CHAPTER II
BACKGROUND AND LITERATURE REVIEW

2.1 Background of PVC

2.1.1 Definition and Manufacturing Process

PVC is a polymer that has an amorphous structure with polar chloride atoms in the molecular structure. PVC has completely different features in term of performance and function compared with olefin plastics, which have only carbon and hydrogen atoms in their molecular structures.

PVC (Polyvinyl-chloride) is a plastic produced by suspension, or emulsion polymerization, of vinyl chloride monomer as shown in Figure 2.1. The process for producing PVC starts from the reaction of chloride production when salt water is decomposed by electrolysis with ethylene, which is obtained from oil or gas via "cracking" process. After several processes, this leads to the production of another gas: vinyl chloride monomer (VCM) which is polymerized to form a fine white powder called PVC. On its own PVC is a hard, brittle and essentially unusable material unless compound with a number of additive. This is the reason why PVC powder is mixed with additives (stabilizer and/or plasticizer) to achieve the precise properties required for specific applications. The resulting PVC granules (compounds) or ready to use powder (premixes) are then converted into the final product. By adding other materials to PVC, it is possible to change the strength, rigidity, color and transparency of the final product.

PVC resin has a high chemical stability due to chlorine atoms within their structure, providing fire retarding properties, durability, and oil/chemical resistance (Lopez *et al.*, 2009).

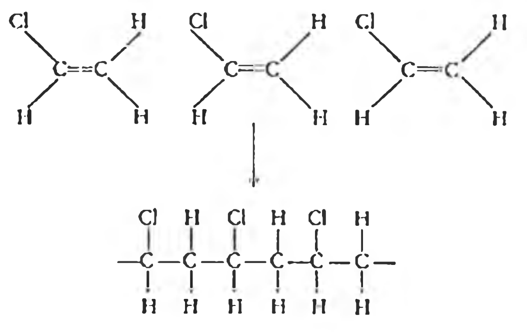


Figure 2.1 Polymerization of vinyl chloride monomer (VCM) (Lopez *et al.*, 2009).

2.1.2 PVC Application

Pure PVC is a rigid material, which is mechanically tough, fairly good weather resistant, water and chemical resistant, electrically insulating, but relatively unstable to heat and light. Heat and ultraviolet light lead to a loss of chlorine in the form of hydrogen chloride (HCl). This can be avoided through the addition of stabilizers. Stabilizers are often composed of salts of metals like lead, barium, calcium or cadmium, or organotin compounds.

The mechanical properties of PVC can be modified through the addition of low molecular weight compounds called plasticizer that are mix with the polymer matrix. The main types of plasticizers used are esters of organic acids, mainly phthalates and adipates (Lopez *et al.*, 2009).

2.1.2.1 The General Information About Hard and Soft PVC

Hard and soft PVCs are used in manufacturing different products based on their physical properties and characteristics. PVC is the abbreviated version of polyvinyl chloride. A kind of thermoplastic polymer, PVC is largely used in the construction sector because of its durability, cost-effectiveness and malleability. Its utility also makes it useful in the health care sector, food packaging, car spare parts, rain gear and toy manufacturing. A PVC product should generally not be exposed to a temperature of more than 158 degrees Fahrenheit.

1) Compounds

Rigid PVC does not typically contain any plasticized element, whereas soft PVC has a high plasticizer concentration. Plasticizers come in two different types, primary plasticizers and polymeric plasticizers. Primary plasticizers include phtalates, phosphates and fatty acid compounds. Adipates, azelates of propylene glycol and sebacates are a few of the polymeric plasticizers. To make PVC more flexible, plasticizers like phthalates, adipates and phosphates are used in greater quantity. The compositions in PVC product both rigid and soft PVC products are shown in Table 2.1.

2) Physical

Hard or rigid PVC is dense and more resistant to gas and air pressure than the flexible or soft PVC. The density of hard PVC can be measured from 1.3 to 1.45 g/cm^3 compared to the density of soft PVC, which is 1.1 to 1.35 g/cm^3. Due to higher level of density, a product made up of hard PVC lasts longer than the one composed of soft PVC.

3) Qualities

Hard PVC is in more demand in the manufacturing sector than the soft PVC because of its stronger thermal, mechanical and chemical resistivity. Soft PVC generally has less utility because it cannot be preserved for a long time due to the excessive application of softeners. However, hard PVC can be preserved for a longer period of time, making it useful for many products.

4) Utilities/Uses

PVC raw materials are used in the construction sector. Hard PVC is used to make window frames, pipes and borders because it can tolerate bad weather conditions. Soft PVC is used in floors, tubes, edge protection frames and insulation because of its flexibility and resistance to oil, grease and chemicals.

5) Benefits

Hard PVC can be recycled and is less hazardous to dispose of than soft PVC because it doesn't contain additional plasticizer concentrations. Soft PVC contains a higher concentration of plasticizer, making it more of a health hazard and difficult to recycle (http://www.ehow.com).

Table 2.1 The compositions in PVC products both rigid and soft PVC products (Ramungul *et al.*, 2012)

Type	Application	PVC Resin	Plasticizer	Filler	Other Additives
Rigid	Rigid Packaging	100	0	0	5 ~ 20
	Pipe – pressure	100	0	2 ~ 5	4
	Pipe – non-pressure	100	0	0 ~ 20	3 ~ 5
	Doors & Windows	100	0	5 ~ 10	7 ~ 6
	Other profiles	100	0	0 ~ 40	5 ~ 15
Soft	Flexible Packaging	100	20 ~ 40	0	1 ~ 20
	Flooring	100	25 ~ 50	0 ~ 300	2 ~ 5
	Cables	100	30 ~ 60	0 ~ 50	3 ~ 10
	Sheets	100	40 ~ 70	0 ~ 30	2 ~ 10
	Coated Fabrics[b)]	100	40 ~ 90	0 ~ 30	7 ~ 20

2.1.2.2 Examples of PVC Products

1) Packaging applications like highly plasticized films for hand-wrapping, sterilized packaging for medical and pharmaceutical product (e.g. blister pack for pills and tablets), thermoformed packaging shell, or labels

2) Leisure product, including garden hoses, footwear, inflatable pools, tent

3) Building product, like window frames, floor and wall covering, roofing sheet, lining for tunnels, swimming pool and reservoirs. PVC is the most widely used polymer in building and construction applications and over 60% of Western Europe's annual PVC production is used in this sector

4) Piping, including water and sewerage pipe and fittings, and ducts for power and telecommunications

5) Medical products like blood bags, transfusion tube and surgical gloves

6) Coating, including tarpaulins, rainwear, and corrugated metal sheets

7) Insulation and sheathing for low voltage power supplies, telecommunications, applications, appliances, and automotive applications (Ramungul *et al.*, 2012).

Moreover, the following Figure 2.2 and Table 2.2 present the main applications of PVC in Europe and the percentage of overall use. The great number of applications is characterized by a wide range of lifetimes ranging from several months to more than 50 years for some construction products. The main applications of PVC in Europe are in the building sector, which accounts for 57% of all uses and where products also have the longest average lifetimes.

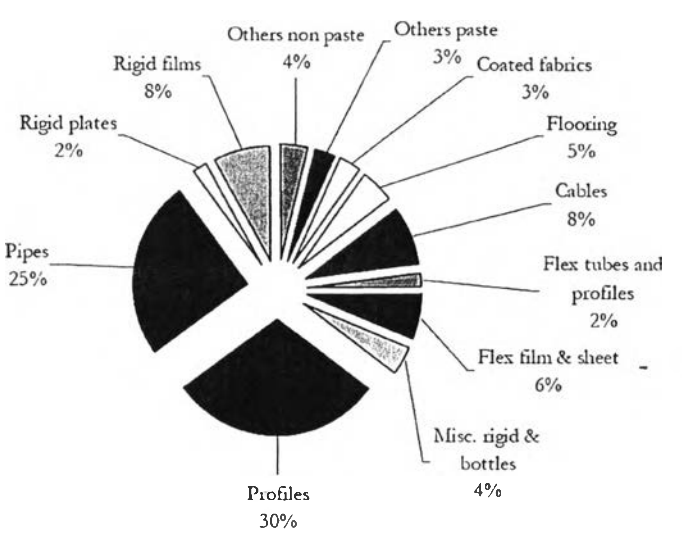


Figure 2.2 PVC application sold in Western Europe and Czech Republic, Hungary, Poland and Slovakia in 2007 (Lopez *et al.*, 2009).

