Packaging Tomorrow

Modelling the Material Input for European Packaging in the 21st Century

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1 Introduction

1.1 The Matter Project.

This report is a result of the MATTER project (MATerials Technology for CO_2 Emission Reduction). The project focuses on CO_2 emission reductions that are related to the Western European materials system. The total impact of the reduction options for different scenario's will be modeled in MARKAL (MARKet ALLocation). To model the European material system several research groups (Bureau B&G, CAV-VU, ECN, IVEM-RuG, NW&S-UU) worked together to supply the input data for the MARKAL model at ECN. The MATTER project is started as a result of the EMS (Energy and Materials use Scenario for reduction of CO_2 and other greenhouse gas emissions) project for The Netherlands. In appendix II a comparison is made between the packaging input data of the EMS study and this report.

The most important materials and product flows from a CO_2 point of view for Europe have been investigated and described in separate reports. The material studies focused on metals (IVEM-RuG), plastics (NW&S-UU), natural organic materials (NW&S-UU) and ceramic and inorganic materials (ECN). Products studies are done for buildings (ECN), vehicles (IVEM-RuG) and packaging (NW&S-UU).

1.2 Packaging in Europe

Packaging is an important product category from a CO_2 point of view. In Table 1.1 a first order estimate for the energy and CO_2 balance for packaging materials are stated.

Table 1.1: Energy and CO_2 balance of packaging in Europe based on van Heijningen (1992), van Heijningen (1992a), APME (1996), de Beer *et al*., (1994) and van Duin (1997)[1]

Consumption of Packaging materials	Consumption (Mtonne pa)	CO_2 (Mtonne pa)	Share in total CO_2 emission (%)
Paper	28	14	11
Glass	17	6	5
Plastics	12	61	50
Metal	6	28	23
Others (incl. Wood)	13	13	11
Total	75	122	100

The total CO_2 emission of 122 Mtonne for all packaging materials can be compared to the total Western European emission of approximately 3500 Mtonne [Gielen, 1997]. The materials that are analyzed in this report represent 3.5 percent of the total

1 The CO_2-emission is calculated by using the figures in Annex 3 of van Duin (1997). The CO_2 emission of metal is calculated by assuming a 50/50 share of steel and aluminum.

Western European CO_2 emission. Plastics, paper and metal are the most important contributors to the CO_2 emissions from packaging.

1.3 Aim and structure of this report

The aim of this report is to provide input data for the MARKAL model regarding materials for packaging in Europe. To do so the current methods are described to pack consumer and industrial products in Europe. An estimate is made concerning the current use of materials for packaging. For several packaging categories options are defined to use less (product design), other (substitution) or recycled materials.

The following packaging categories are described in this report:

- food bottles
- non-food bottles
- boxes for primary packaging
- flexible packaging
- carrier bags
- Industrial boxes
- Pallets

These packaging categories will be described in the Chapters 4 till 11. Per packaging category we will describe the current demand in Europe and the standard materials that are used today. Furthermore we will describe the current research and developments in that packaging segment. We will then define standard packaging options that can be modeled in the MARKAL model to construct the current situation. After this we will define several new packaging options that use either less material or use different materials. These options are based on the developments that are described in the beginning of the chapters.

For all improvement options the year of implementation is stated. This is the expected year for which it is technically possible to use the options. For most options there are no technical limits for 100% penetration in 2000. However, many implementation barriers make it very unlikely that a 100% penetration in 2000 will be reached. In the MARKAL model a minimum use of these options should be modeled for 2000 by using higher prices than for the standard packaging options.

The target years that are used in the MARKAL model are 2000, 2020 and 2050. This report only states improvement options that may be implemented in the target years 2000 and 2020. Options for 2050 are not described because we have no ground that options are likely to be implemented in that year based on literature review and current developments.

When for all packaging categories the basic packaging options and the possible improvement options are described in Chapter 4 till 11, we will translate these data into a different format (Chapter 12). The change in format is necessary because the MARKAL model can not work with the packaging categories as used for the Chapters 4 – 11. For example, if the model creates a demand for food bottles, no substitution is possible with flexible packaging because the two categories are modeled separately and therefore no interaction can be modeled. In Chapter 12 other demand categories are defined that allow maximum substitution.

Numerous material substitution and product design options have a direct effect on the costs of a packaging system. In Chapter 3 we therefore describe how we will estimate the costs of different packaging technologies.

Many modeled developments will probably take place without exogenous measures that are used in the model. These autonomous developments are described in the next Chapter.

2 Autonomous Developments

Autonomous developments are important to describe because they show which measures are likely to take place without any extra policy measures and therefore state which part of the technical potential will be met without these extra measures. The autonomous developments are very likely to be influenced very heavily by the current developments in European policy regarding packaging materials and waste. We will use these developments to estimate the autonomous development. Of course one can argue that developments that are so strongly influenced by policy measures are not autonomous but policy directed. In future MARKAL scenarios this argument may be used to model different autonomous developments.

2.1 European policies in reducing packaging material.

In December 1994 the European Union adopted the Directive 94/62 on Packaging and Packaging Waste [EU, 1994]. The goal of the directive is to harmonize national measures on packaging and packaging waste management. The member states of the European Union had to implement the directive by national law before 30 June 1996 and within 5 years after the adoption of the directive the goals of the directive should have been reached. For the reduction of packaging waste this implicates that the member states have to recover between 50 and 65% of the packaging waste and recycle between 25% and 45% of packaging waste with a minimum of 15% by weight for each packaging material [EU, 1994].

The directive also indicates that within 10 years from the implementation of the directive in national law higher targets must be reached than those that are set in the current directive. These targets have to be determined by the European Council at a later stage [EU, 1994].

In Europe several countries were dealing with packaging waste before the directive was adopted. Two countries already have taken measures for a more stringent reduction policy than the EU directive. These countries are Germany and The Netherlands.

In Germany the Topfer law from 1991 led to the Duales System Deutschland (DSD) that was started in 1992 with the collection of transport packaging [Anon., 1993]. The basic idea behind the DSD program is that producers have a responsibility for the products that they produce. The producers were obliged to take back the packaging that they produced. So a second collection system was introduced into Germany by 600 companies parallel to the existing waste collection system. The industries in Germany dedicated themselves to recover 80% of each packaging material.

In The Netherlands the so called Packaging Covenant was established in 1991. This voluntary agreement between the Dutch government and the packaging industry had several goals. The most important ones were to reduce the amount of packaging in 2000 with 10 percent compared to 1986 and to re-use at least 60% of the packaging.

Since then many initiatives in The Netherlands have been developed to reach the goals that were set in the covenant.

Currently, the Dutch government and the packaging industry are working on a second covenant[2]. The goals of this new covenant are a reduction of the amount of packaging waste with about 28% in 2001 compared to 1995. This goal is supposed to be reached by prevention and re-use. The covenant is divided in 6 specific covenants of which 5 deal with specific materials and the other with producers and importers of packaging material [VROM, 1997]. In the paper covenant the parties agreed on reusing 85% of paper packaging. For glass a reuse percentage of 90% was negotiated and for metal, plastics and wood reuse percentages of 80, 35 and 15% respectively were negotiated.

2.2 Autonomous developments for the MARKAL model

To model autonomous developments for the MARKAL model we will define these as all developments that take place without the influence of climate policy.

For the year 2000 we have collected data that are the result of developments that take place in countries that have policies focussed on reduction of packaging material. The reason for this is that in these countries more information is available on packaging reduction options. These data are extrapolated to Europe in 2000. Therefore we may assume that these data include autonomous developments for the average European situation.

For the next target year of the MARKAL model (2020) many prevention and recycling options will become available. A part of these options may be implemented because of climate policy actions and another part may be implemented autonomously. The Packaging Directive is not focused heavily on prevention measures and we will therefore assume a reduction in packaging material per pack unit of 5 – 10% in 2020 compared to 2000.

The EU directive has set more stringent goals in case of recycling, e.g. a minimum of 15% per packaging material. For 2020 we will use a recycling rate of 25% as autonomous development. Recycling rate is defined as the share of re-used material in the total demand for packaging material and it therefore does not include thermal energy recovery.

[2] The covenant was signed at 12 December 1997

3 Costs and energy calculations method for packaging options

3.1 Introduction

The introduction of new packaging (technology) is associated with a change in costs, both to the producer of the packaging as well as to the user (packager, transport, consumer). The viability of a material efficient packaging system will depend on the level of the costs. It is therefore, necessary to assess the costs of the various packaging systems.

In this study we will assess the costs for the change in production of a packaging system. It is stressed that costs for the production *alone* is not the determining factor in the assessment of the viability of a changing packaging concept. Costs may be incurred by other actors in the total production chain of the packaged product, i.e. loss of value of or damage to the product. Hence, packaging materials and products should always be assessed in relation to the packaged product. We acknowledge this by trying to quantify the impact of a changing product in the variable costs, as well as a qualitative estimate of the behavioral changes needed to implement a measure.

The costs of changing packaging can be subdivided in capital costs for converting a packaging line, (annual) variable costs (e.g. the type and volumes of materials purchased, changes in material losses, labor costs, and other costs), as well maintenance or repairing costs of the packaging (e.g. collection, transport, cleaning and repairing). We will also look at the costs for waste management for packaging wastes.

A change in packaging technology might lead to the early depreciation of capital. However, within the time frame of this study we will assume that no accelerated capital depreciation of existing infrastructure and equipment is needed, and that different packaging methods are compared on the same cost basis.

All costs are expressed in 1994 ECU (European Currency Unit), which equals approximately 1.1 US$ (1994) and 2.16 Dfl (1994).

3.2 Capital Costs

The capital or fixed costs represent the costs for the production facility (excluding the building and utilities, which are assumed to be present). Packaging can be produced on-site, or purchased from the packaging industry. After production or purchasing the package is filled with the product in the filler or packed in the packaging machine, and labeled.

We assume that the capital costs include the packaging production machine and the filler. We assume that the machines have an average lifetime of 10 years, or different when specified. The specific costs of the filling or packaging machine depend on the operation, the cycle time, and the capacity. Economies of scale have an impact on the total costs, although large plants often have a few parallel machine lines.

Two types of investment costs can be discerned: costs for making the package, e.g. bottle, can and box, and the costs for filling the package. Due to the very high throughput of most packaging machines, the investment costs of most packages are low compared to for example the material costs of the package. In Table 1 the first three rows state an overview of the investment costs and the material costs for three types of packaging products [Packaging Week, 1992-1997]. It shows that the relation between package product making investments and filling lines investments varies a lot but the total investments are less then the material costs. In the other rows we have estimated the investment costs for the other packaging products as defined in Chapter 1.

Table 3.1: Investment costs and material costs for several packaging categories

	Investments for filling (ECU/ 1000 pack units)	Investments for packaging making (ECU/ 1000 pack units)	Material costs (ECU / 1000 pack units)
PET bottles	5	1.5	100
Cans	1.5	5	30
Industrial bags	0.3	1	60
Glass bottles	3	3.5	90
Other bottles	5	1.5	60
Carrier bags	0	2	70
Boxes	0.3	3	33
Flexibles	0.3	2	3

For pallets and crates the investment costs are depending strongly on the type of product. We will describe the costs in more detail in the chapters about these packaging products. To calculate the total packaging costs, no filling costs will de attributed to secondary packaging like pallets and crates. We assume that these costs are already part of the filling costs of the primary package.

3.3 Variable Costs

The variable costs can be s**u**bdivided in material purchasing costs, labor costs, energy consumption, and other costs.

Material Purchasing Costs

As seen in Table 3.1 material costs are an important part of the total production costs of the packaging products. The material costs will depend on the quantity needed as input (including material losses during packaging) and the type of materials used per unit of packaged product. Although prices may vary depending on the volume purchased average market prices in European Union are assumed in the MARKAL model. Note that the market prices of these commodities vary widely over the past period, and may well do so in the future. Therefore, the figures are an indication for the market prices in the modeled period. The needed quantity and type of material needed will be specified with each option to change the packaging.

Table 3.2. Specific average market prices and fluctuation for packaging materials in the European Union for 199x, expressed in ECU (1994) per kilogram.

Class	Material	Costs (ECU/kg)	Sources
Plastics	PE granulate PP granulate PS granulate PVC granulate PET granulate	0.72 (±40%) 0.70 (±40%) 0.92 (±25%) 0.68 (±25%) 1.03 (±25%)	Average for 1994, 1995, 1996 (K&R) (Rieckman,1995)
Paper	Packaging Paper Boxboard Corrugated board	0.47 (±20%, 1994) 0.75 (±15%, 1995) 0.30 (±30%, 1994)	Derived from (PPI,1997)
Glass	Containers	0.18	Foreign trade statistics
Steel	Sheet steel	0.58	Gielen and van Dril, 1997
Aluminum	Extruded/sheet	1.51 (±40%, 1996)	1996 average, London Metal Exchange
Wood	Pallet/Crates	0.46 (±30%, 1990)	(Renia,1991)

Labor Costs

Labor is another cost factor in the production, application and re-use of packaging. There is not much bottom-up labor cost information available for the packaging industry. The labor costs depend largely on the level of automation of packaging lines. Generally, the labor costs in modern packaging lines are small. Heineken for example owns a filling line with a capacity of 90.000 cans per hour which needs a crew of 5 persons per shift [van Vugt, 1993]. This equals 18000 cans per man-hour. At the Coca Cola bottling line in Dongen, The Netherlands the output per person per hour amounts to 670 PET-bottles (1.5 liter) [van Vugt, 1992].

There is a clear trend visible towards faster packaging machines and a more intense use of robotics which will lead to even less labor input per packaging [Packaging Week, 1992-1997]. For the MARKAL model we will assume 1.000 packages per person per hour. Assuming a labor cost of 15 ECU per hour, the labor costs amount to 15 ECU per 1000 packages.

Costs for Transport, Maintenance and Re-Use

One-way packaging normally needs no maintenance. However, re-useable or refillable packaging needs to be treated (or maintained) before being re-used. The costs for maintenance and re-using a package include the collection, transport and cleaning (e.g. rinsing) of the package, after which it is returned in the original physical form to the filling line (see figure 3.1 for the possible transport routes of packaging). The product and material losses depend on the packaging system and materials used and are addressed in the packaging efficiency improvement options.

Collection and transport costs depend on the collection system. We will assume a system where the same truck that brings the products will return the containers/ packages. Collection costs are the determined by the costs for transportation and the costs for loading and unloading.

We assume a transport distance of 100 km and a total delivery time of 3 hours. We also assume a loading time of 1 hour and an unloading time of 1 hour. Assuming 14 pallets per truck and 5 layers of 10 transport boxes per pallet and a box content of 14 small (e.g. 300 ml) primary packages the total amount of primary packages per truck amounts to 9800. Assuming a total cost of 22 ECU per hour for the truck and labor the transport costs amount to 6.7 ECU per 1000 packages and loading costs amount to 2.2 ECU per 1000 packages.

Return transport costs are in this case 2.2 ECU per 1000 packages higher than for single trip packages. For large (e.g. 1.5 liter bottles) the costs are assumed to be a factor 5 higher.

Another difference in the collection system of one-way or re-usable packaging is that the latter needs to be stored for a certain period of time in on the premises of the retailer. We assume a price of 160 ECU / m^3.yr, a continuous loading grade of 1 pallet on that area and an average space occupying time of 1 day per package. Taking into account the same load per pallet we estimate the cost of storage at 4.5 cents per 1000 300 ml packages and 22.4 cents for 1000 1.5 liter packages.

The costs of cleaning are taken to be equivalent to that of rinsing bottles, as most of the re-usable packages that need to be cleaned will probably be containers for liquids.

The cost of cleaning not only consists of the actual costs for cleaning but also all the other equipment and space that is needed for the refill system. The empty used bottles that enter a production facility need to be sorted, de-capped, cleaned and inspected. The bottles that are not in a good enough state to be refilled need to be separated from the other bottles. Special detection equipment is necessary to detect whether the bottle contained other liquids. In other words many extra machines, equipment and floor surface is needed to the return system. We estimate that the investments for a facility that is capable of handling returnable packages are twice the amount needed for a facility that processes virgin material.

In case of material recycling we will model a system where all packaging material are separately collected based on a voluntary system where the consumer brings the packaging materials to a central collection point. A system like this is already in use in The Netherlands for glass and paper recycling. We will assume the same transport distances (100 km) for returning the materials to the materials processing industry. The cost of collection vary strongly per material. Plastics bottles are very voluminous and therefore have high collection costs: 400 ECU per tonne [Sas et al., 1994]. Glass on the other hand can be collected in pieces which increases the density. The collection costs are therefore much lower: 15 ECU per tonne [SPG, 1994].

Waste Management

Waste collection and management is also a cost factor in the packaging cycle. Reduced waste production due to material efficiency improvement will lead to lower life cycle costs. The costs of collection and transport (including transport to a regional waste collection or treatment center) depend mainly on the collection costs. The collection costs are estimated at 45-55 Dfl./tonne [VVAV,1994] in The Netherlands. We will assume this value to be representative for Europe, equal to 23 ECU/tonne (1994). The road transport costs are estimated to be 0.18-0.25 Dfl/tonne.km [VVAV,1994] for a return-trip. Assuming a distance of 50 km, the transport costs equal 2.5 ECU (1994). The total costs for collection and transport are assumed to be 52 ECU/tonne.

The energy recovery through incineration or other thermal treatment depends on the heating value of the material, efficiency of the incineration, and share of MSW treated. Various future scenarios can be developed for Europe (for The Netherlands, see for example Hekkert (1996). These values are part of the MATTER model, and not modeled separately in this study.

In Appendix 1 an overview is given of the total life cycle cost per packaging type. This is done for all packaging types discerned in this report.

3.3 Energy use

Packaging making

Energy use for packaging is generally very small, compared to the energy content of the materials and the energy use for production. Hence, we will assume an average specific energy consumption for packaging, based on internal transport and the power demand of the equipment. Electricity demand for internal transport is equal to 0.5-0.9 MJ_e/tonne-meter [Perry *et al.*, 1984]. Assuming an average transport distance of 100 meters the energy use is 58 MJ_e/tonne. Energy consumption for the filling machines and palletisers is estimated at approximately 72 MJ_e /tonne [Perry,1984]. Energy use for packaging is estimated to be equivalent to 144 MJ_e per tonne packaged product plus the specific energy consumption for the different packaging types as stated in Table 3.4.

Table 3.4: Energy consumption for several types of packaging making [BUWAL, 1991, BUWAL 1996]*

Type of packaging making	Example packaging	MJ_{el}/kg
Blow moulding	Plastic bottles	12.2
Injection moulding	Plastic crates, pallets	3.1
Thermoforming	Plastic boxes	5.5
Film making	Stretch film, pouches	2.6
Corrugated box making	Transport box	-
Glass blowing	glass bottle, jar	-
Can making	Can	2.33

*“-“ means: energy use for packaging making can be neglected compared to energy use for material production

One way and multiple trip packaging

The life cycle of one way packaging and returnable or multiple trip packaging is different. In figure 3.1 the possible transport routes of packaging are depicted. Three types of lifecycles can be read from figure 3.1.

The first is the life cycle of one way packaging. The package goes from producer to the consumer via stores and ends up as waste after it is used. In this study we will model that a full truck delivers the products to the store and that an empty truck drives back. We will assign energy consumption figures to both.

The other possible life cycle is the case of material recycling. The first part of the life cycle is the same as for one way packaging but after the package is used it is separately collected and transported to the packaging producer. The use of secondary material by material production processes is modeled in other parts of the MARKAL model. We will therefore only model this step in terms of collection and transport to the packaging or material processing industry.

The last possible life cycle is that the package is returned to the store where it is originally bought and from there it is transported to the filler where it is cleaned and used again. To model this life cycle we will model the energy consumption of th efull truck load to the store, the truck load with returnable packaging back to the producer/filler and the cleaning stage.

