Closed-loop Supply Chains Based on By-Product Exchange

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Abstract—**This paper emphasized on the by-products of closed-loop supply chain (CLSC) system. The cooperation processing based on by-products exchange in CLSC is discussed with the decision-making criterion of eco-efficiency maximization. Accordingly, a pricing model is given. The sustainability of the CLSC system is discussed under the circumstances of exergoeconomics. The metric of "system negative environment effect" is introduced to measure CLSC system performance. A case study of Guangxi Guitang Group in China is analyzed at last, which shows the multi-win brought by closed-loop supply chain management (CLSCM).**

Keywords-closed-loop supply chain; by-product; exergoeconomics; system negative environment effect

I. INTRODUCTION

Closed-loop supply chain (CLSC) is of great importance to enterprises' operation and environment protection. The research and practice of CLSC also witnessed fast development in recent years. In fact, over the last several years, changes in environmental laws and the new returns demands of market returns have raised the requirement for effective reverse logistics to a new level, reverse logistics issues are gaining justifiable popularity among society, governments and industry worldwide. They are mainly regulatory-driven in Europe, consumer-driven, market-driven and profit-driven in North America and in incipient stage in other parts of the world, including China, where both consumer awareness and globalization are likely to lead to greater economic, consumer and regulatory pressures in the coming future. Only very recently, some companies in consumer durables' and automobile sectors in China have introduced exchange offers to tap customers who already own such products. Presently, these returned products are either resold directly or after repair and refurbishment by firm franchisee/local remanufacturers in the seconds' market. They are not remanufactured or upgraded by original equipment manufacturers (OEMs). In Chinese society is particularly price sensitive and to a little extent quality sensitive (quality for a given price) but not environment sensitive in its buying and promotion behavior in past years. Therefore, reverse logistics has not received the desired attention and is generally carried out by the unorganized sector for some recyclable materials such as paper and metal. As well, manufacturers must deal with returns from retailers, the channels of distribution, or end customers with warranty issues. To the cement supply chains, they are faced with environmentalist, so they must consider return activities, such as exhaust emission and waster disposal, dismoded cement recall etc. For example, in 2005 there was more the emitted cement tunnage's amount than two cement factories outputs, reported by Chinese News. Each return is taking the manufacturers from 4 to 12 weeks to fully process (Cruz, M., 2000). Returns are a small percentage of sales for the retailer or manufacturer, however, in high volume environments like consumer goods and the cement product, this small percentage adds up to a large reverse logistics problem (Guojun Ji, 2007).

This paper is divided as follows: The benefits of implementing CLSC are discussed in section 2, which are also the drivers of CLSC. Next, the cooperation process of by-products exchange is studied by game theory and a pricing model is described. A case study of Guangxi Guitang Group is analyzed in section 4.

II. BENEFIT OF CLSC

The reverse supply chain contains items that are defective, damaged, or otherwise unneeded by the intended user. Probably the first contributors in designing a CLSC were (Thierry *et al.*, 1995) with their model of an 'integrated supply chain'. This chain of companies has been defined as a supply chain, which comprises service, product recovery, and waste management activities. In this model, products return from the end-user to undergo a product recovery operation, such as re-use, repair, remanufacture or recycling. Thereafter, products are integrated back into the 'forward' supply chain. Further discussion has shown that the additional activities the reverse supply chain includes comprise product acquisition, reverse logistics, test, sort, disposition, refurbish as well as distribution and marketing (Guide & Van Wassenhove, 2003). While there are a variety of theoretical considerations for conventional supply chain management, there is still a lack of a theory for CLSC management, particularly with regard to the additional elements that the CLSC incorporates. From these mentioned, these items appeared in CLSC must be returned to the supplier for credit or disposal. The items in CLSC take longer to identify and process. This delay coupled with a lack of visibility of the items moving backward slows

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the movement of items into and out of major distribution centers. This delay can have an impact on readiness of combat units and increase the amounts of supplies retained at the unit level. Therefore, how to evaluate the performance of CLSC is very important meaning.

An increased focus on CLSC practices has been evident due to external factors such as environmental legislation and customer requirements, as well as internal factors, such as business profit. Among them, the primary ones are economical, social and environmental efficiencies.

A. *Economical Benefits*

Even though CLSC is proposed primarily based on environmental and social considerations, studies have shown that a number of economic benefits and added-value can arise from different aspects.