Table 2.2 Main use categories of PVC in Europe (1999) (Lopez *et al.*, 2009)

Use/application	Percentage	Average life-time (years)
Building	57	10 to 50
Packaging	9	1
Furniture	1	17
Other household application	18	11
Electric/Electronic	7	21
Automotive	7	12
Others	1	2-10

2.2 Overview PVC Industry in Thailand

2.2.1 Industry Review for 2009

The summary situations and prices of PVC in 2009 as shown below

1) The average price of PVC in 2009 was $ 775 per ton. It decreased from 2008 by $ 260 per ton. Main causes came from decreased demand due to the economic circumstances, and decreased feedstock costs.

2) The price of the world market's oil drastically decreased. The average price of oil in 2008 as $ 100 per barrel decreased to $ 62 per barrel in 2009. Although the price of PVC varied according to the price of oil, they varied at different rates. In 2009, the price of PVC decreased only 25% while the price of oil decreased by 38%.

3) Situations of PVC in the world market could be divided into two periods. In 2009, the price of oil was still low. (It was lower than $ 60 per barrel.) Producers of Ethylene-based PVC had an advantage over producers of Acetylene-based PVC (which calcium carbide used as a raw material) in terms of production costs. Therefore, during this period Acetylene-based PVC producers in China had to cease production because the selling price was lower than production costs. It caused 10 million tons of PVC supplies per year to disappear immediately. The price had to

increase in order that producers had an incentive to reproduce PVC. In 2009, each nation's government began quantitative easing strategies to stimulate the economy. The price of oil re-increased and this led Acetylene-based PVC producers to have lower production costs than Ethylene-based PVC again. Therefore, the price of PVC in the second period increased a little bit less than prices of other plastics because of low production costs of PVC producers in China that forced the price down.

4) During Q4 2009 most statistics show that the price of PVC decreased because of decrease in the need for PVC in the world market from long holidays such as China's National Day, Ramadan, Christmas Day and New Year's Day; and decreases in the need for PVC in construction in wintertime. However, 2009 was the first year of many years that the price of PVC in December increased because in the northern part of China, it snowed the heaviest in 50 years and China's northern transportation system was paralyzed. Therefore, PVC producers in the north could not shipped PVC to other parts of China and Russia. PVC's raw material calcium carbide-could be shipped neither. Some producers had to reduce production rate. This resulted in a shortage of PVC in China and the higher need for imported PVC. Also, the production costs of Ethylene-based PVC producers increased according to much higher price of Ethylene because of problems of production in the Middle East and the price of Naphtha which was higher than $ 700 per ton (Connect@TPC, 2010).

2.2.2 Industry Review for 2010

During the first quarter of 2010, Thailand PVC's supplies had sharply decreased from a normal situation. Therefore, domestic PVC buyers had encountered shortage problems of purchasing PVC from three main producers. The summary about problems as follows:

1) The Map Ta Phut Industrial Estate Problem:

The Supreme Administrative Court has granted a temporary restraining order for 65 investment projects in Map Ta Phut Industrial Estate.

2) The Unplanned Shutdown of GLOW:

GLOW, the large electricity generating company in Map Ta Phut Industrial Estate, had an emergency shutdown on February 10th, 2010. It consequently caused many factories which were GLOW's customers, including ethylene crackers, to shut down. It resulted in the shutdown of PVC producers whose ethylene was needed as feedstock. This incident decreased the domestic PVC supplies by 10% in February.

3) PTTCH's shutdown for annual maintenance:

The shutdown had affected utilities such as steam needed for producing PVC to be cut. In March TPC cannot operate at full capacity, particularly a PVC grade with a low K value and PVC's special grades, because production lines had been affected by the shortage of utilities.

Obviously, every PVC producer in Thailand had not expected aforementioned troubles before except PTTCH's shutdown for annual maintenance. These problems have led to strain the domestic supplies very much in the first quarter. However, they expected that PVC supplies would be almost regained in the second quarter except the dropped production capacity which was caused by the Map Ta Phut problem (Connect@TPC, 2010).

2.2.3 Industry Review for 2011

Thailand's PVC production dropped 6% as producer reduced operating rate in tandem with Apex Petrochemicals closed out its plant due to the difficulty in business expansion and the PVC over supply. Meanwhile, Thailand's PVC consumption plummet 10% in 2011, from roughly 500,000 tons a year to 460,000 tons a year as Thailand's PVC market was saturated and severe flood halting production of some PVC converters (Asia Petrochemical Industry Conference, 2012).

2.2.4 Industry Outlook for 2012

Based on a TPC securities analysis conducted by Asia Plus Securities Public Company Limited on November 17, 2011, it is predicted that PVC demand will rebound distinctly in Q1/2012 because

1) Q1 was typically a high demand period for PVC, thus helping to boost sales volume.

2) The flood situation since late August 2011 would likely lead to a growing local consumption of PVC as triggered by the post-flood business and property rehabilitation.

Moreover, according to the Ministry of Industry's industrial economics report 2011 and outlook for 2012, petrochemical industry was expected to continue to grow healthily amid the post-flood rehabilitation, with the government measures to start to be concretely implemented from early 2012 to restore the manufacturing sector's confidence. Meanwhile, the private and household sectors would spend more on their post-flood business rehabilitation and house renovation, thereby helping to increase demand for the products. Another contributing factor was the government's local spending stimulation policy (Advisory Plus Company Limited, 2012).

The summary of capacity, production and consumption of PVC in Thailand from 2008 to 2012 are shown in Table 2.3 and Figure 2.3 (Asia Petrochemical Industry Conference, 2012).

Table 2.3 The capacity, production and consumption of PVC in Thailand from 2008 to 2012 (kton/year)

	Historical				**Estimated**
	2008	**2009**	**2010**	**2011**	**2012**
Total Capacity	1,035	896	945	846	846
Production	832	825	833	779	761
Consumption	446	458	512	462	468
Export	424	424	382	387	
Import	37	56	61	70	

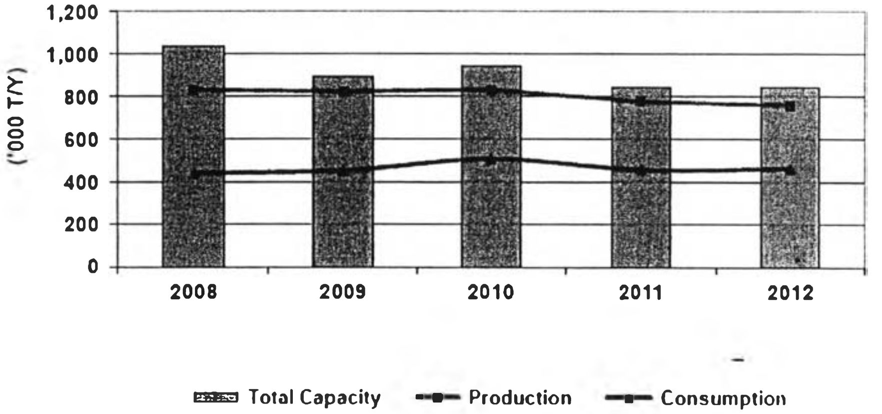


Figure 2.3 Bar chart of capacity, production and consumption of PVC in Thailand from 2008 to 2012.

2.2.5 Thailand is a Member of ASEAN Vinyl Council (AVC)

ASEAN Vinyl Council (AVC) was established on 17th November 2010. Members of the vinyl industry from ASEAN countries including Thailand, Indonesia, Malaysia, the Philippines and Vietnam as shown in Figure 2.4 committed to responsible and sustainable development of the industry across the regional by signing a charter to establish the ASEAN Vinyl Council (AVC) advisory body.

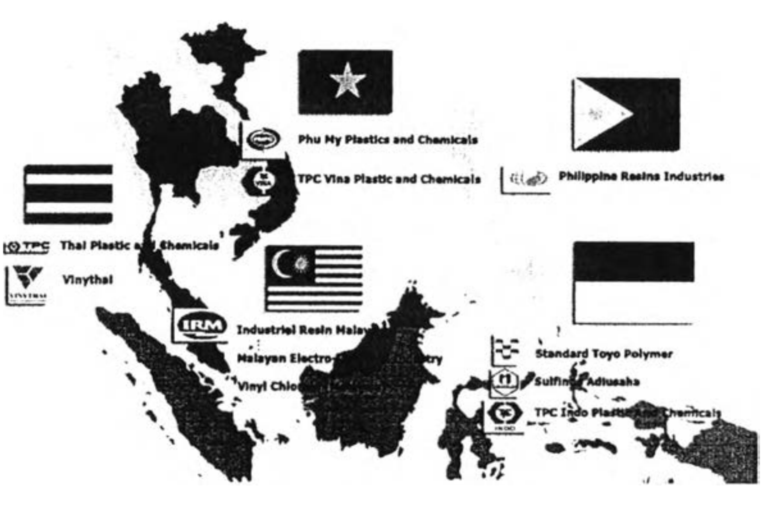


Figure 2.4 All members of ASEAN Vinyl Council (AVC) (http://www.aseanvinyl.org).

