RUBBER COMPOUNDS

A MARKET OPPORTUNITY STUDY

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UNITED SOYBEAN BOARD
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EXECUTIVE SUMMARY

There is significant potential for soy products in the rubber and synthetic elastomer industry as plasticizer oil and filler alternatives for petroleum-based process aids and additives. There are several factors supporting this emerging opportunity,

Product technology

- Soybean products already have some established uses in the rubber and plastics industry as a plasticizer, acid scavenger, and process aid.
- Published research and patent applications have shown that soy products can function as process aids / plasticizers and as a reinforcing filler in a range of rubber compounds.

Market

- Rubber manufacturing and fabrication is a large global industry. The International Rubber Study Group forecasts that total rubber consumption should increase 4.5% this year, totaling 25.7 million metric tons, and that in 2012 consumption will increase 7.5% to 27.6 mmt.
- Rubber is a formulated product containing elastomeric polymers, fillers, processing aids, cure systems, and a variety of chemical additives. Soy products, as a component in a formulation, need to demonstrate functional performance at favorable economics, rather than validate their performance as a stand-alone, new product.
- The supply of natural rubber has decreased due to the reduction in land use dedicated to growing rubber trees. Vulcanized vegetable oils, notably soybean, have the potential to extend the use of natural rubber in compounds.

Resources

- The supply chain capability is largely in place, needing some new connections among suppliers and manufactures.
- Several industry, academic, and research organizations have developed expertise in utilizing soybean and other bio-based materials in rubber and plastic products.

Economics

- Petroleum feedstocks used in rubber elastomers and compound additives continue to exhibit price and supply volatility.
- There is ample supply of soybean derivative products.

Trends

- Due to increasing regulations and concerns about the environmental impact of polyaromatic hydrocarbons present in process oils, alternative solutions are being sought.
- The use of natural oils in rubber compounds has already been commercially demonstrated by the incorporation of d-limonene, sunflower oil, and castor oil by three manufacturers in the large, high performance application of passenger car tires.

The overall rubber market is quite diversified with a wide range of end uses and performance requirements. Automotive and truck tires are the largest rubber market. Industrial, non-tire automotive, consumer, and miscellaneous end uses represent a large and diversified marketplace for rubber goods.

The rubber industry value chain is complex with a number of large producers of elastomers, a range of large to small suppliers of rubber compound ingredients, and many compounders, fabricators, and original equipment manufacturers using rubber.

Petroleum-based plasticizers are now being further distilled to comply with regulations. Some rubber parts manufacturers, faced with the need to change formulations, are opting to convert to more sustainable materials.

Growth of current uses and successful development of new uses for soy products for the rubber industry can be supported by encouraging collaboration among soy products suppliers and rubber compounders and manufacturers. Sponsorship of research and development projects will help in understanding the advantages and limitations of soy products as plasticizers, process aids, extenders and fillers in rubber compounds in end use applications. Specific product and performance information needs are highlighted in the Product and Market Development Strategies for Soy Products in Rubber Compounds section later in this report.

Research and development investigations on using soy oil and solids in several rubber systems combined with trends in the marketplace lay the foundation for expanding and creating new uses in this market. This report is the initial United Soybean Board Market Opportunity Study of this market.

STUDY OBJECTIVES

The objective of this study is to define the potential market in North America and identify the technical challenges for soy derivatives as process aids and fillers in the production of performance rubber and synthetic elastomer products. This report provides a comprehensive background on rubber compounds and additives and the rubber market and applications. The study will be an introduction to the rubber industry for soy products suppliers to better understand the rubber industry and for rubber parts manufacturers to stimulate interest in expanding their raw material options to include soy products. As the market for soy products in rubber compounds develops, future market opportunity studies will build on this foundation.

In developing an understanding of the use of plasticizer oils in rubber processing and the needs for rubber and synthetic elastomer process additives and extenders, the potential for soy oil and meal derivatives is better recognized. Barriers to entry, including regulatory, environmental and technical factors, are considered.

To introduce a new material into established applications, both product and market factors need to be considered. This report highlights recent research on soy derivatives as ingredients in rubber formulations that form the basis for their consideration as raw materials. The overall rubber industry is discussed to better understand the market dynamics and application requirements.

Information and insights for this study were developed through industry expert interviews, secondary market research sources, and analysis of published research and patent applications. Key consideration was focused on the technical needs for soy oil and meal derivatives as rubber compound ingredients and the existing use of soy derivatives and other biobased materials in rubber and elastomer products currently being produced.

Factors such as regulatory, environmental, and technical barriers to entry need to be understood to guide the successful introduction and penetration of soy derivatives as process aids. Next steps are proposed to continue development of soy derivatives for use by the rubber and elastomer industry.

THE RUBBER MARKET

The rubber market is categorized as natural rubber (NR), which is obtained from rubber trees, and synthetic rubber, which is manufactured with petroleum-based feedstocks.

The tire manufacturing industry accounts for almost 60% of global rubber consumption, with the remainder going into the general rubber products sector. There are thousands of different goods manufactured by this sector, serving many industries, including transportation, construction, health, mining, and many more.

The International Rubber Study Group (IRSG) is an intergovernmental organization recognized as an international body. Its mission is to be the authoritative source of statistical data and analysis for all aspects of the rubber industry, including production, consumption and trade in rubber as well as rubber products. The secretariat prepares current estimates and analyzes future supply and demand trends.

The IRSG reports that total rubber consumption should increase 4.5% this year, totaling 25.7 million metric tons, and that in 2012, consumption will increase 7.5% to 27.6 mmt. The increases are based on forecasts for worldwide vehicle production to increase 5.6% this year and 8.1% in 2012. World tire production should increase 5.5% this year with a 7.6% increase next year to 89.7 million units.

Global synthetic rubber consumption is forecast to increase 5% to 14.5 mmt this year, with a 9% increase next year to 2012. Global natural rubber consumption is expected to rise 3.8% this year to 11.2 mmt, and another 5.4% in 2012 to 11.8 mmt.

Figure 1
WORLD CONSUMPTION OF RUBBER BY REGION
(000 mt)

	2010	2011	2012
North America	2,997	3,118	3,165
Europe	4,602	4,838	5,143
Asia	14,996	15,753	17,191
Middle East	185	195	207
Africa	243	263	286
Latin America	1,499	1,467	1,565
Oceania	47	42	40
World	24,610	25,718	27,637
% change	15.3%	4.5%	7.5%

International Rubber Study Group, Rubber World, July 2011

All geographic regions experienced absolute growths in tonnage while suffering decelerations in the growth rate during the first quarter. Asian rubber demand reached 15.3 mmt in March, while the European Union and North America were at 3.6 mmt and 3.0 mmt, respectively, for the same period. Asia, however, had the sharpest deceleration, with a growth rate of 4.9% compared to the 10.3% in December.

There are several estimates of the rubber market. By most measures, the rubber industry is a mature market and is influenced by global economic conditions. The overall market is very large and it continues to grow and incorporate new products and technology.

Figure 2
STATISTICAL SUMMARY OF WORLD RUBBER SITUATION
('000 tonnes)

	2008	2009	2010
NATURAL RUBBER PRODUCTION			
Latin America	247	253	263
Africa	447	423	459
Asia	9,399	9,042	9,622
TOTAL (1)	10,128	9,690	10,384
NATURAL RUBBER CONSUMPTION			
North America	1,179	790	1,071
Latin America	587	488	613
EU-27	1,256	829	1,132
Other Europe	228	176	226
Africa	126	94	102
Asia/Oceania	6,854	6,984	7,617
TOTAL (1)	10,175	9,329	10,765
WORLD SUPPLY-DEMAND SURPLUS/DEFICIT	-47	361	-381
WORLD STOCKS (2)	1,519	1,880	1,499
SYNTHETIC RUBBER PRODUCTION			
North America	2,410	2,069	2,458
Latin America	639	598	653
EU-27	2,481	2,210	2,607
Other Europe	1,208	989	1,181
Africa	75	60	66
Asia/Oceania	5,966	6,363	7,065
TOTAL (1)	12,741	12,261	13,987
SYNTHETIC RUBBER CONSUMPTION			
North America	1,858	1,606	1,925
Latin America	848	762	887
EU-27	2,351	1,951	2,400
Other Europe	893	675	844
Africa	113	99	113
Asia/Oceania	6,306	6,819	7,611
TOTAL (1)	12,658	12,019	13,845
WORLD SUPPLY-DEMAND SURPLUS/DEFICIT	83	242	142
WORLD STOCKS (2)	3,097	3,339	3,481
% SR IN TOTAL RUBBER CONSUMPTION	55.4	56.3	56.3

Figure 3
RUBBER PRICE AND RELATED INDICATORS

	2008 Year	2009 Year	2010 Year	2011 Q1
NATURAL RUBBER PRICES				
Europe, TSR20 €/tonne	1,772	1,331	2,600	3,939
SICOM, RSS3, S$/tonne	3,685	2,800	4,091	5,744
SICOM, TSR20, US$/tonne	2,530	1,800	3,380	5,251
SYNTHETIC RUBBER PRICES				
USA SBR Export Values US$/tonne	2,511	1,936	2,505	2,789
Japan SBR Export Value '000Yen/tonne	260	187	222	231
France, SBR Export Value €/tonne	1,702	1,499	1,803	2,028
RELATIVE NR/SR PRICE RATIO				
SICOM, TSR20 / USA SBR	100.7	93	134.9	188.3
RELATED INDICATORS				
Brent Crude oil, US$ per barrel	98.5	62.3	80.2	104.9
Butadiene, US cents per lb[3]	84.3	45	84.2	98

(1) May include balancing adjustments.
(2) Stocks refer to end of period volumes.
(3) Butadiene contract price - major feedstock used in production of volume elastomers, SBR and BR.
Source: All data taken from Rubber Statistical Bulletin, April-June 2011 edition

Despite the greater price pressures on rubber manufacturers, there have also been several investments announced, particularly in developing markets such as Asia, where demand continues to grow rapidly. Global synthetic rubber consumption is forecast to reach 13.4m tonnes/year by 2015 from 2010 estimates of 11.4m.

Figure 4
THE WORLD MARKET FOR SYNTHETIC RUBBER IS GROWING

Region / country	2003	2010	2015
North America	2,240.26	1,561.98	1,629.38
Japan	1,229.56	1,005.57	1,076.86
Europe	3,515.55	2,794.12	3,067.27
Asia-Pacific	2,866.96	5,015.11	6,468.93
Rest of World	843.8	1,026.32	1,181.43
TOTAL	10,693.13	11,403.10	13.423.87

ICIS Chemical Business, August 1-14, 2011
Source: Global Industry Analysts

RUBBER COMPANIES

Trelleborg, a global engineering group, reports the top ten global industrial rubber companies based on sales as:

1.	Trelleborg	Sweden
2.	Hutchinson	France
3.	Continental	Germany
4.	Bridgestone	Japan
5.	Freudenberg	Germany
6.	Tomkins	UK
7.	Cooper-Standard Automotive	USA
8.	Tokai Rubber	Japan
9.	Parker-Hannifin	USA
10.	NOK	Japan

Other large industrial rubber companies include:

Bando Chemical Industries Ltd.	Michelin
Carlisle Companies Incorporated	Mitsuboshi Belting Ltd.
ContiTech AG	Myers Industries Inc.
Delphi Corporation	Nichirin Co. Ltd.
Eaton Corporation	Sumitomo Rubber Industries Ltd.
EnPro Industries Inc.	The Goodyear Tire & Rubber Company
Federal-Mogul Corporation	The Yokohama Rubber Company Ltd.
JSJ Corporation	Total S.A.
LANXESS	Toyo Tire and Rubber Co. Ltd.
Meiji Rubber & Chemical Co. Ltd.	

RUBBER ASSOCIATIONS

The Rubber Manufacturers Association (RMA) is the national trade association for tire manufacturers that make tires in the United States. http://www.rma.org/index.cfm

The International Rubber Study Group (IRSG) is an intergovernmental organization recognized as an international body located in Singapore, formally established by a Headquarters Agreement with the Government of Singapore. http://www.rubberstudy.com/default.aspx

The International Institute of Synthetic Rubber Producers (IISRP) is an international not-for-profit trade association with 39 corporate members domiciled in 21 countries who produce 95 percent of the world supply of synthetic rubber. Incorporated in 1960 and headquartered in Houston, Texas, the Institute also supports offices in Milan and Tokyo. http://www.iisrp.com/index.html

The Association of Natural Rubber Producing Countries (ANRPC) is an inter-governmental organization established in 1970. http://www.anrpc.org/

The Tire Industry Association (TIA) is an international association representing all segments of the tire industry, including those that manufacture, repair, recycle, sell, service or use new or retreaded tires, and also those suppliers or individuals who furnish equipment, material or services to the industry. http://www.tireindustry.org/

The North American Recycled Rubber Association (NARRA) was created in August 1994 to bring together the various stakeholders affiliated with the recycled rubber industry, including: haulers, processors, manufacturers, distributors, dealers, government representatives, consultants, and members of other Associations.
http://www.recycle.net/recycle/assn/narra/

The Rubber Association of Canada (RAC) is the national trade association representing the interests of tire and other rubber manufacturers and importers of rubber goods into Canada, together with rubber recyclers and suppliers whose goods or services directly relate to our industry. http://www.rubberassociation.ca/rubberroom/Welcome.html

Partnership Agreement between United Nations Conference on Trade and Development (UNCTAD) and International Federation of Agricultural Producers (IFAP)
http://www.unctad.org/infocomm/anglais/rubber/sitemap.htm

The International Rubber Association The International Rubber Association was inaugurated in Ottawa, Canada in 1971 and now represents sixteen countries. The objectives of the Association are to:

- Discuss international commercial matters relating to natural rubber and facilitate the continual improvement of international trade in natural rubber
- Consider problems in connection with the international rubber trade and submit reports and recommendations to members for their consideration and adoption
- Establish an International Contracts Committee to formulate International Contracts for natural rubber and ensure observance and enforcement of International Rubber Association contracts

http://intrubberassoc.org/

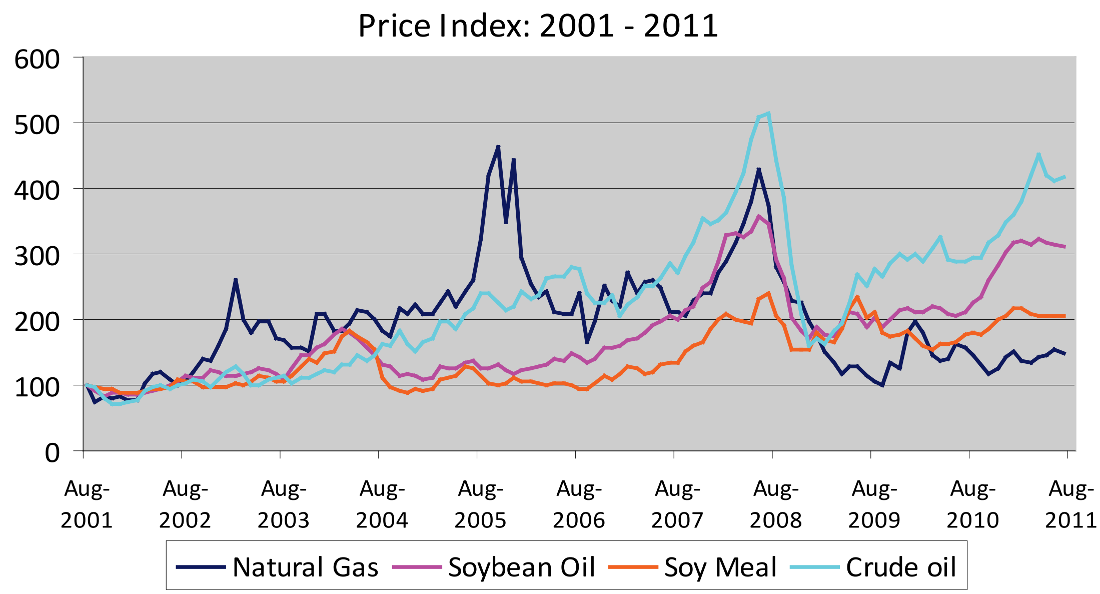
European Type & Rubber Manufacturers Association (ETRMA) ETRMA primary objective is to represent the regulatory and related interests of the European tire and rubber manufacturers at both European and international levels.
http://www.etrma.org/

Rubber and Plastics Research Association, Limited (RAPRA) is a not-for-profit membership association for companies in polymer manufacturing, processing or end use. For over 90 years it has been contributing to research and development of innovative new materials, products and processes by providing members with privileged access to a range of services including technical, information, business development, skills and training
http://www.rapralimited.org/

PRICE TRENDS

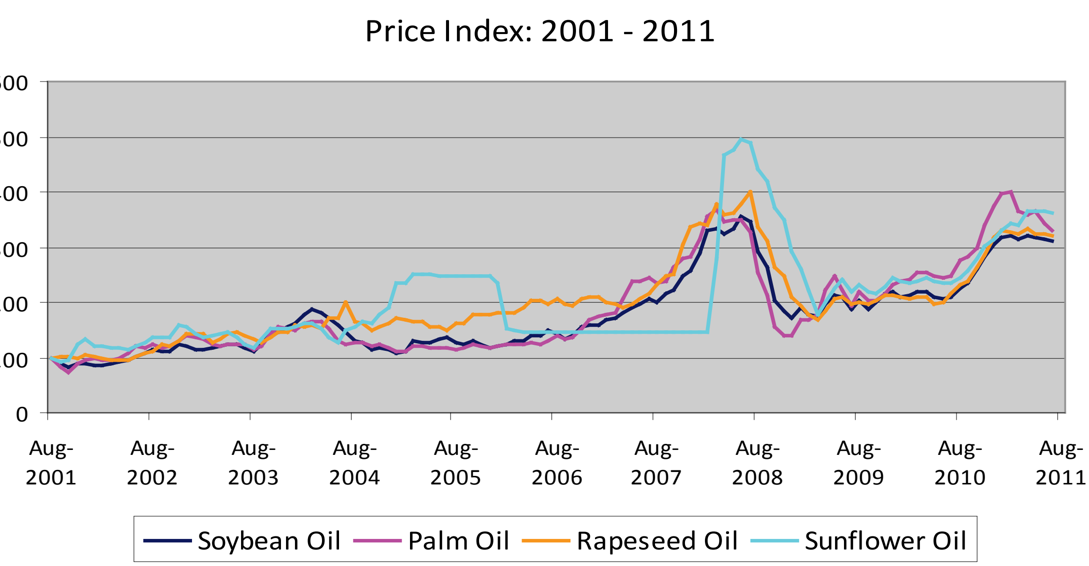
In addition to the benefits of being a better environmental raw material choice, soy chemistry is being recognized more for its economic competitiveness. This provides an additional driving force for greater investment in new research and development and partial substitution of soy derivatives for petrochemicals.