(1) Decreases the cost of supply chain. In CLSC, the creation of economic value is based on efficient processes that minimize consumption of scarce resources. For example, waste materials during production, distribution and use are collected, sorted, and recycled. Products and service packages are designed in such a way that repair and maintenance, updates, and returns of products are synchronized with value recovery processes, such as remanufacturing and refurbishing. These processes extend the life of products and parts to several use cycles. When firms cooperate to make decisions regarding environmental issues, it is found to be positively linked to the selection of pollution prevention technologies, which usually generate benefits in terms of cost and quality (Klassen and Whybark, 1999). Similarly, Desrochers (2004) thought building recycling networks between companies could reduce waste treatment and disposal costs, gain access to cheaper materials and energy, and to generate income from residues. Purchase cost of raw material also can be reduced by the enterprise's cooperation since the by-product of the upstream enterprise may be delivered directly as the raw material to the downstream enterprise. Proactive management of the suppliers' environmental performance can lead to product and process simplification and the more efficient use of resources. The relationship between firms in the CLSC, is close, stable and long-term, so that the transaction cost is reduced. In addition, CLSCM can let firm escape stern punishment brought by the increasing execution degree of environment laws. In a word, attention to “end-of-life” product disposal issues can lessen waste liability, reduce the cost of materials and improve asset utilization.

(2) Creates a green image. The company of CLSC would be looked as environmental friendly, responsible, involved with community, and ecologically active. Now the cost and quality of products are not the only aspects that the customers are concerned with. With increased awareness and means of communication, customer satisfaction and loyalty also depend on how the company has produced the goods or services, whether the company considering the social, environmental and other such aspects. In the United States, an estimated 75% of consumers claim that their purchasing decisions are influenced by a company's environmental reputation, and 80% would be willing to pay more for environmentally friendly goods (Lamming and Hampson, 1996). Based on these arguments, a green image can improve both the sales and the value of the company (its brand goodwill). The price of green product is often higher than the normal product. For example, the price of green sugar is almost 4 times of normal sugar. There is a growing demand for eco-friendly products in both European and other major world markets. It is obvious that green product make firm get differential advantage, avoid intense price war, develop new market, so gain high return。

(3) Generates more profits. The application of environmental manufacture mode, such as clean production, can improve the firm performance. (Gladwin, 1993; Hart, 1995; Shrivastava, 1995; Reinhardt, 1998). Using a case study, COATO, Enrique Claver (2006) tested a positive correlation between the environment-friendly strategy and the improvement of firm performance with respect to the other firms in its sector. A survey of North American manufacturers, is also used by Stephan Vachon and Robert (1999) to examine the impact of environmental collaborative activities on manufacturing performance. The result showed that the benefits of collaborative green practices with suppliers were broadest. In addition, firms also can gain profit by by-products exchange. In some industries, there has been a tradition of by-products exchange within the industry. For example, firms in petroleum chemical industry usually seek the methods of using effectively products and by-products, and the food processing industry also gains profit by selling their by-products. Especially, high value materials can be extracted from some by-products with special technologies.

（4）Improves competitive advantage. The adoption of eco-efficient manufacturing methods creates the possibility of more flexible plant configuration and enhanced productivity. Companies that can lower their exposure to risks, such as increased costs resource input (e.g. energy) and resource scarcity, and/or reduce their dependence on limited/non-renewable resources within their supply chain, will gain in long term competitiveness and be increasingly more attractive to shareholders due to lower risk exposure. Enrique Claver (2006) found environmental strategy favored the development of new organizational capabilities that have contributed to the appearance of advantages derived from the greater accumulated experience of employees in creating new projects that are designed to reduce residues and pollution. He also pointed that enterprises has also obtained a competitive advantage in differentiation thanks to an improved brand image and to its increased credibility in business relationships. And manufacturer can focus on the company core business, when they empower their eco-partner in the collection process or sell their by-product to them. Certainly, a “green” firm can get the support of government by tax reduction or financial bonus. In 2007, the Central Government of China allocates 23.5 billion to encourage energy conservation.

