Swedish Chemicals Agency

Chemical Substances in Elastomer Materials

A study within the government assignment on mapping hazardous chemical substances 2017–2020

PM 4/18

Swedish Chemicals Agency

The Swedish Chemicals Agency is supervisory authority under the Government. We work in Sweden, the EU and internationally to develop legislation and other incentives to promote good health and improved environment. We monitor compliance of applicable rules on chemical products, pesticides and substances in articles and carry out inspections. We review and authorise pesticides before they can be used. Our environmental quality objective is A Non-toxic Environment.

Article number: 511 296.

Preface

In December 2016, the Swedish Government assigned the Swedish Chemicals Agency to map the presence of hazardous chemicals in products and articles that are not already regulated within EU. The assignment should focus on substances of very high concern but also include other hazardous substances that are relevant for the protection of human health and the environment. Children and youngsters should be prioritized and a gender equality perspective should be taken into account. The mapping of hazardous chemicals should focus on consumer available articles and products. For further information, see https://www.kemi.se/om-kemikalieinspektionen/verksamhet/regeringsuppdrag.

The Swedish Chemicals Agency will approach the overall assignment of identifying chemical substances of concern and particular relevance for consumer exposure in several ways. Mapping substances in specific materials is one of these approaches. This report is an account of a study carried out by Sweco Environment AB with the aim to identify elastomer materials of relevance for consumer available articles and products. The report presents key information on the most used elastomer materials and identifies chemical substances potentially present in the materials. The substances are included in a database with further information on their function, uses in different elastomers and concentrations, when available. The database is not complete in its present form and the Swedish Chemicals Agency intends to further analyze the data in due course. The current study does not include an assessment of any intrinsic hazardous properties for the identified substances. The Swedish Chemicals Agency will deal with the assessment of potential human health or environmental hazardous properties for the identified substances in separate subprojects.

Sweco Environment AB received the assignment to carry out the mapping of chemical substances in elastomer materials on 5 September 2017. The assignment manager was Petra Wallberg. Other members in the working group were Mats Ericson, at Lysmask Innovation AB; Susanne Keiter, Sara Thorén, Anna Älgevik, Sophie Taintor and Carina Björkblom at Sweco Environment AB; Martin Sjöström at Sweco Position AB; and Konstantin Kalinichenko at Sweco Society AB. The assignment was finalized on 19 December 2017. The report is written by Sweco Environment AB and Lysmask Innovation AB and any opinions and conclusions presented in the report are entirely those of the authors and do not necessarily reflect the Swedish Chemicals Agency’s point of view. The target group of the report is primarily stakeholders with expertise in chemistry and toxicology with an interest in materials chemistry.

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Summary

This study maps the most widely used elastomer materials and their content of chemical substances. Elastomer materials is a collective name for polymer-based materials with high elasticity, for example rubber. The study is part of the assignment for the Swedish Chemicals Agency to map out the prevalence of hazardous substances in chemical products and articles that are not restricted within the EU. In the study however, no assessment of the hazards of the substances is made. Assessing the hazards of the substances in elastomer materials is a later step in the work of the Swedish Chemicals Agency.

The chemical substances that we identified in elastomer materials have been included in a database.

The elastomer materials that we included in the study are

- general purpose elastomers, the most common elastomers, for example natural rubber
- specialty elastomers, elastomers that are designed to have special properties, such as silicone rubber
- thermoplastic elastomers, materials with properties similar to elastomers but having a different chemical structure
- rubber blends, materials consisting of mixtures of the above-mentioned materials

The study describes global and Swedish material flow. We describe material recycling and common surface treatment methods for the materials. We also have information about existing trends on substitutions of chemical additives for the materials.

We have identified about 3000 potential chemical substances present in elastomer materials. For about 800 of these substances we have additional information, for example the specific function of the substances. We also have information, where this is available, on what kind of elastomer materials a specific substance may be present in and in which concentrations.

Sammanfattning

Den här studien kartlägger de mest använda elastomera materialen och vilka kemiska ämnen de innehåller. Elastomera material är ett samlingsnamn för polymerbaserade material med stor elastisk töjbarhet, till exempel gummi.

Studien är en del i Kemikalieinspektionens uppdrag att kartlägga farliga ämnen i produkter och varor (som ännu inte är reglerade i EU). I den här studien görs dock ingen bedömning av ämnenas farlighet. Att bedöma ämnenas farlighet är ett senare steg i Kemikalieinspektionens arbete.

De kemiska ämnen som är identifierade och ingår i elastomera material har samlats i en databas.

De elastomera material som vi har inkluderat i studien är

- generella elastomerer, de vanligaste elastomererna, till exempel naturgummi
- specialelastomerer, elastomerer som är designade för att ha speciella egenskaper, till exempel silikongummi
- termoplastiska elastomerer, material med egenskaper som liknar elastomerer men som har en annan kemisk uppbyggnad
- gummiblandningar, material som består av blandningar av ovan nämnda material

Studien beskriver materialflödet i Sverige och globalt. Vi beskriver också hur materialåtervinningen för respektive material ser ut. För varje materialslag finns information om vanliga ytbehandlingsmetoder. Vi har också information om vilka trender som finns inom substitution av additiv, det vill säga substitution av sådana kemiska ämnen som tillsätts för att ge materialen specifika egenskaper.

Vi har identifierat cirka 3000 potentiella kemiska ämnen som förekommer i elastomera material. För cirka 800 av dessa ämnen har vi mer information. Bland annat vet vi ämnenas funktion i materialen. I studien har vi också kartlagt i vilka elastomera material som ett specifikt ämne kan förekomma och i vilken koncentration ämnet finns i materialen, i den mån som sådan information har varit tillgänglig.

Abbreviations

ACM	Ethylene acrylate copolymer rubber
AECM	Acrylic rubber
AEM	Ethylene acrylic elastomers
AO	Antioxidant
ATH	Aluminium trihydroxide
ATO	Antimony trioxide
BaP	Benzo[a]pyrene
BFR	Bundesinstitut für Risikobewertung; German Federal Institute for risk assessment
BHT	Butylated hydroxytoluene, an antioxidant
BIIR	Bromo butyl rubber
BIMS	Brominated isobutylene-co-p-methyl styrene
BR	Butadiene rubber
CAS	Unique numerical identifier assigned by the Chemical Abstracts Service (CAS) to chemical substances
CBS	N-cyclohexyl-2-benzothiazole sulfonamide, a rubber accelerator
CIIR	Chlorobutyl rubber
CM	Chlorinated polyethylene rubber, also abbreviated CPE
CO	Epichlorohydrine homopolymer rubber
CPE	Chlorinated polyethylene rubber
CR	(Poly)chloroprene rubber
CSM	Chlorosulfonated polyethylene
DCP	Dicumyl peroxide, a rubber crosslinking agent
DINP	Diisononyl phthalate, a plasticizer
DOP	Dioctyl phthalate, a plasticizer
ECHA	The European Chemicals Agency
ECO	Epichlorohydrine rubber
EMEA	Europe, the Middle-East and Africa
ENB	Ethylidene norbornene
EPDM	Ethylene propylene diene monomer
EPDM	Ethylene propylene diene rubber
ETRMA	The European Tyre and Rubber Manufacturers Association
ETU	Ethylene thiourea, an accelerator
EU	European Union
EU/AU	Urethane rubber, ester and ether
EVA	Ethylene-vinyl acetate rubber
FDA	Food and Drug Administration
FFKM	Perfluoro elastomers
FKM	Fluoroelastomers, also called FPM
FPM	Fluoroelastomers, aslo called FKM
GDP	Gross domestic product
GRG	General rubber goods
HDPE	High density polyethylene
HER	Hydroxyethyl ether of resorcinol (polyurethane curative)
HNBR	Hydrogenated nitrile rubber

HRH	Hexamethylenetetramine-resorcinol-Hisil adhesive or hexamethoxymethylmelamine-resorcinol-Hisil adhesive
IIR	Butyl rubber
IR	Polyisoprene rubber, synthetic natural rubber, isoprene rubber
LDPE	Low-density polyethylene
LLDPE	Linear low-density polyethylene
MBS	2-(4-Morpholinothio)-benzothiazole, a rubber accelerator
MBTS	2-2'-Dithiobis(benzothiazole), a rubber accelerator
MDI	Methylene di-p-phenylene isocyanate
NBR	Nitrile rubber (nitrile butadiene rubber)
NR	Natural rubber
OEM	Original equipment manufacturer
PAH	Polycyclic aromatic hydrocarbons
PE	Polyethylene
PHR	Parts per hundred rubber
PNR	Polynorbornene rubber
PP	Polypropylene
PPE	Polyphenylene ether
PUR	Polyurethane rubber
PVAc	Polyvinyl acetate
PVC	Polyvinyl chloride
PVMQ	Phenyl vinyl methyl silicone rubber
RFL	Resorcinol formaldehyde latex
SBR	Styrene-butadiene rubber
SBS	Poly(styrene-butadiene-styrene) rubber (belongs to TPE-S)
SDAB	Svensk Däckåtervinning AB
SEBS	Styrene-ethylene-butadiene-styrene (belongs to TPE-S)
SEPS	Styrene-ethylene-propylene-styrene (belongs to TPE-S)
SIS	Styrene-isoprene-styrene rubber (belongs to TPE-S)
SR	Synthetic rubber
SVOC	Semivolatile organic hydrocarbons
TBBS	N-tert-butyl-benzothiazole sulfonamide, a rubber accelerator
Tpa	Tons per annum
TPE	Thermoplastic elastomers
TPE-0	Thermoplastic elastomer – olefin
TPE-A	Thermoplastic elastomer – amide
TPE-E	Thermoplastic elastomer – ester
TPE-Q	Thermoplastic elastomer – silicone
TPE-S	Thermoplastic elastomer – styrene
TPE-U	Thermoplastic elastomer – urethane
VOC	Volatile organic hydrocarbons
XNBR	Carboxylated nitrile rubber

1 Introduction

The Swedish Government has assigned The Swedish Chemicals Agency to conduct a survey of hazardous substances in products and articles which are not yet restricted within the EU. The survey will focus on chemical substances of very high concern, but also include other hazardous chemicals of relevance for the protection of human health and the environment. Special focus will be placed on consumer products.

The current assignment regarding elastomer materials, performed by Sweco Environment AB, is part of this government assignment.

2 Scope of the assignment

The overall aim for this assignment was to map out the most widely used elastomer materials and their content of chemical substances. Since the knowledge of chemical intrinsic properties in most case is lacking, all potential chemicals in elastomer materials have been included regardless if they have been identified as hazardous or not. Identified chemical substances in elastomer materials, used as functional additives or present as impurities or degradation products, should be included in the survey.

Elastomer materials included in this assignment are divided into three main groups; general purpose elastomers, specialty elastomers (including *silicone elastomers*) and thermoplastic elastomers.

The initial criteria for selection of elastomer materials, defined by the Swedish Chemicals Agency, were:

- consumer exposure
- consumption/use (quantities) within Sweden and the EU
- potential presence of functional chemicals and surface treatment (in recycled and virgin material, respectively)

In addition, common mixtures of the elastomer materials should be included, and in terms of rubber, both natural and synthetic origin.

For the selected elastomer materials, the following aspects should be described in the report:

- common surface treatment methods
- global and Swedish material flow (including import and export)
- description of material recycling
- potential trends in additive substitution

2.1 Database of chemical substances

At least the following functional chemicals should be included in a database:

- Accelerators
- Activators
- Antioxidants
- Antiozonants
- Antistatic agents
- Binder/coupling agents
- Biocides
- Blowing agents
- Carriers
- Dispersing agents
- Fillers
- Flame retardants
- Lubricating oil or wax
- Masticating agents
- Odorants
- Other ageing protection or stabilizer
- Other processing aids
- Pigments
- Plasticizer, softener, paraffin
- Release, or anti-blocking agents
- Retarders
- Light and UV-stabilizers

Available information on variations in chemical content in different elastomer materials, as well as information on variations in function for different substances in different elastomer materials should be included when available. Content of chemical substances in the elastomer materials should be estimated.

Also, substances that might exist as contaminants and unwanted residues should be included. Potential presence of (rest)monomers, degradation products, etc. should be taken into consideration and information about migration of such substances should be included, if such information is available.

2.2 Boundaries of the assignment

This assignment included elastomer materials in products and articles that are available to consumers, including exposure in the public domain, e.g. artificial turf, soft asphalt in playgrounds or tyres. Thus, applications that only are of relevance for industrial applications were not included. Also, process technologies to produce raw materials or products and details on formulations etc. were not included in the assignment.

3 Survey methodology

3.1 Identification of elastomer materials on the market

For each of the elastomer main groups (general purpose elastomers, thermoplastic elastomers and specialty elastomers), information on elastomers, name, CAS number, annual production volumes (Europe/Global) and applications with assumed consumer exposure was compiled. Data was collected from technical reference literature covering surveys on elastomer materials and publicly available databases such as the Polymer Properties Database. The Polymer Properties Database provided information on elastomer materials and their use and applications. Production volumes were mainly gathered from a technical handbook on plastics. For more details on information sources, see the reference list.

3.2 The database on chemical substances in elastomer materials

The information in the database has been included in an excel-file, see Appendix 1.

3.2.1 Working process

Before the surveying of chemical substances related to elastomer materials started, a database in Microsoft Access was constructed to contain several attributes used to characterize these substances. Approximately 40 attributes were established. Attributes related to general information about the chemical substances were mainly defined as text (e.g. substance name, CAS number, EC number, applications). Attributes related to chemical content were defined as numbers whereas attributes related to, for instance, additives (e.g. processing additives, special function additives) and consumer contact (Sweden and/or EU/Global) were defined as true/false (Boolean). Primary focus during the development of this database was mainly on usability and data input efficiency with more emphasis on front end than back end. A simple Microsoft Access user interface was therefore constructed which would allow for swift data input.

Given the large number of chemical substances related to the elastomer materials identified, the survey on chemical content was initially carried out in a stepwise manner. To test the structure of the database, the gathering of information and to illustrate the outcome of the database for the Swedish Chemical Agency, the survey started with additives in tyres, products based on TPE-S and pigments. The materials were selected based on production volume and expected access to publicly available data. The pigments were included after request from the Swedish Chemicals Agency. Data was collected from peer-reviewed literature, technical reference literature, manufacturer/suppliers, open databases and regulatory databases. Detailed information on chemical content of elastomer materials is often publicly restrained; therefore, this approach proved to be time consuming, as well as inefficient.

At one stage in the process, data from the European IUCLID database, the Swedish Products Register and the American CPCat database were provided by the Swedish Chemicals Agency (see Regulatory databases, section 3.2.2). The datasets included information on chemical substances used in elastomer materials and subsequently, the approach shifted to search for information regarding the chemical substances and their use in elastomers. Hence, information in the database is oriented towards a wide range of elastomer materials and functional additives rather than selected elastomer materials based on consumer exposure and production volume.

Data originating from the IUCLID database covered information on name and CAS number for chemicals categorized under the following descriptor codes; Article of category (AC) 10: “Rubber articles” and Sector of use (SU) 11: “Manufacture of rubber products”. Data provided from the CPCat database covered information on name and CAS number on chemicals related to rubber manufacturing etc. (See section 3.2.2, Regulatory databases).

In the survey, information on substance name, CAS number (or, if not available, EC number), function and content in elastomer material, main elastomer, consumer application and migration/emission/wear was documented for each chemical substance, when possible. In case no information on CAS or EC number was available, chemical identity relied upon substance name solely. When information was only given for a group of chemical substances covering multiple CAS numbers, CAS number was replaced with the note “group”.

When data on chemicals used in elastomer materials was received from national and international data sets (see Regulatory databases, section 3.2.2 below), the survey was prioritized to find information on function, which elastomer material it is used for and at what content (wt%). Detailed information on chemical content in elastomer materials (wt% or parts per hundred -PHR) was often not found but was, where possible, replaced by a rough estimation based on industrial know-how. Differences in chemical content of consumer applications nationally (Sweden) and internationally (Europe/Global) were hard to find, but were recorded where possible.

When information on main elastomer was missing, the note “*unknown*” was entered. The chemical substances received from the regulatory databases which, due to the time limit of the assignment, could not be assessed in this survey, were entered as “*not assessed*”.

If information on elastomer material was available, however unspecific, e.g. “rubber”, the note “*unspecified*” was entered.

3.2.2 Information sources

Regulatory databases

The Swedish Products Register. Product codes (sector of use) of relevance for this survey were related to rubber production and are listed in Table 3-1. From the Swedish Products Register, information on name and CAS number for 534 chemical substances were collected. Data extracted from the Swedish Products Register covered the years 1995 to 2014. Chemical substances with two information providers or less were excluded due to confidentiality restrictions.

Table 3-1. Product codes (sector of use) related to rubber production used for information extraction from the Swedish Products Register.

Sector of use	Description
C20.17	Manufacture of synthetic rubber in primary forms.
C22.1	Manufacture of rubber and plastic products.
R30300	Raw materials for production of rubber products.

The IUCLID database. The Reach registration dossier must contain a brief general description of the identified uses based on the descriptor system consisting of six descriptors lists with standard entries and codes. Substances covered by the descriptor codes AC10: “rubber articles” and SU11: “manufacture of rubber products” were extracted from IUCLID and implemented in the survey. Information on individual sub categories belonging to AC10 are not yet publicly available via ECHA, hence, rubber articles could not be further specified in this survey. Information from the IUCLID database covered a total of 1188 chemical substances.

CPCat (Chemical and Product Categories) is a database compiled by U.S. EPA containing information on categorical chemical use and function for more than 43 000 unique chemicals. The sources are publicly available data, such as Substances in Preparation in Nordic Countries (SPIN) database, information provided by companies, trade associations, and regulatory agencies, such as the U.S. EPA and Food and Drug Administration (FDA). Unique chemicals extracted from the CPCat database were covered by descriptions associated with building materials (rubber), vulcanizers, rubber and plastic manufacturing, raw materials for production of rubber products, polishing agents for rubber products, softeners (rubber-, plastic-, paint-, adhesive-), synthetic rubber manufacturing, foaming agents (solid materials, plastic, rubber etc.) and fibre, leather, rubber and polymerised materials preservative. A total of 2152 chemicals were extracted from the database.

Open databases

Several publicly searchable databases have been used in the survey, e.g. ChemNet, LockChem, PubChem and SpecialChem. Open databases were mainly used to collect complementary information on CAS number, function in elastomer material and application. Information on chemical name and CAS number was also retrieved from the publicly available webpage of the European Chemicals Agency (ECHA).

Technical reference literature

Substantial information regarding chemical names, function in elastomer and applications were retrieved from books containing compiled data on elastomer materials. Given continuous material substitutions within the elastomer industry, only up to date literature was used for the survey.

Manufacturer/Supplier

Websites of manufacturers and suppliers of elastomer materials and applications were searched for information on chemical content. Given company confidentiality, information on e.g. rubber recipes, CAS number and function in elastomer materials is often publicly restricted. For this survey, information has largely been extracted from technical data sheets, material safety sheets and product brochures.

Scientific literature and reports

Environment pollutants were not prioritized in this work but were, included when stumbled upon. In the survey on chemical content in SBR, data was partially collected from peer-reviewed articles and national/international reports investigating rubber crumb from artificial turf fields. Data mainly consisted of chemical analyses of rubber crumb leachate including substances such as polyaromatic hydrocarbons, polychlorinated biphenyls and various heavy metals. For information on peer-reviewed articles and reports, see reference list in the database.

3.3 Import/Export of rubber goods in Sweden

Data has been ordered from Statistics Sweden, department for economic statistics. Statistics Sweden is a government agency which is responsible for producing official statistics, including statistics on national external trade in goods and services. The data for external trade is collected partly from the Swedish Customs Service (for extra-EU trade) and partly from importers and exporters directly (for intra-EU trade, via Intrastat system).

The data collected include the type of goods (provided as a so-called CN-code), price, weight, etc. CN-code nomenclature covers all possible types of goods that may be produced, imported and exported, from agricultural goods to works of art and high-tech equipment. A list of CN-codes may be found at http://tulltaxan.tullverket.se (in Swedish and in English).

The data received from Statistics Sweden contained the following data fields: commodity code (CN6-code), description of the goods, year of reference, as well as domestic production, exports (within and outside the EU), and imports (within and outside the EU), in tons per annum (tpa). The goods for which the data was provided were different kinds of rubber and rubber goods, from natural gum Arabic to pneumatic tyres and rubber floor coverings. Some data was not available due to confidentiality, for the most part due to low number of producing/exporting/importing companies and organizations (less than three per commodity code).

While the original data set covered the years 2008 - 2015, we have concentrated our analyses on data for the year 2013, exclusively, as a high number of data cells were blanked out due to confidentiality for all years except 2013.

The preparation of the raw data prior to the analyses included cosmetic processing, transposing, and aggregation of the numbers in the original data set. Numbers for intra- and extra-EU trade were summed up, and the original explanation texts for CN6-codes were improved where it was needed. Finally, data on more general CN4-level was derived from the original data (on CN6-level).