Figure 5



The soy meal price has not escalated as rapidly as soy oil, which should encourage research and development of new opportunities for soy meal or protein derivatives.

Figure 6



Commodities units of measure and currency:

Crude Oil (petroleum): simple average of three spot prices; Dated Brent, West Texas Intermediate, and the Dubai Fateh (US Dollars per barrel)

Heating Oil: New York Harbor No. 2 Heating Oil Spot Price (US Dollars per gallon)

Natural Gas: Natural Gas spot price at the Henry Hub terminal in Louisiana (US Dollars per thousand cubic meters of gas)

Palm oil: Malaysia Palm Oil Futures (first contract forward) 4-5 percent FFA (US Dollars per metric ton)

Rapeseed Oil: Crude, fob Rotterdam (US Dollars per metric ton)

Soybean Oil: Chicago Soybean Oil Futures (first contract forward) exchange approved grades (US Dollars per metric ton)

Soybean Meal: Chicago Soybean Meal Futures (first contract forward) Minimum 48 percent protein (US Dollars per metric ton)

Soybeans: U.S. soybeans, Chicago Soybean futures contract (first contract forward) No. 2 yellow and par (US Dollars per metric ton)

Sunflower oil: Sunflower oil, US export price from Gulf of Mexico (US Dollars per metric ton)

Since market prices reflect much more than raw material costs, it was not always expected that the prices of intermediate chemicals or finished products would rise and fall in line with their underlying feedstock prices. The further a product is removed from the underlying feedstock and the more costs involved to be recovered by the final product sale, the longer the lag time will be in capturing the raw material cost escalations and the less the impact of the raw material price change will show in the ultimate market price.

Historically, the prices of oil and natural gas commodities have moved in tandem because the demand for both moved in conjunction with the economy and weather. The historical oil-to-gas price ratio has ranged from 6:1 to 10:1. For example, at a 10:1 ratio, if the price of natural gas is $7 per MMBtu, then the value or price per barrel of crude oil is expected to be around $70 per barrel. However, the oil-to-gas price ratio changed significantly in mid 2009. As crude oil climbed to over $80 per barrel, natural gas NYMEX prices fell to $4 per MMBtu, taking the oil-to-gas price ratio to 20:1.

Given recent history, it appears that the prices of crude oil and natural gas are not as related and interchangeable today. About fifteen years ago there were a greater number of older power-generation facilities that could switch back and forth between oil and natural gas, and fuel-switching between the commodities could impact the price of each commodity. Today, transportation accounts for 70 percent of U.S. oil consumption, while natural gas is primarily used for heating, power generation and industrial processes. Fuel switching by power generators has declined substantially, and the ability to switch fuels in response to short-term price signals no longer exists.

Crude oil sometimes serves as a proxy for energy demand, and investors buying energy commodities, may have included both crude oil and natural gas. However, the chart shows that relationship has wavered over the past year and is not nearly as consistent as it was in 2007 and 2008. With the potential development of natural gas reserves in shale formations, the two commodities will become even less linked.

RUBBER PRODUCTS

The two categories of commercial rubber products are natural rubber and synthetic rubber. Natural rubber is produced from latex obtained from rubber trees. The purified form of natural rubber is the chemical polyisoprene, which can also be produced synthetically.

Synthetic rubber is made from the polymerization of a variety of monomers including isoprene (2-methyl-1,3-butadiene), 1,3-butadiene, chloroprene (2-chloro-1,3-butadiene), and isobutylene (methylpropene) with a small percentage of isoprene for cross-linking. Some of the most important synthetic rubbers are ethylene propylene, polybutadiene, styrene butadiene, butyl, nitrile, and chloroprene.

Natural Rubber (NR)

The rubber tree flourishes in the tropics with annual rainfall of 2,000-4,000 mm evenly spread throughout the year, and temperatures ranging between 24-28°C. Accordingly, the production of natural rubber (NR) is concentrated in a few tropical countries. However, as a result of intensive breeding programs, rubber tree areas can be found in locations with an annual rainfall of as little as 1,500 mm per year and a dry season of up to five months. Natural rubber is cultivated over a long gestation period of about 6-7 years and is highly labor intensive. Trees grown in large plantations as well as being produced by small farmers in the developing countries of Asia (Thailand, Indonesia, Malaysia,…), Africa (Liberia, Cameroon, Nigeria,…) and Latin America (Brazil, Guatemala,…). Worldwide, nine countries account for 92% of the global rubber output and 83% of the total production is from the top four countries (Thailand, Indonesia, Malaysia, and India). Since the majority of rubber production is derived from petroleum, the price of natural rubber is determined largely by the global price of crude oil.

The economic life period of rubber trees in plantations is around 32 years. Depending on conditions, the rubber tree takes 5-10 years to reach maturity, the stage when tapping can be started followed by about 25 years of the productive phase.

The decline in natural rubber planted area for many producing countries is attributable to several reasons. Some estates have converted to more profitable commodities, such as palm oil. Some countries' governments have committed to restraining the extension of new areas to reduce production levels as an attempt to sustain prices. Declines in natural rubber planted area in many traditional producing countries were more than offset by some increases in planted area in certain large producing countries (notably, Indonesia, Thailand, China and India).

Properties

Vulcanized natural rubber products have high mechanical strength and can be compounded to have excellent elasticity. It has very good dynamic mechanical properties and is, therefore, used in tires, rubber springs, and vibration mounts. It is one of the few elastomers that have high strength in gum vulcanizates (cured, low hardness rubber, containing no fillers), which, combined with natural rubber's good resilience, makes the gum excellent for fine particle impact applications.

It also has very good low temperature resistance down to -57°C. Its high temperature heat aging resistance limit for continuous use is about 75°C. Inherent weather resistance (UV light and ozone) of the raw gum elastomer is poor. Addition of carbon black to a compound gives resistance to UV; antiozonants and waxes helps with ozone resistance.

Electrical insulation properties are very good. Dilute mineral acid (although not oxidizing acids such as nitric) and dilute base resistance is good. Solvents follow the polarity rule, thus resistance to petroleum oils is poor while resistance to alcohols (such as ethanol and methanol) and ketones (such as methyl ethyl ketone and acetone) is much better. Synthetic polyisoprene has basically similar properties to those of natural rubber and has a more consistent rate of curing and processing characteristics.

End uses

Tires - Despite the competition of synthetic compounds, natural rubber continues to hold an important place in tire consumption. In particular, its superior tear strength and excellent resistance to heat build up, makes it better suited for high-performance tires used on racing cars, trucks and buses, and aircraft. Its good tack properties make it easier to build a tire and most natural rubber is used in tires (about 70% of the total production). In passenger car cross-ply tires, natural rubber is used in the carcass because of its good tear resistance, building tack, and ply adhesion. In radial ply tires, natural rubber is also widely used in the sidewalls due to its lower heat generation and better fatigue resistance. In the treads of passenger car tires in the United States, Western Europe, and Japan, virtually no natural rubber is used, except in winter tires. In large truck and off-the-road tires, which require low heat generation and high cutting resistance, almost 100% natural rubber is used.

Separate rubber compounds are used for different parts of the tire. Generally, the larger the tire the greater the percentage of natural rubber. The table below refers to relatively small-size truck tires.

Figure 7

Tire	Passenger	Truck
Average weight: New	25 lbs	120 lbs
Natural rubber	14%	27%
Synthetic rubber	27%	14%
Carbon black	28%	28%
Steel	14 - 15%	14 - 15%
Fabric, fillers, accelerators, antiozonants, etc.	16 - 17%	16 - 17%

Source: Rubber Manufacturers Association (RMA)

Industrial and Consumer Goods - Industrial products include a range of products such as conveyor belts, transmission and elevator belts, hoses and tubes, industrial lining, rubberized fabrics and components for the consumer and industrial markets. Natural rubber is used in consumer products such as golf or football balls and other recreational and sporting goods, rubber bands, pencil erasers, footwear and other apparel.

Engineering Products - Engineering applications include parts such as bridge bearing pads, seismic bearing pads, dock fenders, springs, anti-vibration mountings and vehicle suspension systems. Here the high mechanical strength and low creep under load are important properties as well as the good heat build up properties. Other significant uses of rubber are door and window profiles, matting, flooring, and dampeners.

Other - Other end uses include articles for use in the medical and health sector (notably, condoms, catheters and surgical gloves) and latex articles (typically condoms, gloves, threads, adhesives, and molded foams). Gloves (medical, household and industrial) and toy balloons are also large consumers of concentrated latex. Natural rubber is used as an adhesive in many manufacturing industries and products, such as the paper and the carpet industries.

Natural Rubber Production

The production of NR depends on prices, exploitation of land for cultivation and on continuation of planting policies. IRSG reports and projects:

Figure 8

	2000	2005	2010	2015	2020
Worldwide Production of NR (000 tonnes)	**7,416**	**8,576**	**9,828**	**11,844**	**13,805**
(among which)					
Thailand	2,437	2,725	2,956	3,540	3,809
Indonesia	1,776	2,138	2,690	3,428	4,179
Malaysia	1,000	994	911	856	846

IRSG

The combined share of the three major producing countries (Indonesia, Thailand, and Malaysia) in the supply of the European industry has gradually increased to become the dominant origin. In 2010 the three countries together represented 67% of the total world production.

Extreme weather and aging trees in the key rubber-growing countries of southeastern Asia are expected to reduce NR production to 10.25 million metric tons in 2011. Meanwhile, NR consumption is expected to be around 10.31 million metric tons. Looking ahead, projected demand of 11.26 million metric tons in 2011 will outpace anticipated production of 11.0 million metric tonnes.

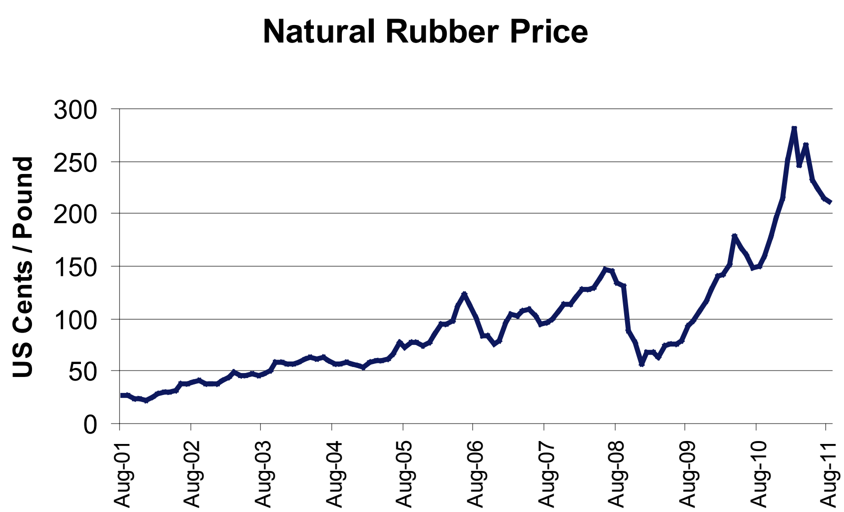
The slower growth rate of NR production capacity the world over is the result of low levels of planting after the Asian crisis in 1997 stretching well into the first decade of this century. Massive new planting by rubber farmers during 2005-2008 will have a significant effect on the supply situation starting in 2011-2012. It is expected that prices of natural rubber will continue to remain quite high well into 2011. The effect of the new planting will presumably result in somewhat lower prices starting from 2012 onwards, but it is unlikely that prices will collapse.

Natural Rubber consumption

IRSG reports global natural rubber latex consumption was 1.2 million tons in 2010, 9 percent lower than in 2009. Across the major latex consumers, Chinese, Malaysian and Indian consumption dropped by 9.9 percent, 4 percent and 2.4 percent, respectively, in 2010, driven by rising NR latex prices.

The European Union is the second biggest consumer of NR (1.3 million tonnes in 2009) after China (3.6 million tonnes). In 2010, China consumed more NR than Europe, Japan and North America together (3.1 million tonnes). Moreover, Chinese consumption is estimated to double in ten years (to 6.4 million tonnes) while that of the Europe, Japan and North America would remain largely the same (together 3.4 million tonnes).

Figure 9



Singapore Commodity Exchange, No. 3 Rubber Smoked Sheets, 1st contract, US cents per Pound
Source: Index Mundi

Selected natural rubber producers and dealers	Country
Apex Fasteners	USA
Astlett Rubber Inc (Toronto, ON)	Canada
A V Thomas Group Companies	India
Bogawantalawa Plantations Ltd	Sri Lanka
The Boustead Group	Malaysia

Dong Hoang Thien Trading And Manufacturing Company	Vietnam
Fulford R&D Inc	Canada
Golde Hope	Malaysia
Honest Company (BC)	Canada
Jakarta Rubber Industry Corp	Indonesia
Kerala State Cooperative Rubber Marketing Federation Ltd.	India
Kerala State Rubber Co-operative Ltd.	India
Kuala Lumpur Kepong	Malaysia
The Kumpulan Guthrie Group	Malaysia
Malaysian Rubber Development Corporation	Malaysia
Persero	Indonesia
Rubbernet (Asia) Pte Ltd	Singapore
Sunray International Limited	China
Rubberwood India Private Ltd.	India
Tiong Huat Rubber Factory Sdn. Bhd. (THR)	Malaysia
Titi Latex Sdn Bhd	Malaysia

Source: United Nations Conference on Trade and Development (UNCTAD)

Polybutadiene (BR)

Polybutadiene is a homopolymer of 1,3-butadiene usually produced by a solution process. Various controlled microstructure polymers are made, of which the largest volume is high *cis*-1,4-polybutadiene, which is produced with Ziegler-Natta catalysts. North American producers of polybutadiene include LANXESS Corp (Buna CB), Firestone Synthetic Rubber (Diene), and Goodyear Chemical (Budene®).

Polybutadiene is the second-largest end use for butadiene worldwide, accounting for about a quarter of total butadiene consumption. This is second only to styrene-butadiene rubber (SBR) which accounts for about a third of butadiene consumption. Polybutadiene elastomers are the second-largest group of synthetic elastomers consumed worldwide.

Butadiene is a by-product of ethylene production. Prices are expected to increase further in the future along with a steady rise in demand. ICIS reported that butadiene spot prices surged by more than $800/tonne from mid-May to peak at $4,300/tonne CFR (cost & freight) NE Asia (northeast Asia) in mid-July, before declining to around $3,800/tonne CFR NE Asia in mid-August. United States butadiene prices continued to rise during the summer of 2011 with demand continuing to run ahead of supply and as crude C4 supply remained extremely tight. Prices ranged from $1.75 – 1.86/lb ($3,857 – 4,099/tonne) in August. ICIS is part of Reed Business Information (RBI), a division of Reed Business and a member of Reed Elsevier plc.

Properties and Applications

Vulcanized polybutadiene elastomers exhibit high resilience (the ability to recover size and shape after stress) with low heat buildup, abrasion and cut growth resistance, and low-temperature flexibility, making it well suited for tires, polybutadiene's largest market. Impact modifiers for ABS and polystyrene plastics are the next largest market.

Polybutadiene elastomers can be heavily loaded with carbon black and oil, more so than natural rubber. Polybutadiene has poor oil resistance (which is good for oil addition), poor wet traction, and poor tear resistance, as well as low resistance to heat and ozone.

Polybutadiene is widely used in truck and passenger tires, where its very low glass transition temperature gives excellent resilience and excellent abrasion resistance. High *cis*-1,4-polybutadiene does not have good traction properties, so the tread portions of a tire must also contain a second elastomer with a higher glass transition such as natural rubber or styrene butadiene rubber.

Tires containing vinyl polybutadiene and solution-process high-vinyl SBR improve fuel economy by providing reduced rolling resistance and improved traction while maintaining adequate tread wear levels. Vinyl butadiene homopolymers are used mainly in truck tire treads and sometimes in passenger tire carcasses. Styrene, isoprene and butadiene terpolymer improves the heat resistance of high performance tires and racing tires.

Polybutadiene-containing tire components include sidewalls, body plies, treads, chafer and bead compounds. These components utilize the high resilience, abrasion resistance and good flex fatigue characteristics of polybutadiene. High and medium cis-polybutadienes provide excellent abrasion resistance and low rolling resistance, but have poor wet traction characteristics. Elastomeric polybutadienes have poor tear resistance which limits their use in off-road tires. Although the after-market tire industry generally compounds to improve treadwear while maintaining traction, reduction of rolling resistance is typically the focus for the original equipment tire manufacturer. The polymer, filler and oil types have a large influence on rolling resistance.