B. *Social Efficiency*

Constructing CLSC system makes for the human society sustainable development, which add values to the entire society and sets up correct expense view. Li *et al.* pointed out that established environmental-friendly supply chain by the cooperation of enterprise was an inevitable trend which would increase social welfare. (1)Ecological design may reduce the harmful components of product so as to avoid consumer endangered at the process of consumption. By carrying out clean production and by-product exchange, the enterprises can reduce largely the emission of wastes, consequently create a depurated working environment for employees, maintain clean environment for communities. （2） Recovery of used products lessens the social burden of treating lot of wastes, the external diseconomy of environment. CLSCM make the competitive ability of firm stronger, which can benefit to investors and create more job opportunities, improve resource efficiency, resulting to prompt the development of local economy. Government also can benefit from recycling of waste by increasing revenue. （3） Deficiency of water resource would be lessened since industrial waste water reuse can decrease the demand of water. Energy conservation and diversified energy usage have a positive relation with environment protection and energy conservation. For example, a few of enterprises in Holland, Belgium and Luxemburg have established the joint system which can realize heat energy sharing or recycling controlled by the intellectualized computer system. It can save 20% of their national electric power consumption and reduce 15% of emission of Carbon Dioxide and other harmful gases.

C. *Environmental Efficiency*

Roland (2000) found recovery of used products for recycling or reuse, may bring a major reduction in environmental impact along the whole supply chain, and Taeko Aoe (2002) quantitatively shows that producers can achieve absolute decoupling of environmental impacts and functionality at the product level by ecological design. By-products exchange between firms can recycle materials in a wider scope, consequently reduce resource consumption and improve resource efficiency. As a result, "green effect" is lessened. For example, a power plant in Finland improved utilization efficiency from 40% to 85% by by-products exchange. According to statistic data from Bureau of Environmental Protection of the United States, waste steel used as the replacement of iron ore in steel-making can decrease almost 70% of energy consumption and 86% of waste gas emission. Similarly, replacing virgin steel by waste steel collected from used electrical home appliances can reduce 97% of mining waste, 86% of air pollution, 76% of water pollution, 40% of water consumption and 74% of energy consumption. Note that waste steel has the same performance with virgin steel.

III. PERFORMANCE EVALUATION MODELS

Based on thermodynamics, exergy is defined as the maximum amount of work which can be produced by a system or a flow of matter or energy as it comes to equilibrium with a reference environment. With the quantity of energy, exergy deals with both quantity and quality of energy. The combination of exergy analysis and economics is represented by exergoeconomics.

A CLSC system can be simply activities with resources (labor, cash, material etc.) and energy (information, technology etc.) are the inputs, and products, wastes (excess material, the defect etc.) and waste energy are the outputs of the system. Some of the outputs can be reused, such as excess materials, but others are turned into real wastes and can not be used again. Therefore, resource utilization and environmental impact determine the sustainability of a CLSC system and become the key performance indicators. Environmental impact can be decreased using by the increasing of the exergy efficiency of a reverse supply chain (Ji 2006). Considering characteristics of a CLSC, the environmental impact will reflect three ways:

(1) Order destruction and chaos emergence. The components of a CLSC are scattered geographically. It is easy to see the CLSC become chaos and hard to find out the causes based on the complexity theory. For example, the existing uncertainties result in the operation difficulty in a CLSC such that our environment is too bad. In fact, the more destructed the CLSC system is, the lower the exergy efficiency is, and the worst the performance is.

(2) Resource degradation. Three main factors can result in resource degradation: poisonous composition of the used resource, harmful pervasion from the reactivity of the used resources and the defects damage to the society or human life. The principal general techniques that are applied in reducing the environmental impact are green design which takes the environmental factors and economy rationality into consideration, so that improve the exergy efficiency and minimize the exergy losses of every process in the whole product life cycle so as to lower the environmental impact.

(3) Waste exergy emissions. The exergy of wastes is a consequence of not being in stable equilibrium with the environment and represents a potential to change. Usually, emitted exergy causes a change which may be damaging to the environment, such as radiation harmfulness for human due to the disused mobile phones, although in some cases the change may be perceived to be beneficial (e.g. the achievement of closed loop for the whole product life cycle).

First, the exergy analysis is extended to take the environmental impacts of a CLSC system into consideration. The CLSC system influences the environment because of the waste discharged by it which includes two parts: one is from the emitted heat; the other is the physical exergy and chemical exergy of the waste itself. However, the various components in the wastes, with different chemical nature, bring different harm to the environment. A harm coefficient can be defined to denote this. Environment negative effect is defined as ENE, $ENE = \sum_i B_i E_{x,i}$, where $E_{x,i}$ denotes the physical and chemical exergy of the component i in the system's wastes; and B_i is the harm coefficient of component i to the environment.

