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## New Industrial Revolution and Environmental Protection

**Abstract** Serious environmental problems have appeared in China since the rapid economic growth 30 years ago, which affect human's health and become a limiting factor for further development. It has brought about the rethinking of traditional ways for economy development and environmental protection, and realized that the change in the model of development and environment protection is of significance. A new industrial revolution is needed for protecting the environment and promoting sustainable development. This paper discusses the characteristics of the new industrial revolution for sustainable development including cleaner production, circular economy, and industrial ecology. Lessons from China and abroad will be introduced to prove that new strategies for environment protection and economic development are needed.

**Keywords:** new industrial revolution, environmental protection, cleaner production, circular economy, industrial ecology

The industrial revolutions in the last two centuries have caused serious environmental problems which affect people's health for worse and become limiting factor for further growth around the world. Environmental protection has attracted people's concern since the 1950's. However, End of Pipe treatment has been the major strategy for minimizing pollution for quite a long period of time. Environmental problems in China have been more serious because of the economic development in the last 30 years has been much faster than the developed countries in the world (Qian & Tang, 2000).

Experiences and lessons from the practices around the world have proven that the end of pipe treatment is not a cost-effective way or even make conflict between development and environment severer because of the higher consumption of resources and large amount of capital and op-

eration costs needed. Sustainable development strategy has been accepted by the world and China in 1992, which called a new industrial revolution because industry is a major resource consumer and environment pollutant producer (Qian, 1998).

The major characteristics of the new industrial revolution are: low resource consumption and low pollution discharge. Both can be attained by raising production efficiency, production eco-design, and even systematic transition. Cleaner production, circular economy, and industrial ecology are the major improvements reached in the last 40 years and have attracted higher and higher attention in China.

China, facing serious environmental pollution, resource shortage, and health issues, it urgently needs to promote a new industrial revolution. Cleaner production, circular economy, and industrial ecology are the major symbols of a new industrial revolution. It is clearly that all the engineers and scientists in different fields, including the environmental protection field, should take the responsibility of promoting a new industrial revolution.

Cleaner production has been developing since the 1970's rapidly, and it has obtained both environmental and economical benefits in different countries. Circular economy is a new concept with other names like recycling economy, recycling oriented society, or life cycle economy, which have been developed since the 1990's (CCICED, 2003). Industrial ecology is also a new concept and strategy developed in the turn of new century (Suren, 1999). These three concepts and practices have similar targets of minimizing resource consumption and pollution production aimed to sustainable development, but in different scopes.

### 1 Cleaner production—pollution prevention from the beginning of production

The initial concepts of cleaner production were assembled during the mid-1980s. UNEP (United Nation Environmental Programs) has defined that Cleaner Production is the continued application of an integrated preventive strategy applied to products, production and service for enhancing effective-

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Manuscript received January 20, 2014; accepted March 7, 2014

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ness which reduces risks to human and environment and increases economic benefits. For products, Cleaner Production involves reducing negative impacts along the life cycle of a product, from raw materials extraction to its ultimate disposal. For production processes, Cleaner Production involves conserving raw materials and energy and eliminating toxic raw materials, reducing the quantity and toxicity of all emissions and wastes before they leave the process. For services, Cleaner Production involves incorporating environmental concerns into designing and delivering services (Berkel, 2000). Cleaner Production requires changing attitudes, applying the know-how, and improving technology.

Over the last 30 years, a great variety of programs has been launched to facilitate the uptake of Cleaner Production in industry. Many programs had, and continue to have, a strong technical assistance component. Moreover, enabling policy frameworks have been set up on the basis of mandatory planning, voluntary agreements, industry environmental management codes, financial incentives, etc. In addition, Cleaner Production initiatives have supported or spawned a collection of new tools including facility assessments, full-cost accounting, technology assessments, eco-balances, and life cycle assessments. There are international conferences, national roundtables, and an international declaration on Cleaner Production (Shi & Qian, 2002).