The energy use for cleaning return bottles is estimated at 0.1 GJ heat per 1000 bottles and 126 MJ_e per 1000 bottles. For cleaning of return pallets and crates we assume electricity demand of 75 kWh per 1000 pallets/crates

For transport we will assume the following. All transport is done with a 20 tonne truck. This truck uses 0.238 liters diesel per km if it is fully loaded and it uses 40% less when empty [Koudijs and Dutilh, 1993]. Assuming a truck weight of 8 tonnes and a loading capacity of 12 tonnes and taking the heating value of diesel into account leads to the following formula.

$$Et = 5.14 + 0.286 * W \qquad (1)$$

Where:

Et = total energy consumption of 20 tonnes truck per km (MJ)

W = weight of cargo in tonnes (0-12 tonnes)

We will furthermore assume that transport from producer to store is volume restricted. This means that the truck is able to carry more weight but that the volume of the cargo is the limiting factor. For 1000 liters product that is packed in one way packaging we use therefore the following formula:

$$E_{1000l} = E_{tf} + E_{te} / V_t \qquad (2)$$

Where:

$E_{1000}l$ = Energy requirement to transport 1000 liters product with single trip packaging

Etf =Energy requirement of fully loaded truck

Ete = Energy requirement of empty truck

Vt = truck volume (estimated at 66 m3)

For the return trip of multiple use packaging the energy consumption is related to the weight of the packaging that transported back to the filler/producer. Only marginal energy costs have to be taken into account because we assume that for single trip packaging an empty truck drives back to the producer, leading to the following formula.

$$E_{r1000l} = 0.286 * W_{pack} \qquad (3)$$

Where:

Er1000l = energy use of return transport of return packaging capable of packaging 1000l

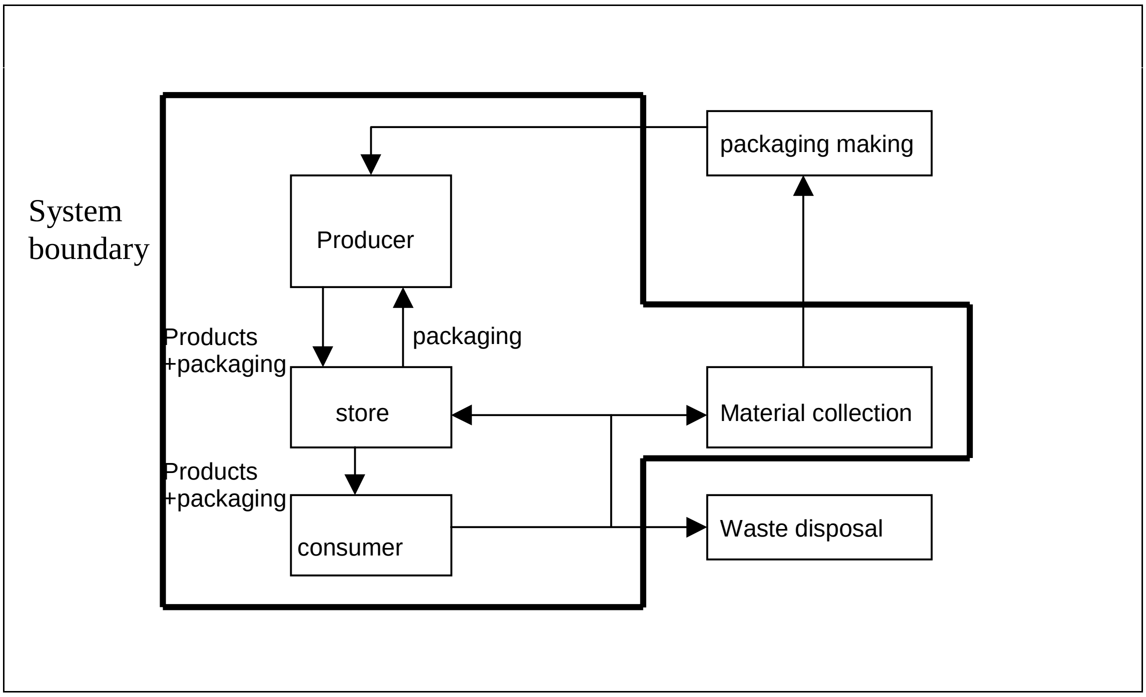
Wpack = Weight of return packaging

In the case of multiple trip pallets we assume that one pallet will be taken back for every pallet delivered.

To use formula’s 1, 2 and 3 we used the following assumptions:

- a truck of 20 tonnes transports 24 pallets
- in case of large bottles (1.5 liter) one pallet contains 40 crates that contain 12 bottles
- in case of small bottles (0.3 liter) one pallet contains 50 boxes that contain 14 bottles

Figure 3.1: Schematic overview of transport of packaging materials



Waste management

For waste management the energy consumption or production is calculated by other input studies for the MARKAL model.

In Appendix 1 an overview is given of the energy consumption during packaging making, transport and waste management for all packaging types that are defined in this report.

4 Current and future material input for food bottles

4.1 European market

The category food bottles is defined as all bottles, cans and jars that are used to pack food. A very large category is liquid packaging. The main liquid types that are packed within this category are dairy products, soft drinks, beer, wine and spirits. Table 4.1 states the consumption in Western Europe for the different products.

Table 4.1: Consumption of consumer liquids in the EU in 1994, based on EC (1997).

liquid category	Million liters
Beer	30007
Drinking milk	29608
Mineral water	24119
Soft drinks	13862
Wine	12863
Alcohol and spirits	774

To pack the different products, several types of packaging are used. Often, the most common type of packaging depends on the packed product. Beer, for example is packed mostly in glass and cans while soft drinks are often packed in PET bottles and cans. We will describe all the possible options for the packaging of the liquid products and later we will assign maximum penetration levels based on the segmentation of the different liquid products.

Besides liquid products the category food bottles not only focuses on liquid products but also on other food products that contain liquids in some form. Most of these are packed in jars and cans. The largest food categories of this kind are the preserved fruit and vegetables including jam, marmalade and jelly. Table 4.2 presents the use of these products in Western Europe.

Table 4.2: Preserved fruit and vegetables in Europe in 1994 based on EC (1997)

Preserved fruit and vegetables category	Million 850 ml tins
Canned vegetables	2598
Canned fruit	1438
Jam, marmalade and jelly	682
Total	4718

The liquid packaging market is a fast moving market where many rapid developments take place. Many different materials are used to pack the liquids and preserved fruit and vegetables. We will focus on glass, PET, metal cans, and liquid cartonboard.

4.2 Glass bottles and jars

Glass bottles and jars are used to pack all of the liquid and food categories that are defined earlier. The glass bottles have had0 competition from other materials since a long time. Years ago, milk in The Netherlands was sold in glass bottles but today the major packaging used are liquid cartons [van der Ent, 1995]. In the soft-drink sector, the same situation occurred. For a long time only glass was used while today PET bottles have taken a very large market share in Europe.

Still, glass has a large market share in the packaging used in Europe. About 23% of the packaging materials is glass which corresponds to 17250 ktonne in 1994 [APME, 1996].

Recycling

When glass is used as packaging material, two ways of recycling are possible. Glass containers can be used for material recycling and a deposit fee system can be used for product recycling. In The Netherlands about 80% of the one way bottles is recycled by means of the glass container. The amount of one way bottles is still relatively low in The Netherlands (25%), but this share is rapidly increasing there as many new products are packed in one way glass [Terwindt, 1996]. Most other European countries have lower recycling rates than The Netherlands. Table 4.3 shows that only Switzerland has a higher recycling rate than The Netherlands. The table shows further that most countries in Southern Europe have low recycling rates and that the European average is 54%.

Table 4.3: Glass recycling in Europe in 1995 (ktonnes) [Anonymous, 1996]

Country	Glass consumption	Glass collected	Recycling rate (%)
Austria	265	199	75
Belgium	336	225	67
Denmark	165	104	63
Finland	60	30	50
France	2800	1400	50
Germany	3712	2784	75
Greece	109	38	35
Ireland	97	38	39
Italy	1640	869	53
Netherlands	465	372	80
Norway	52	39	75
Portugal	217	91	42
Spain	1256	402	32
Sweden	157	96	61
Switzerland	309	263	85
Turkey	300	36	12
United Kingdom	1856	501	27
total	**13796**	**7487**	**54**

Definition of the standard bottle

Because glass bottles and jars are used in many different sizes it is very hard to estimate average sizes and volumes. For the modeling of glass bottles and jars however estimates are needed.

For the MARKAL- model we will define 2 glass bottles (large and small) and 1 jar. The large bottle is defined as a bottle with a volume of 1 liter while the small bottle has a volume of 0.3 liter. The jar has a volume of 0.5 liter (in between the often used standards of 72 and 37 centiliter).

Depending on the packed liquid, bottles with the same volume often differ in weight. An average gin-bottle for example in 1991 in The Netherlands weighed 570 gram while a 1 liter milk bottle in the same year weighed 420 gram [SVM, 1993a]. We will estimate the average weight of the bottles in Europe based on the Dutch situation. We will take into account that The Netherlands were working on reducing the amount of packaging waste by means of voluntary agreements before the rest of Europe. Table 4.4 shows the average weight of the defined bottles in The Netherlands in 1991 [SVM, 1993a]. We will use these numbers as the average European glass bottle weight in 2000.

Table 4.4: standard glass bottle types for Europe in 2000

Bottle type	Volume (liter)	Weight (gram)
Glass bottle large	1	500
Glass bottle small	0.3	250
glass jar	0.5	250

Improvement options

Light weight bottle

The glass bottles as defined in Table 4.4 can be improved in order to reduce the amount of packaging waste. In the Netherlands many projects have taken place to reduce the weight of glass bottles. The weight of milk bottles was reduced with 33%, the weight of several liquor bottles was reduced with 20% and 22% [SVM, 1994]. Therefore it seems possible to reduce the weight of large glass bottles with 25% in 2000.

Also projects have taken place to reduce the weight of small glass bottles like beer bottles with 5.5% [SVM, 1994]. The glass industry in The Netherlands expected in 1993 a reduction of 15% in 1995 compared to 1991. We will use this figure for the improvement of the small glass bottle [SVM, 1993].

A company reduced the weight of mushroom jars with 20% in 1994 and in 1992 vegetable jars were reduced in weight with 14%. Furthermore, some jam and jelly bottles were reduced in weight with 10% in 1995 [SVM, 1992, 1994, 1995].

Based on these numbers we estimate that in 2000 a reduction in jar weight of 20% should technically be possible. In Table 4.5 the improved glass bottles are listed.

Table 4.5: improved (light weight) glass bottles

Bottle type	Volume (liter)	Weight (gram)
Glass bottle large	1	375
Glass bottle small	0.3	215
Glass jar	0.5	200

The costs that are related to weight reduction of the bottles are next to cost savings due to less material input mainly in the development and the transportation phase. The filling line for example will not differ if the bottles weigh a little bit less. The development costs are very hard to estimate but we assume that these costs are negligible per bottle. The transportation costs will differ because the load per truck is less, which will save fuel.

Glass recycling

Besides weight reduction a lot of resources can be saved by glass recycling. Two types of recycling are possible: product re-use and material recycling. As can be seen in Table 4.3 the European recycling rate is already 50%. The Swiss recycling rate is the highest in Europe and can be seen as the absolute maximum for Europe. However, due to the large transportation distances in Europe in rural area's this figure is not very likely to be reached.

We assume a maximum recycling rate in Europe of 70%. The cost of the extra recycling will be higher than the current cost figures. Assuming a transportation distance of 150 kilometer for the last 20% we estimate the costs at 90 ECU because the glass recycling transportation costs for 25 km in The Netherlands are about 15 ECU per tonne [SPG, 1994]. We furthermore assume that color separation is possible for all the glass that is collected separately; in the U.K. already 95% of the recycled glass is sorted on color.

Table 4.6: Costs of glass recycling in Europe

	Costs of transportation (ECU/tonne)	
50% recycling	15	
70% recycling	90	(Only for last 20%)

In The Netherlands beer bottles and some jar types are recycled with a deposit system (product recycling). We assume that this system is an option for Europe after 2000 for beer bottles. Costs and energy use of this option is calculated as described in Chapter 3. The success of such a system depends on the willingness of the consumers to return the package (this can be influenced by the height of the deposit fee) and the willingness of the producers to implement such a system. Standardization of packaging is a strong tool to make product-recycling work. In this way it doesn't matter if the package is returned to producer A or producer B. Standardization for beer bottles is proven technology in The Netherlands. We will therefore only use this option for beer bottles in Europe. We assume a trip number of 20 trips per bottle.

4.3 PET bottles

European situation

PET (Poly Ethylene Terephthalate) bottles were introduced in the soft drink sector to replace the standard 1 liter glass bottles. PET bottles are especially suited to pack carbonated soft drinks. PET bottles also replace the PVC bottle that are often used in South Europe for the packaging of mineral water [Ent, 1995].

50% of the PET bottles in Europe are used to pack soft drinks, 27% is used to pack mineral water, and 5% is used to pack other drinking liquids. The rest (18%) is used for other purposes like food and non-food packaging [Clausse and Mitchell, 1996].

In 1993 about 700 ktonne PET for bottles was used in Europe and projections for 2000 and 2005 suggest a demand for PET of 1.55 million tonne and 2.12 million tonnes respectively [Anon., 1995, Clausse and Mitchell, 1996]. These trends are based on expectations that PET bottles will replace all PVC and a lot of glass packaging.

Refillable PET

The first PET bottles were 1 way bottles but today many PET bottles are refillable. This is especially the case for countries like Germany and The Netherlands. This development was possible because new PET types became available that could be cleaned at higher temperatures (58°C). In 1994 Spadel introduced the Hotwash Pet bottle that can be cleaned at temperatures up to 75°C [Hentzepeter, 1996].

The refillable PET bottles (REF-PET) are designed to make 25 trips during a lifetime of 4 years [Kort, 1996]. Many bottles however make less trips because of the damage done to the bottles during the refill process. This process is called scuffing and research showed that 80% of the damage done to PET bottles is related to scuffing during the refill process. Measures have been taken to decrease scuffing and as a consequence increase the trip number of the bottles. Possibilities to reach a trip number of 30 have been reported [Kort, 1996]. For 2000 we assume a average trip number of 20 trips per bottle.

In Europe not all countries use REF-PET bottles. Countries like the U.K. and France still use only single trip PET bottles [Hentzepeter, 1996]. Two collection systems are used in Europe for single use bottles. In the U.K., France, Spain and Ireland curbside collection systems are used while countries like Italy, Belgium, Austria and Switzerland use drop off points for the collection of the PET bottles [Anonymous, 1995].

Material recycling

Besides an increase in refillable bottles also material recycling is increasing in the PET market. An organization called PETCORE (PET Container Recycling Europe) was founded in 1994 with the goal in increase PET recycling in Europe. In 1996 about 75 ktonne which corresponds to 1.5 billion bottles were collected for recycling. This is an increase of 66% compared to 1995 when 45 ktonne was collected [Anon, 1997]. The recycling process has an efficiency of 80% (defined as the output of the re-extrusion process as share of the PET bottle input in weight), so in 1996 about 61 ktonne recycled PET was produced. The expectations for 1997 are 100 ktonne collected PET [Anon. 1997].

Recycled PET can either be used for the production of new bottles, Coca Cola developed a three layer bottle of which the middle layer consists of recycled PET [Hunt, 1994], or it can be used for the production of PET fibers that can be used for textiles (downcycling).

PEN and PET

Currently new developments in the PET market are related to the appearance of PEN (Poly ethylene Naphtalate) on the market. The advantages of PEN is that the barrier characteristics are better than for PET and that it allows higher temperatures in cleaning and filling (up to 124°C) [Clausse and Mitchell, 1996]. This high temperature tolerance makes it possible to use steam for the cleaning of the returnable bottles which leads to great water savings [Hentzepeter, 1996]. PEN is not commercially used yet but many tests are currently carried out on combinations of PET and PEN in one bottle [Johansen, 1996].

Definition of the standard bottle

For soft-drinks the 1 liter, 1.5 liter and 2 liter bottles are used for packaging. Mineral water can be packed in the same sizes. A 1.5 liter refillable bottle weighs 103 grams. We will use this size and weight as the standard refillable PET bottle for Europe in 2000. We will model the one way PET bottle as a 1.5 liter bottle that weighs 50 grams.

Improvement options

The refillable PET bottle itself can be seen as an improvement option for glass bottles because they are very light and it can also be seen as an improvement for one-way packaging. The refillable PET-bottles themselves can be improved in several ways.

Earlier we described that the trip number could be increased by adaptations in the washing and filling line. The bottles normally are made out of virgin PET but the three layer PET bottle with a recycled PET inner layer can be seen as an improvement option. We will use the bottle with 25% recycled PET as improvement option for the virgin bottle.

Table 4.7: Standard and improved refillable PET-bottle

	size (liter)	weight (gram)	share recycled (%)
REF-PET Bottle	1.5	103	0
Improved REF-PET bottle	1.5	103	25
one way PET bottle	1.5	50	0

In 1994 about 1.5% of the PET-bottles were recycled [Anon. 1997, APME. 1996]. For 2000 we will assume a percentage of 5%. For future target years we do not expect that the same recycling percentages as for glass will be met because PET bottles are lighter and more voluminous and therefore more expensive (per tonne) in transportation. We will assume a maximum recycling percentage of 50% and costs that are 7 times as high as for glass recycling resulting in 110 ECU per tonne in 2000. This figure is based on the difference in density between glass and PET. We Assume that the amount of glass and PET that can be transported per truck is volume restricted and therefore about 7 trips of PET transport are necessary to transport the same weight as for one glass-trip.

For 2020 we may expect that shredders are used in the recycling process in order to reduce the transported volume. The shredders will lead to an increase in collection costs but transportation costs will be the same as for glass. We will model this development by assuming that in 2020 the costs are twice the glass recycling costs or 30 ECU per tonne.

4.4 Liquid board

European Situation

Cartonboard is used to pack liquids for a long time. The Tetra Classic was introduced as early as in 1952 [PPI, 1996]. The most important markets for liquid cartonboard are milk and juice packaging. Less important are wine, water, and soup packaging [PPI, 1996].

In the milk packaging market, it is expected that cartonboard will loose market shares to plastic bottles. Table 4.8 shows that the market for cartonboard in Europe has remained constant in the period 1992-1997 and that the market for blown bottles (glass and plastics) has increased (within this category a lot of substitution has taken place from glass to plastics). The table also shows that a decrease in the Cartonboard market is expected for 2002.

Table 4.8: Packaging of milk in 7 European countries (million units) [PPI, 1996].

	Cartonboard			**blown bottles**		
	1992	**1997**	**2002**	**1992**	**1997**	**2002**
Belgium	858	803	755	304	248	133
France	3609	3315	3319	713	703	669
Germany	5613	5659	3139		786	1965
Italy	3761	3996	4200	90	80	80
Netherlands	986	1034	1215			
Spain	2943	3348	3350	348	918	1235
UK	1641	1342	1006	605	1237	1615
Total	**19411**	**19497**	**16984**	**2060**	**3972**	**5697**

From Table 4.8 it can be read that England is the only country that uses almost as much blown bottles for milk packaging as cartonboard. The other European countries have a tradition that is more focussed on cartonboard.

For the packaging of liquids, cartonboard as mono-packaging would not be very suitable because it would not hold liquids. Therefore the liquid board is laminated with other materials like PE and aluminum. Tetra Briks for example contain 75%

carboard, 20% PE and 5% aluminum [Buelens, 1997]. Cardboard is used as middle layer with a PE and aluminum layer on the inside and a PE outer layer.

In 1995 Tetra Pak introduced a liquid cartonboard with a coating of Silicium-oxide. This glass coating improves the storage life of the product with a factor two. This option will be used for the packaging of juices [Johansen, 1995].