Second, the exergy analysis can be extended to assess the comprehensive effect of the CLSC system considered resource and environmental impact. So, while dealing with the total effect of the CLSC system, the exergy discharge loss should be considered twice, resource waste in the total exergy loss of the system, and impact on the environment in the ENE. However, the resource waste and environmental pollution can not be considered as equal, so the effect coefficient is introduced to use here. The system negative effect (SNE) is defined as $SNE = C_1 E_{xl,tot} + C_2 ENE$, where, $E_{xl,tot}$ is the total exergy loss of the system; C_1 and C_2 are the effect coefficients. It is difficult to determine the effect coefficient of the system's negative effect, since resource waste cannot be compared with environmental pollution in a direct way. To solve this problem, the economic losses often are used to determine the effect coefficients. Let the exergy loss of the system represents as $E_{xL} = \Delta M + \Delta P + R$, where ΔM is the material loss of the system, ΔP is the product loss of the system, and R denotes the residual of the system. Then the economic loss caused can be calculated by the equation that $E_{eL} = \sum E_{xL} P_{in}$, where P_{in} denotes the average input exergy cost of the system.

SNE is an absolute variable, which can be used to evaluate different models of the systems with the same type or the different designed systems, but cannot be used to evaluate the different types systems. So a relative variable $SNEF$ is defined as $SNEF = \frac{SNE}{E_{x,in}}$, where, $SNEF$ is factor of SNE, and $E_{x,in}$ denotes the system's input exergy.

IV. CASE STUDY

As the largest listed company in the Guigang city of Guangxi province in China, Guangxi Guitang Group was established in 1954 to produce cane sugar. Today it is the largest sugar-making company in China which has several other industrial enterprises, such as a pulp-making plant, an alcohol plant, a cement mill and a fertilizer plant etc. The annual total outputs reflect sugar (120,000 tons), paper (85,000 tons), alcohol (10,000 tons), cement (330,000 tons) and fertilizer (30,000 tons) (Zhu *et al.* 2004). All these plants are based on by-products generated from the sugar refinery.

A. The Sugar CLSC of Guangxi Guitang Group

The sugar industry has been one of the major polluter in China, since most small scale refineries don't meet the existing environmental standards. To reduce resource wastage and environmental pollution, a sugar CLSC in the Group is established to recycle these industrial wastes and return from the end channels to gain economical and environmental, social benefits simultaneously. Initially, the environmental supply chain was built within the Group and gradually extended to external enterprises. Now the sugar CLSC consists of an ecological farm, a sugar refinery, sugar distributors, retailers and other enterprises acting as the reclaiming agents. Reclaiming agents include an alcohol-processing plant, a compound-fertilizer plant, a pulp plant, a thermoelectricity plant, a cement mill and other recyclers. Figure 1 shows three main flows in the CLSC of the Group: (1) The forward chain is from sugarcane farmers to customers. (2) The reverse chain is from customers to suppliers. Some returns from consumers are processed within the sugar refinery, some useless wastes are sent to recyclers, such as water depurative plant. (3) The by-products flow is from sugar refinery to reclaiming agents are reused.