3.4 Substitution survey

To investigate trends in substitution of additives within the rubber industries, a survey based on personal interviews with representatives from the rubber industry was performed. Interviews were held with eight persons from eight different organizations, within the EU but mainly Swedish. Four organizations were compounders (mixing raw materials for manufacturing industry), four organizations were product manufacturers, two organizations were product owners and two persons were representatives for two associations (Table 3-2).

Table 3-2. Number of participating organizations in the interviews concerning trends in substitution of additives. Description of "level" is explained in section 4.6.2.

Industrial actor	Number of interviews
Polymers and additives (level 3)	0
Compounders (level 4)	4
Semi-manufactured components (level 4.5)	0
Rubber products (level 5)	4
Original Equipment Manufacturer (OEM)	2
Association	2

All three groups of rubbers (general purpose rubber, specialty rubber and thermoplastic elastomers) are included in the businesses of the interviewed companies. The rubber materials handled by the companies were: NR, SBR, EPDM, IR, BR, IIR, CR, CM, NBR, HNBR, EU, AU, ECO, CSM, FPM, ACM, AEM, EVA, PVMQ, TPE-S (for explanations to abbreviations, see Table 4-1 or list of Abbreviations). The industrial sectors were several (automotive, medical, electrical, marine, food contact, consumer goods and toys, building etc.), but no interview was held with any part of tyre industry.

3.5 Limitations and uncertainties in the database

Industrial confidentiality

Given industrial confidentiality, detailed information on chemical content of elastomer materials is often publicly restrained and represents a limitation of this survey, especially the most recent developments. Industrial confidentiality restricts the information that can be retrieved from regulatory databases and manufacturers/suppliers. This affects the amount of information available for specific years as well as specific chemicals. For the same reason, quantitative and qualitative information on chemical content in consumer applications, e.g. rubber recipes for tyre manufacturing is to a high extent restricted. In many cases, manufacturers and suppliers do not provide information on CAS numbers which adds uncertainty regarding the identity of the chemical.

Low volume chemicals

Information from the Swedish Products Register does not include information on chemical substances distributed in volumes less than 100 kg per year. Information from the IUCLID database is equally restricted to chemical substances manufactured or imported in volumes at or above 1 ton per year.

Substance identification

Data gathered from peer-reviewed articles and national/international reports often did not contain information on CAS numbers. This was especially the case for chemical pollutants and heavy metals identified in leaching studies with rubber crumb of SBR. For organic pollutants, information on CAS number was complemented using publicly available databases as previously described. Regarding the heavy metals, for example zinc, there was a lack of information on substance identity. Information provided was limited to elemental names, thus metals such as arsenic, lead, cadmium, mercury, zinc and tin could not be linked to a specific CAS number and were therefore not included in the survey list of chemicals. The fact that data on rubber granulates do not stem directly from the elastomer industry, but from secondary sources such as scientific studies adds a further uncertainty as to the actual chemical content in elastomer materials. It is also important to note that the availability of chemical substances from manufacturers and suppliers does not *per se* mean that they are in actual use in real applications.

Impurities and residues

Impurities and residues can occur due to several main causes:

1) Contaminated raw material from the beginning. For example, natural rubber (NR), whose raw material is bio based, is classified according to how clean it is from all other (natural) substances that are also found in the latex.

2) Residues from previous reactions / processes, in raw material to compounding. For example, it is common to define how much residual monomers remain from the polymer.

3) Residues from incomplete reactions. During vulcanization or polymerization (e.g. silicones and polyurethanes), chemical reactions occur which create crosslinks in the polymeric network. Unless the mixture is stoichiometric or if the reaction is not given the correct conditions (time and temperature), unreacted molecules will be present as impurities, which often pose a health hazard.

4) Residues resulting from aging and degradation. Heat, solar radiation and ozone break down parts of the elastomer material over time or lead to additive reactions in order to stabilize / protect the elastomer (antioxidants, ozone agents, etc.). Residual products can then be formed, mainly from the organic content.

In elastomer materials, residual products from all the above causes can be found with careful analysis. Practically, however, it is most common for the reasons 2) and 3) to be considered when making new products. The first cause is of course always an issue in the manufacturing of NR. In the case of recycling and landfill, all impurities and residues are of interest. If the choice of raw material is good and the manufacturing process has been controlled and with high quality, the impurity content is usually far below 0.1 wt%, i.e. 1000 ppm.

In the database, an impurity column is present where all main causes for impurities have been classified. In addition, if the substance is an intermediate substance, the substance may be classified as "unknown".

Reinforcing fibres

In the study, the different reinforcing fibres, very commonly used in tyre and belt applications, are not included in the database. The fibre materials typically used are: aramid, carbon, glass, nylon, polyester, rayon and steel. In order for these pre-formed fibres to be incorporated well into the rubber structure, certain adhesive systems are used. These systems, dips for rubber-to-cord adhesion and compounding additives for cord adhesion, are included in the database as binders/coupling agents.

4 Description of materials

4.1 Introduction to elastomer materials

General purpose elastomers are representative of a large group of organic polymers with elastic properties of either natural or synthetic origin. These are the most commonly used elastomers on the global market and are used in countless different applications. To obtain certain desirable properties different additives are added to the materials. Examples of available general purpose elastomers are natural rubber (NR), styrene-butadiene rubber (SBR) and ethylene propylene diene monomer (EPDM).

Specialty elastomers represent a group of polymers designed to have special properties and purposes, e.g. to be oil, heat, or solvent resistant. Chloroprene rubber (CR), perfluorinated rubber (FFKM) and silicone rubber (PVMQ) are examples of specialty elastomers. Specialty elastomers are also filled with additives but generally to a much lower extent compared with general purpose elastomers.

Thermoplastic elastomers represent a group of polymers consisting of materials with both thermoplastic and elastomeric properties. Examples of thermoplastic elastomers (TPE) are TPE-olefin (TPE-O), TPE-urethane (TPE-U) and TPE-styrene TPE-S). The TPE-S is the most common group of the thermoplastic elastomers and TPE-S and TPE-O show generally higher fractions of additives.

In addition, the survey included elastomer materials made up of mixtures of different polymers, so called **rubber blends**. Blending is very common in tyre applications where a very large part (weight fraction) of all rubber products produced are based on blends.

4.2 Identification of relevant elastomer materials

The criteria for selection of elastomer materials were consumer exposure, volumes and potential presence of functional chemicals and surface treatment (Table 4-1). In this chapter the outcome of the selection of elastomer material is discussed, and the annual production volumes, in Europe and globally, are presented in more detail.

If no other reference is stated, the information has been gathered from the books *Raw Materials Supply Chain for Rubber Products* by Charles P. Rader and John S. Dick (2014), from *Henriks plaster* by Henrik Lindberg (2016 in Swedish) and *Gummi! - Ett utbildningsmaterial för gummi-industrin* by Bengt Andersson (2002, in Swedish). Abbreviations used for the elastomers are based on the ISO nomenclature.

4.2.1 Selection of relevant elastomer materials based on the criteria

In general, all materials are used in several different applications, and as materials are blended all groups of elastomer materials can essentially be found within the same group of consumer articles; e.g. toys, shoe soles, etc. Thus, very few elastomer materials can be excluded based on the criterion *consumer*.

Only three elastomer materials have mainly industrial applications and all of them are within the group specialty elastomers: fluororubber (FPM), perfluorinated rubber (FFKM) and ethylenic acrylic elastomers (AEM). FPM are mainly used in automotive, chemical and petroleum applications, aerospace, and energy industry. FFKM is used in the aerospace and defence industries and AEM is commonly preferred in automotive applications, such as power steering, transmissions, and engine seals.

To obtain the required functions, structure and/or appearance in the final product, additives are added to all elastomer materials. Particularly in consumer products appearance, such as colour, is important.

Total production of elastomer materials is expected to soon reach 30 million tons worldwide (discussed in more detail in chapter 4.6.3). General purpose elastomers, and specifically natural rubber (NR) and styrene-butadiene rubber (SBR), constitute the majority volumes in elastomer production, as they are used in tyres (Table 4-1, Figure 4-1).

Priority could not be fully implemented for all three criteria, instead all the identified materials were included in the report. In Table A in Appendix 2 more detailed information about different elastomer name variants is presented.

Table 4-1. The main group, the name, commonly used short name, CAS number, annual production volumes and examples of applications for each elastomer material that have been identified as relevant for this survey.

Main group	Elastomer	Short name	CAS	Annual production volumes Europe (x 1M tons)	Annual production volumes Global (x 1M tons)	Examples of applications with consumer exposure
General Purpose Elastomers	Natural rubber	NR	9006-04-6	1.0	12.0	tyres (65% of global volumes for car tyres), rubber boots, condoms, menstrual cups, adhesives, mattresses, shoe soles, computer "mousepad", protection gloves (health care), garden hoses, windscreen wiper, ostomy pouch
	Styrene-butadiene rubber	SBR	9003-55-8		6.0	car tyres, bicycle tyres, floor mats, artificial turf, wire coatings, toys, shoe soles, tubes, in latex coating on paper (in general competition with NR).
	Ethylene propylene diene rubber	EPDM	25038-36-2		1.0	artificial turf, diving suits, door sealing (in-house and for cars), wire coatings, shoe components, roof covers/membranes, windscreen wipers
	Isoprene rubber	IR	9003-31-0		1.0	car tyres, additive in paints, rubber bands, condoms, medical products, shoes, protection gloves, sport goods, sponges
	Butadiene rubber	BR	9003-17-2		3.0	tyres (2 000 000 ton), shoe soles, shoe heels, rugs/mats, bicycles, toys
Specialty Elastomers	Butyl rubber	IIR	9010-85-9		1.2	wire coatings, adhesives, protection gloves, chewing gum, roof covers/membranes, protection masks, medication with insulin,

						washing machines, fire extinguisher, tumble dryer
	Bromobutyl rubber	BIIR	68441-14-5			shoe soles, protective clothing
	Chlorobutyl rubber	CIIR	68081-82-3			similar to BIIR and IIR, components for breathing apparatus for fire fighters and military, medical articles, protective clothing, tubes
	Polynorborn ene rubber	PNR	25038-76-0			damping materials in shoes, wheels on toys
	Chloroprene rubber	CR	126-99-8		0.4	gloves, wire coatings, clothes, latex, adhesives, masks for Halloween, dry suits and wetsuits, sponges, garden hoses, shoe soles and heels, drum sticks, waders, ankle protection/cover, coated weave, case for computers, tubes for pressurised air, hosiery, sports wear
	Chlorinated polyethylene rubber	CM (CPE)	63231-66-3			wire coatings, cable jackets, seals, coated fabrics
	Nitrile rubber (nitrile butadiene rubber)	NBR	9003-18-3		0.5	protection gloves in laboratory ("non-latex gloves"), protection gloves for nuclear industry, floor cover/mats, wire coating, shoes, coating material for paper, weave and leather, dairy machines, thermometers, washing machines, vacuum cleaners
	Hydrogenated acrylonitrile butadiene rubber	HNBR	308068-83-9			shoe soles
	Carboxylated acrylonitrile butadiene rubber	XNBR				hoses, rubber belts, roll covers, shoe soles, various moulded parts for shoe heels
	Urethane rubber	EU/AU				upholstery for furniture, soft foam e.g. mattresses (e.g. *Tempur* and others), ski boot (downhill), paint and lacquer, additive in car and bicycle tyres, swimsuits, underwear (lycra, elastane, charmeuse, dorlastan, spandex etc.), isolation, pacemaker, medical ligatures (wires for blood vessels), protective clothing,

	Epichlorohydrin rubber	ECO				protection masks, slippers, coatings on weaves
	Chlorosulfonated polyethylene rubber	CSM	68037-39-8			sealing for fridge doors, inflatable boats, wire coatings, roof sheeting, pond liners, fabrics, hoses
	Fluoro rubber	FPM				mainly industrial applications
	Perfluorinated rubber	FFKM				mainly industrial applications
	Ethylene acrylate copolymer rubber	ACM				textiles, adhesives, coatings, driving belts
	Ethylene acrylic elastomers	AEM				mainly industrial applications
	Ethylene-vinyl acetate rubber	EVA	24937-78-8			foam in sport goods (helmet, skates etc.), footballs, gymnastics mats, strap for ski pole, wire isolation, adhesive for tape, shoe components, adhesive for wallpapers, surface coating for paper, sandals, paints
	Phenyl vinyl methyl silicone rubber	PVMQ				face masks, paint, cookware, coating on medicine, menstrual cups, sealing, bellows for respiration unit, syringes, dry cleaning material, telephones, microwave ovens, coffee maker, toasters, TV's
Thermo-plastic Elastomers	Thermoplastic elastomer - olefin	TPE-O		0.18	1.0	handles for tools, handles for ski poles, grips for toothbrushes, phones, knifes, drilling machines, bicycles, shoe soles, scrubbers
	Thermoplastic elastomer - urethane	TPE-U	75701-44-9		0.4	car components (10% of total volume), handles with vibration damping, cover for mattresses, shoe components (30% of total volume), ski boots, wound compress, wind shield wiper, melt adhesive, skates, shoe soles, infusion bags, implants, wheels for furniture, coating on weave
	Thermoplastic elastomer - ester	TPE-E		0.05	0.25	zippers, implants, "joints" in body, shoe soles, ski boots (downhill), components for safety belts, gear shift knob

	Thermoplastic elastomer - styrene	TPE-S		0.5	2.0	soft touch applications, teething ring, rubber mats in car, part of brushes, cyclops, tyres, floor mats, handles in kitchen, handles in sporting goods (SEBS/SBS), cookware, toys (Shore A 65), lunch boxes, swim flippers, shoe soles, sealing in cars, air-bag lids
	Thermoplastic elastomer - amide	TPE-A		0.025	0.1	diapers, moisture tight breathable cloth, wire coating, plastic bags, ski boots, shoe soles, sport clothing, keys for electronic devices, catheter
	Thermoplastic elastomer-silicone	TPE-Q				surface material for phones, watches and tablets

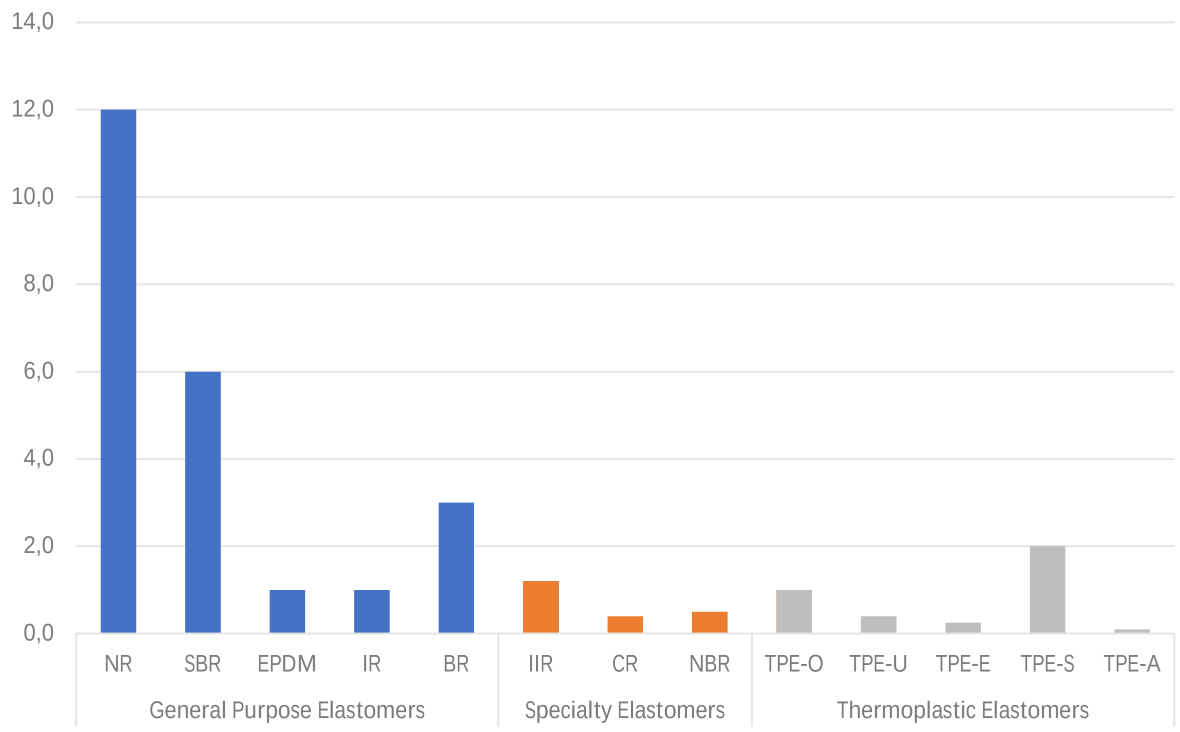

Figure 4-1. Global annual production volumes in million tons described for each elastomer where information has been available. See section 4.2.2 or Table 4-1 for explanation of the abbreviations. Data from Lindberg, Henrik, 2016.

4.2.2 General purpose elastomers

General purpose elastomers include the following:

- natural rubber (NR)
- styrene-butadiene rubber (SBR)
- butadiene rubber (BR)
- ethylene propylene diene rubber (EPDM)
- polyisoprene rubber (IR)

These types of elastomers have good physical properties, good process ability and compatibility and are generally economical. These are typical polymers used in tyres and mechanical rubber goods with demand for good abrasion resistance and tensile properties. General purpose types constitute the largest volume of material used, in total ca. 23 million tons. In the text below each elastomer is described briefly.

Natural rubber

Natural rubber is derived directly from the latex of the *Hevea brasiliensis* (rubber tree) which is grown in regions close to the equator. Today, more than 90% of all natural rubber comes from South-East Asia, although there are also plantations in South America and Africa. It takes six to eight years from when a tree is planted until it can be tapped and brought into production. One tree produces approximately 2 kg of latex each year over a period of 25 - 35 years. About 42% of all rubber consumed in the world is natural rubber, and the remaining rubber consumption is synthetic in origin. About 70% of natural rubber consumption goes into tyre production while the remaining 30% is used by the non-tyre sector.

Styrene-butadiene rubber (SBR)

Styrene-butadiene rubber (SBR) is the largest volume synthetic elastomer used by the rubber industry and represents about 25% of the total monetary value of all synthetic elastomers. It is also usually the least expensive, which may explain its wide use, especially in the tyre sector. SBR is also used in the manufacture of conveyor belts, industrial hose, and footwear. About 76% of SBR is used in tyres, 15% in mechanical rubber goods, 5% in non-tyre automotive and about 4% in miscellaneous applications, such as shoe soles, floor tiles and adhesives.

Butadiene rubber (BR)

Butadiene rubber (BR) is the third largest volume rubber used by the rubber industry today, after NR and SBR. Its global production represents about 25% of the production of all synthetic rubber. The clear majority of BR is consumed by the tyre sector. It has high wear resistance in a tyre tread and flex fatigue resistance in a tyre sidewall. Compared to the consumption of BR in tyres, the use of BR in non-tyre applications is relatively small. However, because of its high resiliency, it is the preferred rubber to make golf ball cores and other applications where dynamic properties are needed. BR is also commonly used as high-impact modifier in thermoplastics (e.g. styrenebutadiene, CAS 9003-55-8).

Ethylene propylene diene rubber (EPDM)

Ethylene propylene diene rubber (EPDM) is the fourth highest volume general purpose elastomer used today in the rubber industry. Unlike NR, SBR, and BR this synthetic rubber is mostly used in the non-tyre sector. Due to its absence of olefinic unsaturation, EPDM has advantages in imparting very good aging resistance to a cured elastomer compound at a reasonable price. It also imparts good aging resistance at higher temperatures and is somewhat resistance to oxygen, ozone, and sunlight attack, and possesses good weathering resistance. EPDM can accept higher loadings of inexpensive fillers than other general-purpose rubbers. EPDM is commonly preferred for making single-ply roofing. It is also used for exterior weather-stripping for automobiles.

Synthetic natural rubber (IR)

There were great expectations when synthetic natural rubber (named Isoprene rubber (IR) in Table 4-1) was first produced in the 1950s. However, today it only represents globally 6.5% of the production of all synthetic rubbers. Synthetic rubber does not vary in composition and is manufactured directly from the isoprene monomer.

4.2.3 Specialty elastomers

Commercial volumes for specialty elastomers are not nearly as large as for general-purpose elastomers, but they still play a vital role in the world economy. These different elastomers exhibit a range of properties and are selected based on how the elastomer performs for the specific application. Thus, many have found niche markets for very specific applications where there is no other practical alternative. Most of the elastomers in this group have some degree of oil resistance. Some specialty elastomers are used in mature markets, such as nitrile rubber and polychloroprene. Others, such as polyepichlorohydrin rubber, have not found their key use yet. The areas having the greatest amount of current research and development activity appear to be with the fluoroelastomers and the silicone rubbers.

Below is a short description of the different specialty elastomers.

