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REPORT
CREED

# Plastics Recycling in China
# an international life cycle approach

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# Preface

This project was conducted within the programme of Collaborative Research in the Economic of Environment and Development (CREED). CREED was established in 1993 as a joint initiative of the International Institute for Environment and Development (IIED), London and the Institute for Environmental Studies (IVM). The secretariat for CREED is based at IIED in London. A Steering Committee is responsible for overall management and co-ordination of the CREED Programme.

The ultimate goal of CREED is to enrich the knowledge base and widen the debate on sustainable development by strengthening research capacity in environmental economics and policy analysis in developing countries. This is achieved primarily through collaboration in research projects, information and dissemination involving initially IIED, IVM and counterparts in developing countries.

This document presents the final report of the CREED project *Recycling and Trade of Waste Plastics in China*. This project is a collaborative study involving the Institute for Environmental Studies (IVM), the Chinese Academy of International Trade and Economic Co-operation (CAITEC), in Beijing, and the Policy Research Centre for Environment and Economy (PRCEE), in Beijing. The project was initiated in early 1997. Several publications among which 2 CREED Working Papers appeared under the project. An interim and a final workshop was organised in Beijing to generate feedback on the preliminary findings and to disseminate the final results. The minutes of the last workshop are presented in Appendix XIII.

## Acknowledgements

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# Executive summary (English)

In the coming years and into the 21st century, plastics gain further importance in Chinese national life. Both consumers and industrial users expand their demand for plastics, both in terms of quantity and quality, with an estimated annual growth of 20 percent. The coming decade is a crucial period for the Chinese plastics industry in meeting this demand. At the same time, the rapidly increasing waste burden of plastics has to be minimised. At present, around 50 to 60 percent of waste plastics is left uncollected or is dumped in an uncontrolled manner on land, in rivers or in the sea. This requires intense efforts on the part of the formal and informal waste management sectors as well as the plastics recycling industry. The Chinese recycling sector can reduce the burden of solid waste by creating a market for recovered materials while simultaneously narrowing the gap between the demand and supply of plastic resources.

This research project analyses the role of the plastic recycling industry in creating a more sustainable plastic cycle in China. This role is addressed here both from a qualitative and a model-based angle. The qualitative study, through a field survey and a literature inventory, highlights the following trends and issues on the plastics cycle in China.

- Final demand for plastics is growing rapidly. The domestic primary plastics industry is unable to meet this demand, as a result of which China is highly dependent on imports of plastics. At the same time, waste management in Chinese cities is incapable of dealing effectively with plastics waste. This effect is exacerbated by the fact that less waste plastics are 'formally' recovered because government involvement is less.
- In China, two types of recyclers are distinguished: the ones using domestic waste plastics and the ones using imported waste plastics. The two types have different characteristics. Labour productivity of the importing recycler is higher due to better quality inputs, scale of operation as well as the higher capital intensity of production.
- The recycling rate of plastics (the actual utilisation of waste plastics in plastics production) is declining mainly because recyclers suffer from lack of supply of waste plastics. Import of waste plastics can partially reverse this trend. Yet, critics of trade in waste plastics argue that this type of imports are in reality a disguise for waste dumping by the exporting country. Moreover, cheap imports of waste allegedly crowd out the local recovery system leading to a domestic waste disposal problem.

To further analyse these issues, various scenarios are operated, based on a sectoral cradle-to-grave planning model using the mass balance approach. This model has a dual purpose. The first is to investigate how the Chinese plastics sector can face the acute shortage of plastics in an economically and environmentally sound manner. Options at hand are, on the one hand, to increase domestic production of primary and/or secondary resin, or on the other hand, to expand imports of primary and/or secondary plastics commodities. The second purpose of the model is to shed more light on the trade of waste and to test the claims put forward by the critics. The model integrates financial, environmental transport and trade issues.

The main conclusions of the modeling exercises are:

- The financial and economic costs of the plastic cycle in China can be reduced by increasing the capacity of the domestic recycling industry. Most of the simulated scenarios highlight the limited existing capacity of the recycling industry. This shortage forces the final goods manufacturing sector to use a higher proportion of primary resin in their final goods than what is economically and technically desirable. This has been one of the reasons for the large import of primary resin.
- The additional required recycling capacity should preferably be met by domestic waste plastics. Not only are transport activities avoided but it also reduces the waste burden created by post-consumer plastics. This requires additional attention for the recovery sector of plastics. The recovery rate of waste plastics, which in the last decade plummeted from 20 to 5 percent of the total amount of generated waste plastics, should be reversed as soon as possible. This may require special policies by the Chinese government.
- Despite this advisability, we do not expect the recovery system to be enhanced on the short term. Too many institutional barriers exist to improve the recovery of the increasing waste burden. Therefore, imports of waste plastics should be allowed to meet the gap between demand and supply of waste plastics in China. This will not have a adverse effect on the balance of payment, as the increase in imports of waste plastics will mainly replace relatively expensive imported final goods.

The qualitative and model-based analysis combined enable us to address the question of how to bring about these changes in a society gradually switching from a centrally planned economy to a market economy. Our recommendations are as follows:

*How to expand the capacity of the plastics recycling industry?*

The role of the government should have an indirect nature by removing obstacles for the industry. It is doubtful whether economic measures are effective because at present most recyclers avoid tax. Also subsidies generally prove to be an ineffective and expensive tool. Alternatively, the government should promote research and development (R&D) focusing on present recycling technologies (i.e. pre-treatment stage), new forms of recycling technologies such as chemical recycling, and the recyclability of end-products.

*How to revitalise the waste plastics recovery sector?*

It is doubtful whether efforts should be intensified towards rebuilding the formal sector. The operating costs both for collecting and recycling of the informal sector are much lower. However, a serious threat to individual operators is the implementation of large scale waste collection systems which do not allow for separate recovery of the recyclable waste. The government should therefore develop a management system which integrates the operations by the informal sector. Yet, the responsibility for waste not lies solely with the government. Increasingly industries are held responsible for their impacts. A convincing example of extended responsibility in the plastics cycle in China is presented in Beijing where the food packaging producers finance a recovery system.

Obviously, it is economically nor environmentally feasible to recover all waste plastics for purposes of mechanical recycling. It is therefore better to designate a specific type of recycling for a specific types of waste. For example, it can be assumed that the principal form of processing of industrial waste plastics, such as cut-offs, is mechanical recycling. Similarly, feedstock recycling mainly focuses on agricultural film, and energy recovery is applied mainly to household waste such as contaminated food packaging. Such a recycling hierarchy becomes ever more appropriate with the expected diversification of technologies and recovery systems.

*How to design a desirable trade policy for waste plastics?*

As mentioned earlier, plastic production in China is unable to meet the needs of the domestic market. Besides boosting imports of plastic products, the domestic shortage raises imports of raw materials, such as monomer, polymers and waste plastics. It is expected that this trend continues over the next few years. However, with the establishment of several ethylene projects in the next century, imports of plastic raw materials are expected to slow down. In the process of substituting domestic for imported materials it will be important for Chinese production to meet international levels of efficiency to avoid protective trade measures.

China is among the largest importers of waste plastics in the world. An obvious explanation for this phenomenon is that due to the low wages in combination with the relatively low import costs, plastics recycling is an attractive economic activity to conduct in China. This trend is supported by the booming demand for plastics in China. Still, due to the occurrence of various incidents, the Chinese government mainly recognises the threat of imports of waste plastics. Policies have been implemented accordingly. Especially with the eye on long term investments, it is important for the recyclers in China to know whether the international market will remain a reliable source of raw materials. The best approach is to further improve the monitoring system of imports of waste plastics to guarantee sufficient supply for the domestic recyclers, while simultaneously protecting China from unwanted imports. Obviously, as recognised in the Basel Convention, a major responsibility also lies with the exporting country. The costs of monitoring and enforcement, ignored in this study, have to be analysed further to show the real trade-off between more imports of secondary plastics versus alternative scenarios.

In addition to the availability of waste plastics on the international market, the effects of imports of waste plastic on the plastic cycle in China are addressed. We assess the risk that imported secondary materials are substituted for domestic secondary materials. In this case, the domestic recovery sector suffers from increased imports. As a result, increased amounts of solid waste are generated. The modelling exercise, however, demonstrates that under current circumstances, this crowding-out effect does not take place. In fact, it was found that imports actually upgrade the quality of the inputs of the recycling industry and thereby improve the marketability of secondary products. In other words, the recovery sector is not damaged by increased imports of waste plastics. Also the argument that promoting the recycling industry would go at the cost of the primary segment of the industry is found to be invalid. The study shows that, given the large increase in demand for plastics in China, and the relative segregation of the primary and the secondary plastics market, it is unlikely that the primary industry will experience any significant effects from increased recycling.

# Executive Summary (Chinese) 摘要

今后几年直至进入 21 世纪，塑料在中国人民的生活中将变得愈益重要，消费者和工业用户对塑料的需求无论数量上还是质量上都将有所提高，估计需求量年增 20 %。未来 10 年对于中国的塑料工业能否满足需求将是至关重要的阶段。与此同时，必须将迅速增加的废塑料减到最少。目前，约有 50 — 60 %的废塑料未经收集或被随意倾倒在土地、河流或海洋中，这要求正规与非正规的废物处理部门以及塑料再生工业付出努力。中国的再生工业可以通过创造一个回收物资市场来减少固体废物，同时缩小塑料供需之间的差距。

本研究项目从定性和模型两个角度，分析中国再生工业在创造一个更加可持续的塑料生命周期中所起的作用。通过实地调查和文献研究的定性研究凸现出中国塑料生命周期中的以下几个趋势及问题：

●对塑料的最终需求增长迅速。国内原生塑料工业无法满足需求，因此中国高度依赖塑料进口。同时，中国城市的废物处理部门无力有效地解决废塑料问题，而由于政府介入减少致使“正规”回收的废塑料减少，又加剧了这一问题。

●中国的再生塑料厂分为两类，一类用国内废塑料，一类用进口废塑料。两类厂有不同的特点，后者由于投入原料的质量较高、生产规模较大、资本密集程度较高，因而其劳动生产率也较高。

●塑料的再生利用率（废塑料的实际使用量占塑料产量之比）正在下降，主要是由于再生厂受废塑料供应不足的制约。废塑料的进口可以部分地扭转这一趋势，但是废塑料贸易的批评者反对说，废塑料进口实际上是出口国废物倾倒的借口。另外，廉价的进口废塑料据说排挤了国内回收系统，从而导致了国内的废物处理问题。

为进一步分析这些问题，在分部门“从摇篮到坟墓”计划模型的基础上，我们运行了多种模拟方案。该模型有两个目的，第一个是研究中国塑料工业如何在经济学上和环境友好的角度上面对塑料的严重短缺。目前的选择是，一方面，增加国内原生树脂或再生树脂的生产，另一方面，扩大原生或再生塑料的进口。模型的第二个目的是更多地关注废塑料贸易，检验批评家们提出的看法。模型综合了财政、环境运输和贸易几个方面的问题。

模型运行的主要结论如下：

●可以通过提高国内再生工业的生产能力而减少中国塑料生命周期的财务成本和经济成本。大多数模拟方案凸现了再生工业现有生产能力的不足，这一短缺迫使最终产品制造业在生产最终产品时，使用原生树脂的比例高于经济上和技术上所要求的比例，这是大量进口原生树脂的原因之一。

●用国内废塑料满足再生能力的增加是更可取的办法，这不仅能避免运输活动，而且减少了塑料消费后造成的废物问题。这要求更多地关注塑料回收部门。废塑料的回收率在过去十年间从占废塑料总量的 20 %跌落至 5 %，这一趋势必须尽快扭转，这要求中国政府采取特殊的政策。

●尽管有这些可取的办法，我们并不指望回收系统能在短期内获得改善，要改进日益增加的废物的回收工作，还存在着太多的障碍。因此，应允许进口废塑料以弥补中国废塑料供需之间的差距。这对收支平衡并无副作用，因为废塑料进口的增加将替代相对昂贵的最终用品的进口。

综合定性的和基于模型的分析，使我们得以解决在从计划经济向市场经济转变的社会中，如何能引起这些转变的问题。基于以上研究结果，我们建议如下：

*如何扩大塑料再生工业的生产能力？*

政府的作用应是间接的，通过消除产业发展的障碍来实现。由于目前大多数再生厂逃税，经济手段是否有效令人怀疑。同样地，补贴一般来说也是一种无效的、昂贵的政策工具。政府应促进研究和开发，重点在现有再生技术（即预处理阶段）、化学再生法等新的再生技术形式、以及最终制品的可再生性。

*如何激活废塑料回收部门？*

人们对是否应加大力度重建正规回收渠道有疑问。非正规渠道的回收和再生成本都大大低于正规渠道，然而，一个严重威胁个体经营者的是大规模废物回收制度的实施，该制度并未考虑到可再生废物的分离回收。因此，政府应制定一个结合非正规渠道的废物管理体制。但是，废物处理的责任不应单由废物管理部门承担，日益增加的工业部门也要对他们的影响负责。在中国塑料生命周期中扩展这种责任的一个令人信服的例子是，在北京，泡沫饭盒的制造厂要向回收部门缴纳费用。

显然，将废塑料全部回收用于机械再生在经济上和环境上都是不可能的，因此，更好的办法是对特定品种的废塑料采用特定的再生方法。例如，假定工业废塑料（下脚料等）的主要加工形式是机械再生，进料再生法主要用于农膜，而能源回收法主要用于家庭废物，如污染的食品包装等。这样的等级制对技术和回收系统的多样化更为适宜。

*如何制定适合的废塑料贸易政策？*

如前所述，中国的塑料产量不能满足国内的市场需求。除了增加塑料制品的进口外，国内的短缺还增加了原材料的进口，如单体、聚合物及废塑料。估计今后几年这一趋势仍将继续。但是，随着下个世纪几大乙烯工程的建成，塑料原材料的进口可望减少。在进口替代过程中，重要的是使中国的生产效率达到国际水平，而避免使用保护性的贸易措施。

中国是世界上最大的废塑料进口国，对于这一现象的显而易见的解释是，由于低工资及较低的进口成本，塑料再生在中国是一项颇具吸引力的经济活动，中国对塑料的旺盛需求又支持了这一趋向。由于一些事件的发生，中国政府仍然主要看到废塑料进口的危害，并已实行相应的政策。尤其当着眼于长期投资，对中国的再生厂来说，重要的是要了解国际市场是否能保持稳定的原料供应。更好的方法是进一步改善废塑料进口的监控体制以保证国内再生厂有足够的供应，同时排除有害物的进口（显然，正如巴塞尔公约中公认的，主要的责任在出口国）。

除了国际市场上废塑料的供应，我们还注意到进口废塑料对中国塑料生命周期的影响。我们评估了进口再生塑料替代国内再生塑料的风险。在这种情况下，国内回收部门将受到进口增加的冲击，结果是，产生的固体废物将增加。不过，模型运行显示，在目前情况下，这种挤出效应并未发生。实际上，我们发现，进口废塑料提高了再生工业投入原料的质量，因而增加了再生制品的销路，换言之，回收部门并未因进口废塑料的增加而遭受损失。同时，促进再生工业的发展将牺牲原生塑料工业的说法也被证明是站不住脚的。研究显示，如果中国塑料需求大幅度增长，并且原生塑料与再生塑料市场相对分离，原生工业不会因再生工业的发展而受到显著影响。

# 1. Introduction

*Pieter van Beukering*

Due to relative low cost, high durability, and low weight, plastics enjoy great popularity in society. As a result, consumption and production levels of plastics have increased rapidly in recent decades. Global consumption of plastics has risen from just over half a million tons in 1945 to 110 million tons in 1995 (Grimaud *et al.*, 1970; ECOTEC, 1995, p.4), mainly due to increased use in industrialised countries. Since plastics consumption is strongly related to income levels, the demand in developing countries is rather small. This can be seen in Table 1.1. It is therefore expected that demand for plastics in developing countries will increase in conjunction with rising income. In China, for instance, per capita consumption increased from 1.2 kilograms in 1980 to 6.7 kilograms in 1994 (National Federation of Light Industry (NFL), 1996). In Appendix 1 of this report, the development of plastics consumption are elaborated.

*Table 1.1 Per capita consumption of commodity plastics in 1987*

| Region | Plastics consumption (kg per capita) |
|---|---|
| US and Canada | 63.1 |
| Western Europe | 42.4 |
| Japan | 48.2 |
| Latin America | 8.6 |
| Asia | 2.7 |
| Africa | 2.4 |

note: commodity plastics include LDPE, HDPE, PP, PS, and PVC
*source: Vergara and Brown, 1988, pp.29.*

The properties which make plastics so useful also cause a range of environmental problems: litter as a consequence of its durability, contamination from chemical additives leaching in landfills, and pollution from emissions of hydrogen chlorides and dioxins from incinerated PVC. Plastics waste also presents a direct hazard to wildlife. Environmentalists estimate that more than one million tons of waste plastics are dumped into the world's oceans each year, affecting numerous sea birds and marine life. Plastic debris can also clog water intakes, pumps and damage propellers. The production of plastics may also result in major ecological impacts.

Recycling can alleviate many of the environmental impacts of the plastics cycle, both pre- and post-consumption: the re-use of plastic materials should reduce the demand for primary resources as well as the scarce space required for landfill. However, constraints, such as the absence of appropriate sorting techniques and the low value of recycled plastic products, mean that current levels of recycling are low. Yet, plastics recycling is gradually becoming more popular, both in the industrialised world and in developing countries. In Western Europe, for example, plastics consumption which grew by 4 percent between 1995 and 1996, was outstripped by the recycling increase of 19 percent (APME, 1998).

Not all recovered plastics materials are recycled in the country of origin. As with most commodities, waste plastics are increasingly traded on the world market. In contrast to the international trade of primary plastics, such as synthetic resin or final plastic products, the majority of traded waste plastics is imported by developing countries, mostly in Asia. In 1992, developing countries imported only 36 percent of globally traded primary plastics, while they accounted for 79 percent of the waste plastics trade (UNCTAD, 1996). Clearly the bulk of traded waste plastics - 78 percent - came from industrialised countries. More detail on international trade can be found in Appendix II.

China is the second largest destination of internationally traded waste plastics in the world. China imports 11 percent of the global trade. The public image of this type of imports has been damaged severely in recent years. Numerous incidents are reported in the newspapers. Soon after stringent legislation on the import of toxic waste had become effective on April 1 1995, Chinese authorities found 640 tons of paper and plastics waste, originating in the Unites States, in a field near Beijing after locals complained about the stench. Not much later, a 540-ton garbage mound, also from the United States, was uncovered in Qingdao port in the province of Shangdong (Sharma, 1995). Most of these shipments had been imported under the false label of recyclable waste.[1]

This raises the question whether the benefits of allowing recyclable waste to be traded are larger than the potential negative effects of receiving hazardous unrecyclable materials. The potential negative effects depend partly on the quality of the monitoring system installed by the customs, both by the importing and the exporting country.[2] Though crucially important, this issue is beyond the scope of this project. This project focuses mainly on the potential benefits and costs of international trade of recyclable materials to an importing country. Little is known about this topic. This lacuna was illustrated by the attitude of the Chinese government in response to the increasing problem of imports of unrecyclable waste materials. As mentioned, a full ban was installed on the imports of waste plastics in April 1995, ignoring the great number of local plastics recyclers which were dependent on these inputs. Upon the pressure of the Chinese recycling industry, the ban on all waste plastics was soon modified into a ban on household waste plastics (grade C) only. Whether this policy is optimal is one of the questions studied here.

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1 Hong Kong takes account of more than 60 percent of the global trade. Although Hong Kong is traditionally a trading nation with highly open borders, importing such an overwhelming quantity of waste plastics is strange. Hong Kong has a relatively small recycling industry, limited incineration capacity and certainly not the landfill space to manage unrecyclable residues. Exports in the form of transhipments to its neighbouring countries such as China is one of the plausible explanations.

2 It should be kept in mind that if the shipments appear to be illegal, it is often the government of the exporting country who is obliged to take back the hazardous materials and process these in its own country. As the costs involved are exorbitant, the exporting country certainly has a stake in preventing these incidents from occurring.

## 1.1 Key characteristics of the plastic cycle in China

The plastic cycle in China faces significant changes. First, along with the rapid development of the economy and a general improvement in people's living standards, the demand and consumption of plastics have increased dramatically. This trend has become evident particularly since the beginning of the 1990s, with average growth rate of 21 percent per annum. One of the main reasons for this increase, has been the growth of the gross national product (GNP) per capita of approximately 20 percent. Another reason is the high rate of substitution of plastics for other materials. Not only does substitution generally improve the characteristics of the final products, it can also lead to significant savings in energy consumption. Although the demand concentrates mainly on primary plastics products, secondary products are becoming more popular in China. In 1994, 16% of the 8.1 million tons of plastics consumed in China, were secondary products. The main constraint of secondary products is still its relatively lower quality.

Second, despite the rapid expansion of the Chinese petrochemical and plastics industries of 11 percent per annum, production is unable to meet the growth in domestic demand for plastic. As a result, large quantities of plastic commodities need to be imported. For example, imported resins have taken a 50 percent share of the domestic market, rising to as much as 80 percent for some varieties such as PET. One of the reasons for the lack of production is the inadequate supply of raw materials. China has a short supply of ethylene and aromatic hydrocarbon raw materials: most of China's oil is heavy and therefore its naphtha content is low. Another reason for the gap between supply and demand is that, compared to the size of international petrochemical enterprises, the local primary industry is still operating a relatively small production scale. This hinders the accomplishment of economies of scale in the Chinese industry. A main question remaining is how the Chinese plastics sector can face the acute shortage of plastics in an economically and environmentally sound manner. Options at hand are, on the one hand, to increase domestic production of primary and/or secondary resin, or on the other hand, to expand imports of primary and/or secondary plastics commodities.

Third, China has many large metropolises where solid waste disposal problems are emerging rapidly. Large quantities of disposed waste plastics are left uncollected causing surface and ground water pollution. Further, sewage and drainage pipes become blocked with drifting plastic polyethylene bags which in turn cause blockage and flooding within the urban areas. A proportion of waste plastics is collected by a comprehensive informal recycling network. However, changing external conditions hinder their operations, with the result that the burden for municipalities to manage the growing volumes of waste plastics is increasing.

Finally, as already indicated above, the Chinese plastic cycle is highly dependent on the international market. While the domestic production of plastics products in 1994 reached 4 million tons, the net imports of plastics in the same year were almost 5 million tons. To ease the effects of shortages, large quantities of waste plastics materials, in addition to massive imports of virgin plastics, were purchased from overseas markets. As indicated by the statistical data from the Chinese customs, China imported almost half a million tons of waste plastics. After the reunification with Hong Kong, China became the largest importer of waste plastics in the world.

## 1.2 Boundaries of the project

As depicted in Figure 1.1, a large number of economic sectors are directly or indirectly related to the issue of waste plastics recycling in China. The connecting mechanism is based on substitution alternatives for the Chinese plastic manufacturers. This substitution can have various dimensions:

- Both *imported and local primary resin* can serve as a substitute for waste plastics. Therefore, the domestic and foreign petrochemical and primary resin industries are related to the waste plastic cycle. For example, the lack of production capacity of the Chinese petrochemical industry in combination with trade constraints for primary plastics resin will indirectly stimulate the Chinese recycling industry.
- Alternatively, *waste management in industrialised countries* is strongly related. For example, the supply of waste plastics in the international market may increase as a result of government policies in the industrialised countries to increase the recovery of waste plastics by prohibiting landfilling. This can drive down the waste plastic price on the world market and thereby crowd-out the local waste plastic price in China. Thus, waste management strategies in industrialised countries are relevant to this study.
- Obviously, *waste management in the Chinese cities* can also be of great impact on domestic recycling. If for example large incineration plants are constructed, this might have a negative effect on the domestic supply of waste plastics. But, in case of illegal dumping of imported unrecyclable waste plastics, domestic waste management can also be the victim of development in the plastic cycle.
- Finally, the relative demand for secondary and new (primary) plastic products plays an important role. For example, changes in consumer preferences may drive up the demand for recycled products. At the same time, an increase in per capita income may enhance the demand for high quality products and thereby reduce the market for secondary plastic products.

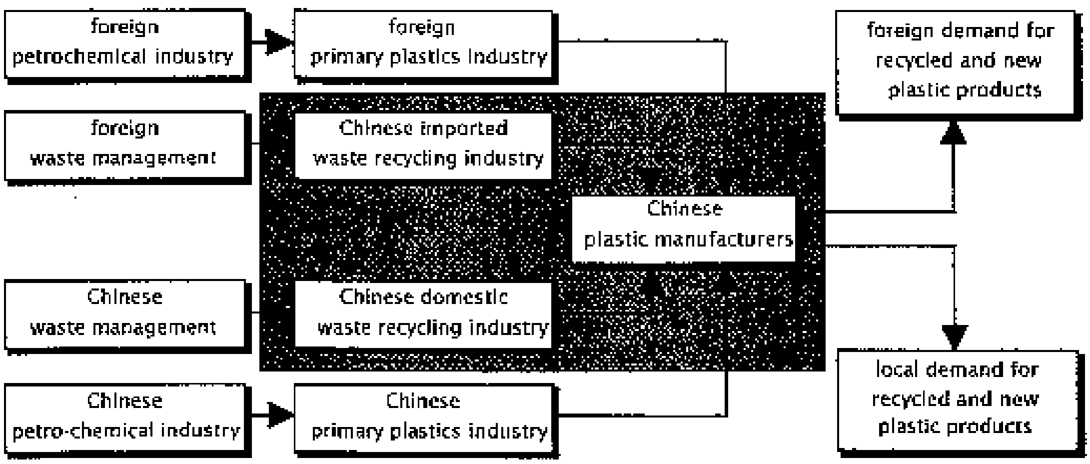


*Figure 1.1 Links to and flows in the plastics cycle in China*

It is beyond the scope of this study to concentrate on all the sectors which are linked to the plastics cycle of China. Although in the coming sections, a full cradle-to-grave study will be presented, only the most relevant sectors are selected for a detailed analysis. This distinction between core-sectors and peripheral sectors in the plastics cycle is depicted in Figure 1.1. The sectors which are studied in detail, consisting of i) the importing recyclers of waste plastics, ii) the recyclers using domestic waste plastics, and iii) the Chinese manufacturing industry using secondary resin as an input, are indicated by the grey area. Sectors outside this area will only be discussed in passing.

## 1.3 Objectives and structure of the study

The aim of this project is to address the economic, environmental and social challenges and threats posed by increased international trade of waste plastics to China. The following specific objectives can be identified:

1. assess the patterns of international trade of waste plastics for recyclable purposes to the 'South' with specific attention to the P.R. of China;
2. determine the economic, social and environmental impact of international trade of waste plastics trade to the P.R. of China;
3. develop recommendations for international and national decision makers with regard to international trade and recycling of waste plastics.

The outcome of this project will be particularly relevant for the Chinese government, but also for institutions and governments in other developing countries to ensure that their international waste trade policies generate the desired impact on the local economy and on its domestic recycling sector in particular. Similarly, the results can support industrialised countries in their decision to prohibit or encourage international waste trade.

The report is structured as follows:

- To become acquainted with the main technical, environmental and economic characteristics of plastics, an overview of the plastics cycle is provided in Chapter 2. For this purpose, national and international literature sources have been used.
- In Chapter 3 the main issues to be researched are identified. The context of each problem is clearly drawn.
- A constraint of research on secondary materials in developing countries is unreliability and limited availability of data. Therefore, a field survey was conducted to supplement the missing data required for the analysis. These are presented in Chapter 4.
- In Chapter 5, a sectoral model is developed in which the complete plastic cycle is captured. This model optimisation model determined the desired configuration of the plastic cycle in China by minimising economic and environmental costs across all stages. Different scenarios are applied, such as a situation with and without the imports of waste plastics. The primary goal of the examination of these scenarios was not meant to identify the best possible scenario, but to learn about the effects of measures in view of the waste and trade policies applied in China.
- Finally, the model results and the qualitative analysis are combined in Chapter 6 in which conclusions and recommendations are formulated.

# 2. Stages in the plastics cycle

*Pieter van Beukering and Zhou Xin*

In this chapter, the current state of the art of the Chinese plastics cycle is explained. Before identifying the main trends and issue, a better understanding of the plastics cycle is required. Therefore, first a short description of the subsequent stages in the plastic cycle and environmental burdens caused by each process, will be provided. A more elaborate description is presented in Appendix III. Roughly, the sequence depicted in Figure 2.1 will be followed. The sequence starts in the oil drilling and cracking stage which generates the naphtha (monomer). Next, in the polymerisation stage the monomer is converted into polymeric structures (synthetic resin). The resin is subsequently processed into plastic products, which after consumption can either be disposed of or recycled.

Because an important focus in this report is on the comparison between recycled or secondary plastics resin with primary resin the term "primary resin industry" is used instead of the common terminology the "petrochemical industry". The primary resin industry is assumed to encompass several steps performed in one location. These steps can be roughly divided into thermal cracking and polymerisation.

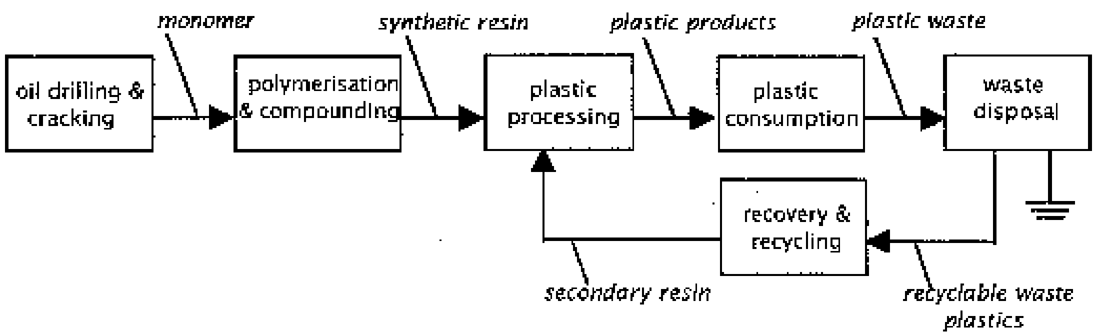


*Figure 2.1 Simplified flow diagram of the plastic cycle*

## 2.1 From oil to monomer

The input for thermal cracking chosen depends on alternative input values, the technical flexibility of the thermal cracker and the market values of the products. The producer has (within certain limits) the ability to change operating variables in order to vary the production of the different monomers. The average distribution of olefins is estimated as follows: ethylene (40%), propylene (15%), butadiene (25%) and aromatics (20%). In this study, butadiene can be considered a by-product which is marketable as a raw material for the production of synthetic rubber. In China the majority of the petrochemical plants are fuelled with domestically produced naphtha. There is an aggregation of the plants producing the different resins due to the inevitable simultaneous production of certain base chemicals during thermal cracking. This way, expensive transport of the often toxic intermediates is reduced to a minimum.

The total production capacity of ethylene and propylene in 1996 in China was respectively 4 and 2 million tonnes per year (MTY). Comprising more than 50% of the total costs, fixed costs of naphtha cracking are significant. Due to local factors such as high transportation costs, thermal cracking plants are relatively small and decentralised in China. The average size of ethylene crackers in China is 300 MTY while the same plant implemented in the US, Western Europe and the Middle East average operates in the range of 450-600 MTY Vergara and Badelon (1990).

Thermal cracking is an energy intensive sector. To process 1 tonne of naphtha, 6330 MJ of electricity is used. Generating air pollutant, water pollutant and solid wastes, thermal cracking is characterised by heavy environmental pollution in its processes. Sources of air pollution are 1) effluents including CO, HC, NOx and SO2 from the production process of thermal cracking; 2) CO, CO2, HC, NOx, SO2 and dust from fuel combustion to heat the pyrolyzer; and 3) pyrolysis tail gases such as hydrocarbon and SO2. Water pollution include sulphide, Na and COD, which are generated in cooling water and washing water in the production process. Waste alkali liquor and oil-containing sludge are remained as solid wastes during thermal cracking.

## 2.2 From monomer to polymer

Next, the monomers are polymerised to produce polymers. Polyethylene (PE) and polypropylene (PP) can be produced straightforward by the polymerisation of ethylene and propylene which are coming out of the thermal cracking process. To get the monomers of polystyrene (PS), polyvinyl chloride (PVC) and polyethyleneterephtalate (PET), other processes using aromatics and rock salt as raw materials are needed. The general characteristics of these polymers are summarised in Box 2.1.

The Chinese primary resin industry is unable to meet domestic demand. The current capacity for the various polymers is depicted in Table 2.1. Although capacities are expanding gradually, it will take several years to be self-sufficient. Moreover, fierce international competition may slow down investments in this sector. As a result, China will for the time being be dependent on imports.

*Table 2.1 Primary resin production capacity in China (1996*

| Plastic type | Production Capacity (in tonnes) |
|---|---|
| LDPE | 1.000.000 |
| HDPE | 603.000 |
| PP | 1.580.000 |
| PS | 565.000 |
| PVC | 1.438.000 |
| PET | 1.820.000 |

*source: National Federation of Light Industry, Ministry of agriculture, Ministry of Construction, National Environmental Protection Agency*

### Box 2.1 What are plastics?

Plastics are based on long molecules called polymers. Their raw materials are oil and natural gas. Additives and reinforcements are added in the primary production process to modify the properties of the plastic products. These substances have the following properties:

- additives - tend to be organic and can be described as influencing a variety of non-strength properties of a polymer, such as wear resistance, flame resistance, colour, degradation resistance, and processability. Examples are plasticizers and colorants;
- reinforcements - are generally inorganic and are used specifically to increase a polymer's load or stress handling capacity. Examples are carbon and glass fibres.

There are two main types of plastics - thermoplastics and thermosets.

*Thermoplastics* - soften when heated and harden again when cooled. These characteristics make it suitable for recycling. More than 80 percent of plastics are of this type. Examples of thermoplastics include:

- high density polyethylene (HDPE) - bottles for food, piping, fuel tanks and toys;
- low density polyethylene (LDPE) - cling film, bin liners and flexible containers;
- polyethylene terephthalate (PET) - bottles, carpets and food packaging;
- polypropylene (PP) - yoghurt and margarine pots, vehicle battery cases, cereal packet lining, milk and beer crates, automotive parts and fibres;
- polyvinyl chloride (PVC) - window frames, flooring, wallpaper, bottles, packaging film, cable insulation, credit cards and medical products.

*Thermosets* - are hardened by curing and cannot be remelted or re-moulded. For this reason thermosets, which account for around 20 percent of plastics, are more difficult to recycle, although they may be ground and used as a filler material elsewhere. Examples of thermosets include:

- polyurethane (PU) - coatings, finishes, gears, diaphragms, cushions, vehicle seats;
- epoxy - adhesives, sport equipment, boats, electrical and automotive components;
- phenolics - ovens, toasters, handles for cutlery, automotive parts and circuit boards.

*Source: APME 1996*

Generally speaking, the primary resin industry is an environmentally intensive sector. Both thermal cracking, polymerisation and the production of basic chemicals consume a large amount of energy. Increasing the energy efficiency has great potential to decrease the emission level from petrochemical industry. Its waste water may contain sulphide, heavy metals such as Hg, benzene and organic compounds. Large scale resin manufacturers constructed waste water treatment plants. To ensure the treatment effectiveness, many factories constructed primary treatment facilities near the sources of water pollution. Solid wastes from the primary plastic industry mainly contain the sludge from waste water treatment, which are incinerated or landfilled.

There are still some small-sized or township petrochemical enterprises with out-of-date technologies. Because of old production processes, unsound management which result in low energy and production efficiency and high level of material consumption, these small-sized enterprises often generate serious environmental pollution. Few of them facilitate pollution control equipment. Initiatives have already been taken to solve this problem. In 1996, heavy polluted small-scale enterprises, including petrochemical sector, pulp-making sector, dyeing and printing industry, cement industry, etc. were closed by NEPA. However, there still lack of mechanism for legislation implementation to stop the existence of heavy-polluted small-sized enterprises.

## 2.3 From polymer to product

The next step in the production is the conversion of the polymer resins into plastic products. The main inputs are resin and electricity. Sometimes, additives are used such as colorant or softener. The outputs, i.e. plastic products, differed in quality depending on the type of resin used, i.e. primary or secondary (recycled) resin. Generally, secondary resin is of a lower quality due to the contaminants present in the polymer structure.

Plastic processing is mostly done by three different techniques: 1) extrusion, 2) injection moulding, and 3) blow moulding. A product can only be made by one of the processes. For a continuous product extruding is used. Solid separate objects are produced through injection moulding and for hollow objects blow moulding is applied.

The total production capacity of plastics product manufacturing is about 9 MTY. Given the relatively high labour intensity and the low wages, China is able to compete successfully on the international market for plastic products. In 1996, the net-export of plastic products was 600.000 tonnes.

Compared to oil refining and primary resin production, plastic product manufacturing is a sector which is less energy intensive and has much lower emission levels. Yet, processing manufacturers are often small and medium sized factories which lack pollution control facilities and environmental management. This may result in uncontrolled emissions and surface water pollution. Because of using various additives in the production process, waste water containing such hazardous substances as cadmium, lead, phenol and cyanide is discharged from plastic processing.

## 2.4 From product to waste

Currently, consumption mainly comprises four types of plastic: polyethylene (PE), polyvinylchloride (PVC), polypropylene (PP), and polystyrene (PS). Apart from these four major varieties, there is a small amount of ABS, PA, PET, AS, PU, etc. In 1994, plastics consumption in China stood at 8.1 million tonnes. The plastics market can be broadly divided into three segments: agriculture, industry and household. Table 2.2 depicts the distribution of plastics market by types and uses.

Each category has its typical characteristics and developments. Agricultural plastics are mainly utilised in producing agricultural film, package for grain and fertiliser and water pipe for irrigation. Thus, the main type is PE (73 percent) which is the raw material for film. PVC (15 percent) is used for film as well as water pipes. As agricultural film has a very short life span, normally 1-2 years, it is a major source of harmful waste. Yet, because of its homogeneity it is also an important input for the recycling industry.

*Table 2.2 Distribution of Plastics application in China 1994-2000 (in 1,000 tonnes)*

| | 1994 | | 2000 | |
|---|---|---|---|---|
| | Consumption | share (%) | Consumption | share (%) |
| *Plastics for agricultural use* | *1960* | *24.2* | *3120* | *24.5* |
| - PE | 1430 | 73 | 2200 | 70.5 |
| - PVC | 300 | 15.3 | 520 | 16.7 |
| - PP | 100 | 5.1 | 150 | 4.8 |
| - PS | 30 | 1.5 | 50 | 1.6 |
| - others | 100 | 5.1 | 200 | 6.4 |
| *Plastics for household use* | *2700* | *33.3* | *4930* | *32.9* |
| - PE | 300 | 11.1 | 500 | 10.1 |
| - PVC | 700 | 25.9 | 1300 | 26.4 |
| - PP | 1270 | 47 | 2230 | 45.2 |
| - PS | 310 | 11.5 | 600 | 12.2 |
| - others | 120 | 4.5 | 300 | 6.1 |
| *Plastics for industrial use* | *2940* | *36.2* | *5950* | *39.7* |
| - PE | 800 | 27.2 | 1500 | 25.2 |
| - PVC | 1500 | 51.0 | 3150 | 52.9 |
| - PP | 400 | 13.6 | 800 | 13.4 |
| - PS | 160 | 5.5 | 300 | 5.0 |
| - PET | 80 | 2.7 | 200 | 3.4 |
| - others | 500 | 6.2 | 1000 | 6.3 |
| Total | 8100 | | 15000 | |

*Source: National Federation of Light Industry, Ministry of agriculture, Ministry of Construction, National Environmental Protection Agency*

Plastics are becoming increasingly important in various industrial sectors and, among the industrial commodities, is predicted to increase the most in the coming years. There are seven sectors which currently, comprise the of the following main consumers: chemical building materials, automobiles, communications, machinery, instruments and apparatus, electrical and electronic products. With 1.5 million tonnes in 1994, PVC was the most popular (51 percent). Its share is expected to increase further in the near future.