High impact polystyrene (HIPS) and mass acrylonitrile butadiene styrene (M-ABS) plastic resins are made by polymerizing the styrene (and acrylonitrile) in the presence of polybutadiene to improve impact resistance. Solid core golf balls use highly resilient *cis* polybutadiene. Other applications such as hose, conveyor belts, and roll covers utilize the low temperature flexibility and good abrasion resistance of polybutadiene. Blends of BR, NR, and ESBR are used for low cost, abrasion resistant conveyor belts. BR is also used in shoe sole applications where abrasion resistance and flex fatigue are needed.

Processing and Curing

The processing of BR is considerably dependent on the specific grade and producer. Products vary in Mooney viscosity, molecular weight distribution, branching, low molecular weight components, and microstructure which influence processing characteristics.

Insufficient tack is often a problem with compounds high in BR, requiring a second polymer to increase the tack. Since BR is used primarily in blends, this is usually not a significant issue, but the processing differences can still require changes in process conditions. It is relatively easy to use different combinations of BR, NR, and SBR, in spite of miscibility problems, since these three polymers all are reasonably similar in compatibility and cure rate.

Ethylene Propylene Diene Monomer (EPDM) rubber

EPDM is an ethylene-propylene terpolymer that has a diene (hexadiene, dicyclopentadiene, or ethylidene norbornene) in the polymer side chain. It has a saturated polymethylene chain and is classified in ASTM standard D-1418 as M class. The ethylene content ranges from 45% to 75%. Higher ethylene content increases the loading capability of the polymer and allows better mixing and extrusion. The dienes, typically comprising between 2.5 wt% up to 12 wt% of the composition, serve as crosslinks when curing with sulphur and resin. With peroxide cures, the diene (or third monomer) functions as a coagent, which provides resistance to unwanted tackiness, creep or flow during end use.

Two types of ethylene-propylene elastomers are produced: ethylene-propylene copolymer (EP or EPM), which requires vulcanization by means of free radical generators, and ethylene-propylene terpolymer (EPDM), made by copolymerizing ethylene and propylene with a small amount of a nonconjugated diolefin that is vulcanized with sulfur or with peroxides. EPDM accounts for a large majority of ethylene-propylene elastomer production.

Figure 10
UNITED STATES EP RUBBER CAPACITY
(tonnes/year)

Company	Location	Capacity
Chemtura	Geismar, La.	91,000
Styron	Plaquemine, La.	100,000
Styron	Seadrift, Tex.	90,000
ExxonMobil	Baton Rouge, La.	180,000
LANXESS	Orange, Tex.	70,000
TOTAL		531,000

SOURCE: ICIS Chemical Business Americas

Plasticizers and Oil Extension for EP Rubber

Ethylene-propylene elastomers can be extended and compounded with oil and carbon black or mineral fillers in larger amounts than any other elastomer except polybutadiene and still retain their physical properties. Oil extension is usually done at the time of polymer manufacture. Oil-extended masterbatches typically contain from 40 to 100 parts of oil per 100 parts of polymer. *The Vanderbilt Rubber Handbook* notes that ethylene-propylene rubber is compatible with either paraffinic or naphthenic process oils. However, high aromatic content does have a detrimental effect on cure; aromatic oils significantly affect the cure efficiency of peroxides and reduce the cure state of sulfur-cured compounds. Paraffinic oil has the potential for exuding out of the compound when used at very high levels in high ethylene crystalline EPDM compounds.

High viscosity oils are less volatile, enhance physical properties development, improve heat resistance, and minimize shrinkage. Lower viscosity oils improve both resilience and low temperature flexibility, and tend to reduce compound plasticity.

As an extender, oil almost always lowers compound cost. Since EPDM compounds often have very high filler loadings, process oil provides several benefits:

- Improved wetting and filler incorporation
- Reduced power consumption during mixing
- Lower batch temperature and reduced risk of scorching
- Improved extrusion and melt fabrication operations

EPDM Performance Properties

Ethylene-propylene elastomers are random, amorphous polymers with mainly a saturated hydrocarbon backbone structure. This provides a range of useful performance properties:

- Outstanding ozone resistance
- Excellent aging and weatherability
- Excellent heat resistance (up to 150°C)
- Wide range of tensile strength and hardness
- Excellent electrical insulation properties
- Low temperature flexibility
- Good polar solvents chemical resistance, poor hydrocarbon resistance
- Good water resistance

In addition, the low density of these elastomers (specific gravity about 0.86 gram per cm^3) plus their ability to accept very high levels of extender oils and fillers often gives them a cost advantage over other elastomers in many applications.

Market Applications

Ethylene-propylene rubbers are widely used where their weathering and heat resistance is required. Applications such as electrical insulation, roofing membranes, rubber mechanical goods, hoses, tubing, belts, plastic impact modification, and motor oil additives, automotive weather-strips and seals, and thermoplastic vulcanizates.

Automotive and Transportation

Nontire automotive and transportation applications, include radiator and heater hoses, belts, body and chassis parts, weatherstripping (door, window, trunk, hood seals), mats and grommets. EPDM is often used in cooling system hoses connecting the water pump, thermostat, valves, cooler, heater, oil cooler, and radiator. EP elastomers may be blended with styrene-butadiene elastomers or natural rubber to improve the ozone resistance of these elastomers.

The use of EP elastomers in automotive parts is expected to increase as improvements lead to greater use of weatherstripping, seals, antivibration, and sound-deadening parts per car. While use of thermoplastic olefins (TPOs) and thermoplastic vulcanizates (TPVs) is increasing as alternatives for vulcanized rubber in such automotive parts, EPDM is still used as the impact modifier in thermoplastic vulcanizates while reactor grade TPOs do not use EPDM.

Polymer Modification

This category includes EP elastomers consumed in the production of thermoplastic polyolefin elastomers as well as EP elastomers used to modify other thermoplastic resins.

Thermoplastic polyolefin elastomers (TPOs) are blends of EP elastomer (typically 25% - 35%) and a polyolefin such as polypropylene. They are either physical blends (lower cost, lower performance) or blends that are partially or fully vulcanized for improved elastomeric properties.

Automotive components are the major end use for TPOs for applications such as bumper parts, exterior body parts (fender extensions, mudguards, weatherstripping, filler panels, rub strips and fascia), interior parts (dashboard panels, steering wheels and gaskets), and under-the-hood parts (front-wheel-drive and train parts, electrical connectors, and hose and tubing). Other use categories are wire and cable insulation and jacketing (welding cable, battery booster cable, appliance cord jackets and connectors) and consumer goods (sporting equipment, power and garden tools, hardware items, industrial hose, weatherstripping, gaskets, mounts, sheeting and profile extrusions).

Single-Ply Roofing

Single-ply roofing membranes have lower labor application costs than traditional flat, built-up roofs on large industrial and commercial buildings and can be installed over existing surfaces with only a small amount of preparation. Roofing membrane materials include EPDM, polychloroprene, PVC, and TPO. Suppliers of EPDM single-ply roofing products include Firestone Building Products, Carlisle SynTec Inc., and Johns Manville Corp.

Wire and Cable Insulation

EP elastomers' excellent electrical properties, resistance to weather and low-temperature flexibility make them well suited for wire and cable insulation and sheathing. Typical applications are lead-in wire for residential and commercial buildings, building wire, mine cable, nuclear plant wire, automobile ignition wire, and control and signal wire. Suppliers include ExxonMobil, DSM, Bayer, and Crompton.

Appliance Parts

EP elastomers are well suited for parts that are in contact with hot detergent-containing water (such as drain hoses, gaskets and agitator boots).

Hoses

The excellent resistance to ozone and aging and the low-temperature flexibility of EPDM are especially desirable for water hose, including high-quality garden hose, while the superior resistance of EPDM to heat is an advantage for steam hose. Flexible, coiled air-pressure hose is also made from EPDM.

Other
Pharmaceutical products and sporting goods use EP elastomers. Sheet materials can be calendered as unsupported sheets or onto a fabric substrate for use as liners for disposal ponds, landfills, reservoirs, and pits and ditches. EP elastomers are also converted into gaskets, seals and O-rings, rubber rolls and belts for general industrial and automotive markets. Other uses include seals for cold room doors, face seals of industrial respirators, extruded parts for solar heat collectors, and playground and pool deck surfacing.

Styrene-Butadiene Rubber (SBR)

Styrene-Butadiene-Rubber (SBR) is a synthetic rubber copolymer consisting of styrene and butadiene in the approximate proportion of 3:1 by weight. It has good abrasion resistance and good aging stability when protected by additives, and is widely used in car tires, where it may be blended with natural rubber. Compared to natural rubber, SBR has better processability, heat aging and abrasion resistance but inferior elongation, hot tear strength, hysteresis, resilience and tensile strength.

SBR can be produced by two basically different processes; (a) from solution using batch or continuous ionic polymerization or (b) as emulsion via continuous free radical polymerization.

Styrene butadiene rubber is the largest volume synthetic rubber. The major use of SBR (about 70%) is in the manufacturing of tires and related products. This is driving the trend towards the increasing use of solution SBR as it is better able to meet the demanding specifications of high performance tires. Other applications include conveyor belts, gaskets, hoses, floor tiles, footwear and adhesives. Latex (emulsion) SBR is extensively used in coated papers, being one of the most cost-effective resins to bind pigmented coatings. It is also used in building applications, as a sealing and binding agent behind renders as an alternative to polyvinyl acetate. While it is more expensive, SBR offers better durability, reduced shrinkage, increased flexibility, and better resistance to emulsification in damp conditions.

The processing of SBR compounds is similar to that of natural (or other) rubber. The normal fillers, plasticizers, antioxidants, and activators are used. SBR requires less sulfur than natural rubber and slightly more accelerator. The ingredients for SBR compounds can be mixed in internal mixers or on open mills, and then may be extruded, calendered, molded, and cured in conventional equipment. Mixing procedures vary with the compound.

The International Institute of Synthetic Rubber Producers, Inc. (IISRP) is responsible for assigning numbers to the various commercial grades of Emulsion SBR, butadiene polymers and latices. The numbering system instituted under the Government Synthetic Rubber program is shown below:

Series	Product Type
1000	hot polymers
1500	cold polymers
1600	cold black masterbatch with 14 or less phr oil
1700	cold oil masterbatch
1800	cold oil-black masterbatch with more than 14 phr oil
1900	miscellaneous dry polymer masterbatches
2000	hot latices
2100	cold latices

Styrene-butadiene rubber extrusion properties are superior to those of natural rubber and SBR has less tendency to scorch in processing. Cold SBR (produced with radical-initiating systems) is often preferable to hot SBR for optimum physical properties because of its lower molecular weight and lesser degree of branching. Hot ESBR types offer processing advantages in highly loaded compounds and are used in non-dynamic applications.

For many uses, blends of SBR and rubbers, such as natural rubber or cis polybutadiene, are used. Compounding recipes balance the requirements for each type of rubber used. SBR does not have the green strength and green tack combination of natural rubber. Although some improvements have been made, natural rubber is still required for radial tire carcasses. Some SBR grades can retain excellent shape in extruded goods and are used in continuous vulcanization applications such as hose.

ICIS reports that contract prices for SBR have risen in the United States due to rises in butadiene feedstock on tight supply and steady demand. SBR demand is expected to increase in 2011, while supply is likely to remain tight due to insufficient butadiene supply.

ICIS reports rising prices for styrene butadiene rubber. In Asia, non-oil grade 1502 prices increased to $3,300/tonne (cost, insurance & freight) China in February 2011, up $600/tonne from November 2010, as demand outstripped supply. At the same time, natural rubber prices rose to $5,600/tonne, up by nearly $1,500/tonne since November 2010. The tire market boosted demand for SBR, as manufacturers adjusted their formulations to use more SBR rather than the more expensive natural rubber. The Southeast Asian and Indian automotive markets further strengthened demand for SBR, with non-oil grade 1502 prices rising to $3,400-3,500/tonne by mid-February.

In Europe, January 2011 contracts settled at €1,900-2,100/tonne (free delivered) in northwest Europe for 1500 grade, €1,900-2,000/tonne for 1723 grade, and €1,850-2,050/tonne for 1783 grade. European SBR demand remained strong through mid-February 2011, strengthened by exports of finished goods to Asia.

Contract prices for SBR generally rose in the United States during the same period, with January 1502-grade material at 113.00-121.00 cents/lb, while 1712-grade SBR prices were 103.00-111.00 cents/lb. November prices were 107.00-114.50 cents/lb and 97.00-104.50 cents/lb, respectively.

Feedstock butadiene price increases due to tight supply and steady demand were the main factor. In addition, natural rubber prices reached all-time highs during the period, affecting spot values. SBR demand is expected to increase in 2011, while supply is likely to remain tight because of insufficient butadiene supply.

Suppliers of styrene butadiene rubber identified by ICIS include:

SBR Suppliers (U.S.)
J. H. Calo Co., Inc.
Hanna Rubber Co.
B.G. Peck Company, Inc.
Pierce-Roberts Rubber Company
ICC Chemical Corporation
Goldsmith & Eggleton, Inc.
Wabtec Rubber Products
B.G. Peck Company, Inc.
Excel Ppolymers
Xytel Corp
United Chemical

SBR Compound Suppliers (U.S.)
Advanced Converting, Inc.
Akron Rubber Development Laboratory, Inc.
Goldsmith & Eggleton, Inc.
Monarch Rubber Company
Sound Specialty Coatings Corporation
Wabtec Rubber Products
B.G. Peck Company, Inc.
PartsBridge Associate, Inc.
Pierce-Roberts Rubber Company
Shercon, Inc. OEM Rubber Products

Butyl Rubber (IIR)

Polyisobutylene is the homopolymer of isobutylene, or 2-methyl-1-propene, on which butyl rubber is based. Butyl rubber is produced by polymerization of isobutylene and a small amount of isoprene. Commercial isobutylene-based elastomers include polyisobutylene homopolymers, isobutylene / isoprene copolymers and their halogenated derivatives, and brominated isobutylene / p-methylstyrene copolymers.

The polyisobutylene portion of the butyl molecule provides a low degree of permeability to gases, which leads to its use in inner tubes. This property is also important in air barriers for tubeless tires, air cushions, pneumatic springs, accumulator bags, and air bellows. Compared to natural rubber, SBR has about 80% permeability, while butyl has 10% permeability.

In addition to exceptionally low gas permeability, isobutylene-based polymers exhibit excellent vibration damping and higher coefficients of friction, thermal stability, and good to excellent chemical, moisture, ozone and oxidation resistance. These unique combinations of elastomeric qualities enable applications in a wide variety of finished rubber articles.

Polyisobutylene and butyl rubber are used in adhesives, agricultural chemicals, fiber optic compounds, fuel and lubricant additives, electrical fluids, paper and pulp, personal care products, pigment concentrates, rubber and polymer modification. It is used to manufacture inflatable ball bladders, sealants for rubber roof repair and maintenance of roof membranes, waterproof tape for repairing and waterproofing metal roofs, seals in gas masks and other protective clothing, and as a chewing gum base (food-grade butyl rubber). The first major application of butyl rubber was tire inner tubes which remains an important market segment.

Nitrile Butadiene Rubber (NBR)

Nitrile elastomers are made by emulsion polymerization of 1,3-butadiene and acrylonitrile (ACN) with acrylonitrile / butadiene monomer ratios in the range of 18 / 82 to 50 / 50. ACN, a polar chemical, provides oil, solvent, and abrasion resistance. The polar nature of NBR also reduces resistance to polar liquids such as ketones, esters, chlorinated solvents, and highly aromatic solvents such as benzene and toluene. Lower ACN content nitrile rubbers have better compression set, low temperature flexibility, and resilience. The weather resistance of NBR is poor, similar to NR and SBR, although it can be enhanced by blending with polyvinyl chloride. NBR has better heat aging resistance than polychloroprene rubber and will withstand up to 107°C for continuous use.

North American nitrile elastomer manufacturers include Zeon Chemicals L.R (Nipol®) and ParaTec (Paracril®). Other producers include Omnova Solutions, Industrias Negromex S.A., JSR Corporation, Korea Kumho Petrochemical Co. Ltd., Lanxess AG, LG Chem Ltd., Nantex Industry Company Ltd., PetroChina Company Limited, Polimeri Europa SpA, and Sibur Holding JSC Synthos SA.

The global market for nitrile butadiene rubber is projected to exceed 585 thousand metric tonnes by the year 2017 according to a recent report by Global Industry Analysts, Inc. Factors driving the market include the increasing industrialization and development of infrastructure projects and automobile industry in the emerging economies of Asia-Pacific, Middle East and Latin America. The expected recovery follows the global economic slowdown that began in late 2007. NBR demand decreased with the automobile production. The construction sector also contributed to a significant drop in demand for NBR. Meanwhile, rising prices for butadiene feedstock caused companies to reduce NBR production.

Nitrile rubber is widely used in the oilfield for applications such as blow out preventers, packers, and seals. NBR is used in automotive applications, particularly for under hood parts, where temperatures have increased with reduced airflow and smaller engine compartments.

