Progress towards a Circular Economy in China:  
The drivers (and inhibitors) of eco-industrial initiative

John A. Mathews* and Hao Tan**1

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* Eni Chair in Competitive Dynamics and Global Strategy  
LUISS Guido Carli University  
Viale Romania 32   00197 Roma   Italy  
Email jmathews@luiss.it

** Research Lecturer  
School of Management, University of Western Sydney  
Parramatta, Sydney NSW 2150  Australia  
Email H.Tan@uws.edu.au or haotan1@gmail.com

1  The first version of this paper was developed when Hao Tan was at Macquarie Graduate School of Management, Macquarie University, as a Research Associate.
Abstract

Eco-industrial initiatives, that close industrial loops by turning wastes at one point in a value chain into inputs at another point, are attracting growing interest as a solution to the problem of sustainability of industrial systems. While Germany and Japan have undoubtedly advanced farthest in building recycling incentives into their industrial systems, and sought competitive advantage from doing so, China is arguably taking the issue even farther (in principle) through its pursuit of a Circular Economy, now enshrined in law as an official national development goal. In this paper we review a number of the eco-industrial initiatives taken in China, and compare them using a common graphical representation with comparable initiatives taken in the West and elsewhere in East Asia. Our aim is to demonstrate some common themes across the case studies such as the transformation from the former linear economy to a circular economy and the evolutionary processes in which dynamic eco-linkages are gradually established over time. We discuss the drivers of these eco-industrial initiatives as well as the inhibitors, setting the initiatives in an evolutionary framework and introducing a notion of Pareto eco-efficiency to evaluate them. We make the argument that China might be capturing latecomer advantages through its systematic promotion of eco-industrial initiatives within a Circular Economy framework.

Keywords: circular economy; China; eco-industrial initiative; eco-industrial parks; Pareto eco-efficiency; linear economy; Kalundborg; Kwinana; Ulsan; Kawasaki
Introduction

The literature on industrial ecology (IE) is concerned at the macro level with bringing the industrial economy and the environment – or the economy and its natural limits – into some form of harmony, and at the micro level with the identification and analysis of a wide variety of ‘eco-industrial initiatives’ that reduce the energy and resource intensity of industrial activities, largely through converting wastes from one process into inputs to another industrial process. At the macro level the IE literature is concerned with identifying the processes through which this grand harmonization between industrialization and its natural limits may be effected, and the kinds of measurement indices that might be used to plot progress (or lack of progress) in approaching such a goal. At the micro level the IE literature identifies cases of synergistic interactions between firms, or industrial symbioses, through which wastes are converted into inputs, on the biomimetic model of the great natural cycles that have evolved on planet Earth. The literature has identified certain canonical cases of such industrial symbiosis, including Kalundborg in Denmark (Jacobsen 2006), and emerging cases such as Kwinana and Gladstone in Australia (Van Beers et al. 2007), and now increasingly, cases from China.

The China cases are the subject of this article. The eco-initiatives (or cases of industrial symbiosis) carried out in China have been seen as a key part of the solution for China’s battle in addressing its environmental problems while maintaining its economic growth.¹ The goal of the eco-initiatives is to eventually establish a so-called Circular Economy or what is otherwise known as a ‘closed loop’ economy. Such an endeavor is supported by a range of institutional and legal arrangements. The law proclaiming the Circular Economy as the country’s central development goal was passed in 2008, and came into effect in January 2009.² It is the world’s first national law proclaiming a different model of an economy from the mainstream linear ‘raw materials in’ at one end and ‘waste out’ at the other -- a model which still dominates theoretical economics, as if natural limits simply did not exist. China is clearly following the lead of Germany and Japan, which are the most experienced and developed in institutionalizing industrial recycling initiatives (Moriguchi 2007).

In general, closed-loop initiatives are taken at three levels. There are those that are confined to a single enterprise or group of enterprises, enhancing energy and resource efficiency; this is what is generally recognized as ‘cleaner production’. At the second level are initiatives
taken at a cluster level, or supply chain level, where a group of co-located firms (e.g. in an eco-industrial park) share certain streams of resources and energy and so enhance their collective energy and resource efficiency. This is what is generally known as ‘industrial ecology’ or ‘industrial symbiosis’ or ‘industrial metabolism’ – where the model is the cycles of nature that keep replenishing the basic requirements for life such as water, carbon, nitrogen and so on. When co-located in an industrial area, they are now known as ‘eco-industrial parks’ (Lowe 1997).

The third level, so far found mainly in China, involves a whole city, or whole municipal area, where recycling and interconnected processes are promoted through positive economic and administrative incentives, and conversely failures to recycle and to make industrial connections are penalized in some way. Demonstration sites are now found throughout China, as discussed in an expanding literature.

While a historical perspective is salutary in clarifying just how prevalent were past industrial practices in turning wastes into sources for new products (Desrochers 2002a; -b), the scale of present efforts in relation to the challenges is miniscule. So far the literature on eco-industrial initiatives analyzed at the meso level remains fragmented, with each of the few papers tending to analyze just one or a few cases – with some notable recent exceptions that take a broader perspective (e.g. Chertow and Lombardi 2005; Zhang, B. et al 2008; Zhang, H. et al. 2009; Zhang, L. et al. 2009). The gap in the literature that we target is a sustained comparison of the existing initiatives across different countries, putting the Chinese cases into the same categories as some of the western examples such as Kalundborg and Kwinana, and recently emerged cases from elsewhere in East Asia such as Ulsan in Korea.