Household plastics are mainly used in packaging and utensils. Currently plastics for household utensil comprise PVC, HDPE, PP, LDPE and PS with finished products ranging from slippers, sandals, soles for synthetic leather, toys, washing basins, etc. In addition, PET is generally used for making soft drink bottles, which are easy to recover. A plastic that deserves special attention, despite its small contribution by weight, is EPS which is widely used in making disposable food packaging and dinner sets. Because of the difficulty in recovering EPS, the latter is the main source of white pollution[3].

[3] The term 'white pollution' is widely used in China to describe the occurrence of EPS food packaging left alongside roads and railway tracks.

## 2.5 From waste to nothing

Collected by municipalities, waste plastics together with other wastes in the municipal solid waste (MSW) stream are either landfilled, incinerated or dumped due to a lack of waste management facilities. The major official waste disposal method used in China is landfill. Compared to other waste management options, landfilling is a relatively simple technique. Also, construction and operation costs are generally lower. For example, the average disposal cost for landfill and incineration are respectively 30 Yuan RMB (US$ 3.5) per tonne and 50 Yuan RMB (US$ 6) per tonne (BESDRI 1997).[4] Though there are technical specifications for landfill construction and specific environmental standards, the environmental management and enforcement of landfills in China is not strong. This results in leachate entering into the ground water and ignition of organic gases.

Plastics' behaviour in the landfill is not fully understood due to its short history. Some reports claim that plastic deteriorates after 1 year while other cite 40 years. In order to cause leachate, plastics would have to degrade in the landfill, but no strong evidence of degradation exits. Thus, it may seem that plastics itself do not significantly contribute to leachate. However, chemical additives such as heavy metal compounds may leach, causing ground water pollution. The characteristics of high durability and non-degradability also implies that waste plastics permanently occupy significant space in the landfills. An advantage of the limited degradation is its minor contribution to greenhouse gas emissions (Hunt 1995).

Since plastics have a similar energy value to oil, incineration of waste plastics is a potential option. However, harmful emissions such as hydrogen chlorides and dioxins coming from PVC may occur if the incinerators are not equipped with proper scrubbing equipment. Moreover, incineration has so far been proved to be a unfeasible option in developing countries because of the high moisture content of MSW in general. This means that waste plastics would have to be collected separately from wet waste in order to generate energy. Incineration in China is still in the pilot stage. Only one imported incineration furnace, constructed in Shen Zhen City, utilises the energy value for electricity generation, while others with low treatment capacity are just used to burn wastes. Although standards have been formulated for controlling air emission from incineration in China, enforcement of these standards is still very weak.

The existing capacity of waste collection, and landfill and incineration facilities is insufficient to properly manage the generated waste plastics in China. It is estimated that roughly 60 percent of the post-consumption plastics are still dumped or left uncollected in China. Besides the lack of waste management facilities, incomplete legislation for solid waste management and weak implementation of legislation are the main causes of this alarming situation. Certainly, this deficiency is one of the most serious environmental problems in the plastic cycle. The burning of plastics is formally prohibited by the Chinese government. In reality, the burning of waste plastics is a common way of treating the garbage.

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4 In October 1997, 1 US Dollar = 8.2843 Chinese Yuan Renminbi (1 Chinese Yuan Renminbi (CNY) = 0.1207 US Dollar (USD)).

Numerous examples can be found of the consequences of this situation. For example, China's consumption of agricultural films in 1994 of 1.9 million tonnes ranks first in the world. However, about 0.3 million tonnes of waste films remain in the farm land annually which do harm to the soil and cause intestines disease when animals accidentally eat them. A more generally known problem is caused by the rapidly increasing volume of plastic dinner-boxes and packages which are littered along roads and railway lines. Lacking landfilling and incineration facilities, collected municipal waste plastics together with other solid wastes are piled up outside the cities which impede further development of cities and pollutes the surface and ground water.

## 2.6 From waste to secondary polymer

The recycling of plastics can be done in several ways. Box 2.2 gives an overview of the available options. The best known and simplest is mechanical (secondary) recycling. Incineration with reuse of the process energy is common in Europe and the US but not practised much in China. Since recycling by cracking the polymer to feedstock or by direct depolymerisation is still in a rather experimental stage, it is hardly found in China.

### Box 2.2 Types of plastic recycling

Waste plastics can be used in different ways:

- ***primary recycling*** the reprocessing of clean factory waste into products with equivalent chemical properties as the reprocessed waste. This type of recycling, which is in fact also a mechanical form of recycling, often takes place within the factory itself;
- ***secondary or mechanical recycling*** the reprocessing of recovered waste materials into products of inferior quality to the original product. This type of recycling generally uses agricultural and packaging waste;
- ***tertiary or chemical or feedstock recycling*** the reprocessing of mixed recovered waste plastics by changing the chemical structure and transforming it into basic chemical blocks, for use as secondary feedstock in refineries, petrochemical plants and chemical reactors (e.g. Hydrolysis, glycolysis and methanolysis);
- ***quaternary recycling*** direct utilisation of the energy value of the materials by incineration of municipal waste.

*Source: Curlee and Das 1996*

Mechanical recycling is characterised as a labour intensive and simple technology. It consists of several processes: 1) separation, 2) washing and 3) processing. In order to be recyclable, the plastics have to be separated into fractions containing only one type of plastic. This sorting process can be done either mechanically or by hand. In the case of automated mechanical separation, floatation devices, rotation drums, and even photo-spectrometric equipment can be used. In general, however, manual sorting by type and quality is a more common practise in China. A large separation effort is avoided if during the earlier stages, specific articles, such as water bottles, are collected separately. This way, the sorting is done by the collectors and waste traders. The collection of waste plastics is discussed in the coming Sections.

To clear the plastic fraction of contamination, they are washed thoroughly. This can be done by hand using detergent or in special plastic washing machines. The quality of the washing process very much determines the quality of the secondary plastic. Mechanical washing can be done in a continuous process, while manual washing is a batch process. Manual washing is very labour intensive and very time consuming. In China, normal washing detergent is used to wash the plastic.

After sorting and, if necessary washing, mechanical recycling is performed. This type of recycling of plastics does not change the structure of the plastic, only to its form. Generally a crusher or granulator is used to reduce the size of the waste plastics after which the waste plastics are fed into an extruder. The extruder converts the waste plastics into secondary resin.

Using recovered waste plastics as input, has advantages in terms of resource savings and lower energy intensity. The emission level of secondary production is also lower than the primary production. Because most enterprises in this sector are small and medium-sized factories, which means low technologies and financial difficulties, environmental problems, such as water pollution and health threats to the workers, can not be neglected. Box 2.3 reports an incident in India which reports of the potential negative environmental impacts of the plastic recycling sector. Similarly, it should be kept in mind that secondary (recycled) products are generally of a lower quality than its primary version. This reduces the lifetime of the product and possibly also the quality of the usage. Thus, a one-to-one comparison between primary production and recycling is not sound.

**Box 2.3 The dark side of plastic recycling**

Despite its environmental image, the plastic recycling industry also generates environmental burdens. The Centre for Science and Environment (1999) reported on a recent incident in Delhi (India). "*A village in outer Delhi is facing a major crisis. Polluting plastic waste recycling industries are poisoning the area. ... Factories have bored holes into the ground. Pipes then carry all the chemical residues through these into the water table. .... The residents observe a code of silence because factory owners are influential persons.*"

*Source: The Centre for Science and Environment (1999)*

## 2.7 The overall plastic cycle quantified

Based on the former evaluation of the subsequent stages in the Chinese plastics cycle, a general overview of the overall cycle can be drawn (see Figure 2.2). This overview is based on various sources and qualities of information. These figures should be interpreted carefully due to uncertainties in the data and the significant changes over time. It forms a snapshot in time which is subject to various bottlenecks and developments.

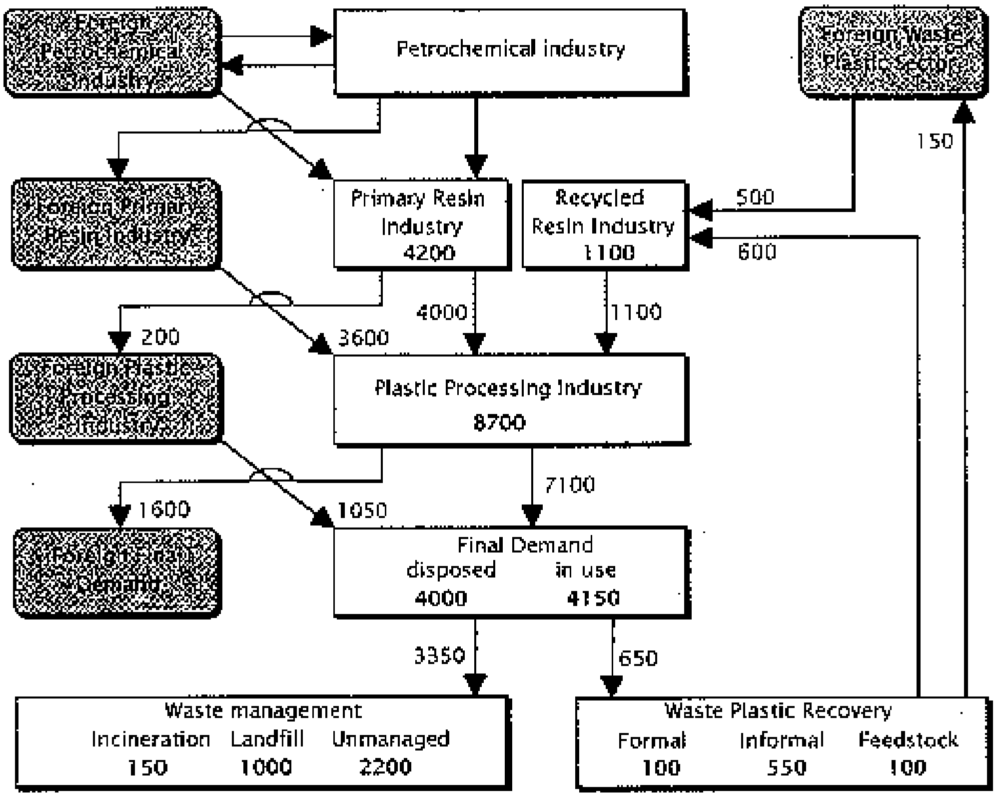


*Figure 2.2 A snapshot of the Plastic Cycle in China in 1994 (in 1,000 tonnes)*

*Source: compiled and calculated by the authors from various sources*

Although the main issues in the plastic cycle in China are discussed and evaluated in the following Chapter, several preliminary impressions can already be identified based on the material flows presented Figure 2.2.

- The material flows in the resin segment indicate that the recycling industry plays a small, but certainly not a negligible role in the plastic cycle. On plastic production side it contributes 21 percent of the domestic resin. On waste management side it absorbs 15 percent of the disposed waste plastics.
- The snapshot confirms the high import dependency of the Chinese plastic cycle. Both in the primary and the secondary segments, approximately half of the inputs come from abroad.
- Figure 2.2 indicates the alarming conditions in the waste management stage of plastics. Almost two third of the non-recycled waste plastics are left unmanaged. This may prove to be 'the' environmental hot spot in the Chinese plastic cycle.

# 3. Trends and Issues

*Pieter van Beukering, Li Yongjiang, Zhao Yumin*

The plastic cycle in China is under constant influence of internal and external factors. Particularly the fact that plastics are a relative new material enhance the dynamic character of this sector. In addition, China is currently transforming rapidly. This Chapter aims to describe the changing plastic cycle and identify the main trends and issues. In subsequent chapters, this description will be the basis of model development and analysis. Note that the main focus will be on the management of waste plastics. Therefore, developments in the primary sector are of secondary importance. In identifying the main issues we will follow the similar sequence as in Chapter 2.

## 3.1 Production is lacking in the primary plastics industry

Since the 1980s, the plastics industry in China has expanded steadily. Production capacity and output have increased approximately 3.5 times within the past 15 years. This implies an annual average growth rate of more than 11 percent. This growth is shown in Figure 3.1.

Several factors have contributed to this development.

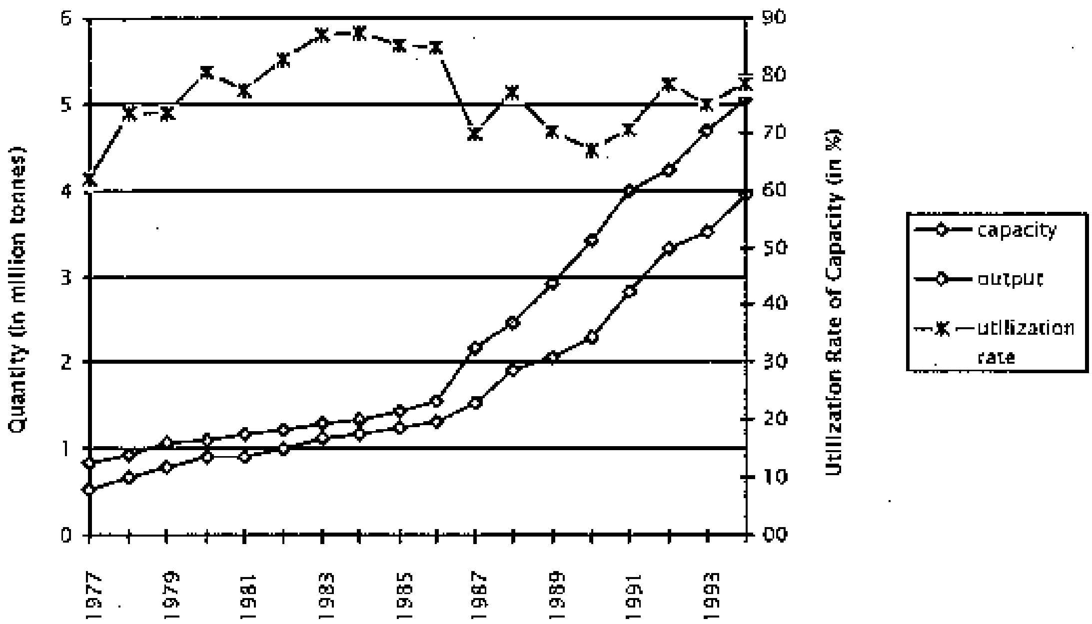


*Figure 3.1 Primary plastic resin production and capacity in China (in million tons)*

*Source: National Federation of Light Industry, Ministry of agriculture, Ministry of Construction, National Environmental Protection Agency*

First, a structural change has taken place in the supply side of raw materials. China is a large producer of oil, but due to its weak petrochemical foundation and backward technology, most of China's plastic chemical raw materials were based on coal, calcium carbide and agricultural products up until the mid-1970s. With the establishment of the ethylene industry at the end of 1970s and the continuous expansion in the following decades, plastics gradually substituted other raw materials.

Second, the development of the plastic industry has been characterised by significant technological improvements. Across all plastic types, the major incentives for these improvements have come from the introduction of technologies and equipment from abroad. Assisted by these imported technology, the plastics industry was able to take off.

Third, the government played an essential role in the development of the plastic industry by providing direct and indirect support to the primary plastic industry at various levels. On the macro-economic level, China's economic policies have experienced noticeable changes since 1978, implying enhanced utilisation of foreign capital and bringing in technology to speed up China's drive for modernisation. Under the guidance of this policy, China has accelerated the process of introducing new technologies and equipment. The government also had a significant influence through a direct reorganisation of the industry. In 1983, the petrochemical industry undertook major readjustments, breaking down the original inefficient system. Currently, only 20 percent of petrochemical enterprises are state-owned (in plastic production this is only 8 percent). The remaining are collectively owned, share-holding companies or foreign-funded enterprises.

Despite the significant progress of the primary plastics industry in China, there are still several main challenge remaining to be solved:

- A large gap exists between demand and supply of the primary plastic industry, particularly from a quality point of view. The plastics industry has been unable to keep up with diversified needs of customers in terms of quality, quantity and variety, especially for the products with a 'high-tech' content.[5]
- The industry suffers from an inadequate supply of raw material (oil and natural gas). The recent increase in demand has led to an increasing reliance on imported oil. Moreover, the proportion of crude oil that is domestically refined for petrochemical production is rather low. In terms of quality, China has short supplies of ethylene and aromatic hydrocarbon raw material as most of China's oil is heavy, implying that its content for naphtha is low. The use of heavy raw materials has resulted in high investment costs, and high consumption of energy and raw material for plastics production.
- Third, the industry is characterised by the relatively small scale of equipment and poor economic efficiency. The scale of production is an important indicator for

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5 For example, most of the domestically produced PP products are wire-drawing materials while there is a massive shortage of polymer structures and membranes. As a result, the gap between demand and supply has been filled through imported goods. Currently, imported resins have taken at least a 50 percent share of the domestic market, rising to 80 percent for some varieties.

measuring the level of development in the petrochemical industry.[6] Owing to the small scale, per-capita labour productivity is low and production costs are high.

In view of the current situation, but even more for the near future, the primary plastics industry will not satisfy the domestic market. Three alternatives are available to address the problem. First, China can choose to rely on the importation of synthetic resins. Given the foreseen growth in population and consumption, this option seems inevitable. Second, China can choose to increase imports of monomers to produce resin. Although this course would promote the development of a less dependent plastic industry than importing resin directly, this approach is vulnerable to extreme fluctuations in import prices of raw materials, and transport costs can be rather high. Therefore, it should only be considered as a supplementary solution. Third, China can speed up the development of its ethylene and aromatic hydrocarbon industries to enhance its total productive capacity and self-reliance rate. This option has been adopted by the Chinese government as the main route to narrow the gap between supply and demand. By the end of 2000, plastics output is expected to increase to almost 9 million tonnes (National Federation of Light Industry (NFL), 1996)

## 3.2 Final demand is growing rapidly

Plastic goods have found wide application in various sectors such as industry, agriculture, construction, health-care, packaging and household necessities. Domestic consumption of plastic goods jumped from around 1.22 million tonnes in 1980 to 8.1 million tonnes in 1994 (NFL, 1996). Consumption per capita increased from 1.24 kg to 6.76 kg during the same period, with rates growing almost 15 percent annually between 1980 and 1990. The 1990s is seen as a high growth period for plastics consumption with an average growth rate of 21 percent. What is the reason behind this remarkable growth for plastics consumption in China?

Several factors play a role. First, income has increased substantially in China. Generally, increases in GNP have a direct bearing on the level of plastic consumption. The 1990s have witnessed extremely high growth rates in annual GNP per capita, roughly equivalent to plastics consumption. Second, both in the industry and in the consumer segment, plastics are rapidly substituting other materials. The advantages of plastics such as reduced energy consumption and its low costs, increase its popularity. Coupled with developments of the domestic plastic processing industry, the emergence of new plastic varieties means that plastics are now being widely used in a range of different sectors. Predictions indicate that trend will continue.

The use of secondary plastics will expand with the advancement of processing technology. By weight, secondary resins account for 10 to 15 percent of the total plastic demand. The secondary products made from recyclable plastics can roughly be divided

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6 In China plastic resin production can be regarded as a capital and technology intensive industry. The scale of equipment is generally large but is nevertheless quite small in relation to international standards. Estimates show that the average scale of a foreign PE device is about 167,000 t/a and that of a PP production device about 127,000 t/a. That of China is respectively 99,000 t/a and 73,000 t/a.

into two categories. One is made by the mixture of virgin and secondary material, with the latter constituting less than 20 percent to ensure the appropriate quality of the end-product. Finished products of this kind are largely those used in households such as washing basins, furniture and waterproof materials in construction. The other kind of secondary products are made totally from recyclable material with no virgin material added. The finished products range from refuse bags, soles for shoes, containers for feeding animals and waterproof materials which do not have strict property requirements.

The preferences for plastic consumption may differ with income. Generally, people with higher income levels prefer the generally more expensive virgin plastic products implying higher prices, while consumers with lower income levels may choose lower-cost secondary plastic products. Recycled products are on average 50 percent of the price of primary products. The quality of the recycled plastic products is generally also less. On the one hand, this may be a limitation for the further development of the recycling sector. On the other hand, it is found that in a rapidly expanding market for a material – in this case plastics – the positive income effects generally dominates the negative substitution effect on the demand for recycled products (Nice, 1995 p.41).

As shown in Table 3.1, the consumption of secondary plastic products and virgin plastic products accounted respectively for 16 and 84 percent of the total consumption in 1994. The household category holds the biggest share of secondary plastic consumption. It is surprising to note that agricultural plastics consist mainly of primary plastic products. Apparently, the quality requirements for these applications, such as irrigation pipes and plastic sheets, are considered more important than the price advantage of secondary plastics.

*Table 3.1 Virgin and secondary plastic consumption in China in 1994*

| Category | Virgin plastic consumption (1000 tonnes) | Secondary plastic consumption (1000 tonnes) | Share of secondary plastic consumption |
|---|---|---|---|
| Industrial plastics | 2,540 | 400 | 14 % |
| Household plastics | 2,100 | 600 | 22 % |
| Agricultural plastics | 1,885 | 75 | 4 % |
| Others | 475 | 25 | 5 % |
| *Total* | *6,810* | *1,300* | *16 %* |

*Source: Information Centre Of The Ministry Of Chemical Engineering (1995)*

## 3.3 Waste management is unable to deal with plastics waste

No accurate estimates were established for the total amount of waste plastic in China; however, given the existing European consumption/waste ratio of 67 percent (IPST 1997, p.26), and the fact that the life expectancy of plastics in China is longer, it is assumed that 4 million tonnes of waste were generated in China in 1994. Due to inadequate legislation and environmental standards for waste management and weak infrastructure, only a small fraction of post-consumption plastic was recycled. In 1994 approximately 15 percent of waste plastic was recovered and roughly 30 percent was landfilled or incinerated. This implies that 50 to 60 percent was left uncollected or dumped on land or in rivers and seas. These facts imply that the present waste management system and its recovery counterpart require significant improvement.

Minimisation of waste plastics and re-use of plastics is only briefly considered. The minimisation of waste plastics has two scopes. On the one hand, reducing the amount of excessive plastic packaging is a distinct option to abate environmental damage in the plastic cycle. On the other hand, the plastic packaging industry can also rightly claim that plastic packaging substitution for traditional materials in itself reduces environmental impact. For example, a German study reports the following increases in case plastic packaging would not be applied: 414 percent in weight of packaging, 256 percent in waste volume, 201 percent in energy consumption and 212 percent in economic costs (Ogilvie 1996).

The plastic waste stream emerges from three main sources: agricultural, industrial and municipal solid waste, which account for respectively 63, 16 and 21 percent (NFLI *et al.* 1994). One of the main reasons for the relatively large share of agricultural waste in the plastic waste stream in China is its short life-span. Agricultural plastics have an average life of only 1 to 2 years while industrial and household plastics may be in use for at least 3 to 5 years and 6 to 9 years respectively (Xu Tongkao 1992).

As a proportion of the total municipal waste stream, the share of plastics has traditionally been small in China compared to other countries. However, due to the rapid growth of the packaging industry this situation has changed significantly in the last few years. In Beijing, for example, the share of plastics in the municipal waste stream increased from 0.6 percent in 1993 to 12.6 percent in 1996 (Suo Zhiwen 1997; BESDRI 1997).

The Chinese government is aware of the current situation and is therefore taking several initiatives to improving solid waste legislation and management. Its environmental plan, incorporating Agenda 21 (1994), cites waste management as an important factor in an integrated strategy for natural resource and energy conservation and pollution control. All cities are expected to construct landfill and incineration facilities for the safe disposal of solid waste by 2010. The short term objective for the recovery of recyclable resources is to formulate legislation and establish a development plan. Municipal solid waste management will increasingly emphasise source separation in order to increase the recovery rate of recyclable resources. With regard to plastics, this tendency lead to a ban on the use of styrene foam food packaging in several cities in China. An elaborate description on waste management in China is provided in Appendix IV.

## 3.4 Less waste plastics are 'formally' recovered

The China's plastics recovery sector has undergone structural changes. Originally, during the period from 1950 to 1978, recovery was dominated by the state-owned formal sector. During this period stable recovery rates of over 20 percent were attained. Since 1978, China has experienced a weakening of this sector. Gradually, individual ownership dominated recovery activities. Although the volume of recovered waste plastics increased from 24 million tonnes in 1980 to 73 million tonnes in 1994, the recovery rate decreased from 20 percent to 9 percent. A likely explanation for this that it is not economically feasible to recover waste plastics without government support.[7]

At present, the state- and collectively owned formal sector accounts for approximately 20 percent of total recovered waste. The sector employs a total of 880,000 labourers. As these two networks are involved with a range of recyclable wastes, it is difficult to determine how many employees are actually involved in plastic recovery. Most waste plastic recovered by the formal sector comes from industrial waste which is less contaminated than the post-consumer stream. The average cost for one tonne of collected waste plastic is up to RMB 2,500 Yuan which is higher than in the informal sector. There are problems of collection, higher transport costs as well as a lack of systematic and effective networks. The majority of the formal enterprises are suffering economic losses, and therefore are losing their share of the market for secondary plastics.

The informal sector consists of self-employed individual collectors who are farmers seeking alternative employment in urban areas. By the end of 1995, nearly 3 million private individuals were engaged in this sector (NFSMC 1996; MOA 1996). The sector is able to operate profitably because it uses an efficient house-to-house collection method within local districts, thus limiting transport costs. The average cost of the informal recovery of one tonne of waste plastic is RMB 1,700 Yuan - 800 Yuan per tonne less than the formal sector. The collection of waste plastic by the informal sector increased to 580,000 tonnes in 1994, accounting for 80 percent of the nation's total. The development of the sector has not only provided a livelihood for many surplus labourers from the countryside, but has also promoted the recycling of waste plastics.

## 3.5 The recycling rate is declining

Until the early 1980s the utilisation rate[8] of waste plastics in China was at a level of over 20 percent (see Figure 3.1). This is much higher than most industrialised countries, e.g. Europe and the United States, where, on average, the rate is 5 or 6 percent (APME 1996, Curlee and Das 1996). At present, 1.1 million tonnes of waste plastics are used in the production of plastic products. The plastic recycling industry is characterised by a high degree of individual, collective and small sized township factories, with little evidence of state-run factories. It is estimated that China's secondary industry employs between 200,000 and 270,000 labourers. PE, which is the main input for agricultural film, is the most recycled product, followed by PS and PVC. PET is becoming more popular in the industry.

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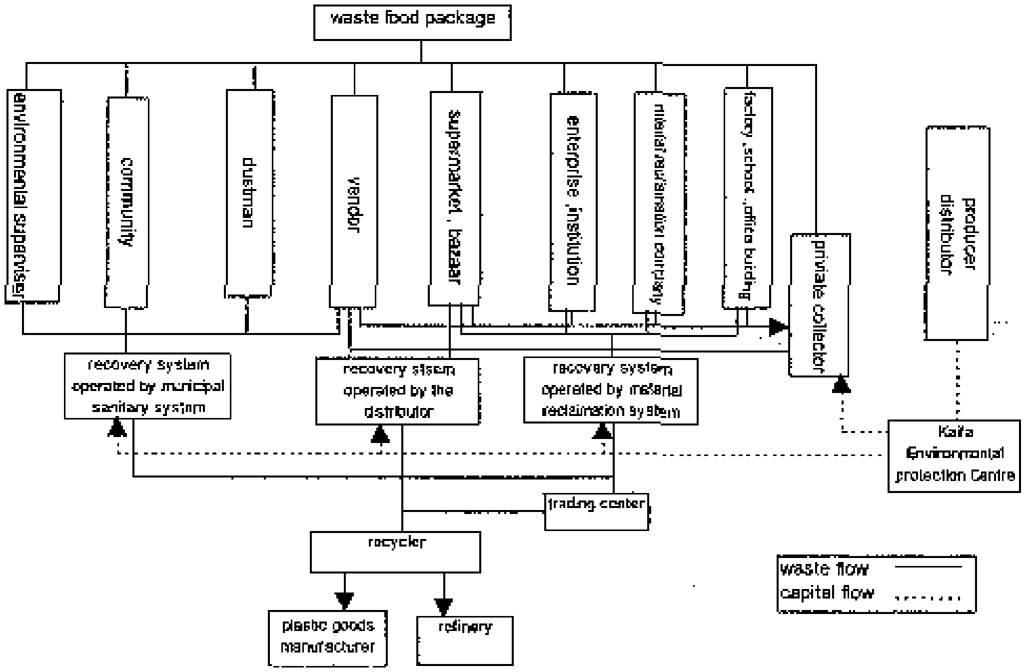
7 The recovery rate of waste plastics is the total volume of recovered waste plastics as a share of the total consumption of plastic articles in China. If for example in year x, 5 million tonnes are recovered for the purpose of recycling of the totally disposed quantity of waste plastics of 50 million tonnes, the recovery rate is 10 percent.

8 The utilisation rate of waste plastics is the share of secondary resin used in the production of plastic products in China. For example, if the manufacturing of plastic products in China would be 10 million tonnes in year x, and the use of secondary resin would be 2 million tonnes that year, the utilisation rate would be 20 percent.

## Box 3.1 Experiment on New Recovery System

Disposable food packaging made by PS enjoys high popularity among consumers in China especially in big cities. However, with ever increasing consumption, there has developed an apprehension about the solid waste coming along with it. In June 1997, Beijing Environmental Protection Bureau and Industrial and Commercial Bureau jointly promulgated "Circular Notice on Recovery of Disposable Food Package" which prescribes the recovery for reuse by the producer, distributor and their trustees of disposable food package. The recovery rate must come up to 30% in 1998, 50% in 1999, 60% in 2000. Those who fail to accomplish this are not eligible to stay in the business. Under this degree, a new recovery system was put into trial operation since September 1997. The structure of the system is depicted in the flow chart below.




*The Flow Chart of the New Recovery System on Trial*

The main idea of this system is to finance the collection of waste food package by charging the producer and distributor. The key player of this system is Beijing Kaifa Environmental Protection Centre, a state-run institute, under which 8 collection centres have been established. Kaifa is mandated to impose charges on the producers and distributors to cover the collection and operation costs. The charges are mainly determined by the amount of the waste packages collected. Kaifa pays the recovery centres for the waste package at 3 Yuan per kilogram, who then pay 2 Yuan to the individual collectors.

The system has operated very well with regard to the collection of waste package. The problem now is to find suitable applications for these waste materials. The technology for converting them into gasoline and diesel seems not well developed yet. Although the technology for producing adhesive for construction out of the recovered material is available and the product quality can also be assured, fund shortages impose constraints for large scale production. Since the technology for secondary resin is simple and relatively cheap, Kaifa's main focus is on mechanical recycling.

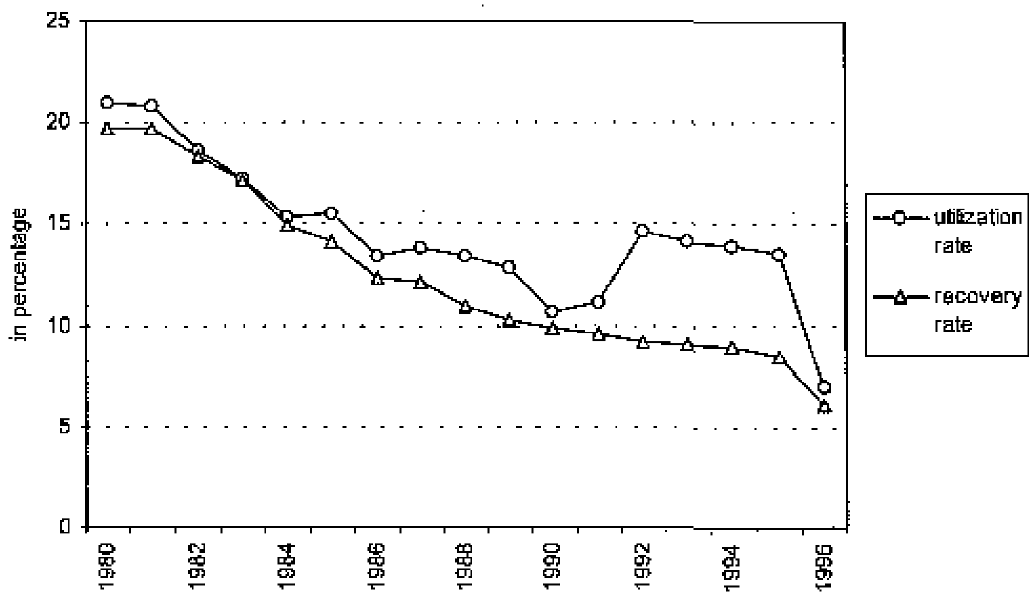



*Figure 3.2 Development of the utilisation and recovery of waste plastics in China*

Various factors contribute to the high level of recycling. First, domestic factors such as demand and cheap labour have traditionally been favourable for plastic recycling in China. Moreover, production methods of mechanical recycling require little and simple investments. Recycling factories with 10,000 tonnes of production capacity are considered large.

Second, external factors boosted the development of the recycling industry. Since the 1980s, for example, a change has taken place in plastics recycling industry in China as encouraged by foreign investment, mainly from Hong Kong and Taiwan, several processing factories specifically engaged in secondary production of plastics have been established along the coastal areas. As a result, production technology and industrial scale have been enhanced.

Third, especially in recent years, the government plays a positive role. Legislation for recycling was not introduced until 1995[9]. In addition to an income tax reduction measure designed to encourage enterprises to use recycled plastics as the principal raw material, preferential treatment and effective measures are being considered to promote the development of waste plastic recycling in China. With government support, scientific institutions and universities are now intensifying research efforts into this issue, while enterprises in plastics recycling are granted tax reductions or preferential rates for rent.

9 The Law on the Prevention and Control of Solid Waste Pollution to the Environment was passed by the 16th Session of the Eighth National People's Congress on 30 October 1995 and came into force on 1 April 1, 1996. The law encourages the reclamation and utilisation of packaging materials and agricultural films.

Despite the observation that the recycling industry has done rather well in absolute terms, in relative terms, secondary manufacturing has gradually yielded ground. This can be recognised by the declining utilisation rate. Several factors attributed to this trend. First, the decline is caused by the fact that production of primary plastics has increased faster than the production of secondary resin. This does not necessarily highlight a deficiency of the recycling sector. Second, limited funds have been allocated in China for the development of plastic recycling technologies. Therefore, many factories have been forced to rely on outdated facilities or to curtail their production. Third, due to the collapse of the formal recovery system, the local supply of waste plastics reduced. In first instance, the decline of the utilisation rate could be somewhat mitigated in the beginning of the 1990s by the fast growth of imports of waste plastics along with the increasing involvement of foreign investors. However, as soon as a ban on waste plastics was implemented, the utilisation rate continued to drop as can be seen in the period 1996 (see Section 3.7).

At present, the following problems hamper the functioning of the plastics recycling industry:

- The supply of recovered plastic is rather volatile due to the decrease in the recovery rate year by year and the dependency on the fluctuating international market.
- Most plastic recycling enterprises are small and medium sized factories with obsolete equipment and technologies. Financial limitations are a constraint to the technical improvements needed to satisfy market demand.
- China's plastic recycling industry operates under difficult economic conditions. Recent years have seen the relative prices of waste plastic, energy and raw materials increase, with the result that a number of enterprises have suffered economic losses.
- Plastic cannot be recycled indefinitely. A "cascade principle" can be envisaged whereby after continuous recycling, plastic becomes too contaminated and degraded for use as a secondary material. A case study in India identified this phenomenon as a constraint in the plastic recycling industry (Beukering 1994). In that case alternative management options such as tertiary recycling should be available.
- Pollution occurs during the recycling process. Some factories cannot afford to install pollution control facilities and must therefore discontinue production (see Box 2.3).

## 3.6 The plastic cycle is highly dependent on import

Since the onset of economic reform, China has increased trade of various plastic materials. Overall, the import dependency has grown. The main categories of trade are raw materials (e.g., ethylene, chloride), synthetic resin (e.g., PE, PVC), plastic products (e.g., film), and waste plastics. The main developments in trade of different plastic commodities is shown in Figure 3.3. Various observations can be made. First, because of outdated facilities and technologies, the domestic industry cannot meet the growing demand for plastic materials. Over the last 15 years China has had to import increasing volumes of resins: the average growth rate till 1995 was 22 percent. The only recorded decreases occurred between 1989 and 1990 when foreign trade and the economy experienced a downward trend as a result of the "Tiannamen Incident" in June, 1989.

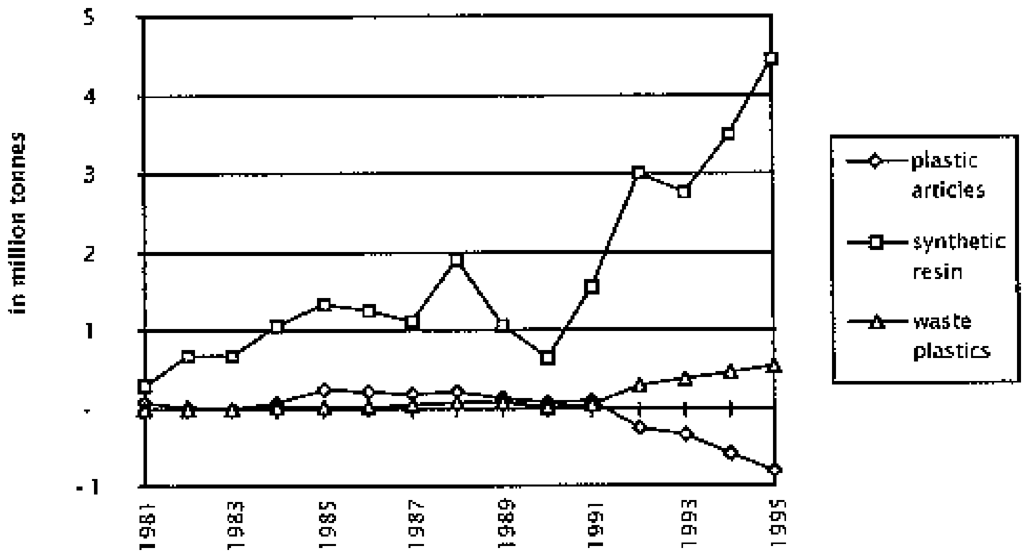



*Figure 3.3 Net imports of main plastic commodities in China*

*Source: International Trade Research Institute, 1996*

Both the synthetic resin and waste plastics are increasingly imported. Compared to synthetic resin, imports of waste plastics, which accounted for slightly more than half a million tonnes in 1995, seem rather insignificant. Still, the average annual growth rate of imported waste over this period was as high as 80 percent. One of the reasons for the rapid growth is the fact that imported waste plastics of a similar quality is often cheaper than domestic waste plastics. Typical for trade in waste plastics is the volatility of the international market. The volatility of the international market for secondary materials is often attributed to its relatively small volume which makes it more vulnerable to fluctuations in supply (Grace *et al.* 1978).

The trade in plastic articles in China differs from other plastic commodities. Since the early 1990s exports have outweighed imports. In 1981 exports accounted only for 1 percent of domestic production of plastic articles; in 1994 this share had increased to 16 percent. At present, the export of plastic articles, mainly consisting of household products, is almost twice as high as imports, which mainly contain semi-products for industrial purposes.

Absolute numbers do not necessarily provide a clear insight into the relative importance of a particular trade flow in the plastic cycle in China. One has to compare the trade flow with the total volume consumed or produced of a particular commodity in the Chinese economy. Figure 3.4 illustrates how China's average dependency increased. In 1980, for example, less than 1 percent of the recycled plastics in China came from abroad. By 1994, this share had increased to more than 35 percent. For synthetic resin a similar trend may be identified. The content of imported resin used in the plastic processing industry increased from 16 percent in 1980 to 43 percent in 1994. The increase in dependency on imported plastic articles was less notable. Another interesting observation is the sudden decrease in dependency on plastic inputs in the years 1989 and 1990. As mentioned above, an obvious reason for this distortion could be the "Tiannamen Incident".