Butyl rubber (IIR)

Butyl rubber represents 7% of the world production of synthetic elastomers. It is the fifth largest volume rubber used today and the highest volume of specialty elastomer. The major reason that butyl rubber is used in the tyre industry is its resistance to air permeability, as well as other gases, which makes it ideal for use in making tyre inner liners and inner tubes. In addition, certain grades of butyl rubber are used in medical applications. Butyl rubber is also used in the manufacture of sealants and caulking materials. Special approved grades of butyl rubber are also used in chewing gum.

Halobutyl rubber

The halogenated form of butyl rubber has replaced a significant amount of regular butyl rubber consumption over the last few decades, because it is compatible in blends with general-purpose elastomers such as natural rubber. There are two variants of halobutyl rubber: chlorobutyl rubber (CIIR) and bromobutyl rubber (BIIR). These halobutyl rubbers are made directly from regular butyl rubber and are used mostly to make the inner liner compound for today’s modern tubeless tyres. This is because they are compatible with general-purpose rubbers, can be co-vulcanized with them, and can impart good adhesion to them.

Chloroprene rubber (CR)

Polychloroprene rubber (CR) is the oldest synthetic elastomer that is still being produced. When it was introduced in 1931 it was under the name neoprene. At the time of its introduction it possessed superior resistance to oxidative aging, ozone, and oil. Today, because of its pricing, compared to many other newer specialty synthetic elastomers, it is used in many non-tyre applications including diving suits, belts, hose, footwear, and rubber rollers. CR is also used extensively in the adhesive industry, usually as a latex. It still represents about 2.5% of all synthetic rubber productions.

Chlorinated polyethylene rubber (CM or CPE)

Chlorinated polyethylene rubber (CM) is used extensively in critical hose and many cable applications as it has very good resistance to air aging, heat aging, ozone and weathering. CM is also used in blends with thermoplastics as an impact modifier.

Chlorosulfonated polyethylene (CSM)

Chlorosulfonated polyethylene (CSM) is very similar to CM except that CSM offers a greater choice in cure options, but may cost more to produce than CM. CSM compounds possess high resistance to ozone attack, oxidation, and weathering, even for nonblack products, and usually possess some oil, water, and chemical resistance. Therefore, CSM compounds are used in environmental applications (especially pond linings), insulation for cables, spark plug boots, coated fabrics, hose covers, single-ply roofing, rafts, and folding kayaks.

Epichlorohydrin rubber (ECO)

Epichlorohydrin rubber (ECO) is a common choice in the automotive industry when a good combination of heat, fuel, and oil resistance is needed, but its total production volume is relatively small compared to other specialty elastomers. There are two types of epichlorohydrin rubber: the homopolymer and the copolymer form with ethylene oxide. Often, when good heat, fuel, and oil resistance are needed, epichlorohydrin rubber is selected, especially for seals. This elastomer is used to make gaskets and rollers, and because of the dynamic properties that epichlorohydrin imparts to a compound, it is used to make belts.

Nitrile rubber (NBR)

Nitrile rubber (NBR) is a copolymer of acrylonitrile and butadiene (BR). About one billion pounds of NBR are manufactured in the world each year, which is almost 4% of the total production of synthetic elastomers. The reason for its relatively large worldwide use is because it is a relatively inexpensive rubber for use whenever good oil resistance is needed, for example in hose applications, belting, “under the hood” automotive applications, and “downhole” oil drilling applications.

Hydrogenated nitrile rubber (HNBR)

The hydrogenation to convert NBR to HNBR changes the butane backbone to a methylene backbone, which improves the strength of the HNBR material. HNBR has significant advantages over NBR in that it imparts superior heat and oxidative resistance compared to the less-expensive NBR, without loss in oil resistance. When very good heat aging resistance, oil resistance, dynamic mechanical properties, and good strength are all needed, HNBR is used. One example is automotive timing belts, which represent about 50% of the market for HNBR.

Carboxylated nitrile rubber (XNBR)

An improved version of NBR is carboxylated nitrile butadiene rubber (XNBR). In this execution, there are beside the sulphur bridges also carboxyl groups on the double bond of the butadiene part. These groups will make ionic cross links with zinc to give improved physical properties as compared to a non-carboxylated nitrile rubber. Typical applications for XNBR includes oil resistant applications in automotive, marine and aircraft fuel systems where high strength and abrasion resistance is required.

Polynorbornene rubber (PNR)

Polynorbornenes (PNR) are hydrocarbon rubbers and can be blended with large amounts of plasticiser and, thus, are available in very soft forms. They can also be formulated with damping characteristics.

Acrylic rubber

Acrylic rubber, named ethylene acrylate copolymer rubber (ACM) in Table 4-1, is a relatively low-volume specialty elastomer that is used when very good oil and high-temperature resistance are needed at a reasonable price. Thus, ACM is not selected if very good low-temperature properties or water resistance is needed. This makes ACM a good choice for certain automotive engine gaskets, oil seals, automotive packings, and some hose applications. Acrylate rubbers are produced from different acrylate esters.

Ethylene-vinyl acetate rubber (EVA)

Ethylene-vinyl acetate (EVA) is a rubberlike polymer that sometimes can be processed on either rubber or plastics processing equipment. EVA has good clarity and can be compounded with peroxide curatives and sometimes blowing agents (for foam) for use in athletic shoes, ski boots, hoses, tubes, wire insulation, solar cell encapsulation and medical applications. EVA is used in the rubber industry to impart a good appearance to the product as it easily accepts selected colorants. Also, EVA can be peroxide cured to greatly improve its rubbery properties. It works well with certain blowing agents to produce a foamed product for athletic shoes.

Silicone rubber

Silicone rubber is also named phenyl vinyl methyl silicone rubber (PVMQ; as listed in the Table 4-1). Although silicone use has been growing faster than any other conventional elastomer, liquid silicone rubber still represents less than 2% of all rubber consumption. Silicone rubber is an expensive specialty elastomer that gives very good resistance against heat aging and oil exposure. Its molecular backbone consists of silicon and oxygen instead of the usual carbon-carbon backbone. Because of this it retains its flexibility over a much wider temperature range than any other known elastomer. The molar mass of silicone rubbers can vary over a wide range, and consequently there are liquid materials as well as traditionally resinous rubbers available. Applications for silicone rubbers include electrical equipment and technical products in high temperatures, medical devices and hospital supplies, roll coverings, cable coverings and insulators, lining compounds, moulds, O-rings and seals for the aeronautics industry.

Urethane rubber, ester and ether (EU/AU)

Urethane elastomers are widely used when a flexible mould material is required and the more expensive and less abrasion-resistant silicone rubber is not desired. However, their use requires careful application of release agents as urethanes are adhesive. When used in conjunction with sealant and a release agent, urethane rubber can be poured or brushed to make accurate moulds or elastomeric components such as engine mounts. Urethane rubber develops a viscosity similar to water when in liquid form, so vacuum degassing is not usually necessary. Urethane rubbers cure with negligible shrinkage to a durable rubber that will last in production.

4.2.4 Thermoplastic elastomers

Thermoplastic elastomers (TPEs) are a whole family of rubber materials that exhibit rubber performance properties but can be melted and reprocessed and are used in areas where elasticity over a wide temperature range is required. They are polymeric materials that are processed into fabricated articles in the same manner as a conventional thermoplastic (injection moulding, extrusion, etc.), yet, these articles have the properties and functional performance of a thermoset rubber. They have been gaining a significantly larger market share over the past three decades within non-tyre applications, and the main applications are in the automotive industry and sport accessories. The processing advantage, with realized economic savings in rubber processing costs, overcomes the higher material cost of TPEs, and TPEs will therefore continue to replace traditional thermoset rubber in the future. Emerging nations will be faster in increasing their use of TPE alternatives as they are building new plants and do not have to replace older, conventional processing equipment.

In the sections below short descriptions of the different main groups of TPEs are presented. In Table A in Appendix 2 many subgroup elastomers belonging to the TPE group are also described.

Thermoplastic elastomer – olefin (TPE-O)

TPE-Os have been very successful in the automotive industry replacing plasticized PVC used in car interiors. A major use of TPE-Os is in the manufacture of automotive fascias, where appearance is very important. TPE-Os can be blends of polypropylene and uncross linked EPDM.

Thermoplastic elastomer – urethane (TPE-U)

TPE-Us are being used to make automotive instrument panels, ski goggles and boots, radiator grills, and weatherproof outdoor clothing. Commonly TPE-Us are replacing many thermoset rubber applications as well as plasticized PVC.

Thermoplastic elastomer – ester (TPE-E)

Polyether-ester block copolymer thermoplastic elastomers are high performance engineering materials that bridge the gap between cross-linked elastomers and rigid thermoplastics. They exhibit toughness, impact resistance, load bearing capacity, and low temperature flexibility. They are used for membranes, hoses, sheathings, bellows, cover caps, buffers, coupling and drive elements, seals and body panels. Because of its processability, the material is suited to the production of profiles, hoses, belts, mouldings etc.

Thermoplastic elastomer – styrene (TPE-S)

A TPE based on styrene block copolymers are commonly referred to as a TPE-S. TPE-S have high flexibility and elasticity and are used for injection moulding, extrusion, blow moulding and calendaring.

Thermoplastic elastomer – amide (TPE-A)

Properties of thermoplastic polyamide elastomers include good heat resistance (up to 170°C), good chemical resistance and good abrasion resistance. Common applications are components in car motors and under the hood, wire and cable coatings, hoses, footballs, skiing boots and films penetrating water vapour.

Thermoplastic elastomer- silicone (TPE-Q)

Thermoplastic silicone elastomers are referred to as TPE-Q and are considered quite rare. The Q stands for Quartz, the mineral that contains silica. Industries have a need of elastomeric thermoplastics that can survive long-term exposure to temperatures as high as 150 °C and ones that can take a combination of heat and contact with automotive fuels, and therefore TPE-Q was developed. TPE-Q combines the typical properties of silicones with advantages of a thermoplastic elastomer and is today used for medical, automotive and other applications.

4.3 Rubber blends

Rubber blends have gained much attention in the rubber industry because, when properly formulated, the blend could combine the best features of the individual blend partner. Desirable outcomes could be many objectives, such as specific properties, material price, processability etc. For example, NR is widely known to possess good mechanical properties, such as high tensile and tear strengths. The elasticity and dynamic properties of NR are also excellent. However, due to the existence of numerous reactive double bonds on the molecular backbone, NR is highly susceptible to degradation by thermal aging and ozone attack. In addition, oil resistance of NR is relatively poor, compared to some polar synthetic rubbers, such as CR or NBR. Thus, to overcome such shortcomings, NR is frequently blended with synthetic rubbers. Furthermore, blending is also common between elastomers and thermoplastics, e.g. NR and polystyrene (PS) or NR and polyvinylchloride (PVC).

As blending is very common in tyre applications a very large part (weight fraction) of all rubber products produced are based on blends. As there are many possibilities regarding the selection of elastomers and mixing ratios, it is obvious that the list of different formulation variants with rubber blends is practically endless. In Table 4-2 examples of different rubber and thermoplastic elastomers blends and possible applications are presented.

Table 4-2. Examples of rubber blends and applications. Part per hundred rubber (PHR) means that the compound ingredients are given as parts per 100 by weight of the rubber polymer.

Application/Component		Polymer 1	(PHR)	Polymer 2	(PHR)	Polymer 3	(PHR)	Number of additives	(PHR)
1	Wear layer for winter car tyres	NR	80	BR	20			9	143
2	Sealing layer inside car tyre	NR	40	CIIR	60			10	128
3	Radial passenger tyre tread	SBR	80	NR	20			9	90
4	Tread cap for truck tyre	NR	70	BR	30			11	93
5	Side wall for truck tyre	NR	60	BR	40			11	70
6	Radial passenger car tyre - carcass	NR	70	SBR	20,5	BR	15	12	64
7	Bicycle tyre treads - premium	NR	60	BR	10	Re-claim	60	14	95
8	Low cost EPDM recipe	EPDM	70	SBR	30			8	139
9	Many products at home	TPE-S	100	PP	70			3	40
10	Example	SEPS	100	PP	20			2	70
11	Example	TPE-S (SEBS)	100	PP	60			3	50
12	Cable insulation	TPE-S	100	PP	20				
13	TPE-O example 1	EPDM	100	PP	40			5	10
14	TPE-O example 2	EPDM	100	PP	40			5	15
15	TPE-O example 3	PP	100	EPDM	70			4	10
16	TPE-O example 4	EPDM	100	LDPE	43			5	15
17	Gears, springs, hinges	TPE-E	100	AECM	20			1	2
18	Silky feel, over moulding	TPE-A	100	TPE-Q	30			2	4
19	Automotive interiors, low odour	TPE-S (SEBS)	100	PPE	40			2	5
20	Power tools handles	TPE-U	100	SEBS	80			3	100
21	Glue, sealants	NR	100	PIB	50				
22	Rubber with release agent	EPDM	100	PE (wax)	25			11	55
23	Soft padding	TPE-S	100	PP	30			3	70

One of the main questions in this survey is if rubber blends require any other additive than each individual elastomer? In general, the answer is no, but since most polymers are immiscible some applications may need so called “compatibilizers”.

Compatibilization is carried out in non-reactive or reactive mode. In a non-reactive mode, an external polymeric material, often a block or graft copolymer or modified filler particles, is added. The essential function is to “wet” the interface between the elastomer phases. It is also possible to perform non-reactive compatibilization by surface activation of particle/granulate surfaces (often used in scrap tyre recycling).

In a reactive mode, block and graft polymers may be formed *in situ*, during mixing of the components. For some elastomer combinations, the crosslinking process during vulcanization may develop crosslinks between phases and thereby compatibilize the phases. Adding compatibilizers may alter many properties of the rubber blend, from mechanical properties to processing behaviour. In the database compiled within this assignment, compatibilizers are therefore reported for several functions; “Binder/Coupling agent”, “Other function” (e.g. as impact modifier etc.) and “Other processing aid”. Examples of commonly available compatibilizers are presented in Table 4-3 below.

Table 4-3. Commercially available compatibilizers and their corresponding CAS number.

Compatibilizer		**CAS**
1	Ethylene acrylic acid copolymer	9010-77-9
2	Propylene maleic anhydride copolymer	25722-45-6
3	Maleic anhydride grafted EPDM	-
4	Maleic anhydride grafted SEBS	-
5	Maleic anhydride grafted EVA	-
6	Maleic anhydride grafted LLDPE*	-
7	Malieated ethylene octene copolymer	-
8	Maleic anhydride grafted HDPE**	-

*LLDPE, Linear low density polyethylene, CAS 25087-34-7 **HDPE, High density polyethylene, CAS 9002-88-4

4.4 Additives

Polymers (both polymers and elastomers) can be used both in mixtures or as additives (see Figure 4-3 below). Many general-purpose elastomers and thermoplastic elastomers are used together with other elastomers or polymers, e.g. NR together with BR in wear layer on winter tyres for cars and TPE-O and PP in many TPE-applications. In addition, to produce the desired properties in end applications, additives must be added to elastomer materials. Filler systems, binders and chemical additives have many different applications in compounding. These applications range from improving material strength to altering aesthetic properties and can be divided into subgroups depending on the type of function (Table 4-4). The list below is not exhaustive as there are a range of other ingredients that are sometimes added to compounds to achieve specific properties (see further section 4.4.4) as well as unknown functions. The different reinforcing fibres, very commonly used in tyre and belt applications, are not included.

Table 4-4. Subgroups of additives depending on type of function.

Subgroup	**Additives**
Processing additives	Masticating agent Lubricating oil/wax Release/anti-blocking agent Blowing agent Carrier Dispersing agent Retarder Binder/coupling agent Other processing aid
Vulcanizing system	Vulcanization/curing agent Accelerator Activator Antioxidant
Ageing protection	Light- and UV-stabilizer Antiozonant Other ageing protection, stabilizer
Special function additives	Filler Plasticizer, softener, paraffin Antistatic agent Biocide Flame retardant Pigment Odorant
Others	Other function Unknown function Residue, degradation, impurity

4.4.1 Processing additives

Masticating agent. In short, mastication is a preliminary stage to processing the raw rubber. Before adding compounding ingredients, such as activator (zinc oxide and stearic acid), accelerator and sulphur, into the rubber for vulcanization purposes, the high molecular weight rubber needs to be softened, especially natural rubber (NR), so that a homogeneous dispersion of all ingredients into the rubber matrix becomes possible. This process of softening by means of mechanical shearing is known as mastication. Sufficiently masticated rubber will form a rolling bank on top of a nip in between two rotating rollers. This is the case if the mixing step is carried out on an open mill (2-roll mill). This process involves the use of special mechanical equipment and additives (e.g. aromatic mercaptans – sulphur-containing compounds) at low temperatures to shred the rubber molecules into smaller units. This improves the plasticity and reduces the viscosity.

Lubricating oil/wax. In elastomer compounding, different oils or plasticizers are used to achieve wanted final properties. Some of these oils are mainly added to improve process ability, e.g. the ability for the very high viscous rubber to flow during moulding. Plasticisers need to be compatible with the polymer. They reduce hardness with a given level of filler, and can help with filler incorporation and dispersion. Special types of plasticiser can improve the low temperature flexibility of some rubber types (e.g., nitrile and neoprene). Process aids can also assist with filler dispersion, although they are normally added to improve processability downstream.

Release/anti-blocking agent. Release agents are added to decrease tacking/adhesion between raw materials (granulates, stripes etc.) and between finished products. In the latter case, it could be regarded as a surface treatment for finished goods.

Blowing agent. Some rubber products are not solid: they contain gas bubbles. To develop these gas bubbles during processing a blowing agent is added. Rubber sponges are also formed by blowing agents. Sodium bicarbonate was the first commercially used blowing agent, which reacts with stearic acid to produce carbon dioxide at vulcanisation temperatures. Today’s commonly used blowing agents rely on the formation of nitrogen as the expansion agent.

Carrier. Many additives that are added in relatively small amounts, such as pigment, stabilizers etc., often need support to become easy to disperse into the high viscous elastomer compound before vulcanization. A carrier substance, often with similar chemistry as the main elastomer in question, is used.

Dispersing agent. Dispersing agents are additives that disperse certain particles, like pigments and/or fillers.

Retarder and inhibitor. Retarders and inhibitors are sometimes used to extend time to reach critical degree of vulcanization during processing (“scorch safety time”) for elastomer compounds. Retarders are used to prevent premature curing of compounds during processing and storing. During mixing and further processing in a calender, extruder or moulding press, the elastomer is continuously subjected to heat which can result in premature curing, or pre-curing. To prevent this, retarders are mixed with the compound. Excessive use of retarders results in porosity in compounds and they are rarely used today.

Binder/coupling agent. Substances that are used to improve or facilitate adhesion between the different components in the elastomer compounds, e.g. between rubber and particles (e.g. filler). Compatibilizers, previously mentioned in section 4.3, are also part of this group of additives.

Other processing aid. Other processing aid means other additives that support the processing of elastomer compounds.

4.4.2 Vulcanizing system

Vulcanization/curing agent. The vulcanization agent is the molecule that forms the cross-link between the giant elastomer molecules. Sulphur is used as a vulcanizing agent in 90% of all rubber. Only elastomers that contain some chemical unsaturation (that is, carbon-carbon double bonds) can be cured with sulphur. Generally, the remaining 10% of elastomer compounds have cure systems based mostly on peroxides. However, a small number of compounds based on halogenated elastomers (such as polychloroprene) have cure systems based on metal oxides.

Accelerator. The vulcanization reaction rate is often very low. Accelerators are added to accelerate the reaction in order to shorten the processing time. Accelerators will speed up the cure. Modifications in their levels can control the cure speed and elastomer properties. It is common to use more than one accelerator in a formulation. Peroxide cured materials often use what is known as a co-agent along with the peroxide which can act like an accelerator or modify the physical properties.

Activator. Activators are used to start (activate) the cross-linking process, most often triggered by temperature.

Antioxidant. Antioxidants are often required to decrease the oxidative degradation to extend the products useful service life.

4.4.3 Ageing protection

Light- and UV stabilizer. UV irradiation often degrades the elastomer material. An UV stabilizer decreases the degradation and extends the service life. Light stabilizers and UV absorbers are included in this class.

Antiozonant. Antiozonants are special antidegradants used by the rubber industry to protect cured rubber products from attack by atmospheric ozone. Rubbers with carbon-carbon double bonds are most susceptible to ozone attack, especially when the products are deformed by load.

Other ageing protection, stabilizer. Other stabilizing agent may be added to elastomers, e.g. to stabilize for high temperature usage.

