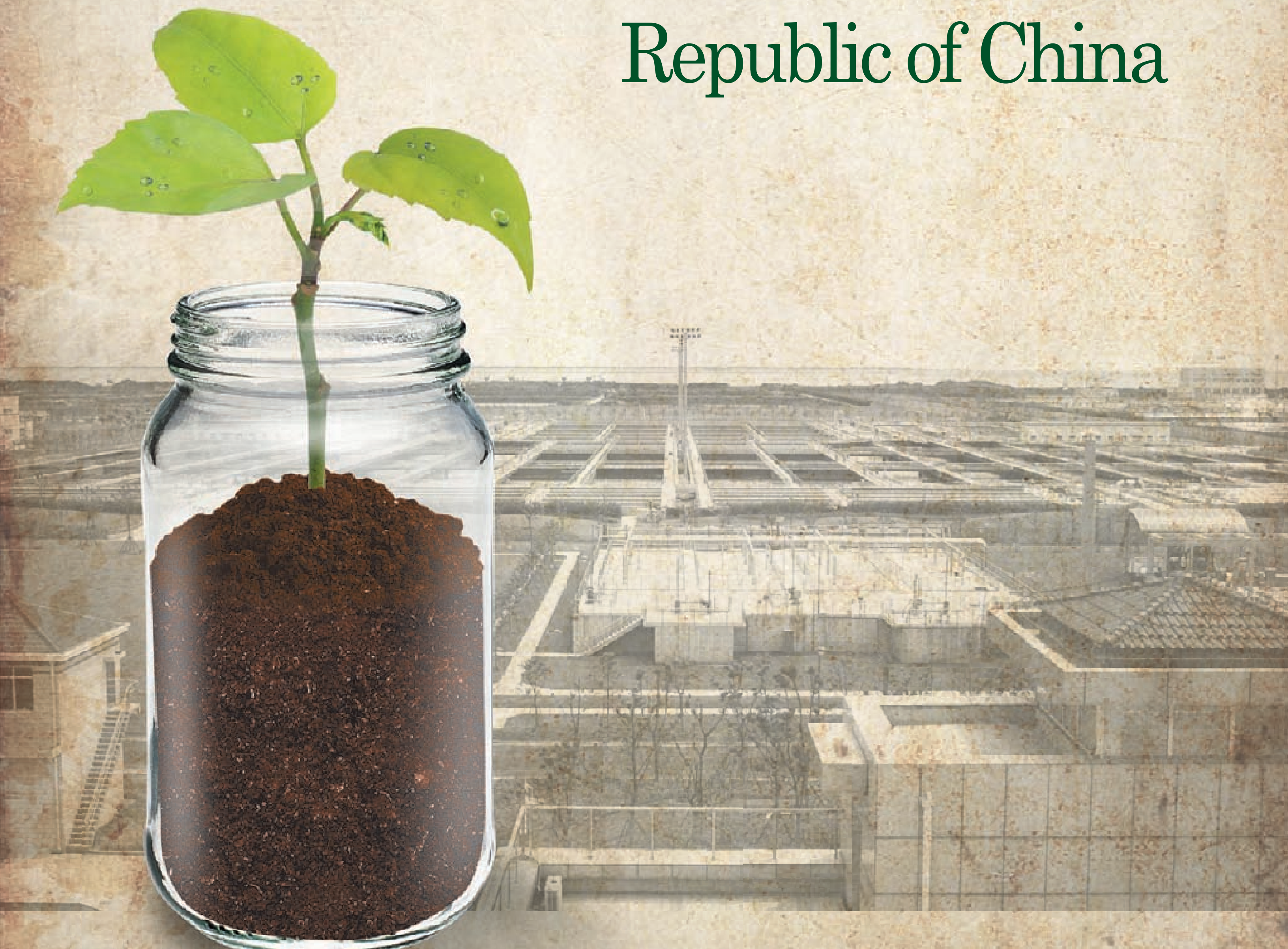
Promoting Beneficial Sewage Sludge Utilization in the People's Republic of China



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Foreword

The recent widespread improvements in sanitary services and infrastructure in the People's Republic of China (PRC) have delivered great benefits to the population and contributed significantly to the cleanup of land and water resources. Central to this has been the rapid increase in the construction and commissioning of wastewater treatment plants, supported in many parts of the country by the Asian Development Bank (ADB).

With the growth in wastewater treatment comes a consequent increase in sewage sludge production. Sludge is produced from all forms of wastewater treatment processes—from the simplest, such as land seepage or settlement ponds, to advanced tertiary treatment. Very often sludge management and disposal has been approached in the PRC as a separate policy and planning issue from wastewater management and treatment. This compartmentalization can result in a disconnect between the planning and resourcing of wastewater management and its most intractable product, sludge.

It was not until 2006 that PRC national sector plans recognized the significance of sludge production, both as a threat through secondary pollution, and as a source of energy and nutrients. Recognizing this, the Government of the PRC requested support from ADB for a study on urban wastewater reuse and sludge utilization in the country. In 2008, ADB approved a technical assistance grant to undertake a wide-ranging study of sludge treatment and utilization.

In this study, international experience of sludge treatment and utilization was reviewed and the best international practices identified and evaluated for their potential relevance to the PRC. This comprehensive review looked not only at sludge utilization applications and required treatment technologies but also the surrounding planning, institutional, regulatory, and economic frameworks that allow these technologies to be implemented.

Two features of the review were given special emphasis. First, sludge should be perceived as a resource with opportunities for utilization that result in considerable environmental and energy-saving benefits. Carbon "footprinting" is rapidly becoming an important factor in technology selection, and this is especially true for sludge treatment. Second, the social acceptability of sludge reuse in land application, composting, or preparation of building materials needs to be built up to overcome resistance at the community level.

A corresponding analysis of the treatment, utilization, and disposal of sewage sludge in the PRC was carried out at two levels: a detailed investigation of two case study cities, Beijing and Shanghai, and a broader review of the situation across the country.

The study compares international best practices and prevailing practices in the PRC, and identifies lessons from the case study cities. The study is thus able to identify the main issues that need to be addressed to develop an environmentally sound, technically feasible, and economically viable framework for sludge management and utilization in the PRC.

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The authors appreciate the quality inputs of the consulting team from AECOM Asia that conducted the study on urban wastewater reuse and sludge utilization in the PRC, especially Liu Shengbin, Peter Jaques, Jeff Howard, Echo Leung, Jim Hart, Yang Xiang Ping, Zhang Chen, Yan Wei, Dai Xiaohu, and Mike Lee. Several reviewers in ADB offered valuable comments, including Arnaud Heckmann, Jingmin Huang, Satoshi Ishii, Amy Leung, Sergei Popov, and Sonia C. Sandhu.