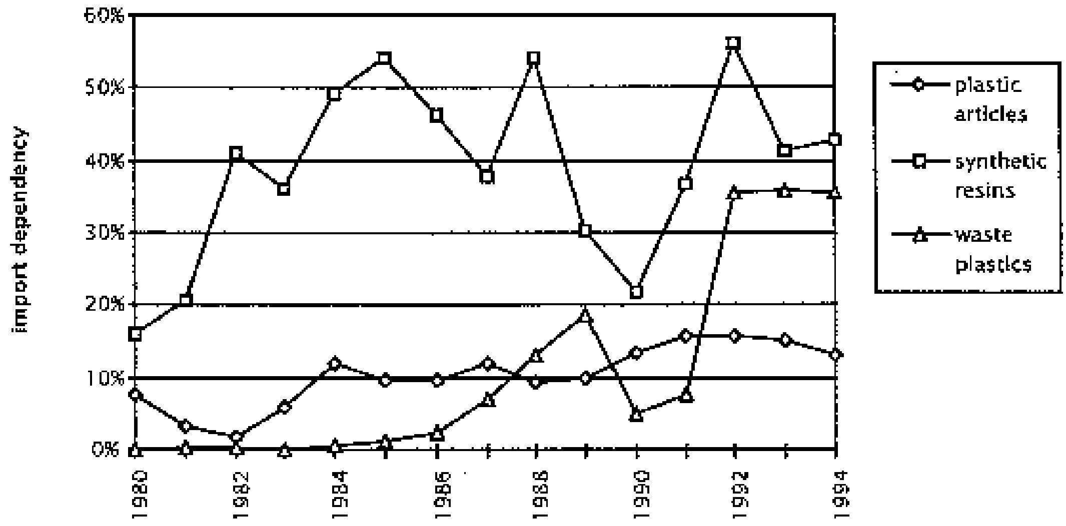



*Figure 3.4 Import dependency of main plastic commodities*

*Source: International Trade Research Institute, 1996*

There are many reasons for China's large-scale imports of plastic raw materials. First, in recent years, China's expanding export market for processed plastic products relies heavily on imported raw materials. Second, inadequate research on processing and application of resins has affected the market share, with the result that demand and supply are often mismatched. For example, most domestically produced polypropylene is in the form of wire drawing materials, although there are shortages of polymer structures, fibre and membrane. Thus large quantities of polypropylene have been imported, even though local resin production has expanded and in some cases supply has outstripped demand. Thirdly, at present the world's large petrochemical producers are engaged in intense competition for China's markets. Their large scale production, advanced technology and high labour production give them a competitive edge relative to local prices.

In recent years, China has adopted a series of measures to open its market. For example, in 1996 China dramatically cut tariffs from 66 percent to 23 percent. At the same time the basic tax rate of most of the duty on plastic commodities dropped from 30-35 percent to 18-20 percent. Reducing tariffs has helped reduce import costs, and no doubt will be help to satisfying the demand of the domestic market. It will also bring greater pressure on China's plastic industry.

More elaborate observation on trade are described in Appendix V.

## 3.7 Are waste plastics imported for dumping or for recycling?

Based on the above description, a range of highly relevant issues emerge regarding trade and the plastic cycle. In the context of this report, which ultimately focuses at recycling, the controversy over importing recyclable waste plastics and waste dumping is a very important one. In this context, the government of China has taken various rigorous measures in recent years. In November 1994, the National Environmental Protection Agency (NEPA) established "The Provisional Rules on Tightened Control of Waste Materials Imports from the European Community". This legislation lists waste plastics among waste materials that are not permitted until being examination and sanction by the authorities. The regulation also applies to waste imports from non-EC countries.

However, in the past two years, some local and overseas businessmen have broken the law and were found to be importing unrecoverable waste under the pretext of raw material utilisation. This problem reached a climax in 1995 when a series of "overseas container trash incidents" occurred consecutively in a number of Chinese cities. These incidents have provoked a response in the form of a rule, introduced in 1 April 1996, which completely banned imports of waste plastics in China.

Given the present characteristics of the plastic cycle in China, such as the underdevelopment of the plastics industry, serious shortages of supplies, limited recycling capabilities and relatively high recovery costs, the local plastic recycling industry was severely damaged. Faced with a lack of alternative inputs for production, the industry requested the Chinese government to relax the trade ban. The government modified the ban on waste plastic imports in October 1996 to allow industrial waste plastic to be imported but maintained the ban on household waste plastics.[10]

In the meantime, the State Commodity Inspection Bureau issued "The Administrative Measures for Preshipment Inspection of Import Waste" in September 1996, which prescribes a preshipment inspection on imports of permissible waste to be used as raw materials. This inspection is to be conducted by SCIB accredited agencies with a legal person status in the exporting countries (or regions), while the Bureau will supervise the related business performance of the agencies. Given the recent implementation of this measure, it is difficult to assess its success. However, whatever the outcome in the long-term, it is clear from these sudden and inconsistent policy interventions, that the precise role of waste plastic imports is still not well-understood.

## 3.8 Can the environmental impacts de dealt with effectively?

As shown in Table 3.2, each stage in the plastic cycle has some kind of impact on the environment. This impact is expected to increase in conjunction with the growth in production and demand. Substitution effects and technological improvements may mitigate this trend. In Appendix VI, a more elaborate overview of the subsequent environmental impacts in the plastic cycle is provided as well as the main technologies available to mitigate these impacts. The question remains whether the Chinese governments and the involved stakeholders can manage the environmental problems effectively.

[10] In international trade waste plastics are subdivided according to quality. Industrial waste is generally of grade A or B. Household waste, which is much more heterogeneous and contaminated is generally classified as grade C. The modification of the trade ban on waste plastics consisted of the allowance of import of grade A and B. Importation of Grade C remains prohibited.

*Table 3.2 Environmental problems in the plastic cycle*

| Stage | Main Environmental impact |
|---|---|
| oil drilling and refining | • waste water containing oil discharge which finds its way into surface water |
| synthetic resin production | • waste water containing chemical and organic compounds, such as heavy metals, benzene, chloride, acid and alkali<br>• waste water containing nutrients as fat, protein and ammonia, may cause eutrophication<br>• production of PVC emits vinyl chloride |
| plastic processing | • waste water containing hazardous substances such as cadmium, lead, phenol and cyanide<br>• resin disposal in water body cause problems with aquatic wildlife which mistake it for food |
| recycling process | • loss of quality of the output which inevitably shortens the life span of the product<br>• odour during recycling process<br>• waste water from the packaging cleaning process containing residues of original product (i.e. food, oil, chemicals) |
| dumping and littering | • blocking water ways, sewage and drainage systems<br>• breeding ground for mosquitoes<br>• fire hazard<br>• threat for wild life or cattle consuming plastic film |
| landfilling | • leaching of chemical additives such as heavy metal compounds causing ground water pollution<br>• occupying scarce space |
| Incineration | • air emissions pollution such as hydrogen chlorides and dioxins coming from PVC causing damage to human health<br>• air emissions causing damage to materials such as corrosion to buildings<br>• generation of hazardous fly ash |

In general, China's environmental legal system is inadequate and the enforcement of environmental laws and regulation is weak. Legislation on solid wastes management was non-existent until quite recently[11]. However, it is clearly stipulated by law that packaging materials and agricultural film should be easily recyclable or 'environmentally friendly' disposable and it encourages the reclamation and utilisation of recyclable packaging and farm films. Reducing solid waste, promoting recycling and the safe disposal of solid wastes are strategic policies for the prevention and control of solid waste pollution.

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[11] On 30 October 1995, The Law on Prevention and Control of Solid Waste Pollution was passed by the 16th Session of the Eighth National People's Congress and came into force on 1 April 1996.

Several measures need to be introduced to ensure their success. These include:

- Shift from end-of pipe measures towards a life-cycle approach by using cleaner production process to reduce emissions and wastes.
- Technological and economic policies based on the polluter pays principle need to be formulated to encourage the recycling of secondary materials. For example, recycling may be promoted through a Waste Exchange System, where wastes generated by one organisation would supply feedstock to another organisation.
- In 1991, China's National Environmental Protection Agency and Customs Administration jointly issued an Announcement on Strict Control of Transboundary Hazardous Wastes to Move into China. Corresponding enforcement measures have also been published.
- Separation at source of household refuse by the public should be gradually promoted. At the same time, municipal refuse needs to be disposed of safely.
- Promotion of an eco-labelling scheme in China. 'Environmentally friendly' recycled products would be marked with eco-labels and promoted through the scheme.
- Strengthening international co-operation in the area of waste management. Through multilateral and bilateral co-operation, more technical and financial support would ensue.

# 4. A field survey of the recycling sector

*Pieter van Beukering, Li Yongjiang, Zhao Yumin, Zhang Xiaoyu, Bai Ming*

Lack of qualitative and quantitative information on the recycling industry in developing countries is a common phenomenon. This handicap seriously restraints research in this area. To compensate for the lack of information, a survey was conducted for the plastics recycling industry in China. Besides gaining qualitative information, the survey provided the quantitative data necessary to design and operate the model presented in the next Chapter. The survey focuses on four segments following the sequential stages of the operations of the recycling sector, as shown in Figure 4.1. Various parts of the country are covered. For each segment, 30 interviews were held, bringing the total number at 120.

An elaborate version of the survey results is presented in Appendix VII. A summary of the most important results from the field survey is provided in Table 4.1. In the following sections, a description and interpretation of the eight most important findings of the survey are provided.

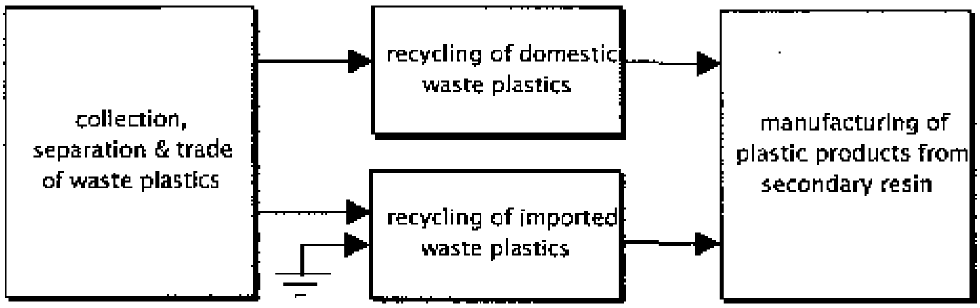


*Figure 4.1 Four targets in the Survey*

### 4.1 Recyclers suffer from lack of supply

There is a noticeable difference in size in operation between the interviewed entrepreneurs. The local trader of waste plastics processes on average 53 tons of waste plastics per month. The manufacturer of plastic products has an average capacity of 42 tons per month. The most interesting distinction exists between the domestic and the importing recycler. The former has a monthly capacity of 23 tons while the importer can process up to 186 tons per month. The configuration of these average figures is depicted in Table 4.2. The capacity difference stems from both the size of the machine units as well as the number of machines. One reason for the large difference in size is the possibility of the importers to purchase rather large quantities of input. The supply to local recyclers usually takes place in much smaller badges.

*Table 4.1 Selection of the basic data of the recycling sector in China*

| Averages | waste plastics trader | domestic waste recycler | imported waste recycler | plastic product manufacturer |
|---|---|---|---|---|
| establishment year | 1995 | 1994 | 1992 | 1990 |
| area | 205 $m^2$ | 350 $m^2$ | 1680 $m^2$ | 942 $m^2$ |
| capacity | n.a. | 23 tonne / month | 186 tonne / month | 42 tonne / month |
| production | 53 tonne / month | 12 tonne / month | 92 tonne / month | 26 tonne / month |
| utilisation rate | n.a. | 50% | 50% | 61% |
| input composition | household 67%<br>industrial 30%<br>agricultural 3% | local 100%<br>import 0% | local 20%<br>import 80% | primary resin 18%<br>secondary resin 81%<br>additives 1% |
| monthly turnover | 36,400 Yuan | 49,800 Yuan | 501,400 Yuan | 247,800 Yuan |
| monthly profit | 3,400 Yuan | 5,100 Yuan | 61,300 Yuan | 36,900 Yuan |
| profit rate | 9% | 10% | 12% | 15% |
| growth last 3 years | 38% | 127% | -35% | -10% |
| total labour | 3.5 workers | 5 workers | 22 workers | 37 workers |
| male / female | 2 m. / 1.5 f. | 3.5 m. / 1.5 f. | 10 m. / 12 f. | 20 m. / 17 f. |
| labour productivity | 11 kg / hour | 6 kg / hour | 9 kg / hour | 4 kg / hour |
| wage level | 525 Yuan / month | 445 Yuan / month | 664 Yuan / month | 486 Yuan / month |
| price level input | 2350 Yuan / ton | 3200 Yuan / ton | 4100 Yuan / ton | 6000 Yuan / ton |
| price level output | 2800 Yuan / ton | 4150 Yuan / ton | 5450 Yuan / ton | 9500 Yuan / ton |
| output composition | n.a. | low quality 11%<br>med quality 78%<br>high quality 11% | low quality 9%<br>med quality 43%<br>high quality 48% | n.a. |
| electricity | n.a. | 210 kWh / ton | 368 kWh / ton | 571 kWh / ton |
| tax payment | 50 Yuan / month | 250 Yuan / month | 1,050 Yuan / month | 4,850 Yuan / month |
| capital assets | 36,700 Yuan | 46,000 Yuan | 610,000 Yuan | 440,000 Yuan |

The actual production levels stay significantly behind the capacity of the waste plastics recycling industry. The operating rate now stands only at 50% for secondary resin production with both local and imported waste plastics, and at 61% for recycled plastics goods production. Most industries claim that shortages in supply of inputs is the main reason for the poor performance. For the domestic segments this is caused by the low recovery level of plastics in China. For the importing industry the shortages in supply result from restrictions on waste plastics imports for the past few years as well as fierce competition among an increasing number of recycled plastics factories.

*Table 4.2 Capacity Distribution of Surveyed Recyclers*

| Production Capacity | Domestic recycler | Importing recycler |
|---|---|---|
| > 10 tonnes / month | 47 % | 0 % |
| 11 - 25 tonnes / month | 43 % | 13 % |
| 26 - 50 tonnes / month | 0 % | 20 % |
| 51 - 100 tonnes / month | 7 % | 34 % |
| > 100 tonnes / month | 3 % | 33 % |

## 4.2 Domestic and importing recyclers develop differently

During the past five years, the different fronts of the waste plastics recycling and plastics manufacturing industry have shown ups and downs. The output by traders and domestic recyclers rose by an annual 38 and 127 percent respectively. However, the output of resin from imported raw materials decreased by 35 percent and that of recycled plastics products by 10 percent. These opposite trends are depicted in Figure 4.2. Only the firms which have operated for more than three years are included in the average.

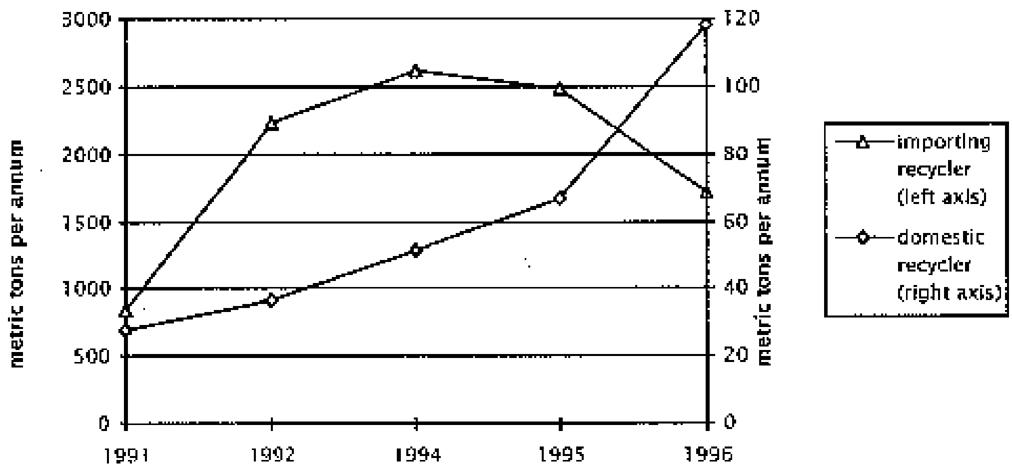


*Figure 4.2 Development of average production*

Different explanations are possible for this divergence in development. First, as China was shifting to the market economy, the formal collection and recycling system began to lose considerable market share to the informal system. The state-owned recycling sector was unable to compete under conditions of opening competition. Their system of planned production did not match well with the existing demand, their labour costs were much higher as a result of the contribution to the social security system, and the management systems responded too slow to changing conditions. This gave room for the domestic informal recycler to expand their market share as shown by the rapid growth in average production. Second, the steep fall in average secondary resin production from imported waste plastics resulted from constraints on imports over recent years, which evolved into a temporary ban in 1996. Today, only imports of industrial waste plastics are allowed to be imported. Lack of supply hampered the operation of the importing recycler. Finally, it is claimed that, particularly in South China where most importing recyclers operate, the demand for household articles made by recycled products is declining. This is due to rising income in this region which leads to a shift in living standards of household, causing a higher preference for articles made of primary resin.

Domestic and importing recyclers differ in their opinion about the most important factors to improve the quality of their products. Local recyclers indicate that improvements in the sorting techniques would be most efficient. Two other important factors, according to the local recyclers, are the higher quality waste plastics and more abundant availability of raw materials. This implies that his supply is characterised by scarcity, heterogeneity and low quality. The importing recyclers' are of the opinion that the increased availability of a higher quality, is the most important factor to improve quality. Moreover they suggest that a more constant supply and better skilled personnel would improve the quality of output. These outcomes are plausible given the high volatility of international trade of waste plastics and the relatively high capital intensity of the production.

## 4.3 Labour productivity of the importing recycler is higher

Labour input varies according to the scale of operations. Obviously, the scale of operation largely determines the absolute size of the labour force. The labour force of waste plastic traders averages only 3.5 persons per operative unit. The local recycler is slightly larger with approximately 5 employees. The importing recycler and the producer of recycled plastics goods are, on the other hand, demanding more labour, owing partly to the more complex processing and more labour-intensive production for the manufacturers.

As shown in Table 4.3, the importing recycler has a higher labour productivity than the domestic recycler. This can be attributed to the use of more sophisticated equipment as well the higher quality of inputs used in the production process needing less hand-sorting and hand-washing. However, this difference in productivity is compensated by higher wage levels, due to the requirement of more skilled labour and the generally higher wages in the South of China. It is clear that the manufacturing of plastic products is the most labour intensive process in the plastic cycle in China.

*Table 4.3 Labour inputs and costs of different groups*

| | labour hours per tonne of output | | | average wage | labour costs per ton |
|---|---|---|---|---|---|
| | *male* | *female* | *total* | | |
| waste trader | 64 | 25 | 89 | 525 | 156 |
| local recycler | 121 | 35 | 156 | 445 | 231 |
| import recycler | 52 | 62 | 114 | 664 | 252 |
| manufacturer | 139 | 110 | 249 | 486 | 403 |

## 4.4 Seasonal fluctuations have a distinct impact

Different seasonal fluctuations appear to be present in the recycling and production process. A business indicator is depicted in Figure 4.3 that highlights this difference. The indicator lies between 0 and 100. In general, waste plastics collection and recycling with domestic inputs and the production of finished goods show similar seasonal variations, with collection and local recycling having an almost identical fluctuating curve. This may be attributed to the linkup and inseparability of these operations. Since a greater part of the country is very cold in winter, conditions are adverse for collection and production, and preceding November through coming February are consequently the dull periods for the businesses. The production of secondary resin with imported waste plastics, however, shows an opposite pattern. It usually booms in summer and winter, when most deliveries are due at port, and becomes slack in spring and autumn.

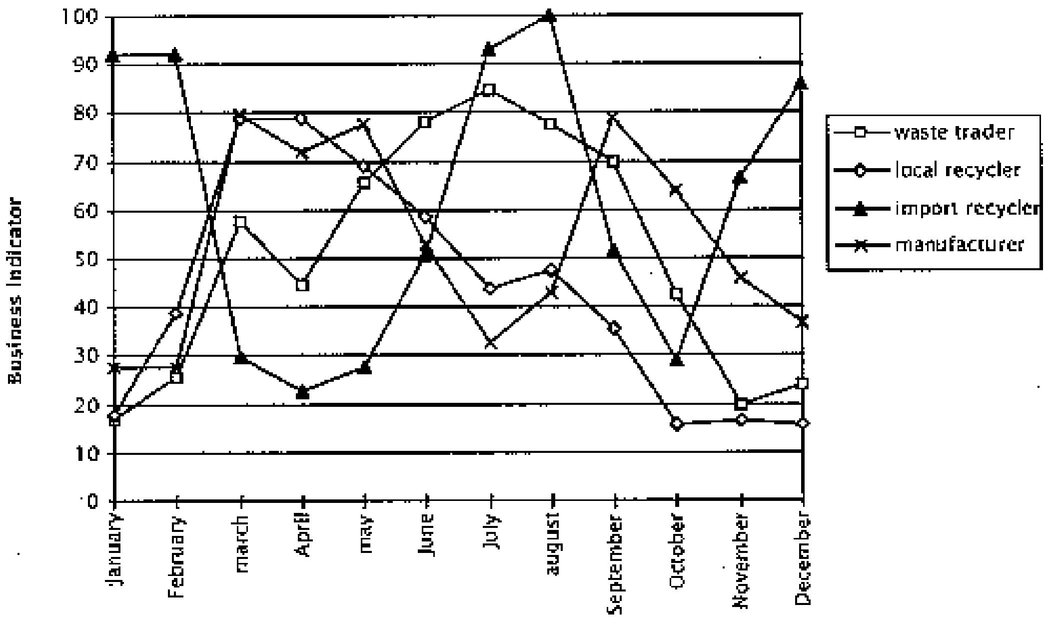


*Figure 4.3 Seasonal fluctuations*

A plausible conclusion of the opposite seasonal patterns is that local and imported waste plastics substitute each other in times of scarcity. However, as manufacturers cannot differentiate between these, this hypothesis could not be confirmed by available data. It might quiet well be the case that the market in which the local recycler operates is completely segregated from the imported waste plastic recycling market. Nevertheless, Figure 4.3 hints strongly towards substitutability.

## 4.5 Capital intensity and environmental management go hand in hand

Electric power is the main source of energy consumed in the production of secondary resin and recycled plastics goods. Consumption is 210 kWh per tonne for re cycling with local raw materials and 368 kWh for recycling with imported waste. This confirms the higher capital intensity of the latter. For the same reason, power consumption now runs to 571 kWh per tonne for recycled goods manufacturing.

It is difficult to judge the overall environmental performance of the individual surveyed categories. Within one category of enterprises, often very clean and very dirty enterprises are found. In general the trader only generates environmental pressure through the disposal of rejected materials and in some cases through the discharge of waste water. The manufacturing of recycled plastic products is clean for the most part, and thus causes limited environmental concerns.

The process of converting waste plastics into secondary resin seems to be the most polluting activity, especially the washing of the waste. The majority of the domestic recyclers discharges the waste water without treatment or reuse. Reusing the water and filtering it before discharging is a much more common practice of the importing recyclers.

As a result, the importing recycler who uses 2 $m^3$ water per tonne of output is more efficient in its water consumption than the local recycler who uses approximately 2.6 $m^3$ per tonne of resin.

Also in terms of air quality control, the domestic recycler takes less precaution than the importing recycler. If it is considered necessary, his measures are mainly limited to opening the window (23 percent). In contrast, the importing recycler uses electric ventilation (95 percent) and some even operate with a air sucker (13 percent). Air pollution was found particularly dominant in units which used low quality waste plastics and a high portion of additives. This is particularly harmful for the employees.

## 4.6 Importing recyclers use higher quality inputs

Given the differences in activities, the source of waste plastics supply varies over the various categories of entrepreneurs. Table 4.4 shows this variation. Mobile vendors are rather important for both the local trader and the domestic recycler, supplying respectively 75 and 62 percent of the total supply. Not surprisingly, the majority of supply of the importing recyclers is purchased through importing agents. As importing recyclers specialise in processing industrial residues, factories also have a share of 8 percent.

In the survey, approximately 67 percent of the overall amount processed by the domestic recycler stems from households, whereas industrial and agricultural waste plastics stand respectively at 30 and 3 percent only. This finding reflects typically the consumption and collection of plastics in big and medium-sized cities across the country. Had the study been conducted in towns and villages, the proportion of waste plastics from farms would be much higher. But that would not typify the essence and main trend of local waste plastics collection.

While recyclers with local waste plastics rely on solely domestic raw materials, 80 percent of the raw materials used by their counterparts are imported waste plastics, with the remainder supplemented by local materials. The ratios between domestic and foreign raw materials vary with the types of plastics. For example, in the case of PVC and PET the ration is approximately 70:30. This unusual large share of domestic plastics is caused by material specific trade measures. For PET, it is the official ban since 1996 on import of used soft drink bottles made of PET which reduced the share of imports. For PVC, NEPA strictly constrained the import and processing of abandoned electric cable, which is an important source of PVC from abroad.

*Table 4.4 Composition of suppliers to the plastic recycling sector*

| supplier | waste plastics trader | domestic recycler | importing recycler |
|---|---|---|---|
| mobile waste vendor | 75 % | 62 % | 0 % |
| waste material trader | 6 % | 34 % | 12 % |
| waste plastic importer | 0 % | 0 % | 80 % |
| plastic generating factories | 4 % | 2 % | 8 % |
| other (i.e. households) | 15 % | 2 % | 0 % |

In the analysis of the manufacturing sector, it is important to realise that the focus is on manufacturers using secondary resin. On average, primary resin accounts for 18 percent of the input and secondary resins for 81 percent. Additives account for the remaining 1 percent. As the output of local primary resin is set to jump in the next few years, possibly accompanied by a lower price, the utilisation of primary resin is expected to go up.

As can be seen in Table 4.1, differences are also observed in the ratios of quality between the two kinds of recycled secondary resins. While the low, medium and high grades represent 11, 78 and 11 percent respectively for secondary resins recycled from local raw materials, the ratio stands at respectively 9, 43 and 48 percent for the low, medium and high grade resins from imported waste plastics. Again this confirms the bias towards processing industrial waste plastics by the importing recyclers.

Table 4.5 summarises the recorded input prices mentioned as indicated by the entrepreneurs. Three categories of materials are considered: local waste purchased by the domestic recycler, local waste purchased by the importing recycler, imported waste plastics purchased by the importing recycler. Similar to the conditions on the primary market, PVC and PS belong to the cheapest category materials. HDPE, LDPE and PET have medium values while ABS is much more expensive.

In the last row of Table 4.5, the unweighted average of various categories of purchasing prices is calculated. Clearly, the price of the waste materials purchased by the domestic recycler are 20% lower than materials bought by the importing recycler. Not much difference is recorded between the imported and local materials used by the importing recycler. This situation illustrates that the importing recycler in China concentrates mostly on high qualities, possibly forced by trade constraints for low qualities. The average price for waste plastics on the international market is generally lower than US$486. This proves that the ban on household waste plastics is successfully enforced, although still some unreported trade was identified.

*Table 4.5 Various categories of prices for waste plastics (in US$ per tonne)*

| | local waste purchased by domestic recycler | local waste purchased by importing recycler | imported waste purchased by importing recycler |
|---|---|---|---|
| HDPE | 494 | 499 | 537 |
| LDPE | 499 | 506 | 544 |
| PVC | 300 | 412 | 393 |
| PP | 305 | 407 | 468 |
| PS | n.a. | 308 | 293 |
| PET | 346 | 479 | 422 |
| ABS | n.a. | 778 | 741 |
| *average* | *389* | *484* | *486* |

The output prices of the recyclers are also shown in Table 4.6. In the third column, the values for secondary reported in the literature are listed. For further use an overall average is derived in the last column. A distinction was made between high quality and low quality secondary resin. In general, the domestic recycler was slightly cheaper than the importing recycler. This apparent advantage of domestic resin is not necessarily a sign of better competitiveness strength of the resin, it is most probably the result of a different definition of quality. For example, for each material the low quality of the importing recycler is significantly more expensive simply because he rarely or never uses grade C (the lowest quality) inputs. Taking into account the input prices reported during the interviews it was calculated that the gross margin lies between 1250 and 2000 Yuan per ton. The markets for HDPE, PVS and PS seem to be relatively profitable. LDPE is the only material which has a consistently low profit margin.

*Table 4.6 Various categories of prices for secondary resin (in US$ per tonne)*

| | domestic recycler | importing recycler | literature values | average value |
|---|---|---|---|---|
| 1. HDPE (high quality) | 818 | 746 | 785 | 783 |
| 3. HDPE (low quality) | 545 | 573 | 664 | 594 |
| 4. LDPE (high quality) | 684 | 686 | 736 | 702 |
| 6. LDPE (low quality) | 463 | 483 | 604 | 517 |
| 7. PVC (high quality) | 584 | 644 | 519 | 582 |
| 9. PVC (low quality) | 322 | 582 | 471 | 458 |
| 10. PP (high quality) | 546 | 629 | 591 | 589 |
| 12. PP (low quality) | 422 | 483 | 507 | 471 |
| 13. PS (high quality) | n.a. | 558 | 616 | 587 |
| 15. PS (low quality) | n.a. | 522 | 543 | 533 |
| 16. PET (high quality) | n.a. | 682 | 773 | 727 |
| 18. PET (low quality) | 409 | 531 | 616 | 519 |

## 4.7 Scale of production and profitability go hand in hand

Profit margins seem to differ for the collection, recycling and production processes. As can be seen from Table 4.7, the profitability is strongly related to the price difference between the input and the output. This confirms the principle of lower profit rates for simple treatment and higher returns for more complex processing, and also shows that the scale of production goes hand in hand with profitability. The rate of returns for recycling with imported waste plastics is higher than that of recycling with local raw materials. The difference can be attributed to the scale of production.

The information on the level of taxation as presented above in Table 4.1 and used in Table 4.7 is rather unreliable, as they were obtained directly from the individuals involved. On the basis of the obtained data, tax payments increase with the value added of the activity. Yet, these payments are not proportional to the amount of profit. The trader and importing recycler pays as little as 1.5 percent of their profit as tax, while the domestic recycler and the manufacturer pay respectively 5 and 13 percent of their profits.

Thus it may be concluded that of tax reduction measures can only be effective with the manufacturing industry. Yet, it should be noted again that these estimates are not very reliable. It is our general impression that the recycling sector is probably paying very little tax.

*Table 4.7 Profitability of Segments in the Recycling Sector (in US$ per tonne)*

| Averages | waste plastics trader | domestic waste recycler | imported waste recycler | plastic product manufacturer |
|---|---|---|---|---|
| price level input | 284 | 386 | 495 | 724 |
| price level output | 338 | 501 | 658 | 1147 |
| value added | 66 | 115 | 163 | 422 |
| profit rate | 9% | 10% | 12% | 15% |

## 4.8 Performance of recyclers is strongly dependent on their location

As shown in the first row of Table 4.1, the domestically based entrepreneurs – the waste plastic trader and the domestic recycler – entered this industry most recently in 1995. This finding illustrates the switch which has taken place in the last few years from state-owned to private enterprises. The importing recycler and the manufacturer of plastic products have traditionally been operating on a commercial based. At present, public-owned enterprises in the plastic recycling industry are practically non-existent.

The location of the subsequent activities in the plastic cycle reveals a typical pattern. Not surprisingly, most of the collection and sorting takes place in and near the metropolises. The majority of the materials is collected by individuals using tricycles. Actual processing near the metropolises was hardly found as cheap labour is scarce and the municipalities discourage and sometimes even prohibit recycling under the presumption that it damages the environment and deteriorates health conditions.

Therefore the waste plastics are transported to local recycling enterprises which are concentrated in rural areas and towns away from big cities. China has basically three of these domestically based concentration areas in which, according to our study and data at hand, 80% of the domestic waste is recycled. The areas are centred in the Baoding and Langfang prefectures of Hebei Province, the Suqian prefecture of Jiangsu Province, and the suburbs of Nanijng. The concentration areas were formed approximately one decade ago with the transition in the recycling sector from state-owned to private industries. For instance, the Wen'an County in Baoding prefecture is the biggest trading centre of waste plastics in the North, linking more than 10 provinces across the north and also part of the southern region. As the trade on waste plastics bloomed over the years, Wen'an and its neighbouring counties gradually turned into the hub of secondary resin and plastics goods industry. The main reasons for this strategic location are the availability of waste plastic within reasonable distance from the collection centres and the presence of abundant and cheap labour.

Not surprisingly, the importing recyclers are strategically situated near the main ports of the country. Two main centres were identified: the Ningbo prefecture of Zhejiang Province, and the Pearl River Delta of Guangdong Province. The latter concentration area also has the advantage of being located near Hong Kong through which most waste plastics enter China. Hong Kong has traditionally been the gate keeper of trade relation with foreign nations. The disadvantage of the relatively high wages is compensated by the large demand of this economically prosperous region.

According to our study, the emergency and growth of secondary resin producers is on the whole quite similar to that of the recycled plastics goods enterprises. Nowadays, local waste plastics trading centres are to some extent also the bases for both secondary resin makers and recycled plastics goods producers. However, the plastic manufacturers are much less concentrated than the recycler. Once the product has been produced, transportation costs increase drastically given the large volume of the goods. Therefore, it is often more beneficial to transport the resin to the demand centres instead of the final products.

# 5. Life cycle model for plastics in China

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In a separated form, ample information is available on the various steps in the plastic cycle. This information base covers economic, social as well as environmental factors. Yet, to design a strategy which leads to an optimal situation for the plastic cycle as a whole, a more integrated approach is required. The advantage of an integrated life cycle approach for plastics lies particularly in the interaction between the segments in the life cycle, and in the integrated appraisal of environmental and economic issues.

In this Chapter, a sectoral model presented which covers the life cycle of plastics in China in an integrated manner. Sectoral models were first developed to help in the designing of industrial sectors in developing countries (Kendrick and Stoutjedijk 1978). These early models paid with little attention to environmental impacts. As the importance of environmental issues grew over the last two decades, it became imperative not only to look at the economics of production but also at the environmental impacts in the life cycle of the produced material and the economics of disposal and recycling. The model presented here is a static cost minimisation planning model. This model is meant to incorporate a cradle-to-grave analysis in combination with the associated environmental impacts caused by the complete product cycle. The mathematical model is presented is presented in Appendix IIX.

## 5.1 Main features of the model

As mentioned, the model captures the complete life cycle of the plastics industry, beginning from the thermal cracking of naphtha to the final disposal of waste plastic. By incorporating a life cycle within traditional sectoral modelling, it is possible to: (1) keep track of the use and production of the various materials (life cycle analysis); and (2) to evaluate the trade-offs that occur within and between economic and environmental variables at each stage of the cycle (sectoral analysis). Moreover, the model decision platform provides a sound basis to facilitate comparisons between the different objectives which can be formulated by a decision maker. Before presenting the results of the model, the main features of the model are described.

### The spatial dimension

The *spatial dimension* of the model is based on the identification of the activity centres for the plastic sector (see Figure 5.1). These are: (1) primary resin production centres; (2) demand and waste collection centres; and (3) recycling and final product production centres. Obviously, the centres are not mutually exclusive. Often, waste recovery centres are located close to demand centres due to the large availability of post-consumer plastics. By explicitly formulating the spatial dimension of the Chinese plastics cycle, transportation logistics, both from an economic cost and environmental impact perspective can be taken into consideration.

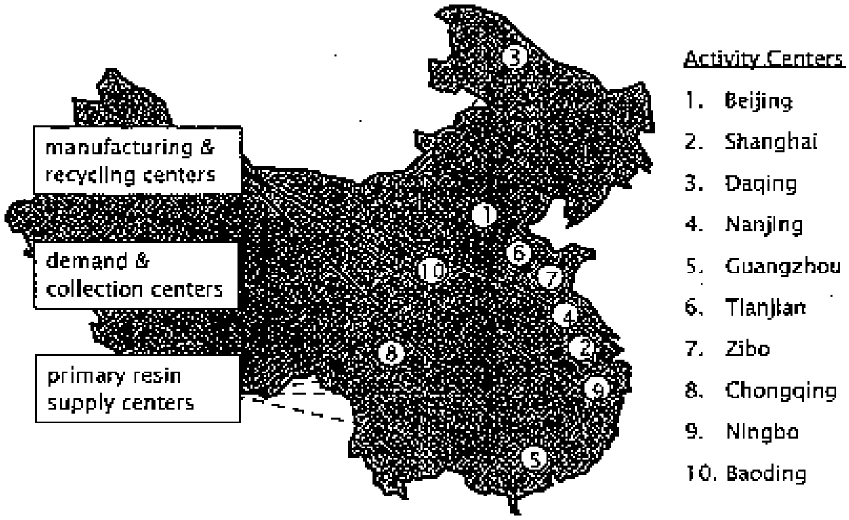


*Figure 5.1 Geographical distribution of activity centres in China*[12]

## The technological dimension

The technological dimension of the model is based on Best Available Technologies (BAT) for all processes in the cycle, modified for Chinese conditions. Associated with each process is a unique input-output vector, also known as a technology matrix, which describes the various inputs used and the outputs produced. Table 5.1 gives an example of a technology matrix for feedstock recycling. The individual processes are linked through a series of mass balance equations which in essence stipulate that total mass of material used must be equal to total mass of material produced.

*Table 5.1 Example of a technology matrix for feedstock recycling*

| | | Quantity | Unit |
|---|---|---|---|
| input | mixed waste plastics | 1000 | kg |
| | H2 | 34 | kg |
| | labour | 4 | man-hour |
| | electricity | 28.2 | GJ |
| output | syngas | 67.6 | GJ |
| | $CH_4$ | 0.14 | kg |
| | CO | 0.066 | kg |
| | $CO_2$ | 499 | kg |
| | HCL | 0.016 | kg |
| | $N_2O$ | 0.003 | kg |
| | $NO_x$ | 0.094 | kg |
| | $SO_2$ | 0.054 | kg |
| | Solid Waste | 19 | kg |

*source: CE 1997.*

[12] See Appendix XI for an elaborate illustration of the spatial dimension of the model.

Associated with processes are capacities. All processes have capacity limits based on currently existing plant structures and sizes in China. It is this feature of the production process which highlights existing bottlenecks in the sector and policy options to mitigate or eradicate these inefficiencies. The important point here is that a limit is imposed such that infinite production levels are not allowed and which can lead to misleading or unrealistic results.

By linking the various stages in the cycle through a series of material balance flow equations, the level of raw, intermediate, final and pollutant goods used and produced can be computed. These equations state that the total mass of products produced at a point must be equal to the total mass of inputs used in the process. The level of inputs can be a combination of products produced within the centre, shipped from another centre or imported. The transportation logistics are also taken into account in addition to the economics of production.

## The environmental dimension

From the emission and material levels resulting from the technology matrices, the environmental dimension can de composed. There are two options of modelling the environment in the model. Environmental services are introduced as a scarce but variable parameter or an upper bound on environmental use is fixed. The latter is the more commonly used route as it is the simplest. However, it involves a degree of arbitrariness as the constraints are determined in many cases in an *ad hoc* manner.[13] The former method, albeit more difficult, theoretically provides a design strategy which is the most cost effective, both from an economic and environmental perspective.

Figure 5.2 illustrates the overall procedure of the environmental appraisal followed in this project. In the first step, the technology matrices are applied to calculate the overall emission levels. In order to determine the environmental impact, the concentration levels of each pollutant need to be determined taking into account the physical properties of the site. For example, an air pollutant emitted during sea freight will do less harm than the combustion of plastics in a densely populated area. Also climatic conditions can be of great influence. It is beyond the purpose of this model to take into account this level of detail. Therefore, standard values are applied. In other words, transfer coefficients are used to translate emissions to concentrations, assuming factors such as population density, and age distribution.