Recycling

Recycling of liquid cardboard is not as easy as for normal waste paper and paperboard due to the contamination with PE an aluminum. Still, projects are initiated by Tetra Pak to collect liquid packaging board. The packages are baled and shipped to several paper mills in Europe where the board is repulped and the PE and aluminum are separated from the pulp [Buelens, 1997]. Special pulpers are necessary to separate the fibers from the laminates. The PE fraction is burnt in cement kilns and the aluminum fraction is used in the production of cement.

Another recycling method is the production of a kind of construction board that is made out of shredded liquid cartonboard. The board is called Tectan and the production is an initiative of Tetra Pack. The shredded board-flakes are spread out in the shape of a plate and then heated to 170°C to form the board. The PE laminate layers melt and serve as glue in the process [Buelens, 1997].

Besides projects in Belgium and some private projects in The Netherlands, the recycling of liquid cardboard has not taken a high rise in Europe yet.

Sizes and improvement options

The cardboard liquid package is not expected to undergo radical changes in future years. To keep up the competition strength more plastics may be used for easier openings and better closures. Material savings are reported by increasing the size of the 1 liter package to 1.5 liter. This saved 9% packaging material per liter [SVM, 1994]. We will model the liquid carton as a one liter package that weighs 28 grams [SVM, 1994]. In table 4.9 the basic characteristics of the package is stated.

Table 4.9: Characteristics of liquid carton in 2000 in Europe

	Total	liquid board	PE	Aluminum
Weight (gram)	28.0	21.0	5.6	1.4
Volume (liter)	1			

4.5 Metal packaging

The European market

In 1995 around 4 million tonnes of packaging steel was used in Europe compared to 3.8 million tonnes in 1993. Furthermore another 3.1 million tonnes of aluminum was used. The aluminum consumption also showed an increase compared to 1993 when total consumption amounted to 2.7 million tonnes [Depijpere, 1996].

For the beverage market 14.3 billion steel cans were used in 1995. The consumption of aluminum cans in the beverage sector was even larger (17.5 billion cans).

In Europe there is a strong competition between steel and aluminum beverage packaging. Almost all lids of European beverage cans are made out of aluminum while 50% of the bodies of the cans are made out of steel and another 50% out of aluminum [Depijpere, 1996]. In the U.S. the situation is totally different. Almost all cans that are used in the beverage industry are made out of aluminum (95%) [Meert, 1995]. Table 4.10 states the use in beverage cans for different European countries.

Table 4.10: Use of beverage cans in Europe (in million cans) [Meert, 1995]

	Total	Steel	Percentage Steel
Germany	5900	5310	90%
United Kingdom	8278	1705	21%
Ireland	260	40	15%
Italy	1650	15	1%
Greece	720		
France	1500	1275	85%
Spain	2400	1800	75%
Portugal	190	75	39%
Belgium / Luxembourg	634	580	91%
Netherlands	600	570	95%
Denmark	0	0	
Total	22132	11370	51%

For food cans the situation in Europe is entirely different. Tin-plated steel commands 100 percent of the food can market [Abbott, 1995]. The size of the “steel” food market is estimated at 2000 ktonnes [Meert, 1995, Depijpere, 1996].

The competition between steel and aluminum is influenced strongly by the prices of both metals. Some packaging manufacturers have substituted their feedstock to steel because of the price developments in the last years. Contrary to steel, which has shown a very stable price level in the last 25 years, the prices of aluminum have fluctuated strongly. Price differences of $900 per tonne are not uncommon with an average of $1800 per tonne [van der Ent, 1995].

Another development that influences the position of steel is the strong technical improvements that have been made in the last few years. The quality of packaging steel improved dramatically and the thickness of the steel plates is reduced significantly. So the weight difference between aluminum and steel packaging is reducing.

Recycling is fairly easy for both metals. Steel is magnetic so large scale recycling of steel cans is possible because they can be collected by strong magnets at incineration plants. Aluminum cans are not very difficult to recycle either. Eddy Current systems at waste separation plants can separate the aluminum packaging from the other materials. Large amounts of waste is still landfilled in Europe so for 2000 fairly low recycling rates should be modeled in the MARKAL-model.

Technological developments in packaging steel

Lighter beverage cans

Many developments have been going on in the last decades to reduce the weight of steel cans in order to save materials costs. In the last decade the weight of steel cans have been reduced by 20% [Depijpere, 1996]. To reduce the weight of the steel can, two main routes can be followed. First, the steel wall thickness can be reduced and on the other side the diameter of the (aluminum) lid can be reduced.

Not too long ago the standard diameter of the aluminum lid at a steel can was 208 (58 mm). At the moment Europe is working on the introduction of the 202 can (52 mm) that should replace the current 206 can. This means a saving of 1.3 grams compared to the old lid.

The current body of a steel 33 ml can weighs about 27 grams. It is already possible to produce a steel can that weighs 23 grams. Hoogovens is working on ultra thin steel that should make it possible to produce cans that weigh 18 grams in 2000 [van der Ent, 1995, Depijpere, 1996, van Deijck, 1994]. The wall thickness is then reduced to 0.09 mm.

All steel beverage can

A new development in the steel can business is the introduction of the all steel can. The can is developed by Hoogovens, British Steel and Rasselstein. The difference with the normal steel can is the steel ‘push in’ lid. The advantage of the all steel can is that the can be recycled entirely. Aluminum that normally is part of the can, can not be recycled because it is incinerated in the recycling process [van Deijck, 1994].

The lid of the all steel can weighs about 8 grams. The total weight of the all steel can in 2000 will be around 26 grams.

Lighter food cans

A half a liter food can weighs 47 grams at the moment in stead of 63 grams in 1985 (savings of 25%). The liter cans weigh around 88 grams in stead of 115 grams in 1985 (savings of 35%) [van Stijn, 1996].

Continental Can is currently working on a 'honeycomb can'. This can has a honeycomb structure which makes the can stronger. Currently cans already contain slots what makes the can stronger to withstand forces from the side. The honeycomb structure also works for withstanding vertical forces. This structure makes it possible to produce a can that weighs 30% less [van Stijn, 1996].

We expect the market penetration to be lower then 100% because labels can not be attached as easily and the printability is worse than for normal cans.

Technological developments in packaging aluminum

The developments in aluminum cans are very similar to the developments in steel cans. Producers have also been working on reducing the weight of the cans. The current body of an aluminum can weighs around 11.5 grams. The current 202 lid weighs another 2.7 grams, instead of the 3.9 grams of the old 208 lid) which leads to a total can weight of around 14 grams [Depijpere, 1996, van der Ent, 1995].

Alcan, a large aluminum producer, estimates a reduction of the current wall thickness of 0.312 mm to 0.241 mm in 2000. The body of the can will weigh 10 grams. By using a 202 lid the total weight of the can will add up to 13 grams [Goddard, 1994]. It is expected that a total weight of 10 grams can be reached in the future [Goddard, 1994].

Sizes and improvement options

To model metal packaging in the MARKAL-model we will use the weight of the different cans that are mentioned above. The all steel can and the weight reduction figures will be modeled as improvement options. In Table 4..11 the input figures are stated. Table 4.1 also states the year of implementation which represents the year that the option is technically mature which of course is no guarantee for actual implementation.

Table 4.11: Standard and improved steel packaging 3

	steel (gram)	Aluminum (gram)	volume (liter)	Year of implementation
Standard steel bev-can	23	2.7	0.33	2000
Standard alu bev-can		14	0.33	2000
Standard steel food can	47		0.5	2000
Ultra thin steel bev-can	18	2.7	0.33	2000
all steel bev-can	26	2.7	0.33	2000
Ultra light alu bev-can		13	0.33	2000
Super ultra light alu bev can		10	0.33	2020
Honeycomb food can	33		0.50	2000

4.6 PC and HDPE bottle

The poly-carbonate (PC) bottle and the HDPE bottle are taken together in this paragraph because they compete both with the glass bottle and the liquid cartons in the milk market and they both are used in small parts of Europe.

The HDPE bottle is especially popular in England where it is used in sizes varying from 1 to 6 pint (0.5 – 2.8 liter). The market share of the HDPE bottle is growing with a minimum of 10% since 1986 [Melchior, 1997]. The HDPE-bottle is not reused but recycling programs are set up for HDPE recycling.

The PC-bottle is introduced in March 1996 on the Dutch market to replace the glass bottle. The PC bottle is a light bottle (80 grams for a one liter bottle) and it can be reused about 30 times. Afterwards they can be recycled to other products like pallets and crates. Production of new PC bottles out of recycled PC is prohibited in The Netherlands due to hygiene considerations [Anon. 1996a].

Sizes and improvement options

Both the HDPE bottle and the PC bottle might be options to replace the earlier described packages. The PC bottle is an option if it is used as a multi trip package while the HDPE bottle is used as a one-way bottle. We will use the PC bottle as improvement option for the packaging of milk. No data were collected on the improvement of the PC bottle.

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3 Year of implementation states the year in which it is technically possible to use the packaging option. Due to many implementation barriers and time needed for production changes only small penetration grades are expected in 2000 for the improvement options. For the standard options 2000 is stated as year of implementation because the first years that is modeled in The MARKAL model is the year 2000.

Table 4.12: Characteristics of the refillable PC-bottle

	material	weight (gram)	trip-number	volume (liter)
PC bottle	PC	80	30	1

4.7 Plastic Pouch

Both Tetra Pak and Elopak have introduced flexible packaging (pouches) for milk and juice packaging. The pouches are made out of plastic. Tetrapak uses LLDPE and Elopak uses multiple layer PP laminates [Couwenhoven, 1996].

The advantage of using pouches for liquid packaging is that they are extremely light. An empty 1 liter pouch from Elopack only weighs 10 grams while an empty 1 liter pouch from Tetra Pak only weighs 4 grams.

The pouches are harder to handle than non-flexible packaging. After opening they need to be set into a multiple use can. Even though the pouches have a very small cost price, it is not expected that they will gain a large market share in Europe [Couwenhoven, 1996]. Because this option is not as easy to implement we will model this option by using a maximum bound of 50%.

Sizes and improvement options

We will model pouches as (light weight) improvement option for the packaging of liquids. No improvement of the pouch will be modeled because the pouch itself is an improvement option. We will model pouches with the characteristics of the Tetra Pak pouch. In Table 4.12 the characteristics of the pouch are stated.

Table 4.13: Characteristics of flexible liquid packaging (pouch).

	material	weight (gram)	trip-number	volume (liter)
Pouch	LLDPE	4	1	1

4.8 Thermoformed cups

Cups made from thermoformed plastics are used for packing of yogurt and butter. Popular materials are PS, PP and PVC with market shares of respectively 52, 15 and 25% [APME, 1996]. The total amount of thermoformed plastic used in Europe is 1220 ktonnes. A large part of this is used to produce plastic boxes for the food and non-food sector.

The thermoformed cups are used in a market segment that has a total magnitude of 19 Mtonnes (estimate based on EC (1996)). 10% of this is butter and the other 90% is yogurt consumption.

Butter cups are typically made from PP (80%) and a smaller amount from PS (20%). A typical PP cup with a capacity of 500 grams weighs 19 gram and a PS cup is slightly heavier (22 grams). Yogurt cups with the same capacity weigh less. A PS cup (market share of 90%) weighs 14 grams and a PP cup (market share of 10%) weighs 12 grams [Phylipsen, 1993].

We will model two cups. One is made from PS and has a weight of 14 grams and capable of packing 500 gram product. The other cup is made from PP and weighs 12 gram.

5 Current and future material input for non-food bottles

Non-food bottles are used to pack shampoos, detergents and other cleaning liquids, lubricants, and light cleaning chemicals. Contrary to food bottles not as many different materials are used to pack the liquids. The food sector puts high demands on the quality of the material because factors like CO_2 and oxygen permeability are very important for the durability and quality of the packed product. In the non-food sector these factors are less important.

The main material used to produce non-food bottles is HDPE. We estimate the amount of non-food bottles on the HDPE blow moulding data for Europe. In 1994 about 1125 ktonne HDPE bottles were used in Europe [APME, 1996]. Besides non-food bottles also the U.K. milk bottles are made out of HDPE. We estimate the amount of HDPE used for U.K. milk bottles at 75 ktonnes based on Table 4.8. This leaves 1050 ktonne HDPE for non-food bottles.

For the Markal model is it necessary to calculate a demand for non-food bottles in Europe. By defining a standard HDPE non-food bottle of 0.5 liter that weighs 50 gram we calculate a demand of 21 billion bottles. In Table 5.1 these assumptions and definitions are summarized.

Table 5.1: Demand and definition of non-food bottles in Europe

Material	HDPE
Volume (liter)	0.5
Weight (gram)	50
demand (ktonnes)	1050
demand (billion units)	21

5.1 Improvement options

To make a more efficient use of materials many projects have been taking place in order to reduce the amount of packaging material for non-food bottles. The most important options are listed below.

- Increase of the packed product quantity has led to savings of 10-14% [SVM, 1994, SVM, 1996].

- Concentration of the packed product has led to very large material saving. This measure is especially important in the detergent and cleaning product market. Material savings of 10-66% have been reported in The Netherlands in the last few years [SVM, 1992, SVM, 1994, SVM, 1995, SVM, 1996].

- Shape renewal is also an attractive material saving option. In the shampoo and bath lotion market savings of 9 – 20% have been reported [SVM, 1994, SVM, 1996].

- The use of thinner material is an option that has been used in many different non-food market segments. Savings of 14 – 25% have been reported but savings of 20% were most common [SVM, 1995]

- The pouch is a possible light weight substitute for the HDPE bottle. The pouch is described earlier in the food bottle section. Savings of almost 50% have been reported [SVM, 1994].

- The last option for material savings is the use of recycled material. Because no foodstuffs have to be packed in the bottle legislation towards the use of recycled materials is not as strict as it is for food bottles. For shampoo bottles percentages of 25% recycled material content have been reported and one bottle types uses 80% recycled material [SVM, 1992, SVM, 1994].

Making use of the options that are listed we are able to model several alternatives for the standard HDPE non-food bottle. In the next section these alternatives are described.

-25% non-food bottle

The options stated above can be separated in options that are very easy to implement because they have no effect for the product filling line or the handling of the package while other options require a higher degree of adaptation by the producer or the consumer. Options in the first category are the increase of product quantity, thinner material, shape renewal, and in some cases concentration. The latter is of course an adaptation in the packed product itself but very often these measures are very easily implemented [Anon., 1994]. For 2000 we may expect that many of these measures have taken place to some degree. We estimate that the material consumption by non-food bottles in 2000 can be reduced by 25% by implementation of these measures.

We will model this material reduction as a non-food bottle that is reduced in weight by 25%.

Pouch

Besides these easy to implement more radical option are possible like the introduction of the plastic pouch. This pouch will be modeled as a flexible package made out of HDPE that weighs 5 grams and has a volume of 0.5 liter (based on Elopack pouch as stated in paragraph 4.7). We estimate that pouches can have a maximum market share of 50% in 2020 (second target year in the MARKAL model).

Use of recycled HDPE

Another option that will be modeled separately is the use of recycled HDPE. Shares of recycled material that have been used today are typically 25% [SVM, 1994]. We expect that 50% recycled material should be possible for these types of bottles. Furthermore we have not found technical barriers for a 100% implementation of these types of bottles. Therefore we will use a maximum implementation level of 100%.

Use of a refill system

The refill option has large potentials. Savings up to 80% are not uncommon. The refill system works as follows: first, a multiple use bottle containing the product is sold. Then the consumer can buy a refill package that is lighter than the original bottle. Often, no closing system is added to the refill package so the content needs to be poured in the multiple use bottle. Two refill systems are possible: the pouch and the cardboard package. The pouch is already modeled above and we will model the carton for a market segment of 20%. This option is not complementary to the plastic pouch. Based on the liquid cardboard package as defined in § 4.4 we define a 0.5 liter cardboard pack that weighs 14 grams and consists of 80% cardboard and 20% PE.

In Table 5.2 the characteristics of the improvement options of the standard bottle are stated. Also the possible market share is stated.

Table 5.2: Characteristics of improvement options for non-food bottles

	HDPE (gram)	Recycled HDPE (gram)	cardboard (gram)	volume (liter)	Year of implementation	max penetration (%)
Light non-food bottle	37.5			0.5	2000	100
Pouch	5			0.5	2000	50
Recycled bottle	19	19		0.5	2000	100
Refill package	3		11	0.5	2000	20

6 Current and future material input for boxes as primary packaging

6.1 Food and non-food boxes

The category ‘boxes (primary packaging)’ consists of all the non-flexible packaging that is used as primary packaging to pack food and non-food products. Both food and non-food are taken together in this category because from a modeling perspective, the packages are not very different from each other.

In real life, the difference is obvious. Primary food packaging has to deal with many regulations concerning the transfer of contaminants of the package to the packed products. This has immediate consequences for recycling. An example is the new PC milk bottle in The Netherlands. This bottle can not be recycled into a new milk bottle due to the current Dutch regulations in this field.

Another large difference is that food must be kept fresh in the package while this is not the case for many non-food products. In the food packaging sector, inner bags are often used to keep the product fresh and an outer box is used for protection and commercial purposes. The food packaging market also makes use of laminates to cover the inside of boxes and thereby increase the lifetime of the packed product.

When these boxes are modeled however the majority of the packaging materials are the same and many similar reduction options are possible. Another reason to model the two groups together is the lack of information about the share of boxes used for the packaging of food and non-food.

6.2 Materials for boxes

To estimate the amount of boxes used as primary packaging in Europe we make use of statistics on the materials that are used to make the boxes. Most boxes in this category are made out of cardboard. Examples are boxes to pack washing powder, shoes, nails, toys, chocolate sprinkles, and cookies. To estimate the amount of boxes we can make use of the statistical data on cardboard packaging.

In PPI (1997) the total amount of packaging board consumption in Western Europe is estimated at 4.8 Mtonnes. This includes all the types of board that are not used to produce corrugated board. The main board type in this category is cartonboard which consists of boxboard, folding boxboard, solid bleached sulfate and graphical board. The category also includes liquid packaging board as used to make cartons for milk, for example. This all means that the amount of 4.8 Mtons is an overestimation of the amount of board used to make boxes. Subtracting the share for liquid packaging (745 ktonne, see Table 12.2) leaves 4.1 Mtonnes of board.

Besides cardboard, also plastic is a popular material for the production of boxes. The boxes made out of plastics have a totally different character than cardboard boxes. In the food market they are used to pack fresh products like mushrooms, strawberries, and meat products. Furthermore they are used as trays to pack cookies and bonbons.

In the non-food packaging market, plastic boxes are often used for trays, small boxes and blister packaging.

In general plastic boxes have very thin walls and are not very durable. Due to these characteristics we estimate that the majority of these boxes are made out of thermoformed sheets. Furthermore we estimate that the majority of the thermoformed sheets that are used as packaging are part of the category ‘boxes’.

In Europe the amount of thermoformed sheets that are used as packaging is 1220 ktonnes in 1994 [APME, 1996]. We will use this number as an estimate for the amount of plastics in Europe that are used for plastic boxes.

6.3 Improvement options

A large number of actions have taken place in The Netherlands during the past years to decrease the amount of packaging material in boxes due to the influence of the packaging covenant. Many of these options are based on the removal of unnecessary packaging material. Several of these types of options are listed below.

It is not seldom possible to use smaller boxes for the same packaging purposes. Reduction percentages of 12% are reported if nothing else is changed to the way the products are packed except the removal of unnecessary material [SVM, 1992, SVM, 1994]. In the DIY sector saving of 15% have been reached by reducing box sizes [Couwenhoven, 1992]

When a combination of packaging materials are used like plastic trays in a cardboard box options are demonstrated where the tray is removed leading to a smaller outer box. Reduction possibilities of 20% are reported [SVM, 1994].

Sometimes the complete outer box can be removed if the package contains a flexible inner sack. The flexible package is in some cases enough protection for the product. Reduction possibilities are very large; savings up to 63% have been reported [SVM, 1995, SVM, 1995, SVM, 1996]. A famous example of the removal of boxes is the removal of the cardboard box around toothpaste tubes.