Abbreviations

ADB	–	Asian Development Bank
EARD	–	East Asia Department
EU	–	European Union
MOHURD	–	Ministry of Housing and Urban–Rural Development (PRC)
PRC	–	People's Republic of China
UK	–	United Kingdom
US	–	United States

Executive Summary

The treatment and beneficial utilization, or (as a last resort) disposal of sludge from municipal wastewater treatment facilities in the People's Republic of China (PRC) are still at the initial development stage and have lagged behind the construction and operation of basic wastewater treatment facilities. As a consequence, cities in the PRC are facing the sizeable challenge of how to properly manage increasing amounts of sewage sludge.

This policy brief is based on a study of urban wastewater reuse and sludge utilization in the PRC. The study was conducted by an expert team led by the consultant firm, AECOM Asia, which was engaged by the Asian Development Bank. It was implemented under the guidance of the Ministry of Housing and Urban–Rural Development, which is the ministry responsible for developing national policies and guidelines for wastewater management, including sewage sludge treatment and disposal. The study was implemented in close consultation with the water authorities of the pilot study cities—Beijing and Shanghai—which plan and oversee the implementation and operation of wastewater projects and facilities.

A review of sludge treatment and utilization in a number of other countries was undertaken to identify the best international practices. The countries and region selected for detailed review were Australia; Hong Kong, China; India; Japan; the Republic of Korea; Singapore; South Africa; Taipei,China; the United States; and the European Union.

International best practice now recognizes sewage sludge as a resource rather than a liability. Disposal of sludge in landfills is not only a threat to local environments and an unsustainable use of land, but is also a waste of this resource. Most countries are phasing out landfilling of sludge in favor of some form of sludge utilization, primarily land application. Applying properly treated sewage sludge to soils completes the nutrient cycle in our food chain by providing numerous benefits to soils and crops.

Where land application is constrained, the next best utilization pathway is energy recovery through anaerobic digestion with biogas collection followed by volume reduction treatment and incineration with heat recovery.

Other key characteristics of international best practice are that carbon footprint analysis is widely applied in developing sludge management strategies and selecting technical routes for sludge treatment and disposal, and that a regulatory framework with clearly defined sludge utilization practices and assured and enforced quality standards is crucial for establishing confidence in sludge utilization.

The main differences between current PRC sludge management practices and typical international practices are that institutional, planning, and regulatory arrangements for sludge management are immature, and sludge management plans are seldom based on a strategic assessment of possible beneficial reuse options. These factors result in low sludge utilization and energy recovery rates in the PRC.

A causal factor is the low level of cost recovery in the PRC, which inhibits private sector involvement. Sludge management still relies heavily on government financing.

In addition, insufficient attention is paid to impacts and risks to environmental and public health during strategic planning of sludge disposal and utilization, and the impact on climate change is not fully considered in evaluating sludge management options.

From comparisons of international best practice and PRC practice, as well as lessons from the case study cities, the following guiding principles can be identified for developing a strategic approach to managing sludge and promoting its beneficial utilization in the PRC:

- The sludge management strategy should be compatible with the government's goal of creating a circular economy and its "3R" policy for the reduction, recycling, and reuse of waste. As such, opportunities for the beneficial utilization of sludge should be pursued where technically and economically feasible.
- Approaches to sludge management should reflect local circumstances and needs—there is no viable "one solution fits all" approach.
- Sludge management is an integral part of wastewater treatment and should be planned and implemented accordingly.
- Sludge management solutions must be vigorously appraised to ensure they do not endanger public health or the environment.
- Effective regulation, monitoring, and control of all stages of operation are required.
- The selection of technical routes should take account of climate change impact.
- Transparency and enhancing public awareness are critical to retaining public confidence in sludge treatment and sludge-derived products.

This policy brief presents a range of technical routes for sludge treatment and utilization and briefly assesses their applicability to PRC conditions. It identifies a number of principles and practices that might usefully contribute to improved sludge management in the country. The most important principle is that sludge should be perceived as a resource with opportunities for utilization that result in considerable environmental and energy-saving benefits. Attention is also drawn to the potential significance of sludge treatment, utilization, and disposal as contributors to greenhouse gas emissions, and therefore, the importance of including carbon footprint analysis in the evaluation of sludge management technical routes.

International Best Practice in Sewage Sludge Management

This chapter focuses on the identification of policies and development trends, main sludge utilization applications, common and promising technical routes for sludge treatment, and sludge utilization marketing and promotion strategies.

Multilateral International Policy Approach

The United Nations Agenda 21[1] summarizes the general goal for waste management as minimization and beneficial utilization. It proposes three major program areas to promote this goal:

(i) minimizing wastes, maximizing environmentally sound waste reuse and recycling;

(ii) promoting environmentally sound waste treatment and disposal; and

(iii) extending waste service coverage.

These areas are interrelated and mutually supportive, and if implemented in an integrated way will result in a comprehensive and environmentally responsive framework for managing municipal solid wastes, including sludge. This approach is currently being pursued in the Asian Development Bank's (ADB) country and regional programs (Box 1), and by the United Nations Environment Programme and the World Bank.

Box 1 **The Wuhan Urban Environmental Improvement Project**

In line with international best practice, the Asian Development Bank (ADB) is demonstrating the principles of integration in a series of projects in particular municipalities in the People's Republic of China. In the city of Wuhan, in parallel with the early phases of the Urban Wastewater Reuse and Sludge Utilization Policy Study, the ADB-funded Wuhan Urban Environmental Improvement Project aims to address immediate sludge handling and disposal challenges. The project design responds to policy discussions during project preparation, which reoriented the city's sludge master plan. Using a decentralized and integrated approach, the project facilities will treat and reuse or dispose of approximately 50% of the sludge generated by the city. Adapting best international practices to local conditions, the proposed scheme attempts to fully address concerns over secondary pollution and climate change impacts, and supports the principles of a circular economy. The selected technical routes, which promote beneficial reuse of the sludge through land application, maximize utilization of sludge as a resource and minimize energy use in the treatment process.

Source: ADB. Forthcoming. *Managing Wastewater Treatment Sludge: The Case of Wuhan City*. Manila.

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[1] Agenda 21 is the global action plan on sustainable development adopted at the United Nations Conference on Environment and Development held in Rio de Janeiro, Brazil, in 1992.

Sludge Is a Resource

The major driver for sludge utilization is increased regulatory control over previous disposal methods—landfilling is banned or being phased out in most of the countries reviewed—and the recognition of sludge as a resource. Australia, Europe, Japan, and the United States (US) are the leaders in beneficial sludge utilization.