Nitrile Rubber Applications

O-rings	Diaphragms	Molded Rubber Goods
Adhesives	Flexible Magnets	Oil Field Products
Air Conditioning Hose	Flooring	Printer Supplies
Auto Crash Pads	Fuel Hose	Roll Covers
Belts	Gaskets	Seals
Calendered Sheets	Grouts	Show Products, Footwear
Cements	Highly loaded Stocks	Valve Seals
Chemically-blown Sponge	Hose Tubes and Covers	Weather Stripping, Cable
Coated Fabrics	Modification of PVC, ABS	
Coatings	Molded Automotive Parts	

Source: The Vanderbilt Rubber Handbook

Chloroprene Rubber (CR)

Most chloroprene processes are based on butadiene. Butadiene is converted into the monomer 2-chlorobutadiene-1,3 (chloroprene) via 3,4-dichlorobutene-1. Chloroprene is produced from 2-chlorobuta-1,3-diene.

CR rubber is classified as general purpose, adhesive and liquid dispersion types. General-purpose types are used in a variety of elastomeric applications, particularly molded and extruded goods, hoses, belts, wires and cables, heels and soles of shoes, coated fabrics, and gaskets. The adhesive type is used in solvent-based adhesives that are characterized by quick set and high bond strength. The liquid dispersion types are generally used in adhesives, binders, coatings, dipped goods, waterborne adhesives, elasticizers, and foams.

Market

According to a recent Global Industry Analysts report on chloroprene rubber, the global market for chloroprene rubber is forecast to reach 445.3 thousand metric tonnes by the year 2017 despite competition from natural rubber and other synthetic rubber alternatives. Asia-Pacific and Latin America markets are expected to prefer chloroprene rubber in industrial and automobile components applications. Increased demand is anticipated from industrial rubber products, adhesives and automobiles.

The growing use of thermoplastic elastomers (TPEs) has reduced the use of synthetic rubber. Consumption of industrial rubber products is expected to increase in sectors such as construction, aerospace, mining and forestry, OEMs, replacement, household appliances, computer and office equipment. The adhesives market represents a large share of overall chloroprene rubber demand.

Chloroprene producers include Asahi Kasei Chemicals Corporation, Denka Group, Styron, DuPont Performance Elastomers, Lanxess AG, Showa Denko K.K., Tosoh Corporation, Chongqing Longevity

Chemical Co., Ltd., Nairit Plant CJSC, China Bluestar New Chemical Materials Co., Ltd., Shanxi Synthetic Rubber Group Co., Ltd, and Zenith Industrial Rubber Products Pvt. Ltd. One common trade name for chloroprene is Neoprene®, from DuPont.

Properties

CR is not characterized by one outstanding property, but its balance of properties is unique among the synthetic elastomers. It has:

- Good mechanical strength
- Good aging resistance
- Good resistance toward chemicals
- Adhesion to many substrates
- High ozone and weather resistance
- Low flammability
- Moderate oil and fuel resistance

Chloroprene rubber is notable for its high elasticity, resistance to solvents, heat, ozone, weather aging, and perspiration. It is widely used as hoses and belts in motor vehicle components, as electric wire, as an architectural rubber product and as a general industrial material.

CR was one of the first oil resistant synthetic rubbers. While having only moderate resistance to petroleum based oils and fuels, it is considered a good general purpose rubber with an excellent balance of physical and chemical properties. It has better chemical, oil, ozone and heat resistance than natural rubber but a somewhat lower level of physical properties. Chloroprene tends to slowly absorb water and its electrical properties are poor. Its gas permeability is fairly low and flame resistance is excellent. Chloroprene gives excellent rubber-metal bonds and good resilience.

Polychloroprene Applications

Wire and Cable — selected for oil, abrasion, and weather resistance - power cable, service entrance, drop wire, ship wiring, portable cables, and cords.

Covers and Tubes for Hose — selected for resistance to heat, chemicals, abrasion, oil and weather resistance, physical toughness - industrial and automotive hose, hydraulic hose, welding hose, oil suction and discharge hose, oil delivery hose, and air hose.

Belts — selected for heat and flex resistance - V-belts and other power transmission belts used in automotive, agricultural, and industrial applications, conveyor belts for industrial and mining service where flame resistance is important.

Molded and Extruded Parts — selected for balance of properties – numerous automotive and industrial applications, appliance parts, pipe gaskets, air springs, bridge bearings, building bearings, building seals, O-rings, and cellular products.

Adhesives — selected for its polar nature and crystallinity (leading to development of early and improved bond strength and high auto-adhesion) – industrial, shoe, furniture, automotive, and construction industries.

Other Uses – wet suit sponge, coated fabrics, shoe soles and heels.

Plasticizers

Softeners, plasticizers, and extenders are frequently added to chloroprene rubber to facilitate processing, enhance specific properties, or reduce cost.

Aromatic process oils are nearly completely compatible with polychloroprene and are used to increase uncured tack, but may cause staining. Naphthenic oils can be used at levels of up to 20 phr, and are preferred to aromatic oils in light colored, nonstaining products. They also provide better long-term heat resistance. Paraffinic oils should be avoided because they will often bloom at levels as low as 5 phr.

Ester plasticizers provide increase flexibility at low temperatures but tend to increase the crystallization rate of the polymer. Dioctyl sebacate is often used for its balance of low temperature flexibility, volatility, and cost. Butyl oleate is effective at low temperatures, but it is relatively volatile at 100°C. Phthalates enhance low temperature properties but may be limited in their use by regulations.

Polymeric, hydrocarbon, or coumarone-indene resins can retard crystallization, improve building tack and frictioning, but do not improve low temperature flexibility. Phosphates are used to achieve self-extinguishing characteristics. Solid forms of chlorinated hydrocarbon and chlorinated wax plasticizers are preferred as the liquid form tends to cause mold sticking.

Vegetable oils can also be used as plasticizers. Rapeseed oil provides exceptional heat resistance, while linseed oil can improve the ozone resistance of vulcanizates and safflower oil can improve the weather resistance of vulcanizates. Other vegetable oils are less compatible and may reduce the heat and/or ozone resistance of vulcanizates. Vulcanized vegetable oils can be used to extend or add body and dryness to highly extended polychloroprene compounds. These plasticizers also improve processing of low durometer compounds containing large amounts of plasticizer.

Rubber Compounds and Materials

The inherent properties unique to each elastomer, such as the oil resistance of NBR or the ozone resistance of EPDM or the high resilience of natural rubber significantly determine the suitability of an elastomer for any given application. To be commercially useful, a variety of materials must be added to improve and protect the elastomer properties.

Rubber Compounding

Compounding is the process of adding additives, fillers, polymers, or reinforcements to polymer materials in a homogeneous polymer mixture to optimize properties to meet a given set of performance requirements.

Rubber formulations are processed in internal mixers which generate high shear forces that disperse the fillers and raw materials into a uniform, quality compound. After mixing, the compound is dropped onto a mill or extruder or pelletizer.

The specific ingredients chosen for a compound will be driven by the ultimate physical properties of the finished product, the processing characteristics required by the manufacturing process, and the acceptable economics for the finished product. Compounding ingredients may be categorized as:

- Elastomer (natural or synthetic rubber)
- Vulcanizing or crosslinking system
- Accelerators, accelerator activators and retarders
- Stabilizer system (antioxidants and antiozonants)
- Processing aides (plasticizers, softeners, tackifiers, etc.)
- Reinforcing fillers (carbon black, silica, mineral fillers) and resins
- Inert fillers and diluents
- Special purpose materials (abrasives, blowing agents, colors, pigments, reodorants, etc.)

Fillers and processing aids are relevant to the study of opportunities for soy products in rubber compounds.

Fillers

Fillers significant influence rubber processing and vulcanizate properties. Fillers are used to reinforce and increase strength properties, color the material, extend and dilute, lower costs, and change processing characteristics. The size and shape of filler particles have a major effect on these properties. Generally, fillers with a particle size of larger than 10 microns can reduce physical properties by creating localized areas of stress. Fillers with a particle size between I and 10 microns, such as ground limestone and clays, are relatively neutral on vulcanizate properties and serve as material and cost diluents. Fillers which improve strength and modulus properties have particle sizes from 0.1 to 1 micron. Higher levels of reinforcement are achieved with fillers having particle sizes of 0.01 to 0.1 microns.

Process Oils

Various oils are added to the rubber compound to improve processing and to lower cost without affecting vulcanizate properties. Processing oils, such as castor oil and sulfonated petroleum oils, can be added up to 10 parts per hundred of rubber (phr) to soften the rubber and aid processing. Paraffinic, naphthenic, and aromatic oils are used at higher loadings to extend the rubber compound and reduce cost without compromising physical properties. At this high loading, good compatibility between the elastomer and the oil is essential. Paraffinic oils are more compatible with the more highly saturated rubbers (EPDM and IIR), while aromatic oils are the most compatible with SBR, NR and BR. Rubber in contact with light colored organic finishes may stain the surfaces in contact with the rubber (contact staining) and surfaces adjacent to or beyond the rubber (migration staining), especially under conditions of heat, pressure, or sunlight. Staining increases in the following order - paraffinic oils show less staining than naphthenic oils which show less staining than aromatic oils.

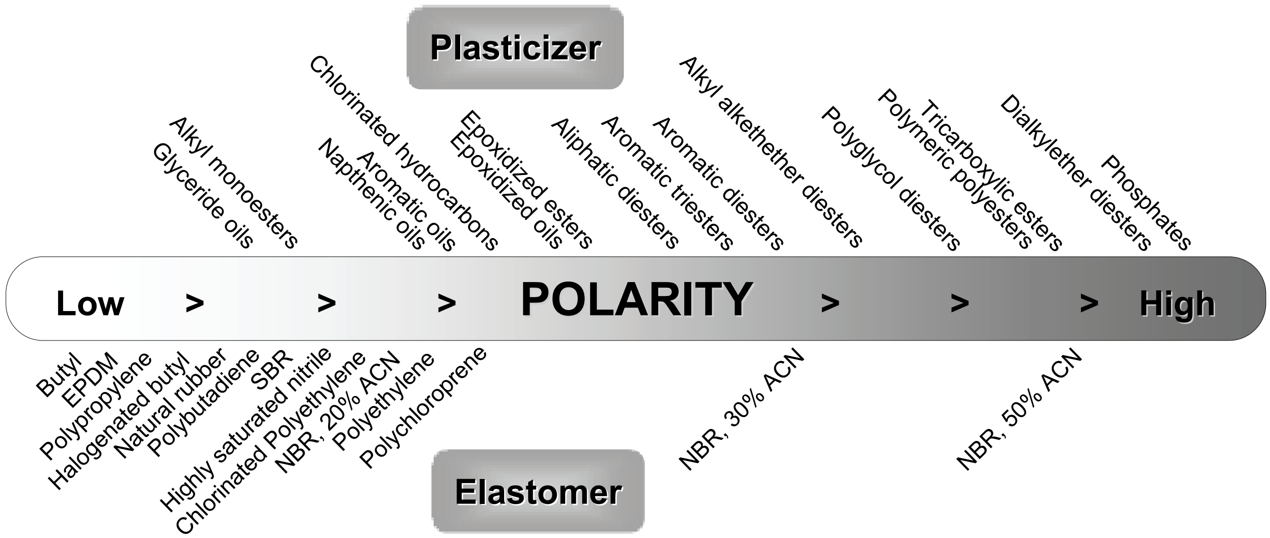
Process Aids and Plasticizers

The functional role of process aids and plasticizers in rubber compounds is to reduce the frictional heating of the ingredients during processing. Process aids facilitate the incorporation of fillers and allow processing at lower temperatures and power requirements.

Plasticizers soften the rubber compound, reducing modulus and hardness, increase elongation, and in some cases, improve low temperature flexibility. They also improve flow in extrusion and molding by making the uncured compound less elastic and reducing viscosity and friction. At low levels, plasticizers aid in the dispersion of fillers. At higher amounts, they reduce uncured compound viscosity, often lower the overall raw material compound cost, and reduce vulcanizate stiffness.

The Handbook of Specialty Elastomers defines plasticizer as any material (primarily liquid) that is added to a compound to facilitate easier mixing, extruding, molding, and curing through modification of the basic physical properties of the uncured and cured compound (e.g. viscosity, hardness, modulus, low-temperature flex). Plasticizers may be monomeric (such as glycol esters, monoesters, diesters, and triesters) or polymeric with viscosities from 400 to 200,000 cps.

Plasticizers are ranked according to how compatible they are with polar elastomers. Generally, polar groups such as acrylates, acrylonitriles, glyucols, aromatic / phenyl groups, and halogens add degrees of polarity. Olefins are nonpolar. Paraffinic process oils have little to no polar characteristics while process oils with aromatics content are compatible with semipolar elastomers.



Petroleum oils are one of the major sources of plasticizers. These oils are divided into three chemical categories - aromatic, naphthenic, and paraffinic. The paraffinic types give better rebound resilience and lower hysteresis, while aromatics are better for tensile strength and resistance to crack growth. Elastomers which have little or no oil resistance are the ones most suited for compounding with petroleum oils.

Paraffinic process oils contain a minimum of 55% parafinic side chains and have excellent resistance to discoloration and oxidation due to the high level of saturates. The low aromatic content results in poor solvency and less compatibility with polar elastomers. With a minimum total aromatic content of 30%, naphthenic process oils are compatible with semipolar elastomers. Aromatic process oils contain a minimum of 70% aromatic content and are compatible with semipolar and polar elastomers. The high level of unsaturation affects color stability, oxidation resistance, and cure characteristics. OSHA regulations require all aromatic extract process oils to be labeled as carcinogenic.

Figure 11
THE AMERICAN SOCIETY OF TESTING AND MATERIALS (ASTM) STANDARD CLASSIFICATION OF VARIOUS TYPES OF PETROLEUM OILS FOR RUBBER COMPOUNDING, ASTM DESIGNATION: D2226

Types	Asphaltenes max %	Polar Compounds max %	Saturated Hydrocarbons, %	Common Name
101	0.75	25	20 max.	Highly aromatic
102	0.5	12	20.1 to 35	Aromatic
103	0.3	6	35.1 to 65	Naphthenic
104	0.1	1	65 min.	Paraffinic

Type 104 oils are further classified into two subtypes 104A and 104B for SBR polymers only. Type 104B oils are those that have a viscosity-gravity constant of 0.820 maximum (Test Method D

2501). Type 104A oils are those that have a viscosity-gravity constant greater than 0.820 (Test Method D 2501). It is recognized that certain Type 104 oils may not be satisfactorily classified for polymers other than SBR by this subclassification.

Some North American producers of process oils include:

Ashland (aromatic)	Exxon Mobil (paraffinic, naphthenic)
Calumet (paraffinic, aromatic)	San Joaquin Refining (aromatic, naphthenic)
Cross Oil (naphthenic)	Sunoco (paraffinic, aromatic)
Ergon (paraffinic)	Valero (paraffinic, aromatic)

For oil resistant elastomers, liquid plasticizers such as esters (polar liquids) are used which also improve low temperature flexibility. Elastomers such as EPDM and polynorbornene can hold large amounts of plasticizer and filler without appreciable degradation of properties. For these, oil extended rubbers (raw gum elastomers with the plasticizer already mixed in) are available to facilitate the compounding operation. Chlorinated oils are used to enhance flame retardation properties.

Figure 12
STARTING POINT COMPOUNDS (RUBBER AND PROCESS OIL ONLY)
Oil levels are in parts per hundred of rubber (phr).

High quality conveyor belt cover		*Medium quality conveyor belt cover*	
SBR extended with aromatic oils	137.5 phr	SBR extended with aromatic oils	137.5 phr
Aromatic oil	10.0	Aromatic oil	40.0
Total	229.2	Total	289.7
Automotive mat		*Shoe sole – high quality*	
SBR extended with naphthenic oil	150 phr	SBR (45-55 ML4)	100 phr
Naphthenic plasticizer	30	Naphthenic oil	5
Total	525.9	Total	168
Flooring or cove base		*Passenger Tire Tread – Carbon black*	
35% Styrene SBR	100 phr	PLF 1723 SBR	110 phr
Naphthenic plasticizer	30	BUD 1207 BR	20
Total	524.4	Naphthenic Oil	7.75
		Total	215.1
Passenger Tire Tread – Silica		*Dual Durometer EPDM Automotive Extrusion Compounds for Microwave/ Hot Air Curing*	
Buna VSL 5025-2 HM, SBR	96.25 phr		
BUD 1207 BR	30	Royalene 547	100 phr
Naphthenic Oil	5	Sundex 2280 Paraffinic Oil	110
Total	228.45	Total	409.3
Super-soft Closed Cell EPDM Extruded Sponge Compound for Microwave/ Hot Air Curing		*RMA Grade 1 Conveyor Belt Cover*	
		Natural Rubber, Grade 20	80 phr
Royalene 694	175 phr	SBR 1500	20
Sudex 2280 Paraffinic Oil	80	Aromatic Oil	10
Total	456.2	Total	176.8

RMA Grade 2 Conveyor Belt Cover Polybutadiene Rubber 20 phr SBR 1500 80 Aromatic Oil 10 Total 176.8	*Radiator Hose, Electrochemically Resistant, ASE J20D3* Vistalon 7500 EPDM 100 phr Paraffinic Oil, Type ASTM 104B 70 Total 351.6
Firm Polyisoprene Sponge Natsyn 2210 Polyisoprene 100 phr Paraffinic Oil (Low Viscosity) 20 Total 203	*EPDM Roofing Compound* Vistalon 5601 100 phr Paraffinic Process Oil 8 Total 319.7
Butyl Body Mount Compound Exxon Butyl 268 100 phr Paraffinic Oil 20 Total 188.5	*Automotive Coolant Hose Compound* Vistalon EPDM 7001 100 phr Sunpar 2280 80 Total 356.9
EPDM Roof Sheeting Membrane Compound (Autoclave Cure) Vistalon EPDM 3702 100 phr Felxon 815 Oil 60	

Source: *The Vanderbilt Rubber Handbook*

Vulcanized Vegetable Oil (VVO)

Vulcanized vegetable oil, also known as factice, was originally developed as an extender and substitute material for more costly natural rubber. Various processing properties are improved and cured rubber properties are enhanced by factice addition. The economic impact is seen in increased production throughputs, reduced energy consumption, and lower compound volume prices.

