Sludge strategy for the People's Republic of China: *promoting sustainable solutions*

The People's Republic of China (PRC) has been developing its urban wastewater treatment, but is now facing the challenge of how to manage increasing volumes of sludge in a way that does not pollute the environment. **ANTOINE MOREL** and **PETER JAQUES** discuss the PRC's current situation and highlight international best practice with regards to sludge treatment and utilization.

The People's Republic of China (PRC) has made rapid and sustained progress over the last 15 years towards constructing and operating state-of-the-art urban wastewater treatment plants (WWTPs) to serve the country's around 700 cities, and this programme is extending to cover smaller urban areas, especially those located in environmentally sensitive areas. The priority objective was to halt environmental degradation of the country's inland watercourses, as well as its estuaries and coastline, and much has been achieved with the urban wastewater treatment rate reaching 75% in 2009. However, this success has brought with it a new challenge – how to manage the ever increasing volumes of WWTP sludge that is produced every day in a way that does not create secondary pollution.

This article explores the sludge maagement challenge faced by the PRC's wastewater industry. In doing so, the article examines best international practices in sludge management, analyses the current PRC situation relative to this best practice, and suggests a pathway for the PRC to follow in modernizing its approach to sludge management. It also identifies barriers and obstacles to overcome and discusses the positive role the national Government, most notably the Ministry of Housing and Urban-Rural Development (MOHURD) and the National Development and Reform Commission (NDRC), are playing to promote improved sludge management.

An underlying theme of the article is that sludge should be managed recognizing it is both a potential pollutant and a potential resource. Sludge is a resource as it is typically rich in nutrients (nitrogen and phosphorus) and high in organic content that allows for energy recovery. However, if not properly managed it can create significant environmental damage through uncontrolled greenhouse gas (GHG) emissions, contamination of land and groundwater, and odour nuisance, as well as having adverse public health impacts via the food chain if spread on arable land in an uncontrolled manner.

Information is drawn principally from the Urban Wastewater Reuse and Sludge Utilization Policy Study in the People's Republic of China[1], which was undertaken by AECOM Asia Ltd on behalf of MOHURD under the technical assistance programme of the Asian Development Bank (ADB). Although this study and article relate primarily to the Chinese situation, the issue of sludge management is undoubtedly relevant to any developing country faced with rapid urbanization, growing cities and increased sludge volumes.

International best practice of sewage sludge management

Drivers and trends

The international trend is to utilize treated sludge as a resource, rather than to simply dispose of it as an unwanted residual – alternative beneficial uses are being extensively explored and adopted. Drivers for increased sludge utilization are a lack of landfill space, increased costs and environmental concerns associated with sludge landfill and incineration, a ban on ocean dumping, the prohibition of the direct land application of raw sludge, and increased public environmental awareness. GHG emissions from sludge

Figure 1: Typical steps in the definition of a WWTP sludge management strategy

Step 1 - Establish project context	• Identify project objectives • Review stakeholders' needs
Step 2 - Establish basis of sludge strategy	• Assess current strategy, compliance with national and local policies / plans • Determine sludge production and characteristics
Step 3 - Identify options	• Identify sludge utilization options • Identify sludge treatment options
Step 4 - Define and implement strategy	• Multi-stakeholder assessment of options • Recommend and implement sludge strategy

The Beijing Panggezhuang sewage sludge composting plant treats 300 tons of dewatered sludge (80% moisture content) per day. Credit: Liu Shengbin.

processing, and increased emphasis on climate change mitigation, are becoming increasingly important in decisions on sludge treatment and utilization.

Sludge utilization applications

Sludge utilization is generally understood to be the use of dewatered and stabilized sludge for any beneficial use, instead of disposal at a landfill or incineration without resource recovery. Use of suitably treated sludge on land as a fertilizer or soil conditioner is the most common utilization practice. Other options include use as a construction material (e.g. in cement or brick manufacture), or as an alternative fuel (in the form of pellets or through carbonization). Recovering energy from sludge during the sludge treatment process is increasingly practiced, and may involve capturing and using biogas produced during anaerobic digestion of sludge, or energy recovered from high temperature treatment processes.