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[13] There are various ways in which environmental effects can be aggregated. In the "distance-to-target" approach weights are derived from the extent to which actual environmental performance deviates from some goal or standard (Powell et al. 1995). Alternatively, multi-criteria techniques can be used to determine the weights. In this method, scores are derived from panels of experts and interested parties (Beinaut 1995). These two approaches have several disadvantages. As experts generally over-represent their own interests, the weights applied are rarely representative for the society as a whole. Another handicap is the fact that the ultimate environmental score is not reported in monetary values. Consequently, integration with the financial analysis is impossible. For a more elaborate exposé on valuation, we refer to van Drunen and van Beukering (1999).

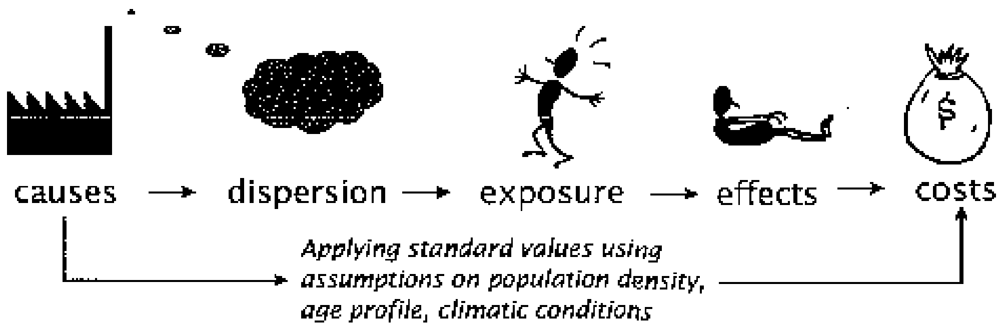


*Figure 5.2 Economic valuation using standard values*

Next, these environmental impacts are translated into monetary values, again making strict assumptions about income levels and property values. The concept of economic valuation of environmental externalities is mainly applied in policies in industrialised countries. Especially in the United States economic valuation methods are commonly applied due to its juridical system where environmental claims are often expressed in monetary terms (i.e. the oils spill of the Exxon Valdez in Alaska in 1989). European and developing countries generally prefer to base its environmental systems on environmental standards. The ground principles of this approach are very different from economic valuation. Economic valuation was selected as the main environmental approach in this project for various reasons which will be explained below. In Appendix IX various valuation methods are discussed.

The monetisation of environmental impacts is called economic valuation. In this approach, the economist's monetary measure of economic value is the Willingness-to-Pay (WTP). The WTP is defined as the maximum amount of money a person is willing to pay to obtain a good or service. An individual's WTP for a good is a reflection of his preferences for this good relative to other goods. Environmental economist work with the assumption that a person also has a certain WTP for environmental goods.

There are various techniques to measure the WTP. First, the values can be based directly on market values of productivity. For example, if extensive emissions of air pollutants from a coal fired electricity plant adversely affect agricultural yields in the region, these foregone crop losses can be used as a measure of the environmental damage of the electricity plant. Second, values can be based on market prices for surrogate products or services. For example, deforestation may lead to a shortage of fuel wood. The alternative fuels which may need to be imported may again represent the external environmental costs of deforestation. In both examples, market prices are directly or indirectly indicative for the environmental impact. Often, the value of environmental goods such as biodiversity or human health can not be derived from market prices (see Box 5.1). In that case, individual preferences (WTP) may be revealed through interviewing techniques.

This approach has several advantages. First, economic valuation enables one to compare the benefits of some environmental improvement with the associated costs. If the benefits, as measured by the WTP for these benefits, are less than the costs then the conclusion would be that the individual prefers to have this improvement to not having this improvement. For example, suppose a program designed to reduce air pollution would result in less cases of an adverse health effect associated with air pollution, say asthma attacks. If some person is willing to pay US$ 75 for preventing these adverse health impacts while the costs of the program to him would be only US$ 50, then one can conclude that he would prefer the situation with the reduced air pollution even though this would mean he has less (US$ 50) to spend on other goods. Thus, the fact that economic valuation allows us to combine the derived external values with internal "financial" costs enables a full cost-benefit analysis.

Second, economic valuation is applicable from secondary literature since large pool of literature is available on this method. From this literature, standard values can be derived for each pollutant or impact (Beukering *et al.* 1998). These standard values allow us to translate emissions directly into costs bypassing the concentration computation stage. It should be mentioned that this simplification may lead to a certain level of inaccuracy. Yet, in the sensitivity analysis the impact of this potential error will be tested. Eventually, we feel that economic valuation albeit conducted under strong assumptions reduces the degree of arbitrariness as compared to emission regulatory standards.

### Box 5.1 The Economic Toll of Pollution's Effects on Health.

Methods for the valuation of health impacts can be grouped in two broader categories. The first one includes methods that measure only the loss of direct income (lost wages and/or additional expenditures). These measures, however, do not include inconvenience, suffering, losses in leisure and other less tangible impacts to individual and family well-being, and may seriously underestimate or completely ignore the health cost of people who are not members of the labour force. Therefore, these methods indicate only the lower bound of the social costs and understate the total costs to individuals. The second category includes approaches that attempt to capture the Willingness-To-Pay *(WTP) of individuals for avoiding or reducing the risk of death or ill-health.* The principal techniques are summarised in the Table below.

*Methods to costs related to human health.*

| *Valuation Methods* | *Example* |
|---|---|
| Human Capital | Earnings foregone due to premature death as a result of exposure to air or water pollution |
| Cost of Illness | Lost workdays plus out-of-pocket costs (medical and other) due to health effects of pollution |
| Preventive/Mitigative Expenditure | Purchase of bottled water to avert health effects of polluted water. Installation of air conditioners to avert air pollution in the residence. |
| Wage Differential | Value of reduction of risk to health implicit in the wage difference in otherwise similar occupations. |
| Contingent Valuation | Direct questioning to provide a value for a potential change in air quality or health. |

*source: World Bank, 1998, p.76.*

Obviously, the approach also has serious disadvantages. The fact that the actual estimation of the weights of the various environmental impacts – and thus the WTP – is a rather time-intensive procedure, implies a major disadvantage of economic valuation methodology. Generally, extensive surveys have to be organised to gather data. Part of this effort can be avoided by applying benefit transfer[14] to existing values from other studies, in which data from other similar situations are used.

Another disadvantage resulting from the comprehensiveness of economic valuation is the fact that the final result is accompanied with a significant degree of uncertainty. Also, the fact that economic valuation expresses values in monetary terms, for example for human health, makes it a rather politically sensitive approach. Although a monetary value has exactly the same impact on a policy decision as a value expressed in a different nominator, economic valuation of human health does trigger ethical perceptions which are not necessarily based on economically rational principles.

In constructing the economic valuation, we found that pollutant emissions from the plastic cycle had significant contribution to five environmental impacts: (1) global warming potential; (2) eutrophication; (3) human toxicity; (4) solid waste; and (5) acidification. The values applied for these five environmental effects were compiled from a series of existing studies (Beukering *et al.* 1998). Through benefit transfer, these values which mainly refer to Europe and the United States, have been corrected for Chinese conditions. This can be done by, for instance, applying a factor representing relevant aspects such as income differences between the countries, population density and the property value of houses and land.

### The financial dimension

Like most sectoral models, this model also incorporates financial costs. These consist of costs for materials, energy, labour, and in case of small investments such as bicycles and cars, also of capital costs. By-product revenues from outputs in the life cycle not used in the production of plastics, such as butadiene, are deduced from the financial costs. Since the present model is static, the financial costs are based on variable costs. Therefore, the capital costs of large investments such as petrochemical plants are taken into account in the form of capital constraints. The philosophy behind this is that the decision maker is in the position to increase his variable activity level by processing more materials, but he is unable to install additional petrochemical plant capacity in the short term. Such investments have to be made in substantial batches and take several years to be completed. Imported goods are valued at their port price plus the necessary transportation costs.

In Appendix X, the financial and environmental data used in the model are presented. Appendix XI summarises the sources of information.

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[14] The definition of benefit transfer is 'an application of monetary values from a particular valuation study to an alternative or secondary policy decision setting, often in another geographical area than the one where the original study was performed' (Navrud 1994).

### The optimisation procedure

To close the model, an objective function is specified based on minimisation of costs. In either case, based on the policy makers objective, the model solution provides an optimal design strategy. The question at hand is which strategy provides the most cost effective solution. For example, this structure provides a useful basis for an analysis of trade-offs between the use of primary versus secondary resin. The objective function applied in this model has determines the optimal configuration of the plastic cycle, based on the minimisation of financial costs. This form represents decision makers who are primarily interested in economic growth.

Based on these two forms, five scenarios are tested. The scenarios are inspired by the latest economic and political developments in the plastic cycle in China.

- *Technological change scenario* in which some of the technical parameters governing the input mix of virgin and secondary resin in the manufacture of final products are modified.
- *Environmental integration scenario*: in which the optimal configuration of the plastic cycle is based on the minimisation of the sum of financial and environmental (external) costs. This scenario represents the more sustainable decision maker.
- *Trade regime scenario* in which a comparison is made between a situation in which waste plastics are freely traded and a situation in which a total ban on the imports of waste plastics is enforced.
- *Import price scenario* in which import prices for waste plastics are modified in order to test the sensitivity of the results to changes in the international market.
- *Recycling capacity scenario* in which the production capacity of the plastic recycling in China is modified.

To solve the model under these various forms and scenarios, the optimisation program GAMS Release 2.25 was used (Brooke, Kendrick and Meeraus, 1996). The results are presented below.

## 5.2 Results

Figure 5.3 depicts the present actual levels (bold) as well as the levels determined by the base model (italic). Overall, the simulated and the actual mass flows differ very little. The main differences are observed in the production of final goods, import of primary resin, and the production of primary and secondary resin.

There are two reasons for the lower production in final goods. First, since we omit exports, a lower overall demand for final goods results, reducing production. Second, as the technology matrix for production of final goods in this model allows only fixed inputs proportions of primary and secondary resin, no substitution is allowed between the two types of resin if a shortage is witnessed in either category. Thus, since the recycling industry is already supplying the maximum amount of secondary resin – note that secondary resin cannot be imported – additional demand can not be met by increasing the supply of primary imported and domestic resin but by increasing imports of final goods. Subsequently, domestic production as well as import of primary resin are reduced.

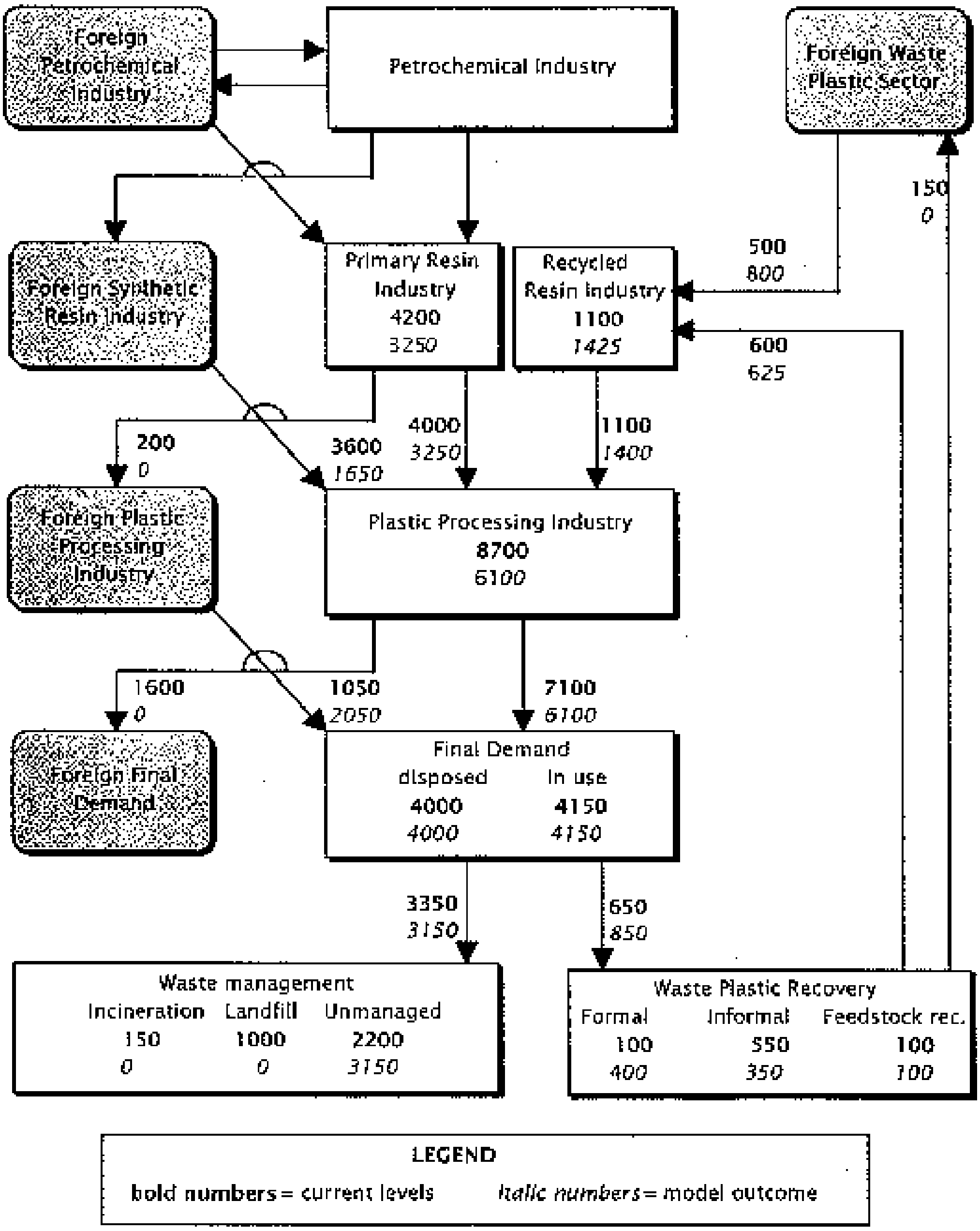


*Figure 5.3 Current levels compared to the model outcome (1000 tonnes)*

## Technological change scenario

Thus, given the assumption of fixed input proportions between primary and secondary resin, the limited recycling capacity forms the main bottleneck in the model. To test the impact of this assumption, the technology matrix on the input mixture for the production of final goods is modified. High quality plastic products are no longer allowed to contain secondary resin, while the content for medium quality plastic products is reduced from 80 to 50 percent. The proportion in low quality products is kept constant at 70 percent.

Table 5.2 shows the resulting change in imports at three levels in the plastic cycle. The results confirm the earlier suspicion. Now that primary and secondary resin are less mutually dependent, the cycle is also less dependent on imports of final goods. Instead the domestic industry supplies products which are produced by imported and locally produced resin. As shown in Table 5.3 the financial costs also reduce as the cost of importing primary resin is much less than the cost of importing final goods.

*Table 5.2 Imports with standard and modified technology matrix (million tonnes)*

| Imports | base scenario | technology scenario | change in imports |
|---|---|---|---|
| primary resin | 0.6 | 1.0 | + 67 % |
| waste plastic | 0.8 | 0.5 | - 38 % |
| final products | 2.1 | 1.3 | - 38 % |
| *total import* | *3.5* | *2.8* | *- 20 %* |

*Table 5.3 Cost with standard and modified technology matrix (billion Yuan)*

| costs | base scenario | technology scenario | change in costs |
|---|---|---|---|
| production cost | 18.2 | 19.2 | + 5 % |
| transport cost | 1.9 | 1.9 | - 1 % |
| import cost | 38.9 | 35.2 | -10 % |
| by product revenue | -3.8 | -3.8 | 0 % |
| *total financial cost* | *55.2* | *52.5* | *- 5 %* |

*note: Differences in totals in these and following tables are due to rounding out errors.*

Note also the decrease in imports of waste plastics. The imports of waste plastics reduce in almost the same proportion as final products. The reason for this decrease lies in the fact that domestic waste plastics are cheaper. It shows that in case the overall demand for secondary resin decreases, the domestic waste plastics are utilised first, leading to relatively less imports of waste plastics. This scenario also shows that in these conditions, in principle, sufficient recycling capacity exists. The bottleneck rather lies with a lack of local recovery of waste plastics. Importing is a feasible option but does lead to slightly higher costs. Most importantly it can be concluded from the technology scenario that enhancing the substitutability between primary and secondary resin can lead to significant cost savings. This should primarily be achieved through the improvement of the quality of secondary resin.

## Environmental integration scenario

The government of China and the industry, are increasingly paying attention to environmental issues. Therefore it is important to evaluate the effect on the plastic cycle if the perspective of the decision maker is changed from a purely financial planner to a perspective where environmental impacts are incorporated. The optimal configuration is likely to change.

In this scenario we distinguish two types of total costs. Financial costs which consists of the traditional components, and the economic costs which are the sum of financial and environmental costs. In the base scenario we optimise on the basis of the financial costs and separately calculate the environmental costs. In the environmental integration scenario we optimise the economic costs, thus explicitly incorporating environmental costs in the decision process.

It should be realised that the values of environmental costs should be considered as very rough estimates. As mentioned, standard values were used from other studies. Moreover, certain categories such as ecotoxicity and groundwater leakage are not included because of lack of reliable data. Therefore, the estimate given in this paper should be considered a lower boundary for the real environmental damage.

Table 5.4 depicts the cost difference between the base and the environmental scenario. Various observations can be made. First, the environmental costs do not weigh heavily on the economic costs in the base scenario, accounting for less than 7 percent. Thus although not being completely neutral, it is not recognised as a very dominant factor. Second, as soon as environmental costs are taken into account, the environmental costs to society reduce by 74 percent, leading to an economic cost decline of 6 percent. This welfare improvement requires a limited financial sacrifice: financial costs increase by 1 percent. These enhanced costs mainly results from larger imports of mainly primary resin. Producing abroad is more expensive, but also cleaner. Typically also domestic transport which creates substantial pollution is less in the environmental scenario.

Another relevant observation from the environmental integration scenario is the fact that the recycling industry returns to a situation of maximised utilisation of its capacity. Instead of increasing the import of foreign waste plastics, most of the increased recycling activity is supplied by the domestic market. From this shift is can be concluded that the production of secondary resin particularly based on domestic waste plastics is environmentally less intensive than primary resin production processes. Recycling has become more economically profitable – note that this does not count in the financial sense – now that environmental avoided burdens are taken into account in the planning process. Environmental burdens are mainly avoided in the waste and the primary production stages.

*Table 5.4 Costs for base and environmental integration scenario (billion Yuan)*

| | base scenario | environmental scenario | change |
|---|---|---|---|
| production cost | 18.2 | 14.7 | - 19 % |
| transport cost | 1.9 | 1.7 | - 15 % |
| import cost | 38.2 | 41.8 | + 7 % |
| environmental cost | 3.9 | 1.0 | - 74 % |
| by product revenue | - 3.8 | - 3.5 | - 7 % |
| *total financial cost* | *55.2* | *55.6* | *+ 1 %* |
| *total economic cost* | *59.0* | *55.6* | *- 6 %* |

## Trade regime scenario

As mentioned in Chapter 3, the imports of waste plastics are a major in China. In the last few years various trade policies were installed with regard to the import of this commodity. To simulate the impacts of these policies, a *trade regime scenario* is presented in which a comparison is made between a situation in which waste plastics are freely traded and a situation in which a total ban on the imports of waste plastics is enforced. Table 5.5 summarises the main results of this scenario.

Clearly, refraining from import constraints gives the most cost effective regime. The financial cost increase by approximately 26 percent if a ban on waste plastics is installed. The cause of this increase is obvious. The domestic recycling industry is now suffering from a severe lack of inputs. Since the domestic plastics recovers are unable to fill this gap, due to low financial margins and limited capacity, the demand for final plastic products have to be imported. Because importing final products is more expensive than waste plastics, costs of imports increase by 37 percent.

The Chinese government introduced the ban on waste plastics primarily for environmental reasons. It is therefore important to evaluate the environmental costs of the trade regime scenario. As opposed to the intention of the Chinese government, Table 5.5 shows how environmental costs increase due to the ban (16 percent). This is the result of the slight increase in domestic production in the primary sector as well as the decreased activity in the recycling sector.

We also made a comparison between the plastic cycle with and without free trade of waste plastics, optimised for economic costs thus taking into account environmental costs. Similar to the former environmental scenario, domestic activities are reduced and imports of primary commodities are increased. Under these environmental conditions the negative effect of the import ban on the environment are magnified. Environmental costs increase by 34 percent.

Despite this quantitative indication that free trade has its environmental and economic merits, reality sometimes proves different. The model did not take into account the incidents were imports of waste plastics occurred which were so contaminated that recycling was practically impossible. Formally, these related environmental costs of landfilling or incinerating should be accounted for. Also, it should be noted that free trade of secondary materials can only be beneficial to the environment if monitoring systems are sufficiently in place. The costs of customs control were also ignored in this model.

*Table 5.5 Costs under free and restricted trade regimes (in billion Yuan)*

| | base scenario | waste plastic import ban | Change |
|---|---|---|---|
| production cost | 18.2 | 18.3 | + 1 % |
| transport cost | 1.9 | 1.6 | - 14 % |
| import cost | 38.2 | 53.2 | + 37 % |
| environmental cost | 3.9 | 4.5 | + 16 % |
| by-product revenue | - 3.8 | - 3.8 | 0 % |
| *total financial cost* | *55.2* | *69.3* | *+ 26 %* |
| *total economic cost* | *59.0* | *73.8* | *+ 27 %* |

### Import price scenario

In the import price scenario, the sensitivity of the plastic cycle is tested for changes in the import price of waste plastics. Simulations are conducted of respectively a price increase and decrease of 50 percent. Although this modification is unusually high for sensitivity tests on primary materials, fluctuations of this magnitude are rather common in the international secondary market.

The results are presented in Table 5.6. A price increase of foreign waste plastics hardly has any effect on the plastic cycle. For example, only an increase of 2 percent is observed in financial costs. This increase is primarily caused by an increase in the import of final goods, suggesting that at this price level it is cheaper to import products rather than to import waste plastics to generate products through the domestic recycling sector. This conclusion is supported by the lower domestic secondary resin production.

A reduction in the import price of waste plastic generates much explicit changes in the material flows of the plastic cycle. The import of waste plastics increases by 23 percent while the use of domestic waste drops by 30 percent. This suggests that the local recovery sector is sensitive to international market prices for waste plastic. If these prices fall, the domestic recycling industry is likely to substitute domestic waste for imported waste. This crowding-out effect, advocated by critics of trade in waste plastic, thus poses a real threat which policy makers must address when policy prescriptions are formulated. On the other hand, less domestic and imported resin is used for the production of final goods, decreasing both the financial and environmental costs. Therefore overall, the increased import of waste plastics is beneficial to society.[15]

*Table 5.6 The sensitivity to import price changes for waste plastics*

| | base scenario | units | price increase of foreign waste plastics of 50 % | price decrease of foreign waste plastics of 50 % |
|---|---|---|---|---|
| domestic primary resin | 3.2 | million tonnes | + 0.0 % | - 0.3 % |
| imported primary resin | 1.6 | million tonnes | - 0.1 % | - 1.0 % |
| domestic secondary resin | 1.4 | million tonnes | - 0.2 % | + 0.0 % |
| imported waste plastics | 0.8 | million tonnes | - 0.3 % | + 23.1 % |
| domestic waste plastics | 0.6 | million tonnes | + 0.0 % | - 29.8 % |
| domestic final goods | 6.1 | million tonnes | - 0.1 % | - 0.4 % |
| imported final goods | 2.1 | million tonnes | + 0.1 % | + 1.1 % |
| *financial costs* | *58.1* | *billion Yuan* | *+ 2.2 %* | *- 2.4 %* |
| *environmental costs* | *0.9* | *billion Yuan* | *+ 0.0 %* | *- 0.1 %* |

[15] A word of caution must be mentioned here. Our analysis does not take into account of the social costs which accrue to the economy when unemployment goes up in the recovery sector.

## Recycling capacity scenario

An important feature of the previous scenario is that the recycling industry is always operating at full capacity. To investigate the relative importance of this factor, we run a scenario in which the production capacity of the recycling industry is increased by 20% while the imported waste plastic price remains constant. In the fourth column of Table 5.7 the main results are presented. The import of primary resin and even more of final goods reduce significantly. As the supply of secondary resin is no longer a limiting factor, the plastic sector is able to produce a larger quantity of final goods domestically. The drop in total financial costs stems directly from the lower import cost of final goods *vis a vis* the import cost of waste plastics. The environmental cost goes up slightly as there is a relatively higher domestic activity level.

These savings in costs are even higher if the import price of waste plastics is half of the current level as clearly shown in the last column. What also prevails from this scenario is the rejection of the crowding-out effect hypothesis. The results clearly illustrate that a drop in price of imported waste plastics does not necessarily have an effect on the use of domestic waste - the quantity of imported waste goes up but not at the expense of domestic waste. Thus domestic capacity is more important to focus on than on the price.

*Table 5.7 Results of the Sensitivity Analysis*

| | base scenario | units | capacity increase of 20 %, no import price change | capacity increase of 20 %, import price decrease of 50 % |
|---|---|---|---|---|
| domestic primary resin | 3.2 | million tonnes | + 0.7 % | + 0.4 % |
| imported primary resin | 1.6 | million tonnes | - 3.6 % | - 4.1 % |
| domestic secondary resin | 1.4 | million tonnes | + 18.5 % | + 18.5 % |
| imported waste plastics | 0.8 | million tonnes | + 34.6 % | + 52.9 % |
| domestic waste plastics | 0.6 | million tonnes | + 0.6 % | + 0.6 % |
| domestic final goods | 6.1 | million tonnes | + 3.7 % | + 3.5 % |
| imported final goods | 2.1 | million tonnes | - 11.0 % | - 10.2 % |
| *financial costs* | *58.1* | *billion Yuan* | *- 3.3 %* | *- 6.4 %* |
| *environmental costs* | *0.9* | *billion Yuan* | *+ 0.6 %* | *+ 0.6 %* |

## 5.3 Main lessons

The primary objective of the model presented is to shed light on the present status of the plastic cycle. The model focuses on both financial and environmental aspects. Despite this broad focus, certain limitations should also be highlighted. First, the model presents a static situation. Although specific effects such as technological change, increasing prices and varying capacities can be simulated, this model is not well equipped for such dynamic analysis. Second, environment is included in a rather standardised manner. Average environmental values have been adopted from other studies. In reality, external conditions may be very different in specific locations in China relevant for the plastic cycle. Moreover, certain values have been excluded due to lack of information. Third, institutional aspects such as an enforcement system for the monitoring of imports of waste plastics have not been considered. It may well be that the true costs to society of recycling foreign waste plastics, including possible dumping of hazardous waste, is higher than currently represented in the model. The model may thus be overestimating the advantages of importing this commodity.

Despite these caveats of the model, we are still able to draw some general lessons from the modelling exercise. The three main ways in which the plastics cycle in China can move to better performance are:

First, increase the capacity of the waste plastics recycling industry: the total financial and economic costs of the plastic cycle in China can be reduced by increasing the capacity of the domestic recycling industry. Most of the simulated scenarios highlight the limited existing capacity of the recycling industry. This shortage forces the final goods manufacturing sector to use a higher proportion of primary resin in their final goods than what is economically and technically desirable. Since the second best option – the production with domestic primary resin – is also constrained by a lack of industrial capacity, the plastic cycle has to resort to the third best option of foreign dependency. This has been one of the reasons for the large import of primary resin.

Second, regain the performance of the waste plastics recovery sector. The additional recycling capacity should preferably be met by domestic waste plastics. Not only are transport activities avoided but the waste burden created by post-consumer plastics is reduced as well. This requires additional attention for the recovery sector of plastics. The presently plummeting recovery rate should be reversed as soon as possible. This may require special policies by the Chinese government.

Finally, we do not expect the recovery system to be enhanced on the short term. Therefore, imports of waste plastics should be allowed to meet the gap between demand and supply of waste plastics in China. This will not have a negative effect on the balance of payment, as the increase in imports of waste plastics will mainly replace relatively expensive imported final goods.

How these recommendations fit in the qualitative assessment made in the earlier sections of this report, is presented in the following Chapter.

# 6. Summary and recommendations

*Li Yongjiang and Pieter van Beukering*

In the coming years and into the 21st century, plastics will gain importance in Chinese national life. Developments in the pillar industries, such electronics, automobile manufacturing and construction, will mean growing demands of the synthetic resin and plastics industry. Moreover, households will expand their demand for plastics, both in terms of quantity and quality. The coming decade will be a crucial period for the plastic industry in meeting this challenge. At the same time, the rapidly increasing waste burden of plastics will have to be minimised. This will require intense efforts on the part of both the formal waste management and informal recovery sectors. The actual utilisation of the plastics recycling industry will be of crucial importance in this process. It may reduce the burden of solid waste by creating a market for recovered materials while simultaneously narrowing the gap between the demand and supply of plastic resources.

In this research project, the role of the plastic recycling industry in creating a more sustainable plastic cycle in China, is analysed. This question is addressed in both a qualitative and a quantitative manner. The qualitative study combines an elaborate field survey combined with an extensive literature inventory. The quantitative is addressed through a static sectoral model dimension of the plastic cycle. Neither of these approaches provide all encompassing answers. The quantitative approach tends to ignore possibly important details in the plastics sector while in the qualitative approach it is difficult to maintain the overall picture. Therefore, this Chapter aims to combine the findings of these two approaches.

To recapitulate the current situation, we first summarise the main trends and issues in the plastics cycle in China:

- Final demand for plastics is growing rapidly;
- The domestic primary plastics industry is unable to meet this demand, as a result of which China is highly dependent on imports of plastics;
- Waste management is incapable of dealing effectively with plastics waste;
- Less waste plastics are 'formally' recovered because government involvement is less;
- The recycling rate of plastics is declining mainly because recyclers suffer from lack of supply of waste plastics;
- In China, two types of recyclers can be distinguished: the ones using domestic waste plastics and the ones using imported waste plastics;
- These domestic and importing recyclers develop differently. Labour productivity of the importing recycler is higher due to better quality inputs, scale of operation as well as the higher capital intensity of production;

Taking this inventory as a starting point, three main recommendations will form the centre of further debate.

## 6.1 Expand the capacity of the plastics recycling industry

The secondary plastics industry has yet to make a significant contribution towards meeting the needs of China's economic development. In principle, the potential exists to do so. Both financial and environmental costs of a well balanced primary and secondary production system in China are favourable compared to a scenario in which the focus is solely on primary production. Obviously, relying on imports of primary resin and final products is environmentally preferable for the Chinese society but the associated financial costs amply outweigh a more domestic scenario. Therefore, the currently declining recycling rates of waste plastics is undesirable. The study clearly indicated that expansion of the capacity of the plastics recycling industry in China is required.

The question remains how this expansion can be achieved. In previous years, direct government involvement was necessary to maintain a high level of recycling. It is clear that a similar approach is not realistic in a society which is gradually moving away from direct government intervention. The role of the government should have a much more indirect nature by removing obstacles for the industry. An obvious indirect intervention would be to apply economic measures to improve the operation of the sector. Yet, it is rather doubtful whether such measures would be effective because at present most recyclers avoid paying taxes so that tax and other incentives are an ineffective and/or expensive tool.

Alternatively, the government could operate as a facilitator. For example, the survey revealed that technological improvements are rather slow in this industry. Additional research and development (R&D) could alleviate these constraints. In this context, the following issues should be considered.

First, R&D should focus on recycling technologies. Experts predict that the most important technological progress in plastics recycling will not occur in mechanical recycling but in the pre-treatment stage, more specifically the sorting of waste plastics. The major determinant of the quality of recycled plastic products is the quality of the input. Pre-treatment of waste plastics includes several processes such as volume reduction, separation, crashing, washing, and drying. All of these processes have a direct bearing on the quality and cost of secondary products. For example, the market price of clear PET regranulate is five times higher than baled, coloured PET. Moreover, the cost will drop significantly if the volume of waste plastics collected for recovery can be reduced on the spot, through sorting, cleaning and separation.

At the same time, R&D should concentrate on other forms of recycling technologies which are relatively new and thus still have a large improvements to be realised. The experience in industrialised countries indicates a maximum rate of mechanical recycling of 20 percent of total waste plastics (IPTS 1997).[16] Beyond this level, other types of recycling become feasible, for example, chemical regeneration with single and mixed waste plastics as raw material. Products from this process include chemical raw material and

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[16] Estimates show that even if all economic limitations were to be removed, it is unlikely that mechanical recycling would provide a sensible economic and environmental solution for more than about 20 percent of plastic waste (IPTS 1997). It is claimed that feedstock recycling will provide a route for increased recovery of plastic waste in the future (Curlee and Das 1996).

fuel. The advantage of fuel outputs is that it effectively diverts the low quality material flows from the economy. This technology is especially useful for household residues where waste plastics are supplied in a mixed form. Successful developments have occurred in the technology of gasfication of mixed waste plastics and depolymerisation of PET and PP in recent years. Although the economic feasibility of chemical recycling is still very limited, this technology may become a useful management option in future.

Second, R&D could also focus on the characteristics of the end-products of the recycling industry in various ways. On the one hand, the currently limited market of secondary plastic applications could be expanded. For example, existing products could be designed such that they would be more suitable to contain a higher content of secondary resin. Also, new products could be designed which are specifically fit as a secondary inputs. The adoption of these products in the markets can be supported by the government through government procurement policies of recycled plastic products. On the other hand, R&D could also focus on the pre-production stage. A more thought-out product design may increase the recyclability of the good after its consumption. This can for example be achieved by avoiding the application of different types of plastics in one product, as well as by improvement products.

Often, the argument is heard that promoting the recycling industry would be at the expense of the primary segment of the industry. The study showed, however, that given the large increase in demand for plastics in China and the relative segregation of the primary and the secondary plastics market, it is unlikely that the primary industry will experience any significant effects from increased recycling.

## 6.2 Revitalise the waste plastics recovery sector

With the growth of plastics consumption, the burden of waste plastic is rapidly increasing. Since embarking on policy reform and a movement towards a market economy, the volume of waste plastics collected by the formal recovery sector in China has decreased. This has been due to high operating costs and the low potential for generating profit. It is doubtful whether efforts should be intensified towards rebuilding the formal sector. Perhaps from an environmental perspective, it would be defensible. However, the cost-effectiveness of other environmental investment in the plastic cycle could be higher. Thus from an economic perspective, policies to promote the formal sector seem tenuous.

During the same period the volume of waste plastics collected by the informal sector has increased rapidly, accounting for 90 percent of the total collected in 1994. Their operating costs, both for collecting and recycling, are much lower than those of the formal sector. Thus, for most individuals it is still a profitable business. However, a serious threat to individual operators is the implementation of large scale waste collection systems which do not allow for separate recovery of the recyclable waste components. Since these entrepreneurs reduce the waste volume free of cost to society, policies should also recognise and promote the performance of this sector. Unquestionably, they should be included in the preparation and execution of integrated waste management plans.

Yet, the responsibility for waste will not lie solely with the waste management sector. Increasingly industries will be held responsible for their impacts. A convincing example of extended responsibility in the plastics cycle in China is demonstrated in Beijing where the producers of the foam food packaging are financing a recovery system. This example proves that primary industries also benefit from a well organised recovery sector. This interdependency of primary and secondary production illustrates the importance of considering the plastic cycle as an integral system, consisting of various actors and processes which compete and complement each other.

Despite the existence of these potential solutions, certain problems with recovery of waste plastics remain. Obviously, it is nor economically nor environmentally feasible to recover all waste plastics for purposes of mechanical recycling. Moreover, plastics can only be mechanically recycled a limited number of times. As recycling takes many different forms with varying environmental impacts and since the variety of waste plastics in China is large, it would be optimal to design a specific form of recycling for specific types of waste. For example, it could be assumed that the principal form of processing of industrial waste plastics, such as cut-offs, is mechanical recycling. Similarly, feedstock recycling mainly focuses on agricultural film, and energy recovery could be applied mainly to household waste such as contaminated food packaging. Such a recycling hierarchy becomes ever more appropriate with the diversification of technologies and recovery systems.

Another problem in the recovery system is the difficulty in supplying a constant and large flow of high-quality waste plastics, required by the domestic recycling industry. Seasonal fluctuation, caused by for example festivities, yield schedules and climatic conditions, form a major problem for the domestic recyclers. Therefore, solutions should not necessarily be only sought for in the borders of China. Supplementary purchases of waste plastics from abroad should remain a possibility for the recycling sector.

## 6.3 Allow monitored imports of waste plastics

As mentioned earlier, plastic production in China has been unable to meet the needs of the domestic market. Besides boosting imports of plastic products, it has also raised imports of raw materials, such as monomer, polymers and waste plastics. Based on this trend, several conclusions on trade can be drawn. It is expected that this trend will continue over the next few years. From the year 2000 onwards, with the establishment of several ethylene projects, imports of plastic raw materials are expected to slow down. In the process of substituting domestic for imported materials it will be important for Chinese production to meet international levels of efficiency to avoid protective trade measures.

More and more, the factor endowments are dictating the trade patterns of China. As manufacturing of plastic products is generally labour intensive, which can certainly be considered an comparative advantage for China, plastic products have become a major export item for China. This export volume is expected to increase further. In a similar fashion, the imports of waste plastics could be explained.

China is among the largest importers of waste plastics in the world. An obvious explanation for this phenomenon is that due to the low wages in combination with the relatively low import costs, it is a attractive economic activity to conduct. This trend is supported by the general booming demand for plastics in China. Still, due to various incidents, the Chinese government mainly sees the threat of imports of waste plastics. Policies were taken accordingly. Especially with the eye on long term investments, it is important for the recyclers in China to know whether the international market will remain a reliable source of raw materials. Although the international market of waste plastics is expected to grow further, the Chinese government remains quite critical in this respect[17]. The best approach would be to further improve the monitoring system of imports of waste plastics to guarantee sufficient supply for the domestic recyclers, while simultaneously protecting China from unwanted imports. Obviously, as recognised in the Basel Convention, a major responsibility also lies with the exporting country. The costs of monitoring and enforcement has to be analysed further to show the real trade-off between more imports of secondary plastics versus alternative scenarios.

In addition to the availability on the international market, the effects of imports of waste plastic on the plastic cycle in China were addressed in more detail in the project. We looked at the risks that imported secondary materials may be substituted for domestic secondary materials, in which case, the domestic recovery sector will suffer from increased imports and increased amounts of MSW will be generated. The modelling exercise demonstrated that under current circumstances, this crowding-out effect does not take place. In fact it was found that imports actually upgrade the quality of the inputs of the recycling industry and thereby improve the marketability of secondary products. Thus, the recovery sector was not damaged by increased imports of waste plastics.

## 6.4 General recommendations

Several more general conclusions can be drawn. First, the interdependency of various stages in the cycle do require a more integrated perspective on the plastic cycle. Future measures for a cost-effective management and optimal use of the resource "plastics" should consider the total amassment of plastics (flows, stocks and final sinks). A mere sectoral approach, e. g. to singular fractions of plastics, may lead to solutions that are costly and scarcely efficient regarding the total flows and stocks of plastics. In line with this conclusion, we feel that the integrative approach is also valid for the disciplinary perspective of researchers and policy makers. Considering only financial aspects, separate from environmental, social and institutional dimensions, decreases its comprehensiveness and applicability.

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[17] "With businesses in the packaging chain to be faced with a statutory obligations to achieve quantified recovery and recycling of packaging wastes, forward-thinking companies will be considering moving forward incorporating recycled plastics in their products particularly where cost savings can be achieved. The level of plastic recycling looks set to increase over the next few years - indeed, an approximate 2 to 3-fold increase in materials recycling of plastics packaging wastes will be necessary to meet the targets of the Producer Responsibility Regulations which reflect the requirements of the EC Packaging and Packaging Waste Directive. This level of increase will pose a major challenge to the industry." (Ogilvie 1996).

