International Journal of Sustainable Development & World Ecology 15 (2008) 231–239
DOI 10.3843/SusDev.15.3:6

Developing the circular economy in China: Challenges and opportunities for achieving 'leapfrog development'

Yong Geng[1] *and Brent Doberstein*[2]

[1]Institute for Eco-planning and Development, School of Management Building, Dalian University of Technology, Dalian, China
[2]Department of Geography, Faculty of Environmental Studies, University of Waterloo, Waterloo, Ontario, Canada

Key words: Industrial ecology, eco-industrial development, ecological modernisation, recycling, capacity building

SUMMARY

China is pioneering a new sustainable development model which has the ability to overcome current environmental and resource management problems, while achieving improvements in resource productivity and eco-efficiency. This model, formally accepted in 2002 and termed the 'circular economy', is understood to mean the realisation of a closed loop of material flows in the Chinese economic system. Successful implementation of this model is seen as one way in which China can 'leapfrog' past environmental damage that is typically seen as economies industrialise. This paper introduces the development of the model in China, and presents the current situation of circular economy practice in China. The paper describes current measures being implemented in China for the long-term promotion of a circular economy, including the formulation of objectives, legislation, policies and measures, so that the country can 'leapfrog' its way from environmentally-damaging development to a more sustainable path. The paper then identifies a series of barriers and challenges to the implementation of the concept in China. Finally, conclusions on the future of the circular economy concept are drawn. Data were derived primarily from an analysis of secondary sources (i.e. previously published papers). Additional primary data derived from the main author's personal involvement in several circular economy initiatives were also employed.

INTRODUCTION

The concept of industrial ecology or eco-industrial development (EID) has become globally popular, both academically and practically. Perhaps the most famous application of the concept is the Kalundborg industrial complex in Denmark (Desrochers 2001; Jacobsen 2006). Although EID has been most vigorously pursued in industrialised countries such as Japan, Belgium, Germany, Sweden, Denmark and the former USSR (Erkman 1997; Yuan *et al.* 2006), industrial ecology is at least as relevant for developing countries. In many cases, eco-industrial development is seen to be more

Correspondence: Yong Geng, National Institute for Environmental Studies, 16-2 Onogawa, Tsukuba, Ibaraki 305-8506, Japan. E-mail: ecoplan@dlut.edu.cn

urgently needed and effectively applied in developing countries, many of which are facing severe constraints on the availability of resources (Erkman 2001; von Hauff and Wilderer 2000). China, as the most populous developing country, is now facing many resource supply and waste assimilation challenges, including land degradation, desertification, acid rain, deforestation, water resource depletion, greenhouse gas emissions, and loss of biodiversity (Jie and Nianfeng 1995; SEPA 2005). With the prospect of further rapid urban and industrial growth under China's current model of economic development, environmental conditions are expected to worsen in the near future. Under these circumstances, China urgently needs a new sustainable development model which has the ability to overcome the current dilemma and 'achieve improvements in resource productivity and eco-efficiency' (Yuan *et al.* 2006: 7). This model, formally accepted in 2002, has been termed the 'circular economy' (Ren 2005; Yuan *et al.* 2006), and is seen as one way China can 'leapfrog' past the environmental damage typically seen as economies industrialise.

The circular economy concept has its origins in EID, which is based on the idea that a healthy economy and environmental health can coexist. EID offers an 'invitingly concrete' way to integrate environmental management and meet environmental, economic and community development goals (Chertow 2000). EID provides strategies to achieve greater efficiency through 'economies of systems integration', whereby partnerships between businesses meet common service, transportation and infrastructure needs, and the concept adds value to businesses and communities by optimising the use of energy, materials and community resources (Ayres 1994; Levine 2006). At a theoretical level, the circular economy model fits closely with ecological modernisation theory which is 'centrally concerned with the relationship between industrial development and the environment' (Murphy and Gouldson 2000: 33). With the promise of EID understood, and with a significant array of conceptual and theoretical guidance already available, the Chinese Government has decided to adopt the circular economy as the national development model piloted across the country.