Treatment technologies

Treatment technologies used are determined by the planned utilization or disposal route. However, the general practice is for sludge to be stabilized and dewatered as a minimum level of treatment, even in less developed countries. Anaerobic digestion is the most common method of stabilization but lime stabilization and storage in stabilization ponds are also commonly used – especially in smaller WWTPs. A relatively new and increasingly favoured technology is the use of thermally assisted anaerobic digestion. Lime stabilization appears to be declining, being replaced by more modern technologies, as the resulting sludge is less marketable. Heat drying to reduce sludge volumes and reduce transportation costs is common for large WWTPs in developed countries, but is an energy intensive process and more carbon friendly approaches such as carbonization, gasification and pyrolysis are under active development, which could also replace the need for conventional sludge incineration in cities with inadequate land resources.

Planning

The maximization of sludge utilization requires systematic and integrated planning, as well as the careful evaluation of alternative approaches for utilization and treatment (see Figure 1). A trend of centralized treatment of dewatered sludge was observed, taking advantage of advanced technology and of economies of scale.

Regulatory frameworks and guidelines

Sludge policies and disposal / utilization standards are normally established at a national level and are established by law or directive. Where specific laws and regulations on sludge treatment, utilization and disposal do not exist, sludge is usually covered in other laws and regulations, such as compost quality standards, air emission standards for incinerators, industrial waste regulations, etc. In relation to sludge application to land, regulations and standards generally define allowable application practices and rates, and set limits for heavy metals, pathogens, and persistent organic pollutants. With regard to incineration, most regulations set emission levels for flue gas, and heavy metal concentrations for landfill of incineration ash.

Economic considerations

Government ownership and financing of wastewater and sludge infrastructure is still dominant in many parts of the world, although private sector financing is becoming more common. Sludge treatment is usually managed as part of wastewater treatment, and hence so too is its financing. Even where sludge is beneficially utilized, recurrent costs for sludge treatment are for the most part financed through wastewater tariffs collected, as sludge products rarely generate sufficient revenue. The level of cost recovery varies significantly, but there is a clear trend towards full cost recovery through wastewater tariffs, and the marketing of wastewater and sludge utilization. This trend is compatible with the 'polluter pays' principle, and with policies to encourage reductions in waste volumes and GHG emissions. Full cost recovery is undoubtedly the best practice if socially affordable.

Public concerns and the promotion of sludge utilization

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. 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. Many farmers are reluctant to use sludge on agricultural land due to the concerns over reduced crop yields or possible land contamination. Incineration also proves controversial

Table 1: Comparison of Chinese sludge management practices with international practices

Similarities	Differences
• Government environmental and waste management policies	• A very low percentage of sludge is adequately stabilized before disposal
• Sludge treatment and utilization is considered an integral part of wastewater management	• Sludge utilization and energy recovery levels are low
• High reliance on government financing, as wastewater tariffs are not sufficient to recover all the costs of sludge treatment.	• Supervision and regulatory enforcement of pollution control at the source are inadequate
• In the large cities there is the technical capacity to manage advanced solutions.	• Carbon footprint analysis is not performed in evaluating sludge management options
• Public awareness and confidence need to be improved	• Insufficient attention is paid to environmental impact and risk in sludge disposal / utilization
	• Institutional, planning and regulatory arrangements are immature

Table 2: Carbon footprints of 15 technical routes for sludge treatment and utilization (Source: AECOM Asia Co Ltd (2011)).

Ref	Technical route	Carbon footprint [t CO_2e per year]
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	1300
7	Composting, land application	2400
8	Heat drying, gasification, energy recovery	4750
9	Lime stabilization, land application	4900
10	Heat drying, incineration, heat recovery	5900
11	Lime stabilization, land application	6200
12	Anaerobic digestion, biogas utilization, landfill without landfill gas management	6300
13	Heat drying (65% moisture content), land application	7600
14	Heat drying (40% moisture content), land application	10,000
15	Landfill without landfill gas management	30,000

due to potential toxic gas emissions. Experience suggests the most effective means of allaying public concerns are independent monitoring and regulatory enforcement, and for details and results to be made publicly available. Public education based on independent expert opinion has also been shown to be effective.