The newly established AVC, which aims to promote responsible and sustainable development across the region, will ensure participating members' comply with governing and applicable standards and industry best practices. Environmental impacts are a key focus and will be controlled in line with targets aligned with best international standards and in conjunction with timeframes set at the AVC General-Meeting.

The advisory body will also encourage future improvements, work with associated industry groups for a better understanding of environmental issues, share knowledge and best practices of innovative environmental control technologies and enhance communications with stakeholders and the general public (http://www.aseanvinyl.org).

2.2.6 Thailand PVC Market

PVC demand in 2005 was 1.3 million MT and it was is expected to grow 7.0 percent from 2005 to 2010.Thailand is the largest consumer of PVC in South East Asia which has PVC supply in 2005 around 1.7 million MT and had a market segmentation 42% among the countries in South-East Asia as shown in Figure 2.5. In that time, TPC group is the largest PVC producer time, and Singapore, Myanmar, Cambodia, Laos have no PVC plant, mostly import from countries in the region (Choonhajutha, 2010).

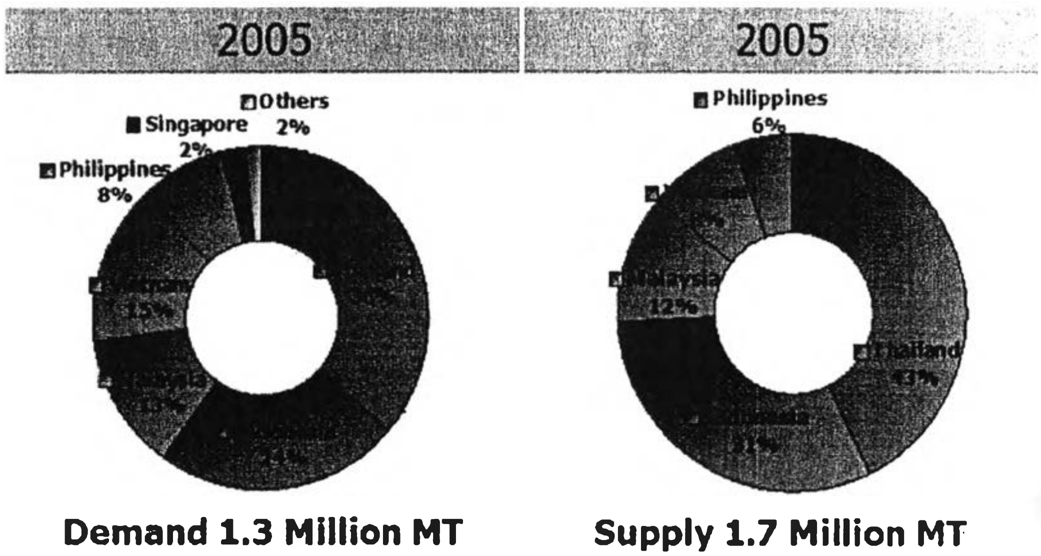


Figure 2.5 PVC Market Segmentation in South-East Asia (Choonhajutha, 2010).

2.2.7 PVC Producers in Thailand

Thailand is a net exporter of PVC and will continue in this position over next five years. There are three major PVC resin producers with total capacity of 760,000 MTPA (Table 2.4). And there are many PVC manufacturers in Thailand (Table 2.5).

Table 2.4 Three major PVC resin producers in Thailand and their capacity (Choonhajutha, 2010)

Company	Capacity (MT) per year
Thai Plastic and Chemaical (TPC)	470,000
Vinylthai (VNT)	190,000
Apex Petrochemical (APC)	100,000

Table 2.5 Examples of PVC products manufacturers in Thailand and their products (Choonhajutha, 2010)

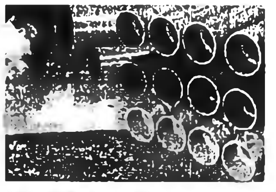
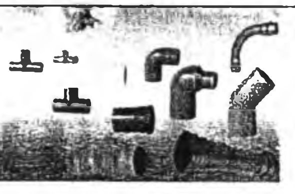
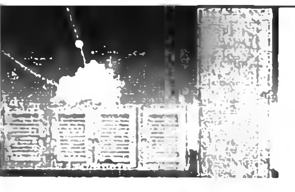
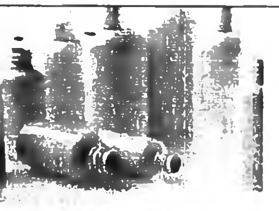
Company	Location	Product
1. Nawaplastic Industries Co., Ltd.	Bangkok	Pipe and fitting
2. Thai Pipe Industry Co., Ltd.	Bangkok	Pipe and fitting
3. Bangkok Paiboon Pipe Co., Ltd.	Bangkok	Pipe and fitting
4. Advanced Pipe Co., Ltd.	Bangkok	Pipe and fitting
5. Untited Enterprise Co., Ltd.	Bangkok	Pipe
6. Thai Vinytech (2002) Co., Ltd.	Bangkok	Pipe
7. S.K.J. Industries Co., Ltd.	Bangkok	Floor covering Table cloth Transparent sheet Artificial leather
8. Decorative Plastic Co., Ltd.	Bangkok	Artificial leather Flexible film and sheet Floor covering
9. Siam World Group Co., Ltd.	Bangkok	Pipe and fitting
10. P & ONE Plastec Co., Ltd.	Bangkok	Air condition PVC duct

2.2.8 Types of PVC Product in Thailand

2.2.8.1 Hard or Rigid PVC Products

The hard PVC products mostly play important role in construction section in Thailand for example pipe, fitting, and profile because of their properties. However, some rigid PVC products such as rigid bottle and rigid sheet still play important role in plastic market as well. The examples of PVC hard producst in Thailand are shown in Table 2.6.

Table 2.6 Examples of hard PVC products in Thailand

Products	Pictures
Pipes	
Fitting	
Profile	
Rigid bottle	
Rigid sheet	

2.2.8.2 Soft PVC Products

There are wide ranges of soft PVC products in Thailand, and they have many useful applications including PVC household product and PVC construction products which are useful in human daily life. The examples of soft PVC products in Thailand are shown in Table 2.7.

Table 2.7 Examples of soft PVC products in Thailand

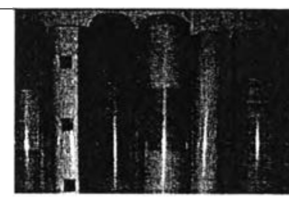
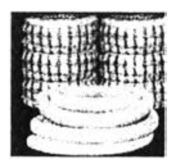
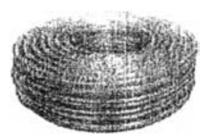
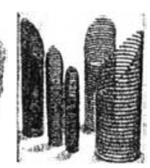
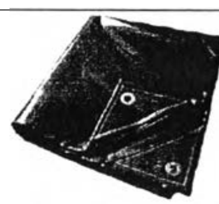
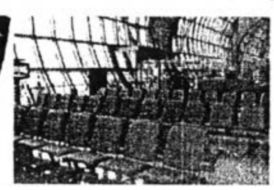
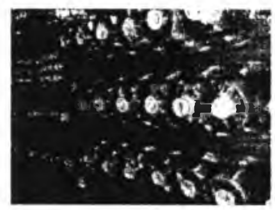
Products	Pictures
PVC Sheets/Flooring	
Hoses	  
Medical devices	
Tarpaulin and artificial leather	 
Boots and foot wears	
Floor tiles	

Table 2.7 (cont.) Examples of soft PVC products in Thailand

Products	Pictures
Wire and cables	
Film and labels	
Other short-life products (Stationery, toys, Christmas tree, etc.)	

2.2.8.3 Service Life of PVC Products

Service life of PVC products depends on type of products. In the present day, there are many articles that mention about PVC service life or life expectancy of PVC in wide range, but do not have the exact service life for PVC product. The lifetimes of PVC product in Thailand was estimated by Ramungul *et al.* (2012) and are shown in Table 2.8. Moreover, lifetimes of PVC product can be classified by period of using time which are shot life, medium life, and long life as shown in Figure 2.6.