The Chinese people have chosen to use the term 'circular economy' as the working language of EID. The terminology may not be very familiar to Western readers, but in China it is understood to mean the realisation of a closed loop of materials flow in the whole economic system. Different from the traditional linear production model, a circular economy approach encourages the organisation of economic activities with feedback processes which mimic natural ecosystems through a process of 'natural resources → transformation into manufactured products → byproducts of manufacturing used as resources for other industries.' In essence, the circular economy approach is the same as the more familiar terms EID and 'industrial ecology', and fits comfortably within a broad range of ecological modernisation initiatives pioneered around the world.

This paper introduces the development of the circular economy concept in China. Data were derived from an analysis of secondary sources (i.e. previously published Chinese and English papers), and additional primary data were obtained through the main author's personal involvement in several circular economy initiatives. The paper first presents the current situation of circular economy practice in China; it then identifies barriers and challenges to the implementation of a circular economy. The main focus is to describe how decision-makers in China make appropriate plans for long-term promotion of a circular economy, including formulation of objectives, policies and measures, so that the country can 'leapfrog' its way from environmentally-damaging development to a more sustainable path. Finally, several conclusions on the future of the circular economy concept are drawn.

CURRENT PRACTICE: IMPLEMENTING THE CIRCULAR ECONOMY IN CHINA

The Chinese circular economy concept comes originally from Germany and Japan, where there was a desire to form a more closed loop society (Wang *et al.* 2004). It advocates that economic systems could and should operate according to the materials and energy cycling principles that drive natural systems. These include ecosystemic self-sustaining properties, through the recycling of essential materials and energy, the capacity for one organism's wastes to be used as a resource by another organism, and through self-organisation capacities. Competition between different species is intense, and, in part, helps in the dynamic

development and change of ecosystems. Such a natural metaphor can and should be applied to economic ecosystems, where different companies locate within the same geographical area, share common infrastructure and services, and compete for resources and, ultimately, economic survival. In implementing the circular economy concept, industrial ecosystems can be created which feature byproduct exchanges between different firms, increased business interdependencies, reduced business risks, reduced pollution and, possibly, improved public images. This concept has special value in China, where resource waste and unintended environmental outcomes have impeded the country's rapid development. Consequently, the circular economy concept has been adopted by the Chinese Government as a main part of national scientific development strategy (Yuan *et al.* 2006: 5).

Academically, research activities related to the circular economy have been widely implemented since the formal acceptance of the concept in China in 2002. With funding provided by governments at various levels, both theoretical and applied studies have been undertaken. For example, scholars have published their research outcomes on how to stipulate appropriate policies to promote the circular economy (Gao *et al.* 2006; Ren *et al.* 2005; Wang and Wu 2004; Xie 2004; Yuan *et al.* 2006). These studies suggest that governments should play a leading role in promoting the concept by reforming existing laws, enacting new regulations, promoting the application of new environmental technologies, and organising public education. Research and development efforts related to the circular economy have been supported by both government and the corporate world. Areas of R & D application include fuel cells, clean and renewable energy, water and energy saving technologies, eco-industrial park planning, process integration, green building, reverse logistics, waste minimization, eco-design and others (Gao *et al.* 2006; Zhao *et al.* 2003). Moreover, in order to measure the performance of circular economy applications, research projects related to the development and use of quantitative indicators have been carried out. By measuring separately quantitative measures of economic, environmental and social performance (Li *et al.* 2004; Lu *et al.* 2003), practitioners will be able to create a roadmap towards overall eco-efficiency and a circular economy.

In a practical sense, the circular economy is implemented through so-called 'three circles'. The first circle includes a suite of corporate-level (micro-level) initiatives such as eco-design of manufacturing plants, waste minimisation, cleaner production and environmental management systems (EMS). To date, cleaner production has been the most significant and successful activity at the micro-level of the circular economy. With the enactment of China's Cleaner Production Promotion Law in January 2003, the cleaner production concept has been accepted as a new reality by corporations across the country. To date, cleaner production demonstration projects have been implemented in 24 provinces, involving a diverse range of industrial sectors, including chemical, construction materials, petrochemicals, pharmaceuticals, machine manufacturing, mining, textiles, power plants, metallurgical industry, light industry, transportation and electronic industry. In order to promote this concept, one national cleaner production centre, four industrial sector cleaner production centres (i.e. petrochemicals, chemicals, metallurgical industry and plane manufacturing), and 11 local cleaner production centres have been established. Such centres have hosted 550 training programmes and over 16,000 persons have been trained (Wang 2004a). In addition, the amended law on pollution prevention and control of solid wastes has been in effect since April 1 2005. This law further required companies to manage their solid wastes and to minimise total wastes (Yuan *et al.* 2006).