In this paper we review progress achieved to date in implementing eco-industrial initiatives in China, and compare them with a sample of those achieved elsewhere, using a common graphical approach. Our aim is to demonstrate some common themes across the case studies such as the transformation from the former linear economy to a circular economy and the evolutionary process in which dynamic eco-linkages are gradually established over time. We do so in the aspiration that the process of monitoring and documenting such eco-industrial initiatives will contribute to a better understanding of the drivers and inhibitors of eco-industrial initiative and of the circular economy in general. We discuss the Chinese ‘Circular Economy’ law and its impact in promoting and shaping eco-industrial initiatives, particularly
in promoting the formation of new Eco-Industrial Parks (EIPs) where industrial symbioses between firms can be designed in from the start rather than added on later as they are identified.

The central propositions of our paper concern the category of ‘eco-industrial initiative’ and how it can be turned into a widely used unit of economic and policy analysis, as well as an object of entrepreneurial initiative and regulatory concern. We indicate in the cases below how the individual eco-industrial areas or parks have evolved, where the circularity of the group is enhanced as the number of connections between firms multiplies. These interconnections can be quantified in terms of ‘connectedness’ or ‘connectance’ of the group (Van Berkel 2009), by analogy with connectance of food webs in ecology (Dai 2009). We discuss the drivers of eco-industrial initiative as well as the inhibitors, putting our discussion into an evolutionary setting where we can characterize such initiatives as leading groups of firms to a kind of ‘evolutionary stable state’ or connectedness equilibrium. We conclude that careful implementation of the Chinese Circular Economy law could bring substantial competitive advantages to China in an era of intense global ecological awareness.

**The idea of the Circular Economy and its development in China**

The interest of the Circular Economy and its promotion in China lies in the fact that it has moved beyond an ‘environmental’ concept to become a mainstream development goal (Geng and Doberstein 2008; Zhu 2008; Yuan et al. 2006; Zhang, L. et al. 2009). China’s national leadership has clearly understood that continued development in the traditional linear manner, starting with resources taken from nature at one end and proceeding via production processes to the creation of wastes disposed in nature at the other end, is simply no longer feasible. It is destructive to the point of ruin, at both ends, and it is costly to both secure fresh resources all the time and lose resources in the form of waste: it is, in other words, both economically and ecologically inefficient.

This is an understanding that China shares with the rest of the developed world, and in particular with Japan and Germany where efforts to embed these insights into a regulatory framework have been taken farthest (Moriguchi 2007; Triebswetter and Hitchens 2005). But only in China has a Circular Economy been made the object of official development goals,
and been taken from the realm of environmental policy into the realm of development and economic policy.

While China’s economic growth has been spectacular, averaging close to 9 percent per year for the past three decades, the level of energy and materials utilized per unit GDP has been much greater than for more advanced economies – leading to both economic and ecological costs that are becoming unacceptable. So China is setting itself ambitious goals in terms of energy and materials (or resource) efficiency. We show in Figs. 1 and 2 what the trend for China’s energy and resource efficiency has been, to demonstrate that there have indeed been improvements consistent with ecological modernization (Mol 2006). Under the current 11th Five-Year Plan (2006-1010), approved by the National People’s Congress in March 2006, the goal for energy intensity is set to be 20% lower in 2010 than that in the end of 2005; 3 and the most recent pronouncements made at the Copenhagen Climate Change summit, in December 2009, set the further objective to reduce China’s ‘carbon intensity’ by 40-45% by the year 2020, compared with 2005 levels. In order to achieve those goals, China is specifying a range of means, including the implementation of circular economy – through interconnecting the chains of resource and energy utilization so that wastes from one process can be captured and used as raw material for another, with energy generation being shared along the value chain. Examples of these synergistic arrangements in the developed world are termed ‘Combined Heat and Power’ (CHP initiatives) and there are hundreds of such examples, particularly in northern Europe. China is drawing inspiration from these initiatives and making CHP a principle of industrial design throughout the economy.

In mid-2008 the Chinese People’s Congress passed a national Circular Economy law, i.e. the Law for the Promotion of the Circular Economy which came into effect on 1st January 2009. While inspired by legislation in other countries, such as the Basic Law for Promoting the Creation of a Recycling-oriented Society passed in 2000 in Japan and the Closed Substance Cycle and Waste Management Act enacted in 1996 in Germany, the Law in China seems to be the first in the world putting Circular Economy as a national strategy of economic and social development. The Chinese law basically provides a framework within which incentives and disincentives (penalties) may be developed, at multiple levels, to promote firms and municipalities to take eco-industrial initiatives, and for the creation of networks of
by-product exchange. The framework of the Circular Economy will be incorporated into the country’s 12th Five-Year Plan, to cover the years 2011-2015; current reports indicate that the new Plan will include resource consumption efficiency measures as basic measures of eco-efficiency.4

Many empirical studies are now appearing in both the Chinese and English-language literature, including firm-level studies of cleaner production such as Yuan and Shi (2009) on eco-industrial initiatives at a smelter, inter-firm studies such as those devoted to eco-industrial parks and ‘green’ supply chains, (see e.g. Zhu et al. 2008) and regional studies such as Dalian (Geng et al. 2009) or Liaoning (Xu et al. 2008). We now turn to review the progress made in these eco-industrial initiatives taken in China, especially those taken at the level of eco-industrial parks that span different value chains and create synergies across wide groups of enterprises, before comparing them with some of the better known cases documented in the developed countries.