What does the PRC need to do to aspire to best practice?

Whilst there are similarities between current PRC sludge management practices and typical international practices, there are also significant differences, some of which give rise to concern (see Table 1).

Several of the differences arise because the wastewater industry in the PRC is relatively new, and the overriding priority in the development of the industry was to tackle water pollution.

Sludge management was therefore largely ignored during the first decade of the industry's development. The PRC Government, especially MOHURD, NDRC and the Ministry of Environmental Protection (MEP), are conscious of the scale and potential seriousness of the sludge management challenge, and the most recent national five-year development plans call for major investment in improved sludge treatment. Shifting the emphasis from sludge disposal to beneficial utilization of sludge is compatible with broader government policies for sustainable urban development and to create a 'circular economy' built around the reduction, recycling and reuse of waste (the '3R' policy). Consideration of carbon emissions as a factor in selecting sludge management solutions is consistent with the PRC's international commitments to act on climate change mitigation.

The PRC is a vast country, with significant regional differences in climate, economic development and wealth, population density and social conditions, industrialization and land availability. Clearly sludge management has to take account of these local differences – there is no 'one solution fits all'. International experience confirms this but does give strong pointers on how sludge management in the PRC might be developed in accordance with government policy:

- Sludge management solutions should be built around a viable and sustainable means of utilizing or (as a last resort) disposing of the sludge
- Technical routes should be selected based on the preferred utilization / disposal approach
- Resources and energy from sludge should be recovered where this is economically viable
- Low carbon solutions should be sought wherever practical.

Alternative sludge technical routes

Carbon footprint analysis

The study investigated different, all well proven, sludge technical routes that are potentially suitable in the PRC, and evaluated the carbon footprints of these using the widely used UKWIR (UK Water Industry Research) methodology[2,3], and based on a typical urban WWTP treating 100,000m^3/day, producing 80t/day of dewatered sludge with 80% moisture content. The common current Chinese practice of landfill without landfill gas utilization was also included in the analysis. The CFP study produced a ranking of carbon footprints, with technical routes 1-5 considered 'carbon friendly', routes 6-9 considered 'mid-range', and routes 10-15 having high carbon footprints (see Table 2).

These results emphasize the importance of energy recovery in sludge processing as a means of reducing carbon footprints. Also, the wide range of carbon footprints suggests that carbon footprints should become a more important factor in defining sludge management strategies. The difference between routes 2 and 11 clearly indicates the benefit of anaerobic digestion as a means of stabilization prior to landfill. The results also show that high cost technology solutions are not needed to give a reasonable carbon footprint – although they may be needed for other reasons, such as the reduction of sludge volume. It should be noted that carbon footprint results for a given technical route will vary due to local factors and therefore carbon footprint analysis needs to be undertaken on a project-by-project basis, with assumptions and values adjusted to the local situation.

Assessment of alternative technical routes for sludge utilization or disposal

The study recognizes that carbon footprint is just one of several evaluation factors that need to be considered during sludge management planning. Availability of land for either application or disposal is traditionally the prime concern of sludge planners and remains at the forefront. Other factors include sludge volume, sludge quality (as this could determine whether a potential utilization is viable), costs, and local factors such as sludge market maturity, public perceptions and financial and technical capacity (for sustainable operations). A broader assessment of the attributes of the different potential technical routes was conducted.

That assessment indicates that where land application is viable then this utilization approach is likely to give the best balance of environmental benefit and cost. A route of anaerobic digestion, biogas utilization and land application performs especially well overall in this respect, but may not be suitable for big cities with large sludge volumes. Also, the treated sludge is not pathogen-free unless thermal hydrolysis precedes the anaerobic digestion, and this significantly increases both capital and operating costs.