The second circle is at the inter-firm level (meso-level), where eco-industrial parks (EIPs) have been initiated in order to capitalise on the trading of industrial byproducts such as heat energy, wastewater and manufacturing wastes (Yuan *et al.* 2006). In order to promote the development of EIP projects, the State Environmental Protection Administration (SEPA) has released national guidelines on EIP (Wang 2004b). This outlines the Chinese method of planning EIPs, emphasising the establishment of integrated material, water and energy management systems at the industrial park level. This integrated approach encourages the creation and maintenance of eco-industrial networks among tenant companies. By supporting green supply chain management and reverse logistics (i.e. everything from recycling or redesigning packaging materials to reducing the

energy and pollution caused by product delivery (Rogers and Tibben-Lembke 1998)), industrial park managers can achieve their targets of minimising overall wastes, while maximising the efficiency of resource use.

It should also be noted that China's industrial parks have dual functions as both production and residential areas. A typical Chinese industrial park has an industrial production area, a scientific research area, a residential area and a business and service area, which is different from the North American model where industrial parks are predominantly manufacturing-based (Geng and Côté 2003). Consequently, the EIP guidelines encourage EIP planners to incorporate both industrial and residential considerations into their plans, advocating that an EIP proposal should include an emergency response plan and a community eco-education plan in order to increase local capacities to respond to emergencies. The guidelines also require establishing a specific EIP working group to coordinate the implementation of EIP plans and create forums where all stakeholders can reflect their opinions.

Following the release of the new guidelines, the EIP concept has become popular nationally. Yuan *et al.* (2006) found that over 100 industrial parks have been guided by EIP principles. Out of these, 16 EIP projects have been chosen as national EIP demonstration projects by SEPA, in order to present a variety of development models for other regions and industrial sectors, and to summarise relevant experiences and lessons.

The third circle of the circular economy concept is at the social level (macro-level). Typical activities include the development of eco-cities and eco-provinces. City governments, including Shanghai, Hangzhou, Yangzhou and Guiyang, and the provincial governments of Liaoning, Hainan, Jiangsu and Jilin have established their plans for constructing an eco-city or an eco-province (Lowe and Geng 2003). Different from the first two levels, this level attends to both production and consumption concerns. From a production point of view, the circular economy concept encourages the establishment of regional eco-industrial networks, and seeks to create a circular society by optimising material use eco-efficiency. 'Scavenger' companies, which perform waste recovery, reuse, repair and remanufacturing functions, and 'decomposer' companies, which enable recycling by breaking down complex wastes into reusable organic, metal, plastic and other components (Geng and Côté 2003), are being promoted by local governments. Preferential industrial recruitment and financial policies (such as low rents for land and low interest loans) are being drafted in order to facilitate the operations of such companies. From a consumption viewpoint, the circular economy concept encourages the creation of a conservation-oriented society, seeking to reduce both total consumption and waste production. Both individuals and governments are encouraged to reduce the impacts of consumption, aiming to guide consumers away from wasteful forms of consumption in favour of energy preservation and environmental protection in their daily life. For example, urban residents are now given the choice of having agricultural products in the supermarket that have not been sprayed with pesticides. Some industrial products, like recycled paper, have been labelled as 'green products', while the production of environmentally unfriendly products, such as refrigeration equipment with CFCs (chlorofluorocarbons), will have been phased out by 2007 (World Bank 2005).

BARRIERS AND CHALLENGES

Although many achievements have been made, there are still many barriers and challenges to the promotion of a circular economy in China. Such barriers and challenges may be categorized into three groups: 1) policy; 2) technology and 3) public participation.

Policy barriers and challenges

From a policy perspective, China's legal system as a whole does not currently create a unified platform for promoting the circular economy. The fragmented regulation system often works against such innovations. For example, some of China's current tax regulations discourage enterprises and the public from reusing or recycling resources. Resource taxes in China are very low, which means in many cases that raw materials are so cheap that industries prefer to purchase virgin raw materials rather than recycled alternatives that sometimes require additional, sometimes costly, processing. Such a reality does not provide an economic incentive for companies to purchase 'second hand' materials.