Sludge Disposal: Phasing Out Sludge Landfilling

Landfilling remains a common sludge disposal practice worldwide. The majority of landfills are mixed fill sites. However, because of the (i) increasing stringency of environmental regulations, (ii) significant greenhouse gas emissions during organic degradation, (iii) potential secondary contamination from leachate, and (iv) the occupation of valuable landfill space, landfilling is being phased out in many countries. For example, the European Community Landfill Directive has set goals for reducing the disposal of organic wastes in landfills, implying that landfilling is not considered a sustainable approach to sludge management in the long term. Increasingly, the landfill option is becoming restricted to the disposal of ash from sludge incineration. Recovery of landfill gas for power production is an emerging trend where landfilling is still being carried out, and this practice significantly reduces greenhouse gas emissions.

Sludge Utilization: Beneficial Uses and Value Addition

Current beneficial sludge utilization practices include land application, energy recovery, use as an alternative fuel source, use as a construction material, and resource recovery from sewage sludge using emerging technologies. The rates of beneficial sludge utilization for selected countries and regions are shown in Table 1. Land application is the predominant form of beneficial utilization.

Table 1 **Sewage Sludge Production and Beneficial Utilization Rates in Selected Countries**

Country or Region	Sludge Utilization Rate (%)	Sludge Production (Million tons dry solids per year)	Main Sludge Applications
United Kingdom	85	1.05	Land application, energy recovery
Australia	80	0.36	Land application
South Africa	80	1.0	Land application
India	80	…	Land application
Japan	74	2.2	Energy recovery, construction products (including products of incineration ash)
Germany	60	2.3	Land application, energy recovery
United States	55	17.8	Land application
European Union	40	9.0	Land application
Republic of Korea	6	1.9	Land application, construction products
Singapore	0	0.12	…
Hong Kong, China	0	0.3	…

… = information not available.

Source: East Asia Department, ADB.

Land application. Sludge is high in phosphorus and nitrogen, the key nutrients for plant growth. Given that phosphorus sources are being exhausted and soil quality is degrading, treated sludge is used as fertilizer and soil conditioner in many parts of the world such as Australia, South Africa, the United Kingdom (UK), and the US. Sludge is applied to the soil in various forms from stabilized and dewatered sludge to sludge-derived compost or heat-dried sludge pellets. The application of raw (untreated) sludge is banned, or in the process of being banned, in most countries.

Energy recovery. Recovery of the organic carbon in sludge in the form of renewable energy such as biofuel is an increasingly popular practice. Anaerobic digestion is commonly adopted to stabilize sludge, with biogas produced as a by-product. Utilization of biogas for power and heat generation is popular in Australia, Europe, and the US. In some cities in Japan, biogas is used in natural gas powered vehicles, thereby reducing emissions from fossil fuels.

Industrial reuse. The most common industrial application is to use dewatered sludge or incineration ash for the production of brick or cement blocks. Industrial reuse is an emerging trend that is already widely adopted in Japan, and is being evaluated in the Republic of Korea and Taipei,China.

Incineration. Sludge is widely incinerated where beneficial reuse is not possible. In Japan, Singapore, and several European countries, incineration is used extensively because of the limited available land (e.g., in the case of Singapore) or local restrictions against land application and landfilling of sludge (e.g., in the Netherlands and Switzerland).

Main Sludge Treatment Processes

Most sewage sludge currently produced worldwide is, at a minimum, dewatered and stabilized.

Anaerobic digestion of sludge with biogas generation and utilization is commonly adopted to stabilize sludge. Above, sludge digester at the Sibao wastewater treatment plant in Hangzhou, Zheijang Province.
Source: AECOM 2010.

This applies equally to developing countries such as India and developed regions such as Australia, Europe, and the US. What differs is that less-developed countries collect and treat a lower proportion of their wastewater. For dewatering, mechanical technologies such as the centrifuge and filter press are generally preferred. Common stabilization methods include anaerobic digestion and lime stabilization, although lime stabilization is declining in use because it restricts utilization options. In most developed countries, sludge is often further stabilized through composting or heat drying so that it can be used for a wider range of applications. Heat drying is energy intensive and associated with relatively high greenhouse gas emissions, but may be necessary where a reduction of sludge volume must be achieved. Thermal hydrolysis is an emerging process for initial treatment that is not yet widely practiced. The process converts complex organic matter into simpler compounds by fermentation under anaerobic conditions, increases chemical oxygen demand degradation, increases dry solids reduction and thereby the gas production in the subsequent anaerobic digestion, and improves the dewaterability of the sludge.

Regulatory Frameworks and Guidelines

Most countries have comprehensive legal frameworks to regulate sewage sludge treatment, reuse, and disposal. Policies and standards relating to sludge disposal and utilization are normally established through national laws or directives. In the European Union (EU) for example, minimum standards are established in the EU's Sludge Directive.[2] In the US, the Environmental Protection Agency has published standards for the use or disposal of sewage sludge.[3] Member states in the EU and the US have developed laws and regulations for sludge management that meet their individual needs and comply with the overarching directives. In the UK, for example, the Department for Environment, Food and Rural Affairs published the Code of Practice for Agriculture Use of Sewage Sludge in 1989, which recommends treatment levels and monitoring requirements of recycled sludge, and discusses operational practices to protect the environment.[4] In 2008, the Department of Agricultural and Rural Development also updated its Code of Good Agricultural Practices for Farmers, Growers and Land Managers, which includes discussion on good sludge application practices to prevent pollution and safeguard human health.[5] Sludge-related standards and regulations are often covered in other laws and regulations, such as compost quality standards, air emission standards for incinerators, and industrial waste regulations.

Investment Mechanisms

Government ownership and financing of wastewater and sludge infrastructure is still dominant in many parts of the world. Sludge treatment is usually managed as part of wastewater treatment, and hence, its financing. Recurrent costs for sludge treatment are mostly cross-subsidized through wastewater tariffs collected, as sludge products do not usually generate sufficient revenue to cover costs. The level of cost recovery varies significantly, but there is a clear trend toward full cost recovery

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2 Council of the European Communities. 1986. The Sewage Sludge Directive 86/278/EEC, as amended, Brussels.

3 United States Environmental Protection Agency. 1993. Regulation (58 FR 9248)—CFR 40 Part 503 Standards for the Use or Disposal of Sewage Sludge (amended biennially).

4 Government of the United Kingdom, Department for Environment, Food and Rural Affairs. 1989. *Code of Practice for Agriculture Use of Sewage Sludge*. SI 1989, No. 1263. London.

5 Government of the United Kingdom, Department of Agriculture and Rural Development. 2008. *Protecting Our Water, Soil and Air: A Code of Good Agricultural Practice for Farmers, Growers and Land Managers*. London.

through a wastewater tariff, and the marketing of wastewater and sludge utilization. This trend is compatible with the "polluter pays" and "waste is a resource" principles, as well as policies to encourage reductions in waste volumes and greenhouse gas emissions.

To establish diversified investment mechanisms, governments are increasingly promoting the participation of private sector capital in the construction of sludge treatment facilities.