Where land application is not viable, either because land is not available or the sludge quality is not suitable, then sludge utilization as a coal substitute should be explored. Gasification is an emerging technology that also shows promise under this scenario, but is high cost and not yet proven in large-scale facilities. In such circumstances the benefits of sludge utilization need to

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Biogas produced in anaerobic digesters in Hangzhou Sibao WWTP is converted to electricity onsite. The plant generates enough electricity to cover around 25% of the WWTP's current electricity consumption. Credit: Liu Shengbin.

be balanced against the high costs involved and, if judged uneconomic, then landfill has to be considered as a last resort.

Where landfill is deemed necessary, decisions need to be made on what pretreatment 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.

In developed countries, use of landfill for organic waste is strongly discouraged, or in some cases prohibited, and landfill costs are rising sharply. In the authors' opinion these trends are quite likely in the PRC and would be compatible with the Government's climate change mitigation commitments. Such trends would enhance the economic viability or regulatory necessity of heat drying in conjunction with incineration in cement kilns or new emerging technologies such as gasification, carbonization and pyrolysis.

It is also noteworthy that thermal hydrolysis is becoming more popular in developed countries, enhances energy recovery, and it is likely that costs will fall as the technology becomes more widespread. Its purpose is to enhance the performance of the downstream processes (in terms of energy recovery and dewaterability), and can be used in conjunction with any form of disposal or use of the residual solids.

Barriers to overcome

Whilst sludge treatment in the PRC is relatively new, the main barriers are not only technical capacity and economic factors, but also concern institutional shortcomings and low public awareness and confidence. Sustainable sludge management requires quality assurance and public confidence in the safety of sludge and sludge-based products. Effective pollution control at the source is fundamental to providing such quality assurance, but enforcement is sometimes lacking. Awareness of the benefits of sludge utilization and adoption of low carbon solutions needs to be improved amongst local government officials, the wastewater industry, potential users of sludge products, and the public at large. Local governments, industry experts and academics in the field all need to make a positive contribution to achieving this goal.

Relative to developed countries, institutional arrangements for sludge management in the form of detailed polices and regulations, planning and other guidelines, and the allocation of institutional responsibilities, are currently immature in the PRC. This creates uncertainty at a local government level and often discourages positive and coordinated action on sludge management. Fortunately, this major obstacle is well recognized within central government, especially MOHURD and NDRC, and action is in hand to provide greater direction and guidance to assist local governments. The study has supported this process.

In conclusion

The drivers for a changed and modern approach to sludge management in the PRC are undoubtedly the rapidly increasing sludge production, the growing scarcity of landfill resources, and the need for sustainable and climate friendly solutions to development challenges. Central Government, via MOHURD, NDRC and MEP, is taking the lead to address the sludge management challenge by including sludge treatment in relevant national economic sector development plans and by developing and promulgating national policies, standards and guidelines[4,5].

The '11th Five-Year Plan of the Construction of Urban Wastewater Treatment and Reuse Facilities' (2006 to 2010) prepared by NDRC, MOHURD and MEP had defined the basic principle of sludge planning, i.e. 'design of sludge facilities should be a part of the design of wastewater treatment facilities, and sludge facilities should be built together with wastewater treatment facilities'. The plan made it clear that the safe disposal and beneficial unitization of sludge is one of the key tasks in the development of urban wastewater treatment facilities. The study has contributed to the preparation of the 12th Five-Year Plan of the 'Construction of Urban Wastewater Treatment and Reuse Facilities' (2011 to 2015), which reinforces the need for the development and implementation of sustainable sludge management strategies at city level.

However, it is local governments who are responsible for drawing up sludge management plans and implementing them within the framework provided by the national government. Key actions for local government include:

- Drawing up or updating their sludge master plans in a coordinated and collaborative manner, paying close attention to environmental impact and risk
- Encouraging greater sludge utilization and energy recovery, whilst discouraging high carbon solutions
- Promoting improved public awareness and public confidence in sludge products
- Exploring diversified financing channels and a socially responsible approach to user tariffs that protects the poor, whilst encouraging waste reduction

International experience suggests that the PRC's sludge management challenge can be overcome and offers potential solutions that can be adapted for use in the country. ●

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