The basic raw material for factice is a fatty oil such as soybean, rapeseed, and castor oil - mixtures of glycerides, mostly triglycerides of mono and polyunsaturated fatty acids. It is this unsaturation that allows for crosslinking. Factices prepared with soybean oil are generally softer and darker than factices prepared with rapeseed oil or castor oil. Factices prepared with castor oil are slightly lighter and firmer than factices prepared with rapeseed oil. Castor oil-based factice is polar in nature and therefore has the best compatibility with nitrile and polychloroprene. It also offers the best oil resistance.

VVO is used in the rubber industry to improve ozone resistance, reduce Mooney viscosity, and improve flow properties in molded and extruded goods. In NR and SBR compounds, soy-based VVO can delay the onset of melt fracture, reduce extrudate swell, smooth extrudate surfaces, and improve dimensional stability.

VVO is made by vulcanizing vegetable oil with sulfur and other accelerators. The most common crosslinkers are elemental sulfur and sulfur monochloride. Unfortunately, the addition of sulfur to the VVO causes issues by decreasing scorch times, increasing heat aging and compression set properties, and causing reversion. When fatty acid chains in the oils are crosslinked with sulfur (brown factice) or with sulfur chloride (white factice), the oil gels to form a rubbery compound. This gives dimensional stability to extruded articles, reduces mold fill and cure cycle time. In addition, it improves ozone resistance of the rubber compound and gives a smooth velvety feel to rubber articles. By absorbing large amounts of mineral oil and liquid plasticizers on the mill and in the Banbury mixer, migration of oils and plasticizers to the surface of low-durometer stocks is reduced, and the ability to flow under mechanical pressure is enhanced.

Some specialty grades are crosslinked with hydrogen sulfide, isocyanate, and peroxide. Factices crosslinked with sulfur are brown in color and softer than factices crosslinked by other means. They exhibit moderate thermal stability, have a high acetone extract, some residual sulfur and are chloride free. These properties translate into higher extractability, a reduction in scorch and cure time and good corrosion resistance. They are available in cake or coarse ground form. Factices crosslinked with sulfur monochloride are white to cream in color and firmer, have good thermal stability, low acetone extract and residual sulfur and chloride. The retardation in cure rate can be lessened with acid buffers. Factices can also be crosslinked with hydrogen sulfide, isocyanate, or peroxide and may also be modified with plasticizers, process oils, fillers and buffers.

The addition of accelerator to vegetable oils in making brown VVO results in a decrease of the free sulfur and the acetone extract values and a reduction in the reaction time necessary to achieve the gel state. Natural rubber vulcanizates containing brown soybean-based VVO show improved retention of tensile strength and 100% modulus after aging compared to those containing VVO based on boiled linseed oil and dehydrated castor oil. The heat resistance of NR vulcanizates containing brown VVO increases as the amounts of the free sulfur and the acetone extract in the VVO decrease. Adding small amounts of brown VVO to NR and SBR compounds helps maintain tensile strength after aging; however, high concentrations reduce the aging properties. The addition of brown soybean-based VVO and tetramethylthiuram disulfide (TMTD), a very active, sulfur-bearing, non-discoloring organic accelerator, to NR compounds enhances the ozone resistance which is important for printer rolls and rubber hoses.

VVO is a permanent softener. As a partial replacement for plasticizer or oil in a compound it is non-blooming, non-volatile, non-migrating, and non-extractable. It will maintain compound durometer and flexibility over time. This is an advantage for challenging service conditions such as flexographic or roll applications.

Adding VVO makes mold removal easier and often improves surface appearance of the molded article. VVO binds the oil and plasticizer in a compound and reduces abrasion resistance allowing better polishing or grinding of roll compounds. This is a useful benefit for pencil erasers. As the surface of the eraser is eroded away, new clean surface is uncovered to wipe away the graphite contained in the pencil lead.

As a process aid, VVO creates a unique thixotropic rheology in a compound, allowing it to flow freely under mechanical pressure but return to a static state when the stress is removed. This quality allows for lower temperature build up during mixing, a wider temperature range for optimum calendering, reduced shrinkage, reduced cold flow, increased green strength, improved mold fill, and reduced die swell. VVO absorbs oils and liquid softeners allowing faster mixing, improved filler dispersion, reduced stickiness, reduced mold fouling, and faster extrusion speeds.

At higher loadings, VVO behaves like a filler without creating hardness or stiffness while improving properties like dimensional stability and green strength in a compound. It will reduce the tack of the compound without affecting the cured knitting of the compound. Its consistency does not change with temperature thereby providing structure and support to an extruded strip or sponge compound prior to and during cure.

Epoxidized Vegetable Oils

Epoxidized vegetable oils (EVO) are gaining increased interest in the polymer industry as an economical, environmentally friendly, non-noxious and renewable choice as a plasticizer and stabilizer. Unsaturation in the triglyceride of fatty acids permits the introduction of 6-7% of an oxirane (epoxide) oxygen content through epoxidation.

Epoxidized soybean oil (ESO) is a non-toxic clear to yellow liquid produced from the oxidation of soybean oil with hydrogen peroxide and either acetic or formic acid. ESO is an epoxidized glycerol fatty ester that is used as a plasticizer and stabilizer in plastic materials. It is the most widely used plasticizer of this group, has excellent resistance to extraction by soapy water and low migration into adjoining materials that tend to absorb plasticizers. ESO has been approved for use in food packaging. It is useful in halogenated polymers, such as polyvinyl chloride and its copolymers, to keep plastics and rubber soft and pliable. The epoxy functionality provides excellent heat and light stability.

Carbon black

Carbon black is the predominant reinforcing filler used in rubber compounds and serves to improve durability and strength. For various types of tires, it is used in innerliners, carcasses, sidewalls and treads utilizing different types based on specific performance requirements. Carbon black is also used in molded and extruded industrial rubber products, such as belts, hoses, gaskets, diaphragms, vibration isolation devices, bushings, air springs, chassis bumpers, and multiple types of pads, boots, wiper blades, fascia, conveyor wheels, and grommets.

Characteristics
Improvement in rubber properties is a function of the physical and chemical characteristics of carbon black - aggregate size, shape and structure, particle size, surface activity, and porosity. Increasing structure or branching typically increases modulus, hardness, electrical conductivity and compound viscosity and improves dispersability of carbon black. Oil absorption is the

measure of structure with a high number representing higher structure. Rubber carbon black is typically sold as a beaded product (pellets).

Typical carbon black primary particle size ranges from 8 nanometers for furnace blacks to 300 nanometers for thermal blacks. Finer particles increase reinforcement, abrasion resistance, and improve tensile strength. Surface chemistry can affect abrasion resistance, tensile strength, hysteresis and modulus. Higher porosity allows compounders to increase carbon black loading, while maintaining compound specific gravity. This leads to increases in modulus and electrical conductivity for a fixed loading of carbon black.

Some empirical guidelines in using carbon black:

Increase in carbon black aggregate size or structure	Improves cut growth and fatigue resistance
Decrease in particle size	Increases in abrasion resistance and tear strength. Drop in resilience, and hysteresis and heat buildup
Decrease in carbon black loading	Lowers tire rolling resistance
Increase in fineness	Raises rolling resistance and traction
Increase carbon black loading	Increases in compound heat buildup, harness, rolling resistance, and traction. Tensile strength, processability, and abrasion resistance go through a maximum then decrease and properties deteriorate.

Use and Market

The leading application for carbon black is as a reinforcing agent in the production of rubber goods, accounting for more than 90% of total carbon black consumption. SRI Consulting reports that in 2010, use in tires accounted for 73% of world consumption, with other rubber goods (hoses, belts, etc.) accounting for an additional 19%; consumption for nonrubber goods (plastics, inks, paints, etc.) accounted for the remaining 8% of world consumption. While specialty carbon blacks account for only 7% of the total market in tonnage, they command a significantly higher selling price than commodity furnace black.

The price of crude oil has a significant influence on carbon black markets. The furnace black process uses heavy aromatic oils as feedstock. The thermal black process uses natural gas, consisting primarily of methane or heavy aromatic oils, as feedstock material. Asia (excluding Japan) is currently the largest producer and consumer of carbon black, accounting for 55% of global production and consumption in 2010, with China accounting for nearly half of total Asian consumption. All major producers are global in the scope of their operations. The four largest producers are Cabot Corporation, Evonik Industries, Columbian Chemicals, and China Synthetic Rubber Corp.

World demand for carbon black is forecast to rise 4.3 percent annually through 2013 according to Freedonia. Higher growth is expected in the non-tire rubber product market than in the dominant motor vehicle tire sector of the 9.4 million metric ton world carbon black industry.

Carbonate, Clay, Silica, and Other Mineral Fillers

The non-black fillers for rubber are calcium carbonate, kaolin clay, precipitated silica, talc, barite, wollastonite, mica, precipitated silicates, fumed silica and diatomite. Of these, the most widely used, by volume and by functionality, are calcium carbonate, kaolin clay and precipitated silica

Filler Properties
Key properties of mineral fillers are particle size, particle surface area, particle surface activity and particle shape. Reinforcement is characterized by particle size:

- Fully reinforcing (0.01 to 0.1 micrometer)
- Semi-reinforcing (0.1 to 1 micrometer)
- Diluent or extending (1 to 10 micrometers)
- Increasing surface area (decreasing particle size) leads to higher compound viscosity, tensile strength, abrasion resistance, tear resistance, hysteresis, and lower resilience.

Larger filler particles (> 10 micrometers) introduce areas of localized stress which contribute to elastomer polymer chain rupture on flexing or stretching. Filler size is usually reported as median size so it is also important to know the particle size distribution. Generally, particle size is measured as equivalent spherical diameter rather than actual size or dimensions. While calcium carbonate is a round or block-shaped particle, clay and talc are more plate-like in shape, making true particle size matching difficult for compounding studies. A filler must make intimate contact with the rubber matrix to contribute to the rubber-filler composite. High surface area fillers have more contact area available.

Increasing filler aspect ratio results in higher viscosity, modulus, hysteresis, lower resilience, extrusion shrinkage, and longer time to mix in. Increasing adhesion to the rubber matrix results in greater abrasion resistance, chemical reaction, higher modulus, and greater hysteresis.

Tensile Properties - Fillers increase modulus by providing resistance to elongation. Better matrix adhesion generally results in higher modulus and on tensile strength because the coupling bonds between the filler and matrix must be broken.

Impact and Flexural Strength - Fine high aspect ratio particles and strong filler-matrix adhesion resist the movement of elastomer chains under compression.

Tear Strength and Flex Resistance - Large or poorly bound filler particles act as flaws and initiate or propagate cracks. Small, high aspect ratio fillers well bound to the elastomer act as barriers to the propagation of microcracks and resist part failure.

Abrasion Resistance — Hard filler particles can protect the rubber against wear especially with good matrix adhesion.

Resilience and Hysteresis — Resilience, or rubber elasticity, is the ratio of energy released on recovery to the energy used to deform the part. Hysteresis is the amount of energy that is converted to heat instead of to mechanical energy as elastic rebound. As filler loading and filler-matrix adhesion increase, the ability to quickly return to the original shape following deformation is lessened and hysteresis increases.

Calcium Carbonate

There are two categories of calcium carbonates used for rubber - ground natural calcium carbonate (limestone) and precipitated calcium carbonate.

Ground calcium carbonate filler has a low aspect ratio, low surface area, and low surface activity. Size classes are 3 - 12 and 0.7 – 2 micrometers. Wet-ground carbonate has better uniformity and finer particle size and is somewhat more expensive than dry-ground product.

Precipitated calcium carbonate is used for applications requiring higher brightness, smaller particle size, greater surface area, lower abrasivity, and higher purity than ground natural products provide. Particle sizes are typically in the 0.07 - 0.7 micrometer median size range.

Kaolin Clay

Kaolin clay is a plate-like aluminosilicate. Its continuous sheet structure produces thin particles which exist in nature as overlapping flakes. Rubber filler clays are classified by their particle size and stiffening effect in rubber. A hard clay (median particle size ~ 250 to 500 nm) will impart high modulus, high tensile strength, stiffness, and good abrasion resistance to rubber compounds. Soft clay (median particle size ~ 1000 to 2000 nm) is used where high loadings (lower cost) and faster extrusion rates are more important than strength.

More hard clay than soft is used in rubber because of its semi-reinforcing effect and its lower cost relative to other fillers. It will substitute for a portion of the more expensive carbon black or precipitated silica in certain compounds, without sacrificing physical properties.

Kaolin clays are also classified by processing method. Airfloat clay is dry-ground kaolin that has been air-separated to minimize impurities such as quartz, mica, and bentonite, and control the particle size distribution. The majority of the kaolin used in the rubber industry is airfloat hard clay. Water-washed clay, usually soft clay, is slurried in water to remove impurities and produce specific particle size fractions. These clays are often chemically bleached and further processed to remove dark impurities and improve brightness.

Precipitated Silica
Precipitated silica is produced by neutralizing sodium silicate solution with concentrated sulfuric, hydrochloric or carbonic acids. Unlike carbon black, which also has small primary particles, the silica structure is not permanent. Hydrogen bonding among particles will form clusters or aggregates, and these aggregates may loosely bond as agglomerates which are disrupted during compounding.

Precipitated silica usually contains about 6% adsorbed free water and the surface is saturated with silanol groups. The water insures that the silica particle is saturated with active silanols, however, it inhibits the reaction of accelerators and soluble zinc with those silanols and the bonding of the rubber matrix to the silica particle. The variations in compound properties from variations in water content can be avoided by adding glycols and amines. As with kaolin, treatment of the silica particle surface with an organosilane facilitates effective rubber-to-silica bonding.

An advantage of silica is the ability to achieve transparency or a particular color in combination with high reinforcement. Silica also improves tear and tensile strength which is important for earth mover and truck tire treads. It is also used in belts, wires, cable jackets, hoses and in rubber adhesion compounds for improved rubber-metal bonding.

Green-Tire Technology was developed in the early 1990s by Michelin in Europe based on a tread compound blend of solution SBR and polybutadiene filled with precipitated silica with an optimized amount of sulfur-functional organosilane. The result was a tire with lower rolling resistance and better wet traction in comparison with traditional tread compounds. Today most original equipment passenger car tires contain this filler system.

Other Mineral Fillers
Talc, barite and diatomite are also used as fillers in rubber in compounds where their characteristic physical properties are needed.

Talc - Talc is a plate-like alkaline magnesium silicate mineral. It is characteristically soft and white and naturally hydrophobic. Talc is used in extruded rubber because the filler plates orient and provide smooth surfaces at high extrusion rates. It is also used to reduce moisture and gas permeability in hoses and inner liners

Barite — Barite is natural barium sulfate (specific gravity of 4.5). It is used in compounds where weight is required and for acid resistant compounds.

Diatomite — Diatomite, also known as diatomaceous earth, is the naturally occurring fossilized remains of single-celled aquatic algae. Its structure provides high porosity and surface area and low bulk density. The absorptive capacity makes it useful as a process aid in high-oil compounds. It is also used as a semi-reinforcing filler, providing hardness, stiffness, and low die swell.

Rubber and Elastomer Applications

Tires

Total shipments of tires in the United States increased more than 10 percent in 2010, according to the Rubber Manufacturers Association (RMA). Total shipments of passenger, light truck and truck and bus tires totaled 317.3 million units last year compared to 288.2 million units in 2009. Production at U.S. plants increased 14 percent in 2010 compared to 2009 with a total of 171.1 million tires produced, according to the RMA. The shortfall between shipments was made up with the importation of 150.4 million tires, an increase of 20 percent.

A 2% growth in tire shipments is forecast for 2011 by the Rubber Manufacturers Association. Analysis by Frost & Sullivan finds that the tire market earned revenues of $3.04 billion in 2009 and estimates revenues to reach $5.29 billion in 2016.

Total light vehicle sales for 2011 are projected to be approximately 13 million vehicles, up from 11.6 million vehicles sold in 2010. Non-RMA imports increased nearly 9 percent in 2010 with another approximate 4 percent increase anticipated for 2011.

Figure 13
UNIT SALES OF TIRES (UNITED STATES)

	2010	2011 forecast
Replacement passenger car tires	200.6 million (+ 5.8%)	203.5 (+ 1.5%)
Original equipment shipments	33.1 million (+ 34%)	36.9 million (+ 12%)
Production of passenger tires	135 million (+ 13.7%)	
Imports of passenger tires	121 million (+20%)	
Light truck replacement tires	28.7 million (+4.4%)	28.7 million (0%)
Original equipment light truck tires	3.6 million (+ 29.6%)	3.6 million (0%)
Light truck tire production	23.9 million (+ 13.2%)	
Light truck tire imports	20.6 million (+ 18.7%)	
Replacement truck and bus tire	15.8 million (+ 22%)	16.6 million (+ 5%)
Original equipment truck and bus tire	3.2 million (+ 31.8%)	4.2 million (+ 30%)
Production of original equipment truck and bus tire	12.3 million (+ 35%)	
Original equipment truck and bus tire imports	8.8 million (+ 31%)	

Source: Rubber Manufacturers Association

New European Union legislation requires that, beginning in 2012, new tires sold in Europe will have to be labeled for fuel efficiency, wet grip and external rolling noise. Auto tire makers in

Japan introduced comparable labeling in 2011, and the United States and South Korea are evaluating similar regulations. Additional German regulations implemented in November now require vehicles to be fitted with winter tires during bad weather, and are boosting buying interest in tires with greater road grip.