Increased Focus on Climate Change and Greenhouse Gas Emissions

Greenhouse gas emissions are important considerations for strategic planning of sludge management. In developed countries, sludge treatment and disposal is typically the largest contributor of greenhouse gas emissions in the water industry. Understandably therefore, in Europe and the US, greenhouse gas emissions from sludge treatment are now seen as an important criterion when evaluating alternative sludge treatment technologies.

The Intergovernmental Panel on Climate Change has published guidelines that have become the standard methodology for performing national greenhouse gas inventories. In addition, various government and nongovernment organizations, including the World Resources Institute and the United States Environmental Protection Agency, have published more detailed instructions for conducting greenhouse gas inventories. One international methodology in this area that enables ready comparison between different sludge treatment options is known as the Local Government Operations Protocol.[6] The protocol considers the scope of greenhouse gas emissions from three perspectives to minimize the potential for double-counting of emissions. A typical evaluation of sludge treatment and disposal options using this methodology will look at greenhouse gas emissions from electricity use, stationary sources, fugitive emissions, landfill, incineration, and polymer use, as appropriate. Various offsets, such as the replacement of chemical fertilizer for land application, are included on the credit side of the audit.

An example for a proposed wastewater treatment plant in the US is shown in Figure 1. Cases vary around the world, but in general, drying and landfill disposal are the sludge management options with the most significant greenhouse gas emissions.

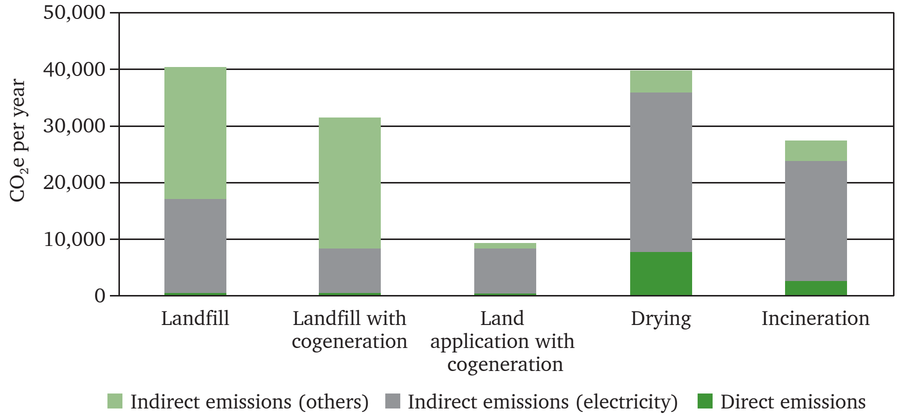
A more exact and inclusive method of looking at the climate change impact of different sludge treatment technologies is to assess their carbon footprint.[7] Carbon footprint analysis is increasingly conducted for sludge treatment and disposal because, often, a large proportion of greenhouse emissions in sludge management is from energy use and transport rather than intrinsic processes of sludge or direct gas production. In this way, the carbon footprint of activity in one sector (waste) will take account of emissions from ancillary but essential activities that are usually counted in other sectors. This will provide a more complete picture.

In the framework for the study, 15 well-proven sludge technical routes were investigated, and their carbon footprints were evaluated using the widely used methodology of the UK Water

[6] Local Governments for Sustainability, California Climate Action Registry, California Air Resources Board, and Climate Registry (2008, amended in 2010). The Local Government Operations Protocol. www.theclimateregistry.org/resources/protocols/local-government-operations-protocol

[7] Carbon footprint can be defined as the total amount of greenhouse gases produced to directly and indirectly support human activities. It is usually expressed in tons of carbon dioxide equivalent.

Figure 1 **Greenhouse Gas Emissions of Different Sludge Management Options Considered for a Wastewater Treatment Plant in the United States**



CO_2e = carbon dioxide emissions.

Source: Scanlan, P., H. Elmendorf, A. Shaw, and S. Tarallo. 2009. Evaluating Greenhouse Gas Emissions: An Inventory of Greenhouse Gases is an Important Piece of the Sustainability Puzzle. *Water Environment and Technology*. 21(4). pp. 31–35.

Industry Research.[8] The results, which are presented in Table 2, emphasize the importance of energy recovery in sludge processing as a means of reducing carbon footprint. The wide range of carbon footprints suggests that it should become a more important factor in defining sludge management strategies.

Emphasis on Public Perceptions and End User Needs

The perceptions of the public and potential end users of sludge products play a key role in the sustainability of sludge management plans. Public attitudes toward beneficial sewage sludge utilization vary among the countries reviewed. The debate over sludge recycling and disposal in most countries shows that uncertainties over possible risks for human health and the environment play a major role in the resistance to its wider use. The main public concerns focus on health and safety issues related to land application, with fears voiced over possible secondary pollution of food crops, soil, and groundwater. Farmers and the agri-food industry are generally supportive of sludge reuse in agriculture, provided that sludge quality can be guaranteed. Customer confidence in the safety of agricultural products is a key priority of these farmers.

Incineration of sludge often faces public resistance due to potential gas emissions. Nature protection associations in several EU member states and the US have repeatedly expressed their hostility toward sludge incineration, mostly due to the associated gas emissions.

International experience suggests that resistance to beneficial sludge utilization is often a result of a lack of information, which leads to distrust, and that comprehensive programs need to be put in place to overcome this problem.[9]

8 UK Water Industry Research. 2011. *Workbook for Estimating Operational Greenhouse Gas Emissions*. London (Reference No.: 11/CL/01/13); UK Water Industry Research. 2008. *Carbon Accounting in the UK Water Industry: Guidelines for Dealing with 'Embodied Carbon' and Whole Life Carbon Accounting*. London (Reference No.: 08/CL/01/6).

9 Examples of successful voluntary programs to increase public acceptance of beneficial sludge utilization include the Environmental Management System of the US National Biosolids Partnership and the Safe Sludge Matrix developed by Water UK and the British Retail Consortium. See www.adas.co.uk and www.wef.org/biosolids

Table 2 **Carbon Footprint of Sludge Technical Routes**

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

( ) = negative.

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

Source: East Asia Department, ADB.

Summary of Key Observations from the Review of International Best Practice

- Sewage sludge is now widely recognized as a resource. Disposal of sludge in landfills is not only a threat to local environments and an unsustainable use of land, but is also a waste of a useful resource. Most countries are phasing out landfilling of sludge in favor of some form of sludge utilization.
- Applying properly treated sewage sludge to soils completes the nutrient cycle in our food chain by providing numerous benefits to soils and crops. At the same time, by offsetting the use of chemical fertilizers that consume energy and resources in their production, land application can lead to significant efficiencies in the agri-food industry.
- Where a lack of access to available land prevents land application, the best utilization pathway will be energy recovery through anaerobic digestion with biogas collection followed by volume reduction treatment and incineration with heat recovery.
- Carbon footprint analysis is widely applied in developing sludge management strategies and selecting technical routes for sludge treatment and disposal.
- A comprehensive regulatory framework with clearly defined sludge utilization practices and assured quality standards is crucial in establishing confidence in sludge use and promoting safe sludge utilization.

