26). Hurricane Sandy's impacts. *Medium*. https://medium.com

213 City of New York, New York City Department of Environmental Protection. (n.d.). NYC wastewater resiliency plan. https://www1.nyc.gov/html/dep/pdf/climate/climate-executive-summary.pdf

214 AECOM, Global External Communications. (2016, October 26). *AECOM awarded US$41.5-million contract for New York City's Wastewater Resiliency Program* [Press release]. https://www.aecom.com

215 Resiliency Plan for NYC Wastewater Facilities Released. (2013, October 29). *Hazen and Sawyer*. https://www.hazenandsawyer.com/news/department-of-environmental-protection-releases-resiliency-plan-for-nyc-was/

216 Huang, D.; Liu, X.; Jiang, S.; Wang, H.; & Zhang, Y. (2018). Current state and future perspectives of sewer networks in urban China. *Frontiers of Environmental Science & Engineerin*g, 12(2).

217 Li, E. (2017, April 15). Southern China's million-tonne raw sewage problem. *South China Morning Post*. https://www.scmp.com

218 Talamini, G., Shao, D., Guo, X., & Ji, X. (2017). Combined sewer overflow in Shenzhen, China: The case study of Dasha River. *WIT Transactions on Ecology and the Environment*,210, 785-796.

219 Jiang, C. (2011). *A general investigation of Shanghai sewerage treatment system* (Master's thesis, Halmstad University, 2011). Halmstad, Sweden.

220 U.S. Environmental Protection Agency, Office of Research and Development. (2001). *Combined-Sewer Overflow Control and Treatment*. Cincinnati, OH: National Risk Management Research Laboratory.

221 Lincoln Institute of Land Policy, & Peking University. (n.d.). *The Current Status of Resilient Urban Development in China* (PPT).

222 Springer, K. (2012, May 21). Soaring to Sinking: How Building Up Is Bringing Shanghai Down. *Time*. http://science.time.com

223 Biswas, A.K., & Hartley, K. (2018, October 15). China's 'sponge cities' aim to re-use 70% of rainwater. *CNN*. https://www.cnn.com

224 Chaisson, C. (2017, December 12). When it rains, it pours raw sewage into New York City's waterways. *Natural Resources Defense Council*. https://www.nrdc.org/stories/when-it-rains-it-pours-raw-sewage-new-york-citys-waterways

225 Carney, M. (2018, November 22). Forget geopolitics, water scarcity shapes up as the biggest threat to China's rise. *ABC* (Australia). https://www.abc.net.au

226 Piao, S., Ciais, P., Huang, Y., Shen, Z., Peng, S., & Li, J., et al (2010). The impacts of climate change on water resources and agriculture in China. *Nature*,467(2), 43-51.

227 Matheson, J. (2016, February 8). Should we put a price on water? *Yale Insights*. https://insights.som.yale.edu/insights/should-we-put-price-on-water

228 Rutkowski, R. (2014, July 22). The Economics of H2O: Water Price Reforms in China. *Peterson Institute for International Economic*s. https://www.piie.com/blogs/china-economic-watch/economics-h2o-water-price-reforms-china

229 Neighbour, Danielle. (2019, June 20). Capless trade: Avoiding stumbling blocks in China's national carbon market. *China-US Focus*. https://www.chinausfocus.com

230 DeLisle, J. (n.d.). Traps, gaps, and law: Prospects and challenges for China's reforms. *The Foundation for Law, Justice and Society, & The Centre for Socio-Legal Studies, University of Oxford*.

231 Appendix 1 Citations: China Daily; China Water Risk; Yi, Jiao, Chen & Chen (2011). An Overview of Reclaimed Water Reuse in China. *Journal of Environmental Sciences*; Zhang et. al., (July 2016). Current status of urban wastewater treatment plants in China. Environment International 92-93:11-22; Zhang et. Al. (15 April 2019). China's Urban Methane Emissions From Municipal Wastewater Treatment Plant. Earth's Future; Deng Tingting (2017, June 2). Current status of urban wastewater treatment plants in China. *The Guardian*. (2 June 2017) In China, the water you drink is as dangerous as the air you breathe. https://www.theguardian.com/global-development-professionals-network/2017/jun/02/china-water-dangerous-pollution-greenpeace; Yi Lili et al. (October 2011) An overview of reclaimed water reuse in China. *Journal of Environmental Sciences* 23(10):1585-93; Lu et al. (2008). Water pollution and health impact in China: A mini review. Open Environmental Sciences 2, 1-5. https://facultystaff.richmond.edu/~sabrash/110/Water_Pollution_and_Health_Impact_In_China.pdf;`Bo et al. (4 June 2012) Agricultural non-point source pollution in China: Causes and mitigation measures. Amio. www.ncbi.nlm.gov/pmc/articles/PMC3393061

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