Table 2.8 Lifetimes of PVC products in Thailand by Ramungul *et al.* (2012)

PVC application	Lifetimes	
Calendering (Rigid+Flexible)	S	0-2 years
Shoes, boots, foot wear	S	
Film	S	
Medical device	S	
Hoses	S	
Bottle	S	
Others	S	
Flooring (floor covering+floortile)	M	2-10 years
Artificial leather	M	
Pipe	L	>10 years
Fitting	L	
Cable	L	
Profile	L	
Auto	L	

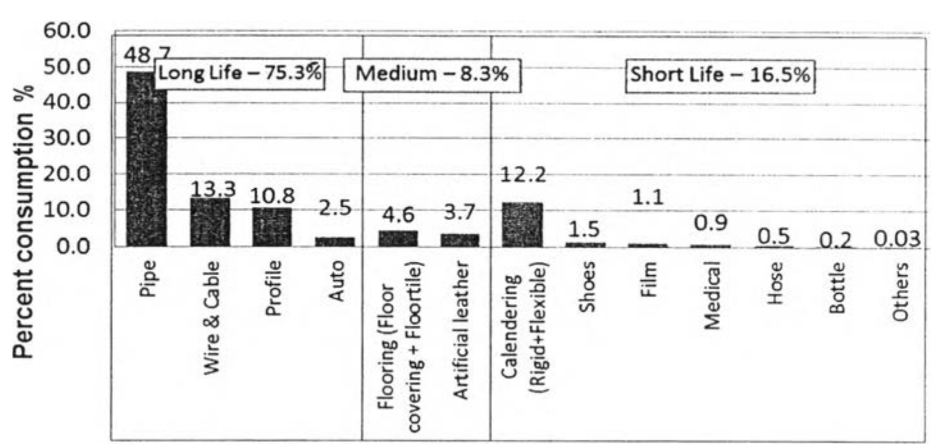


Figure 2.6 Consumption of PVC Grouped by application & products' life (Ramanukul *et al.*, 2012).

2.3 PVC Waste Management

PVC is almost too good as it is durable and degraded very slowly. On the other hand, this same property is what makes PVC a dangerous material. Due to the quantity and different additives added to PVC (PVC products may consist up to 60% of additives) and also due to its chlorine contain, so the final disposal or recycling of PVC is very important.

2.3.1 Landfill

Landfill is the most common -waste management route for PVC waste. All materials in landfill including PVC are subject to different reactive conditions, which are determined by the parameters such as temperature, moisture, presence of oxygen, activity of micro-organisms and the interactions between parameters at different stages of the ageing process of landfills. Four main phases can be distinguished: short initial aerobic phase, anaerobic acidogenic phase (variable duration, longer than aerobic phase), anaerobic methanogenic phase (up to several centuries) and final aerobic phase. The picture of landfill site is shown in Figure 2.7 (http://greenliving.nationalgeographic. com/pvc-disposal recycling).

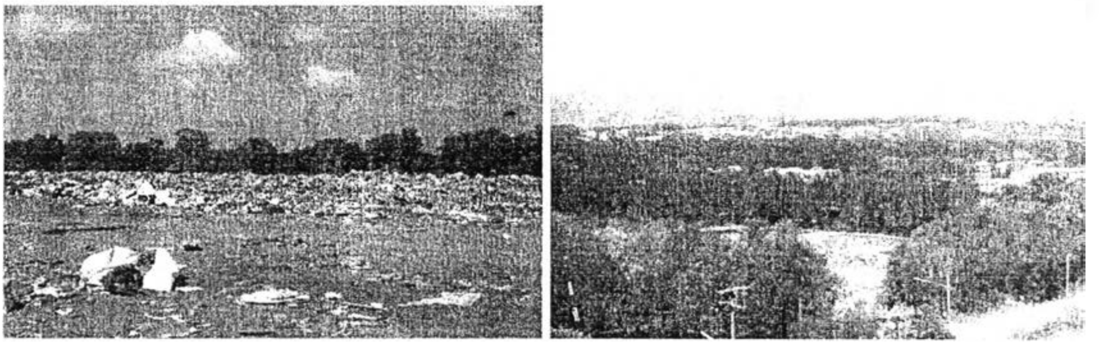


Figure 2.7 Landfill site at Phuket province (Malakul *et al.*, 2012).

2.3.2 Mechanical Recycling

Used PVC can become new source material through mechanical recycling that grinds plastic into a powder base for new products as shown in Figure 2.8. This process does not remove any of the toxins from PVC, but adding new material can dilute the existing toxicity. The mechanical recycling process is a common part the PVC industry in the reuse of post-industrial scraps. Post-consumer PVC recycling rates lag behind due to material retrieval costs, and chemical composition issues. While mechanical recycling for other post-consumer plastics is common, the additives in PVC can contaminate mixed batches and hinder system efficiency. Similarly sourced PVC is easier to recycle mechanically, so many product manufacturers run collection or buy-back programs that accept and process specific post-consumer PVC products (http://greenliving.nationalgeographic.com/pvc-disposal recycling).

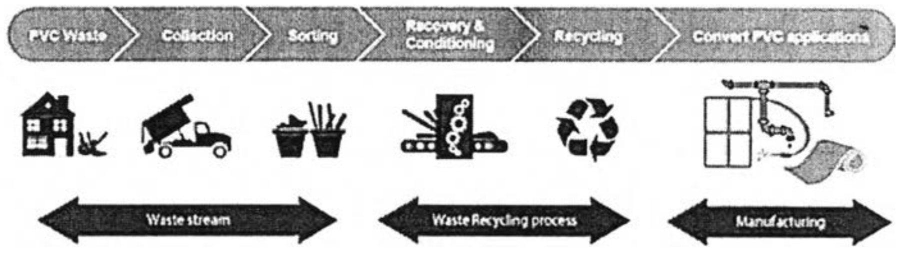


Figure 2.8 The different steps of PVC recycling process (http://greenliving.national geographic.com/pvc-disposal recycling).

2.3.3 Chemical Recycling

Chemical recycling methods break down plastics at a molecular level. This process is potentially beneficial because chemical separation allows the removal and reclamation of chlorine content and other toxins. Chemical recycling requires elaborate, dedicated facilities and is more costly than mechanical recycling. For this reason, the process is less preferred for general PVC waste, but it stands as an option for many materials that are too impure or contaminated for mechanical recycling (http://greenliving.nationalgeographic.com/pvc-disposal recycling).

2.3.4 Incineration

Incineration (Figure 2.9) is a waste treatment process that involves the combustion of organic substances contained in waste materials. Incineration and other high-temperature waste treatment systems are described as "thermal treatment". Incineration of waste materials converts the waste into ash, flue gas, and heat. The ash is mostly formed by the inorganic constituents of the waste, and may take the form of solid lumps or particulates carried by the flue gas. The flue gases must be cleaned of gaseous and particulate pollutants before they are dispersed into the atmosphere. In some cases, the heat generated by incineration can be used to generate electric power.

Nevertheless, the chemicals added to PVC create additional concerns when incinerated, but large amounts of PVC are handled by-municipal and hospital waste incinerators. When burned, PVC releases the gas form of highly corrosive hydrochloric acid. Incineration regulations state that this and other resultant toxins must be contained and neutralized, but troubling amounts have been found to leak into the atmosphere. Ash from PVC incineration also contains toxic elements, most often cadmium and lead. The presence of these two heavy metals means that the ash must be sent to controlled landfills, where space and groundwater contamination are eventual concerns (http://greenliving.nationalgeographic.com/pvc-disposal).

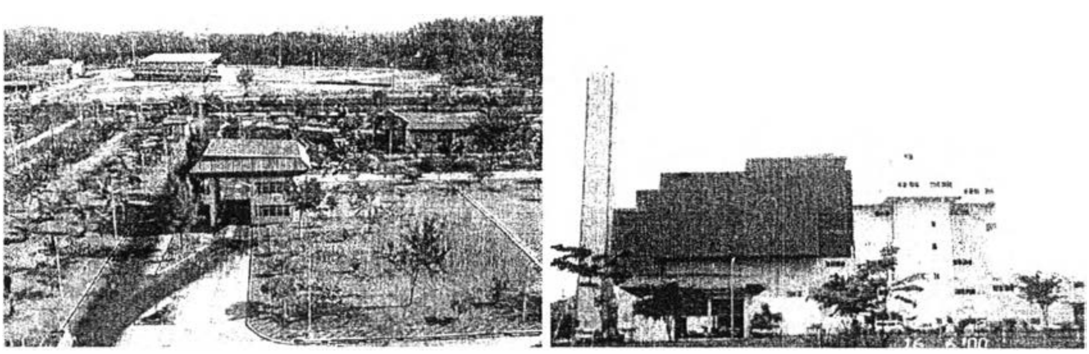


Figure 2.9 The incineration site at Phuket province (Malakul *et al.*, 2012).