Increasing the product quantity has led to savings on packaging material. Savings op to 55% have been reported [SVM, 1996].

In the field of detergents and washing powders large savings have been reached by concentration of the product. By means of concentration less product is needed for the same function so less products need to be sold which results in smaller packages. Typical savings for detergents are about 20% [SVM, 1994, SVM, 1995]

Thinner material is often possible. Typical savings are 10-12%. The Finnish paper and board producer Enso has developed a board that is 10-20% lighter than normal packaging board and has the same strength [Anon., 1997]

Refill packages can lead to large material savings. In the case of washing powders the typical cardboard box is replaced by a paper bag that can be placed in a multiple use cardboard box at home. This option leads to material savings of 80 – 90% [SVM, 1994, SVM, 1995].

Material substitution has been common practice in blister packaging. Many blisters that were a combination of a plastic box on a cardboard sheet have been replaced by a 100% cardboard box [SVM, 1994, SVM, 1995, Van der Kort, 1992]. This option can reach large savings on one way plastic packaging, especially in the DIY sector.

The options as stated above show that large savings are possible by seeking optimum packaging solutions in terms of size, material thickness, shape and function. Some of the above described options may already be implemented in Europe for some products. We estimate that 20% reduction of the amount of cardboard and plastic used for boxes can be reached by seeking optimal packaging solutions in terms of material use at no cost and without large changes in the packaging process.

6.4 Modeling boxes

Definition of model boxes

To model the category boxes for the Markal model we will define two basic types of boxes: the cardboard box and the plastic box. In the case of food packaging many cardboard boxes contain an inner bag made out of plastics or paper. Therefore we will define a cardboard box with and without an inner bag. The standard cardboard box has a volume of 1 liter and weighs 35 grams. The inner bag will add another 3.0 grams to the weight of the box in case of a PE bag (see paragraph 7.4). In case of a paper bag the additional weight is 7 grams. A market share of 20% of the cardboard box market is assumed for the box with the inner bag. The plastic box will contain some cardboard in order to simulate the share of blister packaging. We will define a plastic box with a volume of 0.5 liter that contains 10 grams of plastics (HDPE). Furthermore it contains 2 grams of cardboard to include the blister packaging in the model.

Definition of improved model boxes

Based on the description of the improvement options we define a cardboard and plastic box that is reduced in weight with 20%.In the case of the cardboard box with an inner bag we will model the possibility to remove the box in Chapter 7. This is a substitution of structural to flexible packaging. For the plastic box we model the possibility to substitute plastic by cardboard. In some cases it is possible to remove the inner bag due to sealing of the cardboard box. This option will also be modeled. Table 6.1 states the data that will be used to model boxes for primary packaging in the Markal model. The level of penetration of the improvement options is related to the packing that is replaced. The sealed box for example can replace 100% of the cardboard boxes that contain a bag but the latter only has a market share of 20% of the cardboard boxes. Technically all penetration figures are possible for 2000 but due to implementation barriers and the needed time to change over the actual penetration will be very much lower. The penetration grades as stated will be used in the MARKAL model for 2020.

Table 6.1: Characteristics of boxes for primary packaging

	Volume (liter)	Cardboard (gram)	PE (gram)	PE foil (gram)	penetration (%)
Cardboard box	1	35			80
Cardboard box + bag	1	35		5	20
Plastic box + blister	0.5	2	16		
light cardboard box	1	28			100
light cardboard box + bag	1	28		4	100
light plastic box + blister	1	1.6	8		100
Sealed box	1	28			100
Cardboard blister	0.5	17.5			20

7 Current and future material input for flexible packaging

Because of their large similarity - a bag can be seen as film that is stitched or sealed to form a bag -, flexibles, films and bags are discussed simultaneously.

From a materials point of view this group of packaging materials basically consists of three subgroups: plastic films, paper wrappings and aluminium films. Plastic films can be further broken down into different types of monolayer films, laminates with different combinations of plastic layers and coated films consisting of different plastic carrier layers with different coatings. Furthermore laminates of plastics and/or paper and/or aluminum also belong to this group.

7.1 Western European market

The market for flexible packaging is rapidly changing. There are a lot of different films, with thicknesses of 15 to 1000 µm, consisting of different plastic types and sub-types. The number of monolayer film types is even exceeded by the number of multilayer films, the layers of which can be freely combined to achieve specific combinations of film properties. Multilayer films are facing a growing popularity, they already make up about 70% of food films (Klok, 1997).

The total European market for flexible packaging amounts to some 5.5 million tonnes, of which PE films are estimated to contribute with 3.25 million tonnes (Duffy, 1996). According to the APME (1996) 47% of plastics used for packaging purposes in Europe in 1994, so 5.2 million tonnes, was used as film. Table 7.1 shows the materials used for plastic films. Industrial packaging films are included.

Table 7.1: Plastics films consumption, Western Europe [kton], 1990, 1992, 1994 (APME, 1992, 1994, 1996) and 2000 (estimated)

Plastic type	1990	1992	1994	2000
LDPE (incl. LLDPE)	3420	3460	3666	4000
HDPE	521	480	544	560
PP	600	645	787	1050
PVC	74	67	73	50
PET	37	50	66	110
others	41	48	55	50
total	4693	4750	5191	5820

In 1990, 4240 kton of LDPE films were produced in Europe (APME, 1992). The trade balance of films was approximately zero, so consumption of films in Europe amounted to 4240 kton also. 3420 kton of these were packaging films, the rest (20%) consisting of refuse bags, agricultural films and other non-packaging films. Packaging films were subdivided as follows (Table 7.2): industrial packaging: 52%, food packaging: 41%, non-food consumer packaging: 7% (APME, 1992).

Table 7.2: European consumption of LDPE packaging films [kton], 1990 (APME, 1992) and 2000 (estimated)

Packaging category	1990	2000
Food packaging		
bread bags	38	44
deep freeze	101	118
stretch	24	28
extrusion coating	380	440
laminates	250	300
other food packaging	623	730
Total food packaging	1416	1660
Non-food consumer packaging		
diapers packaging	24	28
other non-food packaging	200	230
Total non-food packaging	224	258
Industrial packaging		
shrink covers	360	420
shrink film	290	340
stretch film	300	350
heavy duty bags	460	540
small carrier bags	370	430
Total industrial packaging	1780	2080
Total	3420	4000

For the other plastic types (HDPE, PP, PET, PVC) no specific consumption data is available. Consumption of PP films is growing quickly (over 6% annually (Beer, 1996)). Therefore, we assume that in the year 2000, 1050 kton of PP packaging films are used: 950 kton for food packaging and 100 kton for non-food consumer packaging. PET consumption has show a very rapid increase (20% annually between 1993 and 1997 (Clauss *et al.*, 1996)). This mainly applies to PET bottles. However, we assume that by the year 2000, PET consumption for packaging films has grown to 110 kton. Consumption of PVC films is decreasing rapidly for environmental reasons. Currently, PVC packaging films are mainly used in the Southern European countries. Probably, after the year 2000 PVC films only play a marginal role. Therefore, we will not take them into account. Furthermore, we assume that by the year 2000 10% of PE and PP food and non food films are replaced by metallocenes. (Metallocenes will be discussed in paragraph 7.3.)

For the year 2000 plastic packaging films consumption is expected to be:

Table 7.3: Plastic types in packaging film consumption, Western Europe, 2000 (estimated)

	Consumption 2000 [kton]
Food packaging films	
Low barrier	
LDPE	1225[1]
HDPE	180
PP	585
metallocene	220
Total food low barrier	2210
High barrier	
LDPE	270
HDPE	45
PP	270
PET	110
metallocene	65
Total food high barrier	760
Total food	2970
Non-food consumer films	
LDPE	235
HDPE	35
PP	90
metallocene	40
Total non-food	400
Industrial packaging films	
LDPE	2080[2]
HDPE	270
Total industrial	2350
Total plastic packaging films	5720[3]

[1]Including extrusion coatings (440 kton) (Table 7.2)
[2]Including heavy duty bags (540 kton) and small carrier bags (430 kton) (Table 7.2)
[3]Total does not match total of Table 7.1 (5820 kton), because of omission of PVC (50 kton) and 'others' (50 kton).

Food films

For food packaging, barrier properties for moisture and gasses, especially oxygen and carbon dioxide, play a crucial role. PE and PP show relatively high permeabilities. PVC and especially PET are better barriers for moisture, oxygen and carbon dioxide. Most food needs to be packed cut off from the outer atmosphere in order to stay fresh, crisp and tasteful. The recent trend to modified atmosphere packaging to enhance food shelf life also asks for packaging materials with good barrier properties, in order to 'keep the modified atmosphere in'. However, if no modified atmosphere is used, fresh fruit and vegetables have to be packed in films with low barrier properties. They need to be able to breathe, so that the ripening process can proceed. The same applies to fresh meat, which has to be able to breathe in order to maintain its red colour.

So food films are divided between low barrier films and high barrier films. In this report this division is made based on the following definitions: *Low barrier films* are films which can be used if barrier properties are not needed. *High barrier films* are films which can be used when barrier properties are obligatory. In practice, all kinds of barrier films exist, with moderate to excellent barrier properties. We only make a division: barrier properties YES or NO. Most of the high barrier films are multilayer films (coextruded laminates or coated films), whereas low barrier films generally are monolayer films. Although this is no universal rule we identify high barrier films with multilayer films (including coated films) and low barrier films with monolayer films.

Barrier properties also depend on film thickness. This means that reducing film thickness also reduces the barrier properties and consequently the shelf life of the packed food. Therefore, reducing film thickness, to meet dematerialisation demands, needs to be accompanied by material quality improvement, in order to keep barrier properties intact.

Mechanical properties are also of major importance. Rigidity is a function of the E-module and film thickness. Two films of different plastic types have the same rigidity if:

$$(d_1 / d_2)^3 = E_2 / E_1$$

where d_1 and d_2 are the thicknesses and E_1 and E_2 the E-modules of the films (Kohlert *et al.*, 1992), (Willems, 1997). In Table 7.4 E-modules of commonly used plastic film types are given, as well as the relative thickness compared to LDPE.

Table 7.4: E-modules of commonly used plastic types (Kohlert *et al.*, 1992) and relative film thickness (compared to LDPE) to obtain the same rigidity

	E-module [N/mm^2]	Relative film thickness [-]
LDPE	300	1
HDPE	1000	0.67
PP	1000	0.67
PET	2650	0.49
PVC (rigid)	3000	0.46

This table shows that, insofar only rigidity is concerned, replacing LDPE films by HDPE or PP films, a thickness reduction of 33% can be obtained. With PET and PVC even reductions of 51% and 54% respectively can be obtained. Currently, PVC films are not used intensively: especially in Northern Europe they suffer from a negative environmental image (Willems, 1997). PET films are only used for food applications.

In The Netherlands, the Packaging Agreement has induced many initiatives to reduce film thickness. Thicknesses of part of present film packaging can be reduced without affecting principal properties, simply by choosing the same film with a lower thickness (SVM, 1993, 1994, 1995, 1996), (Holton *et al.*, 1995). There are still products that are packed using more materials, with thicker films than necessary. Especially in Southern European countries, where Packaging Agreements or other governmental measures are not taken until yet, there is a large potential for material savings through film thickness reduction. We assume that for Europe as a whole an overall reduction of 10% can be achieved by choosing thinner films of the same material. We modelled this as autonomous development in the year 2020.

Low barrier food films

Improved plastic materials allow thinner films. Improvements can be related directly to barrier properties. But also other properties, which formerly stood in the way of application as packaging for specific products, can be improved so that application becomes possible. Examples of the latter properties are: heat sealability, temperature resistance and processing properties.

LDPE and LLDPE have low barrier properties for moisture, oxygen and carbon dioxide, as stated above. This make them suitable as packaging for fruit, vegetables and meat, but for food that is susceptible to oxidation or of losing aromatics it is less suitable. Heat sealing is easy, but heat resistance is limited. So 'boil in the bag' applications and heat filling are impossible. Examples of (L)LDPE food film packaging are: bread bags, sandwich bags, frozen food bags, etc.

HDPE has better moisture barrier properties than (L)LDPE; gas barrier properties are comparable. It has higher heat resistance and stiffness, but heat sealing is problematic. These properties make HDPE usable for wet food that is not susceptible to oxidation or of losing aromatics. The improved properties allow thinner films.

PP properties are comparable to those of HDPE. Toughness and clarity are improved considerably by (biaxially) stretching. Therefore, OPP or BOPP (oriented or biaxially oriented PP) already makes out the major part of PP films (Goddard, 1990). PP films usually contain 2 - 13% PE (random copolymers / block copolymers), mainly to reduce the brittleness of PP beneath 0°C (Goddard, 1990).

PET films could be a possibility to reduce material demand for packaging films. It allows a thickness reduction of up to 50% as compared to LDPE (Table 7.4). Because of its relatively high barrier properties it is currently mainly used for high barrier coextrusion films. PET is not heat sealable. Therefore, the potential for one layer PET films is limited. Its potential can be enlarged by adding a LDPE layer, which enables heat sealing. This, however, increases film thickness and, therefore, partly cancels out thickness reduction.

Currently, new, **metallocene** catalysts are being developed, which allow much better polymerisation control. This leads to polymers with enhanced properties, which are also better controllable. Metallocene catalysts can be used in slurry, solution, high pressure and gas phase processes to polymerise PE, PP and PS. Currently, metallocene PE and PP are commercially available, whereas metallocene PS is still under development. Metallocene polymers can be used as single components, or in blends with conventional Ziegler-Natta polymers. They can be used both in mono- and in multilayer films. Metallocene polymers show enhanced toughness, strength, transparency, heat sealability and heat resistance (the latter especially applies to metallocene PP), but barrier properties are comparable to conventional olefins. (Anonymous, 1995), (Anonymous, 1996), (v. Stijn, 1996), (v. Stijn, 1997). Currently, prices are still high (caused by high prices of metallocene catalysts) and processability is relatively poor. Both problems are minimised by using blends of 10-30% metallocene polymers (Macdonald, 1997). In the nearby future, prices are expected to decline (Anonymous, 1996). Metallocene polymers allow thinner films. Compared to monolayer Ziegler-Natta PE films, metallocene PE films can be about 20% thinner; for multilayer films metallocene PE offers less thickness reduction potential.

For food, **paper** monolayer wrappings and bags are of limited use, because they can only be used for dry products. Because of very limited barrier properties, it can only be used for products that are not susceptible to moisture or loss of aromatics. Therefore monolayer paper food packages are only used for products like sugar, meal etc. Laminates of paper and plastic (LDPE) or aluminium have broader application because of better barrier properties, better sealability and less moisure sensibility.

Aluminum film is mainly sold as rolls and is used to pack lunches *etc.* This way, the excellent barrier properties of aluminum are poorly used, because of limited closing.

High barrier food films

Laminates are films consisting of two or more layers of different materials. Mainly, one layer is chosen because of the material's excellent barrier properties, the other layer serves as carrier: it supplies strength or fine optical appearance to the film, or it is chosen simply because the barrier material is too expensive to be used as monolayer film. Laminates either consist of two or more different plastics, or of a plastic with another material (e.g. aluminium or paper), or of two materials other than plastics (e.g. aluminium / plastic).

Good barrier properties in food packaging are especially needed in aseptic and conditioning packages. Typical food products that are packed in laminates are: bakery products, meat products and other foods like soups, coffee, snacks, cheese and microwave meals. Non food products packed in high barrier laminates are: tobacco, medicines and surgical appliances. whereas they are also used in stretch films.

Barrier properties of plastic films can be improved by applying a thin layer of material with high barrier properties. Barrier materials that are used for this purpose are, amongst others: PVdC (Polyvinylidene Chloride), EVOH (ethylenevinylalcohol), PA (polyamide) and OPET (oriented PET). Usually they are coextruded with carrier layers of PE or OPP. But for special purposes, all kinds of combinations, with up to twelve layers, are possible.

With laminates it is possible to achieve barrier properties that, using monolayer films, would be impossible, or only achievable with very thick films. E.g. a laminate of a 26 μm OPP (oriented PP) carrier layer, weighing 24 g/m^2 with a very thin PVdC barrier layer of 2.5 g/m^2 had to be weighing 1320g/m^2 to achieve the same oxygen barrier with monolayer OPP (Vandendael, 1992). An additional advantage of PVdC and EVOH layers is formed by their good heat sealing properties (Klok, 1997).

Within the group of laminates there is a possibility to reduce film thickness further. E.g. a 100 μm four-layer film of 2 OPP carrier layers, one EVOH barrier layer and one PE layer (for enhanced heat sealability), weighing 96 g/m^2, has the same barrier properties as a 159 μm two-layer PA/PE film, weighing 152 g/m^2 (Johansen, 1997). Film thickness can be reduced without affecting barrier properties by using metallocene PE or PP instead of their Ziegler-Natta equivalents. This way, e.g. the thickness of *e.g.* OPA (oriented polyamide) / PE laminates can be reduced by about 15% (Van der Kort, 19..).

In principle, coextrusion (laminated) films allow the use of recycled materials for inner layers. However, this procedure is more applicable for bottles than for films, because of the low thickness of films.

Because laminates consist of tightly attached layers of different materials, mechanical recycling of laminates is very difficult or impossible. This drawback has been an obstruction for the use of these films. Therefore, effort is made to develop materials with comparable barrier properties and enhanced recyclability. Du Pont, e.g. has developed a laminate consisting of a carrier of non oriented impact modified PET with a barrier layer of OPET. This results in a 15 µm film consisting entirely of PET, which should be easier recyclable (Bauhuis, 1991). Another development to enhance recyclability and moreover achieve further material reduction is the use of coated films, which will be discussed further on.

However, because most food wrappings end up in household waste and are heavily polluted, it is already very difficult to recycle them. So in practice mechanical recycling of food wrappings is not feasible, even if monolayer films are concerned. Apart from that, public opinion is shifting towards the perception that incineration with heat recovery (thermal recycling) is a good alternative for materials for which mechanical recycling is difficult. So limited recyclability becomes still less a drawback and the use of laminates is increasing rapidly. In The Netherlands the use of laminates is expected to grow 5-10% annually (Anonymous, 1993).

Carrier layers or barrier layers of non-plastic materials are also used in laminates. **Aluminum laminate** is used to pack food that needs very high barrier properties. It is widely used for coffee packaging, in order to maintain its highly susceptible aroma. The high barrier aluminum film is provided with an outside PE layer in order to allow heat sealing, as well as an inside PET layer. Aluminium / paper wrappings are used for butter, sweets and chocolate bars. Paper / plastics laminates are used e.g. for snacks. Because of the relatively high thickness of paper and / or aluminium layers, material reduction can generally be obtained by substitution of these laminates by all-plastic laminates or by coated plastic films. E.g. snack packages of monolayer OPP weigh about 30% less than a PET/paper laminate (Johansen, 1997). Substitution of a paper / aluminium laminate for butter packaging by a 5-layer OPP-based laminate enables a material reduction of 40% (Anonymous, 1996b). Another example: an all-plastic laminate with EVOH as barrier layer for coffee packaging weighs 30% less than a metallised inner package with outer paper wrapping and 60% less than a luxurious cardboard outer package together with an inner package of aluminum laminate (Anonymous, 1996b).

Coated films, films with a very thin coating of barrier material were developed, partly because of material reduction, partly because of better recyclability. Coated films consist of one or more carrier layers of PET, OPP or HDPE with a very thin barrier layer of about 0.04 µm. Coatings either consist of metals, mainly aluminium (*metallised films*), or of ceramics, mainly silicon oxide (*glass coated films*; ‘flexible glass’), but also aluminium oxide is used.

With respect to recycling, coated films (metalised as well as ceramic) can be regarded as monomaterials: The concentration of coating material is so limited as to be of no consequence for the recycling process.