Other policy-level problems exist. For example, all Chinese companies need to pay a corporate

value-added tax. In some cases, where recycled materials are actually *cheaper* than virgin resources, production costs are relatively low, yet the proportion of value-added is higher than other companies, resulting in the need to pay higher corporate value-added tax (Mao and Kang 2005). Under this scenario, companies again prefer to use virgin materials. Another example comes from China's current industrial pollution emissions policy. Currently, the fees charged for effluent discharges are too low to compensate for or mitigate environmental losses. Consequently, most companies prefer to simply pay the required fees to discharge their effluent directly to local ecosystems, rather than investing in anti-pollution controls. In addition, the enforcement of environmental regulations is not very efficient due to a lack of qualified personnel and budget. Many local officials are focused mainly on short-term economic benefits and regard rapid industrial development as their main political contribution. Under such circumstances, companies typically discharge their wastes directly, rather than seeking potential buyers of waste byproducts or installing pre-treatment equipment, thus further reducing corporate enthusiasm to develop environmentally friendly technologies and products.

Another policy challenge relates to 'consumption taxes' which have been used by the Chinese Government to regulate and control consumption behaviour. Currently, only 11 items are subject to consumption taxes (e.g. petrol, diesel and automobiles) and thus the ability of such taxes to have direct or indirect impacts on reducing pollution is limited. By contrast, many other products which also pollute the environment are exempt from consumption taxes (e.g. batteries, coal, fertilisers and pesticides) (Ren *et al.* 2005). These tax loopholes discourage the development of a nationwide and systematic public attitude toward green consumption.

Scavenger and decomposer companies do not currently have the capacity to develop new fields, in part because stimulative policies (such as government subsidies and low-interest loans) are not available. Also, due to lack of detailed policies on officially permitted reused and recycled materials, many emerging recycling enterprises have created environmental concerns even though they are ostensibly 'recycling'. The well-publicised environmental problems caused by China's largely unregulated e-waste recovery sector (Pucket *et al.* 2002; Tong and Wang 2004) is perhaps the best known example of this (e.g. heavy metals leaching into groundwater and dioxin/furan release from plastic incineration for copper wire recovery). From the examples given above, it is clear that policies encouraging green production, technologies and consumption are still lacking.

Technology barriers and challenges

Science and technology are key components of a circular economy. New academic achievements in environmental science and environmental technologies, such as those which have contributed to the fields of eco-design, cleaner production and life cycle assessment, will help revolutionise the related fields of biotechnology, information technology and materials science (Chen and Bacareza 1995). This revolution will then help to green industry by achieving the same industrial output while using less energy and fewer raw materials at reasonable cost while producing less pollution. Without the application of such state-of-the-art technologies, it is unlikely that enterprises will be able to improve their eco-efficiency and reduce their total emissions. However, this will not automatically happen in China. Demand for environmentally superior technologies is still weak, and both technical capabilities and financial resources are inadequate, with the result that levels of pollution and energy consumption are outpacing economic growth (Banks 1994). While transfers of technologies from developed countries to China are possible, they are unlikely to be implemented or sustained because, typically, there is a lack of appropriate training and financial resources (Geng and Wu 2000).

In particular, when developing the circular economy, information is needed for effective planning and management, including the creation of scenarios for optimal reduction, reuse and recycling. Every corporate enterprise, from a small business to a large multinational corporation, is part of a larger economic system or web. Companies are interlinked via increasingly complex supply chains. Therefore, an information system adopting a systems approach is required if decision-makers are to find more environmentally and financially beneficial ways to plan and manage their resources. However, such systematic information systems are rare in China. In most cases, accurate information is not available to decision-makers, or is not

conveyed in a timely manner. Moreover, due to fragmented management frameworks, different kinds of information often belong to different agencies. For example, environmental protection agencies maintain control over emissions data while economic development agencies usually collect and control data related to economic performance. Critically, neither of these agencies is subordinate to the other, and cross-agency collaboration is still rare, with the result that neither agency can play a leading role nor collaborate in providing such information to the corporate world.