2.4 Material Flow Analysis (MFA)

2.4.1 <u>What is MFA ?</u>

MFA is a tool which helps decision makers understands the metabolism of their region. It allows regional processes and activities such as construction, transportation, consumption and waste disposal to be linked systematically, together with inputs and outputs. More specifically, MFA examines the materials owing into a given system (private household, company, region, city, etc.), the stocks and flows within this system and the resulting outputs from the system to other systems. Unlike many other traditional environmental management tools, MFA focuses on loadings rather than concentrations. MFA is also useful to examine the relationship between a region or city and its corresponding hinterland (Hendriks *et al.*, 2010).

2.4.2 Historical Development of MFA

Material flow analysis builds on earlier concepts of material and energy balancing. The first material flow accounted on the national level have been presented at the beginning of the 1990s for Austria and Japan. MFA has been a rapidly growing field of scientific interest and major efforts have been undertaken to harmonize the different methodological approaches developed by different research teams. The Concerted Action "Con Account" funded by the European Commission, was one of these milestones in the international harmonization of MFA methodologies. The second important co-operation was guided by the World Resources Institute (WRI), bringing together MFA experts for 4 (5 for the second study) countries. In their first publication, material inputs of four industrial societies have been assessed and guidelines for resource input indicators have been defined. The second study focused on material outflows and introduced emission indicators (Hinterberger *et al.*, 2003).

2.4.3 Methodological Foundations

MFA essentially comprises the following steps:

2.4.3.1 Definition of the Goals and Questions of the Study

2.4.3.2 System Description

The system to be investigated is defined by boundaries in space and time. The relevant processes, goods and substances are defined and linked. The selection of the processes involves identifying those key processes which most efficiently represent and describe the complex system under investigation. This is one of the most critical and demanding steps of an MFA, as one is trying to depict reality in a simplified manner. The selection of goods and substances is dependent on the nature of the study. In research-orientated projects, where the interest may be on understanding the urban metabolism of a region, indicator materials such carbon and nitrogen (essential elements for the biosphere) and the elements lead, iron, aluminium and zinc (some of the most important metals of the anthroposphere) are typically selected. In more applied investigations, where the interest may be on a specific environmental issue, specific problem materials are usually selected. For example, forestry management issues may focus on timber, or eutrophication issues may focus on nitrogen and phosphorus as indicator materials.

2.4.3.3 Data Acquisition

The flows and stocks of the defined system are determined by measurements, market research, expert judgment, best estimates, interviews and 'hands on' knowledge, etc.

2.4.3.4 Material Balances, Modeling and Scenario Building

Material balances are performed on those processes where no data are available (using the principle of mass conservation: mass in = mass out). The basic model of material flow accounting and analysis (MFA) is shown in Figure 3.10. If required, results can be integrated into static or dynamic models. Modeling different scenarios is useful to assess the impact of various measures on the regional stocks and flows of selected materials in view of environmental loads or resource depletion.

2.4.3.5 Interpretation

The results of MFA studies are interpreted taking into consideration loading quantities, the significance of stocks and the comparisons of results against environmental standards and/or sustainable indicators or other assessment approaches. In order to utilize the MFA results effectively for policy making, the interpreted results need to be communicated to the relevant policy makers and stakeholders (water, energy, waste, transport, and environment management bodies, community groups, non-governmental organizations and representatives from neighboring regions, etc.). Workshops may be conducted with relevant stakeholders to determine: what these results mean for each stakeholder and management group in the region and how the region wants to respond to these findings (Hendriks *et al.*, 2000).

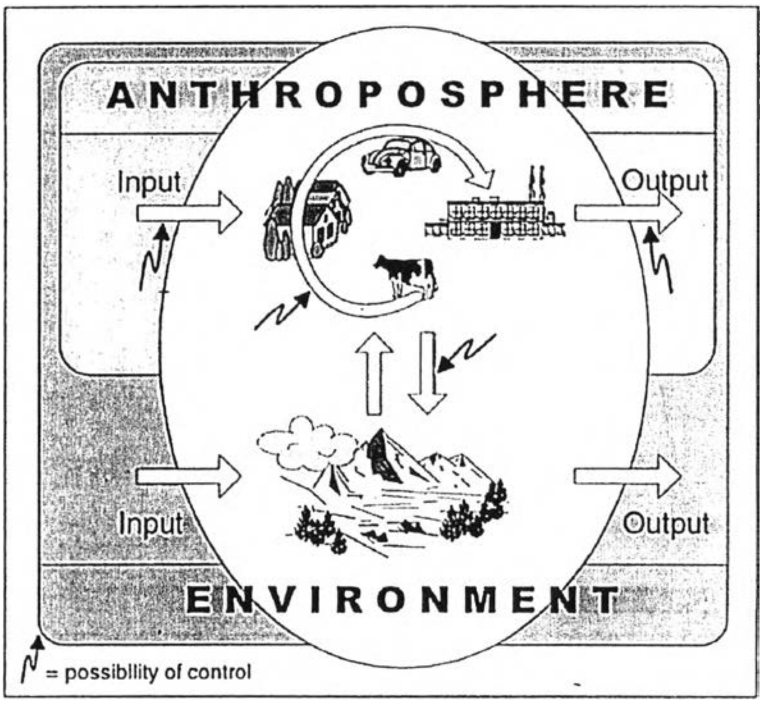


Figure 2.10 The basic model of material flow accounting and analysis (MFA) (Hendriks *et al.*, 2000).

2.4.4 Example of Material Flow Analysis on Some Materials.

2.4.4.1 MFA on Copper

This work was included in a more general project that addresses this issue by developing a new methodology for optimizing resources management. In 2012, Bonnin *et al.* presented the first step, which was applied to the example of copper cycle management in France with the Material Flow Analysis method. This paper showed that copper production and utilization were slowly decreasing while waste production was increasing. Moreover, the recycling rate was lower in France than in the rest of Europe, since there was neither copper extraction nor first transformation industry in France. The first step of this methodology was the mapping of the targeted substance by using a dynamic Material Flow Analysis (MFA), which was an analytical method of quantifying flows and stocks of materials or substances in a system. It was an important tool to assess the physical consequences of human activities and needs, and was used to develop strategies for improving the material flow system in form of material flow management. Figure 2.11 shows a traditional flowchart for tracking substances across countries or continents. It was widely used for the characterization of the European, but also for the Japanese copper cycle. In that context, a dynamic MFA was particularly useful to take into account the evolution of the system in time, in order to define scenarios for potential future development. The copper cycle can be divided into four steps appearing in Figure 2.11: production, fabrication/manufacturing, use, and finally waste management, each one involving more or less detailed sub-stages. This presentation was attractive since it covered copper life cycle in its main forms that were mined and refined copper, semi-product, product and waste for elimination or recycling.

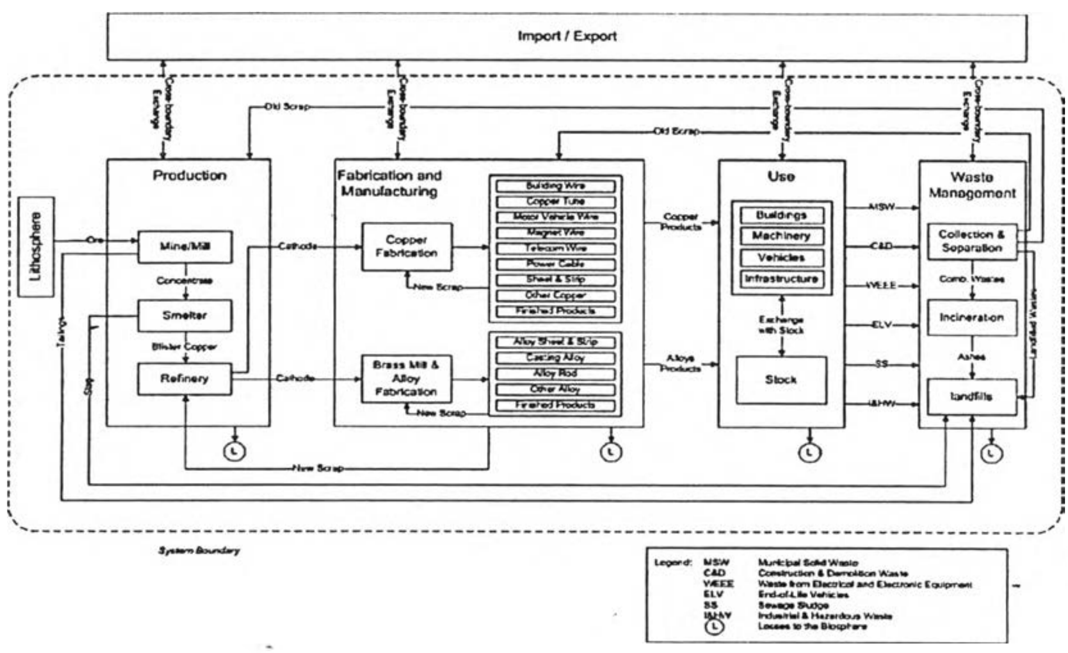


Figure 2.11 French Copper Cycle System Boundary (Bonnin *et al.*, 2012).