Metallised films are produced by applying an aluminium coating to a plastic carrier layer. This is done by thermal evaporating of the metal in a high vacuum atmosphere. Coating layers have a thickness of 0.03 - 0.04 μm (Nentwig, 1991) and weigh about 0.05 g/m^2 (Daniels, 1991). Compared to aluminium monolayer films, only 1/100 (Nentwig, 1991) to 1/250 (Daniels, 1991) of aluminium is needed. PET and OPP are the most applied carrier materials, but in principle all plastic films can serve as such: PC, PA, PVC and HDPE films are also used. In general, relatively thin carrier films are used, allowing long runs per roll in the batch metallising process. The minimum carrier layer thickness is 9 μm for PET and 15 μm for OPP (Nentwig, 1991). A major application of metallised films is in chips packaging. A typical composition of metallised films for this purpose is: ca. 1.7 g aluminium for 1 kg of OPP carrier film (Daniels, 1991). In terms of layer thickness this corresponds to: OPP 18 μm, aluminium 0.035 μm. In The Netherlands, ca. 3000 ton of these chips packaging was used.

Metallised films have good barrier properties compared to monolayer plastic films. Compared to laminates, barrier capacities are competing (Daniels, 1991) or relatively limited (Nentwig, 1991). Because of good barrier properties, metallised films are very useful for chips, snacks, nuts and pastry packaging. Because of their luxurious appearance they are also used for packing other products that do not need their outstanding barrier properties. For coffee, however, barrier properties are not sufficient, because of coffee's very sensitive aroma.

Ceramic coated films are produced by electrolytic vacuum evaporating (Anonymous, 1991). As barrier layer, mainly silicon oxide (SiOx) is used, but aluminium oxide (AlOx) can also be used (SiOx has better properties). All plastics can be used as carrier layer. Coating thickness is about 1 μm (Johanssen *et al.*, 1992). Unlike metallised films, ceramic coated films are transparent. Ceramic barrier layers can also be used in laminates, for example PET / SiOx / PE or OPA / SiOx / PE (Spaeter *et al.*, 1997), (Johansen *et al.*, 1992), (Van der Ent, 1995). In these cases the PE layer is added to enhance heat sealability.

Films for non food consumer packaging

For non food applications, good barrier properties are generally not needed. So only the low barrier films options (LDPE, HDPE, OPP and metallocene films) are used for non food applications. For non food packaging films, rigidity is the most important material property. Switching to other materials allows higher reductions because less different material properties are of importance. In The Netherlands, the Packaging Agreement has induced many initiatives to reduce film thickness. By a whole range of measures, existing films can be reduced. E.g. Popla kitchen rolls, formerly packed in 55 μm films, are now packed in 45 μm films, which means a reduction of 18% (SVM, 1994). Probably similar thickness reductions are possible in other European countries as well. Therefore we assume an autonomous development of 10% overall thickness reduction by he year 2020.

Industrial packaging films

This category consists of two main applications: shrink films and covers on the one hand and stretch films on the other hand. Shrink films are used to bundle small amounts of products (collation shrink films). As such they compete with cardboard boxes. Shrink covers are used to bundle cardboard boxes on a pallet. The latter can also be achieved using stretch films. Shrink films and covers are winded loosely around the products or cardboard boxes and are subsequently heated in order to shrink and form a tight bundle. Stretch films are winded tightly around the cardboard boxes. Thereby they are stretched for about 30% (Zoethout, 1997) and are wrapped ca. 3 times around the load to be bundled. Stretching is less energy consuming than shrinking. Furthermore, stretching can be mechanised more easily. Shrink and stretch films are generally made of LDPE. HDPE has very limited shrinking and stretching properties and is, therefore, unusable as industrial packaging films.

In 1990, 360 kton of shrink covers were used in Western Europe, as well as 290 kton of shrink films and 300 kton of stretch films (APME, 1992).

7.2 Options

Food

Currently about 30-40% of food films have high barrier properties (Klok, 1997). Developments in packaging technology, like protective atmosphere packaging and the aim at higher shelf lives, suggest an increase of high barrier films in the nearby future. We assume that the percentage of high barrier films will rise to 50% in 2020.

Low barrier films

LDPE film

We define a standard low barrier film as a LDPE (or LLDPE) film of 40 μm. Currently this is standard film of moderate thickness. It is usable for heat sealing, but not for heat filling or 'boil in the bag'.

HDPE film

In food applications HDPE film does not play a major role (Table 7.3). Several properties like poor sealability, processabilty and printability make application difficult. Furthermore, PP has the same advantages as HDPE, combined with better sealability, processabilty and printability. Therefore, HDPE is not modelled in this study.

PP film

Because of its higher rigidity, PP films can be much thinner than LDPE films, without reducing the mechanical properties (Table 7.4). If only mechanical properties are taken into account, a 40 μm LDPE film corresponds to a 27 μm PP film. However, because also other properties have to be taken into account, average thickness reduction potential will be lower. We assume that, on average, a 30 μm PP film can replace the standard 40 μm LDPE film. Because of PP's brittleness at low temperatures, PP film is not usable for deep freezing applications (which amounted to 101 kton in 1990 (APME, 1992)). Therefore, application is limited to 90% of non food low barrier film applications.

Metallocene film

Metallocene films, made of metallocene PE / PP, are expected to replace their Ziegler-Natta equivalents during the next 15 years (Donkers, 1997). Because of the wide range of material properties to be expected to be achievable both with metallocene PE and with metallocene PP (Donkers, 1997), there is no need to discriminate between these two materials. Material reductions of 20% are feasible according to (Van der Kort, 19..). Mr. Tool of KIVO Volendam (Tool, 1997) expects that even higher reductions of up to 50% may be achievable. We estimate that a reduction of 20% is achievable. We assume that in 2000 20% of films are replaced by their metallocene equivalents. Because of its general better properties, in 2020 100% of LDPE, HDPE and PP films can be replaced by metallocene films

Paper

To enable substitution of plastic flexibles by paper bags, a paper bag is added as an option. We defined a paper bag made of 80 gram/m^2 paper.

Aluminum

In order to model current use of aluminum films on rolls by households, we modeled an aluminum film of 100 μm.

Table 7.5: Characteristics of food flexibles (films, bags), low barrier

	material	film thickness [μm]	maximum potential [%][1]	year
LDPE film	PE	40	80	2020
PP film	PP	30	90	2020
Metallocene film	PE / PP	24	20	2000
		22	100	2020
Paper		80 gr./m^2	100	2020
Aluminum film	Al	100	20	2020

[1]Maximum potentials are discussed in paragraph 12.6.

High barrier films

Laminates

Laminates that are mostly used are: PP (25-30 μm) with a barrier layer (2-3 μm) of PA, PVdC or EVOH (Klok, 1997). Therefore, we take as a standard laminate film a PP film of 30 μm with a PVdC barrier layer of 2.5 μm. PET films with PVdC or EVOH coatings are also used extensively. PET films can be thinner than PP films: 12-

20 μm is a common thickness (Klok, 1997). So we modelled as an alternative a PET film of 20 μm with a PVdC layer of 2.5 μm. As stated above, metallocene PP as carrier material can be 15% thinner than conventional PP (Van der Kort, 19..).

Coated films

Metallised films generally consist of PET (12 μm) with a coating of Al (0.04 μm). (Klok, 1997). An alternative carrier material, however less frequently used, is PP (18 μm). The latter is e.g. used for chips bags (Klok, 1997). Currently, metallised films make up the majority of coated films. Therefore we take them as representatives for the coated films. as option for MATTER. Analogue to laminates, we assume that 15% material reduction is possible by replacing conventional PP coated film by metallocene PP coated film. Because of the limited barrier of metallised and ceramic coated films compaired to laminates, a limited potential for all coated films together of 10% is chosen.

Aluminum laminate

Aluminum laminate is most extensively used for coffee packaging. Therefore, we take a coffee package as standard option for MATTER. Johansen (1997) describes a luxurious packaging consisting of a cardboard box with an inner bag made of PET / aluminum / PE laminate, which weighs 42.5 gram and packs 250 gram of coffee (approximately 0.5 liter). However, the majority of coffee packages has an outer paper wrapping instead of a cardboard box. To pack 1 liter of coffee, 2 packages are needed. Two luxurious packages weigh 85 gram. A one liter cardboard box weighs 35 gram (Table 6.1); we estimate that two ½ liter boxes weigh 40 gram. This means that for packing 1 liter of coffee, 45 gram of aluminum laminate is needed.

In 1990, 6.8 kton of aluminum laminate were used in The Netherlands (Anonymous, 1993b). For these, 5.0 kton of aluminum were used (Anonymous, 1992). Obviously, aluminum laminates contain 75% aluminum. The rest is divided between PET (15%) and PE (10%). Taking into account this composition, the densities of materials and the area of film (1000 cm^2) needed to pack 1 liter, we calculated a mean thickness for aluminum laminate of 200 μm, divided between: aluminum: 170 μm, PET 170 μm and PE (also 15 μm).

Table 7.6: Characteristics of food flexibles (films, bags), high barrier

	material	film thickness [μm]	maximum potential [%][2]	year
Aluminum laminate	PET / Al / PE	15 / 170 / 15	100	2020
PP laminate	PP / PVdC[1]	30 / 2.5	100	2020
PET laminate	PET / PVdC	20 / 2.5	100	2020
Metallocene laminate	PP / PVdC	25 / 2.5	20	2000
		23 / 2.5	100	2020
Coated PET film	PET / Al	12 / 0.04	10	2020
Coated PP film	PP / Al	18 / 0.04	10	2020
Metallocene coated film	PP / Al	15 / 0.04	2	2000
			10	2020

[1]In MATTER PVC can be chosen as representative for PVdC
[2]Maximum potentials are discussed in paragraph 12.7.

Non food consumer packaging films

For non food consumer packaging, barrier properties play no major role. Therefore, the same options that are described for low barrier food films can also be used for non-food consumer packaging. For non food packaging, less critical properties are demanded, so maximum potentials of the options are higher than for food packaing.

Table 7.7: Characteristics of non food flexibles (films, bags)

	material	film thickness [µm]	maximum potential [%][1]	year
LDPE film	PE	40	100	2020
PP film	PP	30	100	2020
Metallocene film	PE / PP	24	20	2000
		22	100	2020
Paper		80 gr./m^2	100	2020

[1]Maximum potentials are discussed in paragraph 12.9.

Industrial packaging films

Shrink films

The mean thickness of shrink films in Europe is estimated at 30-80 µm; a thickness of 50 µm is used most often (Zoethout, 1997). For example, in the soft drink industry, thicknesses of 55-60 µm are used (Plasthill, 1997). Recently, Honig reduced the thickness of stretch films for bundling soup boxes from 50 µm to 40 µm (SVM, 1996), whereas the thickness of stretch films for sausages cans at Unox were reduced from 60 µm to 45 µm (SVM, 1994). The mean thickness of shrink films we estimate at 50 µm. Furthermore we estimate that a reduction of 10% is possible in 2020.

Shrink covers

Shrink covers, used to bundle loads on pallets, are made of LDPE for the same reasons as shrink films. Until about ten years ago, the mean thickness in The Netherlands lay around 200 µm (Plasthill, 1997). Since then, partly as a result of the Packaging Agreement, it has dropped down to 80 to 125 µm, with an average of 100 µm (Zoethout, 1997). We assume that the mean thickness for Europe in 2000 is 140 µm, dropping down to 100 µm in 2020.

Stretch films

Loads on pallets can also be bundled using stretch films. Before stretching, stretch films have a thickness of 25-40 µm (Zoethout, 1997). We assume a mean thickness of 35 µm. Total thickness, if stretched by 30% and wrapped three time around the load, is calculated at 80 µm. In order to protect the load from damage by water, a top film of about 100 µm has to be added before wrapping.

Table 7.8: Characteristics of industrial packaging films

	material	film thickness [µm]	maximum potential [%][1]	year
Shrink film	PE	50	30	2000
		45	30	2020
Shrink cover	PE	140	80	2000
		100	80	2020
Stretch film	PE	80	100	2000
		74	100	2020

[1]Maximum potentials are discussed in paragraphs 12.12 and 12.14.

Industrial paper wrappings

The category industrial wrappings contains all wrapping paper that is used in industry for the protection of products in transport.

Examples of paper use in industry are sachets for shipping of parts and articles, filling material in boxes or consumer articles like bags and wallets, sheets between stacked boxes, inside covering of crates and boxes, protection paper for very fragile products like glass etc.

Furthermore it contains all present wrapping paper that is used for packaging consumer articles. This is done because no data are available for separating these categories.

The total amount of packaging paper is estimated by subtracting the total amount of packaging board from total packaging paper and board as defined by Pulp and Paper International [PPI, 1997]. This amounts to 8 Mtonne for Western Europe in 1995.

About 1 Mtonne packaging paper is used for options that are described in Chapter 7 about flexible packaging. This leaves 7 Mtonnes packaging paper for this category.

No improvement options have been found for this category because the applications are very diverse and many are very specific.

7.3 Modeling for MATTER

For all food flexibles and non food consumer packaging films, we defined a standard packaging with dimensions 15x10x7 centimeters. This makes it possible to compare them with cardboard boxes (primary packaging), which are described in paragraph 6.4. The standard packaging has a volume of 1 liter. For this packaging a film surface of 1000 cm^2 is required (calculation based on a sugar bag). By multiplying this surface by the film thickness of the option and the density of the material, the weight of the packaging is obtained. In Table 7.9 the results of this calculation for all options is given. Furthermore, an overall autonomous thickness reduction of 10% in the year 2020 is included for all plastic films.

Shrink films are compared to corrugated boxes (paragraph 10.2) and crates (paragraph 10.1). Therefore, the standard dimensions of these industrial packages (40x60x17, 40 liters) are chosen as the standard dimensions for shrink films. For packing this volume, a shrink film of 200x25 cm is needed. By multiplying this surface by the film thickness and the density of the material, the weight of the package is obtained.

Shrink covers and stretch films used to bundle loads on pallets with a standard dimension of 1.0x1.2x1.5 meters. For a shrink cover or stretch film of these dimensions, 7.8 m^2 of film is used (mind that the effect of multiple windings with stretch film is already accounted for in the option description). This has to be multiplied by the thickness and the density to obtain the package weight.

Table 7.9: Flexibles options for MATTER

	material	weight [gram]	maximum potential [%][2]	year
Food, low barrier:				
LDPE film	PE	3.7	80	2000
		3.3	80	2020
PP film	PP	2.7	90	2000
		2.4	90	2020
Metallocene film	PE / PP	2.2	20	2000
		2.0	100	2020
Paper		8.0	100	2000
Aluminum film	Al	27.0	20	2020
Food, high barrier:				
Laminate, aluminum	PET / Al / PE	7 / 33 / 5	100	2020
Laminate, PP	PP / PVdC[1]	2.7 / 0.43	100	2000
		2.4 / 0.40	100	2020
Laminate, PET	PET / PVdC	2.4 / 0.43	100	2000
		2.2 / 0.40	100	2020
Laminate, metallocene	PP / PVdC	2.3 / 0.43	20	2000
		2.1 / 0.40	100	2020
Coated film, PP	PP / Al	1.6 / 0.011	10	2000
		1.45 / 0.01	10	2020
Coated film, PET	PET / Al	1.45 / 0.011	10	2000
		1.3 / 0.01	10	2020
Coated film, metallocene	PP / Al	1.4 / 0.011	2	2000
		1.4 / 0.01	10	2020
Non food consumer packaging:				
Film, LDPE	PE	3.7	100	2000
		3.3	100	2020
Film, PP	PP	2.7	100	2000
		2.4	100	2020
Film, metallocene	PE / PP	2.2	20	2000
		2.0	100	2020
Paper		8.0	100	2020
Industrial packaging films:				
Shrink film	PE	23.0	30	2000
		21.0	30	2020
Shrink cover	PE	1000	80	2000
		750	80	2020
Stretch film	PE	600	100	2000
		550	100	2020

1In MATTER, PVC can be chosen as representative for modelling PVdC.
2Maximum potentials are discussed in paragraphs 12.6, 12.7, 12.9, 12.12 and 12.14.

8 Current and future material input for carrier bags

8.1 European situation

Carrier bags are most often made out of plastics, more specifically PE. Both LDPE and HDPE are used for the production. HDPE bags are normally lighter than LDPE bags [SVM, 1992].

Many different kinds of carrier bags are used in Europe which depends on the specific function of the bag. The thickness varies between 10 to 200 micron [Donker, 1993].

Several initiatives have been taking place in order to reduce the amount of plastics used for plastic bags. Many project focussed of prevention. In the Netherlands this resulted in agreements in 1991 between the government and stores that plastic bags will not be handed out for free [CV, 1992]. These measures resulted in a reduction of the amount of carrier bags because consumers started to reuse bags or make use of durable carrier bags. Other initiatives focussed on alternative materials for carrier bags like paper.

8.2 Modeling carrier bags

We estimate the amount of carrier bags in Europe in 2000 at 430 ktonnes based on a European consumption in 1990 of 370 ktonnes which is linearly extrapolated with the estimated developments of PE in that period [APME, 1992, APME, 1994, APME, 1996]. Furthermore we assume an average weight per bag of 20 grams [Donker, 1993]. This results in a European demand for carrier bags of 21.5 billion bags per year.

8.3 Improvement options

To reduce the amount of plastic consumption for making bags several options can be modeled.

- The first alternative is prevention. This can be done by direct reduction of the consumption of bags or by reducing the weight per bag. The latter is easy to model because substitution of LDPE bags by HDPE bags has shown a material reduction of 20% [SVM, 1992]. Coextrusion of plastic films may also lead to savings of 20% [Donker, 1993]. We assume that in 2000 the carrier bag can be produced with 15% less plastics than the current bag. We will model the direct reduction in bag consumption by defining multiple use bags

- Another option to reduce the plastic consumption is the use of paper bags. Paper bags are heavier than the average plastic bag. We will model a paper bag that weighs 56 gram [Dinker, 1993].

- We assume that in 2000 virgin HDPE can be replaced entirely by recycled HDPE.

- The last option that we will model as a substitute for the plastic bag is the multiple use bag. A large grocery chain in The Netherlands introduced a multiple use bag made out of PE and PE. The bag weighs 240 gram. We will assume a lifetime of 100 shopping trips. The use of a multiple way shopping bag requires a behavioral change for European customers. We assume a market penetration of 10% to be possible at no extra costs but significant investments in education to reach a higher market share.

The characteristics of the standard bag and the possible alternatives are listed in Table 8.1.

Table 8.1: Characteristics of the standard carrier bag and alternatives

	material	Weight (gram)	trip number	possible market share (%)
standard bag	PE	20	1	100
recycled bag	recycled PE	20	1	100
light bag	PE	15	1	100
paper bag	paper	56	1	100
multiple use bag	PE	240	100	10

9 Current and future material input for industrial sacks

9.1 European situation

Industrial sacks are used to pack plastics granulate, cement, animal feed, fertilizers, flour, soda, gypsum, compost etc. In table 9.1 the European apparent consumption of these materials are stated.

Table 9.1: apparent consumption of some bulk materials [EC, 1997, Gielen, 1997]

	Consumption in Europe (Mtonne)
Cement	170
Fertilizers	17
Animal feed	4.5
Flour	26
Granulates	30
Gypsum	23
NaOH pellets	8

Besides in sacks many of the materials are transported for large parts in bulk quantities. Cement for example is distributed for only 10% in bags.

In APME (1992) the total use of plastic industrial bags is estimated at 460 kton. We will use this figure as an estimate for the amount of plastic industrial bags in 2000.

When a weight of 105 kg (see next paragraph) per 100 bags is assumed the total plastic industrial bag consumption is estimated at 4.4 billion bags.

Besides plastic bags also paper bags are used. We will make an estimate for the amount of paper bags based on the amount of cement that is consumed in Europe.

Cement bags are made out of multiple layers of paper because of the bag needs to be very strong. The sacks have a standard carrying capacity of 50 kg which equals 25 liters in the case of cement [ayoup, 1997]. Today a clear trend is visible towards smaller bags because they are easier to handle. The amount of paper bags is calculated at 340 million bags (assuming bags of 50 kg).