Eco-industrial initiatives in China

While eco-industrial development is a relatively new phenomenon in China, it is accelerating and now promises to become one of the main industrial development models in its application. A number of eco-industrial initiatives have been designed and implemented for the purpose of the Circular Economy since the concept was first introduced by Chinese scholars into China in the late 1990s (Zhu 1998). In 2005 the National Development and Reform Commission in conjunction with five other ministries launched the first batch of national pilot demonstration projects, which includes seven industries, four types of economic activities, 13 industrial parks, ten provinces and cities, and 42 enterprises.5 The second batch of national pilot demonstration projects was launched in 2007, among which are counted 31 enterprises from 11 key industries; 17 areas/enterprises engaging to four key activities; 20 industrial parks; and 17 provinces and cities were listed.6 Meanwhile, a program established by the Ministry of Environment Protection in conjunction of two other ministries had designated a total of 30 Eco-Industrial Parks (EIPs) across the country up to December 2008, as shown in Fig. 3.7 According to a progress review by the MEP (2009), all but three of the EIP sites under construction were making satisfactory progress.

Fig. 3 about here
While organized and maintained by different government agencies, these initiatives have seen a number of demonstration sites being listed in both programs. In this section we shall review the leading Chinese eco-industrial initiatives through a graphical representation that brings out their major features and emphasizes their circular character, and then compare these initiatives with some of their leading Western (and East Asian) counterparts. Our purpose is to demonstrate the comparability of the eco-industrial initiatives being taken around the world. In each case, we seek to show how formerly separate chains of activities, which started with taking resources from nature and ended as dumping wastes back into nature, have been interconnected, with wastes being used as raw materials for the next process. Each of these fresh interconnections constitutes what we would call a fresh ‘eco-industrial initiative’. The purpose in introducing the common graphical representation is to emphasize the circularity of the eco-industrial initiatives, through ‘closing the loops’. Those eco-industrial initiatives evolve over time, with new material and energy exchanges being established, and in some occasions, old exchanges broken and reformed.

**Sugar industry: Guigang group**

The Guigang group was founded as a state-owned entity to produce cane sugar in 1954. It started out as a conventional sugar mill, but over the years it has embodied more and more synergies as extra facilities have been built to turn wastes into raw materials for new processes. As the first national eco-industrial park designated by the central government in 2001, today the group composed of a set of enterprises co-located in Guigang and sharing a number of resource and energy flows under a common corporate management; altogether the group produces annually 120 kt of sugar, 85 kt of paper, 10 kt of ethanol, 330 kt of cement, 8 kt of alkali and 30 kt of fertilizer with two main value chains, as shown in Figure 4. There is the sugar process itself, linked to an ethanol production facility, which has now closed the loop through wastes from the ethanol plant (vinasse) being converted into fertilizer and recycled back to the cane farms. The other main chain is concerned with paper, which starts with the crushed cane (bagasse) as raw material, converting this to a pulp that is then turned into paper, and sold to the wider economy. Since 1998, the Group has started the operation in using the filter mud (after being dried) generated from the sugar refinery process as a raw material for cement production, thus creating a new value chain. Furthermore there is recycling of bagasse as fuel for the production of heat and power that is used in all the other
industrial processes found in the Guigang group. As these businesses expand, so the group extends its value chains into the surrounding economy. This is the essence of Circular Economy evolution.

Fig. 4 about here

**Pingdingshan coal mining group**

The Pingdingshan Coal Mining group (simply referred to as Pingmei) was established in 1955 as the first large-scale coal mine after China’s 1949 revolution.\(^9\) It has been very productive, but along the way has accumulated waste piles of coal waste amounting to nearly 54 million tonnes, occupying an area of 2.66 square kilometer – plus emitting each year 2 million tonnes of coal gangue, 0.5 million tonnes of coal slime and 0.2 million tonnes of fly ash. In addition it has caused extensive land subsidence and emissions of harmful gas and sewage. Beginning in the 1980s, Pingmei began to introduce recycling measures and cross-stream and downstream activities to utilize these wastes. By the first decade of the 2000s Pingmei had created a major new building materials business based on the use of coal slime, fly ash and coal gangue to make gangue cement, fly ash cement and fly ash concrete blocks, with plans to expand this aspect of its business (Fig. 5). These initiatives represent substantial improvements in eco-efficiency. Of course carbon dioxide is still being released – but all other contaminants are now being reused in new value chains to produce new products. As recognition of its progress, the group was listed as one of the first batch of Circular Economy Pilot Demonstration sites.

Fig. 5 about here

**Lubei chemical group**

The Lubei group is a chemical complex located in Wudi, Shandong province, near the Bohai Sea. It is a large state-owned industrial group now covering 12 sectors, from building materials to light industry, power generation and machinery production.\(^10\) Annual outputs of the 52 member enterprises include ammonium phosphate (300,000 tonnes), sulphuric acid (400,000 tonnes), cement (600,000 tonnes), sea salt (1,000,000 tonnes), sodium hydroxide
Lubei is one of the largest producers of ammonium phosphate fertilizer in the world, as well as of cement and sulphuric acid.

There are three main value chains within the Lubei group. The first is the sulphuric acid–ammonium phosphate–cement chain, as shown in Fig. 6. The sulphuric acid plant receives inputs of charcoal clay, coal and high-sulphur coal to produce sulphuric acid and a waste, coal slag. The waste is fed into a downstream cement mill (along with limestone as raw material) while the acid is fed into the ammonium phosphate plant, as well as being sold to the wider economy. The second chain is based on seawater utilization for various chemicals such as salt and bromine. The third chain is a salt-alkali-electric power generation system. The main shared resource flows involve sulphuric acid and seawater; the main shared energy flows are steam and electric power; while gypsum and furnace slag are the main wastes. Ion exchange processes act as link between the various flows, while some novel uses of former wastes include aquaculture for warm recycled water, again enhancing eco-efficiency. The building materials chain is notable at Lubei not only because it disposes of considerable wastes as raw materials for the various construction products (cement, hollow blocks etc) but also because of the savings in raw material (limestone) effected.