Status of Sludge Management in the People's Republic of China

Background

Since the beginning of the 21st century, the construction of wastewater treatment plants in the People's Republic of China (PRC) has accelerated rapidly. Data provided by the Ministry of Housing and Urban–Rural Development (MOHURD) show that by the end of March 2011, there were 2,996 municipal wastewater treatment plants in the country with a total capacity of 133 million cubic meters/day. One of the PRC's priority objectives has been to halt the environmental degradation of its inland watercourses, estuaries, and coastline. Much has already been achieved; however, success has brought a new challenge: how to manage the ever-increasing volumes of sludge produced every day in a way that does not create additional pollution.

The treatment and beneficial utilization or disposal of sludge in the PRC are still at the initial development stage and have lagged behind the construction and operation of basic wastewater treatment facilities. As a consequence, cities in the PRC are facing the great challenge of how to properly manage increasing amounts of sewage sludge. Based on an estimated overall wastewater treatment rate of 70%, the total sludge production in 2012 will reach approximately 30 million tons of dewatered sludge (80% moisture content). The

Sanjintan wastewater treatment plant in Wuhan, Hubei Province.
Source: Arup 2010.

approaches taken by the case study cities, Beijing and Shanghai, are discussed in Box 2.

Technical Approaches

Although most of the modern sludge management approaches used worldwide have current practical applications in the PRC, many are only applied in pilot projects or on a small scale. Sludge technical routes that are applicable to specific local situations are not clearly defined.

More than 80% of the sludge undergoes basic treatment at best, including dewatering and thickening. Sludge utilization technologies are being developed in the PRC, but relative to best international practices, the rate of beneficial sludge utilization, including energy recovery, is very low, and sludge stabilization prior to disposal is uncommon. Only about 20% of sludge is

Box 2 **Present State of Sludge Management in the Case Study Cities**

Beijing. The current sludge production in Beijing urban area is 2,400 tons/day (approximately 160 truckloads), of which only 1,310 tons/day (44%) are safely disposed of. More than half of the sludge is disposed of after thickening and dewatering without further treatment. The most common treatment processes include dewatering, drying, composting, and incineration. In suburban areas, sludge disposal through direct land application is still common. It is estimated that by 2015, the sludge production of wastewater treatment plants in urban areas will increase to 3,300 tons/day.

As the water administrative department, the Beijing Water Authority is responsible for sector management of sludge treatment and disposal. The construction of sewage sludge treatment and disposal facilities is predominantly financed by government grants and contributions from the Beijing Drainage Group. In its Twelfth Five-Year Plan, 2011–2015, Beijing defined the ambitious target of 100% safe sludge treatment and disposal, and 90% beneficial utilization. Given the scarcity of land, drying and incineration will be the dominant approach to sludge disposal. Land application and composting will serve as a secondary option.

Shanghai. The projected total sludge production in Shanghai is 3,200 cubic meters/day for 2012 and 4,200 cubic meters/day for 2015 (80% moisture content). For the long term (2020), the predicted sludge production will be 6,000 cubic meters/day (approximately 400 truckloads).

Shanghai is one of the few major cities in the People's Republic of China that has a professionally prepared strategic plan (2009) for sludge treatment, disposal, and utilization. However, on closer review of current performance, there are many areas that need urgent improvement. Of the treated sludge, 86% is treated by thickening and dewatering, and then landfilled. Incineration followed by safe disposal accounts for 11% of sludge. The rate of beneficial sludge utilization thus remains low.

Shanghai's strategic plan foresees a significant shift toward beneficial sludge utilization by 2015. Incineration with heat recovery and production of building materials (65%), and high-temperature anaerobic fermentation with land application (35%) will be the main technical routes that Shanghai will promote. The target of the Shanghai authorities is to reduce landfilling of sludge from 86% to 7% by 2020. This target is very ambitious, given the fact that sewage sludge treatment and disposal is entirely financed by the Shanghai government, because the existing wastewater tariff does not consider the costs of sludge treatment and disposal. Eleven sludge treatment projects, including Bailonggang, Zhuyuan, and Shidongkou, and a cement production facility in Bailonggang are currently under construction.

Source: East Asia Department, ADB.

The dominant practice in the People's Republic of China is to dispose of dewatered sludge in landfills. Above, dewatered sludge being loaded for transport to the municipal landfill in Wuhan, Hubei Province.
Source: AECOM 2010.

stabilized, and only 13% of the stabilized sludge is further utilized for agricultural application or as an alternative fuel for cement kilns or power stations. The dominant practice in the PRC is to dispose of raw sludge in landfills. MOHURD estimates that more than 80% of sludge is disposed of in this way.

Policy Approach

In 2009, MOHURD, together with the Ministry of Environment Protection and the Ministry of Science and Technology, issued the *Policy on Sludge Treatment and Pollution Prevention Technology in Urban Wastewater Treatment Plant (Trial)*.[10] This key policy document of the national government on sewage sludge management states that the objective of sludge treatment is to realize volume reduction, stabilization, and safe disposal. Beneficial sludge utilization is not a specifically stated objective, although recovery and reuse of the energy and resources in sludge is strongly encouraged.

The PRC's vast territory and the great differences between cities make it difficult for the central government to work out rules or policies with nationwide applicability. For this reason, and because of the very recent development of large-scale wastewater treatment plants, national regulations and rules have not yet been promulgated. The current practice of disposing of sludge in landfills is thus comprehensible. At present, in common with the wastewater reuse industry, the institutional responsibility for the

[10] Government of the People's Republic of China, MOHURD, Ministry of Environment Protection, and Ministry of Science and Technology. 2009. *Policy on Sludge Treatment and Pollution Prevention Technology in Urban Wastewater Treatment Plant (Trial)*. Beijing.

overall coordination, planning, and management of sewage sludge treatment, disposal, and utilization is not defined. The management approach and institutional arrangements for sludge are the same as those for municipal wastewater: MOHURD is in charge of national planning and policy guidance, and local governments are responsible for overseeing the construction and operation of sludge treatment and disposal facilities within their jurisdictions. There is currently no legislative or institutional directive to address sewage sludge treatment, disposal, and utilization within the framework of overall urban master planning, or to ensure sludge management is included in the urban master plan as a special subsidiary plan.

Environmental impact and risk assessments of sludge utilization are weak. Although standards for many parameters can often be met after sludge stabilization, potential long-term environmental risks are rarely assessed and adequately mitigated. There are no continuous monitoring data and records, nor is there environmental site monitoring and analysis for landfilling, land application, or incineration.