Many good examples from different countries can be listed and it is for sure that the implementation of Cleaner Production has led to a new industrial revolution which is a good way for achieving sustainable development. Take China as an example, the new strategy of implementing Cleaner Production were proposed and endorsed by the Chinese Government at the Second National Conference on Industrial Pollution Prevention and Control in 1993. Promotion of Cleaner Production was listed as one of the nine top priorities in China's Agenda 21 issued in the same year. A series of efforts have been made since then to implement Cleaner Production in China:

(1) To encourage Cleaner Production implementation in laws and regulations related to environmental protection while they are modified in 1995–1996, a new law named: Law of Promoting Cleaner Production of PRC was issued in 2002 and put into effect in Jan 1, 2003.

(2) To set up Cleaner Production centers at national and provincial levels since 1995.

(3) To carry out training and education program for capacity building on Cleaner Production implementation.

(4) To conduct Cleaner Production implementation projects in China with the help of UNEP, the World Bank, UNIDO, UNDP, and other foreign countries, including Canada, USA, Norway, Australia, UK, European Union, etc. The major contents of these projects include: development of the Chinese Cleaner Production audit manual for enterprises; rising awareness on Cleaner Production; training of Cleaner Production auditors; execution of Cleaner Production audits in demonstration plants and implementation of options requiring low cost or no cost; policy study and recommen-

ation.

(5) To investigate good Cleaner Production technologies in major industrial sectors and try to spread these technologies in whole countries. This work is led by the Ministry of Industry and Information Technology. 13 major industrial sectors are involved and more than 500 advanced Cleaner Production technologies have been selected as the good examples.

It is shown by the experiences of the enterprises who adopt the Cleaner Production concept that the implementation of it can yield both environmental and economic benefits. Most of the enterprises can get their investment back with 2-3 years from the reduction of cost and reduce the pollutant discharge with much lower cost than End of Pipe treatment.

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## 2 Circular economy-eco-innovation from the cradle to the cradle

The circular economy concept and many similar theories practiced in different countries evolved from decades of worldwide efforts in the search for economic development that is in harmony with the natural environment.

### 2.1 Circular economy is a revolution on linear economy

From the angle of material flow patterns, traditional industrial economy is a one-way linear economy consisting of "resource–production–consumption–disposal". In this kind of linear economy, people extensively drain all kinds of materials and energy from nature, then release them as pollution and waste into the air, water, and soil, treating the earth as a "sewer" or "garbage can". Economic activities are characterized by "high exploitation, low utilization, and severe pollution". Circular Economy, which is different, promotes an economy development pattern harmonious with nature by organizing the economic activities to a close-loop process of "resource–production–consumption–regenerated resource" (Zhu, 1998). All materials and energy can be used rationally and continuously in sustained economy cycles, hence the harmful effect to natural environment can be reduced possibly to a minimum level.

When judging the rationality of the economic development in 21st century, we should consider all the three dimensions of sustainable development, i.e. the integration of economic, social and environmental dimensions. According to the need of a sustainable development pattern, first, we should try to make more values in economic aspects. It is the matter of effective distribution of resources, which can be regulated by price. Second, we should try to reduce bad influences on environmental aspects. It concerns the maintenance of a healthy eco-system, of which the prevention of ecologic deterioration can be the major policy goal. Third, we should try to solve the problem of employment in social aspects. It is regarded as the problem of a fair distribution of social wealth, in which tax can be the major policy tool.

## 2.2 “3R” is the major principle of circular economy

The principles of circular economy are “reduce, recycle and reuse” (“3R” principle). Every principle is vital for the successful implementation of circular economy.

(1) Reduction is the principle concerning input, aiming at reducing the input material flows and energy flows into the production and consumption process. In another word, we should produce the essential products with as little resource as possible. We should prevent the waste from generation instead of dispose of them after production.

(2) Recycle is a method concerning processing. We should try to use natural resources and byproducts produced in production process more times in every possible way. By recycling them, we can prevent them from becoming waste, and reduce the consumption of natural resources.

(3) Reuse is a method concerning output. By turning waste into secondary resources, it reduces the waste for final disposal in volume and decreases the consumption of natural resources. Producers should try to use secondary resources to displace natural resources. Consumers should buy the products containing the maximum raw materials made by secondary resources. These will help to close the economy loop.