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# Appendix I. Plastic as a consumed commodity

Figure I.1 demonstrates how the demand for plastics have exponentially increased after the Second World War.

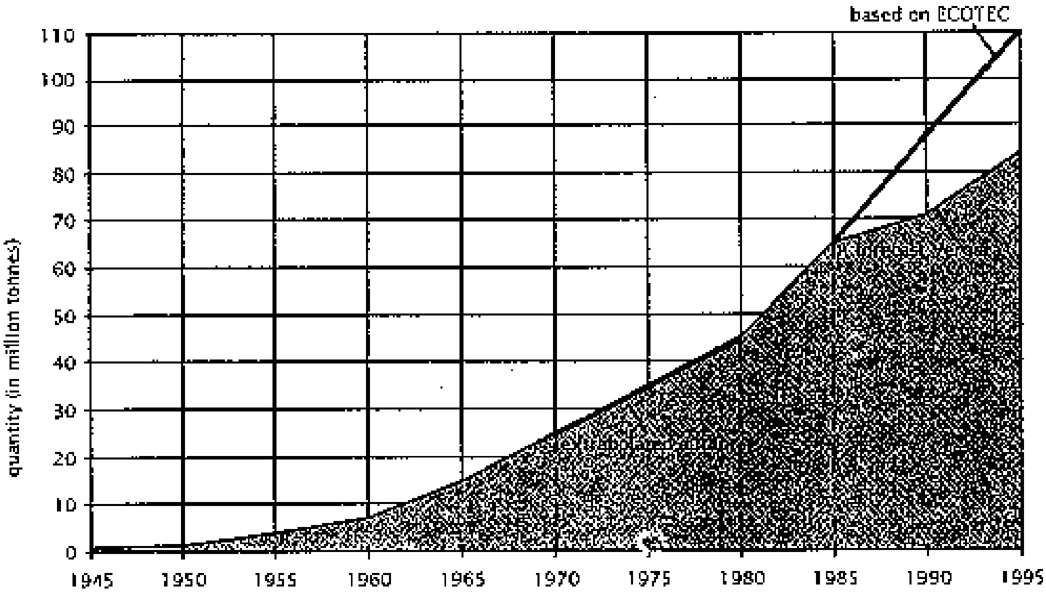
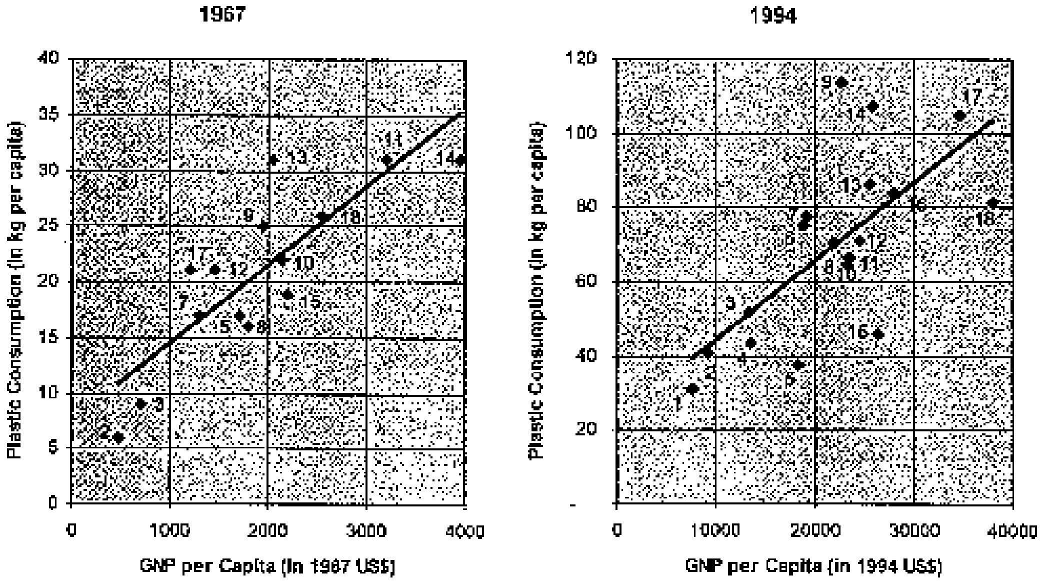



*Figure I.1 Global demand for plastics from 1945 till 1995*
*source: Grimaud et al., 1970; Vergara 1988; ECOTEC 1995*

Figure I.2 illustrates how the relationship between plastics demand and income has changed over the years in Europe and the United States. To measure this relationship, a linear regression analysis was performed for two periods. In 1967 an increase in income of US$ 1,000 was accompanied by an increase in consumption of 7 kilograms. In 1994 a similar income growth results in an increase of 2.1 kilograms. Apparently, especially in the early stages of development of a country, the demand for plastic products increases rapidly.

Not only the level of the consumption for plastics is important to understand possible future developments in developing countries. Also the composition of the demand is relevant. In evaluating the composition of the plastics demand presented in Table I.1 for respectively the United States, Western Europe and China, it is found that differences exist between industrialised and developing countries. For example, thermosets plastics (the last category row 'others'), with a share of respectively 17 %, 18 % and 8% make out only a limited fraction of the plastics demand. Especially in the context of recycling this is an important finding since thermosets are not mechanically recyclable.




$Cp = 0.007\ GNP + 7.4767$
$R^2 = 0.7036$

$Cp = 0.0021GNP + 23.011$
$R^2 = 0.4598$

*Country codes:* 1. Greece; 2. Portugal; 3. Spain; 4. Ireland; 5. United Kingdom; 6. Finland; 7. Italy; 8. Netherlands; 9. Belgium/Lux.; 10. France; 11. Sweden; 12. Austria; 13. Germany; 14. United States; 15. Norway; 16. Denmark; 17. Japan; 18. Switzerland.

*Figure I.2 Relationship between per capita income and plastics consumption over time*
*Source: Compiled from Grimaud et al. 1970; APME 1996*

A clear difference exists between the configuration of the recyclable plastics in the industrialised countries and China. The polyethylene categories LDPE, LLDPE and HDPE dominate the market in the US and Europe. Typically, PVC and PP are very prominent in China. In all countries the share of PET is still relatively small. In terms of growth rate however, PET maintains a top position with an expected annual growth in Western Europe of 12.6 % while the average growth rate is only 3.5 % (CSI 1989).

*Table I.1 Composition of plastics demand in different regions*

| Types of plastics | United States (1995) | Western Europe (1993) | China (1996) |
|---|---|---|---|
| LDPE/LLDPE | 21 | 21 | 13 |
| HDPE | 17 | 13 | 16 |
| PP | 15 | 13 | 23 |
| PVC | 16 | 21 | 32 |
| PS | 11 | 10 | 6 |
| PET | 3 | 4 | 2 |
| other | 17 | 18 | 8 |

*source: Curlee and Das 1996; APME 1995; National Federation of Light Industry 1997.*

## Appendix II. Plastic as a traded commodity

This assessment on international trade of primary and secondary plastics is based on the UNCTAD database TRAINS (1996). This database is compiled of statistics over the period 1991-95 and does not yet provide sufficient data to analyse long term developments. Also, the data base do not yet include trade figures from all countries. Moreover it should be realised that the data are rather unreliable. Often data from the importing country do not match data from the exporting nation. Still, as the most important countries do report trade statistics, the majority of the trade flows can be considered to be captured. In the two most important international trade classifications, the Harmonised Commodity Description and Coding System (HS) and the Standard International Trade Classification (SITC), waste of plastics is normally classified as depicted in Table II.1.

*Table II.1 Waste plastics classification*

| Code | classification |
|---|---|
| HS 391510/SITC Rev.3 57910 | Waste of polymers of ethylene (LDPE, LLDPE, HDPE), & propylene (PP) and their copolymers (i.e. olefin polymers). |
| HS 391520/SITC Rev.3 57920 | Waste of polymers of styrene (PS) |
| HS 391530/SITC Rev.3 57930 | Waste of polymers of vinyl chloride (PVC) |
| HS 391590/SITC Rev.3 57990 | Waste of other plastics |

*source: UNCTAD 1996*

The total plastics trade in 1993 amounted to US$.58 billion. Approximately, 99% of the total was trade in non scrap plastics (including plastics resin and products), and half a billion US$ consisted of waste plastics. In quantity this is equal to almost 1.5 million tons. In 1994 the amount of traded scrap plastics increased to 2.7 million tons with a value of US$ 775 million.

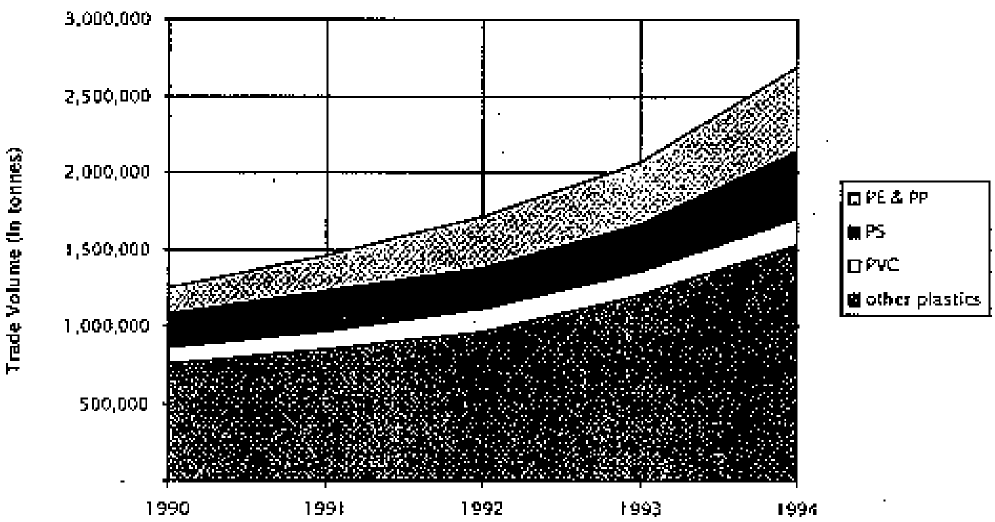



*Figure II.1 Developments of international trade of waste plastics*

An interesting observation from Figure II.1 is the category "other waste plastics" (HS 391590). This category dominates the trade throughout the nineties. Most probably this category consist of materials such as PET and ABS, as well as waste plastics which can not be clearly identified by the customs. The size of the category proves how difficult the classification of waste plastics is. A strong need exists for clear standards to distinguish waste plastics by type and quality.

It is also important to look at the variation in price on the global market of waste plastics. Based on the markets of China and Hong Kong[18], it was found that PE, PS, PVC and other plastics respectively cost US$ 248, US$ 301, US$ 349 and US$ 294 in 1994.

As can be seen in Table II.2, the import of waste plastics is concentrated in only a few countries. The first 10 countries take a account for 98% of the total volume. Hong Kong has a very dominant position in the trade by importing more than 50% of the traded waste plastics. It is not unlikely that a significant share of the waste plastics imported in Hong Kong are actually recycled in mainland China. From the survey among recyclers in Hong Kong's neighbouring province Guangdong (see Chapter 5), it appeared that quite often unregistered quantities from Hong Kong were processed. In reality, China will probably ranks second.

*Table II.2 Main importers of waste plastics in 1994*

| | | HS 391510 (PE & PP) | HS 391520 (PS) | HS 391530 (PVC) | HS 391590 (other plastics) | total |
|---|---|---|---|---|---|---|
| | Total Value (in 1,000 US$) | 136,692 | 132,106 | 59,423 | 447,293 | 775,514 |
| | Total Quantity (in tonnes) | 551,177 | 438,890 | 170,266 | 1,521,405 | 2,681,739 |
| Rank | | import market share measured in value terms (in %) | | | | weighed share (in %) |
| 1 | Hong Kong | 69.9 | 74.8 | 45.9 | 45.5 | 54.9 |
| 2 | U.S. America | 3.7 | 2.0 | 3.2 | 27.9 | 17.4 |
| 3 | China | 11.4 | 20.5 | 26.9 | 9.8 | 13.2 |
| 4 | European Union | 3.7 | 1.0 | 4.2 | 6.3 | 4.8 |
| 5 | Canada | 4.3 | 0.9 | 9.0 | 4.5 | 4.2 |
| 6 | India | 1.6 | 0.1 | 0.2 | 1.8 | 1.4 |
| 7 | Korea Republic | 0.0 | 0.1 | 0.2 | 1.0 | 0.6 |
| 8 | Malaysia | 0.2 | 0.1 | 2.7 | 0.7 | 0.6 |
| 9 | Singapore | 1.4 | 0.0 | 0.0 | 0.7 | 0.6 |
| 10 | Mexico | 0.9 | 0.0 | 1.8 | 0.3 | 0.5 |

*source: UNCTAD; Trains Data Base 1996*

[18] The United States report their imports in value terms only without mentioning quantities. Therefore no prices can be derived from this major importer.

If the above table is divided between developing and industrialised countries, a very typical pattern appears. Approximately three quarter of the total volume is trade to developing countries. For international trade in non-waste related plastics such as primary resins and plastic articles, the import share of developing countries in 1994 was only 36%.

The Trains data base does not provide a full picture of the exporters of waste plastics. Only 67.7% of the total trade could be derived. Despite this handicap it was possible to conclude that the export of waste plastics is dominated by industrialised countries which take account of 80% of the supply. The United States and Japan are by far the largest suppliers of waste plastics (see Table II.3).

*Table II.3 The main exporters of waste plastics (1994)*

| Total trade | Recorded Export (in US$ 1,000) | Share in Recorded Exports (in %) |
|---|---|---|
| 1 U.S. America | 233,983 | 44.8 |
| 2 Japan | 121,072 | 23.2 |
| 3 Germany | 37,753 | 7.2 |
| 4 Saudi Arabia | 26,670 | 5.1 |
| 5 Canada | 23,617 | 4.5 |
| 6 Mexico | 19,770 | 3.8 |
| 7 China | 19,770 | 3.8 |
| 8 Netherlands | 12,332 | 2.4 |
| 9 China Taiwan | 8,773 | 1.7 |
| 10 Korea Republic | 5,248 | 1.0 |
| Covered in this list | 525,328 | 67.7 |

*source: UNCTAD; Trains Data Base 1996*

If the exporters are studied in detail (see Table II.4) it can be seen that especially the emerging economies increase the export of waste plastics. The slower growers, such as the United States, already have a rather strong position in the market.

*Table II.4 Growth rate of Exporters on the World Market[1] for Waste Plastics (1994)*

| | Top 5 "growers" | growth rate (in %) | Bottom 5 "growers" | growth rate (in %) |
|---|---|---|---|---|
| 1 | Saudi Arabia | 225 | Sweden | 20 |
| 2 | Singapore | 155 | Denmark | 20 |
| 3 | Mexico | 136 | Philippines | 19 |
| 4 | Korea Republic | 97 | China | 10 |
| 5 | Germany | 87 | U.S. America | 8 |

[1] the Hong Kong market is used as a proxy of the world market

*Source: UNCTAD, Trains Data Base 1996*

By looking at the average price level of certain exporters it is possible to get a better idea of the qualities traded. The second part of Table II.5 shows which countries supply the most expensive waste plastics and thereby may be considered to trade high quality plastics, and vice versa. Typically, the cheap plastics mainly come from countries which tend to promote the recovery of waste plastics, such as Germany, the Netherlands and Denmark.

*Table II.5 Quality of Exported Waste Plastics on the World Market[1] (1994)*

| | Top 5 "quality" | average price (in US$) | Bottom 5 "quality" | average price (in US$) |
|---|---|---|---|---|
| 1 | Brazil | 620 | Switzerland | 285 |
| 2 | Thailand | 570 | Germany | 275 |
| 3 | Mexico | 530 | France | 245 |
| 4 | Italy | 520 | Netherlands | 243 |
| 5 | Austria | 490 | Denmark | 203 |

[1] the Hong Kong market is used as a proxy of the world market

Source: UNCTAD, Trains 1996

# Appendix III. The plastics cycle in China

In this Appendix, a background will be provided of the general technical aspects of plastics. In most countries, the plastic cycle involve several sectors (see Figure III.1). To get a better understanding of the standard plastic cycle, processes in the plastic cycle and environmental burdens caused by each process will be described in this Appendix. To avoid a too elaborate overview, the stage of oil drilling is skipped. In some cases explicit mention will be made of the situation in China. For a more elaborate overview of the conditions in China, one should study Chapter 3.

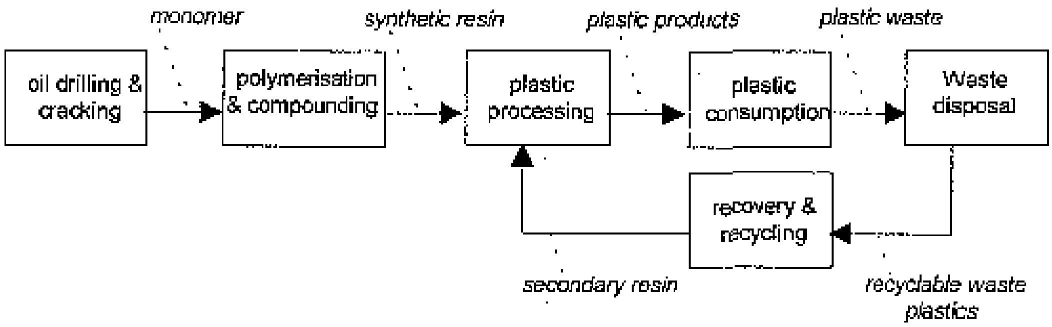



*Figure III.1 Simplified flow diagram of the plastic cycle*

## From oil to monomer

Because the main purpose of the report is to compare recycled or secondary plastics resin with primary resin the term "primary resin industry" is used instead of the common terminology the "petrochemical industry". The primary resin industry is assumed to encompass various steps, which are generally performed in one location. Figure III.2 depicts these various steps in the production process which is roughly divided into thermal cracking and polymerisation.

Almost all organic petrochemicals are made by joining small molecules with just a few carbon atoms in their skeleton, into much larger and more complex structures. The most common process to do this is thermal cracking. The main output, the lower olefins consist of ethylene, propylene and C4 olefins. These monomers are important organic based chemicals.

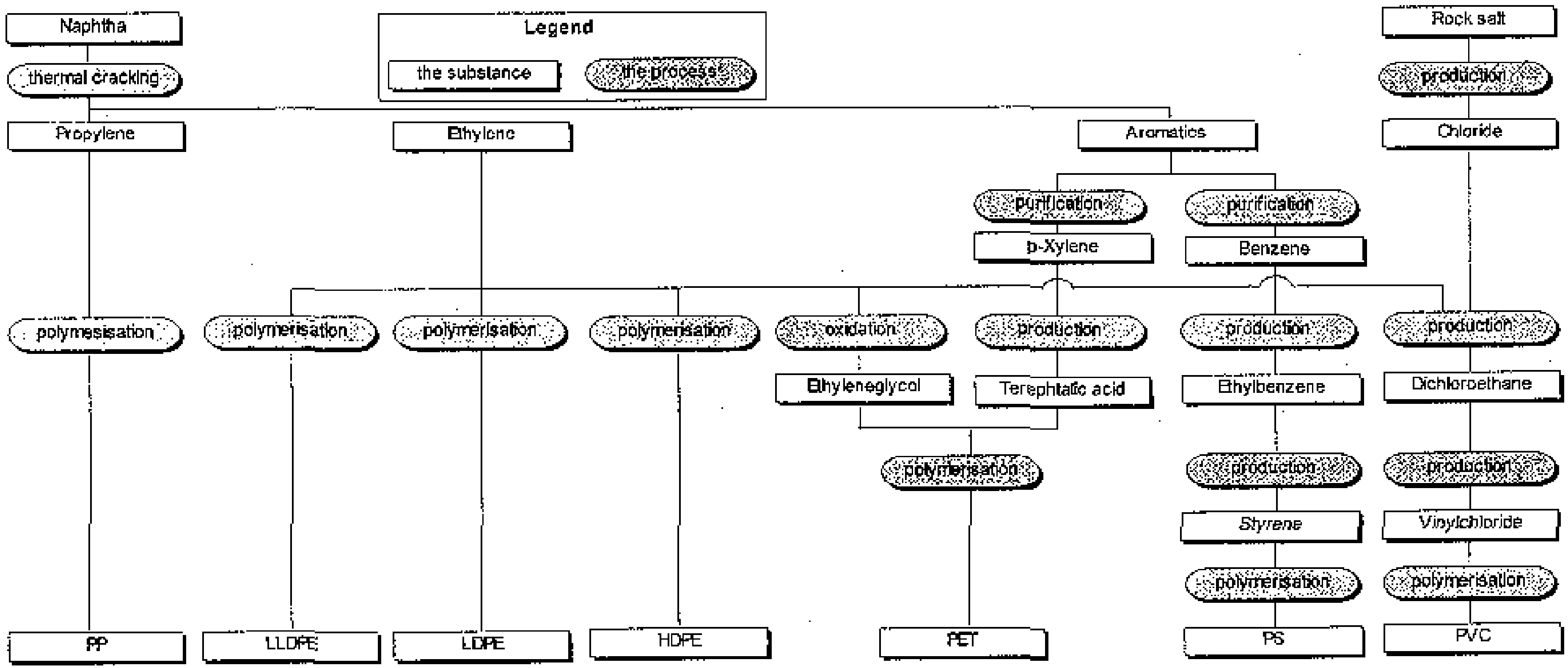



*Figure III.2 Flow chart of primary resin industry*

The feedstock chosen for their production will depend on local availability and price, with producers optimising on the basis of alternative feedstock values, the technical flexibility of the thermal cracker and the market values of the products. The producer has (within certain limits) the ability to change operating variables in order to vary the production of co-products compared to ethylene. Based on various sources, the average distribution of olefins is estimated as follows: ethylene (40%), propylene (15%), butadiene (25%) and aromatics (20%). In this study, butadiene can be considered a by-product which is marketable as a raw material for the production of synthetic rubber.

The monomers have the following characteristics:

*Ethylene* - (or ethene) is a monomer which is a gas (although usually pressure liquidated), a base bulk chemical with a wide variety of applications. Ethylene is used as a base chemical in the production of a variety of plastics, such as PE, PVC and PS. Because it is a specification chemical, it is readily interchangeable with ethylene from other manufacturers who also meet the specifications. Ethylene can be traded on the world market, however transport is expensive and usually the ethylene is processed near its production point.

*Propylene* - can be obtained as a by-product of gasoline manufacture (catalytic cracking), while butylenes are similarly produced in large quantities by normal refinery operations. Steam cracking also produces significant quantities of propylene and crude BBB (butylenes/butadiene/butanes) as by-products. Butylenes are mainly used as feedstock for alkylation units, but their chemical uses are growing steadily.

*Aromatics* - are second only in importance to the lower olefins as a source of organic chemicals. The principal aromatics - benzene, toluene and xylenes (BTX) are liquid hydrocarbons. They have a closed-ring molecular structure, and yield a different series of derivatives, as well as combining with the olefins to produce derivatives such as styrene (ethylene and benzene). Production capacity of benzene and p-xylene are 803.3kt/a and 1060kt/a, respectively.

In China the majority of the petrochemical plants are fuelled with domestically produced naphtha. There is an aggregation of the plants producing the different resins due to the inevitable simultaneous production of certain base chemicals during thermal cracking. Also there is an aggregation for the plants that perform the different steps in the production process. This way, expensive transport of the often extremely toxic intermediates is reduced to a minimum. The total production capacity of ethylene and propylene in 1996 in China were 4,000,000 tonnes per annum and 2,000,000 tonnes per annum, respectively. Comprising more than 50% of the total costs, fixed costs of naphtha cracking are significant.

The selection criteria of for adoption of a particular plant size are elaborately discussed by Vergara and Badelon (1990). They state that: "economies of scale are important in the petrochemical industry. In the case of India and China, despite efforts being taken to revamp and rationalize the existing units, wide sectors of the industry continue to operate small-scale plants that are generally associated with higher manufacturing costs. In both countries the long distances involved and the dispersed nature of the markets have led to the decentralization of production capacity and adoption of smaller-scale plants, other factors that affect selection of scale include marketing constraints, infrastructure available, implementation risks and environmental limitations (p.46)." The production costs of ethylene crackers of different sizes reflecting current or expected practices are depicted in the table below. These compare with crackers in the range of 450-600 MTY being implemented in the US, Western Europe and the Middle East.

*Table III.1 Selected Ethylene Configurations*

| | Feedstock | Size ('000 MTY) | Remarks |
|---|---|---|---|
| Korea | Naphtha | 450 | Established industry, large domestic markets, strong financial position of companies involved |
| India | Ethane/propane | 300 | Regional distribution is important. Market dispersed |
| China | Naphtha | 300 | Domestic feedstock supply is a concern, market dispersed. Regional distribution is important. |
| Thailand | Ethane/propane | 300 | Relatively small market, new industry |
| Malaysia | Ethane/propane | 450 | Very small domestic market. Must compete in the export market. Large feedstock supplies. |
| Indonesia | Ethane/propane | 300 | New industry. Strong competition for feedstock. |

Thermal cracking is an energy intensive sector. To process one tonne of naphtha, 6330 MJ of electricity is used. Generating air pollutant, water pollutant and solid wastes, thermal cracking is also characterised by heavy environmental pollution in its processes. Sources of air pollution are 1) effluents including CO, HC, NOx and SO2 from the production process of thermal cracking; 2) CO, CO2, HC, NOx, SO2 and dust from fuel combustion to heat the pyrolyzer; and 3) pyrolysis tail gases such as hydrocarbon and SO2 . Water pollution include sulphide, Na and COD is 0.00004kg, which are generated in cooling water and washing water in the production process.. Waste alkali liquor and oil-containing sludge are remained as solid wastes during thermal cracking.

## From monomer to polymer

Next, the monomers are polymerised to produce polymers using addition-polymerisation or condensation-polymerisation, depending on the products.. Polyethylene (PE) and polypropylene (PP) can be produced straightforward by the polymerisation of ethylene and propylene which are coming out of the thermal cracking process. To get the monomers of polystyrene (PS), polyvinyl chloride (PVC) and polyethyleneterephtalate (PET), other processes using aromatics and rock salt as raw materials are needed.

*PE* - is made by the polymerisation of ethylene and is produced as HDPE and LDPE. The difference between these forms is the number of monomer molecules per polymer molecule. These forms of PE are used to very different purposes and therefore not interchangeable. Feedstock to produce LDPE and HDPE and emissions are also different, which are shown in the input-output table. The national production capacities of LDPE primary resin and HDPE primary resin are 1000kt/a and 603kt/a, respectively.

*PP* - is polymerised from propylene. The capacity of PP primary resin production in China is 1580kt/a.

*PS* - is produced by the polymerisation of styrene. PS production capacity is 550kt/a. First, benzene, an purified aromatics fraction from a by-product of thermal cracking, together with ethylene to produce ethylbenzene. The production site is most often close to the styrene-plant. The capacity of ethylbenzene production is 200kt/a. Then styrene is made by dehydrogenation of ethylbenzene. Styrene production capacity is 565kt/a.

*PVC* - is made by the polymerisation of vinyl chloride, a monomer which is produced by several processes. The capacity of PVC production is 1438kt/a. In order to make the precursors to PVC, chlorine is produced from rock salt using different processes, i.e. diaphragm process, membrane process and mercury process, which are shown in the input-output tables. The average emissions depend on the mix of production processes in a country. In China, for one kg of chloride, diaphragm process 0.9052kg, membrane process 0.0916 and mercury process 0.0031. The capacity of diaphragm process, membrane proces and mercury are 1561.7kt/a, 235kt/a and 17.8kt/a, respectively. Then vinyl chloride can be made by the addition of chlorine to ethylene by oxychlorination process. The data of the production of vinyl chloride aggregates the processes of the production of 1.2-dichloroethane, its decomposition to vinyl chloride and HCL and the oxychlorination process. The data do include emissions due to energy consumption, since gas is used as an input, and not electricity or "gas energy." The production capacity of vinly chloride is 1438kt/a.

*PET* - is polymerised from two monomers, i.e. ethyleneglycol and terephtalic acid. The capacity of PET production is 1240kt/a. Ethyleneglycol is produced from ethylene by oxidation. The available data on ethyleneglycol is very poor. Even if the losses are not taken into account, the specified amount of ethylene would not be enough to produce the kg of ethyleneglycol. Ethyleneglycol production capacity is 700kt/a. Terephtalic acid is oxidised from p-xylene, a purified aromatics which is won from the aromatics faction of thermal cracking. Data for the production of terephtalic acid is very weak, however, there is no other source for this data. Capacity of terephtalic production is 1820kt/a.

It is difficult to analyse the environmental impact of primary resin production as it contains a variety of individual process (monomer preparation, catalyst compounding, monomer polymerisation, separation, refining, and post treatment) and each process is connected with at least one other process. Moreover, both the type of synthetic resin which is produced and the type of plant are important. However, some generalisations can be made.

Generally speaking, the petrochemical industry is an energy intensive sector. Both thermal cracking, polymerisation and the production of basic chemicals consume high level of energy. The fundamental structure of China's energy depends on coal (75%), with oil (17.5%), natural gases (2%) and hydro power (5.5%). Together with low energy efficiency of the intensive energy-consumption sectors, such as petrochemical industry, metallurgical industry, building materials industry, it is reported that 85% of SO2, 70% of dust, 85% of CO2 and 60% of NOx emitted into the air are coming out of coal combustion. This situation has caused acid rain in some cities with large population or heavy industries and extensive and/or serious respiratory diseases, as well as aggregated to the impact on global warming. Increasing the energy efficiency has great potential to decrease the emission level from petrochemical industry.

The emission level of polymerisation processes is high, including various pollutants, some of which are very harmful to human health and eco-environment. Polymerisation is also energy intensive industry. The main environmental impacts during resin production are air emissions and water pollution. Air pollutants include 1) CO, CO2, NOx, SO2, and dust, which are generated form heating furnace and boiler, and 2) CFC, methane, Hg, vinyl chloride, HCL and aromatics, which are coming out during production processes or from tail gas. Treatment for these pollutants is available and designed to different kind of pollutants. SO2, NOx, HCl and aromatics can be controlled by absorption treatment. Vinyl chloride, which emits from the production of PVC, is particularly harmful in terms of emissions as it may cause dizziness, liver and spleen damage in humans. To control this hazardous gas, several options, such as active carbon and trichlene absorption, are used to reclaim vinyl chloride. Such flamable gases as organic gas and CO can be burned out. Precipitation techniques can be used for dust removal. By improving the technologies of flare, aromatics can be reclaimed and reused in the production process.

Waste water may contain sulphide, heavy metals such as Hg, benzene and organic compounds. Large scale resin manufacturers constructed waste water treatment plants. To ensure the treatment effectiveness, many factories constructed primary treatment facilities which near the sources of water pollution. Solid wastes from the primary plastic industry mainly contain the sludge from waste water treatment, which are incinerated or landfilled.

As mentioned, there are still some small-sized or township petrochemical enterprises with out-of-date technologies. Because of old production processes, unsound management which result in low energy and production efficiency and high level of material consumption, these small-sized enterprises often generate serious environmental pollution. Few of them facilitate pollution control equipment. Initiatives have already been taken to solve this problem. In 1996, heavy polluted small-scale enterprises, including petrochemical sector, pulp-making sector, dyeing and printing industry, cement industry, etc. were closed by NEPA. However, there still lack of mechanism for legislation implementation to stop the existence of heavy-polluted small-sized enterprises.

## From polymer to product

The next step in the production is the conversion of the polymer resins into plastic products. The inputs used are resin and electricity. Sometimes, additives are used such as colorant or softener. The outputs, i.e. plastic products, differed in quality which depend on the combination proportions of feedstock, i.e. primary resin, high quality secondary and low quality secondary resin. In this project, based on general experiences, 1) high quality plastic products are those produced from feedstock consisting of over 90% of primary resin and less than 10% of high quality secondary resin, 2) medium quality plastic products are those produced from feedstock consisting of greater than 80% of primary resin and less than 20% of high quality secondary resin, and 3) low quality plastic products are those produced from feedstock consisting of less than 30% of primary resin and greater than 70% of low quality secondary resin. This is shown in the input-output table for processing high quality, medium quality and low quality products. Plastics can be used in practically every field. The total production capacity of plastic product manufacturing is about 9000kt/a. Because the amount of possible products is so large, simplification of the process is unavoidable.

Plastic processing is mostly done by three different techniques:

- Extrusion
- Injection moulding
- Blow moulding

A product can only be made by one of the processes; for a continuous product extruding is used, for solid separate objects injection moulding and for hollow objects blow moulding. It would not be feasible to blow mould a pipe, which is normally extruded, and neither would it be possible to extrude a complex shape like a bottle, which is blow moulded.

For processing in China, the data used is derived from the emissions in 1994. This data is not divided into separate processing techniques. This does not pose a problem, since the processes are not interchangeable, as was stated earlier. The Chinese data only states production volume, not input. This was derived from the European efficiencies for resin and energy. This data should be considered to have an error margin which is larger than the margin on the output data, but still acceptable.

Compared to oil refining and primary resin production, plastic product manufacturing is a less energy intensive and much lower emission level sector. Yet, processing manufacturers are often small and medium sized factories which lack pollution control facilities and environmental management. This may result in uncontrolled emissions and surface water pollution. Because of using various additives in the production process, waste water containing such hazardous substances as Cd, Cr6+, Pb, phenol and cyanide is discharged from plastic processing.

## From product to waste

Collected by municipalities, waste plastics together with other wastes in the municipal solid waste (MSW) stream are either landfilled, incinerated or dumped because lack waste management facilities.

*Landfill* - The major waste disposal method used in China is landfill. Landfill is characterised by large disposal capacity and relatively easy operation. Also the construction and operation costs are generally lower than other management options. For example, the average disposal cost for landfill and incineration are respectively 30 Yuan RMB per tonne and 50 Yuan RMB per tonne (BESDRI 1997). Though there are technical specifications for landfill construction and environmental standard and monitoring requirements for leachate, the management of landfill in China is not strong, which results in leachate entering into the ground water and ignition of organic gases.

The fate of plastics in landfills is still not fully understood. Experience of landfilling plastic is very limited, so its behaviour in landfill is not fully understood. Some reports claim that plastic deteriorates after 1 year while other cite 40 years. In order to cause leachate, plastics would have to degrade in the landfill, but no strong evidence of degradation exits. Thus it may be concluded that plastics itself do not significantly contribute to leachate. However, chemical additives such as heavy metal compounds, and contaminants such as food residue from plastic packaging may leach, causing ground water pollution. The characteristics of high durability and non-degradability also implies that waste plastics permanently occupy significant space in the landfills. Its contribution to greenhouse gas emissions is very limited (Hunt 1995).

*Incineration* - Since plastics have a similar energy value to oil, incineration of waste plastics may be considered an option. However, harmful emissions such as hydrogen chlorides and dioxins coming from PVC may occur if the incinerators are not equipped with scrubbing equipment. Moreover, incineration has so far been proved to be a unfeasible option in developing countries because of the high moisture content of MSW in general. This means that waste plastics would have to be collected separately from wet waste in order to generate energy. Incineration in china is still in the pilot stage. Only one imported incineration furnace, constructed in Shen Zhen City, utilises the energy value for electricity generation, while others with low treatment capacity are just used to burn wastes. Although standards have been formulated for controlling air emission from incineration in China, enforcement of these standards is still very weak.

*Dumping* - In reality, however, about 60 percent of the post-consumption plastics are dumped or left uncollected in China due to lack of waste management facilities, incomplete legislation for solid waste management and weak implementation of legislation. This is one of the most serious environmental problems in the plastic cycle. For example, China's consumption of agricultural films in 1994 of 1.9 million tonnes ranks first in the world. However, about 0.3 million tonnes of waste films remain in the farm land annually which do harm to the soil and cause intestines disease when animals accidentally eat them. A more generally know problem is caused by the rapidly increasing volume of plastic dinner-boxes and packages which are littered along roads and railway lines. Lacking landfilling and incineration facilities, collected municipal waste plastics together with other solid wastes are piled up outside the cities which impede further development of cities and pollutes the surface and ground water. Though dumping of waste plastics is not a process, it is still considered in this project because it accounts for a larger amount of waste plastics in China and has negative impacts on the environment.

## From waste to secondary polymer

The recycling of plastics can be done in several ways. Box 2 gives an overview of the available options. The best known and simplest is mechanical (secondary) recycling. Incineration with reuse of the process energy is common in Europe and the US but not practised much in China. Other options are recycling by cracking the polymer to feedstock or by direct depolymerisation.

In China, only two ways of recycling are in use at the moment and be considered in this project: Mechanical recycling takes up the biggest part of plastic recycling, a very small part is recycled to feedstock. The other options for recycling are not practised for different reasons: Depolymerisation, which is applicable to esters only, is a state-of-the-art process which demands very sophisticated equipment and has not been developed very much in Europe either. The burning of plastics is formally prohibited by the Chinese government. In reality, the burning of waste plastics is a common way of treating the garbage.

Mechanical recycling is characterised as a labour intensive and simple technology. It consists of several processes: collection, separation, washing and recycling. In this Section, a very brief description of these processes is given.

In order to be processable, the plastics have to be separated into fractions containing only one sort of plastic. This sorting process can be done either mechanically or by hand. In the case of automated mechanical separation, a plant can be fitted with a large number of detection mechanisms. These separate on the basis of physical determination in floatation devices and rotation drums, which can also be used to distinguish films from other plastics. Also photo-spectrometric equipment can be used, such as laser induced spectroscopy, IR spectroscopy etc.

Separation by hand can be very effective but is a labour intensive way to sort plastics into different categories, e.g. PE, PP, PS, PVC and PET, and different grades of quality, i.e. high quality and low quality. The selectivity depends upon the experience of the sorting employees. In China, an other sorting method is also in use: Recyclers in the informal sector only accept certain articles, such as water bottles, which are collected separately. This way, the sorting is done by the collectors, who search the streets for only one or two types of articles. This is a very effective way of sorting, but it can only take care of very abundant articles. The specific collection is also carried out at waste dump or disposal sites, thus reducing the volume of dumped plastics and the plastic fraction of the municipal waste (although only marginally). Separate collection of industrial plastic waste is common practice around the world. But eventually, the waste trader performs the main part of the manual sorting process.

The capacity of collection is represented in different collecting sectors, i.e. formal, informal and waste picker, and in different categories of wastes, i.e. agriculture, industry and household. It is shown that informal sector and waste pickers are much more flexible and therefore have a have much larger capacity than formal sector.

Mechanical recycling can be subdivided into various steps:

*Mechanical Sorting* - In this mechanical sorting method, an amount of mixed waste plastics is separated into sorted fractions of specific types of plastics. First, a conveyer-belt will transport the waste to a sieve which vibrates and sorts out sand and dust. Magnets will separate out the metallic residues. To make the inputs suitable for separation manual sorting will from the conveyer belt is performed. finally, the sorted plastics are pressed into bales. The production capacity is 1,000 tons per annum, in a one shift working scheme which adds up to 2,000 hours of operation per year. This compares to a capacity of 0.5 tons per hour. This form of mechanical separation would be applicable only for the large waste traders in China. The space required is 100 m2. Only 90% of the incoming waste is suitable for recycling. The suitable part consists of 95% recyclable waste plastics and 5% waste plastics for feedstock recycling. Electricity consumption accounts for 46 kWh per tonne of output. Depreciation and maintenance costs are set at 30% of the investment costs which excluding accommodation is approximately US$ 50,000 per year (see below). Besides electricity, no other environmentally related factors show. This process is not included in this project.

*Manual Washing* - To clear the plastic fraction of contamination, they are washed thoroughly. This can be done by hand using detergent or in special plastic washing machines. The quality of the washing process very much determines the quality of the secondary plastic. Mechanical washing can be done in a continuous process, while manual washing is a batch process. Manual washing is very labour intensive and very time consuming. In China, normal washing detergent is used to wash the plastic.