4.4.4 Special function additives

Filler. Different carbon blacks and inorganic fillers are used to improve elastomer compound properties and sometime to reduce material cost. They fall into two basic categories: reinforcing or semi-reinforcing, and diluent (non-reinforcing, generally for cheapening). The most popular reinforcing and semi-reinforcing fillers are carbon blacks, which are categorised primarily by means of particle size. Highly reinforcing fillers can make a compound tough, which can result in poor flow. Nano-fillers such as super-fine clays have a high surface area compared to their volume and can produce better mechanical performance. Although they are more expensive than conventional fillers, the same weight of material last longer because the particles are so much finer. Diluent (non-reinforcing) fillers have a large particle size and do not 'bond' to the polymer in the same way as reinforcing fillers. They are mainly added to reduce cost. Examples include soft clay, calcium carbonate, and talc. Fine-ground natural silica is used to provide dimensional stability, improved thermal conductivity, and good electrical insulation properties at low cost.

Plasticizer, softener, paraffin. Plasticizers are additives that soften the elastomer and decrease its glass transition temperature. In some examples the plasticizer may lower the material cost.

Antistatic agent. An antistatic agent reduces the risk of developing electrostatic load at the product surfaces.

Biocide. Biocide additives give protection against bacteria and fungi in elastomer compounds. It may also prevent surface growth and unpleasant odours.

Flame retardant. Flame retardants are used to slow down fire initiation and growth. Most elastomers support combustion, and the resulting by-products can be extremely hazardous. To improve their flame resistance, several products may be added to the elastomer compound, either inorganic or organic. They include antimony trioxide, zinc borate, aluminium hydroxide and chlorinated paraffin.

Pigment. Pigments are based of coloured particles to control the products colour. Although most elastomer compounds are black, due to the widespread use of carbon black as a filler, coloured elastomer compounds are frequently required to add appeal to consumer items. Colour coding of products is also often desirable. Inorganic or organic pigments are available. Inorganic pigments are often dull and in some cases too opaque to provide the desired colour. Organic pigments generally give brighter shades but are more sensitive to heat and chemicals and are also relatively expensive. They can also fade badly in long-term exposure to sunlight.

Odorant. To improve the smell of rubber products (and working environment for rubber processing) odorants are added to give a more pleasant smell. This class of compounding ingredient was more common in the days when natural rubber was the main rubber for production. The early forms of natural rubber gave products with a distinct aroma and to overcome this a wide range of odorants was offered. Many of the synthetic rubbers have their own distinct aroma and often this must be masked to make the final product acceptable to the user.

4.4.5 Other additives

Other functions or unknown functions. Other functions are those not covered by any other subgroups of additives. There are a range of other ingredients that are sometimes added to elastomer compounds to achieve specific properties. Examples of substances with other functions are acid scavengers and formaldehyde donors. Another example of substances included in this group are intermediates for other additives. Unknown function was, as previously mentioned in section 3.2.1, noted for substances where information on function were not found.

4.5 An overview of surface treatment methods

Surface treatments of components/products are generally done to change the characteristics of the surface to offer other properties than the properties of the base material. It may be the colour, gloss, friction, tackiness, softness etc. but also properties for next step in manufacturing (Figures 4-2 and 4-3 below), e.g. surface energy suitable for gluing.

Generally, however, elastomers do not have surface treatment. Elastomer products most often get their wanted colour, surface roughness from the elastomer compound and forming process. It is actually more common that elastomers act as surface coating since the material group offer great opportunities to create tailored soft and tactile surfaces. Examples include soft handles on tools such as screw drivers and electrical tools, soft silky surfaces on phones and electronic devices etc. Also, some paints for rough marine applications are based on rubber (e.g. CR). Nevertheless, there are several surface treatments used in the rubber industry to:

- change tackiness and gloss
- improve surface energy
- change colour – paint
- change colour – in-mould coating

The technologies for these purposes are briefly described in the sections below with examples for each purpose.

Change tackiness and gloss

High tackiness of semi-manufactured materials (granulates, sheets, rods etc.) and finished goods may create problems of blocking. Examples of anti-blocking agents used for this purpose are listed in Table 4-5.

Table 4-5. Examples of anti-blocking agents, including their respective CAS number, that are used for changing tackiness on rubber materials.

Anti-blocking agent	CAS
Erucamide	112-84-5
Low density polyethylene (wax)	9002-88-4
Silicone glycol copolymer	64365-23-7, 68937-54-2, 68938-54-5
Stearyl/aminopropyl methicone copolymer	110720-64-4

Another method to change tackiness and stickiness is to supply a powder at the surfaces of semi-manufactured materials and finished products. This is very common for NR gloves where the tackiness is overcome by applying a powder like modified absorbable corn starch to the glove. TPE-granulates are most often treated with talc powder to support needed granulate flow properties.

Halogenation is a treatment that smoothens the surface of the gloves (for NR). A light solution of chlorine is applied to the surface of the gloves for a short duration and then fully washed away.

A forth method is to apply a thin coating of a polymeric material-like polyurethane. This polymer imparts a non-sticky surface to the gloves as well as acting as a second layer. The method has been widely accepted, as the polymer layer acts as a coating and barrier against direct contact with the main base material. For users that are particularly sensitive to certain materials (e.g. latex or synthetic butadiene) this may be an advantage. This polymeric coating is made using the combination of two methods. A *diffused coat (outer surface of glove)* is thinner in gauge, more elastic and less slippery which is essential to a user who handles any object. An overly slippery surface will cause the user to lose grip on any equipment, especially when wet. The *applied coat* (inner surface of glove) is a full coat layer that is less elastic but thicker in gauge than the diffused coat, and is an actual fully separable layer. The polymeric coated glove is then fully washed in a suppressed trichloro system which washes away residues of polymers and remove any unwanted impurities from the surface of the glove.

Surface treated rubber crumb is another example. Different processes are developed to treat the surface of the rubber crumb or powder and thereby improve the bonding of the powder to the other ingredients in the compound. The common type of modification is to add a low molecular weight polymer. For products with requirements on good abrasion resistance, crumb made from truck tyres is used, and the good wearing properties can be kept. The processing properties are very often improved by adding some parts of crumb. For example, it is easier to extrude a tyre tread containing some crumb, and by moulding it is easier to get rid of trapped air, which will give less defects and scrap. SBR crumbs, used in artificial turf, are often surface treated with polyurethane (PUR) combined with green colouring to achieve a resemblance with natural grass (Wallberg et al, 2016).

Gloss is often wanted on tyres and other automotive applications and there are numerous liquids on the market to choose from. A few examples of tyre gloss used on the finished product are described in Table 4-6.

Table 4-6. Examples of tyre gloss present on the market. Information about what active chemical (and corresponding CAS number) is used in respective tyre gloss is included.

Tyre gloss	Active chemical	CAS
"Tyre shine dressing" by Ziebart International Corporation (USA)	Distillates (petroleum),hydrotreated middle	64742-46-7
"Turtle wax wet and black tyre dressing" by Turtle Wax	Distillates (petroleum),hydrotreated light	64742-47-8
"Silicone free tyre dressing" by #M	Water based with: Glycerine Poly[oxy(methyl-1,2-ethanediyl)], alpha. -hydro-. omega. -hydroxy- Ethylene glycol monopropyl ether Propylene glycol Sodium di(2-ethylhexyl) sulfosuccinate	 56-81-5 25322-69-4 2807-30-9 57-55-7 577-11-7
"Penrite Oil Tyre Shine" by Penrite	Hydrotreated light petroleum distillate Silicone oil Isohexane	64742-47-8 63148-62-9 107-83-5

Improve surface energy

Surface treatment is often applied to improve the surface energy of elastomer materials, ensuring, for example, good adhesion of printing inks, paints, adhesives, coatings, flocking materials and anti-stick coatings. Surface treatment of elastomer materials, such as rubber, silicone rubber, TPE and EPDM, can be achieved using techniques such as atmospheric plasma, vacuum plasma and corona treatment. Atmospheric and vacuum plasma are techniques that work by means of compressed air which is subjected to a strong electric field ionizing most of its atoms. The resulting super ionized air can then be used for surface modification and surface cleaning. Corona is a surface treatment which involves an electrical discharge causing partial ionization of the surrounding atmosphere. Examples of components processed with these techniques include automotive components, medical devices, cables, keypads, extruded pipes, extruded mouldings and electrical appliances (Dynatechnology, 2017).

Chemical treatments are often used for some of the most commonly used rubber materials including butyl, EPDM, NR, neoprene, nitrile and SBR (Masterbond, 2017). These treatments alter the physical and chemical properties of a surface leading to improved adhesion. For this purpose, various acids and alkalis are used. Typical chemical surface treatments of rubber substrates involve trichloroethylene solvent, modified bleach solution or sulfuric acid solution.

Change colour - Paint

Since elastomers most often are very soft and elastic compared with other engineering materials, it is not very common to paint rubber components. The general rule is to produce the material with the correct colour and surface finish. However, there are a few examples of painted rubber articles, e.g. rubber flooring. One example of rubber paint is Loctite SF F720 (Table 4-7), which is a modified thermoplastic liquid coating that dries to a durable, flexible, rubber-like protective coating.

Table 4-7. Detailed information about chemical content in the rubber paint Loctite SF720 (gathered from the product´s MSDS).

Reinforcing filler (proprietary)	CAS
Reinforcing filler (proprietary)	-
Light aliphatic solvent naphtha	64742-89-8
n-Hexane	110-54-3
Xylene	1330-20-7
Acetone	67-64-1
Ethyl benzene	100-41-4
Silica, amorphous, fumed, crystalline-free	112945-52-5

Change colour - In-mould coating

In-mould coating is sometimes used for polyurethane components, if a controlled colour and surface properties (e.g. harder surface) are wanted. The principle is the same for in-mould coatings for thermoplastic injection mouldings. The core of the polyurethane component is moulded in the first mould. After curing the core is placed in another (slightly larger) mould, where the coloured polyurethane compound is injected and the core is enveloped of the surface material. The surface finish is controlled by the mould surface textures. The material composition of the core and the surface differs somewhat in terms of choice of vulcanisation system and rubber hardness as well as colour. An alternative method for coating cellular polyurethanes is to first mould the core as described above, but instead of changing the tool, the solid surface polyurethane mixture is injected into the same mould, with the compressible cured core inside. The high injection pressure compresses the core and the surface material will envelope the core to produce a new surface.

4.6 Global and Swedish material flow

This chapter describes in brief the structure of the rubber industry, the relations between raw materials in different stages of the global material flow and the import/export of rubber goods in Sweden. As the production of tyres is dominating the rubber industry, the tyre industry and general rubber goods are described separately in more detail.

4.6.1 Introduction

Today the rubber industry is based on the mixing of batches of elastomer compounds, batches typically not bigger than 120 kg – 200 kg per batch, where raw rubbers (base polymers), fillers and other compounding ingredients are mixed together (Figure 4-2). The uncured batches are then processed downstream involving extruders, calendars, injection moulding machines etc., depending on the process set-up for the specific product. The process relies on a continuous flow of properly mixed components.

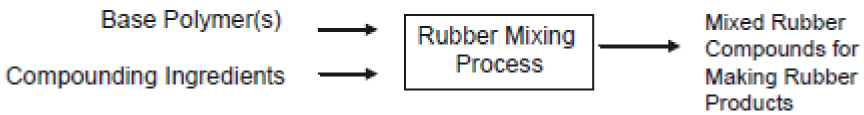

Figure 4-2. The rubber mixing process.

4.6.2 Manufacture of rubber products

The manufacture of rubber products involves a very complex and global flow of raw materials and intermediates (Figure 4-3). A number or basic raw materials are extracted from natural resources. These basic raw materials will give rise to the intermediate feedstocks used in making the polymers and additives needed for manufacturing elastomeric products. Approximately 2000 – 3000 companies are involved only in level 1 to level 3 in Figure 4-3 below. At level 3 (additives) there are more than 20 000 different trade names available at the market (Ash &Ash, 2005). The scope of this project is to list and structure the different polymers and additives at level 3. Rubber products then get their unique properties (elastic and very flexible products with very high deformation before failure) through the very flexible and crosslinked macromolecules. Crosslinking cannot be done before forming the semi-manufactured components or products (Figure 4-3).

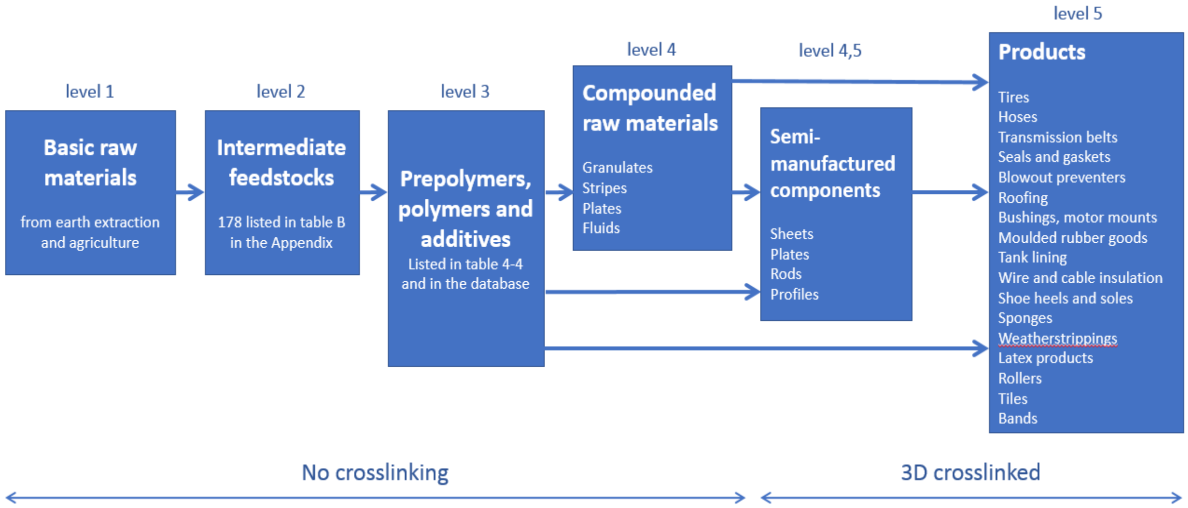

Figure 4-3. Summary of material flow for elastomer materials.

Raw materials of importance for the rubber industry

Material extraction of natural resources, such as fossil fuels, minerals and metal ores, and the subsequent flows are an important element in the understanding of the complexity of these raw materials for making elastomeric products. There are basic raw materials from earth extractions and agriculture that are critical to the success of the rubber industry, as we know it today, and additional basic raw materials that are important but not vital for rubber product manufacture (Table 4-8).

Table 4-8. Materials critical to the rubber industry, and additional basic raw materials that are important but not vital.

Critical materials	Other important materials
Crude oil, naphthenic, and paraffin base	Antimony ore
Natural gas	Bauxite
Natural rubber latex	Clay (kaolin)
Sulphur	Coal
Zinc ore	Cobalt ore
Copper ore	Limestone
Iron ore	Phosphate rock
Silica	Pine trees
Brine (for chlorine)	Tallow (from cattle)
Fluorspar	Titanium ore
	Vegetable oils

Materials critical to the rubber industry

The value chain for all elastomers can ultimately be derived from the fossil fuels *crude oil or natural gas*. Crude oil and natural gas are processed in a multitude of separations and reactions to form the key monomers for elastomer production. About 4-5% of the total petroleum barrel is used for polymers, and thus petroleum is likely to remain as the principal raw material for the indefinite future. An additional energy oil equivalent representing 4% is used to provide the energy needed to convert these petroleum feedstocks into plastics, rubber products, and other chemical products.

Natural rubber is obtained from the latex of the *Hevea brasiliensis* (rubber tree). Today rubber tree plantations in Southeast Asia stands for 85% of the world's supply of natural rubber. Rubber trees require six to eight years after planting before they can be tapped for rubber latex. Typically, new clones of rubber trees have an economic life of about 30 years.

Sulphur is essential for the normal vulcanization of rubber. Sulphur is the tenth most abundant element in the earth´s crust.

Zinc oxide is essential in rubber technology because it is the most commonly used activator for sulphur cure systems. Zinc is fairly abundant in the earth's crust.

Copper is the principal metal in brass alloy that is commonly used to coat steel substrates for metal-to-rubber adhesion. Also, pure copper can be used to achieve good rubber-to-metal adhesion. Lastly, copper can be alloyed with tin to form bronze. Bronze can also achieve good adhesion to rubber under the right conditions.

Iron ore is extremely important to the manufacture of steel, which is important in the rubber industry. In tyre manufacture, steel is necessary to produce steel cord for radial tyres. Also, it is used to manufacture steel cable in the rubber belt industry. Many dynamic rubber parts or components are composites of rubber and steel.

Silica, from natural sources, is used as a feedstock to produce very fine particle precipitated, hydrated, amorphous silica and fumed silica, both commonly used in different ways as reinforcing fillers in rubber technology. Also, silicone rubber, vital to aerospace and medical applications, is ultimately based on silica as a raw material. Silica (silicon dioxide) is one of the most common materials in the crust of the earth.

Sea salt and brine are extremely abundant worldwide. These natural raw materials are very important because through electrolysis chlorine can be obtained for the manufacture of chlorinated elastomers as well as other chlorinated elastomer compounding ingredients.

Approximately 85% of mined *fluorspar (CaF2)* is consumed to make hydrogen fluoride (HF), which is the principal feedstock for manufacturing organic and inorganic fluorine-based chemicals. These are essential for the manufacture of fluoroelastomers used by the rubber industry.

Chemical intermediate feedstocks

Chemical intermediates are a very important segment of the world economy. Raw materials are used to produce these intermediates. They in turn are used to synthesize all the various synthetic elastomers, rubber chemicals, fillers, and additives. There are at least 178 chemical intermediates that the rubber industry relies on daily, and the top 30 chemical intermediates are described in Table 4-9. The total list can be found in Table B in Appendix 2. Many of these intermediate feedstocks are used exclusively to synthesize other chemical products. At least about 2000 – 3000 companies are involved only in level 1 to level 3 (Figure 4-3). At level 3 (additives) there are more than 20 000 different trade names available at the market. There is a risk for presence of impurities and residues in the additives and polymers at level 3 as described in section 3.5.1.

Table 4-9. The top 30 chemical intermediates and their CAS numbers, with the largest economic impact on the rubber industry. For each intermediate, a comment is given concerning the use.

Intermediate feedstocks – top 30	CAS	Comments on use
Acetaldehyde	75-07-0	An important feedstock for synthetic plasticizers
Acetylene	74-86-2	Used to produce FKM, EAM, ACM, CR, etc.
Acrylonitrile	107-13-1	Necessary to produce NBR, HNBR, carbon fibres, etc.
Ammonia	7664-41-7	Needed to make NBR and many accelerators
Aniline	62-53-3	Very important feedstock for many rubber chemicals
Benzene	71-43-2	Needed for resorcinol, polyurethane, DCP, etc.
Butadiene	106-99-0	Key monomer for BR, SBR, NBR, CR, ENB, etc.
Butane	106-97-8	Basic feedstock for over 12 different elastomers
Carbon Disulphide	75-15-0	Basic feedstock for many different rubber accelerators
Cat Cracker Bottoms	-	Very important feedstock for furnace carbon black
Chlorine	7782-50-5	Used for CR, CM, CSM, CIIR, CO, ECO, ADC, etc.
Ethane	74-84-0	Directly used for over ten different rubbers
Ethylene	74-85-1	Used for production of over 14 different rubbers
Formaldehyde	50-00-0	Used for adhesion promotors, tackifiers, curatives, PUR
Isobutylene	115-11-7	Needed for IIR, CIIR, BIIR, BIMS, AO, tackifiers, etc.
Isoprene	78-79-5	Important feedstock for IR and IIR rubber
Mercaptobenzothiazole	149-30-4	Feedstock for TBBS, CBS, MBS, MBTS accelerators
Methane	74-82-8	Needed for carbon disulphide for rubber accelerators
Methanol	67-56-1	Needed for formaldehyde for adhesion, tackifiers, etc.
Nitrobenzene	98-95-3	Used for MDI and aniline for several rubber chemicals
Phenol	108-95-2	Feedstock for numerous rubber chemicals
Propane	74-98-6	Cracked to ethylene and propylene for over 12 rubbers
Propylene	115-07-1	Used to make numerous elastomers, plasticizers, rubber chemicals
Resorcinol	108-46-3	Essential for HRH adhesion, RFL dips, HER for PUR
Silicon Tetrachloride	10026-04-7	Needed for fumed silica and silicone rubber
Sodium Hydroxide	1310-73-2	Needed for many rubber chemicals and rayon
Sodium MBT	2492-26-4	Needed for TBBS, CBS, MBS, MBTS accelerators
Styrene	100-42-5	Used to produce SBR, SBS, SIS, SEBS, STEPS, and RFL dip
Sulphur	7704-34-9	Needed to make many rubber accelerators
Zinc	7440-66-6	Needed for zinc oxide activator used in over 90% of all rubbers

Overview of product manufacturing

The manufacturing of products in elastomers involves many complex operations to turn the semi-manufactured components into a finished product suitable for use. Elastomer compounds can be designed for specific purposes by modifying their characteristics through varying the quantities of their constituents. The scope of this report is not to describe the manufacturing technologies of rubbers in detail, but in short, the process is initiated by mixing elastomers and additives. The elastomers are then shaped by using different kinds of processing methods. Except for thermoplastic elastomers, the elastomer product is vulcanized after shaping so that mechanical properties and the dimensional stability appear. For thermoplastic elastomers, the process of crosslinking is formed by phase separation of the characteristic copolymerized macromolecules.