Climate Change and Carbon Footprint

The climate change impacts of sludge treatment, disposal, and utilization have not yet been systematically evaluated and taken into account in sludge management planning in the PRC. The following difficulties need to be addressed: (i) standard methods to calculate greenhouse gas emissions during sludge treatment and disposal are not available; (ii) applicable emission control standards and policy requirements need to be developed, but basic research has not yet been conducted; (iii) carbon footprint cannot be easily quantified and monitored, therefore there are difficulties and obstacles in technology improvement and development, as well as in

Sludge digester at the Sanjintan wastewater treatment plant in Wuhan, Hubei Province.
Source: Arup 2010.

developing control measures; and (iv) climate change mitigation is not considered financially advantageous, as no carbon emission trading scheme is in place.

How Far Is the People's Republic of China from International Best Practice?

While there are similarities between current PRC sludge management practices and typical international practices, there are also significant differences. The main differences are

- a very low percentage of sludge (20%) is adequately stabilized before disposal;
- sludge management plans are not defined based on a strategic assessment of possible beneficial reuse options, resulting in low sludge utilization and energy recovery rates;
- the impact on climate change is not considered in evaluating sludge management options;
- insufficient attention is paid to impacts and risks to the environment and public health during strategic planning of sludge disposal and utilization;
- institutional, planning, and regulatory arrangements for sludge management are immature;
- a significant gap exists between current levels of funding and that needed to develop safe and sustainable sludge treatment and disposal arrangements; and
- current levels of cost recovery are low and inhibit private sector involvement, therefore sludge management still relies heavily on government financing.

These shortcomings cannot be tackled in a piecemeal fashion. The next chapter discusses necessary steps to align the PRC's sludge management strategy with international best practice.

The Way Forward

Sustainable sludge strategies and management programs that are both economically and technically sound need to be developed to handle the rapid growth in sewage sludge production and support the People's Republic of China's (PRC) rapid urbanization and continued environmental improvement. These strategies need to be flexible enough to accommodate the large diversity found among cities in the PRC in terms of size, economic development, climate, land availability, social conditions, and financial and technical capacity. They also need to be compatible with the PRC's broader goals and policies for sustainable development, and the government's international commitments—especially with respect to climate change mitigation.

The strategic direction should be to achieve a much greater alignment of PRC sludge management practices with international best practices, but with modifications to reflect specific PRC conditions where necessary. International experience suggests that it can be achieved, and that there are potential solutions that can be adapted for use in the PRC.

Overarching Objectives and Principles

The following guiding principles can be used to develop a strategic approach to managing sludge and promoting its beneficial utilization in the PRC:

- Sludge management strategy should be compatible with the government's goal of creating a circular economy and its 3R policy for the reduction, recycling, and reuse of waste. As such, opportunities for the beneficial utilization of sludge should be pursued where technically and economically feasible.
- Approaches to sludge management should reflect local circumstances and needs—there is no viable "one solution fits all" approach.
- Sludge management is an integral part of wastewater treatment and should be planned and implemented accordingly.
- Sludge management solutions must be vigorously appraised to ensure they do not endanger either public health or the environment.
- Effective regulation, monitoring, and control over all stages of operation are required.
- Selection of technical routes should take account of climate change impact.
- Transparency and enhancing public awareness are critical to retaining public confidence in sludge treatment and sludge-derived products.

These principles have been generally embraced by MOHURD. Specifically,

- The Plan for the Construction of Urban Wastewater Treatment and Reuse Facilities, 2011–2015, reinforces the need for the development and implementation of sustainable sludge management strategies at the city level. The plan introduces the concept of technical routes for sludge management, promotes low-carbon approaches to sludge management, and sets the national goal of treating 70% of sludge in large cities and 50% in small cities by 2015.

- The recently published National Technical Guidelines for Urban Sewage Sludge Treatment and Disposal (Trial)[11] aims to regulate and promote sludge utilization practices, and guides the development of local sludge management strategies with a focus on beneficial sludge utilization. The guideline promotes low-carbon solutions, and incorporates comprehensive carbon emission analysis in the evaluation of sludge management options.

These plans clearly indicate the government's efforts to promote modern sludge management. They also show a recognition that shifting the emphasis from disposal to beneficial use of sludge is compatible with broader government policies for sustainable urban development and international commitments to act on climate change mitigation.

However, while national strategies and plans to promote safe and beneficial sludge management are in place, the policy framework is not yet complete, and this greatly hinders their effective implementation at the local level. The study identified policy needs and defined recommendations on the following aspects of sludge management:

- integrated planning at the city level;
- selection of appropriate technical routes for sludge management;
- establishment of quality standards, supervision, and monitoring;
- tariff and financing policies; and
- raising public awareness and confidence.

Integrated Planning at the City Level

The government should reinforce the need for the development and implementation of sustainable sludge management plans at the city level, and should issue guidance on the preparation of such plans. Advice should also be provided on the steps needed to ensure that sludge planning is effectively integrated with overall city master planning and the preparation of other relevant city-level sector plans. More specifically,

- the responsibility for sludge management should be clearly assigned;
- planning of wastewater collection, treatment, and sludge management should be fully integrated;
- coordination among drainage, agriculture, environmental, public health, and industrial departments in cities, districts, and counties should be made effective;
- sludge management solutions should be built around a viable and sustainable means of using or (as a last resort) disposing of sludge;
- technical routes should be selected based on the preferred utilization or disposal approach in consultation with all relevant stakeholders;
- resources and energy from sludge should be recovered where this is economic; and
- low-carbon solutions should be sought wherever practical.

The municipal drainage department of local governments will usually have the overall responsibility for developing sludge treatment, disposal, and utilization plans and construction

[11] Government of the People's Republic of China, MOHURD, National Development and Reform Commission. 2011. *National Technical Guidelines for Urban Sewage Sludge Treatment and Disposal (Trial)*. www.mohurd.gov.cn (in Chinese).

Resources and energy from sludge should be recovered where this is economic. Above, sludge digesters with biogas recovery in Zhujiajiao, Shanghai.
Source: AECOM 2010.

programs, organizing their implementation, supervising service performance and safety, and related administrative activities.

The most readily applicable mechanism for achieving required levels of integration at the city level is the master planning process, already established in all PRC cities and municipalities. However, the case studies in Beijing and Shanghai show that this process is failing to integrate and optimize waste management, largely because of a lack of practical policy direction and guidance. Changes in planning guidelines will be needed to make such integration a reality. Cities should be encouraged to explore opportunities for integrated solutions to sludge and solid waste management. The State Council is currently working on the Urban Drainage and Wastewater Treatment Directive, which will define requirements for developing strategic wastewater treatment and sludge management plans for cities and regions.

Where industrial sewage is a significant contributor to sludge, the involvement of associated industry departments is needed as early as possible in the planning stage of sludge treatment and disposal to ensure adequate pollution control at the source. In the planning of new urban development, separate treatment of industrial wastewater should be provided wherever this is economic (e.g., in large industrial parks).