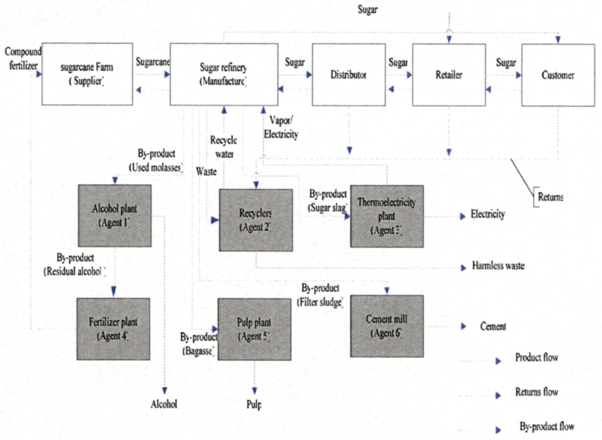

Figure 1. CLSC of Guangxi Guitang Group

To optimize the environmental and economic performance of the whole network of companies within the Group, Guangxi Guitang Group has complied with the ecological design principles to optimize the production process and adopt ecological management. Within the sugar chain, three approaches have been used to process residual products, i.e., reuse, magnitude reduction and disposal. By-products such as sugar residue, consumed molasses and filtered sludge, become the material of the pulp plant, the alcohol plant and the cement mill respectively to produce pulp, alcohol and cement. The by-products of alcohol plant, residual alcohol can also be reused by the fertilizer plant to produce compound fertilizer that is sold to the sugarcane farmers. In order to reduce the amount of residual products, cleaner production technologies are applied. New technologies are used to improve water efficiency, which is expected to reduce wastewater between 30% and 40%. In addition, the sugar refinery delivers sugar residue to the thermoelectricity plant, and the reverse flow is electricity and vapor. The recycle resources, such as water, are also sent back to the sugar refinery. Hence, there are some recycling flows in the sugar CLSC, which not only make the environmental effect minimum and the resource maximum, but also improve these enterprises' financial performance. The Group also maintains close relationships with his primary suppliers, sugarcane farmers. Based on above discussion, the sugarcane farmers can decrease the magnitude of fertilizer. In addition, the Group provides technological and financial supports to farmers to improve the quality of sugarcane and resolve the green production problems, and to encourage them to develop scale economics. The long-term contract with farmers ensures the supply of sugarcane and encourages the farmers. All these efforts make sugar with a higher quality and a lower cost, which increase the competitive advantage of sugar in the international market. The Group produces the best quality sugar in China, and thus shares a large market. Its average sugar price is between 30% and 35% higher than that made by other Chinese sugar refineries because of the good quality.

By taking full advantage of by-products and CLSC in an environmental, social and economical responsible manner, the

Group has realized multi-win of human, nature and society. In the members of the Group, they consider traditional 'waste' as resources, which reduce the material cost. They can share updated information via the common platform and easily set up cooperative relationships. As a result, CLSC management helps the Group to decrease the transaction costs committed from interactions within different companies in the supply chains. Since all sugarcane is produced by the farmers in the Guigang city, the Group can receive benefit from the low transportation cost. Coca-Cola and Pepsi-Cola used to purchase sugar from other countries, but have begun to buy sugar from the Group. Many domestic soft drink companies, such as the Wahaha Group also order sugar only from the Group. The main reason is that the sulfur content in the sugar made by the Group is lower than that of other Chinese sugar plants. This is because the Group improves environmental technologies continually and manufactures higher quality of "green" sugar. Most enterprises in the CLSC are linkage tightly around the Group, which facilitates communication among the actors. The government and employees of the Group also can benefit from the CLSC management, because they can get higher revenue. Considering water resource shortage, the Group not only has improved quality of water from the rivers also constructed the by-products reuse system. Similarly, air quality is improved as most CO2 and other toxic gas must be processed. The rapid development of the CLSC drives the development of the related service industry and increases job opportunities and the living level of local people. The Group can decrease its operational risks efficiently regardless of the occurrence of disruption by frequently improving supply management, demand management, product management and information management. Therefore, the Group has made progress both economically and environmentally while most sugar companies in China are still struggling for survival.

B. The Evaluation of the CLSC

Two cement CLSC systems typically are selected from Guangxi Guitang Group, A and B. The flow charts of system A and B are shown in Figure 2.

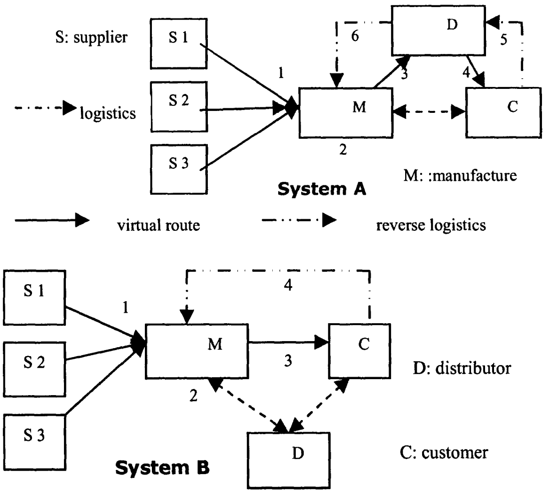

Figure 2. Flow charts of cement CLSC systems A and B

Based on exergoeconomics and in view of the resource utilization and environmental impact, the calculation and analysis of the sustainability of the abovementioned cement CLSC systems performance is considered as follows: (1) Calculate the input exergy, the output exergy, the whole system exergy and the physical and chemical exergy of all wastes in these two CLSC systems. Since the harm coefficients are hard to determined, we use the emissions limit for secondary standard in Cement Factory Atmosphere Emissions Standard constituted by China Environment Protection Department (GB 4915-1996) as the harm coefficients. So the environmental negative effect in supply chain system A is:

$$\begin{aligned} ENE &= 0.00006\times10^6\times0.9+21.1318\times10^6\times1.0+0.0006\times10^6\times2.4 \\ &\quad +0.2376\times10^6\times0.03=2.12\times10^7 kj/T \end{aligned}$$

And that in system B is $ENE = 4.57\times10^6 kj/T$. (2) Calculate the economic loss caused by resource waste. It can be deduced by the average input exergy cost of a system multiplying the total exergy loss of the system. So the economic losses of resource waste in system A is 1,590,800RMB/a, and that in system B is 1,538,000RMB/a. (3) Calculate the economic loss of environmental impact which caused mainly by the powdery dust, CO_2, SO_2 and other oxides emitted from the cement CLSC system. It can be divided into two parts, one is the influence on the natural environment and the other is that on human health. It is hard to quantify the economic loss of the natural environment caused by the system. To some extent, the pollutant penalties are established by the Environment Protection Departments, the processing cost to handle the contamination in the factories, cost of dust catcher and cloth for enveloping the powdery dust on trucks can reflect the approximate costs, so we can use the sum of these to denote the economic loss of environment effect in cement system A is 222,000RMB/a, and that in system B is 191,000RNB/a. The economic loss caused by the influence on human health can be calculated by the sum of direct and indirect economic loss. Cement powder dust is a harmful substance. Inhaling sufficient quantity can result in diseases, such as lung disease, and it deteriorates the working ambience. Direct economic loss concludes medical cost, income loss and cost on dust protection measures for workers. Indirect economic loss is comprised of economic loss based on work delay and food pollution. Therefore, the economic loss of human health caused by both cement CLSC systems is 24,710RMB/a. And then we can calculate the total economic loss of the cement supply chain system A is 249,410RMB/a, and that of system B is about 215,710RMB/a. So, we can calculate that, for system A, SNE is 2.888 and $SNEF$ is 0.0174; for system B, SNE is 0.272 and $SNEF$ is 0.0016.

The above results show that the system negative effect factor can finally evaluate resource utilization and environmental influence in the CLSC system, which are the two key aspects of sustainability and can be used as an objective to further optimize the CLSC. The results show a less effect coefficient of environment negative effect. This is because the effect coefficient is calculated by economic loss. In the present system of price and pollution penalty, the resource waste plays a primary role in system negative effect. But with the increasing recognition of the environmental protection, more restrict criteria of contamination discharge will be issued. Besides, the companies in CLSC think more of the reverse logistics. If not be responsible for the whole life cycle, company will be punished or even excluded from the market place. It can be seen from the results that the main contamination released by the cement CLSC is cement powdery dust. So the system should be improved by reducing the outgoing of powdery dust, for example, utilizing the advanced dust catcher and regulations for envelopment of the trucks. The negative effect coefficient of cement CLSC system B is much less than that of system A, this means that system B is much better than system A in sustainability. It can be easy to see that cement flow in system A is more complicated than system B, thus resource waste increases, environment aggravates.

V. CONCLUSIONS

A great deal by-products would inevitably emerged and cause environment deterioration. By-products reusing could reduce the use of virgin materials as resource inputs and the volume of waste products requiring disposal (with the added benefit of preventing disposal related pollution), increase resource efficiency and the amount and types of process outputs that have market value. Therefore, in CLSC, by-products exchange is an essential part which plays an important role in improving waste material utilization, preventing environmental pollution and bettering firm performance. Firms also can get economical benefits from it. External Diseconomy in resource utilization leads to the conflict between the thought of optimizing ecological efficiency and the behavior of maximizing economical benefit for traditionally economic man. Thus, economic man should become ecological-economic man whose behavior criterion is ecological efficiency maximization. The cooperation processing based on by-products exchange in CLSC is discussed by game theory, with the decision-making criterion of eco-efficiency maximization. According to the above premise, a pricing model of two firms is discussed. Government attention to environment and the advance technologies development can facilitate the by-products exchange.

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