4.6.3 The worldwide rubber demand

The worldwide rubber industry constitutes about 0.25% of the world GDP. The industry is very much dominated by the production of tyres, as about two-thirds of the rubber industry is tyre related. The world rubber demand is illustrated by production and consumption rates in different regions during 2014-2016 (Table 4-10).

Natural rubber production has followed consumption patterns quite similarly. In 2016, some 12.4 million tons of natural rubber was produced worldwide, a considerable increase since 2000, when the global natural rubber production was 6.8 million tons (Statista, 2017). The Asia-Pacific region, with China in the lead, is by far the largest consumer of natural rubber worldwide. While China consumes such a large quantity of natural rubber, their production does not account for their consumption. The consumption rate of natural rubber is higher than the production rate worldwide in 2016.

Consumption of synthetic rubber worldwide from 2014 to 2016 in different regions shows that in 2016 some 8.2 million tons of synthetic rubber were consumed in the Asia-Pacific region, while 3 million tons were consumed in the Americas and a similar consumption (3.6 million tons) in Europe, the Middle-East and the African (EMEA) region. Production of synthetic rubber is also higher in the Asian-Pacific region compared to the other regions. The consumption rate for synthetic rubber is higher than the production rate in 2016. In the worldwide rubber consumption, the amount of synthetic rubber consumed is greater than natural rubber.

Table 4-10. Statistical summary of world rubber situation during 2014-2016 in 000 tons.

	2014	**2015**	**2016**
Natural rubber (NR) production			
Asia-Pacific	11242	11340	11420
EMEA	565	597	645
Americas	335	334	336
Total	**12142**	**12271**	**12401**
Natural rubber (NR) consumption			
Asia-Pacific	8916	8835	9226
EMEA	1553	1597	1665
Americas	1712	1709	1709
Total	**12181**	**12140**	**12600**
World NR supply – demand surplus/deficit	-39	130	-198
Synthetic rubber (SR) production			
Asia-Pacific	7229	7508	7666
EMEA	3873	3914	4130
Americas	2970	3079	3026
Total	**14072**	**14501**	**14822**
Synthetic rubber (SR) consumption			
Asia-Pacific	7706	7939	8226
EMEA	3523	3633	3684
Americas	2930	3072	3026
Total	**14159**	**14644**	**14936**
World SR supply – demand surplus/deficit	-87	-143	-114
% SR in total rubber consumption	53.8	54.7	54.2

From rubberstudy.com WebSiteData June2017. EMEA stands for Europe, the Middle-East and Africa.

During the years 2008-2015 the demand of NR and SR in the tyre industry in the EU has been relatively stable. The total consumption SR was approximately twice the consumption of NR (Figure 4-4).

Figure 4-4. Total and breakdown of consumption of rubbers in the EU during the years 2008-2015 of natural rubber (NR) and synthetic rubber (SR) for general rubber goods (GRG) and for the tyre industry.

4.6.4 Sectors in rubber industry

Tyre Industry

There are over 70 active tyre manufacturers in the world. The three largest tyre companies (Bridgestone, Goodyear, and Michelin) represented about half of the total tyre sales (Table 4-11).

Table 4-11. The top 10 tyre companies in the world based on tyre sales in 2015.

Company	Country
Bridgestone	Japan
Michelin	France
Goodyear	USA
Continental	Germany
Pirelli	Italy
Sumitomo	Japan
Hankook	South Korea
Yokohama	Japan
Maxxis	Taiwan
Giti	Singapore

Within the EU, the leading tyre manufacture companies are Michelin (France), Continental (Germany) and Pirelli (Italy).

In 2010, the world tyre industry produced over 1 billion tyres of all types. The tyre industry sales consist of about 60% passenger tyres and 30% truck and bus tyres, with the remaining 10% represented by farm service, aircraft, motorcycle, bicycle, and earth-moving tyres (also called off-the-road or OTR tyres). Based on the total numbers of tyres, about 80% of all tyres are passenger tyres. There are about eight passenger tyres made for every truck tyre produced.

About 70% of the yearly world rubber production is used within the tyre industry. The growth in world tyre production has been in response to the growth in the automotive industry. Consequently, tyre production has been a driving force behind growth in the world elastomer industry.

The three major components of a tyre are its tread, carcass and sidewall. The approximate amount of rubber, both NR and SR, in these three components are 35, 35 and 15%, respectively with the remaining 15% in the liner. The elastomer content of a car tyre varies from 3.7 kg/tyre in Japan to 5.0 kg/tyre in the USA and Germany; and for commercial vehicle from 9.24 kg/tyre in Japan to 24.28 kg/tyre in the UK. The choice of different types of rubber used in manufacturing tyres depends on prices, processing and service requirements.

Global tyre manufacturing output was estimated to be over 17 million tons in 2016, and is growing nearly 4% per year through 2022, driven by increased demand, tyre innovations, and continuing capital spending and capacity expansion by tyre suppliers (Smithers Rapra, 2017).

The Asia/Pacific region is by far the largest market for tyres, accounting for over half of global tyre demand. Although the majority of tyre demand in China is comprised of motorcycle and bicycle tyres, sales of motor vehicle tyres in the country are also the second highest in the world, behind only the U.S. There is no production of tyres in Sweden.

General rubber goods (GRG)

The industry of General Rubber Goods (GRG) consist of nontyre related industries and can be divided into three categories:

- industrial products, e.g. moulded and extruded products, belting, hose and tube etc.
- consumer products, e.g. footwear, toys, sports and leisure goods
- latex products, e.g. dipped goods, thread, adhesives, carpet underlay, etc.

GRG is about 38% supplier to the automotive industry, 32% to the industrial sector, 12% to construction, 12% to aerospace and other transportation, and 6% to other application areas.

In 2015 the top 10 global GRG companies were based in Germany, France, USA, Japan and Sweden (Table 4-12).

Table 4-12. The top 10 global GRG companies in 2015 ranked in order based on non-tyre rubber sales in million dollars (European Tyre & Rubber Industry, 2016).

Company	Country
Continental Ag	Germany
Hutchinson SA	France
Freudenberg Group	Germany
Cooper Standard Auto	USA
Sumitomo Riko	Japan
Bridgestone Corp.	Japan
Gates Corp.	USA
NOK Inc	Japan
Parker-Hannifin Corp	USA
Trelleborg AB	Sweden

Within the EU, the four-leading global general rubber goods companies are Continental Ag, Hutchinson SA, Freudenberg Group and Trelleborg AB. The highest sale value amounted to 5.3 and 5.6 million US dollars for Continental Ag in 2015 and 2016 respectively (Figure 4-5).

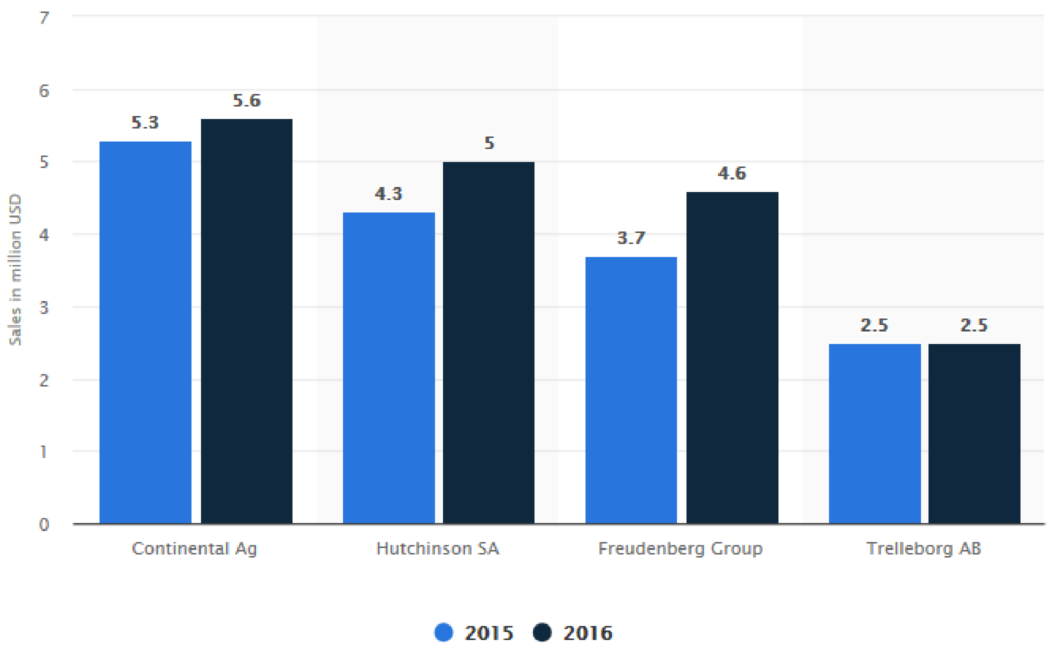

Figure 4-5. Sales by the four-leading global general rubber goods companies within the EU in 2015 and 2016 (million US dollars) (Statista, 2017).

4.6.5 Import/Export of rubber goods in Sweden, 2013

Numbers for production, exports and imports of various rubber goods in Sweden were gathered from Statistics Sweden excluding confidential data. More details of the statistical survey are presented in Table C and Table D in Appendix 2.

Total production of rubber goods in Sweden amounted to approximately 90 000 tons in Sweden during 2013. Import of the same types of goods during 2013 reached approximately 213 000 tons while export of rubber goods equals production, approximately 90 000 tons. Thus, the import of rubber goods was more than double compared to production.

Different articles of vulcanized rubber (excluding hard rubber) as well as unvulcanised compounded rubber were produced in 2013 (Figures 4-6 and 4-7). The largest import was new pneumatic tyres, 111 000 tons, and, thus, more than 50% of total imports of rubber goods. During the same period, 21 000 tons of new pneumatic tyres were exported. As there is no production of pneumatic tyres in Sweden, it can be assumed that the export was related to the export of vehicles.

Various articles of vulcanized rubber accounted for almost one third of the exports of rubber goods. Furthermore, compounded rubber (in primary forms or in plates, sheets and stripe) were also exported in large quantities.

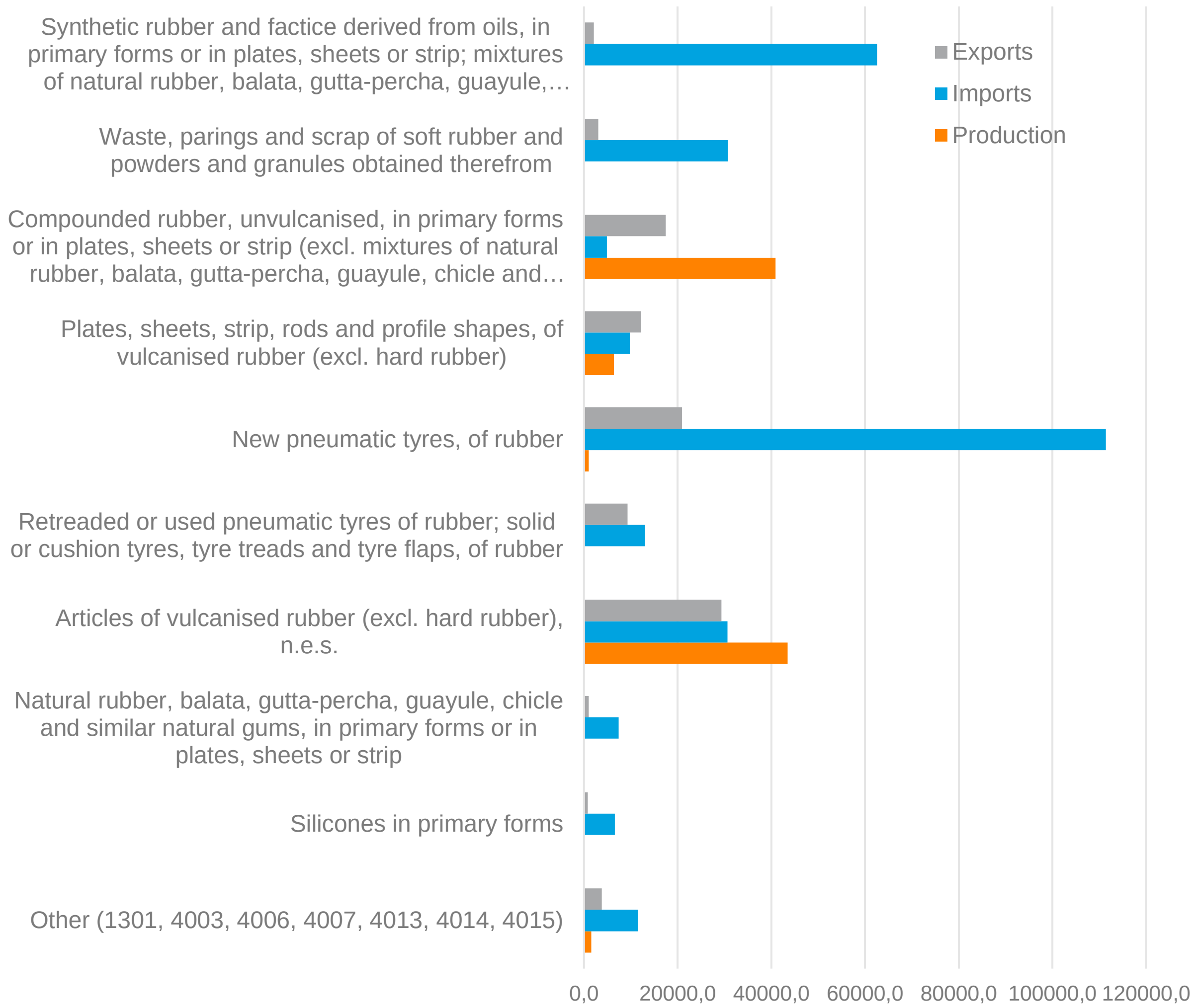

Figure 4-6. Production, exports and imports of various rubber goods in Sweden, 2013, in tons per annum. The numbers in the table do not include confidential data.

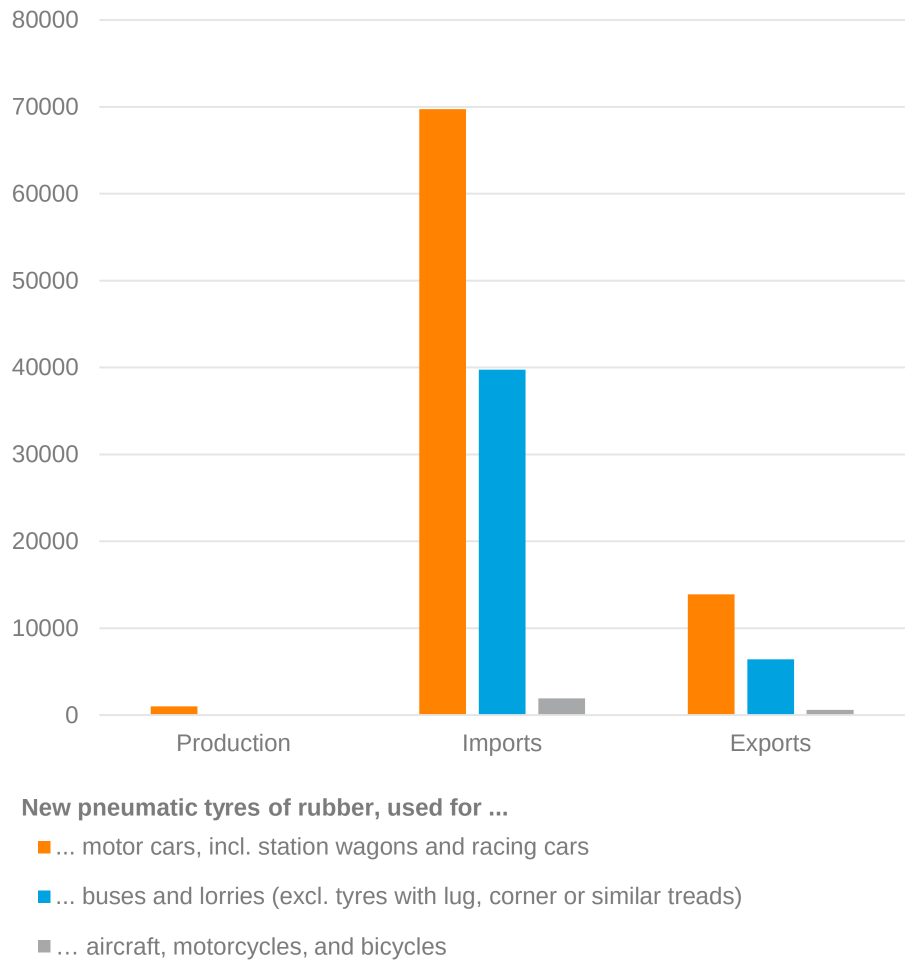

Figure 4-7. Production, exports and imports of new pneumatic tyres in Sweden, 2013, in tons per annum, broken down by usage.

4.7 Material recycling of rubber

According to the European Tyre and Rubber Manufacturers Association (ETRMA, 2015) and as described above, rubber goods within the EU are mainly used within the transport market, followed by the energy sector and in household appliances (Table 4-13).

Table 4-13. Distribution of elastomer material in sectors within the EU.

Market of rubber goods	Distribution
Transport (automotive, rail, ships, aviation, aerospace)	63%
Energy sector	10–12%
Household appliances	10%
Industrial applications (construction, mining, agriculture, farming, machinery)	8–10%
Food contact (drinking water, baby care, medical devices)	4–5%
Leisure and sports equipment	1–2%

Out of these categories, end-of-life vehicle tyres are included in the regulation of extended producer responsibility. Within the EU almost 100% of end-of-life tyres are collected and used for material recycling or incineration (ETRMA, 2015). Rubber waste originating from the other categories are usually only used in energy recovery, through incineration. Disposing rubber in landfills is not permitted within the EU. However, several countries lack capacity for incineration, and rubber may in those cases be disposed of in landfills (even though it is not permitted).

New technology is moving focus from material recycling of rubber that is used for low-tech products, like padding material or explosion blankets, to high quality material, like elastomer powder modified thermoplastics (EPMT). Another example of a new technology is recycling carbon black from rubber products through pyrolysis. The new material is used in applications primarily in the automotive industry (Envirosystems, 2017). These new techniques are promising but are still only a small fraction of the rubber recycling sector.

4.7.1 Recycling of tyres within and outside the EU

In 2015, the tyre production within the EU was estimated to account for 20% of the world tyre production, i.e. 4.8 million tons (ETRMA 2015). In a European context, material recycling of rubber products is mainly made up of end-of-life tyres (ETRMA 2016, ECHA 2017).

There are several recent reports that cover conventional material recycling of tyres in Sweden and within Europe. These studies focus on methods like product reuse (retreading), material reuse (the rubber is salvaged and made into a new material like rubber cuttings or granulate) or incineration (The Swedish Environmental Protection Agency 2016, The Swedish Waste Management Association 2017, ECHA 2017).

Outside of the EU, especially in low-cost production countries like China, there is informal material recycling of rubber products. The recycling is carried out in varying conditions from controlled industrial processes to very simple handling that often is associated with large environmental and health impacts.

According to ECHA, tyre imports to the EU are increasing, and tyres from China are most common in the passenger car and the truck tyre segments (ETRMA Statistics Report, 2014). The report stated that the main differences in the composition of tyres produced within the EU compared to tyres imported outside the EU are the type of extender oils (plasticizers) and the reinforcement used. It is also highlighted that it is difficult to control the oils used during the production as well as the concentration of polycyclic aromatic hydrocarbons (PAHs; ECHA 2017). The practice of using silica reinforcement instead of carbon black for passenger car tyre treads (a practice that is no longer in use within the EU) is also a likely reason for higher concentration of oils in imported tyres than in tyres produced within Europe.

In Sweden about 85 000 tons of used tyres are collected and recycled each year (SDAB, 2017). A large portion (approximately 65%) is material recycled as granulate, clippings, explosion covers etc. (SDAB, 2017). Most of the remaining tyre material is used as fuel feedstock in industrial processes or waste incineration. Hence, the most common material containing recycled rubber of relevance for exposure in the public domain is rubber granulate and clippings in artificial turf used in sports fields and as shock absorbing floor material in playgrounds etc.

4.7.2 Rubber granulates

According to ECHA (2017), rubber granulates are manufactured in approximately 21 countries within the EU, and there are many producers, although the exact number is not known. The demand for rubber granulate is growing as it also has many other applications e.g. within road construction. According to the Swedish National Road and Transport Research Institutes (2017), recycled rubber is an underutilized resource that has potential to be used in different types of constructions.