Fig. 6 about here

Suzhou Industrial Park

The Suzhou Industrial Park (SIP) lies just east of the city of Suzhou, about 100 km from Shanghai. It overlaps with the Singapore-China cooperation area, and has attracted a vast number of international firms – altogether 2,400 foreign-funded enterprises, of which 66 rank in the world’s top 500 enterprises – as well as local entrepreneurial firms, covering such industries as chemical, pharmaceutical, health care, machinery, electronics, IT and software. In particular, SIP has attracted many leading IT manufacturers in the world, producing about 16 percent of the IC products in China and also being the largest export base of LCD panels from China. The park currently has the largest gas-fired combined cycle cogeneration plant in China, serving as both a power generation and district heating system and meanwhile reusing treated waste water as cooling water. In addition to its achievement in wastewater and energy exchange between residential and industrial sectors, enhancing eco-efficiency, SIP has actively pursued a ‘value chain completion’ strategy in its investment promotion by seeking
to integrate firms in the park in wider chains of activity. Today SIP has enacted e-waste recycling across its IT value chain consisting of upstream electronic chemicals manufacturing through semiconductor and TFT-LCD production to downstream consumer products (Fig. 7). Overall the firms in SIP are achieving ecological standards vastly superior to national levels, such as in Chemical Oxygen Demand (COD) and SO$_2$ emissions where the levels are 1/18 and 1/40 of China’s national averages.$^{12}$ In 2008, SIP and its sister industrial park, Suzhou New and Hi-tech Industrial Development Zone, were both recognized as two of the first three approved EIPs in China.

Fig. 7 about here

Tianjin Economic Technological Park

Established in December 1984, the Tianjin Economic-technological Development Area (TEDA) was one of the first eco-industrial areas approved by the State Council for development along ecological lines. TEDA has launched a range of environmental initiatives since its establishment, aiming to create an industrial park with leadership in green manufacturing and recycling of water and waste. Since the early 2000’s the focus has been on the transformation towards an eco-industrial park and the creation of circular economy at the industrial park level.$^{13}$ As a result of those initiatives, the system of industrial symbiosis has evolved over time with a number of wastewater, solid waste and energy exchanges being established. For example, a wastewater treatment plant started operation in 2000 and a water reclamation plant was put into use in 2003, thus substantially reducing the need for freshwater inputs. A co-generation power station was built in 2003 which uses treated wastewater as boiler supply water. A landfill company started operations in 2002 receiving coal powder, cinder and alkali slag as input and converting biosludge from an enzyme company into fertilizer, thereby providing its own eco-services. In addition, a lead recycling company established in 2005 now provides a large amount of regenerated lead from used batteries and other lead waste from Tianjin and Beijing regions to another local battery company. Fig. 8 highlights selected material flows that cross-link firms in the Tianjin area. In recognition of those efforts, TEDA has been adopted as one of the first three approved eco-industrial park in China as well as one of the first batch of Circular Economy Pilot Demonstrations.
International comparisons

We now wish to place these Chinese eco-industrial initiatives on a comparable footing with those that have been taken elsewhere, to see the points of commonality. Certain initiatives have been studied now for several years, and their ‘spontaneous’ evolution documented – as in the cases of Kalundborg in Denmark, and Kwinana in Australia. We shall look first at these cases, and then at two that have been identified more recently, in the industrial park of Ulsan in Korea and Kawasaki in Japan.

Kalundborg, Denmark

The Danish coastal town of Kalundborg is the most intensively studied spontaneous producer of industrial symbioses or as we describe them, eco-industrial initiatives, known in the IE literature.\(^{14}\) It is located on the island of Seeland, 120 kms west of Copenhagen, and best approached by ferry. The town is purely industrial, and built around four basic industries – a coal-fired power plant (Asnaes), an oil refinery (Statoil), a pharmaceuticals and enzymes producer (Novo Nordisk) and a plasterboard manufacturer (Gyproc) – with the municipality also providing various shared utilities and services. Local synergies began to develop spontaneously in the 1970s, and by the 1990s had developed into a network of by-product exchanges as shown in Fig. 9. As described in Ehrenfeld and Gertler (1997), these linkages and by-product exchanges evolved over time with each fresh exchange being established every 2-3 years (see Table 1 in their paper) and were in no sense planned as in the ideal model of an EIP; nor is the industry in Kalundborg self-contained, as numerous raw materials come in from outside. More recent studies (e.g. Jacobsen 2006) also indicate that the industrial symbiosis exchanges have been upgraded from time to time from generally low-value by-product exchanges through a number of intermediate stages to high-value by-product exchanges, resulting not only in steadily reducing intake of raw materials and resources during the past decade, but also in the capture of economic benefits by individual firms in the complex. It remains a benchmark for the cases of industrial symbiosis being identified now around the world, and actively developed in China under the Circular Economy and EIP guidelines.
Kwinana, Australia