9.2 Modeling Industrial Bags

To model industrial bags we will define a plastic bag and a bag made out of paper. A possible alternative is the Flexible Intermediate Bulk Container (FIBC) or big bag. These bags are used to pack products above 100 kg but most bags handle 500 – 2000 kg [Hug, 1988]. We will assume an average carrying capacity of 1000 kg. The most common material for the production of FIBCs is polypropylene.

FIBCs have the disadvantage that they can not be handled as easily as smaller bags. Therefore the cement industry still prefers the use of normal sized paper bags [Ayoub, 1997]

To model the bags we assume that the plastic LDPE bag has a thickness of 150 micrometer. Plastic bags are not as strong as the paper bags and we will therefore assume that 25 kg are packed in 25 liter bags of 40 * 90 cm will be suitable. The bags LDPE has a density of 0.92 g/cm^3 [Bührmann-Vromen, 1997]. The above results in a weight of 105 kg per 1000 sacks. This model bag is equal to the bags used for packing of granulate which are also capable of carrying 25 kg and have a thickness of about 150 micrometer [Zoethout, 1997].

For the paper bag with the same dimensions as the LDPE bag we assume a triple layer bag with paper on the inside and the outside and very thin LDPE layer in between. We modeled this type a bag because more products can be packed in such a bag than with a normal paper bag due to requirements concerning absorption of moisture. Fertilizers for example are packed in multi-wall paper with a PE moisture-proofing layer [Kirk-Othmer, 1993]

Assuming 175 grams Kraftliner and 15 micrometer LDPE results in a bag that weighs 262 grams of which 252 gram Kraftliner and 10 gram LDPE.

The FIBC is made from woven PP straps (200 gram/m^2) and weighs around 1.5 – 2 kg. The carrying capacity is 1000 kg. In principle this bag is only used once. Multiple use bags are also delivered even though they are not used very often. These bags are made from heavier material (240 gram/m2) and have extra strengthened carrying straps [van Well, 1997].

In Table 9.2 the characteristics of these options are stated.

Table 9.2: Characteristics of industrial bags.

Bag type	Capacity (kg)	HDPE (gram)	Paper (gram)	PP (gram)	Number of trips
Plastic bag	25	105			1
paper bag	50	10	252		1
FIBC	1000			2000	1
FIBC	1000			2500	5

10 Current and future material input for industrial boxes

Industrial boxes are used for several purposes. First of all they can be used for packing loose product like fruit, vegetables and machine parts. Secondly, they can be used to pack several (cardboard) boxes or (plastic) pouches. Thirdly, industrial boxes can be seen as the large (wooden) containers to pack large industrial products. To avoid definition problems we will define the first category as crates, the second as transport boxes and the third category as industrial containers.

Within the categories material substitution might be possible but the boxes may also have to compete with other packaging options like industrial sacks or foils. In this section we will describe all the options that are related to industrial boxes but details about competing options may be found in other paragraphs.

10.1 Crates

Crates are normally used to pack loose products like fruit and vegetables, meat and product parts. The crates can be used for one-way shipping or function as a returnable package. The one-way crate is mostly made out of wood and is normally used to pack fruit and vegetables. The single use crate is most often used when industries are organized in such a way that returning systems do not work.

Returnable crates can also be made from wood but plastics are also commonly used. In the vegetable and fruit market many shifts have been made in the use of the different crates. The Dutch auctions for example used 70 million crates just to pack tomatoes, now the use of wooden crates is restricted to pack fruit [anon., 1996c]. Most of the tomatoes are now packed in cardboard crates or trays [Dijk, 1992]. Due to the growing use of wooden crates in the fruit sector, however, the overall use of wooden crates did not decline; the current use of wooden crates in the fruit sector is 75% [anon., 1996d]. This situation which also holds for Belgium and parts of Germany is due to the low prices of wooden crates which is especially important when many crates are not returned. In the rest of Europe the most common crate in the fruit business are plastic crates [anon. 1996c]. The wooden crate of 30*50*25 cm weighs about 2.2. kg and makes about 5 to 6 trips per year. The average lifetime is 5 years [PFK, 1997]. The bulb industry also make use of crates. According to Burggraaf (1997) about 90% of the crates used are plastic crates. The remaining 10% are made out of wood and cardboard.

The plastic multiple use crate is popular because they are easy to clean and they are durable. Especially for fresh products the hygiene argument is important. The plastic crate is more expensive than the wooden crate but it has a longer lifetime than the wooden crate. The longer life time of a crate is only an issue if the transport system is fairly closed. Burggraaf (1997) states that a certain share of plastic crates are not re-used because they are shipped over long distances where no return system has been set up. Besides the vegetable and fruit sector, plastic crates are popular with bakeries. Fresh bread is often transported in plastic crates. Multiple use plastic crates weigh 1.5 – 2 kg and have a volume of 40 liter according to Burggraaf (1997). The crates of

CKW that have a volume of 40 liter weigh 2 kg. We will use this figure to model returnable plastic crates.

The second competitor of the wooden crate is the corrugated crate. Vegetables and fruit are transported in corrugated cases because it looks better to the consumer due to the excellent printability of corrugated board. Another advantage is that cardboard boxes need less storage room because they can be pressed together after usage and are ready for transport to the paper mill. The last advantage is that no organization for returning the crates is necessary.

To model the consumption of crates in Europe we will define a wooden crate, a plastic crate and a cardboard tray. The basic characteristics of these crates are presented in Table 10.1.

Table 10.1: Characteristics of three types of crates.

Type	Material	Weight (kg)	Trip number	Volume (liter)
Returnable crate	HDPE	2	100	40
Returnable crate	Wood	2.2	30	40
One-way crate	corrugated board	0.4	1	40

To estimate the total use of crates in Europe we make use of the APME figures on injection moulded plastic packaging. The total consumption of injection moulded products in Europe amounts to 1500 kton. Subtracting injection moulded pallets leaves 1000 ktonnes. Taking the defined standard crate into account leads to a demand of 500 million plastic crates per year. This number includes the beer crates that also weigh around 2 kg [Eek, 1995]. We estimate the total amount of wooden crates at 100 million based on the argument that they are very frequently used in the Dutch, Belgian and German fruit sector and very little in other parts of Europe. No information is available on the use of cardboard crates in Europe.

10.2 Transport boxes

The category transport boxes differs a lot from the category ‘crates’. This due to the fact that folding boxes made out of corrugated board are the standard. Transport boxes, as we defined them, are normally used to pack other boxes. No data are available on the amount of transport boxes that are used in Europe. In order to make a good estimate we will use the amount of corrugated materials in Europe as indication for the amount of boxes used.

According to PPI (1997) “…corrugated materials are all those grades of paper and board used to make corrugated boxes (the main packaging box, usually brown)”. In 1995 the consumption of corrugated materials in Western Europe amounted 11.7 Mtonnes and the production amounted to 12.1 Mtonnes. We will assume that the indirect imports and exports of Europe are of the same level and use the consumption figure.

To estimate the amount of boxes a standard box should be defined. Boxes are used in many sizes depending on the products that are packed. We will define a standard corrugated box with a volume of 40 liter and a weight of 800 gram. This is a fairly arbitrary choice because a large producer of corrugated boxes sells more than 100 types of boxes, varying in size and quality [BVV, 1995].

Combining the consumption of corrugated board and the standard box leads to a consumption of 14.6 billion boxes.

Improvement options

Several options are available to make a more efficient use of transport packaging. The first option is to make better use of the cardboard boxes themselves. Many initiatives have been taken place lately to use less cardboard boxes or to reduce the weight of a cardboard transport box. To reach the goals of the Packaging Covenant in The Netherlands shows clear examples of these measures.

New box making machines have been introduced to the market for example that make better use of corrugated board to produce boxes due to improved gluing techniques. Savings of 15% corrugated board have been reported [SVM, 1994]. Shape renewal of boxes also have led to the use of less corrugated board. In some cases it is possible to remove the top flaps of the boxes which leads to savings of 20-30% [SVM, 1994, SVM, 1996]. Other developments were more in the efficiency of the packaging operation itself. Standardization of box sizes for example saved 20% board by a milk producer and more efficient stacking of the products in the box showed a board reduction of 4% [SVM, 1994, SVM, 1996].

More radical changes are found in the field of product change. Concentration of the product or a smaller primary package can lead to major savings in transport packaging. Savings of 16 – 30% have been reported by the use of smaller primary packaging and concentration [SVM, 1992, SVM, 1994 SVM, 1996]

Based on these data we assume that 20% less corrugated board is needed to fulfill the same packaging need.

Besides these efficiency options, several substitution options are possible. The most promising options are the use of returnable transit packaging and the use of industrial foils.

Plastic returnable transit packaging

In The Netherlands the Central Bureau for Foodtrade (CBL) has developed a standard plastic crate to replace the corrugated box. The reason to do so is that a lot of time is saved now that supermarkets don’t have to open corrugated boxes. The crate has standard sizes and is especially designed for products of which the trade quantity is larger than the supply to an individual store. This is most often the case with products that have a slow speed of rotation and small articles, e.g. cosmetics. The crate costs around $3.00 and a deposit fee of about $4.00 is advised. The crates have a suspected lifetime of 5 to 10 years [Wiemers, 1996].

Also in the U.K. experiments are going on with returnable transit packaging. Packaging of fresh products was the first initiative because the sector is mainly a closed loop operation [Aysford, 1995]. Chilled food is next on the list to be packed in returnable transit packaging. They are currently manually handled and have primary packaging which is usually flexible. The vast majority of dry grocery goods packaging will remain as one-trip [Aysford, 1995].

At the moment about 9.5 million plastic returnable crates are in use in the U.K. and the average trippage rate is about 25/year [Pitt, 1996].

We will model a plastic crate as improvement option that weighs 2 kg and has a volume of 40 liter [CKW, 1997]. The size of the crate is 600 * 400 * 200 mm. The trippage rate is estimated at 100 trips.

Plastic foil

The traditional corrugated box is also in competition with plastic foil like shrink wrappings. The box is then replaced by a cardboard tray and a foil wrap around mostly dry grocery goods. Weight reduction is the most common argument for this substitution option. Weight reductions of 70% and 85% are reported by substituting corrugated board by plastic foil [SVM, 1992, SVM, 1994]. We will use a shrink foil as defined Chapter 7. For packing a volume of 40 liters 23 grams of foil are needed. This option is not possible for all products that are packed in cardboard boxes because the shape, weight, stiffness, and the necessary protection of many products may cause problems for this type of packaging. For now we assume that 20% of the cardboard boxes may be substituted by this option. Table 10.1 states the characteristics of the options for transport packaging.

Table 10.1: Main characteristics of transport packaging.

Type	Material	weight (kg)	Trip number	Volume (liter)
Corrugated box	corrugated board	0.8	1	40
Improved corrugated box	corrugated board	0.6	1	40
Returnable crate	HDPE	2	100	40
Plastic shrink foil	LDPE	0.023	1	40

10.3 Industrial containers

Industrial containers are used to pack large industrial products for transportation. This category is very diverse because the containers can vary extremely in size. Boxes for the transportation and storage of spare parts in the automotive industry for example have a capacity of about 1 m3 but containers with much more capacity are also in use. Another aspect is that the boxes can be used to pack loose or bulk products. In the latter case the boxes have to compete with industrial sacks. Contrary to category ‘transport boxes’, most industrial containers are already multiple trip containers.

The standard container is made out of plywood or sawnwood [vandekerckhove, 1993]. Plywood systems are used often in the automotive industry [Matthews, 1996].

Plastic containers are used more often in the food industry and the containers. The lifetime is very long (20 years) because the containers have replaceable sides. For the MARKAL model we will not model industrial containers because we expect the share of these containers to be small compared to transport packaging and crates. Furthermore the category is too diverse to create a reliable model input.

11 Current and future material input for industrial Pallets

11.1 The European Market

In many industrial and trade sectors pallets are used intensively for internal and external transport of products. In Europe the production of pallets amounts to 280 million pallets per year [van Belkom, 1994]. About 96% of these pallets are made out of wood. Not too long ago, almost all pallets were used for one single trip and discarded afterwards. Due to environmental legislation a obvious trend is visible towards the use of multiple-use pallets. In Germany for example, the verpackungs-verordnung states that the taking back of pallets by industries is compulsory. The trend towards multiple use pallets has led to a large increase of the number of pallets that are part of pallet pools (see paragraph 11.3). In 1994 about one third of the pallets was returnable [van Belkom, 1994].

11.2 Material options

The most common used pallet in Europe is the wooden pallet. In The Netherlands it accounts for 95% of the pallet market [van den Berg, 1996]. It is expected that the situation in Europe does not differ much from the Dutch situation. Alternatives for the wooden pallet are pallets made out of pressed wood fiber, plastics (PE and PC), cardboard and steel. The different pallet types will be described shortly and Table 11.1 presents the main characteristics of the pallet types.

Wooden pallets

Wooden pallets are the most commonly used pallets by industry. Even though standardization is taking place quickly in Europe many sizes and qualities exist on the European market. The most obvious subdivision within the pallet market is the use of single use and returnable pallets. In The Netherlands almost half of the produced pallets is for multiple use and this share is rising fast [van den Berg, 1996].

The resources for wooden pallets production is mostly softwood (pine, spruce and poplar). The weight of a single use pallet is about 17 kg and a multiple use pallet weighs about 25 kg [Renia and Sikkema, 1991].

The use of wood pallets is popular because they are cheap. Average prices are estimated at about $7.00 [anon. 1993]. Prices of single use pallets are estimated at $5.00 and multiple use pallets cost around $20.00 [van den Berg, 1996]. Other reasons for their popularity are that they have a good carrying capacity (more than 1000 kilo's), that they are easy to repair when broken and furthermore that they are suited very well for small series with deviating sizes because wood is easy to handle [van den Berg, 1996, anon., 1993a].

Plastic pallets

Plastic pallets are used a lot in the food industry because they are easy to clean due to the smooth surface. Furthermore, no liquid can be absorbed by the pallets [Johnson, 1997]. The most common material for plastic pallet production in PE but in some cases also PC is used. Pallets made out of PC are stronger than PE pallets.

Just like wooden pallets, plastic pallets can be used for single and multiple trips. A one-way plastic pallet weighs about 14 kg and a multiple use pallet weighs around 30 kilograms [TNO, 1994, van den Berg, 1996].

The costs of plastic pallets are higher than for wooden pallets. A PE pallet for multiple use costs around $75.00 and a pallet for single use costs about $12.00. If the pallets are made from recycled PE, they are much cheaper. The price for a multiple use recycled PE pallet starts at $25.00. Pallets that are made out of recycled PC are more expensive ($75.00) [van den Berg, 1996].

There is no consensus about the number of trips that can be made with a multiple trip plastic pallet. TNO (1994) estimates that the number of trips is lower than for a wooden pallet (33.6 versus 41.8). In anon. (1993a) the life time of plastic pallets is assumed to be up to 100 trips. We will use a trip number of 75. After MARKAL calculations a sensitivity analysis for the trip number should take place.

Corrugated fiberboard pallets

Pallets made from corrugated fiberboard are an option to replace single trip wooden pallets. Some types are made from very solid corrugated board and are capable of making more than one trip but most pallets made from corrugated board will be used for single trips. The pallet costs about $6.00 which is cheap compared to wooden and plastic pallets [anon. 1993a]. The pallet weighs about 6 kg which makes it a very light-weight pallet. This already has been a reason for some companies to use this pallet because it reduces the weight in the trailer [Witt, 1990].

A large disadvantage is these types of pallets is that they are not resistant to water. Nowadays, some of these pallets are coated with PE to make them more suitable for outdoors handling.

The most important argument for the industry to use corrugated fiberboard pallets is that they are very easy to get rid of because they can be recycled completely [Witt, 1990].

Pressed wood fiber pallets.

Pallets can also be made from pressed wood fibers. The advantage of these pallets is that they can save a lot of space if they are used for multiple-trip purposes because they use a fourth of the space of piled wooden pallets when stacked empty.

Pressed wood fiber pallets are made out low grade fibers, mostly from bark and thinnings. The fibers are molded into a pressed wood pallet with the use of synthetic organic resins.

The average costs of these pallets are about $5.00 and the average weight of the pallet amounts to 16 kg [anon., 1993a].

The number of trips is less than for wooden pallets. We assume 5 trips per pallet.

Steel pallets

Because steel pallets are extremely expensive they are only used for special purposes. The prices of steel pallets can vary between $30.00 and $350.00. The most common application is in the slaughter industry and textile industry. In the textile industry the pallets are used to carry many thousands of kilo's. They also eliminate the need for scaffolds because they can be piled well.

In general steel pallets are only used for storage purposes and not for transportation. Because of this they will not be modeled in the MARKAL model.

Table 11.1: Characteristics of several pallet types

Pallet type	single/multiple use	Weight (kg)	Number of trips	price ($)
Wooden pallet	Single	17	1	5
Wooden pallet	Multiple	25	40	20
PE pallet	Single	14	1	12
PE pallet	Multiple	30	75	75
Recycled PE pallet	Multiple	30	75	25
Recycled PC pallet	Multiple	30	75	75
Corrugated fiberboard pallet	Single	6	1	6
Pressed wood fiber pallet	Multiple	16	5	5

11.3 Pallet pools

Due to environmental legislation the use of returnable pallets is increasing. With the use of returnable pallets also the pallet pools become more important. Pallet pools are organizations that take care of the management of returnable pallets. The basis for a pallet pool are appointment between pallet users about the management and use of the pallets. The pallet users do not own the pallets but make a payment to the pallet pool that is related to the amount of pallets that they use.

To make a pallet pool work the pallets should be easy to recognize and have standard sizes. Several pool systems exist ranging from deposit systems to a system where a full pallet is exchanged for an empty pallet [Engel, 1993].

Pallet pools have the advantage that the return trips of the pallets are more efficient, reparations are cheaper because they are centralized, less pallets need to be in store which saves space and money and finally the costs per pallet can be lower if the pool works efficient [van den Berg, 1996].

In The Netherlands the beer and soft drink industry have standardized their pallets and use a deposit fee of $25.00 [Veul, 1994].

In Europe the Europallet is the largest pallet pool. Another large pallet pool is run by Chep. Chep also uses the same pallet standard sizes as the Europool [Gunn, 1997].

11.4 Costs of pallet production

To determine the cost of pallet production we make a distinction between investment costs, labor and operating and maintenance cost. The material costs are not taken into consideration because they are generated in the MARKAL model. We will make a distinction in production costs for the earlier defined pallets.

The production of plastic pallets is capital intensive because the injection moulding matrix is very expensive for these types of products and depreciation per pallet is high because of the small capacity. Assuming that a multiple use PE pallet costs $50 and a material cost of $25 leads to a production cost of $25. Assuming 5% operating and maintenance cost and 20% labor leaves about $19 investment cost per pallet. For a one way pallet that is half the weight we assume an increase in production capacity and therefore a decrease in costs with a factor 2.

For all plastic pallets we will use these cost figures. This means that we do not differentiate between injection moulding of PE and PC. Only material costs will therefore affect the final difference in pallet costs.

For pallets made out of wood the production process is entirely different resulting in different costs. Making of wooden pallets consists of wood sawing and assembly. We assume that the production costs are not very different than the costs for sawing of wood. In Hekkert et al. (1998) these costs are estimated at $ 250 per tonne where 10% is operation and maintenance and 40% labor. This leaves investment costs of $ 0.125 per kg or $ 2 per pallet.

For the other pallet types no production costs are available. However the pallets are very cheap ($ 5 - 6 per pallet) and therefore we assume the production costs to be $ 3 per pallet. Taking 10% O&M and 40% labor into account leaves investment costs of $ 1.50 per pallet.

The costs described above are used to construct Appendix I in which the production costs and process energy consumption for all packaging products are stated.