2.4.4.2 MFA on Electronic-Waste (E-Waste)

In 2012, Kahhat and Williams studied the management of electronic waste (e-waste), prominent among these was informal electronic recycling in the developing world fed by both international and domestic sources. There was a need to mitigate environmental impacts of informal recycling while maintaining social and economic benefits of refurbishment and reuse. The development of appropriate social responses was hindered by critical data gaps, which included lack of data on trade flows of used and scrap electronics, flows invisible to trade statistics of many countries. They addressed this data gap by proposing and implementing an approach to quantify the exportation of used and scrap equipment from a particular country or region to the rest of the world. The approach was based on material flow analysis and combined collection of primary survey data from residential and business/public sectors with secondary data from available recycling, landfill and computer adoption studies. Exports were estimated through materials balance

The proposed methodology was implemented in a case study of desktop (excluding monitors) and laptop computers in the United States (US) in 2010 as shown in Figure 2.12. Results indicated that 40 million used and scrap computers entered the end-of-life management sector, from which 30% were reused domestically, 6–29% were exported, 17–21% were landfilled in domestic sites and 20–47% were collected for domestic recycling in 2010. The range in results reflects uncertainty arising from inferring end-of-life fate from individual and institutional users. Given sufficient resources to conduct a survey, the proposed materials flow analysis method could be widely applied to other devices and nations.

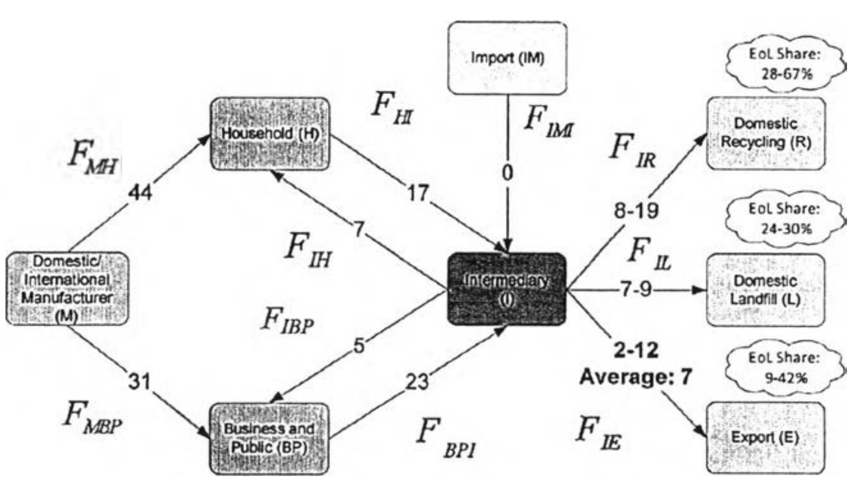


Figure 2.12 Computer material flow analysis for the United States, 2010 (million units) (Kahhat and Williams, 2012).

2.4.4.3 MFA on Steel

In 2011, Park *et al.* investigated the steel resources in Korea using dynamic MFAas shown in Figure 2.13. Iron ore and steel scrap were added as raw material components during the production processes of steel, which was then used in a variety of product groups such as construction products, transportation equipment, machinery/metal products, electrical/electronic devices, and other products through fabrication and manufacturing processes. When such product groups were discarded, they were either recycled or landfilled. With consideration for the lifetimes of various product groups in conjunction with steel resource flows in Korea, dynamic MFA was conducted on the flows of steel stock change and annual scrap generation. By 2020, these two flows were expected to increase by as much as 40% and 30%, respectively, compared to 2008, with transportation equipment, in particular, envisaged to experience high growth. At the current recycling rate, however, it was hard to meet future scrap demand. According to the scenario analysis, 100% of this future scrap demand can be supplied domestically if the recycling rate was increased to over 70% for all product groups, except construction products and transportation equipment, which already had high recycling rates. By 2020, the reduction in scrap importation costs was projected to offer a financial gain of 2.3 billion dollars.

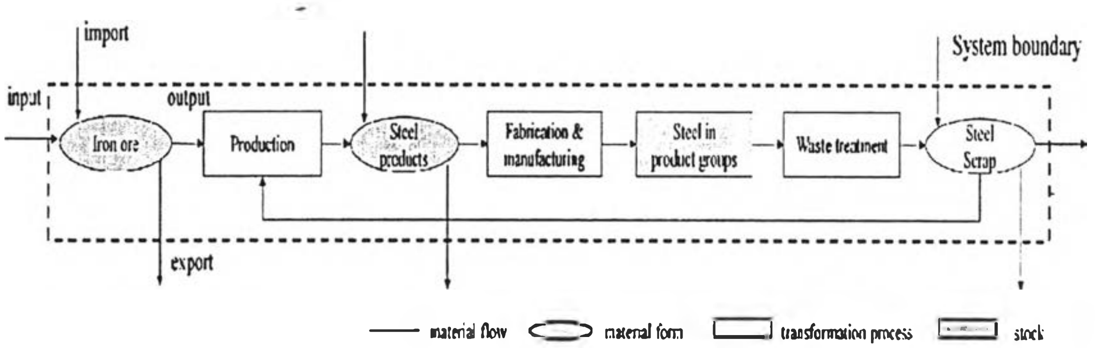


Figure 2.13 Material flow of steel in Korea (Park *et al.*, 2011).

2.5 Material Flow Analysis on Plastic and PVC wastes

2.5.1 Plastic Flow in India

Forecasting material flows was essential for sound policy making on issues relating to waste management. This paper presented the results of the plastics materials flow analysis (MFA) for India. The flow of plastic materials in India is shown in Figure 2.14 In the recent past, India got a substantial growth in the consumption of plastics and an increased production of plastic waste. Polyolefins account for the major share of 60% in the total plastics consumption in India. Packaging was the major plastics consuming sector, with 42% of the total consumption, followed by consumer products and the construction industry. The relationship observed between plastic consumption and the gross domestic product for several countries was used to estimate future plastics consumption (*master curve*). Elasticities of the individual material growth with respect to GDP were established for the past and for the next three decades estimated for India thereby assuming a development comparable with that of Western Europe. In Figure 2.15, the total plastics consumption was projected to grow by a factor of 6 between 2000 and 2030. The consumption of various end products was combined with their corresponding lifetimes to calculate the total waste quantities. The weighted average lifetime of plastics products was calculated as 8 years. Forty-seven percent of the total plastics waste generated was currently recycled in India; this was much higher than the share of recycling in most of the other countries. The recycling sector alone employs as many people as the plastics processing sector, which employs about eight times more people than the plastics manufacturing sector. Due to the increasing share of long-life products in the economy, and consequently in the volume of waste generated, the share of recycling would decrease to 35% over the next three decades. The total waste available for disposal (excluding recycling) would increase at least 10-fold up to the year 2030 from its current level of 1.3 million tons (Mutha *et al.*, 2006).

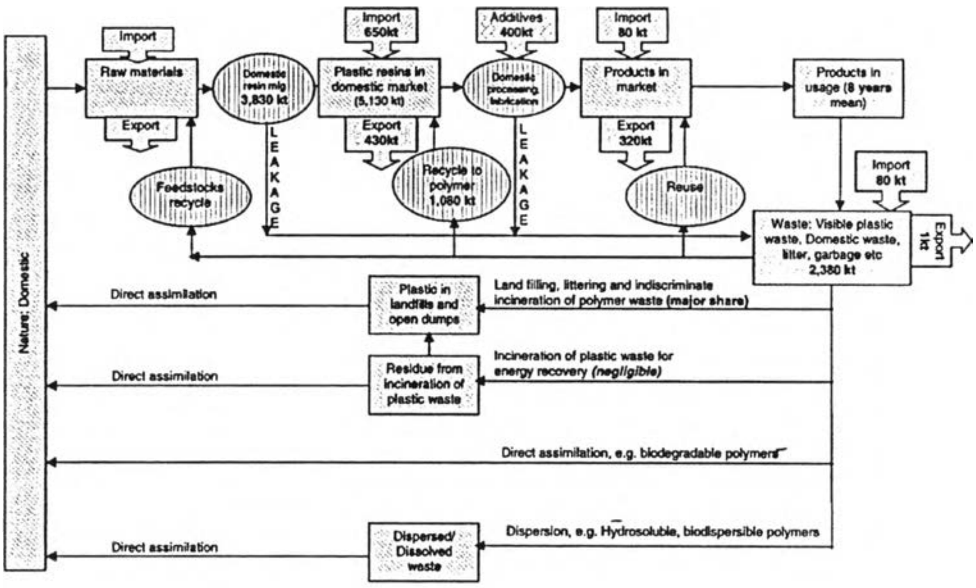


Figure 2.14 The flow of plastic materials in India for 2000/2001 (Mutha *et al.*, 2006).