The Kwinana Industrial Area (KIA) is located on a coastal strip around 8 km long at a point 40 kms south of Perth, in Western Australia. The area was developed first in the 1950s as a location for resource extraction and processing industries, and is still dominated by alumina, nickel and oil refineries, as well as titanium dioxide production and a variety of fabrication and construction activities, along with utilities including two power stations, two cogeneration plants, two air separation plants, port facilities and water and waste water treatment plants (Van Beers et al. 2009). It is one of the leading examples of spontaneous industrial synergy development, with nearly 50 regional synergies being identified, some of which are shown in Figs. 10-A and -B. The main cross-connections resulting in improved resource and energy efficiency are those relating to (1) reuse of gypsum (calcium sulphate) from a chemical plant as a soil amendment; (2) reuse of lime kiln dust from a cement plant for desulphurization; (3) and reuse of silica fume from a fused alumina and zirconia producer in the building sector. In addition many other synergies are under investigation or have been tried and had to be abandoned, for various economic reasons. The recent addition of the BHP HiSmelt pig iron plant has created many new eco-industrial possibilities, including reuse of lime kiln dust from the cement and lime producer.

Ulsan, Korea

In 2005 Korea initiated an ambitious three-phase 15-year development project that would create a number of eco-industrial parks under the guidance of the newly formed Korean National Cleaner Production Center (KNCPC). The first phase (2006-2010) was concerned with identifying eco-industrial improvement possibilities (industrial symbioses) and to focus development around two designated industrial parks, creating an energy-efficient by-product exchange (BPX) network. The second phase (2011 – 2015) is envisaged as spreading the concepts to 20 other parks. The third phase (2016-2020) would review the inevitable flaws and seek to eliminate them, and review the performance indicators developed for the
initiatives (Park et al. 2008). The overall goal is a closed system across all the eco-industrial parks, with zero discharge. Ulsan is the most advanced of these initiatives.

Ulsan is a vast industrial complex in Korea, home to substantial sectors of Korean industry. Ulsan City was given the status of special industrial zone in 1962 and it has been a driver of industrial development in Korea ever since – largely spontaneously until 2006. There are more than 700 companies in the Ulsan industrial complex, some of them industrial giants like Hyundai, Samsung Fine Chemical and Kumho Petrochemical, and there has already been substantial progress achieved between the companies themselves in identifying and acting on industrial synergies. According to Park et al. (2008) so far 70 symbioses have been identified -- 34 coming from collective utility systems (power, water, heat), 19 from by-product exchanges, nine from shared connections for steam, five from use of excess steam and three from links for recycling of industrial water – some of which are shown in Fig. 11. There is active involvement from the Ulsan Metropolitan City in promoting the expansion and further evolution of the Ulsan EIP.

Fig. 11 about here

*Kawasaki, Japan*

Kawasaki, a coastal city next to Tokyo with approximately 1.3 million residents, is an important industrial base in Japan heavily relying on the chemical industry, the steel industry, the food industry, the petroleum industry and the general machinery and appliances industries. The city was selected as one of the four Eco-Towns under the Eco-Town program sponsored by the central government of Japan. Thanks to the program, at least 14 recycling and symbiotic projects have been established, involving symbioses not only between industrial users but also extending to the broader urban area involving the use of municipal and commercial wastes (Van Berkel et al. 2009). Some of the projects and the linkages involved are highlighted in Fig. 12. The key players in those symbioses include a paper mill which takes paper wastes and recycled effluent from a wastewater treatment plant as main inputs, a steel refinery using scrap metals as raw materials and meanwhile providing blast furnace gas to the paper mill as the source of power, a cement mill whose production is based on alternative fuels such as mixed plastics, organic waste and soot, and alternative raw materials such as blast furnace slag from the steel company as well as sludge and construction soils,
and finally waste collectors and recycling firms that turn used home appliances, fluorescent bulbs and plastics into feeds to industrial users.\(^\text{16}\)

Fig. 12 about here

**Discussion**

It is not surprising that the development of Chinese eco-industrial initiatives to a large extent is inspired by the international experiences including those discussed above. The Chinese initiatives share many commonalities with those in more advanced countries. First, it can be observed that most of the initiatives both in China and in other countries apply to existing industrial parks or towns and aim to transform the previously linear value chain to a closed-loop production system. Only one out of the thirty eco-industrial parks approved by the Chinese central government up to December 2008 was purpose-built, namely Qindao New World Eco-Industrial Park which was set up as a regional hazardous waste disposal center (MEP 2009). Similarly, none of the international cases discussed above were ‘designed’ to be an eco-industrial park or an eco-town purposefully from the beginning.

Second, eco-industrial initiatives in both China and other countries are results of evolution and transformation over decades. Activities involving environment protection, supply chain integration and capture of regional synergies occur spontaneously. The focus of eco-industrial initiatives shifts from an early concern with pollution control and cleaner production, to develop a broader conception of industrial synergy. For example, the Suzhou Industrial Park was approved as the first National ISO1400 Demonstration Area in 1999 in recognition of its achievements largely in the fields of cleaner production and waste management. Firms in the Park began to introduce eco-industrial linkages inspired by the Circular Economy in 2002, and it was then listed as one of the CE Pilot Projects in 2005. More recently the Park launched its aspiration to be recognized as a National Ecological Civilization Demonstration Park, with ambitious objectives.\(^\text{17}\) A similar evolution can be observed in the case of Kwinana, under the aegis of the Kwinana Industries Council, as more and more regional synergies are identified and captured (Van Beers et al 2007).