A primary ingredient in automobile tires is styrene butadiene rubber (SBR). LANXESS estimates tire treads are about 70% SBR and about 70% of all SBR is used in tires. Styron notes that solution-styrene butadiene rubber (S-SBR) gives high-performance tires an optimum balance of improved wet grip, high abrasion resistance, low road noise, light weight and low rolling resistance, resulting in better fuel efficiency and lower carbon dioxide emissions.

Tire performance profiles are influenced by rubber material choices. Lower rolling resistance and improved wet grip favors materials such as solution styrene butadiene rubber (S-SBR) and silica over emulsion SBR and carbon black. SBR treads tend to have good wear and good wet-traction. Natural rubber treads have low-rolling resistance. Polybutadiene rubber is added to tread compounds to improve wear and sometimes improve rolling resistance. Compounds based on blends of the three polymers can provide a balance of properties by changing polymer ratios to optimize desired properties

LANXESS notes that tire manufacturers are starting to favor neodymium polybutadiene (Nd-PBR) over standard grades of polybutadiene rubber (PBR) such as nickel-PBR and lithium-PBR since it has a higher linearity and molecular weight, contributing to a lower rolling resistance and lower abrasion. Rolling resistance accounts for 20-30% of fuel consumption. A tire tread typically comprises 70% SBR and 30% PBR. Selecting S-SBR as the SBR and Nd-PBR as the PBR would provide good wet grip with a low rolling resistance.

Passenger Tires

Tire performance is a function of materials, tire tread design, and construction. Material selection involves trade-offs in traction, wear, and rolling resistance, properties which can be related to polymer glass transition temperature (Tg). The key to rolling resistance is a property called tan delta, which is the ratio of the energy dissipated during dynamic stretching of a material to the energy released when it relaxes back to its normal position – lower ratios are better. But good wet grip corresponds to a higher ratio at lower temperatures. However, use of silica fillers has helped improve the rolling resistance and wet grip simultaneously, while solution SBR with silica reduced rolling resistance.

Truck Tires

Performance requirements for tires on trucks used to transport goods include: retreadability, fuel economy, tread life, ride, wet traction and handling. The usable life of the tire is affected by the performance of the casing. The properties of the tread compound must balance fuel economy with other performance and service requirements. Tire retreading provides an economical means of extending the utilization of worn tires since a retreaded tire can provide performance similar to that of the new tire at a fraction of the cost and at lower environment impact. Modern Tire Dealer estimates that over 14 million truck tires are retreaded in the United States.

Truck Tread Compounds

Compared to passenger tire treads, truck tread compounds are usually lower in oil and carbon black levels. Retreaded truck tire treads can be based on synthetic or natural rubber. Proper selection of ingredient type and level will optimize specific properties such as tread wear, fuel economy, traction and resistance to cutting, tearing and chipping.

Extender oils

Tires sold in Europe no longer use extender oils based on distillate aromatic extracts (DAE). Two replacement alternatives are treated distillate aromatic extract (TDAE) and mild extraction solvate (MES). However, the availability of such products and the expected global scope of the tread compound change provides a market opening for other replacement materials. The higher viscosity of low-aromatic extender oils can compensate for the lower high aromatic content with some formulation adjustments. High viscosity naphthenic oils, asphaltene-containing oil blends and residual aromatic extracts (RAE) are also been utilized as extender oils.

Tire Market

Modern Tire Dealer reported domestic replacement tire sales broke the $30 billion mark for the first time, finishing at $30.1 billion. In 2009, sales dropped more than $3 billion to $26.8 billion as the recession took its toll. In 2010, pent-up demand and double-digit price increases resulted in record replacement tire sales of $32.1 billion.

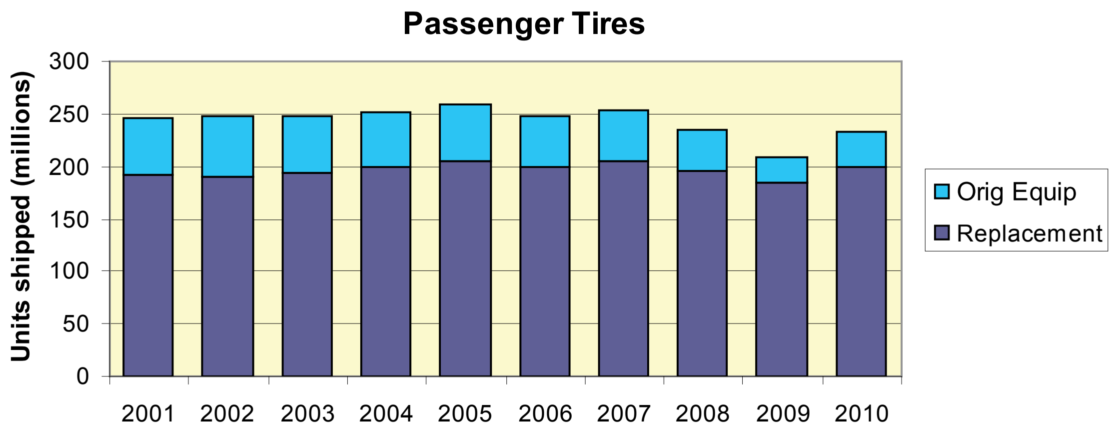
Consumer tires, defined as passenger and light truck tires, represented 81% of total sales, or $26.1 billion. Both passenger ($21.8 billion) and light truck ($4.3 billion) tire sales also set records. Overall tire shipments are expected to rise again in 2011. So are tire prices, reflecting the need to meet rising raw material costs.

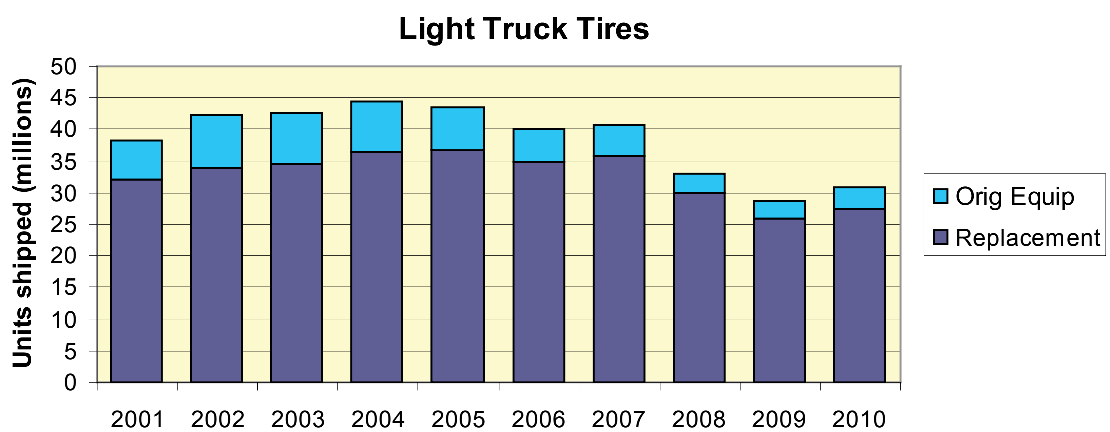
Figure 14
2010 UNITED STATES REPLACEMENT TIRE SALES

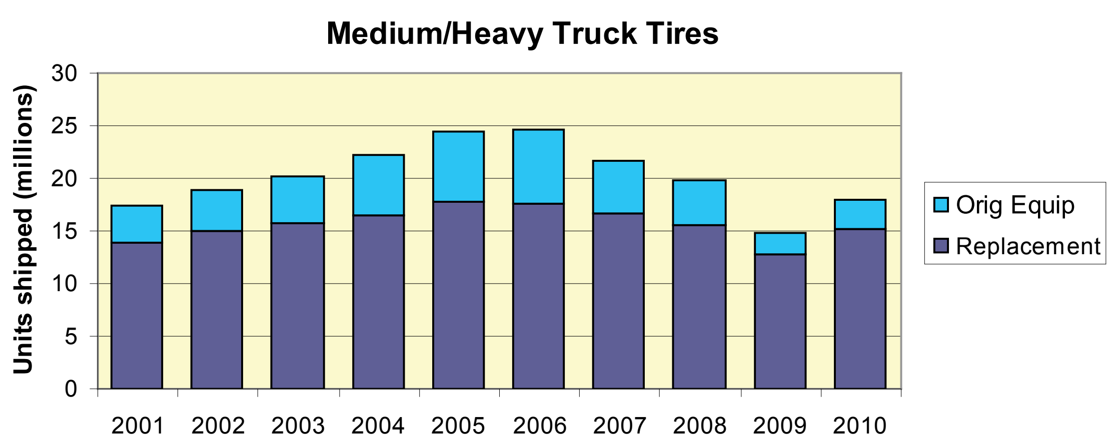
Passenger tires	$ 21.8 billion
Light truck tires	$ 4.3 billion
Truck tires	$ 5.1 billion
Farm tires	$502 million
OTR tires	$401 million

Source: Modern Tire Dealer, January 2011

Figure 15







Source: Modern Tire Dealer, January 2011

Figure 16
NORTH AMERICAN TIRE PLANT CAPACITIES
as of January 1, 2011 (in thousands of units per day)

	Passenger	Light truck	Truck	Others	Total
Bridgestone/Firestone	84.8	21.6	14.2	4.76	125.36
Carlisle Tire & Wheel Co.	0	0	0	41	41
Continental Tire North America Inc.	28	8	4.5	0	40.5
Cooper	73	24	0	0	97
Goodyear	189.8	38.9	18.45	6.15	253.3
GTY (General/Toyo/Yokohama)	0	0	7.3	0	7.3
Michelin	162.5	26.5	7	4.59	200.59
Pirelli Tire North America	1.2	0.5	0	0	1.7
Specialty Tires of America	0	0.4	0	6.2	6.6
Titan Tire Corp.	0	0	0	19.68	19.68
Toyo Tire North America Manufacturing Inc.	6	1	0	0	7
Yokohama/Mohawk	23	1	0	0	24
Grupo Carso/Euzkadi (Continental AG)	15	5	0	0	20
JK Tyre & Industries (formerly CIA Hulera Tornel)	10	5	2	1.04	18.04
Corporacion de Occidente SA de CV	10	7.2	2.8	0	20
U.S. Totals	483	106.3	51.45	77.88	718.63
Canadian Totals	61.3	11.2	0	4.5	77
Mexican Totals	59	21.6	4.8	1.04	86.44
TOTAL	603.3	139.1	56.25	83.42	882.07
2010 vs. 2011	0.6%	2.4%	0.0%	0.3%	0.8%
2009 vs. 2008	-5.4%	-10.7%	0.0%	-2.0%	-5.7%
2008 vs.2007	-3.9%	-4.4%	0.9%	4.0%	-3.7%

Source: Modern Tire Dealer, January 2011

Figure 17

Average Chemistry Value of North American Light Vehicles ($/vehicle)											
	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Rubber Processing Chemicals	18	15	15	14	15	15	16	18	22	23	27
Synthetic Rubber	169	156	169	176	169	185	203	236	274	294	336
Average Materials Content of North American Light Vehicles (lbs/ vehicle)											
Rubber	166	159	166	163	167	169	172	179	188	190	185

Changing Customer Dynamics: Chemistry and Light Vehicles, American Chemistry Council, October 2009

Footwear

Rubber offers advantages over other materials in footwear sole and heel manufacturing, particularly in construction and industrial markets that demand high-performance outsoles. Vulcanized rubber is the preferred material with superior heat resistance compared to a thermoplastic urethane. Since footwear is used in diverse environments, it is often necessary to blend different polymers in order to obtain the unique characteristics of each. Polymer hybrids can combine the heat-resisting qualities of chloroprene with the oil resistance of nitrile rubber to provide the best of both materials in a reliable and lasting product.

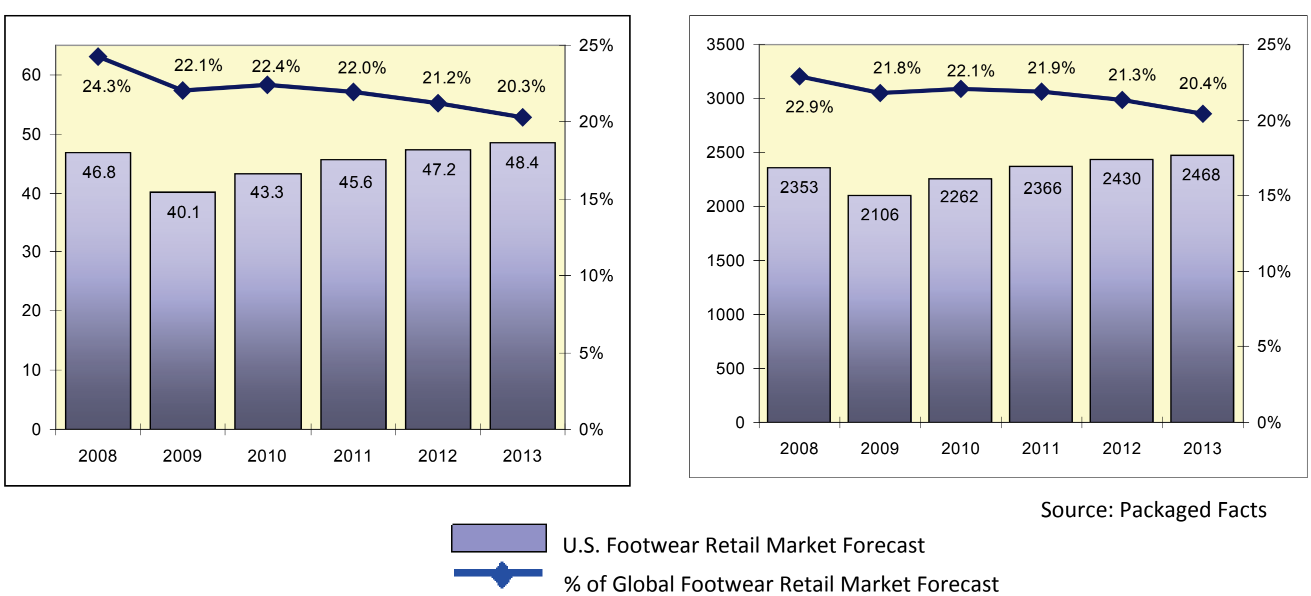
The segments of the footwear industry that use extensive amounts of rubber can be categorized as waterproof footwear that protect the feet from mud and water and fabric upper / rubber soled shoes, typically athletic shoes.

The United States is the world's largest importer of footwear. Many U.S. companies produce a large percentage of their shoes in China, India, and Indonesia, taking advantage of lower labor and material costs.

In the United States, Packaged Facts anticipates slower overall growth and estimates sales of footwear will drop followed by a gain as consumers return to stores. Growth rates are expected to decline to about the three percent mark by 2013 reaching $$48.4 billion.

Figure 18
UNITED STATES FOOTWEAR RETAIL MARKET FORECAST 2008 - 2013

Billion $ Millions of Pairs



Source: Packaged Facts

The North American Industry Classification System (NAICS) 316211, Rubber and Plastics Footwear Manufacturing, covers establishments primarily engaged in manufacturing fabric-upper footwear having rubber or plastic soles vulcanized, injection molded, or cemented to the uppers, as well as rubber and plastics protective footwear. The industry consists primarily of two product categories: (1) waterproof footwear worn over shoes to protect them from inclement weather and (2) rubber soled canvas shoes, sneakers, and sports shoes. Athletic shoes with leather uppers are included in other classifications.

The Shoe and Allied Trades Research Association (SATRA), and its Footwear Technology Centre in England, support the industry's technological development. This group helps to control manufacturing costs and improve quality by evaluating materials and production. It also provides consulting activities and management information systems tailored to the industry. Its members are footwear manufacturers, material and machinery suppliers, repairers, and retailers.

Hose and Belting

Hose and belting products are used in a wide variety of industries and markets such as automobiles, construction, and oil and gas. Transmission belting is used in automobiles, industrial machinery, agricultural and construction equipment, and household appliances. Flat or conveyor belting is found in mining and material handling and food handling and airline luggage conveyor systems. Rubber is the primary material for hoses, except in garden hoses, where plastic takes the majority of the share.

Hose Construction

A hose serves to move material from one place to another. The three basic elements of a hose are the tube, carcass, and cover. The tube is the part of the hose that comes in contact with the fluid and therefore must be resistant to the material. The carcass gives the hose strength to withstand any forces, external or internal, that might be encountered, while the cover protects the product from environmental forces.

Manufacturers and users typically classify hose types by the method of reinforcement. The common hose types include:

Knitted Hose

A knitted hose is a flexible product knitted in an open-loop manner. The garden hose is a typical example of this kind of product and is used at low pressure.

Braided Hose

Braided hose is produced with single or multiple ends of yarn cord or wire woven over the tube to provide strength to the hose. These hose types supply air and water for garden or spray use. They are also used in low-pressure liquid transfer such as hydraulic and steam as well as high-pressure transfer of liquid and gases.

Wrapped Fabric Hose
A wrapped fabric hose is reinforced with an impregnated woven fabric to stiffen hoses used in suction or vacuum applications.

Wire Spiraled Hose
Wire spiraling reduces the twisting effect on hoses are used for high-impulse pressures.

Woven Jacket Hose
Woven jacket hoses are often used as fire hoses. The design allows the hose to lie flat when not transporting water, for more efficient storage.