The priorities of these 3R principles are not equal. Some may simply regard circular economy as the reuse of waste. Actually, the fundamental goal of circular economy is to systematically prevent and reduce the waste in the economy process.

Taking the iron and steel complex in China as an example, according to the “3R” principle, it has made efforts to build three cycles for reducing water, energy consumption, and pollution emission. The statistic shows that it consumed 25m<sup>3</sup> fresh water for producing 1 t steel in 2000 but only 4m<sup>3</sup> fresh water in 2010. It proves that the efficiency for using water had been obviously increased. They also collect all the emissions from the production process then using the heat value to produce electricity. All the solid waste is being used as the raw materials of cement or other products. As a result, an iron and steel complex with the capacity of (8–10) ×10<sup>6</sup> tons of steel can support a power station with 1.2×10<sup>6</sup> kW of electricity and a cement manufacture with 3×10<sup>6</sup> tons of cement. Obviously, pollution emissions have reduced in great degree.

## 2.3 The implementation of circular economy home and abroad

We have long followed the linear growth pattern. As the result, economic growth accelerated at the cost of ecological deterioration. So we must find a new economic pattern for future development, i.e. the organic integration of economic growth, environment and resource protection, and social employment achieved by circular economy.

Recognizing all the constraints arising from resource depletion and environmental degradation, “circular economy”

has been drawn more and more attentions in western industrialized nations. Germany and Japan already lead the world in recycling. By bringing the new Recycling and Waste Management Act into operation in 1996, German has taken the first steps to put the whole economy onto a closed-loop, circular basis. Then, Japan has also enacted a series of similar laws and regulations in 2000, including the Basic Act for Establishing a Sound Material-Cycle Society.

Around the beginning of the new century, China led another wave of implementation of circular economy, first at municipal level, then at provincial level, and finally reached at the national level. In 2005 and 2007, six ministries including NDRC and MEP conducted two batches of circular economy pilot projects, 178 pilots included. In 2008, China issued the Circular Economy Promotion Law. The introduction of the law indicates that China’s circular economy has entered a more normalized phase. Since then, a series of policies and measures introduced intensively, including comprehensive usages of industrial and mineral solid waste, recycling of food waste, urban mining bases, etc.

“From the cradle to the cradle” has vividly describes life cycle analysis which is a basic method to make all the products and production processes environmental friendly by minimizing the resource consumption and make waste as the renewable resource. “Mining the cities” is a new concept which vividly describes that the waste can be useful as natural resource if people play their part right. New processes, technologies, and policies are needed to make the new concept to be a reality, which can accomplish low resource consumption and low waste discharge.

Circular economy is a new method of economy development which not only concerns the change of production pattern but also the change of consumption pattern. For using limited natural resources to support mankind, people should realize it is the responsibility of the present generation to save natural resources as much as possible for the benefit of the future generations. Conservation of water, energy, and mineral resources should be an important part people’s ethics in the world. People at different positions including government officers, enterprises managers, scientist or engineers, workers and peasants etc., should take responsibility at their own positions.

## 3 Industrial ecology-sustainable transition towards eco-industry

Industrial ecology is a new discipline developed in late 1980’s (Frosch & Gallopoulos, 1989). The major concept is that this industrial system is a special ecological system which should be built and operated by using the roles and principles of a natural eco-system. Industrial ecology has established strategy and methodology for increasing efficiency of resource utilization and reducing pollution produced in industrial processes.

The major areas studied in industrial ecology include:

rational material flow and energy flow for de-materialization and de-carbonization, life cycle assessment of all industrial products, raising eco-efficiency by using new technologies for improving resource utilization efficiency in industrial processes, and industrial symbiosis, which is the basic principle of the industrial park.

Industrial ecology is a new discipline which has absorbed the major principles of industry, ecology, biology, and economy. It has attracted vast attention from the world, including China. Many valuable research projects have been carried out and practiced in different industrial sectors, and have been very successful.