Public participation barriers and challenges

Public participation is very important for implementing a circular economy, due to both the complex nature of the concept, and the array of potential contributions that more than one billion Chinese consumers can make. In implementing the concept, there is a need to better manage natural resources, to assure fair and equitable allocation of different resources, and to protect the environment; all of which require full support of all stakeholders (i.e. industrial managers, government officials, staff of research institutions, community and financial organisations). Without broad public involvement, it will be difficult to coordinate their contributions toward the circular economy.

Currently, China lacks the human and institutional capacities to encourage public participation in a circular economy. Environmental management programmes and facilities at many Chinese academic institutions are limited. Most government officials lack a sophisticated understanding of environmental principles. Industrial enterprise managers, usually schooled in production/output activities, lack an appreciation of the benefits of a circular economy. Professional accreditation requirements and processes on eco-industrial parks or eco-regions are not well defined or managed. Also, awareness-raising activities related to the circular economy concept (including TV promotions, newsletters and workshops) should be carried out periodically in order to build understanding, since such initiatives can provide forums at which experiences from different parts of the world and from different institutions could be objectively reviewed and lessons drawn from these combined experiences. These activities can also create opportunities for stakeholders to strengthen their mutual understanding and friendship, which will be the solid foundation for further collaboration on promoting a circular economy. Due in large part to the relative infancy of the circular economy concept, such activities are still lacking. One exception was reported in Gao *et al.* (2006), where educational activities of the Hai Hua Circular Economy Pilot Zone (HHCEPZ) are detailed.

Generally, capacity building is needed in order to directly address the needs and create the overall conditions for the circular economy. Such capacity building should be conceived as a long-term process, with clearly enunciated short-, medium- and long-term goals which can be evaluated periodically. The capacity needs at various levels of circular economy implementation should be specifically considered. Also, better communication, the exchange of information and extensive interactions between different stakeholders and levels are essential requirements for any successful capacity building process. Moreover, functional eco-industrial networks are an effective way to complement traditional technical assistance. Government agencies at various levels should take the leadership role in this process, but one large barrier will be an anticipated unwillingness to prepare innovative public participation programmes on implementing the circular economy.

CURRENT INITIATIVES AND FUTURE PLANS

Considering China's large size and population, and its unbalanced regional development, it is unrealistic to initiate the circular economy concept in all sectors and regions at the same time. A systematic iterative approach that considers Chinese realities will be preferable. Such an approach will first start key projects within key areas and help the country to leapfrog the worst effects of industrialisation. By carrying out pilot studies, the government will collect relevant experiences and lessons, and learn from implementation, in order to set up national regulations and standards and promote the concept to new industrial sectors and regions. In fact, the Chinese Government has recognised the value of such an approach and has initiated some efforts: the State Council and National Development and Reform Committee (NDRC) drafted the first circular economy workplan on October 27, 2005, jointly

with other relevant ministries, including SEPA, the Ministry of Science and Technology, Ministry of Finance, Ministry of Commerce and the National Statistics Bureau (NDRC 2005). Under this workplan, demonstration projects at different levels, with different industries and in different regions are being initiated.

At the enterprise level, 42 companies across the country have been chosen as national circular economy demonstration enterprises, including those in industrial sectors ranging from steel and iron, metal manufacturing, coal excavation and processing, to power generation, chemicals, construction materials and light industries. The main objectives of this phase of implementation are to:

- Seek suitable development models for the corporate world;
- Identify key technologies for promoting the circular economy and key investment fields;
- Study potential linkages between relevant industries for building up industrial symbiosis clusters;
- Set up indicators for evaluating corporate eco-efficiency; and
- Prepare appropriate policies to encourage reduction, reuse and recycling.

Seventeen of the 42 projects are recognised as establishing key priorities for promoting a circular economy. This includes six projects in the area of establishing comprehensive resource recovery and reuse systems, six projects for reusing waste metals, three projects for the collection and reuse of waste home electronic appliances, and two projects for re-manufacturing. The aim of this subset of projects is to establish and perfect resource recovery networks, identify appropriate treatment methods, explore how to extend the producers' responsibility in different areas, and prepare relevant policies.