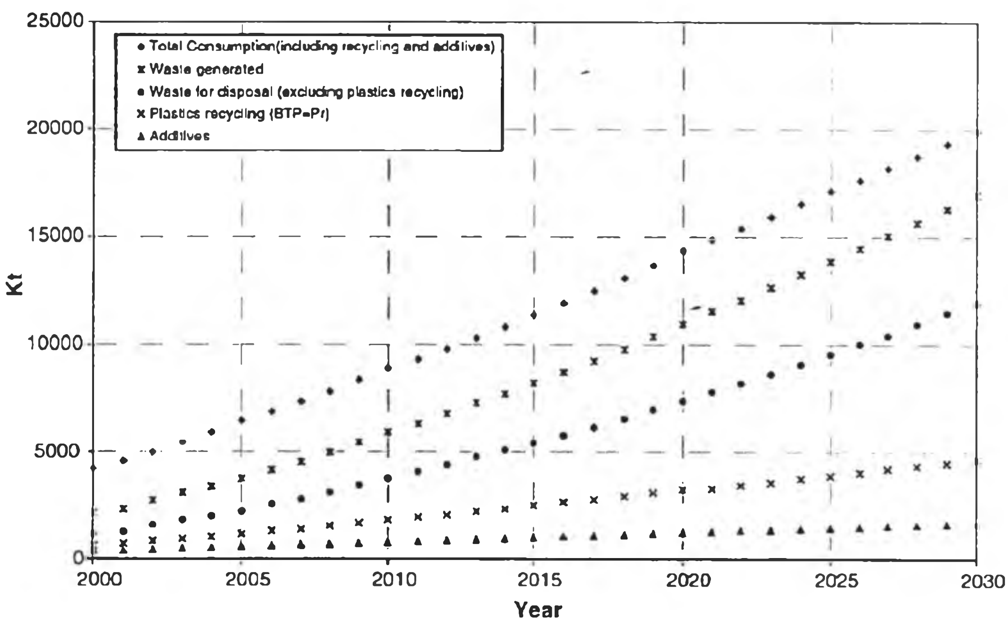


Figure 2.15 Projection of total plastics consumption (including recycling and additives), waste generated, waste available for disposal, waste recycled and additives consumption (Mutha *et al.*, 2006).

2.5.2 PVC Product Flow in China

In China, the rapid development of the polyvinylchloride (PVC) industry would inevitably lead to various environmental problems. In 2013, Zhou *et al*. studied the PVC metabolism further by (1) constructing dynamic models based on material flow analysis (MFA) as shown in Figure 2.16, (2) introducing calculation on detailed lifetime distribution of different types of products and recycling, and (3) obtaining the performances of waste emissions and accumulation as a function of raw material input and time. Based on system evolution theory and population development models, the developing trend of the PVC industry was studied, and annual consumptions in future years were predicted. The annual emission and accumulation after metabolism can be calculated by tracking the amount of raw material input, existing form and process flow for a single year (2003), as well as over a longer period (from 1958 to 2048) in China. Analysis indicated that over 0.6 billion tons of PVC waste would have accumulated in the environment by the end of 2050. In this scenario analysis, the effects of product structure, lifetime distribution, mechanical recycling, chemical recycling and incineration on waste output were all taken into consideration. The product metabolism process could be decelerated by changing these factors appropriately. However, mechanical recycling and chemical recycling were the most effective solutions.

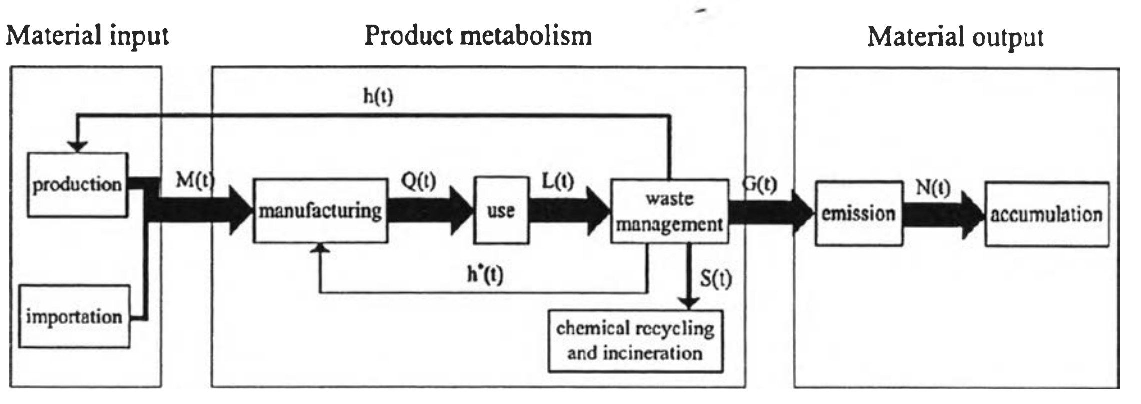


Figure 2.16 Framework of PVC products metabolism process (Zhou *et al*., 2013).

In China, PVC products are divided into three groups, (Table 2.9) i.e. soft products, hard products and other products (flooring, wallpaper, foam), and 11 sub-categories based on their main purposes. According to the data of 2003 in Table 2.9, the dynamic model, the amount of PVC waste emissions and accumulation produced in 2003 and discharged into the environment in following years can be calculated as shown in Figure 2.17. As the processes of mechanical recycling, chemical recycling and incineration were effective only when considering the input during a continuous period of time, instead of one year, they were not considered in this section. As illustrated in Figure 2.18, the amount of PVC waste emissions peaked in 2004 and 2006 because products with life expectancies of 1 and 3 years made up a large proportion of all products.

Analysis on multi-years input based on the results of PVC consumption trend, the metabolism of PVC products manufactured from 1958 to 2048 was studied. By dividing this time frame into 4 stages, the statistics that include products structure and life expectancy for every stage are also shown in Table 2.9.

Table 2.9 PVC products structure and average life expectancy in China during different periods

Products classification	Product number (*I*)	Proportion (%)				Life expectancy
		1958-1991	1992-1997	1998-2003	2003-2050	
Soft products						
Subtotal		73	61.5	50.8	50.5	
Film	1	18.8	20.7	17.8	15.5	1
Cable material	2	16.1	12.9	4.7	4.4	15
Leather	3	15	13.7	12.1	13.2	5
Footwear	4	23.1	11.3	10.9	11.8	3
Others	6	0	2.9	5.3	5.6	3
Hard products						
Subtotal		19.4	29.8	42.3	44.5	
Pipe	7	5.7	8.1	12.8	16.6	30
Planking	8	11.4	14.8	12.6	9.2	10
Profile	9	2.3	3.9	8.9	9.7	15
Bottle	10	0	1.4	3.9	4.8	1
Others	11	0	1.6	4.1	4.2	5
Other products	12	7.6	8.8	7.0	5.0	3
Total		100	100	100	100	

Without considering mechanical recycling, chemical recycling and incineration processes, the PVC waste emissions and accumulation in the environment after metabolism across the nine decades can be calculated annually. It can be concluded from Figure 2.18 that both emissions and accumulation increase gradually, though emissions grew at a decreasing rate, while accumulation grew at an increasing rate. Based on this model, parameters and assumptions constructed in this study, they predicted that by 2050 the annual PVC waste emissions would be close to 16 Mt, and accumulation would exceed 600 Mt. Obviously, if the current trend of the PVC industry continued, there would be considerable quantities of waste discharged into the environment in the coming decades, which can have serious consequences on human life and ecological balance. Therefore, appropriate measures, such as technical support and policy guides, should be taken to avoid the overdevelopment of the PVC industry and to reduce the waste output.