The recycled granules from tyres made of SBR are often called SBR granules. Other materials than SBR can be used to produce granulate, e.g. EPDM, however, in comparison with SBR it is usually smaller amounts. The information regarding how much granulate originates from other sources than SBR is not complete, and it is hard to determine the exposure in the public domain as artificial fields are refilled with material that might differ from the original.

There are several hazardous substances identified in recycled rubber granulates. Substances commonly present are PAHs, metals, phthalates, volatile organic hydrocarbons (VOCs) and semi-volatile organic hydrocarbons (SVOCs). Since 1st January 2010, a total of nine PAHs are covered by the EU REACH regulation, stating that extender oils are not allowed to be placed on the EU market for use in tyre production if the concentration of benzo[a]pyrene (BaP) and the sum of eight other PAHs exceed 1 mg/kg and 10 mg/kg, respectively. Producers of tyres throughout the EU, however, substituted the prohibited PAH-rich oils well before the EU marketing ban took effect in year 2010 (Wallberg et al., 2016 and references therein). With respect to the lifespan of a tyre, there is theoretically a possibility that infill materials, containing concentrations of PAHs exceeding the EU threshold limits, are still in use. Concentrations of PAHs in infill materials are, however, expected to decrease over time.

In recent evaluations of the risk for human health and the environment, the overall conclusions were that reported concentrations of hazardous substances have been at levels that are acceptable for use as infill material for human exposure in, for example, sports fields (e.g. Wallberg et al., 2016, ECHA 2017 and references therein). Thus, based on present knowledge, the reports concluded that there is no reason to advise against playing on synthetic turf containing recycled rubber granules (ECHA 2017). However, the reports also highlighted uncertainties. ECHA (2017) concludes that it is unclear if the samples collected from artificial turf fields are representative of all fields, since material with higher concentrations of hazardous substances has been reported. There are knowledge gaps regarding substances and their concentrations in granulate. The influx of imported tyres and imported rubber granulates from outside the EU is another uncertainty. ECHA recommends that further studies should be carried out and to await the U.S. Environmental Protection Agency’s report on the topic that is due to be released in 2017.

5 Chemical substances in elastomer materials

In previous chapter, different elastomer materials have been described. In this chapter, focus will be on the survey of the individual substances present in elastomer materials that has been compiled in a database. The information in the database has been included in an excel-file, see Appendix 1. The excel-file contains ca 3000 unique substances.

5.1 Comments and introduction to the database

The scope of the assignment was to identify chemical substances in elastomer materials in products and articles that are available to consumers.

There is a large number of chemical substances related to the identified elastomer materials. Based on the assumption that ca 3000 substances are present and ca 800 of them are fully assessed, the coverage of the database is today around 25-30%, regarding its function, weight fraction etc.

Elastomer materials included in this assignment are divided into three main groups; general purpose elastomers, specialty elastomers (including silicone elastomers) and thermoplastic elastomers. Generally, general purpose elastomers have higher additive fraction than the specialty elastomers. In the thermoplastic elastomer group, TPE-S and TPE-O show typically higher fractions of additives.

Almost all identified elastomer materials have significant consumer exposure. In general, all materials are used in several different applications, and as materials are blended all groups of elastomer materials can essentially be found within the same group of consumer articles. Thus, very few elastomer materials could be excluded based on the criterion consumer. Only three elastomers were identified to have mainly industrial applications: fluororubber (FPM), perfluorinated rubber (FFKM) and ethylenic acrylic elastomers (AEM).

The search for substance information was done through open information access (peer-reviewed literature, technical reference literature, manufacturer/suppliers, open databases and regulatory databases) and two methods were adopted. First by searching within three defined areas (tires, pigments and the material group TPE-S) and in a later stage from selected substances from three databases (the Swedish Products Register, IUCLID and CPCat). The last method was found to be more time efficient.

Given industrial confidentiality, information on chemical content of elastomer materials is often publicly restrained and represents a limitation of this survey. Detailed information regarding formulations for certain applications were difficult to find. Most often, only “typical” formulations based upon recommendations from a certain additive supplier were publicly available. As a consequence, it was not possible to define representative applications and elastomer for all identified substances.

Approximately 1 200 rows of data were registered in the database with information regarding the function of the substance in the elastomer material and in which elastomer material it may be found. Information sources are described in detail in section 3.2.2. Information about examples of consumer applications, impurities or degradation products as well as content (percentage of weight) in elastomer materials have been included when this information has been available. These 1 200 rows represent approximately 800 different substances for which CAS number have been identified for a majority. The number of substances differs from the number of rows because the same substance may be present in different content or with different functions in different materials.

Where information on chemical content in elastomer materials (wt%) was missing, it was replaced by a rough estimation based on industrial know-how. The database indicates whether values are based on this estimation or on information on content that was found in actual sources of information.

Based on the data set that was provided from the Swedish Chemicals Agency, there are approximately 2 300 substances yet to be assessed and registered in the database.

5.1.1 Description of columns in the database

A description of the different columns developed for the database is presented shortly below:

Substance name	Generally used name for the substances, often IUPAC name.
CAS number/EC number	CAS number is included if available. If the substance name indicates a group of substances, *group* is used (see section 5.2.4). EC number is only included when CAS number not found.
Short name	Commonly used short name of the substance, whenever found.
Application	Application examples where the substance is used. Simple wording has been used, e.g. if one reference state that the substance is used in footwear and another reference state it is used in shoe soles, the wording *shoes* is used in both cases. However, due to limited access to examples in open sources very few substances have application examples.
Main elastomer	Indicates in what material the substance is used when this information has been available. As previously mentioned, *unknown* is used when no information was found and *unspecified* when the information was vague, e.g. *rubber* or *elastomer*. Commonly used short names for elastomer materials.
Content (wt%)	Information on content (wt%) of the substance in the material, including low and high if given in an interval. If found, the content given in the reference is used. If not found, weight% was estimated according to the approach presented in section 5.2.5.
Content (PHR)	Information on content (PHR) including low and high if given in an interval.
Content uncertainty	To give an approximate valuation of the uncertainty of the content (wt%) of a substance in a material, the uncertainty has been set to high, medium or low in the database. Due to, as previously mentioned, a high level of secrecy in the elastomer industry the most common used level of uncertainty is 'high'. If content is based on industrial know-how the uncertainty is always set to 'high'.
Function	The function of the substance in the elastomer material is marked with an X in the database. One substance may have several functions in the same material or different function in different materials. If the function differs depending on which material the substance is used in, this results in several rows for the same substance, one for each function/material. *Other function* is used when available information on function does not fit into any existing column. *Unknown function* is used when it is known that the substance is used in an elastomer material, but we have been unable to find out the function of the substance. Generally, we have noticed that substances with unknown function often are intermediates for other additives. However, this is not indicated in the database since this has not been fully investigated.
Impurity	This box is checked if the information available states that the substance is found in a material as an impurity, e.g. not intended to be in a material or is a degradation product from another substance.
Migration/Emission	Information on migration or emission of the substance from the material, including information on where in the material life cycle the migration occurs and if migrations is in the form of particles or molecules. If information is found, this is marked with an *X* in the database, if information is unavailable this is marked with a *U* for *Unknown.* Information on migration/emission or wear from material were specified in the database when this information was available. This is most commonly done for impurities or degradation products which has been described in scientific literature when leaching studies have been made.
Reference	References to where information has been found are given in the database. Since information is most often found in open sources or from manufacturers, references are often given as an internet address.

5.2 Limitations and coverage in the database

5.2.1 Coverage of substances

A total of 2931 unique substances were extracted from IUCLID, the Swedish Products Register and CPCat. Of the 534 chemical substances included in the Swedish Products Register, 88 and 447 were also found in IUCLID and CPCat respectively. Of the 1188 substances in IUCLID, 495 existed in CPCat (see table 5-1 below).

Table 5-1. Overview of numbers of substances extracted from IUCLID, the Swedish Products Register and CPCat databases and the existence of the same substance in the respective database.

	The Swedish Products Register	IUCLID	CPCat
The Swedish Products Register	**534**	88	447
IUCLID	88	**1188**	495
CPCat	447	495	**2152**

5.2.2 Elastomer materials included

This assignment has focused on all commonly used elastomer materials on the global market. These have been identified and are described in this report and are also found to some extent in the database.

The approach used for searching information on chemical substances (see section 3.2.1 *Working process*), resulted in some additional materials included in the database. This is because all information that may be relevant has been included instead of risking to miss possibly relevant information. Materials included may be rarely used elastomers with very specific applications, or other polymers, which have elastic properties when used in certain applications. Polymeric materials included in the database but not mentioned elsewhere in this report are summarized in Table 5-2 with short name and full name. This gives an opportunity to search for further information in future surveys. The abbreviation *SR* (Synthetic rubber) is used when this was available from the source of information, a very general description that includes all rubber materials except natural rubber.

Table 5-2. Additional materials, other than already mentioned in this report, included in the database.

Short name	Full name
ABS	Acrylonitrile butadiene styrene
ASA	Acrylonitrile styrene acrylate
BN	Boron nitride polymer
FVMQ	Fluorovinylmethylsiloxane rubber
PFA	Perfluoroalkoxy polymer
-	Polysulfide rubber
PVC	Polyvinyl chloride
SR	Synthetic rubber (general)

5.2.3 Applications

Due to the nature of the rubber industry, available information on applications tends to be mostly focused on industrial ones. Therefore, information in the database on applications is unevenly distributed towards industrial applications, such as hoses, seals or belts. This is probably because producers of functional additives for elastomer materials want to emphasize that their products are suitable for rough conditions, such as elements in cars, resistance to fuel, impermeability to gases or electrically insulating.

The most common directly consumer available application mentioned is when an elastomer material is intended to be used in contact with food. This is probably because there are several regulations regarding this specific application. Surprisingly, this is not as common for toys or clothes. At least for toys, that would be expected due to existing regulations.

5.2.4 Groups of chemical substances

In a few cases, groups of chemical substances have been identified rather than unique substances and these are identified by the word "*group*" instead of CAS number or EC number in the database. This is most common for substances that have been identified in the literature as substances that are probable to leach out from an elastomer material. The clear majority of literature regarding this is referring to rubber granulate used in artificial turf.

5.2.5 Estimation of weight% additives

In the search for additives in the database and their assessment, there were very few data available regarding recommended weight fractions for different elastomers and applications. To estimate approximate weight fractions, simple calculations were done, based on estimations on PHR-levels for each additive function. The results are presented in Table 5-3.

For each additive function a minimum and maximum PHR were estimated (expert judgements). The estimated range is very wide and represent a general range for all elastomers and applications. The weight fraction range of all additive functions (min weight% and max weight%) are calculations based on the estimated levels of PHR for each additive and are also available in the database.

It is important to note that the estimated approximate weight fractions represent contents in the *formulations*, not as vulcanized elastomer. For some (reactive) substances a chemical reaction starts and ideally is carried through during the mixing/forming/vulcanization. This means that the reactive substance has reacted and changed into something less reactive. It is therefore expected that the following functions and substances will transform into something else (less toxic and less reactive) after the mixing/forming/vulcanization:

- Retarder
- Masticating agent
- Vulcanization/curing agent (especially peroxides)
- Accelerator
- Activator
- Blowing agent
- Pre-polymers for polyurethanes and silicone elastomers

Table 5-3. Generalized weight fractions for each additive function. A minimum (min) and a maximum (max) PHR (parts per hundred) number for each additive function as well as for all additives are listed. The min and max weight% for all additives are also calculated.

Additive function	min PHR for additive function	max PHR for additive function	min PHR for ALL additives	max PHR for ALL additives	min weight% for additive function	max weight% for additive function
Retarder	0,1	2	5	250	0,03	1,9
Masticating agent	0,1	1	5	250	0,03	0,9
Lubricating oil/wax	1	80	5	250	0,28	43,2
Release/anti-blocking agent	0,05	2	5	250	0,01	1,9
Blowing agent	1	15	5	250	0,28	12,5
Carrier	0,5	5	5	250	0,14	4,5
Dispersing agent	1	15	5	250	0,28	12,5
Binder/coupling agent	0,5	5	5	250	0,14	4,5
Other processing aid	1	5	5	250	0,28	4,5
Vulcanization/curing agent	0,25	40	5	250	0,07	27,6
Accelerator	1	2	5	250	0,28	1,9
Activator	0,5	4	5	250	0,14	3,7
Antioxidant	2	10	5	250	0,57	8,7
Light- & UV-stabiliser	0,05	3	5	250	0,01	2,8
Antiozonant	1	5	5	250	0,28	4,5
Other ageing protection stabilizer	1	5	5	250	0,28	4,5
Filler	2	200	5	250	0,57	65,6
Plasticizer, softener, paraffin	1	80	5	250	0,28	43,2
Antistatic agent	0,5	1,5	5	250	0,14	1,4
Biocide	0,1	3	5	250	0,03	2,8
Flame retardant	5	150	5	250	1,41	58,8
Pigment	1	15	5	250	0,28	12,5
Odorant	0,5	3	5	250	0,14	2,8

5.3 Trends regarding additive substitution

Substitution of additives is continuously going on in industry and is driven by:

- demands from society or customers to replace an additive
- internal requirements to replace an additive due to either, a) purchase (dual sourcing), b) processing (including working environment), c) product performance
- price reduction and supply shortage

The objective of this section is to briefly describe the trends regarding substitution of additives in the rubber industry, mainly in Sweden, based on eight interviews (see section 3.4). The focus for the interviews was substitution due the demands from society and customers. Since the compounders in the rubber industry are very much competing with their knowledge in formulation and processing details, there is very little willingness to discuss additives on a detailed level. However, it was possible to obtain some general and specific information.

5.3.1 General comments regarding substitution

All companies are continuously working with substitution of additives. The number of questions from customers regarding whether constituent materials are fulfilling certain regulations have increased significantly over recent years and specifically from Nordic countries. Product owners seem to be very focused on reacting promptly to customer requests and news regarding restriction list changes.

For some industrial sectors (e.g. applications for food contact), the low degree of harmonization within Europe (and the rest of the world) forces the industry to handle a much higher number of additives than technically necessary. In the segment of applications with food contact, some actors regarded the demands from China to be the toughest.

Two of the companies work with polyurethane and silicone materials and the handling of additives is minimal since they are not used much within these technologies. The technologies are based on a few raw material suppliers that supply "packages" certified for different industry applications/segments.

Some companies do not use raw material suppliers from outside Europe, since their openness is regarded to be significantly lower. Within Europe there are also differences as suppliers from some countries are known to be less accurate with their documentation (certificates and MSDS). Most companies have developed their own lists to combine regulations and customers' demands.

5.3.2 Specific comments regarding substitution of additives

The interviewed representatives showed different levels of openness regarding detailed discussions on additives. Some of the details are presented below. All interviewed companies have developed their formulations with additives that are approved by regulations and customers, so that they can meet all types of customer requirements.

Regulations for applications with food contact are very much driving substitution of additives in general. For applications in contact with food, mainly three regulative bodies are used by industry in Europe: FDA (USA), BFR (Germany) and "Warenwet" (the Netherlands).

Flame-retardant. Several of the companies are working with flame retardant additives. Aluminium trihydroxide (ATH) is commonly used but is not discussed for substitution. Antimony trioxide (ATO), a flame-retardant synergist with halogenated rubbers, has been under discussion (mainly due to working environmental risks) and is now replaced by several actors.

Plasticizer. It has been known for many years that small amounts of plasticizers can leach out of the products under certain circumstances. There are continuous discussions regarding different plasticizers, and customers are very concerned about what is used. Aromatic oils have been replaced generally. Some of the paraffinic oils used have some harmful ingredients (which therefore are not used for applications with food contact). The plasticizers dioctyl phthalate (DOP) and diisononyl phthalate (DINP) are very much under discussion with customers. Since phthalates have been used for a long time, they continue to be closely studied to ensure that their use is safe.

Vulcanization system. For general purpose rubbers, both sulphur and peroxide systems are used. For some applications, the sulphur systems cannot be used because of unaccepted residues from the forming/vulcanization processes. The accelerator ethylene thiourea (ETU) has been substituted in recent times. When using peroxides, there are many possible systems to choose from, and companies are continuously up-dating their own lists of approved systems.

Pigment. Generally, most rubbers are black, and the most common black pigment is based on carbon black. For some applications, it is very critical to use a carbon black quality with limited level of impurity (as specified). Some pigments have always been under discussion, especially when high temperature resistance is required. Many companies particularly mentioned pigments for red colour to be difficult to use for many applications.

Antioxidant. Some substitutions have been performed during recent years, e.g. butylated hydroxytoluene (BHT).

Processing additive. No specific problems or issues discussed.

Residues. For some applications residues from upstream manufacturing are of interest, e.g. monomers from elastomer polymerization. For some applications regulations regarding water standard (residues and microbiological growth) are of interest.

Processing. Several companies pointed out that differences in quality are often due to poor processing, more specifically products that are not 100% vulcanized. If the cross-linking reaction is not fully performed, there is a risk of leakage of reactive chemicals.

5.3.3 Conclusions regarding substitution

The eight interviewed industrial actors are focused to meet current and future demands from customers and society. They have often developed their own lists of additives and formulations for different sectors. In several sectors, there is no or limited harmonization in regulative bodies, and therefore compounders need to handle significantly larger numbers than technically required. Areas where substitution of additives are most active are: plasticizers, vulcanization systems, antioxidants and pigments. Several actors mentioned that quality differences often are because poor processing results in not fully vulcanized products. Substitution of aromatic processing oils in elastomer compounds are also repeatedly mentioned. According to REACH legislation (EC 1907/2006), highly aromatic oils containing polycyclic aromatic hydrocarbons were banned as of 1st January 2010. Rubber process oil manufacturers have offered some alternative eco-friendly low PAH content process oils for replacing aromatic ones in elastomer compounds (Öter et al, 2011).

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Appendix 1 Identified substances in elastomer materials

See separate excel-file.

Appendix 2 Material specifics

The appendix on subsequent pages includes the following tables:

Table A *Variations in names as well as sub groups of elastomer materials.*

Table B *Full list of chemical intermediates that the rubber industry relies on daily.*

Table C *Production, exports and imports of various rubber goods, broken down by CN4-code, for Sweden year 2013.*

Table D *Production, exports and imports of various rubber goods, broken down by CN6-code, for Sweden year 2013.*

Appendix 2 Material specifics

Table A. Variations in names as well as sub groups of elastomeric materials. CAS is entered where available.

Elastomer family	Short name	Full name	CAS
Ethylene propylene diene rubber	EPM	Ethylene propylene rubber (synonym with EPDM)	9010-79-1
Bromobutyl rubber	Brominated BIIR	Brominated bromobutyl rubber	68441-14-5
Urethane rubber	AU	Ester based polyol/prepolymer	-
	EU	Ether based polyol/prepolymer	-
Epichlorohydrin ethylene oxide copolymer rubber	CO	Epichlorohydrin homopolymer rubber	-
	GECO	Epichlorohydrin ethylene oxide rubber	-
Phenylvinylmethylsilicone rubber	VMQ	Vinylmethyl silicone	68083-18-1
	MQ	Methyl silicone rubber	-
	PMQ	Phenylmethyl silicone rubber	-
	FVMQ	Fluorovinylmethylsiloxane rubber	-
Thermoplastic elastomer - Olefine	TPO-(EPDM+PP)	Thermoplastic olefin - (Ethylene propylene diene rubber + polypropylene)	-
	TPV-(NBR+PP)	Thermoplastic vulcanisate - (Nitrile butadiende rubber + polypropylene)	-
	TPV-(NR+PP)	Thermoplastic vulcanisate - (Natural rubber + polypropylene)	-
	TPV-(ENR+PP)	Thermoplastic vulcanisate - (Epoxidized natural rubber + polypropylene)	-
	TPV-(IIR+PP)	Thermoplastic vulcanisate - (Butyl rubber + polypropylene)	-
Thermoplastic elastomer - Urethane	TPU-ARES	Thermoplastic urethane - Aromatic, polyester	-
	TPU-ARET	Thermoplastic urethane - Aromatic, polyether	-
	TPU-AREE	Thermoplastic urethane - Aromatic, ester and ether	-
	TPU-ARCE	Thermoplastic urethane - Aromatic, polycarbonate	-
	TPU-ARCL	Thermoplastic urethane - Aromatic, polycaprolactone	-
	TPU-ALES	Thermoplastic urethane - Aliphatic, polyester	-
	TPU-ALET	Thermoplastic urethane - Aliphatic, polyether	-
Thermoplastic elastomer - Ester	TPC-ET	Thermoplastic copolyester - Polyether	9078-71-1
	TPC-ES	Thermoplastic copolyester - Polyester	-
	TPC-EE	Thermoplastic copolyester - Ester and ether	-
Thermoplastic elastomer - Styrene	TPS-SBS	Thermoplastic styrene - Block copolymer of styrene and butadiene	-
	TPS-SIS	Thermoplastic styrene - Block copolymer of styrene and isoprene	-
	TPS-SEBS	Thermoplastic styrene - Block copolymer of styrene and isoprene	66070-58-4

	TPS-SEPS	Thermoplastic styrene - Polystyrene-poly(ethylene-propylene)-polystyrene	-
Thermoplastic elastomer - Amide	TPA-ES	Thermoplastic amide - Polyester	-
	TPA-ET	Thermoplastic amide - Polyether	-
	TPA-EE	Thermoplastic amide - Ester and ether	-

Table B. Chemical intermediates that the rubber industry relies on daily. The CAS number for respective intermediate feedstock is shown, as well as examples of manufacturers and applications of the intermediate.