Third, compared with the international benchmarks, eco-industrial development in China is still at an early stage; therefore symbiotic intensities resulted from the initiatives in general
are still low. For example, according to the estimate by van Berkel (2009), the leading initiative of Guitang group in China achieved five synergies between the five constituent firms in 2004, compared with 13 synergies between 11 firms achieved in Kalundborg in 2005, 47 synergies between 22 firms in Kwinana in 2005, nine synergies between 12 firms in Ulsan in 2004 and 14 synergies in Kawasaki by 2007 respectively.

Finally, the case studies in China also indicate that the ‘visible’ hand of the government plays a vital role in establishment of the eco-industrial initiatives in China, as would be expected in a ‘latecomer’ country. Eco-industrial initiatives in China are mainly designed, supported and managed by governments at various levels. For example, 23 out of the thirty eco-industrial parks approved by the Chinese central government up to December 2008 are directly managed by local municipal governments, while the remaining seven are managed by large state-owned enterprises. The eco-industrial initiatives need to be ratified by the government in order for firms to gain various financial and administrative supports, such as low-rate loans, tax relief and priority in land supply. By contrast, a more autonomous approach is usually seen for management of eco-industrial initiatives in the international cases, including various industry organizations such as the self-funded secretariat Kwinana Industrial Council (KIC) and the voluntary Gladstone Area Industry Network (GAIN) committee for the Gladstone group in Australia (Van Beers 2008; Corder 2008). Comparing the two development models, we see the role of government in a ‘latecomer’ country such as China is important in enabling those eco-industrial initiatives at this early stage of development to take off. Latecomers suffer the disadvantages of being far from established markets and sources of technology, but as pointed out by Gerschenkron (1962) they also draw advantages from initial low costs and from the capacity to draw on the technologies accumulated around the world, and from the capacity to lay down fresh industrial pathways without having to replace legacy systems. They can also use state agencies to drive their catch-up efforts, as seen repeatedly in the East Asian context (Lee and Mathews 2010). A latecomer perspective thus helps to explain why China is moving ahead so rapidly with such comprehensive eco-industrial initiatives as compared with the slower pace of such developments in the more industrially advanced countries.

Having put these eco-industrial initiatives, taken in China and elsewhere, on a common graphical footing, we have probed them for their underlying drivers and characteristics and the evolutionary patterns that can be identified. We agree with Andersen (2007) that the idea
of the circular economy is still largely confined to consideration of physical flows, and the economic drivers (and inhibitors) of eco-industrial initiatives have yet to receive sufficient attention. We now turn to consider this aspect of the question with particular reference to China.

Drivers of eco-industrial initiatives in China: a top-down approach and a bottom-up approach

To facilitate the evolution of eco-industrial initiatives, both a top-down approach and a bottom-up approach seem to be needed. The former is ensured by institutional arrangements such as regulatory requirements set in place by the Circular Economy Promotion Law, and the Circular Economy Pilot Demonstrations program and the Eco-industrial Park program established by various government agencies.

Yet a bottom-up approach is arguably more important, as suggested by Desrochers (2002b; 2002a; 2008) and others. In a brilliant series of papers, Desrochers has demonstrated beyond doubt that the idea of ‘industrial ecology’ is as old as industrialism itself and probably a lot older, if we count in the closed-cycle practices of Asian village life in medieval times. Desrochers demonstrates with abundant examples how closing the loop was viewed as a good business opportunity in every facet of industrial activity, and he opens up a new field of inquiry by asking why it is that such activities have become so ‘foreign’ to modern industry, where the linear model of ‘raw materials in’ at one end and ‘wastes out’ at the other end, is totally dominant. In contrast to the ‘Porter Hypothesis’ proposed by Porter and van der Linde (1995) and other proponents which hold that properly designed and enforced regulations can trigger innovative responses of firms, resulting in both more environment-friendly practices and more profits, Desrochers argues that fundamental drivers of actions to mitigate environmental harm, in particular the development of closed loops among firms using one’s wastes as another’s input, would be market incentives supported by enhanced private property rights.

Therefore, we expect a bottom-up approach that sees more and more individual players taking eco-industrial initiatives and embracing the idea of circular economy once those ideas make financial sense for them with changing market dynamics triggered by factors such as higher prices of energy/resources and deregulation of market entry. But we see these
initiatives as shaped by regulatory frameworks. China currently provides a rich source of these kinds of eco-industrial initiatives, both those mandated by state agencies and those created through private initiative between firms.

For example, it is in China that we see both enterprise- and cluster-level eco-industrial initiatives being pursued, as in the cases of Guigang or Pingdingshan or Lubei and many other similar examples, as well as initiatives at the level of eco-industrial parks (such as Suzhou and Tianjin) where the hand of local and state government is clearly visible, driving initiatives that are shaped by the national Circular Economy Law.

Indeed a major feature of the Chinese reforms since late 1970s is their success in adopting the bottom-up approach instead of a big-bang reform that was seen in eastern European countries (Chen et al. 1992; McMillan and Naughton 1992). Thus in one Chinese industry after another, moving from textiles to steel to automotive and now electronics, we see a powerful combination of state-level administrative and institutional frameworks guiding investment into new channels combined with strong entrepreneurial initiative – such as in the cases of Chery and BYD in automotive and now in Electric Vehicles, or the case of Haier in white goods sector. Massive entry by non-state companies into new industries resulting from the reform has brought about Schumpeterian (or innovation-based) type of competition, which has fundamentally contributed to the prosperity of the Chinese economy (Mathews 2009).

We believe that a similar approach is likely to emerge for the establishment of the Circular Economy as well, which will see individual, profit-driven firms taking greater responsibility in the process.