Land availability is likely to be the key driver in sludge management planning at the city level, especially in the selection of technical routes for sludge management, as is the case in developed countries.

Selection of Appropriate Technical Routes for Sludge Management

Technical routes in all situations should seek to follow the basic internationally accepted principles of sludge management, i.e., volume reduction, stabilization, and safe utilization or disposal. The following are guiding principles to help PRC cities select appropriate technical routes:

- Build sludge management solutions around a viable and sustainable means of utilizing or (as a last resort) disposing of the sludge.
- Select sludge treatment methods based on the most suitable utilization or disposal approach.
- Recover resources and energy from sludge where this is economic.
- Seek low-carbon solutions wherever practical.

Besides land availability, other local factors that will affect the viability and sustainability of sludge management solutions include sludge volume, sludge quality (which could determine whether a potential use is viable), costs, sludge market maturity, public perceptions, and financial and technical capacity for sustainable operations.

Landfilling of unstabilized sludge should be discouraged. In most developed countries, this is often done by imposing a high landfill tax. Policies to discourage landfilling in the PRC would also likely encourage innovation and enhance the financial viability of management approaches that promote beneficial sludge utilization. Such approaches include beneficial land application; utilization in cement kilns; and the use of emerging technologies such as pyrolysis, gasification, and carbonization, which seek to maximize resource recovery from sludge.

A new factor is to consider whether proposed sludge management solutions are climate friendly. The trend is for the greenhouse gas emissions of alternative viable solutions, as assessed by project carbon footprint analysis, to be used as an evaluation factor in selecting technical routes for sludge utilization or disposal.

A multi-criteria assessment of 15 different technical routes covering resource demand, costs, energy efficiency, and environmental sustainability was conducted to guide sludge planners in deciding which routes might be suitable to their local situation (Table 3). The main findings are as follows:

- If viable, land application is likely to give the best balance of environmental benefit and cost.
- A process comprising anaerobic digestion, biogas utilization, and land application performs especially well in this respect, but may not be suitable for big cities with large sludge volumes.
- Where land application is not viable, either because land is not available or the sludge quality is not suitable, sludge utilization as a coal substitute can be explored.
- Gasification is an emerging technology that also shows promise, but it is costly and not yet proven in large-scale facilities.
- The benefits of sludge utilization need to be balanced against the higher costs involved and, if judged uneconomic, landfilling must be considered as a last resort.
- Where landfilling is deemed necessary, decisions need to be made on what treatment should precede the landfill process in terms of energy recovery and sludge volume reduction. Best international practice is undoubtedly to maximize energy recovery in this situation, using biogas and landfill gas recovery. This reduces sludge volatility and carbon footprint.

Table 3 **Comparison of Technical Routes for Sludge Treatment, Utilization, and Disposal**

	Technical Route	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Processes involved	Thermal hydrolysis	✓		✓												
	Anaerobic digestion	✓	✓	✓	✓	✓							✓			
	Biogas recovery	✓	✓	✓	✓	✓							✓			
	Composting				✓			✓								
	Lime stabilization									✓						
	Heat drying	✓					✓		✓					✓	✓	
	Incineration										✓					
	Gasification								✓							
	Land application			✓	✓	✓		✓		✓				✓	✓	
	Landfill		✓									✓	✓			✓
	Landfill gas use		✓									✓				
	Coal substitution	✓					✓									
Main attributes	Capital costs	H	M	H	L	L	H	L	H	L	H	M	L	H	H	L
	O&M costs	H	M	M	M	L	H	L	H	M	H	M	M	H	H	L
	Land required	L	M	H	H	H	L	H	L	H	L	M	M	M	M	H
	Volume reduction	H	L	L	M	L	H	M	H	L	H	L	L	M	M	L
	O&M capacity	H	M	H	L	L	H	L	H	L	H	M	L	H	H	L
	Energy recovery	Y	Y	Y	Y	Y	Y	N	Y	N	Y	Y	Y	N	N	N
	Other resource use	Y	N	Y	Y	Y	Y	Y	Y	Y	P	N	N	Y	Y	N
	Carbon footprint	L	L	L	L	L	L	M	M	M	M	M	M	H	H	H
	Treatment footprint	H	M	M	M	M	L	H	M	H	M	L	M	L	L	L
	Pathogen free	Y	N	Y	Y	N	Y	Y	Y	N	Y	N	N	Y	Y	N
Suitable for the PRC?		**Y**	**(Y)**	**Y**	**Y**	**Y**	**(Y)**	**(Y)**	**(Y)**	**(Y)**	**(Y)**	**N**	**N**	**N**	**N**	**N**

L = low; M = medium; H = high; Y = Yes; N = no; P = possibly; (Y) = might be justified in specific contexts, or become suitable as result of technical maturity; O&M = operations and maintenance.

Note: "Land required" is for disposal or application. "Other resource use" is beneficial use of nutrients or other resources present in the sludge, for example through direct application to land, in compost, or the production of fertilizer or construction material. "Treatment footprint" is size of land required for treatment facilities. "Pathogen free" is where residual solids are free of pathogens, potentially allowing unrestricted application to land. Refer to Table 2 for description of technical routes 1 to 15.

Source: East Asia Department, ADB.

Until very recently, there were no clearly defined sludge technical routes that are applicable to specific local situations in the PRC. Even with the recent issue of the *National Technical Guidelines for Urban Sewage Sludge Treatment and Disposal (Trial)*, there is a need to enhance local knowledge in the choice of potentially suitable technical routes. The technical experience in sludge treatment and disposal already acquired through various applications and trials in the PRC, as well as the range of innovative technical routes employed internationally, need to be made more available to local authorities. A "clearinghouse" arrangement, similar to that used for the Global Environment Facility program on land degradation in the PRC might be appropriate.[12]

[12] The People's Republic of China–Global Environment Facility Partnership on Land Degradation in Dryland Ecosystems has established data sharing agreements among provinces and links to two international clearinghouses on methods and pilot studies on combating land degradation (Land Degradation Assessment for Dryland Areas, and World Overview of Conservation Approaches and Technologies).

Greater use of anaerobic digestion would reduce sludge volumes and greenhouse gas emissions, and mitigate the nuisance value (e.g., odors and vector content) of the sludge being transferred. MOHURD also sees a future for thermal hydrolysis to compound the benefits of anaerobic digestion in larger cities that have the most acute problems and the greatest financial and technical capacity.

Quality Standards, Supervision, and Monitoring

Environmental safety standards for sludge treatment and disposal need to be established and enforced to minimize risks to the environment and public health. Standards should specify limits to control the accumulation of persistent pollutants and cover product quality standards for sludge-derived products. However, the existence of quality standards alone is of little value if these are not adequately enforced. To date, the lack of integrity and effectiveness of regulatory systems related to sludge treatment, utilization, and disposal in the PRC has been a significant weakness.