Eco-industrial parks (EIPs) are good examples of the application of industrial ecology. They have used the concept of industrial symbiosis and obtained benefits both in economic development and environmental protection (Chertow, 2000). Following are two good examples of eco-industrial parks, Kalundborg Industrial Park in Denmark (Ehrenfeld & Gertler, 1997) and Guigang Industrial Park in Guangxi province, China (Zhu & Raymond, 2004).

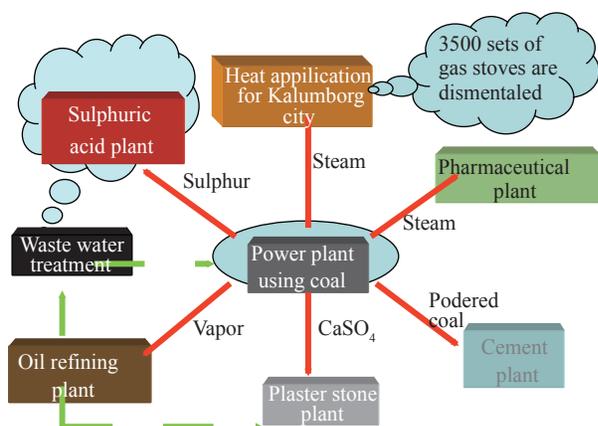


Figure 1. Kalundborg industrial park in Denmark.

By using the waste and steam of the power plant using coal as its resource to be the resources of other three plants, both economical and environmental benefits have been obtained. The statistic shows that it can save 1,200,000 m<sup>3</sup> of water, 19,000 tons of oil, and 30,000 tons of coal, and reduce CO<sub>2</sub> discharge every year.

In Guigang city in Guangxi province, there is a large cane sugar plants. The major raw material is sugarcane. There were great amount of wastes produced during the production of sugar, including sugarcane leaf, the top of the sugarcane, the bagasse, canemolasses, and others. The industrial park includes cattle farm, milk dairy, beef plant, power plant, fertilizer plant, paper mill, etc. All the waste becomes raw material of other products. The industrial park has reached maximum resource utilization and minimum waste disposal, as a result, the maximum economic benefit is also achieved. It is a very good example of a win-win model. In this park,

ecological agriculture is also included.

Being the “world plant”, most of China’s industrial activities are conducted in industrial parks. Up to the end of 2013, China had around 300 national industrial parks and thousands of provincial parks, including the Economic & Technological Development Areas (ETDAs) and the High-tech Parks (HTPs). Many parks have carried out eco-industrial park practices, which mean industrial ecology is growing from a strategic niche to the mainstream of industrial development. In the past 10 years, a great number of success stories on eco-industrial parks became known (Shi, Tian, & Chen, 2012). Take for example the Tianjin Economic and Technological Development Area (TEDA), which has implemented more than 250 inter-firm symbiotic relationships exchanging among the utility, automobile, electronics, biotechnology, food and beverage, and resource recovery clusters. The establishment of an industrial symbiosis network has been the forerunner of a remarkable win-win situation (see Table 1).

Table 1 Industrial Synergies in TEDA (2010-2013)

| Sector                          | 2010 | 2011   | 2012    | 2013    |
|---------------------------------|------|--------|---------|---------|
| Num of membership               | 174  | 536    | 635     | 931     |
| Num of synergies                | 10   | 27     | 43      | 87      |
| CO <sub>2</sub> abatement (ton) | 205  | 11,000 | 42,000  | 89,355  |
| Landfill diversion (ton)        | 50   | 3,000  | 257,000 | 321,076 |
| Raw materials reduction (ton)   | 50   | 3,000  | 872,000 | 936,388 |
| Revenue increase (10,000 RMB)   | 7.23 | 552    | 8,963   | 11,040  |

## 4 Conclusions

Facing serious environmental, pollution, and resource shortage problems, the urgent need in China is to implement Cleaner Production, Circular Economy, and Industrial Ecology, in other word, to carry out a new industrial revolution for sustainable development. It needs innovations in the technical, educational, legal, and instructional fields, as well as financial measures, etc. The long march of ten thousand kilometers has already started. There is long way to go and much more efforts should be made from now on.

## Acknowledgments

I appreciate the comments and supplements to this paper by Prof. Shi, lei, who has been teaching clean production, industrial ecology for years.

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