**Inhibitors of the development of eco-industrial initiatives towards the Circular Economy**

There are technological, financial and institutional barriers that need to be overcome to turn the current eco-industrial initiatives into a Circular Economy operating at a larger scale. Technological development has made many industrial closed-loop connections technologically feasible. For example, Nemerow (1995) discussed ten possible environmentally balanced industrial complexes involving 16 different industries and how those complexes of plants could become mini-‘foodwebs’ with technical process compatibility. Financial barriers, such as large upfront capital investment required to support eco-industrial initiatives, call for financial innovations. Some of the financial instruments that
potentially channel private and public funds into sustainable development have already been intensively discussed in the literature (UNEP and SEFI 2008, 2009; UNFCC 2007, Mathews et al 2010)

Institutional barriers include those created by existing laws, both in advanced economies and in emerging economies. For example, in some countries a potential obstacle to utilization of by-products is location of companies in export zones as regulations do not allow these companies to supply any local companies outside of the zone (Lowe 2001). In countries where environmental regulations are most strict and comprehensive, notably the US, Germany and Japan, it may be the case that some aspects of the recycling laws actively discourage inter-firm exchange of wastes that is the essence of eco-industrial initiative. The argument that environmental laws, and particularly laws on toxic wastes and their control, have acted to inhibit firms’ search for industrial waste-reutilization, is made by Gertler (1995) and by Desrochers (2002a; -b). Indeed Desrochers (2002a) makes the argument that one of the factors involved in the ‘take-off’ of industrial symbiosis at Kalundborg was Danish flexibility over the treatment of wastes, preferring to see their being utilized by a partner firm than ‘controlled’ through disposal. A similar argument is mounted by Schwarz and Steininger (1997) in relation to their discussion of industrial recycling in Austria. Of course the same argument applies with even greater force to the Chinese case, where regulatory controls are still quite lax, and opportunities for market-led ‘closing of the loop’ are numerous. This might help to account for the difficulties encountered in getting regional eco-initiatives off the ground in the US and in Germany (see for example Sterr and Ott (2004) and their discussion of the Rhine-Neckar region in Germany). There are lessons to be drawn from these examples which China as a latecomer will be able to act on when developing its own eco-industrial initiatives, and further study will no doubt reveal such cases where flexibility has facilitated local initiative.

Criteria for success of eco-industrial initiatives

In the interests of taking the study of eco-industrial initiatives further, and placing them within an economic and evolutionary setting, we pose two criteria in examining the success of each such initiative: (1) it must improve the eco-efficiency of the group of firms as a whole; while (2) improving the profit position of at least one firm without damaging the profit position of the others. The first criterion has been intensively discussed in the literature
(Ehrenfeld 2005), and a number of measurements for eco-efficiency have been developed and applied in previous studies, such as a tangible reduction in material throughput, or in energy released, or in carbon dioxide released, or in some biological measure like Basic Oxygen Demand (BOD) of watercourses (Korhonen and Snäkin 2005). But there also needs to be an economic dimension to such initiatives – to bring them within the ambit of ‘ecological economics’. That is why we pose the second criterion. This approach has an analogue with the definition of ‘Pareto efficiency’ in mainstream economics which states that an allocation of goods is subject to a ‘Pareto improvement’ if a new allocation makes at least one person better off, without making anyone else worse off.

Checking the leading Chinese initiatives as described in this paper against those two criteria, we have demonstrated impressive evidence that up to the present they seem to have made Pareto improvements in an eco-industrial sense, leading to the formation of an eco-industrial area or region. In this setting, we are interested in whether the group as a whole can evolve, though a series of eco-industrial initiatives, to the point where the firms in the group can reach a (temporary) ‘steady state’ in the sense that no further eco-improvements are feasible, given the technology employed. In evolutionary theory, this is termed an ‘evolutionary steady state’ and is the equivalent of ‘equilibrium’ in real, evolutionary terms.

The analytical goal of this kind of approach would be to prove an analogue of the central theorem of neoclassical economics, which states that under certain assumptions (convexity etc) the existence and uniqueness of a competitive equilibrium may be demonstrated and that it is Pareto efficient. This is a purely comparative static result, and the ‘equilibrium’ obtained is a purely ideal phenomenon that has never been demonstrated in any real economy. By contrast, in the eco-industrial setting, we are interested in real activity sets that link firms together through their resource and energy flows, and in real developmental changes to the configuration of these activities that encompass ‘eco-industrial initiatives’ that evolve over time. We are interested in securing theorems that describe the development of an ‘evolutionary stable state’ achieved by the application of ‘evolutionary stable strategies’ (ESS) in such a setting, which can be empirically demonstrated in terms of real connections between firms. An analogue of the central theorem in economics would be a theorem (or theorems) demonstrating the existence and uniqueness of an evolutionary stable state between a set of firms generated through their making dynamic eco-linkages with each other,
where the stable state is characterized as being Pareto eco-efficient. We pose this as a challenge for the field.

Such an approach would also provide a framework that would underpin the empirically verified advances in both China and elsewhere as industrial ecological initiatives enter the mainstream. It would also be a way of advancing our understanding of eco-industrial initiatives in a form that is susceptible to modelling in an agent-based simulation system, where the agents are the firms interacting in terms of eco-industrial initiatives, and where the evolutionary stable state could be determined experimentally. Such agent-based simulations could also shed light on the fundamental issue, which is what drives the formation of these industrial symbioses at the micro- or firm-level – or in China’s case, what drives circularity. The interest of such agent-based simulations would lie in demonstrating the macro consequences (or emergent phenomena – in this case closure of industrial loops) of multiple micro decisions, taken within different legal-institutional settings which could capture the flavor of China’s Circular Economy Promotion Law.