*Mechanical washing* - No literature was found on mechanical washing of waste plastics. This is an integrated part of mechanical recycling and can therefore not be separated from the other processes. It therefore proposed to exclude mechanical washing as a potential process. This process is not considered for this project.

*Mechanical recycling* - After sorting and, if necessary washing, mechanical recycling is performed. This type of recycling of plastics does not change the structure of the plastic, only to its form. Generally a crusher or granulator is used to reduce the size of the waste plastics after which the waste plastics are fed into an extruder. The extruder converts the waste plastics into secondary resin.

As mentioned, the other practise in China in plastic recovery is feedstock recycling. Feedstock recycling is a form of recycling in which plastic molecules are chemically reduced (cracked) into smaller molecules, resembling rude oil. This so called "syncrude" can substitute real crude oil. In China, this process is operated, but on a very limited scale and in a very inefficient and polluting form. The European form of feedstock recycling (i.e Veba-öl process) is very high-tech, capital intensive and still in an initial stage of development. The process is not yet ready to be used in China, either because high cost or low quality of output oil. Also because not equipped with environmental facilities, the construction of Feedstock equipment is usually not allowed by local EPB. The capacity for feedstock in China is 100kt/a.

Using recovered waste plastics as feedstock, has obvious advantages in terms of resource savings and lower energy intensity. The emission level of secondary production is also lower than the primary production. Because most enterprises in this sector are small and medium-sized factories, which means low technologies and financial difficulties, environmental problems, such as water pollution and health threats to the workers, can not be neglected. Similarly, it should be kept in mind that secondary feedstock products are generally of a lower quality than its primary version. This reduces the lifetime of the product and possibly also the quality of the usage. Therefore, a one-to-one comparison between primary plastic production and feedstock recycling is not sound.

### Transport

A process in the plastic cycle which is particularly relevant for international trade is transport. Throughout the plastic cycle, materials are moved from one process to the other causing environmental damage. IIED (1995) states that "transport is the fastest growing source of air pollution in both industrialised and developing countries." In addition, is mentioned that "within the OECD region, the transport sector as a whole accounts for 70% of carbon monoxide (CO), 50% of nitrogen oxide ($NO_x$) and 25% of all carbon dioxide ($CO_2$)." Other problems are noise pollution, changes in landscapes and exploitation of exhaustible resources. Particularly for international transportation, such damage is not reflected in the price for fuels. Governments continue to subsidise transport through public provision of infrastructure and not taxing fuels. If internalisation occurs, production and consumption patterns would be quite different.

For the plastic cycle in China, various modes of transport are considered:

*Bicycles* - In China, bicycles are in use by individuals collecting waste plastic on the street and from municipal waste. They should be seen as playing a role in the informal sector, equivalent to the role of waste collection trucks in the formal sector. This mode of transport does not generate any environmental impact.

*Trucks* - Trucks which can be divided into two categories: trucks with a maximum load of up to 20 tons and trucks with a maximum load of over 20 tons, are used for transport within China, especially by small businesses such as collectors of recyclable materials. Analysis of European data concerning trucks <20 tons and waste collection trucks shows that waste collection trucks use 32.7 as much fuel per tonne kilometre as a normal truck.

*Trains* - Trains in China are used for domestic transportation. Since the train system, containing diesel and coal powered engines is very different form the European system, which is almost exclusively electrically powered, the European data is useless in this situation and domestic data will have to be used.

*Ships* - Seagoing vessels are the only means of transportation for import or export of materials and products. Ships are not used for domestic transportation. Since the European data gathered on ships have a global range, no alterations seem necessary for the Chinese situation.

*Pipelines* - Pipelines are used for transport by the chemical industries. These pipelines are identical to the type used in Europe. Therefore, the *operation* requires the same input/output. However, it should be noted that the *risk* involved in operating a pipeline depends largely on the state of maintenance.

# Appendix IV. Waste Management in China

In 1995, China generated 166 million tonnes of municipal solid waste (MSW) (Suo Zhiwen 1997). On average only 28 percent of waste is properly landfilled or incinerated (MOC 1996), with the result that large quantities of refuse accumulate in the suburbs or remain uncollected. Two thirds of the cities in China have been surrounded by refuse heaps. About 60 percent of total post-consumption plastic is stacked with municipal solid waste or left uncollected, which may cause surface and ground water pollution and human health problems.

Landfill is the major method of disposal in China. The capacity to deal with large volumes as well as its relatively easy management means that landfill has significant advantages over alternative waste disposal options. It also has lower construction and operating costs; for example, the average disposal costs for landfill and incineration are respectively RMB 30 Yuan per tonne and RMB 50 Yuan per tonne (BESDRI 1997). Until recently landfilling has been uncontrolled and no attempts have been made to recover gas or prevent leakage. However, in the last few years China has built more appropriate landfill facilities based on foreign knowledge, with the result that costs have also increased. A total of 477,000 people are employed in the management of municipal solid waste, including odd-job personnel. Clearing and collection of MSW is more labour intensive than that of waste disposal. The transportation cost for one tonne of MSW is about 33 Yuan RMB.

Incineration can reduce the waste volume by up to 90% (BESDRI 1997). However, for various reasons, the adoption of incineration is still in its infancy in China. Firstly, due to the composition of the waste stream, the low heat value of incinerated waste is inadequate for generating electricity (However, in the last two years, with increasing proportions of paper and plastics in the waste stream, the heat value of MSW has risen significantly. For example, the heat value of MSW in Beijing in 1996 was 5484KJ per kilogram which is sufficient for incineration with energy recovery). Second, due to financial and technological constraints, the capacity of most incineration furnaces is under 200 tonnes per day. At these volumes, the generation of electricity is not economically feasible and incinerators are only used as furnaces.

China is currently improving MSW legislation and management. Its environmental plan, incorporating Agenda 21 (1994), cites waste management as an important factor in an integrated strategy for natural resource and energy conservation and pollution control. All cities are expected to construct landfill and incineration facilities for the safe disposal of MSW by 2010. The short term objective for the recovery of recyclable resources is to formulate legislation and establish a development plan. MSW management will increasingly emphasise source separation in order to increase the recovery rate of recyclable resources, although this approach has already been adopted in some cities.

## Appendix V. More observations on trade

An essential commodity in the plastic cycle which has not been discussed much so far is oil. Petroleum used to be one of China' s main export commodities: it accounted for 17 percent (13 percent for crude oil) and 23 percent (16 percent for crude oil) respectively of the nation's gross value of foreign exchange earned through exports during the periods of the fifth and sixth "Five-year Plan" (starting from 1976-1985). However, manufactured goods have rapidly increased their share of total export in the last decade or so, and exports of primary products, including crude oil, has declined at the same time. In 1994, the country's oil exports fell to 18 million tonnes from the peak export volume of 30 million tonnes in 1985, dropping by an average 4 percent annually. Meanwhile, demand for oil at home has been growing in the wake of economic development and reshaping of the industrial sector, which has led to an increased reliance on imported oil. Between 1990 and 1994, China's imports of crude oil soared by 147 percent, and the country became a net importer of oil based products in 1993.

Aggregated trade data hide much relevant information and particular issues further attention. First, an important aspect of international commodity markets is their volatility. Obviously, the more volatile a market, the more difficult it will be for entrepreneurs to deal with its uncertainties. Volatility can be measured in terms of price fluctuations and the growth rate of the imported quantities.

Waste plastic is the most volatile of the plastic commodities. Over the period 1981 to 1995, the price of waste plastics decreased 4.4 percent annually, reducing its price to approximately US$200 per tonne in 1995. The import prices of synthetic resin and plastic articles were more constant during this period, and increased at respectively 0.3 and 2.1 percent, resulting in resin and article prices of respectively US$800 and US$1,800 per tonne.

In terms of import volumes, waste plastic is also the most volatile commodity. In the years 1987 and 1992, waste plastic imports grew by more than 200 percent, and in 1990 the imports rapidly declined by 70 percent. Resin and articles generally remained within a range of plus and minus 50 percent. The volatility of the international market for secondary materials is often attributed to its relatively small volume which makes it more vulnerable to fluctuations in supply (Grace *et al.* 1978).

The most prominent change in trade has taken place in the synthetic resin sector. Suppliers from Western Europe and the United States have seen their market share shrink as a result of increasing competition from Asian producers, mainly based in Korea, Japan and Taiwan. Changes in waste plastic imports have been less significant. The European share has increased slightly but is still dominated by supplies from the United States, Taiwan, Japan and Hong Kong, which presently account for more than 80 percent of overall waste plastic imports.

*Table V.1 Changes in the supply of the main inputs to the plastic cycle in China*

| | synthetic resin (in percentage) | | waste plastics (in percentage) | |
|---|---|---|---|---|
| | average 1981-1989 | average 1990-1995 | average 1981-1989 | average 1990-1995 |
| Europe | 34 | 19 | 3 | 6 |
| United States | 21 | 7 | 37 | 36 |
| Asia | 30 | 67 | 56 | 53 |
| other | 15 | 7 | 3 | 5 |

*Source: International Trade Research Institute, 1996*

The remaining input for plastic is oil, which also comes mainly from the Asian continent. Refining facilities along China's coastal area are inadequate for processing sulphur-bearing crude from the Middle East. Sweet crude from Asia is still the preferred variety for all refineries. This is illustrated by the fact that in 1994, 38.3 percent of China's imported oil came from Indonesia and 27.3 percent from Oman. In recent years there has also been a notable increase in imports from emerging oil producers such as Vietnam and Papua New Guinea.

A more detailed investigation into the components of each imported input category will provide a better understanding of trade in plastic. For synthetic resin, in absolute terms, polyethylene (PE) has always been the largest import. Next come polystyrene (PS) and polypropylene (PP). Imports of Polyvinylchloride (PVC) are small since China has a strong local capacity for PVC production. The most import-dependent resin in China is PP of which 81 percent came from foreign sources in 1994. For waste plastics, the picture is less clear.[19] Almost every other year, the hierarchy of imported types differs, although over the longer term, the share of PE, PP and PVC in imports of waste is more or less equal. Similarly to synthetic resin, secondary PVC and PP have a higher value, at around US$300 per tonne, to PE and PP which presently cost US$200 per tonne.

19 For the years 1992 to 1995, trade statistics suddenly indicate a category of "other types" which takes account of almost half the imports of waste plastics. The overall volume of waste plastics for the period before 1992 is corrected for the absence of this category. "Other types" might include PP and PET.

# Appendix VI. Environment impacts in the plastic cycle

Each of the sectors contributing to the plastic cycle impacts to some degree on the environment. This is expected to increase in conjunction with the growth in demand, thus affecting the overall impact of the cycle. However, substitution effects and technological improvements may reduce this trend. In the following, the environmental effects of respectively the post consumption and the pre consumption stages are explained.

If we start with the oil drilling and refining processes which supply the monomer to the resin industry, the major environmental problem is the waste water containing oil discharge which finds its way into surface water. The oil film on the water surface may prevent oxygen from being absorbed by the water. Treatment technologies are available and applied in China.

It is difficult to analyse the environmental impact of synthetic resin production as it consists of several individual processes (monomer preparation, catalyst compounding, monomer polymerisation, separation, refining, and post treatment) and processes are very much interconnected. Moreover, both the type of synthetic resin which is produced and the type of plant are important. For example, small and medium-sized factories may cause relatively more environmental problems due to the lack of funds for installing pollution control facilities. These factories are often scattered and contribute to surface source pollution which is difficult to control. However, some generalisations may be made.

The main environmental impacts during resin production are emissions and water pollution. Waste water may contain chemical and organic compounds, such as heavy metals, benzene, and organic chloride, which can be very harmful to human and animal life. When waste water contain such nutrients as fat, protein and ammonia, it may cause eutrophication in the water body and threaten the ecosystem dependent on these resources. Waste water may also contain acid and alkali, which can be very irritating to eyes and skin, as well as change the pH balance in soil when farm land is irrigated with contaminated water. Some large scale factories have constructed waste water treatment plants for water pollution control, and some have even installed primary treatment facilities to ensure treatment effectiveness. Production of PVC, which emits vinyl chloride, is particularly harmful in terms of emissions as it may cause dizziness, liver and spleen damage in humans. To control this hazardous gas, several options, such as active carbon and trichlene absorption, are used to reclaim vinyl chloride. Box VI.1 depicts some of the most harmful emissions from the plastic cycle.

Compared to oil refining and primary resin production, the emission levels from processing plastics is rather low. Yet, processing manufacturers are often small and medium sized factories which lack pollution control facilities. This may result in uncontrolled emissions and surface water pollution. Processing methods predominantly include extruding, injection moulding and blow moulding, when various additives are used which may result in environmental impacts. Waste water from plastic processing may contain hazardous substances such as cadmium, lead, phenol and cyanide.

**Box VI.1 Harmful substances related to the plastic cycle**

A number of substances exist which are emitted in the plastic cycle either during production, usage, incineration, recycling or landfilling. The most important harmful substances are:

- *benzene* - a colourless and highly-flammable liquid used as a solvent in the production of PVC and LDPE and as a raw material for styrene. A recognised human carcinogen that causes leukaemia and, in case of direct exposure at the workplace, depresses the central nervous system, causing headaches and other irritations;
- *cadmium* - used as pigments in PET, LDPE, HDPE, PP, PP and other plastics and is a suspected human carcinogen. In the past it was used as a stabiliser of PVC, but this function has been replaced by zinc;
- *dioxins* - highly toxic by-product of the production and incineration of some plastics such as PVC, which may cause abnormalities in the male and female reproductive systems, learning disabilities, different cancers, leukaemia and other diseases;
- *vinyl chloride* - a colourless, odourless gas about twice as dense as air, used as monomer for PVC and is known as a human carcinogen. Mortality data of workers in VC and PVC plants indicate shorter life-spans and increased liver and other diseases.

*Source: Wirka 1988, Fehringer and Brunner 1997*

Recycling plastics has advantages as well as disadvantages. Generally, less energy is consumed in remelting waste plastics and, because it already contains additives, less additional inputs are necessary. The disadvantage of plastic recycling is the loss of quality of the output which inevitably shortens the life span of the product. The presence of contamination in waste plastic increases the odour during the remelting process. Besides affecting the factory workers, odours also annoy surrounding neighbourhoods: in Nepal, such impacts have led to the closure of plastic recycling factories (Beukering and Badrinath 1995).

In the post-consumption stage, waste plastics may be landfilled, incinerated or recovered. In reality, however, in China about 60 percent of post-consumption plastic is dumped or left uncollected due to inadequate legislation and environmental standards on solid waste management. This is one of the most serious environmental problems in the plastic cycle. For example, China's consumption of agricultural film in 1994 of 1.9 million tonnes ranks highest in the world. Yet, about 0.3 million tonnes of waste film are left on farmland annually, affecting the soil and causing intestinal disease to animals (Zhang Xiaochuan 1993). The growing problem of litter from plastic dinner boxes and packaging deposited along roads and railway lines is wider known. Municipal plastic and other solid waste is frequently piled up outside cities: this not only pollutes surface and ground water but also affects the prospects for urban development.

Experience of landfilling plastic is very limited, so its behaviour in landfill is not fully understood Some reports claim that plastic deteriorates after 1 year while others cite 40 years. In order to cause leachate, plastics would have to degrade in landfill, but no strong evidence of degradation exits. Thus it may be concluded that plastic itself does not significantly contribute to leachate. However, chemical additives such as heavy metal compounds, and contaminants such as food residue may leach, causing ground water pollution. The characteristics of high durability and non-degradability also implies that waste plastic permanently occupies significant space in landfills. Its contribution to greenhouse gas emissions is very limited (Hunt 1995).

Since plastic has a similar energy value to oil, incineration of waste plastic may be considered an option. However, harmful emissions such as hydrogen chlorides and dioxins coming from PVC may occur if the incinerators are not equipped with scrubbing equipment. Moreover, incineration has so far proved to be an unfeasible option in developing countries because of the high moisture content of MSW in general. This means that waste plastics would have to be collected separately from wet waste in order to be used to generate energy. Incineration in China is still in a pilot stage: only one imported incineration furnace, constructed in Shen Zhen City, utilises the energy value for generating electricity, while others with low treatment capacity are used only to burn wastes. Although standards have been formulated for controlling air emission from incineration in China, enforcement of these standards is still very weak.

Studies from Europe demonstrate that, from an environmental perspective, recovery of waste plastics is often the best choice (Brisson 1997, Fraunhofer-Institut *et al.* 1996, Powell *et al.* 1996). Recovery saves on resources, reduces the volumes of uncollected waste materials and conserves landfill space. Obviously, it is premature to use these studies to draw similar conclusions for China. Social, demographic and economic differences may have a significant impact on the outcome of such evaluations. For example, the environmental impact of related transportation appear to be significant in the European studies. In China, however, the bulk of recovered materials are transported by tricycles in Chinese cities, thereby mitigating the problem urban air pollution. On the other hand, health effects should be taken into account: waste pickers and collectors may suffer from health problems resulting form their direct contact with contaminated plastic wastes.

Secondary production, using recovered waste plastics as feedstock, has obvious advantages in terms of savings in resources and energy. The emission levels from secondary production is also lower than that of primary production. However, since most enterprises in this sector are small and medium-sized factories, using low technologies and suffering financial difficulties, environmental problems, such as water pollution and health threats to the workers, cannot be overlooked. Similarly, it should remembered that secondary products are generally of a lower quality than their primary equivalents. Both their life-span and the quality of their use will be much reduced. This means that a direct comparison between primary and secondary production is not appropriate.

# Appendix VII. A Field Survey on Plastic Recycling

From the literature study presented, it was concluded that to get a better understanding of the performance of the plastic recycling industry in China, a survey had to be conducted to collect additional information. Such a survey enables us to furnish the model with the requisite data, further acquaint ourselves with local waste plastics recycling and utilisation, and deepen our perceptual knowledge of the industry's development.

A seminar was organised to seek advice for the survey. It was attended by officials and experts from several related government agencies and institutions, such as the China National Resources Reclamation Corporation, the China Chemical Industry Information Centre, the Solid Waste Management Division of NEPA, and the Chinese Association of Plastics Processing Industry (APPI). The main conclusions of this seminar are summarised in the Appendix of this report. Based on the collective wisdom, different types of questionnaires were developed covering all the operations. These were then issued in selected areas upon the briefing and recommendation of NEPA and APPI.

As shown in Figure 4.1, the survey falls into four segments following the sequential stages of the operations of the recycling sector. These segments are waste plastics collection, separation and trading, next the recycling of domestic and imported waste plastics into secondary resin, and finally the manufacturing of recycled plastic products from secondary resin. Clearly, the most comparable segments in the study are the recycling of domestic versus imported waste plastics.

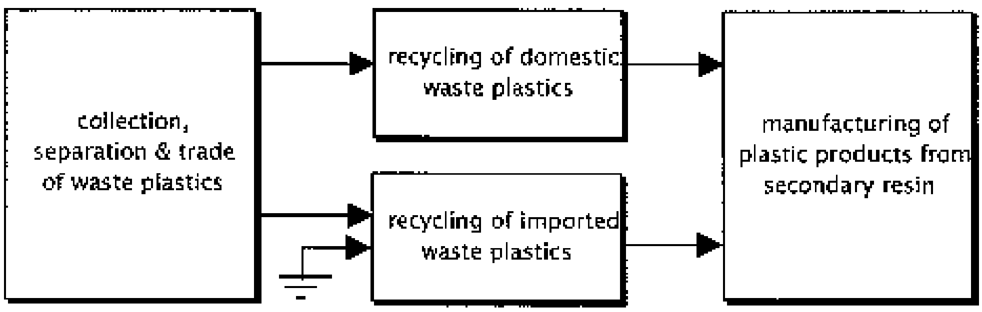



*Figure VII.1 Four targets in the Survey*

The surveys were conducted in various parts of the country. In the course of the survey, we interviewed the individuals concerned and took notes of their responses to the points listed in the ready- made questionnaire. For each segment, 30 interviews were held. Checks were build in the questionnaires to verify the authenticity and reliability of the acquired data. Next, the information was entered into a data base and a statistical analyses was performed, determining general features of the four segments taking into account the variability of the outcomes. The questionnaires are presented in the appendix of this report. In the following Sections a description is given of the most relevant findings of the survey. Comparisons between the segments and the interpretation of the recorded information is discussed in the final Section.

## Waste plastics trader

In the past, the state-run enterprises dominated the trade of waste plastics. Since the reform of the economic system, the private traders have almost completely replaced the state-run enterprises. At present, the share of state-run enterprises is below 5% and is expected to be minimised further in waste plastic trade. The main factor supporting this change is the better economic performance of the private enterprises. Because of this novel change, the average year of establishment of the interviewed firms is 1995, while the oldest waste traders started as recent as 1993.

In consideration of the fact that Beijing is one of the largest plastic consuming centres of China and thus also generates a large amount of waste plastics, we have selected 30 enterprises in its vicinity which trade in waste plastics. All interviewed traders were established in market centres for secondary commodities located in Longwangtang of Wail, group 14 of Wail, Nanjiao, Panjiayuan and Xibajia in the outskirts of Beijing. The recycling concentration areas where most interviewed traders operate handle a range of materials such as waste paper, glass, steel and non-ferrous metal.

The main reasons to operate in the suburbs of Beijing are (1) the business is mainly run by non-natives which migrated to Beijing and therefore settle close to the rural communities; (2) the operational costs are much higher in the centre; (3) public security restricts vehicles' entering the city due to heavy traffic downtown. Therefore, it is difficult for the transport operators of waste plastics to obtain the license to enter the downtown area; (4) to promote their local income, some suburban municipalities offer patches of lands in markets of second- hand commodities against special rates to encourage migrants from other provinces to handle the recycling business; (5) the urban populations, and specifically the institutional organisations such as offices and departments stores, look down up on the informal waste pickers and traders. They therefore do not allow these entrepreneurs to enter their property.

As a result of higher specialisation, these recycling enterprises seldom take up business other than waste plastics. There is a tendency for specialising in limiting trade to one or two types of waste plastics. They never handle the import of waste plastics. The area of these recycling enterprises ranges from 40 to 500 square meters with an average of 200 square meters. The average quantity traded per month is about 13 tons which generates a turnover of approximately 36,000 Yuan. The profit rate is 9% which leads to a monthly return of 3300 Yuan.

The main type of work of the recycling enterprises is mostly manual sorting and package of the waste plastics. No mechanical separation techniques are applied. Most recycling enterprises sort the waste plastics according to their colour, varieties, quality, for customers to make different grades and kinds of resin out of the plastics, in order to improve the quality of recycling of waste plastics. Only 10% of traders offer cleaning and breaking service on the customers' requests. Besides promoting the additional value of the products, it also facilitates storage and transportation since the volume is reduced significantly. The average buying price of the materials is 2350 Yuan. The average selling price is 450 Yuan higher at 2800 Yuan.

The enterprises are privately run and not restricted by the government's prescription of festivals-related vacation and working time. Therefore, all firms exceed the legal 8 hours by operating between 10 to 12 hours. The enterprises are usually operated by families, with only few employees. Because of the physically strengthening working conditions, the enterprises only employ female workers for the separation of the waste plastics. At present, the usual salary of workers is between 500-600 Yuan. The level of the wage is determined by various factors such as the worker's ability, the size of enterprise, and the workers' personal relations between owners and workers.

The final products of most enterprises are sorted waste plastics, except that some enterprises break the waste plastics into chips. The main type of materials are waste plastics from household use (67%), industrial waste plastics (30%) and agricultural waste (3%). Household waste plastics generated the highest selling price (Yuan 3100 per ton), while industrial waste plastics was slightly cheaper (Yuan2300/ton). Agricultural waste plastics had only limited market value (Yuan600/ton).

Because the sorting of waste plastics is done manually without water usage, the government's control of the supply and price of electricity and water have scarcely direct influence on the enterprises' operation. The collected waste plastics contain a certain proportion of unrecoverable materials such as labels and soil. For most waste plastics this share accounts for 1-3% impurity but some even contain 10%. The impurity never considered poisonous. Half of the enterprises dump their residues with the other solid waste to be collected by the municipality. The other half burns the residues.

Through negotiation, the trader and the recycler determine who bears transportation cost in selling. These costs can vary significantly as a result of the volume of the traded goods and the distance of transportation. The enterprises sell most varieties to Wenan, Xiongxian and other areas in Hebei province, with distance from 100 to 200 kilometres. Some varieties are sold in Jiangsu, Zhejiang province, 1000 kilometres away. As enterprises receive waste plastics mainly indirectly from suburbs through peddlers, the distance between the trade shop and their suppliers never exceeds 25 kilometres.

*Table VII.1 Monthly Cost Structure of the Trader (in Yuan)*

| | total | share in costs |
|---|---|---|
| input costs | 30550 | 92,66% |
| labour costs | 1967 | 5,97% |
| electricity costs | 50 | 0,15% |
| capital costs | 306 | 0,93% |
| other costs | 50 | 0,15% |
| tax payment | 47 | 0,14% |

The enterprises have only limited total assets and can therefore not fulfil large-scale storage. A majority of the enterprises can only store a volume of one truck of recycled waste plastics and then sell it. A majority of enterprises only have such simple equipment as handcarts and washing tanks and only a few of them have grinders and trucks. Therefore, the operation of these enterprises is determined by the costs of raw materials (93%) and labour (6%).

The traders operations are sensitive to season variations. On the whole, in summer, as a result of its intense heat, the quantity of city residents' consumption of drinks, shampoo, cleanser, etc. increases considerably. Therefore, recycling enterprises have heavy business from June to August. Before Spring Festival, from December to next February is the slack season for the dealers of waste plastics. Most traders go back to their hometown. From March to May and September to November their enterprises run relatively normally

As for the government's involvement, some enterprises indicate to be supported in terms of exemption of full taxation and through favourable arrangement in obtaining the required land for operation. Only 10% think their business' influenced by the interference of the government through taxation. Most these enterprises do not pay taxes, mainly because taxes are included in their rent to the administrative departments of the second-hand markets. Some tax departments charge these enterprises directly. Because it's difficult to determine the enterprises' taxable value, thus inability to be taxed proportionally, they're required to pay fixed tax every month. The majority of the enterprises (67%) do not experience any other external constraints in their operations. Regarding the future development of their business, most of the surveyed expect to expansion of their business, mainly due to the increasing trend of the quantity of recyclable waste plastics.

### The domestic recycler

Upon the briefing and recommendation of the Waste Plastics Recycling and Utilisation Committee under the Chinese Association of Plastics Processing Industry, we focused this questionnaire survey on Wen'an County in Hebei Province, which is one of the main centres of waste plastics recycling across China. It claims not only the biggest trading centre for domestic waste plastics for some 20 provinces and cities, but is also the most important producing area of secondary resin based on domestic waste plastics.

The survey covers a total of 30 productive establishments engaged in making secondary resin from waste plastics. It was largely done by direct interviews mainly centred on Zhaogezhuang and Yincun townships, both in Wen'an. These two have developed into specialised bases of secondary resin production, in which almost every household takes part. Of the 30 production units surveyed, 17 are from Zhaogezhuang, 7 from Yincun, 1 from Pangerwan, also in Wenan County, and the other 5 are located in the suburb of Beijing.

All of the interviewed enterprises are privately-run. Most of them are located in industrial areas where besides plastic, also other materials are recycled. Because waste plastics are usually collected and traded by rural transients in cities and towns, secondary resin is likewise produced by village labours. The interdependency between the recyclers and the collectors of waste plastics is therefore very strong. Moreover, similar to the collection of waste plastics, the recycling sector experienced a transformation from state-run operations to privately-run enterprises since the early '90s. Therefore, the average year of establishment was estimated at 1994.

In China, secondary resin production is very small in scale, which is predominantly carried out by family enterprises. The operation area measures no more than approximately 350 square meters. The average capacity and production is 23 tons and 12 tons monthly respectively. This implies a capacity utilisation rate of 50%. The premises for production are rather simple, with some production even taking place in the open air. This makes the winter months of each year, November through next February, slack season.

Normally each unit concentrates on the production of one variety only. Altogether 6 varieties of resin are produced, namely, LDPE, HDPE, PVC, PP, PS and PET. HDPE and LDPE are the most popular materials. With the exception of PET, all the varieties are made into granules after being crushed (producers without extruding machines can only crush these materials and then have them granulated by those equipped with the apparatus). The buyers of these resins are either trading firms or manufacturers of secondary plastics products. PET is crushed into flakes and then sent to Jiansu, Zhejiang and other provinces as raw materials for textile fibbers.

The secondary resins can be classified into high, medium and low grades. While the medium and low grades of resins represent roughly 80% and 10% of the total quantities produced, the high grades stands at a small proportion of about 10% only. The average buying price of the waste materials is estimated at RMB¥ 3200 per ton. The average selling price is RMB¥ 4150 per ton, resulting in an added value of approximately RMB¥ 1000 per tonne of output. The average turnover and profit of each recycler is respectively around RMB¥ 50,000 and RMB¥ 5150 monthly which is equal to a profit ratio of 10%.

Apart from only one producer in Beijing suburb that employs some 50 staff, all the other producers covered in our study are household businesses boasting none or very few employees. On average, the domestic recycler employs 5 workers, consisting of 70% males and 30% females. The working conditions are poor, with average wages of RMB¥ 440, and a working schedule of 7 days a week, 11 hours per day. The labour intensity of production is relatively high with 156 man-hours per tonne output. This can partly be attributed to the low quality of the inputs, which therefore requires more manual effort.

In China, producers of secondary resin from local waste plastics are basically businesses with a much smaller capital than that of recycled plastics goods makers. Basically, most recyclers possess a crusher and an extruding machine, worth totally about RMB¥ 10,000-20,000. Taking into account the value of the premise and the average stock, 80% of the recyclers have assets under RMB¥ 50,000. The overall average of capital assets was estimated at approximately RMB¥ 46,000. Except for one or two of them that can obtain bank loans, over 90% of the producers rely on their own savings and borrowings from relatives and friends. Still, as the scale of production is too small to absorb heavy capital input, fund shortage poses no major issue for them.

*Table VII.2 Monthly Cost Structure of the Domestic Recycler (in Yuan)*

| | total | share in costs |
|---|---|---|
| input costs | 38400 | 86,0% |
| additives | 120 | 0,3% |
| labour costs | 2508 | 5,6% |
| electricity costs | 2520 | 5,6% |
| capital costs | 383 | 0,9% |
| other costs | 500 | 1,1% |
| tax payment | 234 | 0,5% |

The producers rarely pay taxes. This is partly due to the suburban location, where the state levies little taxation. Sometimes the payment of rent for land is considered as a tax payment instead. It is doubtful whether these enterprises could pay more rent. Their profits remain low due to the limited added value, the high labour costs which make out 6% of the total costs, and the high electricity costs (also 6%) which amount to about RMB¥ 210 per ton.

The production of secondary resin from local waste plastics has triggered serious environmental problems. Since waste plastics is consumed as raw material in such a production, the collection, preservation and cleaning of waste plastics may all cause contamination. It has been learned through our study that local secondary resin producers often let foul water drain away without any treatment. Approximately 30% of the interviewed recyclers do not experience unrecyclable residues in the supplied waste plastics. Those who do, sort these materials out and either dispose the unrecyclable waste with garbage (50%) or burn these (50%). One case was reported in which the recycler disposed the residues in the waterway. The air conditions are poor as more than 70% of the recyclers do not have any form of indoor ventilation. The remaining firms either open windows or use an electric ventilation. Odour is claimed to be one of the reasons why production on secondary resin is not allowed in urban residential areas and is usually shifted to towns and villages far off the city.

The producers surveyed generally bear little transportation costs, because they can get raw material and sell products both at local trading markets nearby. Even if they buy waste plastics from other sources, or if they need to sell their products directly to the manufacturers, the carriage fares are usually very low and are quite often covered by the manufacturers. This may also be the explanation why waste plastics trading centres are the important secondary resin production bases at the same time.

The average growth rate of production of the enterprises older than 3 years in the past five years is as high as 31% annually. The reason for such a rapid growth is sufficient supply of domestic waste plastics due to the increasing volume of recovery. It is therefore not surprising that more than half of the recyclers are very optimist about the future. They expect a substantial increase of their business in the coming years.

## The importing recycler

Of the 30 enterprises under our investigation 27 are privately owned, one is state-owned, and two are collectively owned. These two latter so-called township enterprises are Sino-foreign joint ventures. Compared to the other surveys in this project, the average year of establishment lying 1991 and 1992, is relatively early. The recycling activities of imported waste are heavily concentrated along the coastal areas such as Guangdong and Zhejiang , in which most of our investigated enterprises are located. Besides being recycling activity centres, these two regions also form important concentrations for plastics manufacturing in China.

The main input are the imported waste of HDPE, LDPE, PP, PVC, PS, and PET. Less frequent forms of imported inputs are PA, ABS, and PU. In these two areas with high proportion of imported waste, domestic waste is also being used. It is interesting to see that imported waste are dominated in the recycling activities of HDPE, LDPE, PP and PS but domestic waste become more important in the recycling activities of PVC and PET.

The average prices of domestic waste of HDPE, LDPE, PVC and PET are higher than those of the imported ones. As for PP and PS the prices of imported waste are higher. Yet, in both cases, the price difference is not big. The colouring agent comes as the most popular additive for plastics recycling. Usually, 0.5 kg of colouring agent is needed to colour one tonne of the resin. The price of colouring agent varies as much from RMB 12,000 Yuan /ton to 2 million Yuan / tonne depending on the quality of agent as well as the colour. Recyclers are usually producing for the domestic market. Of the 30 investigated enterprises only 2 enterprises have exported their secondary resin to Hong Kong and Taiwan. Their export ratios are 60% and 90% respectively.

Most of recyclers are poorly equipped with on average two crushers and two extruders. One third of the recyclers have their own trucks. Yet, more sophisticated equipment such as packing and drying machines, are only available for 10% of the enterprises.

Their production process is similar to the domestic recyclers. It consists of sorting, washing, grinding and granulating. Yet, as opposed to the domestic recyclers, several importing firms do not wash the waste plastics before recycling, for two reasons. First, generally imported waste is rather uncontaminated. Formally, only industrial waste (grade A and B) is allowed to be imported in China. Second, some recyclers subcontract the sorting and washing to other entrepreneurs.

The importing plastic recycling industry operate almost seven days a week with daily schedules of 12 working hours. For most of the enterprises the final product is secondary resin but there are 14% of the enterprises whose output is flake which is intermediate product for secondary resin.

A half of investigated recyclers have a capacity between 100-500 tons per month, another 13 % have a capacity more than 500 tons, the rest less than 100 tons. Though the average capacity is registered at 185 tons the average production stays behind at 91 tons. This results in a utilisation rate of 50% and a monthly turnover of approximately RMB¥ 500,000..The profit rate of the importing recyclers of 12% is higher than that of the domestic recycler, however, in absolute value they dominate evidently (RMB¥ 61,000).

*Table VII.3 Monthly Cost Structure of the Importing Recycler (in Yuan)*

| | total | share in costs |
|---|---|---|
| input costs | 377,200 | 85,7% |
| additives | 920 | 0,2% |
| labour costs | 20,976 | 4,8% |
| electricity costs | 33,856 | 7,7% |
| capital costs | 5,083 | 1,2% |
| other costs | 1,000 | 0,2% |
| tax payment | 1,041 | 0,2% |

Transportation cost of the inputs are included in the buying price, both for domestic and international transportation. The suppliers are responsible for the transportation when he buys and the customers take care of the transportation when he sells. Therefore, most recycler are unable to report these costs. The distance between recyclers and suppliers of waste plastics is quite far and international and inter- regional transportation are usually involved. But recyclers are usually close to the manufacturers of plastic product.

Ninety percent of the recyclers only use their personnel savings as initial investment without any financial support from the bank or local government. As for the two joint ventures, small part of investment comes from the township government, while the large portion from their overseas partners. The size of the total asset vary with the ownership of enterprises. The two Sino-foreign joint ventures top the list, with total assets both close to 10 millions Yuan followed by the state-owned enterprise whose asset is registered more than 5 million Yuan. But most of the private operators possess no more than 100 thousands Yuan.

With 90 % of recycling enterprises being family based, the scale of them can not be very large, averaging at 10 male and 12 female labours. There is no gender discrimination against woman who is able to get the same wage if she engages in the same work with man. But the difference in wages is very obvious between Guangdong and Zhejiang, in the former area the wages run from 600 Yuan to 900 Yuan while in the latter area the difference of the wages is reduced to 400 Yuan to 600 Yuan. The labour cost on average basis is 216 Yuan to produce one tonne of secondary resin.

Imported waste plastics usually contains a certain amount of unrecoverable substances, which may be treated generally in two ways. If they are plastics of other varieties, they may be transferred to other recyclers or returned to the supplier; if they are not plastics they be treated with other garbage. The main environmental problems created in the course of recycling activity of imported waste plastics is mainly in the form of waste water discharged from washing of waste plastics and the foul odour emitted during granulation. For the waste plastics from agriculture and household, washing is usually necessary before granulation. To wash one tonne of waste plastics 2-3 tons of water and 1.5 kg of detergent are needed.

Based on the last five years production record, 80% of recyclers have reduced their production and only 10 % have expanded their production. The main reason for the drop in production is reported as following: In the last few years most of the recyclers have made a relatively big profit, attributed mainly to the abundant and cheap supply of imported plastic waste and relatively fewer operators in this field. The successful story of these recyclers, has attracted a lot of people to enter into the plastic recycling sector. However, the import ban and tighter control on credit scale have reduced the supply of imported plastic waste as well as demand for the secondary resin. The recyclers have different views about future development. 30% of recyclers hold that the business will stay at the same level; 33% of them think the business will increase; and another 36% of recyclers believe there is a small chance of increasing their production in the near future. The main constraints lies in the tighter control on the import of the waste plastic, which not only make it more difficult and also more expensive to get sufficient supply.

## The Manufacturer

Our survey is primarily based on studies in 3 locations, Baoding and Langfang prefectures of Hebei Province, Ningbo prefecture of Zhejiang Province and the Pearl River Delta in the southern Guangdong Province. What makes these areas the focus of our survey is that they form the national centres for recycling waste plastics. It is estimated that these regions accounts for 80% of China's production of recycled plastics articles. While Baoding and Langfang are the main bases for the northern region, Ningbo largely absorbs waste plastics in the south, and the Pearl River Delta sees the processing of waste plastics imports in mass quantities.

In total, 30 waste plastics recycling enterprises were interviewed, including 2 factories in the Chaoyang District of Beijing, 10 in the Xiongxian County of Langfang prefecture, 10 in the Wen'an County of Baoding prefecture, 7 in Ningbo prefecture of Zhejiang Province and 1 in the Guangdong's Pearl River Delta.

Among the 30 enterprises surveyed, 23 are privately-operated businesses, 6 are township businesses of collective ownership, and only 1 is state-owned. This shows the predominant role of privately-owned companies in recovering the country's waste plastics and the insignificant market share of state-owned firms. The average year of establishment is 1990, making the plastic manufacturers the most experienced firms in this survey. Also the size of the area of about 950 square meters, can be considered rather relatively large.

These 30 enterprises are mostly located in towns and counties with a relatively dense concentration of plastics recyclers and manufacturers. They are varied in capacities and productive technologies: 15 of them use blow-moulding method, 8 employ extrusion, 4 take on injection moulding, 2 use melt spinning (which is a special type of processing method for polyester fibber made of PET) and 1 adopts chemical melting. While blow-moulding mainly produces films and tubes for packing, agriculture, construction and civil uses, injection moulding makes containers, articles for daily use and electronics components for households and the electronics industry. Extrusion manufactures produce special-shaped plates and fire-resistant tubes for the industrial sector. Melt spinning generates polyester fibber for textile. The scale of operation varies significantly from 3 to 300 tons per month, with an average capacity of 42 tons.