Enforcement requires the establishment of a comprehensive regulatory system to ensure that the appropriate quality standards are strictly adhered to. Such a regulatory system should provide

- improved environmental impact assessment procedures during the preparation of sludge treatment, utilization, and disposal plans to predict and avoid adverse impacts on the environment;
- an independent third-party quality monitoring system for sludge to ensure the quality of sludge products and the services;
- an institutionally strong and technically capable supervision and management cadre for sludge collection, transport, treatment, utilization or disposal to ensure safe and reliable sludge collection, transport, and application;
- a manifest system for the transfer of sludge to facilitate effective supervision of the whole process from source, transport, and treatment to final utilization or disposal; and
- mechanisms by which local governments will take active source control measures to prevent possible damage to the environment caused by heavy metals, persistent organic pollutants (toxic organic substances), and other pollutants that could be present in sludge.

Tariffs and Financing Policies

As sludge management is accepted as an integral part of wastewater treatment, it is logical that user financing from levying wastewater tariffs should eventually become the principal financing mechanism, as is the practice in some developed countries. However, the current level of wastewater tariffs in PRC cities is generally insufficient to finance modern sludge treatment, especially where major sludge volume reduction is required.

Genuine financial sustainability of sludge treatment will only be achieved when user tariffs finance all or the majority of sludge management costs. International experience suggests that income from sludge products will only make a minority contribution. Government subsidies (most commonly subsidies for the construction of new infrastructure and/or transitional operational subsidies) are commonplace internationally; however, such subsidies conflict with green economy policies such as the "polluter pays" principle and the 3R waste policy. The study identified a clear trend toward the levying of full cost recovery wastewater tariffs that include provision for sludge treatment in several countries.

The levying of full cost recovery tariffs for sludge management in the PRC would be compatible with broader government economic policies—especially encouraging waste reduction. However, average disposable incomes in most cities are likely to make this a medium- to long-term goal with government subsidies needed in the meantime. Protection mechanisms to shelter disadvantaged groups from higher tariffs will be required, as well as alternative streams of financing.

To encourage the industrialization of the sludge sector and to broaden the sources of finance to reduce the reliance on government funding, appropriate sector economic policies are needed, including preferential policies for companies or individuals that use sludge-derived products. International experience suggests that energy recovery, especially digestion biogas utilization in power generation and dried sludge use in cement production, are potentially attractive processes for private sector investment.

There is also a lack of regulations and guidance on the form of accounting records and cost classification methodology for sludge treatment. This created major difficulties for the study in identifying and comparing the costs of sludge treatment using different treatment approaches and between different cities. Price regulators and potential investors will encounter the same difficulties until a standardized accounting and cost allocation method is developed and implemented.

Raising Public Awareness and Confidence

The debate over sludge recycling and disposal observed in many countries shows that uncertainties over possible risks to human health and the environment play a major role in the resistance to its wider use. Public confidence and support needs to be considered at two levels. Firstly, the national government needs to establish appropriate standards and regulations, which it should openly publicize. Secondly, at the project level it is necessary to demonstrate compliance with production and quality assurance

High quality of sludge products must be ensured to overcoming resistance to beneficial sludge utilization. Above, the Panggezhuang sludge composting plant in Beijing.
Source: AECOM 2010.

requirements. International experience suggests that the most effective means of allaying public concerns is for independent monitoring and regulatory enforcement to be carried out, and for details and results to be made public (Box 3). These approaches are equally valid in the PRC and should be incorporated into the national policy and regulatory framework.

Box 3 **Overcoming Resistance to Beneficial Sludge Utilization**

International experience suggests that resistance to beneficial sludge utilization is often a result of a lack of information, leading to distrust. Approaches to remedy this include the following:

- Establish a comprehensive and transparent legal framework with clearly defined sludge utilization practices, quality standards, application rates, etc. Ensure long-term stability of standards to facilitate development of sludge recycling routes.
- Ensure high product quality, and confirm it through independent monitoring.
- Involve different stakeholder groups, including sludge producers, regulators, users of sludge products (farmers, industry), consumer associations, and environmental nongovernment organizations in the development of local management plans.
- Enhance communication on sludge use, including setting up codes of practice, labeling sludge or sludge-derived products, and disclosing independent monitoring results.
- Conduct training programs for various categories of stakeholders, such as farmers, to increase their knowledge on the proper application of sludge and its benefits.

Source: East Asia Department, ADB.

Conclusion

The massive investment in wastewater collection and treatment systems in the People's Republic of China (PRC) has not been matched by complementary investment in sludge management. Consequently, while very significant improvements have been made in reducing surface and groundwater pollution emanating from urban areas, there is now a growing challenge to prevent secondary pollution resulting from inadequate systems for the management of sludge.

Asian Development Bank (ADB) policy dialogue reveals that the problem is well recognized by the relevant central government ministries, especially Ministry of Housing and Urban–Rural Development, the Ministry of Environment Protection, and the National Development and Reform Commission, and there is a strong determination to address the challenge. The need for effective sludge management was recognized in the *Plan for the Construction of Urban Wastewater Treatment and Reuse Facilities, 2006–2010*; and the equivalent plan covering the period to the end of 2015 gives much greater prominence to investment in sludge management facilities. Responsibility for the construction and management of urban infrastructure is now vested in city governments. This arrangement allows cities to respond to the local situation and priorities, provided they adhere to nationally established laws, policies, and economic plans.

The comparison of the current status of sludge management in the PRC with international best practice and emerging technologies and trends identified a number of principles and practices that might usefully contribute to improved sludge management in the PRC. In particular, the study has highlighted sludge as a resource, with opportunities for beneficial use that result in considerable environmental and energy saving benefits. It has also drawn attention to the potential significance of sludge treatment and utilization or disposal as a contributor of greenhouse gas emissions, and therefore the importance of including carbon footprint analysis in the evaluation of sludge management technical routes.

While the study was based solely on the sludge management situation in the PRC, many of the issues raised are potentially relevant to other ADB developing member countries that are facing increased urbanization, and highlight the need to develop a modern wastewater industry.

Promoting Beneficial Sewage Sludge Utilization in the People's Republic of China

Over the last 15 years, the People's Republic of China (PRC) has made rapid and sustained progress in constructing and operating state-of-the-art wastewater treatment plants. However, this success has brought with it the new challenge of how to manage the ever-increasing volumes of sludge in a way that does not create secondary pollution. This report examines best international practices in sludge management, analyzes the current situation in the PRC relative to this best practice, and suggests a pathway for the PRC to modernize its approach to sludge management. In particular, it highlights the trend toward viewing sludge as a resource with opportunities for beneficial use that result in considerable environmental and energy-saving benefits.

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