At the industrial park level, 13 industrial parks have been chosen as pilot parks for the circular economy. Types of industrial parks include economic and technological development zones, chemical industrial parks (Gao *et al.* 2006), agricultural industrial parks, high-tech zones and metallurgical industrial parks. With these projects, the NDRC will attempt to find the most appropriate approach to retrofitting traditional industrial parks as ecosystems, thereby optimising the use of different resources and reducing the overall wastes of the whole park. The main objective of this project is to determine how to set up recruitment requirements in order to form industrial symbioses among tenant companies, how to avoid the allocation of overly large parcels of industrial land, and how to encourage efficient district heating and minimise the total wastes at industrial park level.

Finally, at the regional level, three provinces (Liaoning, the largest heavy industry province in China, Shandong and Jiangsu), and seven cities (including Beijing, Shanghai, Ningbo, Hebi, Guiyang and Chongqing) have been selected as circular economy demonstration regions. The aims of this level of activity include the establishment of regional circular economy assessment indicators, regional policies on promoting the circular economy, development of effective encouragement mechanisms, and development of methodologies on how to develop an environmentally friendly society with resource-saving features.

In implementing these projects, expert committees have been established in order to provide technical support at each level. Financial support has been guaranteed with the involvement of the Ministry of Finance, including low-interest loans, tax reductions, and research and development funds. All leaders of demonstration projects are asked to prepare a detailed workplan for national experts to review, including their objectives and goals, key activities, financial plan and schedules. Then, an expert committee will check the implementation outcomes at different stages and summarise the relevant experiences and lessons. For these key projects, the national development fund will be used, based upon the committee's evaluation results. Lastly, a systematic report on promoting the circular economy concept in China will be produced once all the demonstration projects end. This report is anticipated to be the single most useful reference source for stipulating national law on the circular economy.

CONCLUSIONS

Industrialisation is an important driving force for the Chinese Government to develop their economy. But industrialisation under past models has also brought serious negative environmental impacts to the country. This crisis suggests that sound industrialisation policies are of paramount importance, and calls for smart management of resources and the adoption of a more environmentally responsible development strategies. This

paper suggests that the circular economy provides a feasible way for governments to seek more sustainable forms of development by increasing the overall eco-efficiency of economic systems. By adopting circular economic policies, China has the potential to leapfrog past the environmentally-damaging development path that the developed world has historically taken. Poverty rates in local communities that benefit from such a green revolution will also be reduced as a result of applying the principles of the circular economy. Although a circular economy is not a panacea and does not offer a complete solution, it can at least provide support to efforts to minimise dependence on external resources and reduce harmful local emissions, which is appropriate for China with its low resource base and a heavy population burden.

ACKNOWLEDGEMENT

This research was funded by the Natural Science Foundation of China (70772085), the Fok Ying-Tung Education Foundation (104001) and the National Institute for Environmental Studies, Japan.

REFERENCES

Ayres RU. *Industrial Metabolism: Theory and Policy. in Industrial Metabolism: Restructuring for Sustainable Development*. Tokyo, Japan: United Nations University Press; 1994

Banks RD. How to Spur the "Greening" of Industry in Rapidly Industrializing Countries. *Industry and Environment* (UNEP IE) 1994;17:42–4

Chen X and Bacareza LB. Application of Economic and Regulatory Instruments for Environmental Management in Asian Industrializing Countries. *Industry and Environment* 1995;18:16–20

Chertow MR. Industrial Symbiosis: Literature and Taxonomy. *Annual Review of Energy and the Environment* 2000;25:313–37

Desrochers P. Cities and Industrial Symbiosis: Some Historical Perspectives and Policy Implications. *Journal of Industrial Ecology* 2001;5:29–44

Erkman S. Industrial Ecology: an historical view. *Journal of Cleaner Production* 1997;5:1–10

Erkman S. Industrial Ecology: a New Perspective on the Future of the Industrial System. *Swiss Medicine Weekly* 2001;131: 31–8

Gao C, Hou H, Zhang J, Zhang H and Gong W. Education for regional sustainable development: experiences from the education framework of HHCEPZ project. *Journal of Cleaner Production* 2006;14: 994–1002

Geng Y and Wu CY. Designing and Operating Eco-Industrial Parks in China. *Journal of Central South University of Technology* 2000;6:12–15 (in Chinese)

Geng Y and Côté R. Environmental Management System at the Industrial Park Level. *Environmental Management* 2003;31:784–94

Jacobsen NB. Industrial symbiosis in Kalundborg, Denmark: a quantitative assessment of economic and environmental aspects. *Journal of Industrial Ecology* 2006;10:239–55