*Table VII.4 The average selling price and the buying price of the products*

| Type | Selling price (RMB¥/ton) | Buying price (RMB¥/ton) |
|---|---|---|
| PE | 8800 | 7094 |
| PVC | 3900 | 1820 |
| PS | 6600 | 2500 |
| PET | 8800 | 4500 |
| ABS | 25000 | 8035 |
| average | 9500 | 5704 |

The average total input of raw materials per month is 26 tons, which is composed of 81% secondary resin, 18% primary resin and less than 1% additives. The average scale of plastics recycling enterprises is rather small.

Since plastics manufacturing industry is very labour intensive, the average manufacturer employs 37 workers, which consists of respectively 20 males and 17 females. As many of these factories are privately owned, the conditions for the workers there are generally poor. Only 50% of the interviewed enterprises took some kind of measure to ventilate the working floor. Working hours are long and the wages are low. The work schedule is on average 6.7 days per week, 2 shifts a day and 8 hours per shift. The average monthly wages are RMB¥ 500-600 for male workers and RMB¥ 400-500 for females in the North, RMB¥ 700-800 for males and RMB¥ 500-600 for females in Zhejiang and about RMB¥ 1000 in Guangdong Province. The labour productivity is averaged 316 hours per tonne output.

Export is not the driving force for the recycling manufacturers. Only 17% of the manufacturers sell a limited part of their products overseas. According to the survey, the average turnover of the manufacturer is about RMB¥ 248,000 per month, and the profit is estimated at RMB¥ 36,892, with the profit ratio at about 15%.

The transportation costs have been covered in the purchase or selling prices of raw materials or finished products and are thus borne by the customers. It needs to be noted that, since the absolute majority of the recycled plastics producers surveyed are located in areas where many such factories are grouped, little transportation fare is involved for these factories in getting the raw materials they need. Sharing truck capacity helps the firms in cutting down their production costs and raising the products' competitiveness.

The interviewed plastic manufacturers are comparatively small businesses with a limited production capacity, a low technological level and a small capital input. Therefore, the average fixed assets just over RMB¥ 600,000. The main source of finance consists for 80% of the enterprises of their own personal savings or a loan from relatives and friends. Funding is difficult for them as only those with a registered capital of more than RMB¥ 1 million may obtain bank loans.

With most of the enterprises surveyed, no significant pollution has been recorded. Particularly those that adopt blow-moulding method produce in a clean manner. The secondary resin used by them does not contain unrecyclable substances and therefore does not create inefficiencies. The average electricity per tonne consumed is 520 kWh.

Although the capacity is about 40 tons per month, the average real production is only 26 tons. The past five years have seen the progressive decrease of the average production of the manufacturer of 7.7% annually. The main explanation given by the entrepreneurs was the increasing competition, which led to hikes of raw material costs and decreasing selling prices of finished products. Nevertheless, almost 85% of the manufacturers expect their business to increase in the coming years.

Table VII.5 shows the cost structure of the manufacturer. Except for raw material purchase and wage payment, the biggest spending that affects their operation comes from taxation and energy costs. Companies often complain about heavy tax dues and various tax categories. They also report of a progressive downturn in profits over recent years owing to the increasing emergence of their colleagues, rising costs of raw materials as well as shrinking market demand. We have learned from our study that local governments all adopt a laissez-faire attitude towards these waste plastics recycling enterprises, which then generally complain of fund shortage, bank refusal to extend loans and credits and over-taxation. These issues are bound to hinder the growth of these enterprises.

*Table VII.5 Monthly Cost Structure of the Plastic Manufacturer (in Yuan)*

| | total | share in costs |
|---|---|---|
| input costs | 156,962 | 74,4% |
| additives | 18,200 | 8,6% |
| labour costs | 10,400 | 4,9% |
| electricity costs | 14,846 | 7,0% |
| capital costs | 2,183 | 1,0% |
| other costs | 3,500 | 1,7% |
| tax payment | 4,849 | 2,3% |

# Appendix VIII. Mathematical description of the model

## SETS

| | |
|---|---|
| I | Activity Centres<br>/ Beijing, Shanghai,Daqing, Nanjing,<br>Guangzhou, Tianjin, Zibo, Chongqing, Ningbo,Baoding / |
| PI(I) | Primary Resin Production Centres<br>/Beijing, Shanghai,Daqing, Nanjing<br>Guangzhou, Tianjin, Zibo/ |
| DI(R) | Demand, Collection and Separation Centres<br>/Beijing, Shanghai, Guangzhou, Chongqing, Nanjing / |
| FI(I) | Washing, Recyclng and Final Production Centres<br>/Ningbo, Guangzhou, Nanjing, Baoding / |
| **P** | **Processes** |
| PPR(P) | Primary Resin Production |
| PSR(P) | Secondary Resin Production |
| PFP (P) | Final Goods Production |
| PCL(P) | Waste Collection Processes |
| PSP (P) | Waste Separation Processes |
| PDSP(P) | Waste Disposal Processes |
| **M** | **Machine Units** |
| MPR(M) | Primary Resin Production |
| MSR(M) | Secondary Resin Production |
| MFP(M) | Final Goods production |
| **C** | **Commodities** |
| CRPI(C ) | Raw Material Commodities used in primary resin production centres |
| CIPI(C ) | Intermediate Commodities used in primary resin production centres |
| CFPI(C ) | Final Goods produced in primary production centres |
| CRDI(C ) | Raw Material Commodities used in Collection, Separation centres |
| CIDI(C ) | Intermediate Commodities used in Collection&Separation&disposal |
| CFDI(C ) | Final Goods produced in Collection, Separation and disposal centres |
| CWDI(CRDI ) | Waste Goods produced by sectors |
| CRFI(C ) | Raw Materials used in final production centres |
| CIFI(C ) | Intermediate goods used in final production centres |
| CFFI(C ) | Final Goods produced in final production centres |
| **S** | **Demand sectors for plastic goods** |

## VARIABLES

| | |
|---|---|
| z | Activity Levels |
| x | domestic shipments |
| u | domestic purchases |
| v | imports |
| w | waste level |
| e | emissions |

md middle distillate used
rc raw material costs
vc import costs
dc disposal costs
br byproduct revenue

## DATA

a input-output technology matrix
d fixed demand
α recovery ratio
k capacity available
mud distillate used for transportation
mut transport cost per unit transported
p prices
j capacity utilisation rate

## SET OF EQUATIONS

**Primary Resin Production Centres**

**1. Material Balance Constraint for Raw Materials**

$$\sum_{p} api_{c,p} z_{p,pi} + u_{c,pi} + v_{c,pi} \geq 0 \qquad c \in CRPI, pi \in I$$

The total amount of raw material used in each primary resin production centre must be matched by domestic purchases plus imports. The api coefficient tells us the amount of a particular raw material which is needed by a particular process to produce one unit of output. The units are in physical units. U is domestic purchases while v is the import level.

**2. Material Balance Constraint for Intermediate Materials**

$$\sum_{p} api_{c,pi} z_{p,pi} + \sum_{\substack{pi' \\ pi' \neq pi}} x_{c,pi',pi} + v_{c,pi} \geq \sum_{\substack{pi' \\ pi' \neq pi}} x_{c,pi,pi'} \qquad c \in CIPI, pi \in I$$

Total amount of intermediate products produced domestically by all processes plus interplant shipments from other plants plus imports must be greater than the total amount of intermediate products supplied to all other plants.

**3. Material Balance Constraint for Final Goods**

$$\sum_{p} api_{c,pi} z_{p,pi} \geq \sum_{fi \in} x_{c,pi,fi} \qquad c \in CFPI, r \in R$$

The total amount of each type of primary resin produced at each centre must be greater than the sum of shipments to all final production centres.

**Collection, Separation and Disposal Centres**

**3. Total domestic waste generated by each sector**

$$w_{c,di} = \sum_{s \in S} \sum_{c \in cfi} \alpha_{s,cwdi} d_{c,i,s} \qquad i \in di, c \in CWDI$$

The total amount of a particular waste generated in each demand centre is equal to the sum across sectors of sectoral recovery rate of the particular waste type ( $\alpha_{s,cwdi}$ ) multiplied by the total demand or use of all plastic types by the three sectors in the demand centres. In essence, we have each sector producing a homogenous waste which comes from an aggregation of all plastic types which are consumed.

**4. Raw Material Balance**

$$\sum_{p} adi_{c,p} z_{p,di} + u_{c,i} \geq 0 \qquad c \in crdi, i \in di$$

Total amount of raw materials used must be met by purchases. The main activities here are collection, separation and washing of recyclable waste plus of course the disposal of final waste.

**5. Constraint on domestic purchase of waste**

$$u_{cwdi,di} \leq \sum_{p \in l} adi_{cwdi,p} z_{p,di} \qquad C \in cwdi, di \in DI$$

Domestic purchase of waste (defined by sector of origin) must be less than the total amount collected by the various collection systems.

**6. Constraint on collection of waste**

$$\sum_{p \in l} adi_{cwdi,p} z_{p,di} \leq w_{c,d} \quad c \in CWDI, di \in DI$$

The total amount of all waste types collected by all the collection systems must be less than the total waste generated by the respective sectors.

**7. Intermediate Balance**

$$\sum_{p} adi_{c,p} z_{p,i} = 0 \qquad c \in cidi, i \in di$$

Net intermediate production level plus shipments from other plants must be greater than or equal to shipments to all other plants.

**8. Final Good Balance**

$$\sum_{p} adi_{c,p} z_{p,i} \geq \sum_{fi \in l} x_{c,di,fi} \qquad c \in cfdi, i \in di$$

Total amount of separated but dirty waste must be greater than the total amount shipped to all the recycling centres plus exports.

## Final Recycling and Production Centres

### 9. Raw Material Balance

$$\sum_{p} afi_{c,p} z_{p,fi} + u_{c,fi} + v_{c,fi} \geq 0 \quad c \in crfi, i \in fi$$

Total amount of raw material used in the final production centres must be matched by domestic purchases and as well as imports. Note that one of the raw materials at this stage is the separated but still dirty waste plastics which are bought from the collection and separation centres.

### 10. Intermediate Balance

$$\sum_{p} afi_{c,p} z_{p,fi} + \sum_{\substack{fi' \\ fi' \neq fi}} x_{c,fi',fi} \geq \sum_{\substack{fi' \\ fi' \neq fi}} x_{c,fi,fi'} \quad c \in cifi, fi \in i$$

Intermediate goods at this stage will be clean sorted waste plastic goods. Note no import of this is allowed. Import of waste is captured in the raw material balance in equation 8 above. That waste also undergoes the cleaning process together with the domestic sorted waste.

### 11. Raw material constraint

$$u_{c,fi} \leq \sum_{di \cup pi} x_{c,di \cup pi,fi} \quad c \in cfdi \cup cfpi, fi \in i$$

The purchase of waste plastic products must be less than the total shipment from all the collection and separation centre. Note that the final products of the collection centres and the final product from the primary resin production centres are the raw materials for the final production and recycling centres.

### 12. Final Good Balance

$$\sum_{p} afi_{c,p} z_{p,fi} \geq \sum_{di} x_{c,fi,di} + e_{c,i} \quad c \in cffi, fi \in i$$

Total shipment of final goods to final demand centres must be less than the total amount produced at the production centres.

### 13. Market Demand

$$\sum_{fi} x_{c,fi,di} + v_{c,di} \geq db_{c,di} \quad c \in cffi, di \in i$$

Shipments from all final production centres together with imports must meet final market demand.

**14. Capacity Constraint at all production centres**

$$\sum_{p} b_{m,p,i} z_{p,i} \leq k_{m,i} \qquad m \in MPR, i \in I$$

Total amount of capacity used by all the processes which use a particular machine unit must be less than the total capacity available of that particular machine unit.

**15. Middle distillate used in transportation**

$$md = \sum_{i \in I} \sum_{c \in C} v_{c,i} \mu^{d}_{v,i} + \sum_{i \in I} \sum_{j \in I} \sum_{c \in C} x_{c,i,j} \mu^{d}_{i,j}$$

Total amount of middle distillate used is equal to middle distillate used in transporting: (1) all imported goods; (2) all intermediate shipments; and (3) final goods. The last two are capture by the second term in the equation above while the first term relates to imports.

**16. Total Emissions**

$$\sum_{i} \sum_{p} api_{c,p} z_{p,i} + api_{c,"md"} md = e_{c,i} \qquad c \in CE$$

Total emissions for each pollutant is equal to emissions by all processes at all activity centres plus emissions from middle distillate used in transportation.

**17. Transport Costs**

$$trc = \sum_{i \in I} \sum_{c \in C} v_{c,i} \mu^{t}_{v,i} + \sum_{i \in I} \sum_{j \in I} \sum_{c \in C} x_{c,i,j} \mu^{t}_{i,j}$$

Transport cost is equal to transport of all imported goods to activity centres plus inter-plant shipments between activity centres plus transport of all final goods to activity centres. μ is the transport cost per tonne per activity centre link. The distance between the centres is already computed within the coefficient.

**18. Raw Material Costs**

$$rc = \sum_{i \in I} \sum_{c \in CRPI \cup CRDI \cup CRFI} u_{c,i} \; p^{d}_{c,i}$$

Raw material costs is equal to the various raw materials purchased domestically multiplied by the domestic price of the raw materials. $p^{d}_{c,i}$ is the price for raw commodity c in activity centre i. We capture price differences in the various centres if any.

**19. Import Costs**

$$vc = \sum_{i \in I} \sum_{c \in CRPI \cup CIPI \cup CRFI \cup CFFI} v_{c,i} \; p^{v}_{c,i}$$

The import cost is equal to the import levels of the various commodities which can be imported multiplied by the import prices faced at the various production centres.

**20. Disposal Cost**

$$dc = \sum_{di \in Di} \sum_{p \in pdsp} discost_{p,di} z_{p,di}$$

The disposal cost is equal to the amount of waste disposed multiplied by the unit cost of disposal. Discost tells us the cost of disposing one unit of waste by a particular process in each disposal centre. The summation gives us total costs for all processes and all centres.

**21. By product Revenue**

$$br = \sum_{i \in I} \sum_{c \in Cbp} api_{c,p} z_{p,i} p_c^d$$

By product revenue is equal to the amount of by product commodity c produced by all the processes in all the respective plants multiplied by the price for that commodity.

**22. Total Costs**

Total Cost(TC) = RC+VC+TRC+DC+EC-BR

# Appendix IX. Different forms of valuation

## Using ambient standards

The application of emission and ambient standards has strong advantages. The procedure is relatively simple and practical. If the necessary emission data from the economic activity are available, it requires limited expertise to compare these with the reported maximum allowable levels of air emissions and effluent discharge requirements contained in the national or international guidelines. For illustrative purposes we will discus the World Bank standards and guidelines reported in the Pollution Prevention and Abatement Handbook (1998).

These standards also have several drawbacks. First, the guidelines have been formulated for standard conditions and locations. For example, the same emission standards hold for different locations and countries. Although this generalisation has been taken into account in the determination of the overall standards, certain extreme cases require specific guidance which go beyond the World Bank standards.

Second, meeting the standards gives hardly any information on the actual environmental effects. For example, whether or ecosystems or humans are actually exposed by pollutants is not taken into consideration. Yet, it is the actual impact which is of much more importance for the environmental performance rather than the achieved emission level. An example of this could be waste water discharges into extremely vulnerable or special wetland ecosystems. On the other hand, could certain pollution levels be accepted in industrial areas, whilst in natural areas they would not.

Third, emission standards alone do not guarantee an actual good environmental performance. Proper environmental management and monitoring of the achieved levels is crucial. In this context it is important to realise that the World Bank standards do not provide incentives for performing better than the standards require. Once the standards are met, the company does not have to do anything to decrease its environmental impacts. The standards are usually based on Best Available Technologies (BAT). Hence, they do not stimulate the development of newer and better abatement techniques. In addition, following the emission standards, one is tempted to focus on end-of-pipe measures, while new process integrated measures often result in a far better environmental performance. For example, using natural gas as fuel in combustion units instead of coal reduces the $SO_2$ emissions significantly. This can also be brought about by using a wet scrubber, but this end of pipe technology results in solid gypsum waste which is contaminated by heavy metals.

Fourth, focusing on the emission standards one tends to forget the emissions in the other phases of the product life cycle. It is often useful to investigate in which part of the cycle 'environmental money' is spent most efficiently. For example in clothing manufacture most environmental benefits can be obtained by decreasing the use of pesticides in cotton production.

Finally, if the World Bank guidelines are applied, the project can be approved or rejected. A ranking or a more gradual evaluation cannot be achieved, though there are several situations which may require such comparisons. For instance, in the case of the establishment of the portfolio of a 'green' fund. If a limited amount of capital is available in the overall fund, preferably the best investment projects should be selected. In that case, the projects have to be ranked or valued according to their environmental performance. Alternative approaches need to be considered. Box IX.1 below illustrates this selection process by means of drawing a 'spider-web'. Not on a project scale, but for individual countries, the Asian Development Bank (ADB) often applies a variant of this approach, called the 'environmental diamond' (Rogers et al., 1997).

In recent years, various methods have been developed to weigh different emissions and other environmental parameters against each other, in order to make alternatives with multiple impacts comparable. Some of these methods have specifically been designed for application in project appraisal. Broadly speaking, these methods can be classified as (a) distance-to-target approaches, (b) scoring techniques, (c) abatement and control cost methods, and (d) welfare theoretical approaches. In the following sections, these methods will be explained.

**Box IX.1 Which project is preferred?**

Two projects (A and B), which both meet the World Bank standards, are candidate for funding. Only one project, the most environmentally sound project can be selected. The spider web indicates the environmental scores in terms of damage intensity. Project A scores good on human toxicity and ozone depletion but has significant adverse consequences for the climate. Project B shows an opposite pattern. Based on this representation, no definite outcome can be concluded. If the decision maker has a strong preference to prevent climate change, Project B will be selected. If the other environmental problems get priority, Project A will be funded. A consistent set of weights need to be developed to arrive at a well-considered selection.

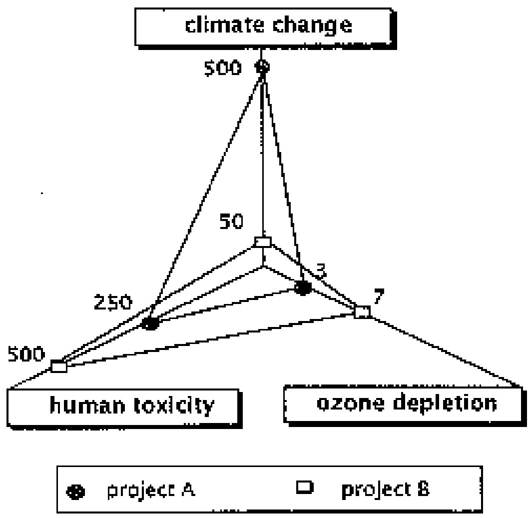



*Figure IX.1 Environmental impact score.*

## Distance-to-target approach

In the 'distance-to-target' approach, the importance of a pollutant is determined by the difference between the actual environmental situation and some objective (e.g. a politically or scientifically defined target 'sustainability level' or 'no effect level'). Put in another way, it focuses on the extent to which society has failed to achieve environmental standards (Powell, 1995).

This method fits best with the World Bank guidelines because it is generally based on a system of standards. The weights from the distance-to-target approach can be derived for all environmental impacts which have quantitative targets. Usually these targets are defined on a national level. The most common impact categories are energy consumption, air pollution, water pollution and waste generation. Equation IX.1 demonstrates how the weights are derived.

$$W^i = \frac{E^i_{aggr} - E^i_{st}}{E^i_{st}} \qquad \text{(IX.1)}$$

$W^i$ = weight for emission of pollutant i
$E_{aggr}^i$ = aggregate emission level of pollutant i
$E_{st}^i$ = maximum allowable aggregate emission level of pollutant i

After the weights for all the pollutants have been derived, the environmental indicator can be calculated by multiplying the weights with the respective pollutant levels. This step is presented in equation IX.2. It can be assumed that the lower the indicator, the less damaging the project will be for the environment.

$$EI = \sum_{i=1}^{n} W^i \cdot E^i_{pr} \qquad \text{IX.2}$$

$EI$ = environmental indicator
$E_{pr}^i$ = emission level of the project of pollutant i

The procedure is best illustrated with an example. Suppose two projects have certain levels of emissions which exceed the maximum allowable standards defined by the World Bank (see Table IX.1).

*Table IX.1 Information of the example of the distance-to-target approach*

| | national target | national level | Project A | Project B |
|---|---|---|---|---|
| Air pollutants | | | | |
| - NOx | 10,000 kg/year | 15,000 kg/year | 15 μg/m$^3$ | 20 μg/m$^3$ |
| - PM10 | 10,000 kg/year | 15,000 kg/year | 15 μg/m$^3$ | 20 μg/m$^3$ |
| Water discharge | | | | |
| - BOD | 20,000 kg/year | 25,000 kg/year | 50 mg/m$^3$ | 30 mg/m$^3$ |
| - AOX | 20,000 kg/year | 25,000 kg/year | 50 mg/m$^3$ | 30 mg/m$^3$ |

By applying equation IX.1 the following weights are derived: $NO_x$ and $PM_{10}$ = 0.5, and BOD and AOX = 0.25. In the next step equation IX.2 is applied in which the project emission levels are combined with these weights and subsequently aggregated by project, the following environmental indicators are calculated for respectively Project A and Project B: EI(A) = 40 and EI(B) = 35. Thus project B should be preferred to project A.

The above example indicates the relative ease with which environmental indicators can be calculated. As long as the necessary data are available – the environmental details of the project and the relating legal standards – the calculation is relatively simple. Yet, several disadvantages of the distance-to-target approach can be highlighted. The emission standards are unlikely to be solely scientifically based. They are generally governed by technical limitations, the feasibility of supervision and control and other institutional and political factors (Powell ,1995). Other disadvantages are that various relevant environmental impacts, such as exhaustion of natural resources and climate change, are often excluded from the analysis, and that it is often complicated to choose the spatial scale of the target (local, national or global).

## Abatement and control cost methods

In the 'control costs' method the (monetary) value of a pollutant is based upon the costs associated with the prevention of its emission. These costs are based upon engineering data and are therefore relatively concrete. The level of the control costs necessary to meet the related environmental standard is usually taken as the value of a certain emission. In that respect, this method is comparable with the distance-to-target approach. This similarity also results in the same critique. The argument can be raised that abatement costs do not necessarily represent the collective willingness-to-pay (WTP) of the society to avoid damage. In other words, damage costs are conceptually different to control costs: the former are a measure of society's loss of well-being while the latter represent what it costs society to prevent a certain damage to occur.

The control costs method basically *internalises* the *external costs*. Loosely speaking, *external* costs are those costs which an individual or firm undertaking some activity imposes on another party through this activity without having to pay for them. For example, an electricity plant emitting $SO_2$ causes damage to agricultural crops thereby imposing a cost on the farmers in the form of lost revenue. *Internal* costs are simply the costs related to an activity borne by the individual or firm undertaking the activity themselves. Thus if, for example, a firm decides to abate a certain amount of air emissions by installing a scrubber, the level of this investment – the control costs – will become part of internal costs. The disadvantage of this approach is that it is not clear whether the control costs are representative of the actual damage it would have done without the abatement investment. After all, we attempt to find appropriate weights for pollutants of economic activities, and not for avoided pollutants. Therefore, we need to know the actual or potential damage costs. This concept will be explained in the next section.

## Multi-criteria analysis

In this approach relative weights are attributed to pollutants by a panel of experts, interested parties and/or the general public. To be as much representative as possible, a cross section of interested parties, should be involved in determining the weights. These can include environmental, consumer, and business groups, who reflect the relevant social and scientific opinions (Powell, 1995). Ultimately the revealed values or weights are combined with the factual information resulting from the environmental assessment, leading to the indication of the best available options (see Figure IX.1).

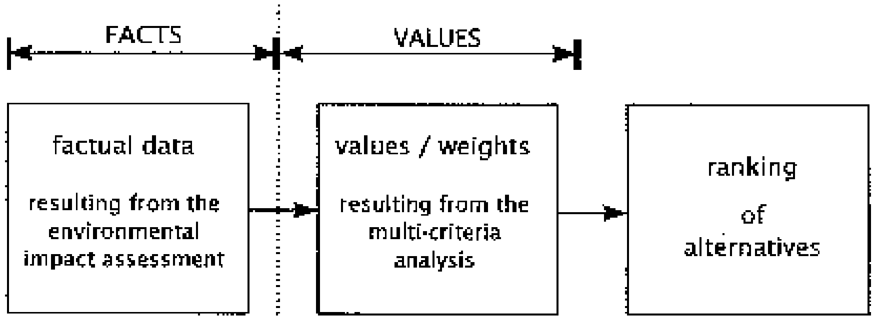



*Figure IX.1 Scheme of conventional decision support system with MCA (based on Beinat 1997).*

MCA has several advantages over other approaches. The fact that standards are not always up to date, is a handicap for, for example the distance-to-target approach. Therefore an alternative method which represents the latest views and know-how is desirable. Scoring approaches are often based on more recent knowledge and ideas. Another advantage of scoring approaches is that they are less costly and time-consuming than several other approaches, such as economic valuation. Finally, multi-criteria analyses allows for the aggregation of varying issues into a single decision. For a better understanding of the standard procedure of the multi-criteria analysis, an example for soil remediation is presented in Box IX.2.

**Box IX.2 Steps in multi-criteria analysis (MCA).**

The total score of the alternatives in an MCA is often computed with the *value functions method*. This method comprises six steps:

1. Selection and quantification of all relevant aspects. The results are organised in the so-called performance table.
2. Selection of two reference or anchor points for each aspect.
3. Assessment of a value function for each aspect.
4. Conversion of the performance table into standardised scores by means of value functions.
5. Assessment of the weight of each aspect.
6. Calculation of the weighted sum of the standardised scores. This results in total score for the alternative considered.

*Source: Beinat et al., 1998*

The approach also has several disadvantages. First, the information for the assessment comes from experience, perception, and extrapolation from similar cases, but may also include expert values. The integration of these aspects into numerical judgements is hardly possible, and often goes beyond the capabilities of the assessor (*Beinat*, 1997). Moreover, experiments have shown that sets of weights derived from multi-criteria analysis, such as depicted in Table IX.2, are rarely repeatable (NOVEM, 1993). This indicates the importance of the composition of the panel and the phrasing of the questions.

*Table IX.2 Evaluation factors for environmental problems*

| Effect score | valuation factor |
|---|---|
| greenhouse effect | 21.0 |
| ozone depletion | 19.7 |
| human toxicity | 11.0 |
| ecotoxicity | 14.6 |
| acidification | 18.7 |

*source: Wit et al. (1993).*

No uniform code exist on the required composition of the group. In Germany the granting of eco-labels is aided by judgements of a group of experts, while in Canada the decisions are made jointly by a government body and the Standards Association (Powell, 1995). Because the selection of the panel is rarely based on the principle of societal representativity it can be concluded that multi-criteria is not a 'democratic' instrument. In addition to the composition of the panel, also complications exist with regard to the timing of the expert judgement. If actual representations are required, the expert panel should gather for each new application. Therefore, there is not a reliable list of weighing factors which can be applied for various projects in time.

## Conclusion on weighing methods

The evaluation of weighing methods does not automatically lead to a single preferred approach. It depends on the objective of the decision maker, which approach should be selected. In Table IX.3 a summary of the evaluation is provided. It shows that in terms of applicability, the distance-to-target approach is the preferred method. In terms of completeness, comprehensiveness (scientific basis) and in terms of representativity of societal preferences, economic valuation should be chosen.

*Table IX.3 Summary of weighing methods*

| Method | Advantages | Disadvantages |
|---|---|---|
| Distance-to-target approach | - good data availability<br>- easy applicability<br>- not costly to apply | - limited scientific basis<br>- not representative for society<br>- not applicable for all environmental issues |
| Control cost approach | - easy applicability<br>- affordable | - focus on avoided instead of actual damage<br>- possibly limited data availability |
| Multi-criteria analysis | - reasonably easy applicable<br>- not cheap but affordable<br>- allows the aggregation of monetary and non-monetary variables | - not representative for overall society<br>- difficult for experts to quantify values<br>- rarely repeatable |
| Economic valuation | - solid scientific basis<br>- representative for society<br>- allows integration of financial / environmental analysis | - politically sensitive<br>- time-consuming<br>- limited data availability |

# Appendix X. Financial and environmental model data

*Table X.4 Units abbreviations*

| abbreviation | |
|---|---|
| t | tonne |
| m.h. | man hour |
| ton km | tonne per kilometre transported |
| MJ | mega joule |
| $m^3$ | cubic metre |

*Table X.5 Input-output technology matrix for collection*

| | FCA | FCI | INFCA | INFCI | WPCA | WPCI | WPCH | MPC |
|---|---|---|---|---|---|---|---|---|
| DWASTEA (t) | -1 | | -1 | | -1 | | | |
| DWASTEI (t) | | -1 | | -1 | | -1 | | |
| DWASTEH (t) | | | | | | | -1 | |
| LABFC (m.h) | 80 | 40 | | | | | | |
| LABINFC (m.h) | | | 100 | 80 | | | | |
| LABWPC (m.h) | | | | | 150 | 110 | 160 | |
| LABMPC (m.h) | | | | | | | | 5.1 |
| RECY (t) | 0.5 | 0.6 | 0.4 | 0.5 | 0.35 | 0.45 | 0.35 | |
| NRECY (t) | | | | | | | | -1 |
| DNRECY (t) | | | | | | | | -1 |
| TRUCK (ton.km) | 8 | 5 | 6 | 4 | | | | 4 |
| TRICYCLE (ton.km) | | | | | 20 | 15 | 10 | |

*Table X.6 Input-output technology matrix for separation (in tonnes)*

| | FHS | INFHS |
|---|---|---|
| RECY (t) | -1 | -1 |
| DHLDPEW (t) | 0.05 | 0.02 |
| DLLDPEW (t) | 0.1 | 0.13 |
| DHHDPEW (t) | 0.06 | 0.03 |
| DLHDPEW (t) | 0.1 | 0.13 |
| DHPPW (t) | 0.08 | 0.05 |
| DLPPW (t) | 0.16 | 0.19 |
| DHPSW (t) | 0.02 | 0.01 |
| DLPSW (t) | 0.05 | 0.06 |
| DHPVCW (t) | 0.15 | 0.1 |
| DLPVCW (t) | 0.2 | 0.25 |
| DHPETW (t) | 0.02 | 0.02 |
| DLPETW (t) | 0.01 | 0.01 |
| LABHS (m.h) | 60 | 90 |

*Table X.7 Raw material prices in different districts*

| | BEIJING | SHANGHAI | DAQING | NANJING | GUANGZHOU | TIANJIN | ZIBO |
|---|---|---|---|---|---|---|---|
| LABPR(yuan/m.h) | 5.8 | 6.4 | 4.2 | 5 | 6.2 | 5.5 | 4.8 |
| NPH(yuan/t) | 1411 | 1411 | 1411 | 1411 | 1411 | 1411 | 1411 |
| H2O(yuan/t) | 0.45 | 0.57 | 0.39 | 0.4 | 0.4 | 0.52 | 0.4 |
| EHV(yuan/MJ) | 0.09 | 0.11 | 0.08 | 0.08 | 0.1 | 0.1 | 0.09 |
| ELECT(yuan/MJ) | 0.1 | 0.12 | 0.08 | 0.1 | 0.13 | 0.11 | 0.1 |
| RS(yuan/t) | 910 | 930 | 890 | 910 | 920 | 920 | 900 |
| O2(yuan/t) | 4373 | 4380 | 4375 | 4368 | 4380 | 4375 | 4375 |
| RFG(yuan/m3) | 2880 | 3180 | 2640 | 2820 | 2880 | 2940 | 2820 |
| NG(yuan/t) | 2775 | 2782 | 2760 | 2775 | 2785 | 2773 | 2770 |

*Table X.8 Prices in other districts*

| | PFINNGBO | PFIGUANGZHOU | PFINANJING | PFIBAODING |
|---|---|---|---|---|
| LABSR(yuan/m.h) | 2.1 | 2.2 | 1.8 | 2.1 |
| LABFP(yuan/m.h) | 2.1 | 2.3 | 1.9 | 2.1 |
| LDPEPR(yuan/t) | 6230 | 6240 | 6210 | 6200 |
| HDPEPR(yuan/t) | 6625 | 6640 | 6610 | 6610 |
| PPPR(yuan/t) | 6340 | 6400 | 6380 | 6340 |
| PSPR(yuan/t) | 7200 | 7200 | 7160 | 7160 |
| PVCPR(yuan/t) | 7050 | 7100 | 7050 | 6900 |
| PETPR(yuan/t) | 11380 | 11400 | 11200 | 11200 |
| DHLDPEW(yuan/t) | 4800 | 5000 | 4700 | 4500 |
| DLLDPEW(yuan/t) | 3600 | 3700 | 3500 | 3500 |
| DHHDPEW(yuan/t) | 4300 | 4500 | 4200 | 4100 |
| DLHDPEW(yuan/t) | 3300 | 3500 | 3100 | 3000 |
| DHPPW(yuan/t) | 3100 | 3200 | 3000 | 2900 |
| DLPPW(yuan/t) | 2500 | 2600 | 2400 | 2200 |
| DHPSW(yuan/t) | 3300 | 3400 | 3200 | 3100 |
| DLPSW(yuan/t) | 2700 | 2800 | 2600 | 2500 |
| DHPVCW(yuan/t) | 2400 | 2500 | 2300 | 2300 |
| DLPVCW(yuan/t) | 2000 | 2100 | 1900 | 1900 |
| DHPETW(yuan/t) | 4600 | 4800 | 4500 | 4400 |
| DLPETW(yuan/t) | 3400 | 3500 | 3200 | 3100 |
| DETERT(yuan/t) | 500 | 500 | 500 | 500 |
| ADDT(yuan/t) | 5000 | 5000 | 5000 | 5000 |

*Table X.9 Labour prices in relevant districts*

| | BEIJING | SHANGHAI | GUANGZHOU | CHONGQING | NANJING |
|---|---|---|---|---|---|
| LABFC(yuan/m.h) | 3.8 | 4 | 4.2 | 2.8 | 3.3 |
| LABINFC(yuan/m.h) | 1.4 | 1.6 | 1.8 | 1.1 | 1.2 |
| LABWPC(yuan/m.h) | 1 | 1.1 | 1.4 | 0.8 | 0.9 |
| LABMCPC(yuan/m.h) | 3.8 | 3.9 | 4.1 | 2.2 | 3.1 |
| LABFS(yuan/m.h) | 3.8 | 4 | 4.2 | 2.8 | 3.3 |
| LABINFS(yuan/m.h) | 1.4 | 1.6 | 1.8 | 1.1 | 1.2 |
| LABW(yuan/m.h) | 1.4 | 1.6 | 1.8 | 1.1 | 1.2 |
| DWASTEA(yuan/t) | 3525 | 3663 | 3720 | 3308 | 3417 |
| DWASTEI(yuan/t) | 3525 | 3663 | 3720 | 3308 | 3417 |
| DWASTEH(yuan/t) | 3525 | 3663 | 3720 | 3308 | 3417 |

*Table X.10 Economic values for environmental externalities (Yuan/tonne)*

| Indicator | GW Global Warming | HT Human Health | AC Acidification | SW Disamenity | EU Eutrophi-cation |
|---|---|---|---|---|---|
| *PPP corr.* | *0.1021* | *0.1021* | *1.0000* | *0.1021* | *1.0000* |
| CO | 14 | 0 | 0 | 0 | 0 |
| Nox | 33 | 5788 | 53 | 0 | 86 |
| dust | 0 | 16808 | 0 | 0 | 0 |
| SO2 | 0 | 7080 | 2378 | 0 | 0 |
| CO2 | 5 | 0 | 0 | 0 | 0 |
| CFCH | 16192 | 0 | 0 | 0 | 0 |
| 12dichlor | 0 | 209167 | 0 | 0 | 0 |
| ch4 | 52 | 0 | 0 | 0 | 0 |
| n2o | 1286 | 0 | 0 | 0 | 0 |
| COD | 0 | 0 | 0 | 0 | 2 |
| Br | 0 | 114855 | 0 | 0 | 0 |
| Hg | 0 | 114855 | 0 | 0 | 0 |
| Phospahte | 0 | 0 | 0 | 0 | 530 |
| Nitrate | 0 | 0 | 0 | 0 | 66 |
| Aorgwas | 0 | 2 | 0 | 8 | 0 |
| orgwas | 0 | 2 | 0 | 8 | 0 |
| toxwas | 0 | 20 | 0 | 8 | 0 |
| inertfwas | 0 | 2 | 0 | 8 | 0 |

*Table X.11 Waste management technology matrix (in tonnes)*

| | DUMP | INC | LDF |
|---|---|---|---|
| LABMCPC | -5 | -10 | -20 |
| DNRECY | -1 | -1 | -1 |
| MERCURY | 5.30E-08 | 0 | 2.70E-08 |
| COD | 5.20E-05 | 0 | 2.60E-05 |
| HC | 2.60E-07 | 0 | 1.30E-07 |
| CL | 4.90E-09 | 0 | 2.50E-09 |
| CU | 3.10E-05 | 0 | 1.55E-05 |
| CO | 8.50E-06 | 0.001 | 4.30E-06 |
| DUST | 3.90E-08 | 9.00E-05 | 2.00E-08 |
| NOX | 3.60E-06 | 0.003 | 1.80E-06 |
| HCL | 6.80E-09 | 1.30E-04 | 3.40E-09 |
| CH4 | 0.004 | 0 | 0.002 |
| CO2 | 0.009 | 0.4 | 0.004 |
| SO2 | 6.10E-06 | 4.00E-05 | 0 |
| Solid waste | 0.9 | 0.2 | 0 |

*Table X.12 Final demand (in tonnes per year)*

| | BEIJING.ARGI | BEIJING.INDUS | BEIJING.HOUSE | SHANGHAI.AGRI | SHANGHAI.INDUS | SHANGHAI.HOUSE | GUANGZHOU.AGRI | GUANGZHOU.INDUS |
|---|---|---|---|---|---|---|---|---|
| HQLDPE(t) | 44038 | 53121 | 71575 | 30566 | 187364 | 72748 | 43638 | 152856 |
| MQLDPE(t) | 6731 | 10080 | 13814 | 4912 | 34881 | 9814 | 5445 | 23627 |
| LQLDPE(t) | 2624 | 4000 | 9814 | 1739 | 16694 | 4907 | 2197 | 12854 |
| HQHDPE(t) | 37846 | 51589 | 33697 | 52045 | 219000 | 33697 | 28239 | 115986 |
| MQHDPE(t) | 6394 | 10689 | 5703 | 6762 | 31097 | 4074 | 3428 | 16262 |
| LQHDPE(t) | 2363 | 4693 | 2738 | 2676 | 118234 | 1695 | 942 | 9190 |
| HQPP(t) | 7071 | 67228 | 197798 | 6327 | 120305 | 186070 | 3917 | 58330 |
| MQPP(t) | 2197 | 18660 | 67204 | 1983 | 33650 | 62215 | 3168 | 18612 |
| LQPP(t) | 578 | 7459 | 47513 | 868 | 14295 | 41085 | 1348 | 9690 |
| HQPS(t) | 2165 | 28691 | 39793 | 1291 | 38028 | 37028 | 1553 | 35305 |
| MQPS(t) | 464 | 11379 | 17589 | 459 | 12123 | 16036 | 691 | 10996 |
| LQPS(t) | 189 | 5445 | 10273 | 223 | 7486 | 9571 | 238 | 5168 |
| HQPVC(t) | 15889 | 88975 | 122872 | 18896 | 402858 | 123983 | 13761 | 217748 |
| MQPVC(t) | 5955 | 29650 | 32267 | 4357 | 81643 | 25626 | 5298 | 116651 |
| LQPVC(t) | 2375 | 22589 | 22170 | 2039 | 59868 | 14615 | 2284 | 54437 |
| HQPET(t) | 0 | 18593 | 22906 | 0 | 22158 | 21621 | 0 | 16350 |
| MQPET(t) | 0 | 1840 | 3489 | 0 | 2262 | 2645 | 0 | 1533 |
| LQPET(t) | 0 | 1035 | 1553 | 0 | 882 | 1610 | 0 | 613 |