12 Calculating the demand for packaging in 2000 and beyond

12.1 Introduction

In the previous chapters an overview is given of material input for 8 packaging categories. The MARKAL model generates a demand for these packaging types and has numerous options to vary the material input.

However, generating a demand for all the packaging categories makes it impossible to substitute between the categories. For example: If the model generates a demand for transport boxes and for plastic films, no substitution is possible between these categories because the quantities are already defined.

In order to model the use of packaging materials it is therefore necessary to define *product categories* that can be packed in different ways. In Blonk and van Duin (1991) for example this was done by defining four food categories and one non-food category plus some industrial categories.

This chapter describes the product categories that will be used in the MARKAL-model. To estimate the quantity of these categories and the amount of packaging that is needed to pack these products we will use descriptions of the European situation as stated in the previous chapters. In this chapter we will also try to make the estimates for the product quantities transparent. The product categories are in some cases virtual which means that they do not represent actual products. This is especially the case if the product category is very diverse.

In the next sections the argumentation for the estimates for all categories will be stated. The final results are stated in Table 12.1. The following product categories are defined.

- Beverages, carbonated
- Beverages, non-carbonated
- Dairy products, no milk
- Wet food
- Dry food, non susceptible
- Dry food, susceptible
- Non-food liquids
- Non food, solid
- Carrier bags

- Industrial bags
- Industrial transport packaging
- Pallets
- Pallet wrapping

In Table 12.1 also the maximum possible material input for 2020 is stated. This is based on the technical possibilities for materials to gain a certain market share. This may lead to very unrealistic modeling results because some very large movements in material use are not very likely. For example, all beverages are packed in refillable PET bottles. However, this exercise shows the possibilities and the maximum potential of material substitution.

12.2 Beverages, carbonated

To model food bottles as described in Chapter 4 we discerned two types of beverages because the use of CO_2 has consequences for the materials that can be used to pack beverages. For the carbonated drinks, material options are metal, PET and glass while the non-carbonated drinks are also packed in liquid board. Furthermore, options that were defined in chapter 3 like the pouch and the PC bottle are best suited for non-carbonated drinks.

The amount of carbonated drinks is estimated by adding the consumption of beer, 30% of the water consumption and 60% of the soft drinks consumption. The rest is assumed to be non-carbonated. The consumption figures are stated in Table 4.1.

The consumption of carbonated beverages is consequently estimated at 46 billion liters.

About 10.5 billion liters are assumed to be packed in cans in 2000. This number is based on consumption figures stated in Table 4.10 and using the assumption that an average can has a volume of 33 ml. For 2000 we assumed that a 50-50 division exists in the consumption of aluminum and metal cans.

We estimate the volume of beverages that is packed in PET at 20.1 billion liter. This figure is including PVC bottles which will be modeled as PET. This number is calculated as follows. The total consumption of PET bottles is 1.1 Mtonne [APME, 1992] and for the packaging of non carbonated water 0.56 Mtonne is needed assuming a average PET bottle of 50 grams containing 1.5 liter. This leaves 0.57 Mtonne for carbonated drinks. We assumed that 1.5% of the bottles are refillable (trip number of 20 and a bottle weight of 103 gram).

To estimate the amount of carbonated liquids packed in glass we took the total use of glass in Europe into account (Table 4.3) and assumed that wine (non-carbonated) is packed in glass entirely (bottle weighs 500 gram/liter). The remainder of the glass consumption is used to pack carbonated drinks. The ratio between small (beer) bottles and large (1 liter) bottles is assumed to be 75% small and 25% large because many bottles are used for beer packing. This results in 7.5 Mtonnes glass that is used for packing carbonated drinks which corresponds to 7.7 billion liter.

For target years beyond 2000 the MARKAL model has the freedom to choose any of the options for 100% because no technical limits exist.

12.3 Beverages, non carbonated

The consumption of non-carbonated beverages is estimated at 65.7 billion liter which is calculated by subtracting the consumption of carbonated beverages from the total consumption. The most important materials in this market segment are glass, liquid board and PET.

The amount of glass is estimated by assuming that all wine is packed in glass. This results in a packed volume of 13 billion liter (Table 4.1). Here all bottles are assumed to be large (see paragraph 4.1).

For the PET consumption we assumed that PET is only used for packing non-carbonated water. This results in a packed volume of 17 billion liters.

The quantity of non carbonated beverages that is left when the shares for PET and glass are taken into account is assumed to be packed in cardboard (mainly milk and juices). This results in a packed volume of 35.8 billion liter.

For target years beyond 2000 the MARKAL model can also choose new options. The possible use of these options is limited because of the necessary properties of these packaging types. Plastic packaging for example is not suited for juice packaging because it absorbs flavoring. For PET bottles we assume that they will only be used for water packaging.

12.4 Dairy products, no milk

The category 'dairy products, no milk' deals with the butter and yogurt consumption that are packed in plastics cups / boxes. The main plastic types that are used are thermoformed PS and PP.

The total amount of thermoformed plastics is 1.2 Mtonne [APME, 1992, APME, 1996]. This quantity is divided over the category dairy products and the category non food. The butter and yogurt products consumption is estimated at 19 Mtonne [EC, 1997]. We based the PS and PP consumption on the assumptions that all butter and yogurt is packed in 500 gram packages that have the weight figures as stated in paragraph 4.8. This results in 16 Mtonne packed in PS and 3 Mtonne packed in PP.

For target years after 2000 we see glass as a possible option for PS and PP for yogurt packaging. Therefore a bound of 90% for glass packaging in 2020 is stated. No technical barriers are present for a 100% market share of PS and PP.

12.5 Wet food

Wet food is a product category that contains all products that are packed in jars and food cans, e.g. jam, canned fruit and vegetables. Table 4.3 shows that the total amount of wet food amounts to 4 billion liter. We will model this as it were packed in cans for 100%. The total amount of tin cans is estimated in paragraph 4.5 at 50% of packaging steel or 2 million tons (including PET-food and cans for other food types).

For target years beyond 2000 we assume that glass and steel cans are the only available options to pack this category. No technical barriers exist for a full penetration of either packaging type.

12.6 Dry food, non susceptible

This category contains all dry food that is not very susceptible, in other words, food that is no especially wet and that does not need packaging with especially high barrier properties for oxygen, carbon dioxide or moisture. It is a combined category with the purpose to integrate the use of boxes (Chapter 6) and flexibles (Chapter 7).

In Chapter 6 no distinction is made between food and non food boxes. We will assume that 75% of the boxes used are used for the food sector.

The amount of cardboard boxes used is calculated by the assumption that 3.3 Mtonnes board is used for boxes in Europe (see Chapter 6) and that an average 1 liter box weighs 35 grams. This results in a European consumption of 94.3 billion boxes or a packed volume of 94.3 billion liter. Taking the 75% for the food sector in account leaves 70.7 billion liter.

The amount of thermoformed plastic boxes used for food packaging is divided over the categories dry food, non-food and dairy products. The total use in 2000 is estimated at 1.22 Mtonnes of which 0.54 Mtonnes is used for dairy packaging. We estimate that 20% of the 0.68 Mtonnes that are left is used for dry food packaging and that 80% is used for non-food purposes. Taking this and also the plastic box definition in Chapter 6 into account leads to a packaging capacity of 4.2 billion liters.

According to Table 7.3, for low barrier food packaging 1225 kton of LDPE are expected to be used, as well as 180 kton of HDPE , 585 kton of PP and 220 kton of metallocene. The figure for LDPE includes 440 kton of extrusion coatings used for liquid board and 50 kton of films in boxes. These are accounted for in paragraphs 12.3 and 12.5 respectively and have to be subtracted of the rest of food flexibles, in order to prevent double counting. With this, LDPE in food flexibles is calculated at 735 kton. Our standard 1 liter low barrier LDPE food flexible weighs 3.7 grams, so LDPE flexible consumption for food, low barrier correspond to 199 billion liters.

Because HDPE films are not used extensively in food films, we do not describe a HDPE option, but we model it together with PP, which has comparable strength, leading to a comparable thickness. Therefore, total PP consumption for low barrier food films is modeled as 765 ktonnes. A standard 1 liter low barrier PP food flexible weighs 2.7 grams, so PP flexible consumption for food, low barrier, corresponds to 283 billion liters.

Metallocene film consumption is estimated at 220 kton. With a weight of 2.2 grams this corresponds to 100 billion liters. We estimate that in 2000, paper makes out 1% of low barrier food flexibles. This applies to paper bags without box (already described above).

Putting all flexible options together, we calculate a total low barrier food flexible packed volume of 588 billion liters. Compared to the other packaging categories in Table 12.1, this may seem a substantial amount (the same can be concluded when comparing high barrier food films and non food films to their respective substitutes) . Firstly we have to bear in mind that a considerable amount of flexible packages, like bread bags and potato bags have a volume of several liters. Secondly, the calculated volume is an overestimation, because it is calculated based on the use of plastic films (in kton) and the weight of our standard flexible. This standard flexible was chosen to pack a volume of 1 liter and has a relatively low thickness, in order to be comparable to and substitutable by our standard 1 liter box, whereas in practice also thicker films are used, for example for potato bags. This means that, for modeling reasons, the packed volume in flexibles is an overestimation, whereas the weight of flexible packaging materials is corresponding to reality.

In 1990, 7.0 kton aluminum film were used in The Netherlands (Anonymous, 1992). Based on this figure, we estimate the aluminum film use in Europe in 2000 at 160 kton. Taking into account the packaging weight per liter (Table 7.9), we calculated the packed volume at 5.9 billion liter.

A part of the food products in this category needs the protection of the rigidity of a box. We estimate that this is the case for 10% of the products. This means that flexibles can maximally be used for 90%. Therefore, metallocenes have a maximum potential of 90%. PP cannot be used for deep freezing applications, so we modeled a maximum potential of 80%. For LDPE film we modeled a bound of 70%, because of its relatively low heat resistance. Paper has an even lower potential (estimated at 60%), because it has no resistance for water, neither from the inside (the product), nor from the outside (*e.g.* rain). The same can be said about cardboard boxes, but their resistance for water is slightly better. Also, their rigidity favors application, so we modeled a bound of 80%. We assume that cardboard boxes with bag, as well as PE boxes, possibly equipped with a sealable layer for closing, have a potential of 100%, because of combined rigidity and good closeability.

12.7 Dry food, susceptible

This category consists of dry food (or food that is not especially wet) that needs to be packed cut off from the surrounding atmosphere and which, therefore, needs a packaging material with good barrier for oxygen, carbon dioxide and moisture. This food is packed in high barrier films, which are described in chapter 7. For high barrier food films it is expected that, in 2000, 760 kton of flexibles is used (Table 7.3). These are divided between the different materials as follows: 270 kton LDPE, 45 kton HDPE, 270 kton PP and 110 kton PET, as well as 65 kton metallocene. These figures refer to laminates and coated films together. Because of lower barrier properties of metallised films, we assume that they are only used for 10% of high barrier food packages. Taking also in consideration that metallised films consist for the major part of PET, we come to the following division between the options for 2000: PP laminate: 565 kton, PET laminate: 60 kton, metallocene laminate: 63 kton, metallised PP: 20 kton, metallised PET: 50 kton, metallised metallocenes: 2 kton (LDPE and HDPE are not modelled for MATTER, but they are included in the PP options). With the weights of standard packages (Table 7.9), the consumption of the options in 2000 can be calculated (in liters). The results are shown in Table 12.1. Based on the layer thicknesses in Table 7.9, the amount of PVdC needed in 2000 for barrier layers is calculated at 112 kton, the amount of aluminium at 0.535 kton. The total volume packed in high barrier flexibles is calculated at 310 billion liters.

Based on the 6.8 kton of aluminum laminate used in The Netherlands in 1990, and assuming a growth of 1.5% annually (see paragraph 7.3), we estimate the use of aluminum laminate in Europe in 2000 at 160 kton. Taking into account, that for packing 1 liter, 45 gram of aluminum laminate is needed, the packed volume in 2000 is calculated at 3.6 billion liter.

Table 12.1 also states the bounds chosen for the options. All laminates can, in principle, be chosen for all high barrier applications. Because of their comparably low barrier properties, metallised films have a much lower potential. We estimate this potential at 10% (for all metallised films together). For high barrier films, paper bags and cardboard boxes are no alternative, because of limited barrier properties.

12.8 Non food liquids

The non food liquids category consists of all products that are packed in non-food bottles as defined in Chapter 5. All bottles in 2000 are assumed to made out of LDPE. The consumption of blown moulded LDPE in Europe is 1 Mtonne. By using the bottle definition as stated in Chapter 5 (a 300 ml non food bottle weighs 50 grams) we define a demand of 21 billion bottles or 10.5 billion liter liquids).

For target years beyond 2000 we define the options as described in Table 5.2. We assume a technical maximum penetration of 50% for the refill package out of liquid board. Even though this option might technically not be a problem, a 50% market penetration asks for very large behavioral adaptations in society. The pouch is assumed to have a technical maximum market share of 100%. This will also require large behavioral changes because pouches are different to handle than bottles.

12.9 Dry non food

This category consists of all non food products, except for non food liquids, which are described in paragraph 12.8 and large products like TV’s and refrigerators, which are packed in corrugated board and which are described in paragraph 12.12.

The products in this category are either packed in flexibles, or in boxes (including blisters).

For non food flexibles, in 2000, 235 kton LDPE, 125 kton PP (including HDPE, which is modelled as PP) and 40 kton metallocenes are used (Table 7.3). With the weights of the non food flexible options (Table 7.9), the packed volume in 2000 is calculated and shown in Table 12.1. We calculated the total volume of non food consumer flexible packaging at 128 billion liters.

The boxes in this category consist of several leftovers from the other categories. The cardboard use is 25% of total cardboard use after the fulfilling the dry food demand. The demand for plastic boxes is the 80% of total demand after fulfilling the demand for dry food. This leads to a packaging capacity of cardboard of 17 billion liters and a capacity of plastic boxes of also 17 billion liters.

We estimate that 80% of this category can be packed in flexibles, the remaining 20% needing the protective rigidity of a box. Closeability and heat resistance are less critical for non food packaging than for food packaging (see also paragraph 12.6), so we don't expect that the potential for each individual flexible option will be lowered for reasons of closeability or heat resistance. Therefore, we modeled a maximum potential of 80% for all flexible options (together as well as individual): LDPE film, PP film and metallocene film. For paper we modelled a lower maximum potential (60%), because of its sensibility to moisture and its limited strength. For the same reasons as stated in paragraph 12.6, cardboard boxes have a maximum potential of 80%, whereas the PE box is useable for all non food products.

For target years beyond 2000 the cardboard blister is modeled as improvement option. This can only replace the plastic blister. The blister has an assumed market share of 20% of the plastic boxes. The maximum penetration level is therefore set at 5%.

12.10 Carrier bags

In Chapter 8 the total demand in Europe for carrier bags was calculated at 21.5 billion bags. The model PE bag will be modeled for 100% in 2000 and no technical limitations stand in the way of full market penetration of the other defined options.

12.11 Industrial bags

In chapter 9 the demand for industrial bags is estimated at 340 million paper bags and 4.4 billion plastic bags. When we assume a capacity of 50 kg for the paper bag and 25 kg for the plastic bag the total capacity of the bags is calculated at 128 Mtonnes. FIBC's will have a relatively small market share in 2000 which we estimate at 10% or 12 Mtonnes.

The FIBC's are not in all cases a valid option. We will put a maximum bound of 40% on future market penetration of the FIBC. No large deviations in the competition between paper and plastic bags are expected due to totally different characteristics of the bags. For future target years we will therefore assume the same penetration levels as for 2000.

12.12 Industrial transport packaging

This category contains all secondary packaging for transporting food and non food products between two industries, or from industry to trade (crates, corrugated boxes and shrink films). It also contains the corrugated boxes (primary packaging) to pack large consumer goods like TV's and refrigerators.

The amount of corrugated boxes is taken from paragraph 10.2. In paragraph 10.1 the amount of plastic crates that is consumed in Europe per year is stated. Because crates can be used for a number of years the consumption per year is not equal to the amount used per year. We estimated that the annual production ads 30% of the current stock. Taking the assumption that crates make about 5 trips per year into account leads to the shares as stated in Table 12.1.

For shrink films, in 2000, 340 kton of LDPE are used (Table 7.2). This corresponds to 14.7 billion standard packages of 40 l., weighing 23.1 gram each. This means a packed volume of 589 billion liters.

In principle, plastic crates and corrugated boxes can be used for 100% of this category. For the wooden crates a maximum share of 20% is assumed because of limitations due to hygienic reasons. For the cardboard crate the same market share is assumed because it does not have many advantages over the corrugated box except in specific sectors like the fruit sector. Shrink films can only be used to bundle products which are rigid or the packaging of which is rigid. The shape of the products or their packages has to be regular. Furthermore, the products and their packaging must be able to endure the pressure of the shrink film and the heat of the shrinking process. For these reasons we modeled a maximum potential of 30%.

As described in paragraph 7.3 about 7 Mtonnes paper wrappings are used. No improvement options are modeled for this category so no demand category is defined. It is part of the options as described above. In Table 12.2 however the total amount of paper used in this category is of course included.

12.13 Industrial pallets

In Chapter 11 the demand of pallets in Europe is stated: 280 million per year. To model the demand for pallets we need to define some sort of transport function in order to model multiple use pallets. We will therefore define the demand unit: pallet trip. A pallet trip can either be fulfilled with a returnable or a one way pallet.

About one third of the 280 million pallets is returnable which leads to total of pallet trips that is very much larger than the number of pallets.

We assume (based on chapter 11) that 60% of the pallets in 2000 is made out of wood of which a third is returnable with a trip number of 40. The last 10% is made out of PE and has a trip number of 75.

Taking this into account a total number of pallet trips per year can be calculated at 5.6 billion.

For target years beyond 2000 all pallet types as defined in Table 11.1 are possible improvement options. No technical barriers stand in the way of full penetration of these pallet types.

12.14 Pallet wrapping

This category consists of the wrappings used to bundle loads on pallets. This can be done either with shrink covers or with stretch films. Loads of corrugated boxes can also be bundled using glues. By using this option, pallet wrapping can be disposed of. Pallet bundling using plastic bands is not modeled, because of serious drawbacks of this method (difficult application, no weather protection, damage caused by local band pressure, need of much bands if much units are to be bundled).

For shrink covers, in 2000, 420 kton of LDPE are used (Table 7.2). This corresponds to 0.42 billion standard shrink covers of 1,20x1,00x1,50 meters, with thickness 140 μm, weighing 1000 gram each. In 2000, 350 kton of LDPE is used for stretch films. To bundle a standard pallet load of 1,20x1,00x1,50 meters, using 80 μm stretch film, 600 gram is needed. This means that, in 2000, 0.58 billion standard pallet loads are bundles using stretch film.

Stretch films can, in principle, be used for bundling all kinds of pallet loads. For shrink covers, however, a well defined, rectangular form is needed. Therefore, we estimate the maximum potential at 80%. We estimate that, in 2020, 30% of pallets that are currently bundled using wrappings, can be bundled using glues instead. The potential is limited, because this bundling method offers no weather protection and is only useable to bundle corrugated boxes.

Note that not all loads on pallets need to be bundled. Pallets are also used to transport large products piece by piece, so no bundling is needed. Furthermore many pallets are often used for indoor use only like storage. Finally, if pallets are used for transportation of crates no wrapping is necessary because crates can be stacked.