	Intermediate feedstocks	CAS	Example of manufacturer	Application (indirect or direct feedstock for)
1	Acetaldehyde	75-07-0	BP Chemical, Rhodia, Wintersum Chemical (USA), Total Speciality Chemicals	Plasticizers, e.g. DOP, DOA and DOS
2	Acetic Acid	64-19-7	Celanese, Eastman Chemical, Millenium Chemical, Sterling Chemical, DuPont, Primester	EVA
3	Acetone	67-64-1	Sunoco, INEOS Phenol, Mount Vernon Phenol, Shell, Dow Chemical, Georgia Gulf	Antioxidant, e.g. TMQ and 6PPD antiozonant
4	Acetylene	74-86-2	BASF, Gulf Cryo, Linde Gas AG, SOL Spa,	Filler materials, tackifying resin, ACM, EAM, FKM
5	Acrylonitrile (ACN)	107-13-1	INEOS, Solutia, Asahi Kasei, TongSuh Petrochemical, Formosa Plastics, DSM, etc.	Necessary to produce NBR, HNBR, carbon fibres, etc.
6	Acrylonitrile Butadiene Rubber (NBR)	9005-98-5	Zeon Chemical, Lanxess	To make HNBR and TPV NBR/PP
7	Adipic Acid	124-04-9	ICC Chemical, Ivanhoe Industries, Neuchem Inc., Vreckridge Chemical Co.	Direct feedstock for DBEEA, a polymeric plasticizer, nylon tyre cord fibres, polyol for polyurethane rubber
8	p-Alkylphenol	-	Fellek Chemical	Direct feedstock for phenol disulphide accelerator
9	4-Aminodiphenylamine (4-ADPA)	101-54-2	Infine Chemicals, Beckman Chemikalienm NSTU Chemicals Hangzhou, Chemos GmbH, Eastman Chemical	For manufacturing of 6PPD antiozonant
10	Ammonia	7664-41-7	Nitron Chemical, Coyine Chemical, Miljac Inc., Slack Chemical, Univar USA,	Needed to make NBR and many accelerators
11	Ammonium Thiocyanate	1762-95-4	Alemarck Chemical, American International, Charkit Chemical, Ronas Chemicals, Westco Chemicals	ETU accelerator
12	t-Amylene	-	INNEOS Koln GmbH	IR, IIR, SIS (TPE)
13	Aniline	62-53-3	Rubicon’s Geismar, BASF, DuPont, First Chemical	MDI for polyurethane elastomers and polyurethane rigid foams.
14	Aniline Hydrochloride	142-04-1	Pharmasi Chemicals, Jai Radhe Sales, Mallinckodt Chemicals, Garuda Chemicals, AK Scientific Inc.	Direct feedstock for several antioxidants
15	Antimony	7440-36-0	Shenyang Huachang Antimony Chemical Co, Kiaoning Tianyuan Industrial and Trade Co. Ltd.	To make flame retardant antimony trioxide (ATO)
16	Antimony Trichloride	10025-91-9	Alfa Aesar-Johnson Matthey, Chemical and Metal Industries, Noah Chemical	To make flame retardant antimony trioxide (ATO)

	Intermediate feedstocks	CAS	Example of manufacturer	Application (indirect or direct feedstock for)
17	Benzene	71-43-2	ICC Chemicals, US Petrochemical Industries, TCI Europé NV	Needed for resorcinol, polyurethane, DCP, etc.
18	Benzothiazyl Disulphide (MBTS)	120-78-5	Chemos GmbH, Krahn Chemie GmbH	For accelerators TBBS and CBS
19	Borates (Borax)	1303-96-4	Rio Tinto Borax, American Borate and Searles Valley Mineral	To make zinc borate hydrate (flame retardant) and glass fibres
20	Boric Acid	10043-35-3	Allchem Industries, American Borate, Bruchem Inc, Coyne Chemical, Graham Chemical, Miljac Inc.	To produce zinc borate hydrate (flame retardant)
21	Bromine	7726-95-6	Houghton Chemical, Tetra Technologies	To make Bromo butyl rubber (BIIR)
22	Butadiene	106-99-0	Huntsman, Sabina Petrochemicals, Equistar Chemical, Texas Petrochemicals, Shell Chemica, etc.	Key monomer for BR, SBR, NBR, CR, ENB, etc.
23	Butane	106-97-8	Calor Gas, Flogas Britain Ltd., UGI International	Basic feedstock for over 12 different elastomers
24	1,4-Butanediol (BDO)	110-63-4	BASF, Gulf, Invista, ISP, Lyondel, Mitsubishi, Sichhuan Tianhua, Gulf Advanced.	Is a curing agent for polyurethanes etc.
25	Butanol (Butyl Alcohol)	71-36-3	BASF, Dow Chemical, Celanese, Eastman Chemical	To make curing agent for polyurethane (TMP) and butyl oleate plasticizer
26	n-Butyl Acrylate	141-32-2	Rohm and Haas Chemical, Dow Chemical, BASF	monomer for ACM rubber
27	t-Butylamine	75-64-9	Arcema Inc., BASF, TCI Europé, Merck NV Speciality Chemicals	For TBBS accelerators
28	n-Butyl Chloride	109-69-3	Degussa Corp., BASF, NSTU Chemicals Hangzhou	For ZnDBC accelerators
29	t-Butyl phenol	98-54-4	Jinan Haohua Industry, Hangzhou Meite Chemicals, AK Scientific, Fabrichem	For different tackifying resins
30	n-Butyraldehyde	123-72-8	Kinbester Co., Chemos GmbH, BP Chemical, Oxochimie, Tedia Company, Krahn Chemie GmbH	Curing agent TMP for polyurethane and different plasticizers
31	Calcium Carbide	75-20-7	Chemos GmbH, Jinan Haohua Industry, ICC Chemical	To make tackifying resins, fillers, and ACM
32	Calcium Hydroxide	1305-62-0	Allan Chemical Corp., Jinan Haohua Industry Co., Sattva Chemical, BCH Bruthl Chemikalien Handel	To make calcium carbonate filler etc.
33	Calcium Oxide	1305-78-8	Miljac Inc., Kraft Chemical, Honeywell Speciality Chemicals, Wintersum Chemical, VWR International	For Calcium Carbonate (filler)
34	Caprolactam	105-60-2	BASF, Honeywell, DSM Chemicals	For nylon tire cord (fibre), and ACM rubber
35	Carbon Disulphide	75-15-0	Akzo Nobel, Arkema, PPG Industries, ICC Chemical Corp., Kinbester Co., Chemos GmbH	For rayon fibre, TMTM accelerator, MBT accelerator
36	Chlorine	7782-50-5	Dow Chemical, Formosa Plastics, Occidental Chemical, Olin, Oxy Vinyl, PPG Industry	For IIR, CIIR, CM, CSM etc.

	Intermediate feedstocks	CAS	Example of manufacturer	Application (indirect or direct feedstock for)
37	Chlorobenzene (Monochlorobenzene)	108-90-7	Hainan Zhongxin Chemical, Shanghai Sunwise Chemical, Chemos GmbH	For making aniline
38	Chlorodifluoromethane	75-45-6	Altair Partner, Pfaltz and Bauer	For tetrafluoroethylene
39	Chlorohydrin	96-24-1		For polyol for polyurethane rubber
40	Coal Tar	8007-45-2		For Carbon Black (active filler, UV protection)
41	Crotonaldehyde	123-73-9	Richman Chemical	Curative for polyurethane elastomer, TMP
42	Cumene	98-82-8	Flint Hills Resources, CITGO Petroleum, Georgia Gulf, Shell Chemical, Sunoco, INEOS Phenol etc.	For TMQ Antioxidant, ADPA Antioxidant, 6PPD Antiozonant
43	Cyclohexane	110-82-7	Chevron Phillips, Huntsman, Exxon Mobil, BASF, BP, Cepsa, Erdol-Raffinerie Emstand etc.	Nylon-6 tire cord (fibre), DOA Plasticizers, DBEEA plasticizer
44	Cyclohexanone	108-94-1	Gulf Chemical International, ICC Chemical	Nylon-6 tire cord (fibre)
45	Cyclohexylamine	108-91-8	Air Products, US Amines	CBS Accelerator
46	Cyclohexyl Mercaptan	1569-69-3	Chevron Phillips Chemicals	CTP Inhibitor
47	Cyclopentadiene	542-92-7	Hangzhou, Yangli, Petrochemical Co., Hallochem Pharma Co., Konbester Co.	For EPDM rubber
48	p,p'-Diaminodiphenylmethane	101-77-9	J&L Industrial Supply, Biddle Sawyer Corp.	Curing agent MDI for polyurethane
49	Diaminotoluene	615-45-2	Infine Chemicals Ltd., Wuhan Huayuan Fine Chemicals, Junwee Chemical, etc.	Isocyanate TDI for polyurethane elastomers
50	Dibutyl amine	111-92-2	Arkema Inc., Ashland	Accelerator ZnDCB
51	Dichlorodimethylsilane	75-78-5	NSTU Chemical Hangzhou, Wacker Chemie, TCI Europé NV, Green Fine Chemical Co., etc.	Silicone rubber MQ
52	Dicyclohexylamine	101-83-7	Advanced Technology and Industrial Co., Alfa Aesar GmbH, etc.	Accelerator DCBS
53	Dicyclopentadiene	77-73-6	Texmark Chemical, Yangli Petrochemical	For EPDM rubber
54	Diethyl amine	109-89-7	Zhejiang Chemical, Aabtonsmart Chemical, Kraemer % Martin GmbH	Accelerator TeDEC
55	Diisobutylene	25167-70-8	Neochem Corp., TCI Europé NV, Chemos GmbH, Sojitz Corp.	Antioxidant and tackifying resins
56	Dimethylamine	124-40-3	Allchem Industries, Continental Industries, Kessler Chemical	Accelerators TMTD, TMTM and ZnDMC
57	Dimethyl Terephthalate	120-61-6	Miljac Inc., JTR Chemical	Polyester tire cord (fibre)

	Intermediate feedstocks	CAS	Example of manufacturer	Application (indirect or direct feedstock for)
58	p-Dinitrobenzene	100-25-4		Antioxidant DNPD
59	2,4-Dinitrotoluene	121-14-2	Aceto Corp.	Prepolymers for polyurethane elastomers
60	Diphenylamine	122-39-4	Neochem Corp., GFS Chemicals, King Tang Chemical, Nanjing King-Pharm, etc.	Antioxidants and 6PPD antiozonant
61	Diphenylmethane-4,4'-Diisocyanate (MDI)	101-68-8	BASF, Bayer, Dow Chemical, Afini Fine, Yantal Wanhua, etc.	Polyurethane elastomers
62	Epichlorohydrin	106-89-8	ICC Chemical, Richman Chemical, Gulf Chemical International, Kimlink Chemical, etc.	EO and ECO elastomers
63	Ethane	74-84-0		Directly used for over ten different rubbers
64	Ethyl Acrylate	140-88-5	Merck Schuchardt OHG, Chemos GmbH, GJ Chemical, Hallochem Pharma	ACM elastomers
65	Ethyl Alcohol	64-17-5	Cangzhou Goldlion Chemicals, Ashland, Eastman Chemical BV, Sasol Chemical Europé	For isocyanate MDI, acetaldehyde, ethylene, butadiene
66	Ethylbenzene	100-41-4	Chevron Phillips, CosMar, Dow Chemical, Lyondell Chemical, Sterling Chemicals, NOVA Chemicals, etc.	For Styrene
67	Ethylene	74-85-1	Equistar Chemical, Exxon Mobil, Dow Chemical, Chevron Phillips, etc.	Used for production of over 14 different rubbers
68	Ethylene Carbonate	96-49-1	Gulf Chemical International, Yixing Kairun, Shanghai Sunwise Chemical, etc.	Polyurethane curative HER
69	Ethylene Chlorohydrin	107-07-3	Alchimica, Wintersun Chemical	Monomer for AEM elastomer
70	Ethylenediamine	107-15-3	Akzo Nobel, Allchem Industries, Brook-Chem, Coyne Chemical	Neoprene accelerator ETU
71	Ethylene Dichloride	107-06-2	Dow Chemical, Formosa Plastics, Geismar Vinyls, Georgia Gulf, Occidental Chemical, etc.	PVC (for NBR) and ETU accelerator
72	Ethylene Glycol (EG)	107-21-1	INEOS Oxide, BASF, Dow Chemical	PET tire cord (fibre) and polyol for polyurethane
73	Ethylene Oxide (EO)	75-25-8	BASF, INEOS, Dow Chemical, Akzo Nobel, Clariant, IQA, Lukoil Neftochim, Shell, etc.	ECO elastomer and HQEE curative for polyurethane
74	2-Ethylhexanol (2EH)	104-76-7	BASF, Dow Chemical, Eastman Chemical	Plasticizers DOP, DOA and DOS
75	5-Ethylidenenorbornene	16219-75-3	Nesseki Chemical Texas, TCI Europe, Chemos GmbH, Acros Organics	EPDM elastomer
76	Formaldehyde	50-00-0	Hexion Speciality Chemicals, Georgia Pasific Resins, BASF, Bayer, Caldic, etc.	Used for adhesion promotors, tackifiers, curatives, PUR
77	1,4-Hexadiene	7318-67-4		EPDM elastomer

	Intermediate feedstocks	CAS	Example of manufacturer	Application (indirect or direct feedstock for)
78	Hexamethylenediamine	124-09-4	Inchem Chemiehandel, Dayang Chemicals, BASF, DuPont, Rhodia, Roland SA, Tanabe Europe,	Nylon-6,6 tire cord (fibre)
79	Hexamethylenetetramine (HMT)	100-97-0	Chattem Chemicals, Hummel Croton, Lanxess, SCI International, Supreme Resources, Wrigt Corp.	For HRH adhesion system
80	Hydrazine	302-01-2	Charkit Chemical, Lanxess, Univar USA	Blowing agent ADC
81	Hydrochloric Acid	7647-01-0	Bayer, Chou Chemical Co., ICC Chemical, Ruger Chemical, Seeler Industries, etc.	For antioxidant ADPA
82	Hypochlorous Acid	7790-92-3		ECO elastomer and polyol for polyurethane elastomer
83	Hydrogen	1333-74-0		HNBR elastomers and DOP plasticizer
84	Hydrogen Fluoride	7664-39-3		Flouroelastomers
85	Hydrogen Peroxide	7722-84-1	Arkema, Degussa, EKO Peroxide, FMC, Georgia Pacific, Solvay Chemicals	Peroxide additives (e.g. DCP)
86	Hydroquinone	123-31-9	Biddle Sawyer Corp., Charkit Chemical, Ruger Chemical, Yancheng Fengyang Chemical, etc.	Curing additive HQEE for polyurethane
87	Iron	7439-89-6		Steel tire cord and cable for conveyor belts
88	Isobutylene	115-11-7	Air Products, Bayer, Chevron Phillips, ExxonMobil Chemical, L'Air Liquide Berge, etc.	IIR and BIMS elastomers
89	Isobutylene-Isoprene Rubber (IIR, Butyl Rubber)	9010-85-9	ExxonMobil, Lanxess	CIIR and BIIR elastomers
90	Isocyanate-Terminated Prepolymer			For isocyanates TDI or MDI
91	Isoprene	78-79-5	Jinan Haohua Industry, Nizhnekamskneftekhim Scandinavia, Mitsui & Co. Europe,	For IIR and IR
92	Isopropyl Alcohol	67-63-0	Aqua Chemical, Brainerd Chemical, Bruchem, Coyne Chemical, Puritan Products, Warner Graham	For antioxidant TMQ
93	p-Isopropylphenol	99-89-8	Alemark Chemicals, Chemos GmbH	For triaryl phosphate (flame retardant)
94	Melamine	108-78-1	Hefei Chemicals, Henan Junma Chemicals, Jianfeng Chemicals, BASF, Cytec Industries, DSM, etc.	HRH adhesion system
95	Mercaptobenzothiazole (MBT)	149-30-4	Alemark Chemicals, Allchem Industries, Lanxess, Krahn Chemie GmbH	TBBS accelerator, TBBS, CBS, MBS and MBTS accelerators.
96	Mesityl Oxide	141-79-7		Antiozonant 6PPD
97	Methane	74-82-8		Needed for carbon disulphide for rubber accelerators and rayon tire cord fibre

	Intermediate feedstocks	CAS	Example of manufacturer	Application (indirect or direct feedstock for)
98	Methanol	67-56-1		Needed for formaldehyde for adhesion, tackifiers, etc.
99	Methyl Acrylate	96-33-3	Alemark Chemicals, GJ Chemicals, Sojitz Corp., BASF	AEM and ACM elastomers
100	Methyl Chloride	74-87-3	Dow Chemical, Dow Corning	For silicone elastomers
101	Methylethyl Ketone (MEK)	78-93-3	ExxonMobil, Celanese	Process oils, protective waxes, antiozonants
102	Methyl Isobutyl Ketone (MIBK)	108-10-1	Shell Chemical, Dow Chemical, Celanese, Sasol Solvents	Antiozonant 6PPD
103	p-Methylphenol (p-Cresol)	106-44-5		Antioxidant methylene-bis-methylbutyl phenol
104	p-Methylstryrene	622-97-9	Chemos GmbH, Merck Schuchhardt, Dayang Chemicals	BIMS elastomer and BIMS/PA thermoplastic vulcanizate
105	Morpholine	110-91-8	Amelia Chemicals, Coyne Chemical, Hainan Zhongxin Chemical, Wintersun Chemical, etc.	Sulphur donor DTDM and accelerators MBS and MBSS
106	Naphthalene	91-20-3	Anshang Tianchang, Beijing SHLHT Chemical, Collinda, Halterman	Cure retarder, plasticizers and accelerators
107	b-Naphthol	135-19-3	Leap Labchem, Kraemer & Martin, Hainan Zhongxin Chemical, Collinda	Antioxidant DNPD
108	a-Naphthylamine	134-32-7	Hainan Zhongxin Chemical, Chemos	Antioxidant PAN
109	Nitric acid	7697-37-2		Antioxidant PAN
110	p-Nitroaniline	100-01-6	Aceto Corp, Alchemie USA, Biddle Sawyer, Parchem	Aramid fibre, DNPD and DOPD antiozonants
111	Nitrobenzene	98-95-3		Used for MDI and aniline for several rubber chemicals
112	a-Nitronaphthalene	86-57-7		Antioxidant PAN
113	n-Octanol (octyl alcohol)	111-87-5	BP Chemical, KD Feddersen, SRM Limited	DOPD (i88PD)
114	p-t-Octylphenol (p-tert-Octylphenol)	140-66-9	Aceto Corp., ICC Chemical, Austin Chemical	Tackifying resins and curing compounds
115	Oleic Acid	112-80-1	Acidchem, Amato International, Condor, KIC Chemical, Hain Zhongxin, Kraemer % Martin GmbH	Plasticiser butyl oleate
116	Phenol	108-95-2	INEOS Phenol, Shell, Sunoco, Dow Chemical, ICC Chemical, etc.	Feedstock for numerous rubber chemicals
117	p-Phenylenediamine (PPDA)	106-50-3	Aceto Corp., Alchemie USA, Infine Chemicals, DSL Chemicals, ATIS Inc.,	Aramid fibre tire cord, antidegradants DNPD and DOPD
118	Phosgene	75-44-5	Dow Chemical, DuPont, Bayer CropScience, BASF, Bayer Materials Science, etc.	Isocyanate MDI for polyurethane