Hand-Built Hose
Hand-built hoses are large and have high strength and crush resistance. Uses include rotary drill hoses and oil suction and discharge hoses.

Hose use
Hose can also be categorized by working pressure (high, low) and by the nature of the substance conveyed (material handling, automotive).

High-Pressure Hose
High-pressure (several hundred to several thousand psi) are relatively rigid and inflexible and are often reinforced with steel wire or high tensile textiles. Common types of high-pressure hoses are used for steam, mining operations, and hydraulic systems. Materials used in the inner (tube) and outer (cover) components must be formulated to be compatible with the fluid in use and resistant to the external environment. For example, steam hose needs superior heat resistance. Mining hose needs abrasion, chemical, and water resistance. Hydraulic hose tube materials must be resistant to hydraulic fluids and be able to withstand pressure impulses.

Low-Pressure, Small ID Hose
Low-pressure, small, less than one inch, inside diameter hose makes up the bulk of the hose market. This broad category can be grouped by use – fuel, chemical / hydrocarbon, air / water. Fuel dispensing hose includes conventional filling station pump hose and fuel dispensers for aircraft, marine, and farm applications. Chemical / hydrocarbon hoses are used for many applications including such diverse end uses as welding gases, anhydrous ammonia fertilization, hot tar and crude oil transfer, and liquid propane gas delivery. Air / water hose includes garden and agricultural hoses, home appliances hoses (washing machines and dishwashers), and spray / wash-down hoses.

Material-Handling Hose
Material-handling hoses usually have a large inside diameter since they are used to convey materials in bulk by either gravity or suction. Such materials are often abrasive (concrete, cement, sand, and other building materials). Material-handling hoses can also convey chemicals, water, oils and fuels. While the operating pressures of these hoses are usually relatively low, a rigid wire is included to maintain the shape of the hose so it does not collapse when suction is

applied. Materials of construction are selected to withstand wear and abrasion and be compatible with the substances conveyed.

Automotive Hose
A variety of fuels, lubricants, and cooling media are either circulated or transported in the engine compartment. End uses include radiator, air conditioning, heater, oil cooler, hydraulic brake, and power steering. In addition to resistance to the chemical fluid being transported, automotive hoses must be able to withstand high under-the-hood temperatures.

Belting
Power transmission belts, or V-belts, transmit power and motion between V-shaped sheaves. Major applications are in automotive, industrial, agriculture, fractional horsepower, and recreational uses.

Flat belting is used in some limited power transmission applications, but the primary use is conveying. Conveyor belt layers include the carcass, the load-bearing layer made from piles of rubber-coated textile fabric or a single layer of steel cable; the rubber cover, which provides the wear layer; the breaker, for adhesion between the carcass and cover; and the skim coating, to hold the load-bearing plies together. Conveyor belts are used for grocery market check-out, coal mining, and in recycling and waste management programs.

Rubber-Covered Rolls

Rubber-covered rolls are used in many industries, such as graphic arts, paper manufacturing and processing, steel processing, textile and leather processing, and metal coating.

Graphic arts
Rolls are used in letterpress and offset printing presses to break down and convey the ink to the printing plate. These rollers are made of oil-resistant rubbers (typically 20 to 40 Shore A hardness) and are mostly less than 7 inches in diameter. Newer inks based on soy oils and acrylates are gaining market share and require appropriate rubber formulation. Offset lithography rolls primarily use nitrile, PVC/nitrile, urethane, EPDM, and polyamide. Gravure rolls commonly use nitrile, cholorprene (CR), PVC/nitrile, EPDM, urethane and polyalkylene oxide. Flexography rolls use nitrile, PVC/nitrile, EPDM, natural rubber, and urethane.

Converting industry
The converting industry often uses a combination of offset, flexographic, letterpress, and gravure printing in which a variety of drive and transport rollers are used. Rolls are also used for coating, laminating, corona treating, embossing, die cutting, and spreading.

Paper industry

The paper industry uses large diameter rolls. Press rolls squeeze the water out of the newly formed paper web and compact it to the desired thickness. Common cover materials are nitrile, EPDM, Hypalon®(CSM), SBR, chloroprene, natural rubber, and urethane.

Steel mills

Steel mills use rubber-covered rolls in strip-processing lines such as pickling, galvanizing, tin or chrome plating, and cleaning. Rubber coverings provide traction, wringing action between processes, corrosion protection for metal rolls, and reduction in noise levels. Rolls are typically 6 to 35 inches in diameter and 4 to 6 feet long and covered with nitrile, Hypalon, chloroprene, or urethane rubber.

Textile mills

Textile mills use rubber-covered rolls to pull fibers through the yarn-spinning process, in the slashers that apply sizing before weaving, and in the washing process to remove the sizing. Most of the textile processes involve squeezing water or water solutions out of the cloth. Nitrile, Hypalon, and urethane are the most commonly used elastomers.

Metal-coating industry

Metal coating is applied by rubber-covered rolls on continuous coils or on pre-cut sheets. Roll covering must be formulated to resist the solvents in the coatings and cutting by the metal edges. The covers for metal decorating coater rollers are usually urethane or EPDM compounds.

Leather and plastics processing

Rolls are used to convey leather through various operations and are normally made of oil resistant rubbers in the medium hardness range. Rubber-covered rolls provide support in plastics calendering and embossing operations. These rollers may be made from nitrile, Hypalon, silicone, or urethane.

Pulley lagging rollers

Several industries use wheel-like rollers with belts to convey ore, rocks, grain, minerals or other particulate materials. The rolls provide cushioning, metal protection, damping or noise reduction. The rubber compounds are typically SBR, natural rubber, nitrile, or urethane.

Miscellaneous

Specialty rollers include copier rollers; spreaders; high-release, traction or high-tack rollers; controlled electrical conductivity rollers; grooved and crowned rollers; very high-pressure rollers; specialty pulley coverings and waxing rollers. These require unique rubber compounds.

Roofing and Geo Membranes

Membrane roofing is used on flat or nearly flat roofs and are made from synthetic rubber, thermoplastic (PVC or similar material), or modified bitumen. Membrane roofs are most commonly used in commercial application, although they are becoming increasingly more common in residential roofs. Membrane roofing eliminates much of the leakage concern associated with flat roofing systems. Material requirements include water barrier, chemical resistance, flexibility, tensile and tear strength, and weather resistance.

Roofing Membrane Types

Synthetic rubber membrane roofs are made of large, flat pieces of synthetic rubber pieces are welded together at the seams to form one continuous membrane. The finished roof’s thickness is usually between 30 and 60 thousandths of an inch. Thermoplastic membranes are constructed with lap seams that are bonded (melted or dissolved) with heat or solvents. Modified bitumen types are an evolution of asphalt roofing. There are several ways of connecting pieces of this material. In a heat application process, the seams are heated to melt the asphalt together and create a seal. There are also cold-applied adhesive application processes and self-adhesive forms of this system.

EPDM is the dominant type of rubber used in roofing membranes due to its excellent weathering and ozone resistance.

Geomembrane Types

The material characteristics of each type of geomembrane material affect installation procedures, lifespan, and performance. PVC geomembranes are flexible and can conform to uneven surfaces without becoming punctured. EPDM rubber is flexible and has excellent UV and weathering characteristics, but is not suitable for use in long term contact with oils and hydrocarbons. Low density polyethylene is susceptible to UV radiation. High density polyethylene has excellent chemical resistance, but is relatively stiff and is subject to environmental stress cracking and thermal stresses.

Geomembrane uses and typical rubber compounds used include:

Pond liners — EPDM is used for long lasting UV resistance.

Canal liners — for recycling agriculture-use water. EPDM is used for its UV resistance.

Landfill liners — EPDM is used for its resistance to UV and water resistance. Depending on the application, compounding with solvent and oil resistance polymers may be required.

Landfill covers — EPDM is used for its water and soil resistance. Other rubber types are used when oil and solvent resistance are needed.

Wire and Cable Insulation

Electrical wire and cable insulating materials include thermoplastics such as polyethylene and polyvinyl chloride and elastomers such as EPDM, chloroprene, chlorinated polyethylene, ethylene vinyl acetate, chlorosulfonated polyethylene, silicone, and fluoroelastomers. Key performance properties include dielectric strength, dielectric constant, insulation resistance, dielectric loss, and power factor.

Ethylene-propylene elastomers have excellent corona, ozone and heat resistance and superior electrical and low temperature properties (down to -50°C). They can be compounded to get the desired flame resistance. They are widely used in wire and cable applications such as appliance wiring, fixture wires, and motor lead wires.

Nitrile rubber is used for insulation requiring oil resistance properties. A blend of nitrile and PVC improves ozone, abrasion, and weathering resistance. The blend is more flexible than PVC alone because of the rubber.

Polychioroprene has better weathering, oil, flame, ozone and corona resistance than natural rubber and SBR. It is used as a flexible jacketing material in shipboard and mining cables and in the internal wiring of appliances.

Chlorosulfonated polyethylene is used for its toughness, colorability, and good electrical properties. Applications include control cables, appliance wires, power cables, locomotive and military cables, mining cables, nuclear power station wiring. Chlorinated polyethylene insulation is used in welding cables, locomotive cables, military wires, heating and power cords, and appliance cord jacket.

Opportunities for Soy Products in Rubber Compounds

Initiatives by companies in the rubber industry, by university research groups, and with research sponsored by the United Soybean Board New Uses Committee, have generated considerable potential for a new market segment of soy products in rubber and elastomer compounds.

Some of the research has discovered novel compositions, new methods, and performance improvements. A listing of patents and patent applications relating to the use of soy products in rubber compounds is included in the Resources section of this study.

Recent work on the use of soybean and other vegetable oils suggests that soy oil can be used as a partial or complete substitute for petroleum-based process oil in rubber compounds. Other studies have found defatted soy flour to be an effective reinforcing filler in rubber.

Soy-based oils offer a range of chemical properties and compatibility with different types of elastomers used in tire tread applications. One study evaluated the effect of replacing part of the aromatic oil with a variety of different soy and alternative plant oil chemistries in low rolling resistance tread compounds. Results show that, as with petroleum based oils, several trade-offs exist in using new oils in tire tread compounds. Degummed soy oil exhibited many of the key physical properties and performance predictors as the aromatic control samples, with some loss in ice and wet traction. Vulcanized soybean oil and linseed oil were also identified as two promising oil sources based upon the performance predictors and physical properties. Compounds using these oils showed improvement in rolling resistance predictors based upon dynamic mechanical analyses, while other bio-oils maintained fuel economy compared to the control. The use of these oils could be further optimized by adjusting the formulation to maintain durometer levels and alkalinity similar to the aromatic oil control compound.

These results indicated that replacing a portion of the petroleum processing oil in silica-filled tire tread formulations can provide many desirable processing, physical and performance properties. This supports the potential for rubber formulations in applications beyond the tire market, including footwear, belts and hoses, conveyer belts and other consumer and industrial molded rubber goods.

United Soybean Board Sponsored Projects

The United Soybean Board (USB), through soybean checkoff investments, is committed to funding the research, development and commercialization of new industrial uses for soybeans. The USB is supporting advancements in soy-based research and technology for the rubber industry.

Figure 19
RECENT, CURRENT, AND PROPOSED USB SOY IN RUBBER AND ELASTOMERS PROJECTS

USB Project	Organization	Description
7425	Ford Motor Company	Use of Soy Meal as Filler in Various Polymer Matrices for Automotive Applications
8425	Ford Motor Company	Use of Soy Meal as Filler in Plastics for Automotive Applications
9425	Ford Motor Company	Soy Flakes and Soy Oil in Automotive Thermoplastic Applications
0425	Ford Motor Company	Soy Oils and Polyols in High Performance Elastomeric Compounds
1419	Goodyear	Soybean Oil as a Replacement for Petroleum Derived Oils in Oil in Extended Rubber
1496	University of Michigan	Mechanical Behavior of Soy-Based Plastics and Rubber
2413	Pittsburg State University	Development of Applications for Polymerized Soybean Oils
Proposed	Akron Rubber Development Laboratory	Chemical Bounding of Free Sulfur in Soybean Vulcanized Vegetable Oil Compound

Research and Development - Process Oil

Replacement of Paraffinic Oil with Soy Oils in EPDM Formulations (Ford)
This study was conducted to increase the bio-content in rubber formulations while maintaining properties. Formulations were modified to replace one third of paraffinic oil with soy oil and soy polyol (hydroxyl numbers OH#50, OH#167, and OH#347) blends.

It was found that partial replacement of petroleum oil with soy oil or soy polyol provides improvement in rubber elongation. The amount of soy processing oil in the formulation was limited as 100% replacement caused the rubber to crumble. The ability to tailor rubber properties based on selection of soy oil type (hydroxyl number) was demonstrated.

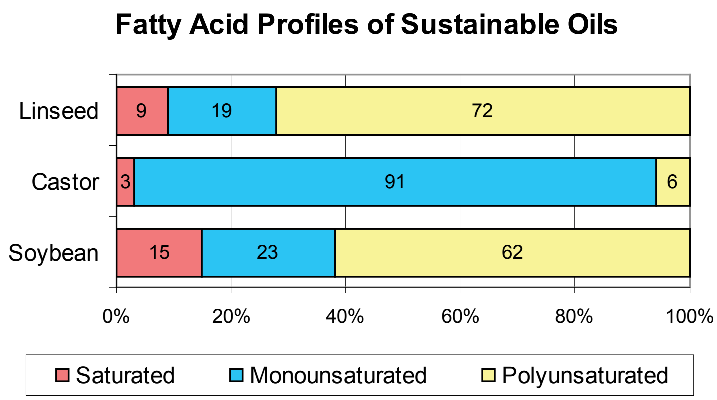
Evaluation of Sustainable Oils in Tire Tread Compounds (Ford)
In one trial, a variety of soy oils, at different loading levels, were evaluated as replacements of aromatic processing oil. The trial included:

- Naphthenic Oil Control
- 30% Low Sat Soybean Oil
- 50% Low Sat Soybean Oil
- 100% Low Sat Soybean Oil

Results showed 30 wt % soy oil was preferred for its performance in rolling resistance predictor, modulus, and processing parameters.

In another trial, soy oils were compared to other sustainable oils as a replacement of petroleum processing oil. Unsaturation provides bonding opportunities with the rubber. Different bio-oils have various distributions of saturation and unsaturation as shown below.

Figure 20



Findings may be summarized as:

- Compounds with lower viscosity typically compound more easily through the tread extruder.
- Linseed, orange and vulcanized vegetable oil (VVO) showed higher viscosity levels than the control.
- Linseed oil increased hardness by 9 points and VVO showed slight increase, which may be due to crosslinking between unsaturation sites on triglyceride chains.
- Castor oil exhibited blooming which is an undesirable effect of using this oil.
- Degummed soy oil and tall oil showed favorable elongation at break.
- Linseed oil had substantial decrease and VVO had a slight decrease in elongation.
- In heat aging tests (504 hours at 70°C) degummed soy oil, tall oil, and castor oil showed the best retention of physical properties.
- A low tan delta value at 60°C is desirable as predictor for rolling resistance. Linseed and VVO have lower tan delta values and soy, tall, castor, and orange oil compounds have similar values as aromatic control.
- Rolling resistance and wet traction predictors are subject to trade-offs and optimization. Orange oil showed similar performance predictors as the aromatic control. Linseed and VVO exhibited promising results for rolling resistance and wet traction.
- Tire performance predictors (dynamic mechanical analysis tension) are also subject to trade-offs and optimization. Trade-offs were noted between several of the key tire performance predictors for the bio-oil compounds. Degummed soy oil and vulcanized soy oil were blended to optimize properties. Predictors for fuel economy, dry handling, and winter traction indicate the soy oil blend is preferred over petroleum control compounds.

Conclusions from the study are:

- Soy based oils provide a potential raw material for rubber compounds
- Several trade-offs exist when using new oils in tire tread compounds
- Degummed soy oil compounds exhibited many similar physical properties to compounds using aromatic control and orange oil
- Degummed soy oil and VVO (soy-based) were identified as promising alternatives to petroleum oils
- Studies using soy oil varieties in rubber compounds are recommended

Research and Development – Fillers

In order to have useful properties, rubbers must be reinforced with small filler particles to make a composite material. Petroleum-based carbon black is a typical filler. Resulting properties depend on the degree of dispersion of the filler particles and their characteristic properties (e.g., particle size, surface area, aggregate structure, and surface activity) and on rubber–filler interactions.

Soybeans can be used as a filler in rubber compounds. Soybeans can be processed into soybean oil and defatted soy flour (DSF). DSF can be further processed into soy protein isolate (SPI), soy protein concentrate (SPC), and soy spent flakes (SSF). SSF contains about 15% protein and insoluble carbohydrate. These defatted soy products can be used as fillers to reinforce composites. Soy flake, after the hulls and oil are removed, can be crushed into defatted soy meal. One source of soy meal is as a byproduct of the soy-based biodiesel industry. It is inexpensive and is usually used as animal feed. The soy meal can be ground into soy flour (SF) that contains about 50% protein content. The soy flour can be converted to soy protein concentrate (SPC), which contains about 60–70% protein and insoluble carbohydrate, by removing most of the water-soluble components. After sugar and other water-soluble materials as well as fiber have been removed, the defatted soy flour contains soy protein, soy carbohydrate, and soy whey. DSF is an abundant renewable commodity and can be processed into soy protein isolate that contains about 90% protein. Structurally, SPI is a globular protein and its aggregates in water consist of sphere-like protein particles.