Table 12.1: The use of packaging for the demand categories as defined for the MARKAL model, including possible improvement options and possible market shares for 2020.

category	demand	unit	packaging types	share in 2000 (%)	possible share in 2020 (%)
beverages, carbonated	46	billion liter	steel bev can	8	100
			aluminum bev can	8	100
			all steel can	0	100
			ultra light alu can	0	100
			ultra light steel can	0	100
			PET one way	37	50
			PET Refill	7	50
			improved PET refill	0	50
			glass large	10	100
			glass small	27	100
			glass small returnable	3	100
			light glass	0	100
beverages, non carbonated	66	billion liter	liquid board	54	100
			PET one way	26	30
			PET Refill	0	30
			improved PET refill	0	100
			glass large	20	100
			light glass	0	100
			pouch	0	50
			PC bottle	0	50
dairy products, no milk	19	Mtonne	PS cup	84	100
			PP cup	16	100
			glass jar	0	90
			light glass jar	0	90
wet food	4	billion liter	glass jar	50	100
			light glass jar	0	100
			steel food can	50	100
			honeycomb steel can	0	50
dry food, non susceptible	663	billion liter	cardboard box	8	80
			cardboard box + bag	2	100
			PVC box	1	100
			LDPE-film	30	70
			PP-film	44	80
			metallocene	14	90
			paper	1	60
dry food, susceptible	310	Giga liter	PP-laminate	67	100
			PET-laminate	8	100
			metallocene -laminate	9	100
			PP-metalised	4	10
			PET-metalised	11	10
			metallocene -metalised	1	10

Table 12.1(continued): The use of packaging for the demand categories as defined for the MARKAL model, including possible improvement options and possible market shares for 2020.

category	demand	unit	packaging types	share in 2000 (%)	possible share in 2020 (%)
non-food liquids	10.5	billion liter	HDPE bottle	100	100
			recycled HDPE bottle	0	100
			pouch	0	100
			liquid board	0	50
dry non-food	168	billion liter	cardboard box	14	80
			PVC box	10	100
			cardboard blister	0	20
			LDPE-film	37	80
			PP-film	27	80
			metallocene film	11	80
			paper	1	60
carrier bags	21.5	billion bags	PE bag	85	100
			recycled bag	0	100
			paper bag	10	100
			multiple use bag	5	100
industrial bags	200	Mtonnes	PE bag	82	82
			paper bag	9	9
			FIBC one way	9	40
			FIBC returnable	0	40
transport packaging	1670	billion liter	plastic crates	16	100
			wooden crates	1	20
			cardboard crate	1	20
			shrink foil	32	50
			corrugated box	50	100
			improved corr. Box	0	100
pallets	5.6	billion trip units	wood one way	3	100
			wood returnable	60	100
			PE returnable	37	100
			PE one way	0	100
			PE recycled	0	100
			PC recycled	0	100
			Corrugated fibreboard	0	100
			pressed wood	0	100
pallet wrapping	1.0	billion trip units	shrinkcovers	42	80
			stretchfilm	58	100

A combination of Table 12.1 with the definition of the packaging types as done in Chapter 4 till 11 leads to Table 12.2. In Table 12.2 the total use of material for the different packaging demand categories is stated.

Table 12.2: Material input per packaging demand category

demand category	material input (ktonnes)	type of material
beverages, carbonated	252	Steel
	153	Aluminum
	562	PET
	10654	glass
beverages, non carbonated	745	board
	569	PET
	4950	glass
	199	PE
	18	Alu
dairy products, no milk	447	PS
	73	PP
wet food	800	glass
	188	steel
non-food liquids	1050	PE
dry food, non susceptible	2577	cardboard
	120	PVC
	840	PE
	880	PP
	47	paper
dry food, susceptible	650	PP
	110	PET
	112	PVC
	1	Aluminum
non-food	798	cardboard
	672	PVC
	260	PE
	140	PP
	10	paper
carrier bags	430	PE
industrial bags	600	PE
	504	paper
	400	PP
transport packaging	1000	PE
	220	wood
	11700	corrugated board
pallets	4956	wood
	840	PE
Pallet wrapping	770	PE

In Appendix 1 all energy and cost data per packaging type are stated which is based on the cost and energy data as described in Chapter 3 and the characteristics of the packaging types as described in Chapters 4-11. These data will be used as input for the MARKAL model. The model will complete these data with figures on costs and energy requirement for material production and CO_2 emission factors based on modeling of the energy system in Europe.

In Table 12.3 we will present first order estimates on total costs (including material costs) and CO_2 emissions for the different packaging types. The estimates are based on the material prices as stated in Chapter 3, the CO_2 emission factors for materials as stated in van Duin (1997) and the following CO_2 emission factors for energy carriers: 0.1 kg CO_2 / MJel. and 0.072 kg CO_2 / MJ prim. Even though the results are preliminary (the MARKAL model should provide the actual results) we think it is valuable to show them because it creates more insight total costs and the effects on CO_2 emission than Appendix I. This allows a better comparison of the different packaging options.

In order to make a good comparison possible we expressed most data per 1000 liters products that can be packed with the packaging types. For pallets and carrier bags we used other units, namely 1000 trip units and 1000 pieces respectively.

Table 12.3: The use of packaging for the demand categories as defined for the MARKAL model, including possible improvement options, possible market shares in 2020, costs and CO_2 emissions (CO_2 emissions and costs are expressed per 1000 liter packed (for pallets per 1000 trips, for carrier bags per 1000 pieces).

demand category	demand in 2000		share 2000 (%)	max. share 2020 (%)		material related CO_2 emissions (kg)	process related CO_2 emissions (kg)	material costs (ECU)	process costs (ECU)
beverages, carbonated	46	billion liter	8	100	steel bev can	128	44	45	70
			0	100	all steel can	143	47	50	70
			0	100	ultra light steel can	103	40	36	70
			8	100	aluminum bev can	250	35	64	70
			0	100	ultra light alu can	232	34	59	70
			37	50	PET one way	233	70	34	15
			6	50	PET Refill	24	43	4	26
			1	50	improved PET	15	43	4	26
			10	100	glass large	180	24	90	23
			27	100	glass small	300	24	150	76
			0	100	light glass	135	24	68	23
			3	100	glass refill	15	96	8	115
beverages, non	66	billion liter	20	100	glass large	180	24	90	23
			0	100	light glass	135	24	68	23
			54	80	liquid board	60	21	21	15
			26	50	PET one way	233	70	34	15
			0	30	PET Refill	24	43	4	26
			0	30	improved PET	15	43	4	26
			0	50	pouch	20	25	3	18
			0	50	PC bottle	20	28	2	20
dairy products, no milk	19	Mtonne	84	100	PS cup	164	62	26	44
			16	100	PP cup	168	57	17	44
			0	90	glass jar	180	24	90	45
			0	90	light glass jar	144	24	72	45
wet food	4	billion	50	100	glass jar	180	24	90	45
					light glass jar	144	24	72	45
		liter	50	100	steel food can	154	49	142	46
					honeycomb can	108	49	99	46
dry food, non	663	billion liter	8	80	cardboard box	18	13	26	19
			2	100	cardboard box +	20	13	30	15
			1	100	PVC box	140	13	24	39
			30	70	LDPE-film	19	8	3	18
			44	80	PP-film	19	8	2	18
			14	90	metallocene	11	8	2	18
			1	60	paper	4	7	4	18
dry food, susceptible	310	billion liter	67	100	PP-laminate	22	8	2	18
			8	100	PET-laminate	20	8	3	18
			9	100	metallocene -	14	8	2	18
			4	10	PP-metalised	11	8	1	18
			11	10	PET-metalised	11	8	2	18
			1	10	Metallocene-met.	7	7	1	18

Table 4.1 (continued): The use of packaging for the demand categories as defined for the MARKAL model, including possible improvement options, possible market shares in 2020, costs and CO_2 emissions (CO_2 emissons and costs are expressed per 1000 liter packed (for pallets per 1000 trips, for carrier bags per 1000 pieces).

demand category	demand in 2000		share 2000 (%)	max. share 2020 (%)	Packaging type	material related CO_2 emissions (kg)	process related CO_2 emissions (kg)	material costs (ECU)	proces costs (ECU)
non-food liquids	10.5	billion liter	100	100	HDPE bottle	500	161	72	44
			0	100	Rec. HDPE	250	161	72	44
			0	100	Pouch	50	27	7	36
			0	50	Liquid board	14	24	21	44
dry non-food	168	billion liter	14	80	Cardboard box	18	13	26	19
			10	100	PVC box	140	62	24	39
			0	20	Cardboard	18	13	26	39
			37	80	LDPE-film	37	8	3	18
			27	80	PP-film	27	8	2	18
			11	80	Metallocene film	22	8	2	18
			1	60	Paper	8	7	4	18
carrier bags	21.5	billion bags	85	100	PE bag	100	6	14	3
			0	100	Recycled bag	60	6	14	3
			10	100	Paper bag	28	0	26	3
			5	100	Multiple use bag	12	1	168	2
industrial bags	200	Mtonnes	82	82	PE bag	21	1	3	1
			9	9	Paper bag	3	0	2	1
			9	40	FIBC one way	10	6	1	0.3
			0	40	FIBC returnable	3	3	0.4	0
transport	1671	billion liter	16	100	Plastic crates	3	17	0.4	17
			1	20	Wooden crates	2	0	0.5	15
			1	20	Corrugated box	10	0	6	93
			32	50	Shrink foil	3	0	0.4	3
			50	100	Cardboard crate	5	0	3	93
			0	100	Improved corr.	8	0	5	93
pallets	5.6	billion trip units	3	100	Wood one way	17000	0	4250	2667
			60	100	Wood returnable	625	20	156	378
			37	100	PE returnable	2000	159	288	649
			0	100	PE one way	70000	4861	10080	12666
			0	100	PE recycled	1000	139	288	649
			0	100	PC recycled	1000	139	412	649
			0	100	Corrugated	3000	0	1800	2000
			0	100	Pressed wood	3200	0	800	142
pallet wrapping	1.0	billion trip units	42	80	Shrinkcovers	5000	291	720	760
			58	100	Stretchfilm	3000	175	432	760

13 Discussion of results

13.1 Packaging volume

In Table 13.1 the figures as stated in Table 12.2 are compared with the results of van Duin (1997). The latter describes the material use in Europe in 2000 as input for the MARKAL model.

Not all figures match exactly which has several reasons. In general our figures are on the low side because we have left out certain packaging categories because they were either very small or no developments in that field were expected. Another general reason for deviation is that in van Duin (1997) higher growth figures are assumed for the period 1995 to 2000 than in this report.

For several materials the difference in material consumption is larger than 15% (in van Duin (1997) a deviation assessment that does not exceeds 15% is seen as the best available reliability in material flow studies of this kind).

Our steel consumption data are 40% lower than in van Duin (1997). The reason for this is that we only took steel beverage and food cans into account. We did not study steel consumption for sprays, lids and industrial drums (packaging of paint etc.).

The aluminum data are also lower than in van Duin (1997). The reason for this partly related to the strong growth figures (almost double in the period of 10 years). Also we did not take all packaging categories into account due to a lack of information.

The paper and board consumption in this study is closely related with the PPI (1997) figures which state a total consumption of 25 Mtonnes of packaging paper and board.

The PS consumption in this study is very much lower than in van Duin (1997). This is entirely due to the fact that we did not take EPS foam into account.

The PP consumption deviates because a lareg growth is expected van van Duin (1997). We haven’t taken this growth into account due to the autonomous developments as described in paragraph 2.2. Furthermore many packaging options contained both PE and PP which is often modeled in this report as PE (non food bottles are a good example).

PVC figures are not very important due to the small amount of PVC use in 2000. We have often assumed that PVC is not an option in 2000.

13.2 Packaging reduction

In the Chapters 4-11 many options are described that may influence the amount of materials used for packaging and the related CO_2 emissions. In Table 12.3 a first order estimate is stated of the possible reductions in CO_2 emission and the associated costs.

It shows that a lot of CO_2 emission reduction is possible. In general we can say that returnable packaging has the largest potential in terms of CO_2 emission reduction. The process costs are higher than for single trip packaging but due to lower material costs returnable packaging seems to be cheaper than single trip packaging. Also natural organic materials like paper and wood seem to be a competitive packaging materials from a CO_2 emissions point of view (substitution). Only returnable plastic packaging has lower CO_2 emissions but behavioral changes are necessary when this packaging type is widely implemented in Europe. Finally, very thin packaging like films offer significant potentials for emission reductions.

Table 13.1: Comparison of packaging material consumption in 2000 in this study with van Duin (1997) (ktonnes).

material type	this study	van Duin, 1997	share
steel	2252	3750	60%
aluminum	484	900	54%
PET	1266	1500	84%
glass	16404	16250	101%
board	24229	32000	76%
PE	7501	8240	91%
PS	447	1160	39%
PP	2159	3150	69%
PVC	232	510	45%
wood	5215	5350	97%
Total	60189	72810	83%

13 Conclusions

The packaging sector is an important sector from a material consumption point of view. The sector is responsible for about 3.5 percent of the European CO_2 emission. The most important materials used in this sector in terms of CO_2 emission are plastics, metal and paper and board.

Many options are possible to reduce the amount of packaging material. This report shows that many options are available that on first sight may lead to a reduction of CO_2 emission by the packaging sector with at least a factor 2 by the year 2020. The options will de used as input data for the MARKAL model in order to calculate the total CO_2 emission reduction possible.

The options dealt within this report are specified per product category or per packaging type. However, in general the options can be classified by four categories: lighter (more efficient) packaging, reusable packaging, material substitution and use of recycled material.

Making more efficient use of packaging materials often leads to cost effective savings of 10 - 20% packaging material and comparable CO_2 emission reductions. The use of reusable packaging has great potentials. Returnable or reusable pallets, crates and PET bottles have trip numbers varying from 5 to 100 trips which has large effects on the amount of packaging material per packaging service. Large CO_2 emission reductions are possible by implementing these packaging types in Europe. The MARKAL model should create more insight in this matter. The use of recycled materials is in some parts of the sector (industrial transport) very promising and in others it is less promising (food packaging).

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Appendix I: Lifecycle costs and energy consumption

In appendix I the lifecycle costs and the energy consumption for all packaging types defined in this report are stated. The underlying data are described in chapter 3 and 11. All figures are calculated per 1000 packaging services (trips).

		Energy consumption		Costs Investm	Labor	Other VAR	Total
		(MJ_{el})	(MJ_{prim})	(ECU)	(ECU)	(ECU)	(ECU)
beverages, carbonated	steel bev can	127	0	6.5	16.3	0.3	23
	aluminum bev can	99	0	6.5	16.3	0.3	23
	PET one way	913	0	6.5	15.4	0.1	22
	PET Refill	492	106	5.1	31.5	0.9	38
	glass large	202	0	6.5	15.9	0.2	23
	glass small	61	0	6.5	15.9	0.2	23
	light glass	202	0	6.5	15.9	0.2	23
	improved PET refill	492	106	5.1	31.5	0.9	38
	all steel can	134	0	6.5	16.3	0.3	23
	ultra light alu can	97	0	6.5	16.3	0.3	23
	ultra light steel can	115	0	6.5	16.3	0.3	23
	glass refillable	187	107	3.2	31.5	0.2	35
beverages, non carbonated	liquid board	202	0	0.0	15.0	0.0	15
	PET one way	913	0	6.5	15.4	0.1	22
	glass large	202	0	6.5	15.9	0.2	23
	steel bev can	127	0	6.5	16.3	0.3	23
	aluminum bev can	99	0	6.5	16.3	0.3	23
	ultra light steel can	115	0	6.5	16.3	0.3	23
	ultra light alu can	97	0	6.5	16.3	0.3	23
	PET Refill	492	106	5.1	31.5	0.9	38
	improved PET refill	492	106	5.1	31.5	0.9	38
	pouch	212	0	2.3	15.5	0.1	18
	PC bottle	222	0	5.1	15.0	0.0	20
	light glass	202	0	6.5	15.9	0.2	23
dairy products,	PS cup	272	0	6.5	15.4	0.1	22
no milk	PP cup	247	0	6.5	15.4	0.1	22
	glass jar	101	0	6.5	15.9	0.2	23
	light glass jar	101	0	6.5	15.9	0.2	23
						0.0	0
wet food	glass jar	101	0	6.5	15.9	0.2	23
	steel food can	211	0	6.5	16.3	0.3	23
dry food, non susceptible	cardboard box	101	0	3.3	15.8	0.2	19
	cardboard box + bag	101	0	0.3	15.0	0.2	15
	PVC box	51	0	3.3	15.8	0.2	19
	LDPE-film	60	0	2.3	15.5	0.1	18
	PP-film	58	0	2.3	15.5	0.1	18
	metallocene	56	0	2.3	15.5	0.1	18
	paper	51	0	2.3	15.5	0.1	18

		Energy consumption (MJ$_{el}$)	(MJ$_{prim}$)	Costs Investm (ECU)	Labor (ECU)	Other VAR (ECU)	Total (ECU)
dry food, susceptible	PP-laminate	59	0	2	16	0	18
	PET-laminate	57.8	0.0	2	16	0	18
	metallocene -lam.	57.5	0.0	2	16	0	18
	PP-metalised	54.7	0.0	2	16	0	18
	PET-metalised	54.4	0.0	2	16	0	18
	metallocene -met.	54.1	0.0	2	16	0	18
non-food liquids	HDPE bottle	711	0	7	15	0	22
	recycled HDPE bottle	711	0	7	15	0	22
	pouch	114	0	2	16	0	18
	liquid board	101	0	7	15	0	22
dry non-food	cardboard box	101	0	3	16	0	19
	PVC box	270	0	3	16	0	19
	cardboard blister	51	0	3	16	0	19
	LDPE-film	60	0	2	16	0	18
	PP-film	58	0	2	16	0	18
	metallocene film	56	0	2	16	0	18
	paper	51	0	2	16	0	18
carrier bags	PE bag	52	0	2	1	0	3
	recycled bag	52	0	2	1	0	3
	paper bag	0	0	2	1	0	3
	multiple use bag	6	0	0	2	1	2
industrial bags	PE bag	273	0	20	5	0	25
	paper bag	0	0	20	5	0	25
	FIBC one way	5200	0	200	53	1	255
	FIBC returnable	1300	0	40	12	1	53
transport packaging	plastic crates	62	1	11	4	2	17
	wooden crates	0	1	9	4	2	15
	corrugated box	0	0	70	19	5	93
	shrink foil	60	0	2	1	0	3
	cardboard crate	0	0	70	19	5	93
	improved corr. Box	0	0	70	19	5	93
pallets	wood one way	0	0	2000	533	133	2667
	wood returnable	0	277	50	223	104	378
	PE returnable	1240	279	253	278	118	649
	PE one way	43400	0	9500	2533	633	12666
	PE recycled	1240	9	253	278	118	649
	PC recycled	1240	9	253	278	118	649
	Corrugated fiberb.	0	2	1500	400	100	2000
	pressed wood	0	5	300	290	121	711
pallet wrapping	shrinkcovers	2600	0	600	160	0	760
	stretchfilm	1560	0	600	160	0	760

Appendix II: Comparison with EMS study.

In the EMS study the product group packaging is seen as part of the product group 'short life products' [Gielen and Okken, 1994]. Five product types were discerned: consumer packaging, pallets/crates, clothing, paper products and others (including board boxes/plastic bags/steel drums).

For consumer packaging 8 packaging alternatives were modeled:

- Steel can
- Aluminum can
- Glass multiple use bottle
- Board packaging
- Plastic one-way
- Plastic multiple use
- Glass one way bottle
- Bioplastic one way

Because more detail would distort the model no improvement options for these alternatives have been modeled. The glass multiple use bottle is modeled because the study focuses on The Netherlands where this is a common option.

The data described in this report are much more detailed then the EMS data. Besides the possible improvements of the 8 alternatives we modeled much more alternatives like flexible packaging, pouches, different types of plastic packaging etc. Furthermore we differentiated between packaging markets that have a direct influence on the possible alternatives where the model can choose from.

For pallets and crates the EMS study modeled wooden and plastic pallets, both returnable. Crates are not specifically modeled. In this report much more pallets are modeled and also several types of crates. Furthermore we paid attention to pallet wrappings.

For the other packaging categories no data were available for the EMS study. In this report we modeled several categories that are nor described at all in the EMS model like industrial bags, carrier bags, cups for dairy products, blister packaging, liquid board etc. Where the EMS model modeled 10 packaging types, this report describes about 80 packaging options for 13 demand categories.