	Intermediate feedstocks	CAS	Example of manufacturer	Application (indirect or direct feedstock for)
119	Phosphorous	7723-14-0	Eastman Chemical	Flame retardants and plasticizers
120	Phosphorous Oxychloride	10025-87-3	Lanxess, Alfa Aesar-Johnson Mattey, Green Fine Chemical, FMC Corp., Rhodia	Flame retardant plasticizer triaryl phosphate
121	Phosphorous Pentoxide	1314-56-3	Parchem, Honeywell Speciality Chemicals, Gangu Chemical, Connect Chemicals, etc.	Flame retardant plasticizer triaryl phosphate
122	Phosphorous Trichloride	7719-12-2	Green Fine Chemical, Shanghai Mintchem Development, Alchimica	Flame retardant plasticizer triaryl phosphate
123	Phthalic Anhydride	85-44-9	BASF, ExxonMobil, Koppers, Stepan Chemical, Sterling Chemical	Plasticizers DOP and DIDP
124	Phtalimide	85-41-6	Ethox Chemical, Lanxess, Parchem, BASF, TCI Europe, Richman Chemical, etc.	Prevulcanization inhibitor CTP
125	a-Picoline	109-06-8	Aceto Corp., Kinbester Co.	SBVP latex and RFL dip for rubber/textile adhesion
126	Polyacrylonitrile	25014-41-9	Complex Quimica SA, Chemos GmbH	Carbon fibres tire reinforcement
127	Polypropylene	9003-07-0	ExxonMobil, Dow Chemical, Basell USA, Formosa Plastics, Borealis, Domo, etc.	TPE
128	Polypropylene Glycol	25322-69-4	BASF, BP Chemicals, Kemlink, Keyser & Mackay CV, Vaneyck Chemie	Polyol for polyurethane
129	Polyvinylchloride	9002-86-2	CertainTeed, Colorite Speciality Resins, Dow Chemical, Formosa Plastics, etc.	Additive for improved ageing in NBR elastomers
130	Potassium Bromide	7758-02-03	alfa Aesar-Johnson Matthey, Allan Chemical, Barker Industries, Cater Chemicals, etc.	BIIR elastomer
131	Propane	74-98-6		Cracked to ethylene and propylene for over 12 rubbers
132	Propylene	115-07-1	Basell, BASF, Borealis, BP, Dow Chemical, ExxonMobil, Huntsman, INEOS, etc	Used to make numerous elastomers, plasticizers, rubber chemicals
133	Propylene Glycol (PG)	57-55-6	Dow Chemical, Lyondell	Polyol for polyurethane
134	Propylene Oxide	75-56-9	Dow Chemical, Lyondell	Polyol for polyurethane
135	Quinone (1,4-Benzoquuinone)	106-51-4		Antiozonant DPPD
136	Resorcinol	108-46-3	INDSPEC	Essential for HRH adhesion, RFL dips, HER for PUR
137	Sebatic Acid	111-20-6	ICC Chemical Corp., Ivanhoe Industries, Vilax, Beyo Chemical, Connect Marketing GmbH, etc.	Plasticizer DOS
138	Silicon Metal	7440-21-3	Honeywel Speciality Chemicals, Atlantic Equipment Engineers Micron Metals, Camida	MQ elastomers

	Intermediate feedstocks	CAS	Example of manufacturer	Application (indirect or direct feedstock for)
139	Silicon Terachloride	10026-04-7	ATI Wah Chang, Gelest Inc., Yixing Karun, Air Products, Camida, Wacker Chemie, etc.	Fumed silica (filler) and MQ elastomers
140	Sodium Bromide	7647-15-6		BIIR elastomer
141	Sodium Carbonate	497-19-8		Hydrted precipitated silica
142	Sodium Dimethyldithiocarbamate (NaDMC)	207233-95-2	Complex Quimica SA, BASF, Hallochem Pharma, Dayang Chemicals, FMC Foret SA	Accelerator TMTD
143	Sodium Hydroxide (Caustic Soda)	1310-73-2	Dow Chemicals, Formosa Plastics, Occidental Chemical, PPG	Needed for many rubber chemicals and rayon
144	Sodium Hypochlorite	7681-52-9		MBTS, ethylene chlorohydrin, epichlorohydrin
145	Sodium Mercaptobenzothiazole (NaMBT or Sodium MBT)	2492-26-4	Ak scientific, Dayang Chemical, Roland	Needed for TBBS, CBS, MBS, MBTS accelerators
146	Sodium Nitrate	7631-99-4		Accelerator TMTD
147	Sodium Phenate	156150-40-2		Retarder salicylic acid
148	Sodium Silicate	1344-09-8	FMC Foret, Kinbester, Hainan Zhongxin Chemical	Precipitated silica (filler)
149	Sodium Sulphate	7757-82-6	Ashland, Saltex, Shore Chem, Univar, Veckridge Chemical	Rayon fibres tire cord
150	Sodium Sulphite	7757-83-7	Calabrian, INDSPEC, Southern Ionics, Solvay Chemicals, Olympic Chemical	RFL dip for rubber/textile adhesion
151	Stannous Chloride	7772-99-8	Atotech, Brook Chem, GFS Chemicals, Hainan Zhongxin Chem, Shanghai Mintchem	Stannic chloride
152	Stearic Acid	57-11-4	Aceto Corp, Acidchem, Alemark, Amato International, Bruchem, etc.	Activator
153	Styrene	100-42-5	Lyondell Chemical, Chevron Phillips Chemical, Dow Chemical, Nova Chemical, etc.	Elastomers SBR, SBS, SIS, SEBS, STEPS, and RFL dip
154	Sulphur	7704-34-9		Needed to make many rubber accelerators
155	Sulphur Dioxide	7446-09-05	Calabrian, Chemtrade Logistics, OLIN chlor-Alkali	CSM elastomer
156	Sulfuric Acid	7664-93-9		Rayon fibres for tire cord, and antioxidant
157	Sulfuric Monochloride	10025-67-9	Complex Quimica SA, Lanxess, Kinbester Co.	Processing aid vulcanized vegetable oil
158	Terephyhalic Acid	100-21-0	Advansa, BP, DAK Americas, Eastman Chemical, Equipolymers, etc.	Polyester (PET) tire cord (fibre)
159	Tetrafluoroethylene	116-14-3		FKM elastomers

	Intermediate feedstocks	CAS	Example of manufacturer	Application (indirect or direct feedstock for)
160	Tin	7440-31-5	Belmont Metals, Dayang Chemicals, G. Collard et P Collete SA, VWR International	Bronze alloy for tire bead wire, curing agent for EPDM/PP TPVs
161	Titanium Tetrachloride	7550-45-0	Advanced Research Chemicals, Thann & Mulhouse, NSTU Chemicals Hangzhou, Chemos GmbH	Titanium dioxide filler (pigment)
162	Toluene	108-88-3	Shell, BP, Sunoco, Polimeri Europa, ExxonMobil, CEPSA, PKN Orlen Petrogal, etc.	Elastomers SBR, SIS, SBS, SEBS, SEPS
163	Toluene Diisocyanate (TDI)	584-84-9	BASF, Bayer, Dow Chemical, Korea Fine Chemical, Lyondell, Mitsui Chemical, etc.	Flexible polyurethane foam and castable polyurethane elastomers
164	o-Toluidine (ortho-Toluidine)	95-53-4	Aceto Corp., GFS Chemicals, Lanxess, Wintersun Chemical	Accelerator for CR, AEM and IIR elastomers
165	1,1,1-Trichloroethane	71-55-6	Ashland, Coyne Chemical, PPG Industries, Shanghai Mintchem Development	Halogenated solvent for degreasing metals
166	Trichlorosilane	10025-78-2	Gelest Inc., Air Products, Austin Chemical, Wacker Chemie, Dayang Chemicals	Fumed silica (filler)
167	1,1,1-Trimethylolpropane (TMP)	77-99-6	Allchem Industries, Ivanhoe Industries, Lanxess, Neuchem, Wintersun Chemicals, etc.	3D crosslinking agent in polyurethane
168	Urea	57-13-6	Agrium, Bay Chemical, Bruchem, Graham Chemical, Nitron Chemical Corp., etc.	HRH adhesion systems for rubber/metal adhesion
169	Vinyl Acetate	108-05-4	Celanese, Dow Chemical, DuPont, Lyonell Chemical	EVA elastomer
170	Vinyl Chloride Monomer	75-01-4	Dow Chemical, Formosa Plastics, Geismar Vinyls, Georgia Gulf, etc.	Additive PVC for NBR
171	Vinyl Floride	75-02-5	Air Products, DuPont, Shanghai Sinofluoro Scientific, Chemos GmbH	Elastomer FKM
172	Vinyl Pyridine	100-69-6	Alcan Speciality, Infine Chemicals, Hainan Zhongxin Chemical, Kowa America, etc.	RFL dip for rubber/textile adhesion
173	Wax	8002-74-2		Processing aid and flame retardants
174	Xylene	1330-20-7	BP, CEPSA, ExxonMobil, Deutsche Shell, Huntsman, Naftan, etc.	Retarder phthalic anhydride
175	Zink Metal	7440-66-6	Hummel Corton, Univar, Kraft Chemical, VWR International	Activator Zink Oxide, and brass-coated steel wire cord
176	Zink Carbonate	3486-35-9	CPS Union, Century Multech, Hummel Croton	Zinc borate hydrate (flame retardant)
177	Zink Stearate	557-05-1	Allan Chemical Corp., American International, Hummel Croton Miliau Inc.	Activator and dusting agent
178	Zink Sulphate	7733-02-0	Bay Zink, Tetra Micronutrients, Mineral King Minerals, Old Bridge Chemicals	Zinc oxide activator

Table C. Production, exports and imports of various rubber goods, broken down by CN4-code, for Sweden year 2013, measured in tons per annum (tpa). The numbers in the table does not include confidential data (denoted as 'c') and n.e.s. stands for not especially specified.

CN4 code	Description	Tpa Production	Tpa Import	Tpa Export
1301	Natural gum Arabic	0.0	787.1	0.9
3910	Silicones in primary forms	94.0	6580.6	829.5
4001	Natural rubber, balata, gutta-percha, guayule, chicle and similar natural gums, in primary forms or in plates, sheets or strip	0.0	7390.8	989.5
4002	Synthetic rubber and factice derived from oils, in primary forms or in plates, sheets or strip; mixtures of natural rubber, balata, gutta-percha, guayule, chicle or similar types of natural rubber with synthetic rubber or factice, in primary forms or in plates, sheets or strip	0 c	62575.834 c	2086.5
4003	Reclaimed rubber in primary forms or in plates, sheets or strip	361.9	1217.7	12.7
4004	Waste, parings and scrap of soft rubber and powders and granules obtained therefrom	c	30712.0	3085.6

4005	Compounded rubber, unvulcanised, in primary forms or in plates, sheets or strip (excl. mixtures of natural rubber, balata, gutta-percha, guayule, chicle and similar natural gums containing synthetic rubber or factice derived from oils)	40894.9	4916.2	17455.0
4006	Rods, bars, tubes, profiles and other forms of unvulcanised rubber, incl. mixed rubber, and articles of unvulcanised rubber, incl. mixed rubber (excl. plates, sheets and strip which, apart from basic surface-working, have not been cut, or have merely been cut into square or rectangular shapes)	45.0	849.8	219.8
4007	Vulcanised rubber thread and cord (excl. ungimped single thread with a diameter of > 5 mm and textiles combined with rubber thread, e.g. textile-	0.0	851.9	18.8

	covered thread and cord)			
4008	Plates, sheets, strip, rods and profile shapes, of vulcanised rubber (excl. hard rubber)	6390.2	9754.2	12124.7
4011	New pneumatic tyres, of rubber	1013.6	111411.1	20917.6
4012	Retreaded or used pneumatic tyres of rubber; solid or cushion tyres, tyre treads and tyre flaps, of rubber	0 c	13005.47 c	9295.536 c
4013	Inner tubes, of rubber	0.0	1150.9	416.9
4014	Hygienic or pharmaceutical articles, incl. teats, of vulcanised rubber (excl. hard rubber), with or without fittings of hard rubber, n.e.s. (excl. articles of apparel and clothing accessories, incl. gloves, for all purposes)	1167.5	346.9	360.0
4015	Articles of apparel and clothing accessories, incl. gloves, mittens and mitts, for all purposes, of vulcanised rubber (excl. hard rubber and footwear and headgear and parts thereof)	0.0	6303.5	2804.5

4016	Articles of vulcanised rubber (excl. hard rubber), n.e.s.	43469.7 c	30612.1	29360.9
	TOTAL	**49967.1**	**212884.7**	**90682.9**

Table D. Production, exports and imports of various rubber goods, broken down by CN6-code, for Sweden year 2013, measured in tons per annum (tpa). The numbers in the table does not include confidential data (denoted as 'c') and n.e.s. stands for not especially specified.

CN6 code	Description	Tpa Production	Tpa Import	Tpa Export
130120	Natural gum Arabic	0	787.066	0.892
391000	Silicones in primary forms	94	6580.567	829.501
400110	Natural rubber latex, whether prevulcanised	0	1569.176	924.432
400121	Smoked sheets of natural rubber	0	c	c
400122	Technically specified natural rubber (TSNR)	0	5534.957	28.488
400129	Natural rubber in primary forms or in plates, sheets or strip (excl. smoked sheets, technically specified natural rubber "TSNR" and natural rubber latex, whether prevulcanised)	0	265.391	36.129
400130	Balata, gutta-percha, guayule, chicle and similar natural gums	0	21.307	0.415
400211	Styrene-butadiene rubber latex "SBR"; carboxylated styrene-butadiene rubber latex "XSBR"	0	27862.322	729.913
400219	Styrene-butadiene rubber "SBR"; carboxylated styrene-butadiene rubber "XSBR", in primary forms or in plates, sheets or strip (excl. latex)	0	15544.076	266.364
400220	Butadiene rubber (BR)	0	2726.06	78.633
400231	Isobutene-isoprene (butyl) rubber (IIR)	0	172.294	20.505
400239	Halo-isobutene-isoprene rubber "CIIR" or "BIIR", in primary forms or in plates, sheets or strip	0	28.124	1.097

CN6 code	Description	Tpa Production	Tpa Import	Tpa Export
400241	Chloroprene latex "chlorobutadiene rubber, CR"	0	703.306	16.097
400249	Chloroprene "chlorobutadiene rubber, CR", in primary forms or in plates, sheets or strip (excl. latex)	0	185.109	19.552
400251	Latex of acrylonitrile-butadiene rubber "NBR"	0	c	53.408
400259	Acrylonitrile-butadiene rubber "NBR", in primary forms or in plates, sheets or strip (excl. latex)	0	3117.505	383.373
400260	Isoprene rubber (IR)	0	64.986	0.343
400270	Ethylene-propylene-non-conjugated diene rubber (EPDM)	c	7408.397	348.725
400280	Mixtures of any product of heading 4001 with any product of this heading	0	17.889	0.758
400291	Synthetic rubber and factice derived from oils, in primary forms or in plates, sheets or strip (excl. styrene-butadiene rubber "SBR", carboxylated styrene-butadiene rubber "XSBR", butadiene rubber "BR", isobutylene isoprene rubber "IIR", halo-isobutene-isoprene rubber "CIIR" or "BIIR", chloroprene rubber "CR", acrylonitrile-butadiene rubber "NBR", isoprene rubber "IR" and non-conjugated ethylene-	0	1186.516	12.916

CN6 code	Description	Tpa Production	Tpa Import	Tpa Export
	propylene diene rubber "EPDM")			
400299	Synthetic rubber and factice derived from oils, in primary forms or in plates, sheets or strip (excl. latex, styrene-butadiene rubber "SBR", carboxylated styrene-butadiene rubber "XSBR", butadiene rubber "BR", isobutylene isoprene rubber "IIR", halo-isobutene-isoprene rubber "CIIR" or "BIIR", chloroprene rubber "CR", acrylonitrile-butadiene rubber "NBR", isoprene rubber "IR" and non-conjugated ethylene-propylene diene rubber "EPDM")	0	3559.25	154.831
400300	Reclaimed rubber in primary forms or in plates, sheets or strip	361.9	1217.706	12.744
400400	Waste, parings and scrap of rubber (other than hard rubber) and powders and granules obtained therefrom		30711.971	3085.564
400510	Rubber, unvulcanised, compounded with carbon black or silica, in primary forms or in plates, sheets or strip	24168.3	2448.97	14131.898
400520	Solutions; dispersions other than those of subheading 400510	0	119.36	20.951
400591	Compounded rubber, unvulcanised, in the form of plates, sheets or strip (excl. rubber	16726.6	1513.747	931.885

CN6 code	Description	Tpa Production	Tpa Import	Tpa Export
	compounded with carbon black or silica, and mixtures of natural rubber, balata, gutta-percha, guayule, chicle and similar natural gums containing synthetic rubber or factice derived from oils)			
400599	Compounded, unvulcanised rubber in primary forms (excl. solutions and dispersions, those containing carbon black or silica, mixtures of natural rubber, balata, gutta-percha, guayule, chicle or similar types of natural rubber with synthetic rubber or factice, and those in the form of plates, sheets or strip)	0	834.15	2370.281
400610	‘Camel-back’ strips for retreading rubber tyres	0	28.795	0.065
400690	Rods, bars, tubes, profiles and other forms of unvulcanised rubber, incl. mixed rubber, and articles of unvulcanised rubber, incl. mixed rubber (excl. plates, sheets and strip which, apart from basic surface-working, have not been cut, or have merely been cut into square or rectangular shapes, and 'camel-back' strips)	45	820.967	219.754
400700	Vulcanised rubber thread and cord (excl. ungimped single	0	851.924	18.768

CN6 code	Description	Tpa Production	Tpa Import	Tpa Export
	thread with a diameter of > 5 mm and textiles combined with rubber thread, e.g. textile-covered thread and cord)			
400811	Plates, sheets and strip of cellular rubber	797.4	1181.801	1985.196
400819	Rods and profile shapes, of cellular rubber	1779	726.957	1442.546
400821	Plates, sheets and strip, of non-cellular rubber	3813.8	7845.416	8696.954
401110	New pneumatic tyres, of rubber, of a kind used for motor cars, incl. station wagons and racing cars	1013.644362	69730.5	13895.227
401120	New pneumatic tyres, of rubber, of a kind used for buses and lorries (excl. tyres with lug, corner or similar treads)	0	39758.983	6423.412
401130	New pneumatic tyres, of rubber, of a kind used for aircraft	0	19.027	
401140	New pneumatic tyres, of rubber, of a kind used for motorcycles	0	1011.19	401.69
401150	New pneumatic tyres, of rubber, of a kind used for bicycles	0	891.439	197.253
401211	Retreaded pneumatic tyres, of rubber, of a kind used on motor cars "incl. station wagons and racing cars"	0	64.967	76.871
401212	Retreaded pneumatic tyres, of rubber, of a kind used on buses or lorries	c	3316.229	1450.402
401213	Retreaded pneumatic tyres, of rubber, of a kind used on aircraft	0	c	c

CN6 code	Description	Tpa Production	Tpa Import	Tpa Export
401219	Retreaded pneumatic tyres, of rubber (excl. of a kind used on motor cars, station wagons, racing cars, buses, lorries and aircraft)	0	103.641	157.774
401220	Used pneumatic tyres of rubber		6214.793	6931.633
401290	Solid or cushion tyres, interchangeable tyre treads and tyre flaps, of rubber	0	3305.84	678.856
401310	Inner tubes, of rubber, of a kind used on motor cars, incl. station wagons and racing cars, buses and lorries	0	109.788	32.01
401320	Inner tubes, of rubber, of a kind used for bicycles	0	474.562	87.757
401390	Inner tubes, of rubber (excl. those of a kind used on motor cars, incl. station wagons and racing cars, buses, lorries and bicycles)	0	566.511	297.147
401410	Sheath contraceptives, of vulcanised rubber (excl. hard rubber)	337.0730467	169.236	201.386
401490	Hygienic or pharmaceutical articles, incl. teats, of vulcanised rubber (excl. hard rubber), with or without fittings of hard rubber, n.e.s. (excl. sheath contraceptives and articles of apparel and clothing accessories, incl. gloves, for all purposes)	830.4	177.661	158.627
401511	Surgical gloves, of vulcanised rubber (excl. fingerstalls)	0	1286.823	390.368

CN6 code	Description	Tpa Production	Tpa Import	Tpa Export
401519	Gloves, mittens and mitts, of vulcanised rubber (excl. surgical gloves)	0	4847.766	2356.833
401590	Articles of apparel and clothing accessories, for all purposes, of vulcanised rubber (excl. hard rubber and footwear and headgear and parts thereof, and gloves, mittens and mitts)	0	168.875	57.297
401610	Articles of cellular rubber, n.e.s.	42.1	253.046	187.688
401691	Floor coverings and mats, of vulcanised rubber (excl. hard rubber), with chamfered sides, rounded corners or shaped edges or otherwise worked (excl. those simply cut to rectangular or square shape and goods of cellular rubber)	2974	6101.894	1088.256
401692	Erasers, of vulcanised rubber (excl. hard rubber), conditioned (excl. those simply cut to rectangular or square shape)	0	162.687	22.629
401693	Gaskets, washers and other seals, of vulcanised rubber (excl. hard rubber and those of cellular rubber)	c	11388.403	7112.342
401694	Boat or dock fenders, whether inflatable, of vulcanised rubber (excl. hard rubber and those of cellular rubber)	164	208.121	23.665

CN6 code	Description	Tpa Production	Tpa Import	Tpa Export
401695	Inflatable mattresses and cushions and other inflatable articles, of vulcanised rubber (excl. hard rubber and fenders, boats, rafts and other floating devices, and hygienic or pharmaceutical articles)	0	1045.924	48.229
401699	Articles of vulcanised rubber (excl. hard rubber), n.e.s.	40289.6	11452.034	20878.056
	TOTAL	**93436.82**	**288466.00**	**99978.39**

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