Jie T and Nianfeng L. Some problems of ecological environmental geology in arid and semiarid areas of China. *Environmental Geology* 1995;26:64–7

Levine SH. Comparing products and production in ecological and industrial systems. *Journal of Industrial Ecology* 2006;7:33–42

Li J *et al.* Study on Evaluation Index of Circular Economy-Oriented Enterprise Performance. *China Population, Environment and Resources* 2004; 14:121–5 (in Chinese)

Lowe E and Geng Y. *Gongye Shengtaixue He Shengtai Gongyeyuan. (Industrial Ecology and Eco-Industrial Park)*. Beijing: China Chemical Industry Press; 2003 (in Chinese)

Lu YT *et al.* Research and Application on a Sustainable Development Index in China. *Nature Ecological Conservation* 2003;11:17–22 (in Chinese)

Mao P and Kang SY. Building up a Circular Economy Model with Chinese Characteristics. *Green Economy* 2005;4:56–60 (in Chinese)

Murphy J and Gouldson A. Environmental policy and industrial innovation: integrating environment and economy through ecological modernization. *GeoForum* 2000;31:33–44

NDRC. *Organizing the first National Circular Economy Demonstration Projects*. Beijing: NDRC Official Document; 2005:2199 (in Chinese)

Puckett J, Byster L, Westervelt S *et al. Exporting Harm: The High-Tech Trashing of Asia*. Seattle WA: BAN/SVTC (Basel Action Network/Silicon Valley Toxics Coalition) http://www.ban.org/E-waste/technotrashfinalcomp.pdf; 2002. Accessed May 19 2006

Ren Y *et al.* Policy and Legal Framework for Promoting a Circular Economy in China. *China Population, Resources and Environment* 2005;15:131–6 (in Chinese)

Ren Y. Policy and Law Framework for Circular Economy in China. (English translation of Chinese paper in *China Population, Resource and Environment*). http://www2.minambiente.it/Sito/settori_azione/pia/docs/ce_3R_03_10_05/yong_policy_law_china.pdf; 2005. Accessed May 19, 2006

Rogers DS and Tibben-Lembke RS. *Going Backwards: Reverse Logistics Trends and Practices.* Reverse Logistics Executive Council, Center for Logistics Management. University of Nevada, Reno; 1998

SEPA. *China's Annual State Environmental Report 2005.* Beijing: State Environmental Protection Agency Official Document; 2005 (in Chinese)

Tong X and Wang J. Transnational Flows of E-Waste and Spatial Patterns of Recycling in China. *Eurasian Geography and Economics* 2004;45:608–21

von Hauff M and Wilderer MZ. *Eco Industrial Networking: A practicable approach for sustainable development in developing countries.* Presentation at the Helsinki Symposium on Industrial Ecology and Material Flows. Helsinki. 31 August–September 3; 2000

Wang H *et al.* Learning Necessity of Setting up a Circular Economy from Chinese Pollution Control Data. *Pollution Control* 2004;10:26–9 (in Chinese)

Wang SY and Wu Y. Legal Reflections on Promoting Circular Society Development in China. *Environmental Protection* 2004;1:9–12 (in Chinese)

Wang Y. Cleaner Production in China. *Yunnan Environmental Science* 2004a;23:26–9 (in Chinese)

Wang YQ. How to Promote a Circular Economy in Environmental Protection Departments. *Environmental Protection* 2004b;9:3–7

World Bank 2005. Protecting the Ozone Layer: China and Venezuela Ban Dangerous Chemicals. http://web.worldbank.org/WBSITE/EXTERNAL/COUNTRIES/LACEXT/VENEZUELAEXTN/0,,contentMDK:20289363~menuPK:331773~pagePK:141137~piPK:141127~theSitePK:331767,00.html; 2005. Accessed May 19, 2006

Xie ZH. Reflections on Circular Economy Theory and Policy. *Environmental Protection* 2004;1:3–8 (in Chinese)

Yuan ZW *et al.* The Circular Ecology: A New Development Strategy in China. *Journal of Industrial Ecology* 2006;10:4–8

Zhao P *et al.* Research on Establishing Circular Economy Systems in China. *Urban Environment and Urban Ecology* 2003;16:17–19 (in Chinese)