In this paper we have offered examples of the kind of economic analysis needed where closed loop economic inter-firm relations are seen as the norm, rather than the exception. Linear economic analysis remains the overwhelming (and unthinking) preference in formal economic modelling – driven by an assumption that economic activities can be thought of as ‘single production’ activities rather than as ‘joint activities’ which is actually the case in reality – as argued convincingly by Kurz (2006). We look forward to a renaissance in economic thought emanating from China, that parallels the rise of eco-industrial initiatives on a large scale, and that takes the Circular Economy as its inspiration and guide. Such a program calls for ‘root and branch’ reform of economic analysis itself, dispensing with the linear flow model and replacing it with a circular flow model, bringing China, to use Mol’s (2006) phrase, to the ‘frontiers of ecological modernization’.

References


Figure 1 Historical trend of China’s energy intensity, 1980-2008

Source of primary data: U.S. EIA International Energy Statistics Database
Unit: Total Primary Energy Consumption per Dollar of GDP (BTU per Year 2005 US$ using Purchasing Power Parities)

Figure 2 Historical trend of China’s resource efficiency, 1980-2006

Source of primary data: Sustainable Europe Research Institute (www.materialflows.net)
Figure 3 National Eco-industrial Parks (EIPs) up to December 2008 in China

Source MEP (2008)
Note: There have been six additional EIPs approved for construction since Dec 2008 till April 2010. See http://kjs.mep.gov.cn/stgysfyq/m/200807/t20080718_125900.htm (in Chinese) for the latest list.

Figure 4 Selected industrial symbioses in Guitang Group, Guigang City

Source: Based on Fang et al. (2007), Lowe (2001) and Zhu & Côté (2004)

Figure 5. Selected industrial symbioses in Pingdingshan Coal Mining Group
300 km$^3$ of concrete block

External eco-economic system

Building materials plant

Coal processing

Chemical plant

Methyl alcohol

Nylon, plastics etc.

170 kt of coal gangue and 100 kt of fly ash

20 million tons of coal

150 kt of cement

300 km$^3$ of concrete block

60 million hollow bricks

170 kt of coal gangue and 100 kt of fly ash

20 million tons of coal

Source: based on Long and Zhang (2009); Pingmei’s website (www.pmjt.com.cn)
Figure 6. Selected industrial symbioses in Lubei Industrial Park

Source: Based on Fang, Cote et al. (2007); Yu C.-x et al. (2007); Lubei’s website www.lubei.com.cn
Figure 7. Selected industrial symbioses in Suzhou Industrial Park

Source: based on Zhang et al. (2009) Note: PCB = Polychlorinated biphenyl
Figure 8. Selected material flows in the industrial symbiosis in Tianjin Economic Development Area

Source: based on Tan and Bao (2006); Geng et al. (2007); Shi et al. (2010)

Figure 9. Selected industrial symbioses in Kalundborg, Denmark

Source: Based on Jacobsen (2006)

Figure 10-A Selected industrial symbioses in Kwinana, Australia (1)
Figure 10-B  Selected industrial symbioses in Kwinana, Australia (2)

Source: Based on van Beers et al. (2007)

Figure 11. Selected industrial symbioses in Ulsan industrial complexes, Korea

Source: Based on van Beers et al. (2007)
Figure 12. Selected industrial symbioses in Kawasaki, Japan

Source: Based on van Berkel et al. (2009)
The literature on industrial ecology utilizes several terms to indicate the essentially ‘ecological’ nature of industrial linkages that tend to close industrial loops – such as industrial symbiosis, industrial ecosystem, eco-industrial development, eco-industrial park and so on (see e.g. Chertow 2007; Gibbs et al 2005). We choose to use the term ‘eco-industrial initiative’ because this seems to capture the flavor of the various approaches, and coincides with our introduction of the concept of Pareto eco-efficiency, to be discussed below.


The full list is available at [http://kjs.mep.gov.cn/stgysfyq/m/200807/t20080718_125900.htm](http://kjs.mep.gov.cn/stgysfyq/m/200807/t20080718_125900.htm) (in Chinese)

Sources for the Guigang group include Fang et al. (2007), Lowe (2001) and Zhu and Côté (2004)


Sources for the Lubei group include Feng (2003), Fang et al. (2007); and Lubei’s website: [www.lubei.com.cn](http://www.lubei.com.cn)

The description of SIP is based on Zhang, H. et al. (2009) and MEP (2009) and SIP’s website. See the official webpage of the Suzhou Industrial Park, at: [http://www.sipac.gov.cn/english/zhuanti/jg60n/gjlnbtsj/](http://www.sipac.gov.cn/english/zhuanti/jg60n/gjlnbtsj/)

Sources for the TEDA include Shi et al. (2010) and specifically on water resources, Geng and Yi (2006).

Sources include Ehrenfeld and Gertler (1997) and Jacobsen (2006).

Sources include Van Beers et al.(2007) and Van Beers (2008)

The reduction of carbon dioxide emissions at a cement plant in Kawasaki through industrial symbiosis initiatives is also the subject of a recent study by Hashimoto et al. (2009).


See for example the recent study by Chertow and Lombardi (2005) as well as more general eco-industrial measures such as those discussed by Zhang B. et al (2008) and van Berkel (2009).

For some of the recent studies utilizing agent-based simulation in an eco-industrial context, see Beck et al. (2008); Becka (2008) and Karlsson and Wolf (2008).