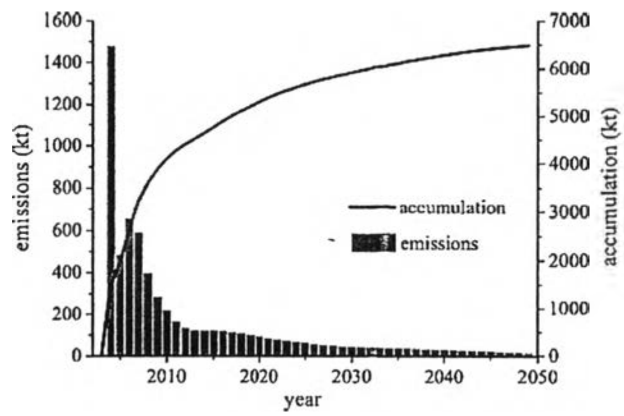


Figure 2.17 Annual emissions and accumulation of PVC material input in 2003 in China (Zhou *et al.*, 2013).

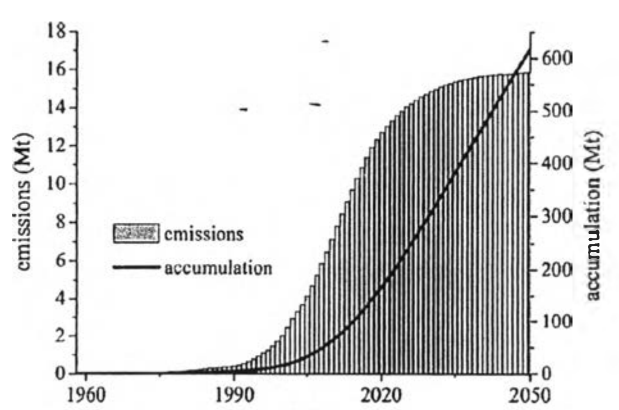
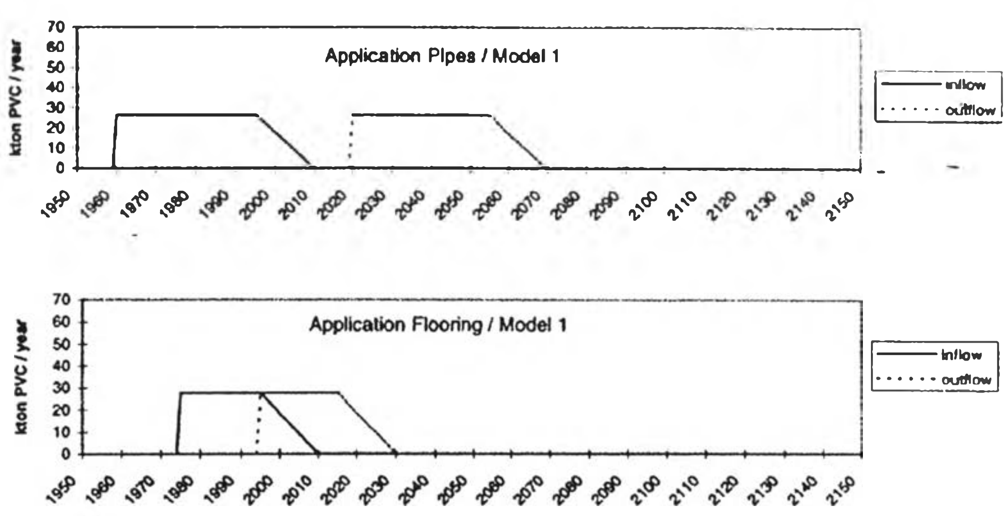


Figure 2.18 Annual emission and accumulation of PVC wastes after metabolism in China from 1958 to 2048 (Zhou *et al.*, 2013).

2.5.3 PVC Product Flow in Sweden

In 2000, Kleijn *et al.* studied in the topic of today's stocks are tomorrow's emissions and waste flows. As a result of the time lag introduced, flows seemed to be under control could easily rebound (Figure 2.19). In this paper, an example was given of how signal processing could be used in dynamic Substance Flow Analysis for estimating the future generation of waste and emissions from present societal stocks. An approach was outlined to estimate the outflow of waste products from stocks on the basis of assumptions on the shape of the distribution describing the inflow of new products, the average life span of the products, and the life-span distribution. To exemplify the approach they used a theoretical case of PVC in Sweden. It was found that the delaying mechanisms of the stocks could make the outcome counterintuitive. Furthermore, the chosen shape of the input-distribution function had the most influence on the predicted outflows, especially in the case of possible fashion-type (exponentially increasing) markets. The choice of the shape of the inflow distribution can be based on qualitative knowledge of the market of the different products. The life-span distribution appeared to have a more subtle influence on the height of the peaks and the time that they occur, and normal distribution was considered in this study, and the results are shown in Figure 2.20.



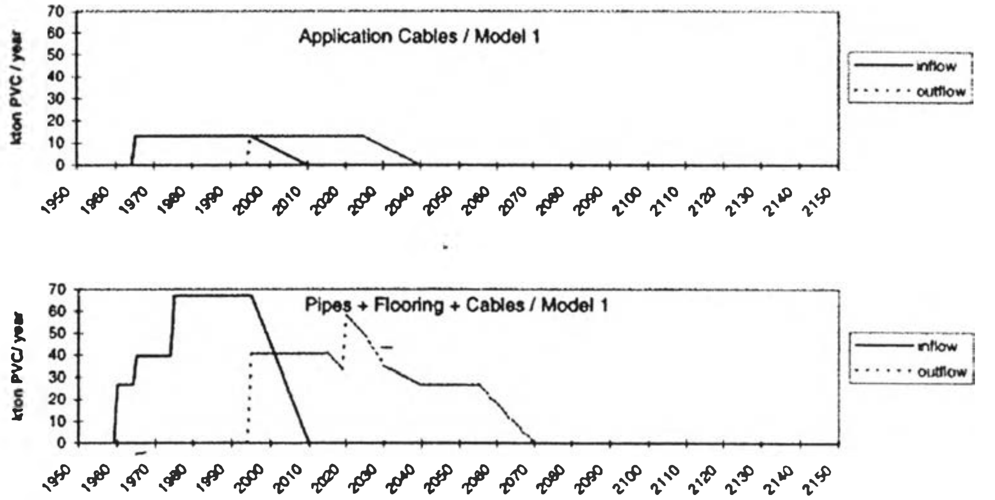


Figure 2.19 Development of the inflow of new products and the outflow of waste of the three major PVC applications using model 1,from top to bottom. 1a: PVC pipes, inflow and outflow; 1b: PVC flooring, inflow and outflow; 1c: PVC cables, inflow and outflow;1d: pipes, flooring and cables combined, inflow and outflow (Kleijn *et al.*, 2000).

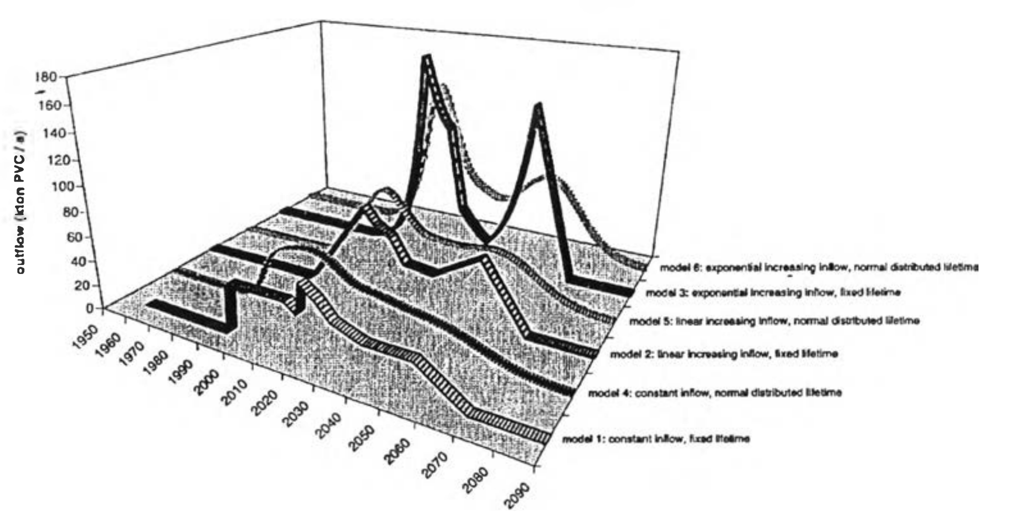


Figure 2.20 Development of the generation of PVC waste as a result of the dynamics of the three major PVC applications, assuming different models (Kleijn *et al.*, 2000).