*Table X.13 Final demand continued (in tonnes per year)*

| | GUANGZHOU.HUSE | CHONGQING.AGRI | CHONGQING.INDUS | CHONGQING.HOUSE | NANJING.AGRI | NANJING.INDUS | NANJING.HOUSE |
|---|---|---|---|---|---|---|---|
| HQLDPE(t) | 46400.94053 | 55115.78384 | 77281.56647 | 69014.73223 | 24560.49783 | 84161.70592 | 31467.3045 |
| MQLDPE(t) | 14560.29513 | 7562.819962 | 12213.5809 | 9386.856934 | 4864.098593 | 16853.67495 | 5120.103782 |
| LQLDPE(t) | 8320.168646 | 2730.722017 | 8053.496574 | 4640.094053 | 1733.368468 | 9333.52252 | 2186.71099 |
| HQHDPE(t) | 19097.36285 | 14124.22706 | 79876.51253 | 23040.67497 | 38207.76144 | 93075.20187 | 14111.19132 |
| MQHDPE(t) | 5931.262864 | 2652.773611 | 10982.61311 | 3095.988858 | 7019.747368 | 11634.40023 | 2150.897522 |
| LQHDPE(t) | 3193.756927 | 1179.734702 | 6354.924498 | 1140.627474 | 1385.047647 | 76193.91526 | 912.5019791 |
| HQPP(t) | 142945.9948 | 3624.016748 | 60416.26862 | 146351.7551 | 6281.469136 | 69530.27501 | 80491.06689 |
| MQPP(t) | 50558.75119 | 2909.286774 | 16429.19572 | 59552.83644 | 1746.051749 | 18228.01276 | 27366.00337 |
| LQPP(t) | 26406.63428 | 1009.73597 | 10097.3597 | 37175.55235 | 779.487388 | 11056.7288 | 19475.19259 |
| HQPS(t) | 47598.38701 | 1214.418185 | 16440.37228 | 30519.96665 | 1239.940109 | 19736.95404 | 16185.15305 |
| MQPS(t) | 12378.13282 | 693.3455839 | 6444.285641 | 13675.49725 | 563.6091403 | 6189.066408 | 7167.406802 |
| LQPS(t) | 7146.138533 | 274.3606758 | 4019.702925 | 8422.2347 | 165.8925017 | 3530.532728 | 4211.11735 |
| HQPVC(t) | 86086.94708 | 9801.123599 | 228067.4554 | 96653.39771 | 15197.91357 | 174988.3226 | 59226.43706 |
| MQPVC(t) | 20960.08548 | 7872.993238 | 120650.1033 | 24144.83345 | 5070.908784 | 37328.20877 | 12146.48063 |
| LQPVC(t) | 17725.96157 | 2602.111908 | 53449.45237 | 17108.76235 | 2261.417939 | 20984.77345 | 864.0789067 |
| HQPET(t) | 15583.4136 | 0 | 10523.11693 | 21736.27432 | 0 | 10139.76113 | 9296.378347 |
| MQPET(t) | 2415.141591 | 0 | 1015.892892 | 2242.631478 | 0 | 996.7251011 | 1245.906376 |
| LQPET(t) | 1667.597765 | 0 | 440.8591793 | 1169.235215 | 0 | 594.2015026 | 843.3827779 |

*Table X.14 Input-output technology matrix for hand washing waste plastics*

| | HWHLDPE | HWLLDPE | HWHHDPE | HWLHDPE | HWHPP | HWLPP | HWHPS | HWLPS | HWHPVC | HWLPVC | HWHPET | HWLPET |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DHLDPEW(t) | -1 | | | | | | | | | | | |
| DLLDPEW(t) | | -1 | | | | | | | | | | |
| DHHDPEW(t) | | | -1 | | | | | | | | | |
| DLHDPEW(t) | | | | -1 | | | | | | | | |
| DHPPW(t) | | | | | -1 | | | | | | | |
| DLPPW(t) | | | | | | -1 | | | | | | |
| DHPSW(t) | | | | | | | -1 | | | | | |
| DLPSW(t) | | | | | | | | -1 | | | | |
| DHPVCW(t) | | | | | | | | | -1 | | | |
| DLPVCW(t) | | | | | | | | | | -1 | | |
| DHPETW(t) | | | | | | | | | | | -1 | |
| DLPETW(t) | | | | | | | | | | | | -1 |
| H20(t) | 3 | 4 | 3 | 4 | 3 | 4 | 2.5 | 2.6 | 5 | 6 | 4 | 5 |
| DETERT(t) | 0.002 | 0.003 | 0.002 | 0.003 | 0.002 | 0.0024 | 0.0015 | 0.0017 | 0.0016 | 0.0021 | 0.001 | 0.0042 |
| LABW(m.h) | 40 | 50 | 40 | 50 | 30 | 35 | 25 | 30 | 35 | 40 | 50 | 55 |
| ELECT(MJ) | 126 | 136.8 | 129.6 | 151.2 | 144 | 180 | 136.8 | 162 | 162 | 180 | 180 | 216 |
| CHLDPEW(t) | 0.97 | | | | | | | | | | | |
| CLLDPEW(t) | | 0.96 | | | | | | | | | | |
| CHHDPEW(t) | | | 0.975 | | | | | | | | | |
| CLHDPEW(t) | | | | 0.965 | | | | | | | | |
| CHPPW(t) | | | | | 0.965 | | | | | | | |
| CLPPW(t) | | | | | | 0.955 | | | | | | |
| CHPSW(t) | | | | | | | 0.96 | | | | | |
| CLPSW(t) | | | | | | | | 0.95 | | | | |
| CHPVCW(t) | | | | | | | | | 0.955 | | | |
| CLPVCW(t) | | | | | | | | | | 0.945 | | |
| CHPETW(t) | | | | | | | | | | | 0.97 | |
| CLPETW(t) | | | | | | | | | | | | 0.965 |

*Table X.15 Mechanical Recycling & Feedstock Input-Output*

| | MRHLDPE | MRLLDPE | MRHHDPE | MRLHDPE | MRHPP | MRLPP | MRHPS | MRLPS | MRHPVC | MRLPVC | MRHPET | MRLPET |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CHLDPEW(t) | -1 | | | | | | | | | | | |
| CLLDPEW(t) | | -1 | | | | | | | | | | |
| CHHDPEW(t) | | | -1 | | | | | | | | | |
| CLHDPEW(t) | | | | -1 | | | | | | | | |
| CHPPW(t) | | | | | -1 | | | | | | | |
| CLPPW(t) | | | | | | -1 | | | | | | |
| CHPSW(t) | | | | | | | -1 | | | | | |
| CLPSW(t) | | | | | | | | -1 | | | | |
| CHPVCW(t) | | | | | | | | | -1 | | | |
| CLPVCW(t) | | | | | | | | | | -1 | | |
| CHPETW(t) | | | | | | | | | | | -1 | |
| CLPETW(t) | | | | | | | | | | | | -1 |
| LABSR(m.h) | 20 | 40 | 30 | 45 | 20 | 30 | 10 | 20 | 15 | 35 | 20 | 40 |
| ELEC(MJ) | 1440 | 1620 | 1476 | 1656 | 1476 | 1692 | 1512 | 1728 | 1548 | 1764 | 900 | 828 |
| ADDT(t) | 0.0005 | 0.001 | 0.0005 | 0.001 | 0.001 | 0.002 | 0.0015 | 0.003 | 0.0015 | 0.003 | 0.0005 | 0.001 |
| HLDPESR(t) | 0.98 | | | | | | | | | | | |
| LLDPESR(t) | | 0.97 | | | | | | | | | | |
| HHDPESR(t) | | | 0.975 | | | | | | | | | |
| LHDPESR(t) | | | | 0.965 | | | | | | | | |
| HPPSR(t) | | | | | 0.97 | | | | | | | |
| LPPSR(t) | | | | | | 0.96 | | | | | | |
| HPSSR(t) | | | | | | | 0.965 | | | | | |
| LPSSR(t) | | | | | | | | 0.95 | | | | |
| HPVCSR(t) | | | | | | | | | 0.95 | | | |
| LPVCSR(t) | | | | | | | | | | 0.94 | | |
| HPETSR(t) | | | | | | | | | | | 0.97 | |
| LPDTSR(t) | | | | | | | | | | | | 0.96 |

Table X.16 Distances between relevant cities (in km)

| | BEIJING | SHANGHAI | DAQING | NANJING | GUANGZHOU | TIANJIN | ZIBO | CHONGQING | NINGBO | BAODING |
|---|---|---|---|---|---|---|---|---|---|---|
| BEIJING(km) | 0 | 1462 | 1348 | 1157 | 2313 | 137 | 634 | 2552 | 1806 | 175 |
| SHANGHAI(km) | | 0 | 2813 | 305 | 1811 | 1325 | 1108 | 2501 | 344 | 1369 |
| DAQING(km) | | | 0 | 2508 | 3661 | 1488 | 1985 | 4014 | 3157 | 1523 |
| NANJING(km) | | | | 0 | 2116 | 1020 | 803 | 2552 | 649 | 1064 |
| GUANGZHOU(km) | | | | | 0 | 2450 | 3024 | 2040 | 1777 | 2133 |
| TIANJIN(km) | | | | | | 0 | 497 | 2689 | 1669 | 312 |
| ZIBO(km) | | | | | | | 0 | 2663 | 1452 | 401 |
| CHONGQING(km) | | | | | | | | 0 | 2467 | 2372 |
| NINGBO(km) | | | | | | | | | 0 | 1713 |
| BAODING(km) | | | | | | | | | | 0 |

Table X.17 Plastics manufacturing (in tonnes)

| | LLDPEP | MLDPEP | HLDPEP | LHDPEP | MHDPEP | HHDPEP | LPPP | MPPP | HPPP |
|---|---|---|---|---|---|---|---|---|---|
| LDPEPR | -0.311 | -0.517 | -1.035 | -0.311 | -0.517 | -1.035 | -0.311 | -0.517 | -1.035 |
| HLDPESR | -0.207 | -0.518 | | -0.207 | -0.518 | | -0.207 | -0.518 | |
| LLDPESR | -0.517 | | | -0.517 | | | -0.517 | | |
| ELEC | -3.6 | -2.88 | -1.98 | -3.6 | -2.88 | -1.98 | -3.6 | -2.88 | -1.98 |
| LABFP | -12 | -10 | -8 | -12 | -10 | -8 | -12 | -10 | -8 |
| NG | -0.0683 | -0.0683 | -0.0683 | -0.0683 | -0.0683 | -0.0683 | -0.0683 | -0.0683 | -0.0683 |
| HQLDPE | | | 1 | | | 1 | | | 1 |
| MQLDPE | | 1 | | | 1 | | | 1 | |
| LQLDPE | 1 | | | 1 | | | 1 | | |
| CO2 | 0.175 | 0.175 | 0.175 | 0.175 | 0.175 | 0.175 | 0.175 | 0.175 | 0.175 |
| CO | 0.00009 | 0.00009 | 0.00009 | 0.00009 | 0.00009 | 0.00009 | 0.00009 | 0.00009 | 0.00009 |
| NO2 | 0.00013 | 0.00013 | 0.00013 | 0.00013 | 0.00013 | 0.00013 | 0.00013 | 0.00013 | 0.00013 |
| SO2 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 |
| INERTFWAS | 0.035 | 0.035 | 0.035 | 0.035 | 0.035 | 0.035 | 0.035 | 0.035 | 0.035 |

*Table X.18 Plastics manufacturing continued (in tonnes)*

| | LPSP | MPSP | HPSP | HPETP | MPETP | LPETP | HPVCP | MPVCP | LPVCP |
|---|---|---|---|---|---|---|---|---|---|
| LDPEPR | -0.311 | -0.517 | -1.035 | -1.035 | -0.517 | -0.311 | -1.035 | -0.517 | -0.311 |
| HLDPESR | -0.207 | -0.518 | | | -0.518 | -0.027 | | -0.518 | -0.207 |
| LLDPESR | -0.517 | | | | | -0.517 | | | -0.517 |
| ELEC | -3.6 | -2.88 | -1.98 | -3.6 | -2.88 | -1.98 | -1.55 | -2.88 | -1.98 |
| LABFP | -12 | -10 | -8 | -12 | -11 | -9 | -13 | -11 | -10 |
| NG | -0.0683 | -0.0683 | -0.0683 | -0.0683 | -0.0683 | -0.0683 | -0.0683 | -0.0683 | -0.0683 |
| HQLDPE | | | 1 | 1 | | | 1 | | |
| MQLDPE | | 1 | | | 1 | | | 1 | |
| LQLDPE | 1 | | | | | 1 | | | 1 |
| CO2 | 0.175 | 0.175 | 0.175 | 0.175 | 0.175 | 0.175 | 0.175 | 0.175 | 0.175 |
| CO | 0.00009 | 0.00009 | 0.00009 | 0.00009 | 0.00009 | 0.00009 | 0.00009 | 0.00009 | 0.00009 |
| NO2 | 0.00013 | 0.00013 | 0.00013 | 0.00013 | 0.00013 | 0.00013 | 0.00013 | 0.00013 | 0.00013 |
| SO2 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 | 0.0003 |
| DIPHT | | | | | | | 0.00002 | 0.00001 | 0.00002 |
| VOS | | | | | | | 0.002 | 0.002 | 0.002 |
| VCWAS | | | | | | | 5.00E-07 | 5.00E-07 | 5.00E-07 |
| INERTFWAS | 0.035 | 0.035 | 0.035 | 0.035 | 0.035 | 0.035 | 0.035 | 0.035 | 0.035 |

# Appendix XI. Sources of Information

In the model a wide range of technical, environmental and economic data have been used. In the following Section the origin of these data are presented. Where relevant, an explanation of the underlying assumption have been added.

*Table XI.1 Technical Data used in the Model*

| Process | Source / Assumption / Symbol |
|---|---|
| thermal cracking | C.C.M. Steinhage et al.: Milieuinventarisatie verpakkingsmaterialen, CPM TNO, 1990<br>M.E. Reinders: Handbook of emission factors part 2. industrial sources, VROM 1983<br>Data of labor used in thermal cracking are from life interview or telephone interview with factories and expert consulting.<br>assumption 1: The original data on thermal cracking for ethylene, thermal cracking for propylene and thermal cracking for aromates has been aggregated into one process in the model as thermal cracking, because ethylene, propylene, aromates and butadiene are all main outputs from thermal cracking simultaneously and can not be separated into three processes. The distribution ratio is: ethylene 42%, propylene 15%, aromates 19% and butadiene 24% based on various sources.<br>Symbol: TC |
| LDPE production | Van den Bergh en Jurgens, Rotterdam, Holland, 1990<br>Data of labor used are from life interview or telephone interview with factories and expert consulting.<br>Symbol: LDPEP |
| HDPE production | C.C.M. Steinhage et al.: Milieuinventarisatie verpakkingsmaterialen, CPM TNO, 1990<br>Data of labor used are from life interview or telephone interview with factories and expert consulting.<br>Symbol: HDPEPP |
| PP production | R.G.lim, E.W. Lindeijer: Milieubeoordeling van beglazingssystemen: eindrapportage, IVAM, 1994<br>C.C.M. Steinhage et al.: Milieuinventarisatie verpakkingsmaterialen, CPM TNO, 1990<br>Data of labor used are from life interview or telephone interview with factories and expert consulting.<br>Symbol: PPPP |
| chlorine production diaphragm method | SPIN: Booij, H.; Produktie van chloor; RIVM/LAE; March 1993<br>Data of labor used are from life interview or telephone interview with factories and expert consulting.<br>Symbol: CD |
| Chlorine production membrane method | SPIN: Booij, H.; Produktie van chloor; RIVM/LAE; March 1993<br>Data of labor used are from life interview or telephone interview with factories and expert consulting.<br>Symbol: CM |

| | |
|---|---|
| chlorine production mercury method | SPIN: Booij, H.; Produktie van chloor; RIVM/LAE; March 1993<br>Data of labor used are from life interview or telephone interview with factories and expert consulting.<br>Symbol: CR |
| vinylchloride production | C.C.M. Steinhage et al.: Milieuinventarisatie verpakkingsmaterialen, CPM TNO, 1990<br>Data of labor used are from life interview or telephone interview with factories and expert consulting.<br>Symbol: VCL |
| polyvinylchloride production | C.C.M. Steinhage et al.: Milieuniventarisatie verpakkingsmaterialen, CPM TNO, 1990<br>Data of labor used are from life interview or telephone interview with factories and expert consulting<br>Symbol: PVCPP |
| benzene production | CPM-TNO 1990 & Novem, 1992<br>Data of labor used are from life interview or telephone interview with factories and expert consulting.<br>Symbol: BEZ |
| ethylbenzene production | Van den Bergh en Jurgens, Rotterdam, Holland, August 1990<br>Data of labor used are from life interview or telephone interview with factories and expert consulting.<br>Symbol: ETLBEZ |
| styrene production | Van den Bergh en Jurgens, Rotterdam, Holland, Ausust 1990<br>Data of labor used are from life interview or telephone interview with factories and expert consulting.<br>Symbol: STY |
| polystyrene production | Van den Bergh en Jurgens, Rotterdam, Holland. Ausust 1990<br>Data of labor used are from life interview or telephone interview with factories and expert consulting.<br>Symbol: PSPP |
| ethyleneglycol production | Van den Bergh en Jurgens, Rotterdam, Holland, Ausust 1990<br>Data of labor used are from life interview or telephone interview with factories and expert consulting.<br>Symbol: ETLGLY |
| p–Xylene production | Van den Bergh en Jurgens, Rotterdam, Holland, Ausust 1990<br>Data of labor used are from life interview or telephone interview with factories and expert consulting.<br>Symbol: PX |
| terephtalic acid TT | CPM-TNO 1990 & Novem, 1992<br>Data of labor used are from life interview or telephone interview with factories and expert consulting.<br>Symbol: |
| PET production | Van den Bergh en Jurgens, Rotterdam, Holland, Ausust 1990<br>Data of labor used are from life interview or telephone interview with factories and expert consulting.<br>Symbol: PETPP |

| | |
|---|---|
| production of low quality, medium quality and high quality final products | Kunststofverwerkende industrie, RIVM Bithoven 1993<br>Data of labor used are from life interview or telephone interview with factories and expert consulting.<br>assumption: Based on general experiences, the quality of final products are defined as: 1 high quality plastic products are those produced from feedstock consisting of over 90% of primary resin and less than 10% of high quality secondary resin; 2 medium quality plastic products are those produced from feedstock consisting of greater than 80% of primary resin and less than 20% of high quality secondary resin, and 3 low quality plastic products are those produced from feedstock consisting of less than 30% of primary resin and greater than 70% of low quality secondary resin. The original data can be applied as, for example, 1 to produce one tonne of high quality LDPE products using 1.03570% = 0.72 tonne of low quality LDPE secondary resin and 1.035-0.72 = 0.315 tonne of primary LDPE resin as input; 2 to produce one tonne of medium quality LDPE products using 1.03580%=0.83 tonne of LDPE primary resin and 1.035-0.83=0.205 tonne of LDPE high quality LDPE secondary resin; and 3 to produce one tonne of high quality LDPE product using 1.03590%=0.932 tonne of LDPE primary resin and 1.035-0.932=0.103 tonne of high quality secondary resin, etc.<br>Symbol: LLDPEP, MLDPEP, HLDPEP, LHDPEP, MHDPEP, HHDPEP, LPPP, MPPP, HPPP, LPSP, MPSP, HPSP, LPVCP, MPVCP, HPVCP, LPETP, MPETP, HPETP |
| hand washing of waste plastics | questionnaires from 120-factory field survey in Beijing suburbs, Baoding, Wenan, Xiongxian and Bazhou in Hebei Province, Nan Hai County, Fushan, Shunde, Panyu in Guangdong Province, Ningbo, Yuyao and Hangzhou in Zhejiang Province and Nanjing in Jiangsu Province.<br>assumption: average data of 120 factories<br>Symbol: HWHLDPE, HWLLDPE, HWHHDPE, HWLHDPE, HWHPP, HWLPP, HWHPS, HWLPS, HWHPVC, HWLPVC, HWHPET, HWLPET |
| mechanical recycling of waste plastics | questionares from 120-factory field survey in Beijing suburbs, Baoding, Wenan, Xiongxian and Bazhou in Hebei Province, Nan Hai County, Fushan, Shunde, Panyu in Guangdong Province, Ningbo, Yuyao and Hangzhou in Zhejiang Province and Nanjing in Jiangsu Province.<br>assumption: average data of 120 factories<br>Symbol: MRHLDPE, MRLLDPE, MRHHDPE, MRLHDPE, MRHPP, MRLPP, MRHPS, MRLPS, MRHPVC, MRLPVC, MRHPET, MRLPET |
| feedstock recycling | source: CE 1997 Evaluation of the Texaco-gasification process for treatment of mixed plastic household waste: final report of phase 1&2<br>assumption: 175-200kton capacity<br>maximum of 51% of waste stream can be recovered for feedstock method<br>Symbol: FS |
| waste plastic collection | questionares from 120-factory field survey in Beijing suburbs, Baoding, Wenan, Xiongxian and Bazhou in Hebei Province, Nan Hai County, Fushan, Shunde, Panyu in Guangdong Province, Ningbo, Yuyao and Hangzhou in Zhejiang Province and Nanjing in Jiangsu Province.<br>assumption: average data of 120 factories<br>Symbol: FCA, FCI, INFCA, INFCI, WPCA, WPCI, WPCH, MCPC |

| | |
|---|---|
| hand separation | questionares from 120-factory field survey in Beijing suburbs, Baoding, Wenan, Xiongxian and Bazhou in Hebei Province, Nan Hai County, Fushan, Shunde, Panyu in Guangdong Province, Ningbo, Yuyao and Hangzhou in Zhejiang Province and Nanjing in Jiangsu Province.<br>assumption: average data of 120 factories<br>Symbol: FHS, INFHS |
| dumping plastics | to be added<br>assumption:<br>Symbol: DUMP |
| incineration of waste plastics | to be added<br>Symbol: INC |
| landfill plastics | to be added<br>Symbol: LAND |
| Transport by truck and ship | to be added<br>assumption:<br>Symbol: |

*Table XI.2 Economic Data used in the Model*

| Process | Source / Assumption |
|---|---|
| raw commodity prices | China Price Year Book 1994, 1995 & 1996<br>assumption: average price of the year 1994, 1995 and 1996 when available to avoid the impact of price fluctuation on result |
| import prices | China Customs Statistics 1994, 1995 & 1996<br>assumption: import price is C.I.F. price and average price of the year 1994, 1995 and 1996 when available to avoid the impact of price fluctuation on result |
| export prices | China Customs Statistics 1994, 1995 & 1996<br>assumption: export price is FOB price and average price of the year 1994, 1995 and 1996 |
| dump, incineration and landfill cost | Beijing Environmental Sanitation Design Research Institute & expert consulting |
| eco-cost | Beukering, van Pieter, Frans Oosterhuis, and Frank Spaninks (1998) Economic valuation in Life Cycle Assessment: Applied to recycling and solid waste management. Institute for Environmental Studies (IVM). Amsterdam W98/02. |
| fixed demand | China Light Industry Annual Report 1994, 1995 &1996; China Statistical Yearbook 1994, 1995 & 1996<br>assumption: based on real average data in 1994, 1995 & 1996 in each demand center then be blown up to national level of 1994, since most data in the model are in 1994. |
| waste ratio | China Agriculture Statistical Information 1994, 1995 & 1996<br>assumption: average data in 1994, 1995 & 1996 |

*Table XI.3 Capacity of the processes in the plastic cycle*

| Capacity | Source | Assumption |
|---|---|---|
| TCM, CDM, CMM, CRM, VCLM, BEZM, ETLBEZM, STYM, ETLGLYM, PXM, TTM, LDPEPRM, HDPEPRM, PPPRM, PSPRM, PVCPRM, PETPRM, LDPEM, HDPEM, PPM, PSM, PVCM, PETM, FCAM, FCIM, INFCAM, INFCIM, WPCAM, WPAIM, WPCHM, MCPCM, FHSM, INFHSM, HWLDPEM, HWHDPEM, HWPPM, HWPSM, HWPVCM, HWPETM, MRLDPEM, MRHDPEM, MRPPM, MRPSM, MRPVCM, MRPETM, FSM, LDFM, INCM | China Chemical Information Centre; China Chemical Products and Manufacturers Database; State and Prediction of China One Hundred Main Chemical Products 1995; Ethylene Industry 1996, China Light Industry Annual Report 1994, 1995 & 1996; China Statistical Yearbook 1994, 1995 & 1996; Beijing Environmental Sanitation Design Research Institute & expert consulting | real data in production centres then blown up to national level of 1995 and 1996 |

# Appendix XII. Spatial impact of environmental integration

In this Section, the spatial dimension of the environmental integration scenarios is discussed in detail. The transportation logistics are depicted in three figures. The shipments patterns which are indicated by dotted lines indicate shipment within the centres. There are a number of centres which are a combination of primary resin production, secondary resin and final product manufacturing centres and finally demand centres. An overview of the various activity centres is given below and their respective locations in China are shown in figure three.

The figures given below are for the sustainable strategy under the original technology matrix. Three sets of results are shown. The first set shown in Figure XII.1, describes the transportation of primary resin from the production centres to the final product manufacturing centres.

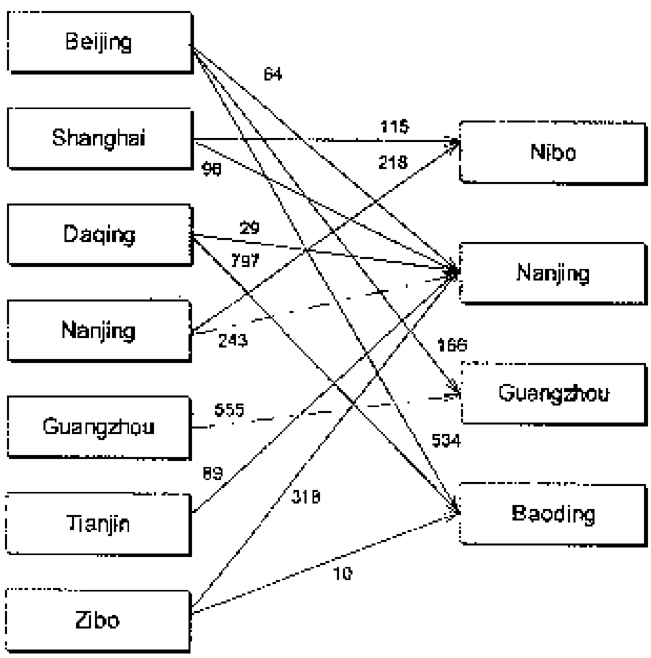



*Figure XII.1 Material flows of primary resin within China*

Two interesting observations are noted. The first is the supply link between Beijing and Guangzhou and the second is the link between Daqing and Nanjing. The distance between the centres in these two links are significant and one would have expected production centres located strategically closer to supply the primary resin to the two final goods production centres. The reason was traced to a combination of transport logistics and capacity constraints. Taking into consideration distances between centres, it would seem logical for Guangzhou to get supplies from Shanghai or Nanjin, which are both nearer. However, capacity constraints in these two centres plus the lower transport cost to the demand centres of Ninbo and Nanjin make it cost effective to let Beijing supply Guangzhou. A policy option to reduce this dependence is to increase the capacity in Guangzhou itself or as the next alternative Shanghai or Nanjin.. The same dynamics prevail for the Daqing-Nanjing link.

Figure XII.2 below describes the shipments patterns of final products from the manufacturing centres to the final demand centres. No real surprises were observed in the shipment patterns although at first observation it would seem odd to see Chongqing being supplied by Baoding. However, on closer scrutiny of the results, the closest supply centre, Guangzhou is already operating at capacity and no other alternative is possible except Baoding, the next closest centre. A policy option would be to increase the capacity in Guangzhou but a word of caution should be mentioned here. As the demand by Chongqing is relatively large, the increase in capacity in Guangzhou must be substantial. Therefore, the decision to invest in Guangzhou must be made in the context of the transportation costs plus the possibility of future expansion in demand. This in turn would require the model to be extended from the present static model to a inter-temporal model.

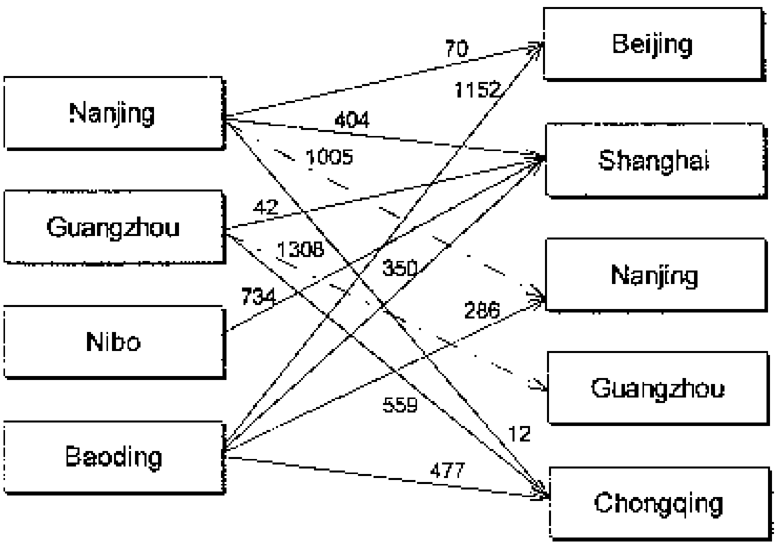



*Figure XII.2 Material flows of final products within China*

The last transportation link shown in Figure XII.1 is the supply of the separated waste plastic to the recycling centres. The shipment patterns were determined solely by transport costs, with the nearest being supplied first followed by the next and so on. But what is interesting is the quantity of waste which is supplied to the recycling centres.

We implicitly assumed that all recyclable waste is recycled. Mapping the quantity of waste shipped to Guangzhou plus its own waste to the capacity available for mechanical recycling, we computed an excess of approximately 80.000 tons of different types of recyclable waste plastics. Therefore, it seems that there is an acute shortage of recycling capacity which goes to support our earlier findings. This is in essence the reason for substituting secondary resin with primary resin for a number of plastic products.

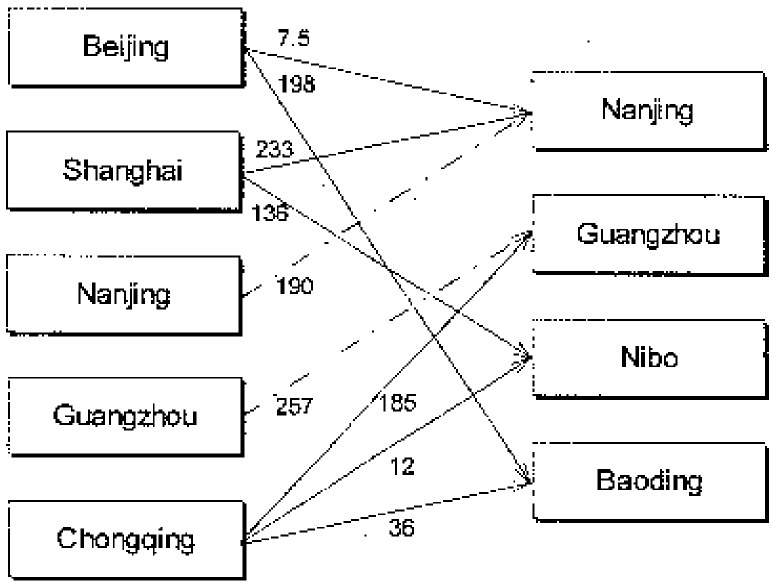



*Figure XII.1 Material flows of recyclable waste plastics within China*

# Appendix XIII. Final Workshop at CAITEC

On the 20th of January 1998 a seminar was organised at the Chinese Academy of International Trade and Economic Co-operation (CAITEC) in Beijing. The tentative results of the study in the last year on economic and environmental issues related to the plastic recycling industry in China were presented. The main purpose of the workshop was to receive feedback from the most important stakeholders in the plastic cycle in China. Based on these comments, additional analysis can be performed before the final report is completed.

The issue of the rapidly increasing demand for plastic products in China was addressed. It was concluded that China has neither the productive capacity to keep pace with demand, nor the management systems to adequately deal with the increasing burden of plastic waste. These problems highlight the potential role for plastics recovery in waste management and recycling in the industry. The agenda of the workshop is presented below.

## Agenda

| | | |
|---|---|---|
| 9:00 | Opening of the Workshop | Shi Yonghai (CAITEC) |
| 9:10 | CREED programme | Anantha Duraiappah (IVM) |
| 9:20 | Overview of project & purpose of the workshop | Pieter van Beukering (IVM) |
| 9:30 | Questions & Comments | Participants |
| 9:45 | International Trade of Waste Plastics | Li Yongjiang (CAITEC) |
| 10:15 | Questions & Comments | Participants |
| 10:45 | Recycling Industry (the survey) | Zhao Yumin (CAITEC) |
| 11:15 | Questions & Comments | Participants |
| 11:30 | Lunch | |
| 13:00 | Environmental problems in the Plastic Cycle | Zhou Xin (IRI) |
| 13:30 | Questions & Comments | Participants |
| 13:45 | The model & results | Anantha Duraiappah (IVM) |
| 14:15 | Questions & Comments | Participants |
| 14:30 | Tea break | |
| 14:45 | More elaborate discussion on prime issues | Participants |
| 16:45 | Summary of main conclusions | Li Yongjiang (CAITEC) |

The ultimate goal of the discussion is to retrieve a list of recommendations to be included in the final report. The general discussion of the workshop which was the final part during the day, was facilitated by a list of statements. The statements were structured into different categories, in synchrony with the earlier presentations (international trade, the recycling industry, waste management). Challenging and provocative statements were formulated. These statements do not represent the outcome of the project, but were simply meant to provoke the participants.

## Statements on international trade

1. Imported waste plastics create extensive competition to the domestic market of waste plastics and should therefore be banned.

*Reply of Participants*: We must be very careful to make conclusions on international trade because it will have significant impact on domestic recycling industry on the long term. Most of the participants suggested government let it develop naturally, neither encourage nor discourage. If there exists market demand for imported waste plastics, i.e., domestic waste cannot meet with the demand in terms of quantity or quality, import should be permitted.

2. The monitoring of the current trade measures on import of waste plastics (only allowing grade A and B) is too difficult, thereby creating high risks of allowing unrecyclable waste plastics in the country. It is therefore safer to ban this type of trade completely.

*Reply of Participants*: According to an official from NEPA, there are a series of laws and regulations on the import of waste plastics, from import permission, inspection to customs procedure. Furthermore, the criterion is very strict and easy to put to use. The imported waste can be judged whether it is in accordance with the relevant regulations and criteria without chemical inspection method. Therefore, it is not so difficult as before to monitor the trade measures on import of waste plastics. From this point, it is unnecessary to ban international trade of waste plastics.

3. Given the shortage on the local market of high quality waste plastics, the possibility to import grade A and B waste plastics is the only way to expand the recycling industry of waste plastics. Therefore import of high quality waste plastics should be encouraged.

*Reply of Participants*: There are arguments among participants. Some participants thought imported waste plastics is beneficial to the recycling industry. For instance, according to Mr. Liao Zhengpin, deputy director of Plastics Industry Office of China National Council of Light Industry, the gap between supply and demand of plastics is more than 1 million tonnes in 1997, while recovered domestic waste plastics is less than 1 million tonnes. Therefore, import of recyclable waste plastics is one way to meet the gap, besides efforts in increasing recovery rate of domestic waste. But some others argued that the resource of domestic waste is rather abundant, thanks to rapid growth of plastics consumption, and there is no shortage of high quality waste plastics. The import of waste plastics was a profitable business in the early 90s when the supply of plastics was insufficient. But it is different in recent years. The key problem now is lack of adaptable recycling technology, instead of lack of raw material (waste plastics). However, as mentioned in [comment1], either encouragement or discouragement is not necessary, no matter whether the imported waste is of high quality or not.

4. Imports of waste plastics supports the recycling industry but on the longer term has a negative impact on the technological progress since it discourages the creation of domestic solutions to take care of the material scarcity and the waste problems in China.

*Reply of Participants*: The participants do agree with this opinion.

## Statements on the plastic recycling industry

1. The plastic recycling industry is completely driven by commercial incentives. Therefore direct government involvement is not desirable and further privatisation should be aimed for.

*Reply of Participants*: The government should involve in the plastic recycling industry through formulating relevant environmental and economic policies. In order to expand plastic recycling industry, the government assistance is required to establish more collection channels and make the industry well-organized. It is not important if the enterprise is state-owned or private. But no specific measure is put forward at the workshop.

2. The plastic recycling contributes to environmental pollution and should therefore not receive any preferential treatment such as tax reduction.

*Reply of Participants*: No comments.

3. The main problem at present to increase recycling of plastics in China is not the recycling industry itself but the lack of demand for recycled plastic products. Special policies should be designed to encourage this demand such as improvement of the image of the recycled plastic product.

*Reply of Participants*: No comments.

4. Novel technologies such as back-to-feedstock recycling should first find commercial appliance in the OECD countries before being installed in China.

*Reply of Participants*: Quite agree with it! We must be very careful to introduce any kind of new technology. For instance, degradable material is not as environmental sound as it is said. Actually, degradable material can create more severe pollution without adaptable degradation technology.

## Statements on waste management

1. China's overall conditions are so different from OECD countries (in terms of climate, environmental preferences and economics) so that there exists very little potential for technology exchange between China and the OECD countries in the recycling industry to reduce negative impacts?

*Reply of Participants*: The adaptable technology is desirable. It is suggested that OECD countries transform relevant recycling technology simultaneously if they want to export waste plastics to China.

2. The recovery of waste plastics is presently not organised sufficiently. More government involvement is required to increase the quantity and quality of recovered waste plastics in China. Informal recovery should be discouraged.

*Reply of Participants*: All the participants agreed that more government involvement is required to increase the quantity and quality of recovered waste plastics in China. Beijing Kaifa Environmental Protection Technique Centre is a good example to introduce governmental assistance and the initiative is quite successful in terms of establishing a formal collection system to force producers pay for the cost of recovery. Nevertheless, it doesn't indicate that informal recovery should be discouraged. As mentioned above in [comment5], diversified collection channels (formal or informal, state-owned or private) will be helpful to increase recovery rate.

3. Although landfilling is at present the cheapest way to manage waste plastics, it is ultimately not the preferable approach as it does not utilise the material or energy value of plastics.

*Reply of Participants*: Although the cost of landfilling is approximately RMB30 Yuan per ton, the total cost (including operating cost, transportation cost) is up to more than RMB 70 Yuan per ton, according to an expert attending the workshop. It is not the preferable approach in terms of economic and environmental protection. Landfilling, as well as incineration, is to be used only when there is no other means to deal with the waste.

4. The solution to the waste problem of plastic lies not in the increase of recycling but in the prevention of waste plastics. Therefore more attention should be paid to the reduction of the demand for packaging materials, design for recycling and the extension of the lifetime of plastic products.

*Reply of Participants*: It is very important to raise public awareness of environmental protection. Again, government involvement is desirable. For example, government should expand investment in establishing sorting collection system and publicising the recycling market.

A programme of Collaborative Research in the Economics of Environment and Development (CREED) was established in 1993 as a joint initiative of the International Institute for Environment and Development (IIED), London, and the Institute for Environmental Studies (IVM), Vrije Universiteit, Amsterdam.

The ultimate goal of CREED is to enrich the knowledge base and widen the debate on sustainable development by strengthening research capacity in environmental economics and policy analysis in developing countries. This is achieved primarily through collaboration on research projects, information exchange and dissemination involving initially IIED, IVM and counterparts in developing countries.