Dry soy protein and carbohydrates are rigid and can form strong filler networks through hydrogen-bonding and ionic interactions. They are also capable of interacting with polymers that possess ionic- and hydrogen-bonding groups. Through filler-filler and filler-rubber interactions, the rubber modulus is significantly increased. SPC shows a greater reinforcement effect in rubber composites than high protein SPI or high carbohydrate SSF. This indicates a certain combination of soy carbohydrate and soy protein yields the greatest reinforcement effect in the composites[1].

Study on Rubber Compounding with Soy Meal and Soy Polyols (Ford)

Using a commercial EPDM formulation, carbon black, soy meal, soy flour, and blends of soy filler / carbon black fillers were tested at loading levels from 0 to 50%. The effect of compounding and molding processing methods was investigated and physical performance factors were evaluated.

In replacing 10% carbon black filler with soy flour in a commercial EPDM formulation, all specification properties (tensile strength, elongation, modulus, tear, durometer, density) were met except low temperature (3 min.@ -40°F) brittleness.

Prototype parts, including a HVAC mounting plate, were molded with the 10% soy flour filled compound. The molding evaluation found excellent part appearance, good texture, excellent overflow tear, and no odor concern. Lowering the tool temperature did improve part appearance and properties.

Future work is planned to adjust EPDM base polymers (ethylene content, MW) for target performance and to optimize processing methods for using soy fillers including cure accelerators, compounding methods, and molding parameters (temperature, time).[2]

Thermoplastics and Rubber Modified Plastics (Ford)

In a study of soy fillers in rubber modified plastics, it was found that

- Use of 10% soy filler loading level is preferred
- Soy hulls provide another promising filler in addition to soy flour and soy meal
- Processing issues were encountered using soy fillers in TPE compression molded parts
  - Polymer crumbled and could not sheet out through rollers
  - Reformulating base polymer system to improve rubber
- There was noticeable odor with injection molded samples but not for compression molded samples
- Acceptable properties were demonstrated for most material systems
- Prototype parts were successfully molded with 10% soy flour, including HVAC mounting plate

These studies point to potentially more opportunities for soy fillers in a variety of plastic matrices such as rigid polyurethane foam, natural rubber, EPDM, polypropylene, and TPO (thermoplastic polyolefin).

Potential automotive applications for soy fillers include:

- Cowl plugs and fender stuffers (PVC, TEO)
- Cargo mats, underbody components, shields, air seals, consoles (TPE, EPDM)
- Interior trim, mounting plate (TPO, TEO)

Flour – Styrene-Butadiene

Research indicates a partial substitution of carbon black with DSF results in higher strength and reduced filler cost. A 30% DSF reinforced composite exhibited 230 fold increase in shear elastic modulus compared with unfilled SB rubber, showing a significant reinforcement effect by DSF. Mixtures of DSF and CB at different ratios showed a greater elastic modulus than the carbon black reinforced composites within the strain range measured. [3]

In another study, soy carbohydrate increased the tensile stress in the small strain region, but reduced the elongation at break. Soy carbohydrate and soy whey also improved the recovery behavior in the non-linear region. At small strain, the shear elastic modulus of 30% filled composites at 140 °C was about 500 times higher than that of the unfilled elastomer, indicating a significant reinforcement effect generated by DSF. Compared with soy protein isolate, the stress softening effect and recovery behavior under dynamic strain indicate the addition of soy carbohydrate and soy whey may have increased the filler-rubber interaction. In general, the DSF composites gave better mechanical properties compared with the protein composites and is a more cost effective option in terms of both mechanical properties and cost.[4]

Protein – Styrene-Butadiene

The aggregate size of filler has a significant effect on rubber modulus. Elasticity is increased when the aggregate size of soy protein is reduced. In one study, nanocomposites formed by mixing hydrolyzed SPI (HSPI) nanoparticle aggregates with styrene-butadiene latex showed significantly higher loss modulus compared to the unfilled SB rubber. Compared to SPI, the glass transition temperatures and dynamic mechanical analysis indicate that HSPI has a stronger filler-polymer interaction and is more homogeneous in its polymer immobilization effect.[5]

The modification of SPI by phtalic anhydride increases the number of carboxylic acid functional groups on the protein surface and therefore the amount of its anionic charges. Tensile strength, elongation, Young's modulus, and toughness of hydrolyzed/modified soy composites are comparable to those of carbon black reinforced composites at 10-15% filler fraction.[6,7]

Nanocomposites can be formed by mixing hydrolyzed soy protein isolate (HSPI) nanoparticle aggregates with styrene-butadiene (SB) latex, followed by freeze-drying and compression molding. Compared with unreinforced SB matrix, SPI/SB nanocomposites exhibited a significant increase in their shear elastic modulus. Nano-sized SPI particles increased the elasticity of nanocomposites by forming a more flexible particle-matrix network.[8]

Elastomers filled with soy protein showed a substantial reinforcement effect when compared with unfilled elastomers. Approximately 400 times the increase in shear elastic modulus was observed when 40% by weight of protein is incorporated into the elastomers. At the higher temperatures, the shear elastic modulus of soy protein filled composites does not decrease as much as that of the carbon black filled composites. The behavior of elastic and loss modulus is similar to that of carbon black reinforced styrene-butadiene rubber. However, carbon black composites show a better recovery behavior after eight cycles of dynamic strain.[9]

While soy products (protein isolate, defatted flour, protein concentrate, and spent flakes) all show reinforcement effects, the different protein / carbohydrate ratios provide different reinforcement effects. In one study, it was found that soy filler with higher protein content had higher moduli than the composites with higher carbohydrate content. Soy carbohydrate also appeared to have ability to immobilize polymer chains compared to soy protein. Overall, the study concluded that soy fillers with higher protein / carbohydrate ratio have potential to be used as rubber reinforcement.[10]

Flour – Natural Rubber
Mixtures of DSF and carbon black can be used as reinforcing fillers in natural rubber composites. In one study, a 40% co-filler reinforced composite with 1:1 ratio of DSF to carbon black exhibited a 60-fold increase in the shear elastic modulus compared with unfilled natural rubber. This effect, however, is lower than the carboxylated styrene-butadiene rubber composites reported in other studies, indicating a significant effect of rubber matrix. The co-filler composites have elastic moduli between those of DSF and carbon black reinforced composites. The recovery experiments indicated the co-filler composites with a higher carbon black content have a better recovery behavior.[11]

Soy Meal – Natural Rubber
Soy protein is hydrophilic while rubber polymers are hydrophobic, leading to incompatibility. Research has found that calcium sulfate dihydrate acts as a safe, inexpensive physical cross-linker for soy protein to improve the properties of the soy meal and natural rubber blends. Compared with the neat soy meal, hydrophobic natural rubber improved the water resistance of the blends. The morphology showed that the natural rubber component was well embedded in the soy meal matrix, indicating the presence of interaction between the rubber and the soy meal.[12]

Soy Flakes – Styrene-Butadiene
Soy spent flakes (SSF) is a plentiful, renewable material from the waste stream of commercial soy protein extraction and has little commercial value. SSF contains mostly soy carbohydrate. Earlier studies found that the elastic moduli of SSF reinforced rubber composites are greater than that of carbon black reinforced composites, but the SSF reinforced composites have lower recovery behaviors. In recent research, a mixture of SSF and carbon black showed that the substitution of carbon black with 50% to 75% of SSF yields a greater elastic modulus than that of the carbon black composites; and the co-filler composites have recovery behaviors similar to that of the carbon black composites.[13]

Vulcanized Soybean Oil

There are plentiful supplies of vegetable oils available with appropriate unsaturation for conversion to factice, but cost, geography, and efficiency considerations make soybean, rapeseed, sunflower seed, castor, and safflower seed oils the best candidates. The dominant oils used today are soybean and rapeseed.

Meadowfoam and rapeseed oils produce high-quality brown factice. While soybean oil produces a lower quality factice, it has been shown that a one-to-one mixture of soybean and meadowfoam or rapeseed oil produces a factice that has similar physical characteristics to factice produced from 100% meadowfoam or rapeseed oils. In addition, meadowfoam oil and rapeseed oil act as accelerators when mixed with castor or jojoba oils. White factice productions from soybean oil can also be improved when mixed with meadowfoam or rapeseed oils. The difference in cost, obtained by using as much as 50% soybean oil instead of the higher-costing oil, represent significant savings in rubber compounds[14].

An industry expert provided the general formulation guideline that two parts plasticizer can be replaced with one part VVO. Passenger and commercial tires may use 10 - 20 phr or less while racing tires may use up to 200 phr of VVO. Molded parts could use 5 phr or less. Roll compounds using about 40 phr provide a soft compound that will maintain its hardness over time. Brown VVO 700 improves chemical resistance to nitrile rubber compounds. Industry bulletins provide recommended usage levels for factice by rubber type and process.

Figure 21
RECOMMENDED USAGE LEVELS FOR FACTICE BY RUBBER TYPE AND PROCESS

Rubber / Process	Extruded	Calendered	Molded
NR, IR, SBR	15-30 phr	15-25 phr	10-20 phr
ACM	5-10		5-10
CR, NBR	10-20	10-15	10-15
CSM	10	10	5-10
ECO	5-10		3-50
EPDM, IIR	10-20	10-15	3-10
Peroxide cured	5-15		5-10

D.O.G. Product Range bulletin

Figure 22
COMMERCIAL GRADES OF VULCANIZED SOYBEAN OIL

Product	Grade	Description
31-B	White	Soybean oil, chlorosulfurized, magnesium salt
74 Brown	Brown Coarse	Soybean oil, sulfurized
74 Brown	Brown Cake	Soybean oil, sulfurized
Akrofax A	Milled crumb/cake	Soybean oil
Akrofax A Soft	Milled crumb/cake	Soybean oil
Car-Bel Ex 20	Brown-Cake	Soybean oil, sulfurized
Neophax A Regular	Brown-Cake	Soybean oil, sulfurized
Neophax A Regular	Brown-Cake, Screened	Soybean oil, sulfurized
Neophax A Regular	Brown Coarse	Soybean oil, sulfurized
Neophax A Regular	Brown Coarse, Screened	Soybean oil, sulfurized
Special French 32	White	Soybean oil, chlorosulfurized, magnesium salt

Figure 23
STARTING POINT COMPOUNDS (RUBBER AND VVO ONLY) FROM
THE VANDERBILT RUBBER HANDBOOK

Natural rubber extrusion compounds		*SBR extrusion compounds*	
SMR-5	100 phr	SBR 1502	100 phr
Neophax A	30	Neophax A	25
Total	226.45	Total	234.6
Neoprene extrusion compounds		*Dual Durometer EPDM Automotive Extrusion Compounds (Dense) for Microwave/ Hot Air Curing*	
Neoprene TW	100 phr	Royalene 547	100 phr
Neophax A	35	Brown Fractice	15
Total	225.5	Total	409.3
Xtra-Firm EPDM Sponge		*Super-soft Closed Cell EPDM Extruded Sponge Compound for Microwave/ Hot Air Curing*	
Vistalon 3666B	100 phr	Royalene 694	175 phr
Brown Fractice	10	Brown Fractice	2
Total	307.95	Total	456.2

Application Development

Ford scientists have recently engineered a new rubber using renewable soy oil to be capable of replacing 25% of the petroleum-based oil usually used in the manufacturing of automotive components. The new formula will reduce the material's environmental impact and improve its stretchability by two-fold. The new material may find use in floor mats, cup-holder inserts, air baffles and radiator deflector shields.

In other work at Ford, it was found that soy fillers could provide an inexpensive and environmentally friendly partial replacement of carbon black, the petroleum-based material traditionally used to reinforce rubber. Used together, soy oil and soy fillers could replace up to 26% of the petroleum-based content in automotive rubber applications.

In a joint development, Ford and Recycled Polymeric Materials have combined recycled tires with bio-renewable content to make environmentally friendly seals and gaskets for Ford Motor Company vehicles. The gaskets and seals are derived from 25 percent post-consumer particulate from recycled tires and 17 percent bio-renewable content from soy. In total, more than 2.2 million pounds of rubber from recycled tires has been made into RPM seals and gaskets and more than 210,000 used tires have been recycled. Additionally, 150,000 pounds of soy has been used to create the materials. The green gaskets and seals are used on eleven 2011 model-year vehicles, including the F-150, Escape, Mustang, Focus and Fiesta. In addition, the seals also offer a weight savings, with more than 1,675 tons of weight removed from Ford vehicles on the road.

[1] Jong, L. 2011. Reinforcement Effect of Soy Protein/Carbohydrate Ratio in Styrene-butadiene Polymer. *Journal of Elastomers and Plastics*. v. 43(1):99-117

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Issue Analysis

High Aromatic Hydrocarbons

A recent challenge for rubber and tire producers is the replacement of extender oils, which contain polycyclic aromatic components (PAC), with environmental friendly oils. The primary oil used has traditionally been Distillate Aromatic Extracts (DAE) due to its solvency and ability to vulcanize rubber. DAE, however, is suspected to have carcinogenic effects. The European Union has mandated in Directive 2005/69/EC that only oils with low levels of Poly Aromatic Hydrocarbons (PAH) be allowed in tires manufactured or imported into the EU starting in 2010.

Appropriate alternative process oils, which comply with the upcoming directives, are TDAE (Treated Distillate Aromatic Extract), MES (Mild Extraction Solvate) or TRAE (Treated Residual Aromatic Extract). The chemistry of these products is close to the polymers used in tires so acceptable mechanical and physical compound performance can be achieved. The dynamic performance of a compound extended with a high-aromatic oil, however, is more difficult to match. A one-for-one replacement of the high-aromatic oils with the new types usually changes the dynamic properties. Highly refined naphthenic oils are one of the best alternatives when it comes to compatibility with the common polymers. Extensive research is needed to make sure that the rubber compounds meet the high requirements for tires in rolling resistance, abrasion, wet grip, shelf life and quality of the tires.

Tires are produced by using extender oils that may contain various levels of polycyclic aromatic hydrocarbons that are not added intentionally. During the production process PAHs can be incorporated into the rubber matrix and can be present in various amounts in the final product. Benzo(a)pyrene (BaP) can be a qualitative and quantitative marker for the presence of PAHs. BaP and other PAHs have been classified as carcinogenic, mutagenic and toxic to reproduction. In addition, due to the presence of these PAHs, several extender oils as such have been classified as carcinogenic, mutagenic and toxic to reproduction.

Directive 2005/69/EC provides that extender oils may not be placed on the market and used for the production of tires or parts of tires, if they contain more than 1 mg/kg BaP, or more than 10 mg/kg of the sum of all listed PAHs. These limits are regarded as kept, if the polycyclic aromatics extract is less than 3 % by mass, as measured by the Institute of Petroleum standard IP346: 1998 (Determination of PCA in unused lubricating base oils and asphaltene free petroleum fractions — Dimethyl sulphoxide extraction refractive index method), provided that compliance with the limit values of BaP and of the listed PAHs, as well as the correlation of the measured values with the PCA extract, is controlled by the manufacturer or importer every six months or after each major operational change, whichever is earlier.

Sustainability

The political, economic, social, and technology trends supporting environmental awareness and sustainability are well established. Several recent news articles provide relevant evidence that the use of soy products in rubber compounds would be supported.

Breakthrough Technology: Orange Oil-Infused Tire
Yokohama Tire Corporation developed a technology combining orange oil with natural rubber as part of their overall global environmental strategy. It is now used in race tires and passenger car tires and claims improved fuel efficiency with a 20 percent reduction in rolling resistance. During active cornering and braking, the orange oil generates heat more quickly for better traction than other low rolling-resistance tires according to Yokohama. The company claims better traction and tread life compared to conventional low rolling-resistance tires.
Source: Yokohama, 2009

Ford, Ohio State Look to Put Dandelion Roots to Use in Cupholders, Floor Mats and Interior Trim
Ford and The Ohio State University are looking at dandelions in a new way by researching their potential use as a sustainable resource for rubber. A milky-white substance that seeps from dandelion roots is used to produce the sustainable rubber.
Source: Ford Motor Company - May 10, 2011

New Nokian WR Winter Tyres – Forget the Forecast
The new tyres' tread rubber compound, the Cryogenic Canola Compound, is a novel combination of natural rubber, silica and canola oil that optimizes winter grip, wet grip, and wear resistance in varying temperatures. The new kind of full-silica compound contains so-called Cryo silane, which enhances the functionality of the rubber mix. Canola oil provides higher resistance to tear and improves ice and snow grip. The high silica content enables very low rolling resistance, lower fuel consumption and fewer harmful emissions compared with the traditional competitors.
Source: Nokian Tyres - February 16, 2011

Farmers Find New Market for Sunflowers in the Tire Industry
The recently launched MICHELIN® Primacy™ MXM4® luxury passenger tire incorporates one of the four primary types of sunflower oil – oleic – into its formulation to create the unique rubber compound that delivers its performance. Sunflower oil, used in the patented MICHELIN® Helio Compound™ technology, allows the new performance tire to maintain its edge in wet and snowy weather while still delivering safety, all-weather handling, ride quality and comfort that consumers demand.
Source: Michelin North America - January 24, 2011

Momentum builds for the development of bio-based chemicals for rubber manufacture
Development of renewable-based chemicals for rubber manufacture is expanding amid rising prices for petroleum-based rubber chemicals.
Source: *ICIS Chemical Business*, July 29, 2011
http://www.icis.com/v2/magazine/Issue.aspx?Volume=280&Issue=3

Bioplastics and Bio-based Additives are Gaining Momentum
SpecialChem analyzed the number of published documents in their Bioplastics Formulation and Bio-based Solutions Channels. Documents included industry news, articles, R&D highlights, community insights, and e-training courses. The average number of new documents published per month for each quarter of 2010 showed an increasing trend. 1Q-2010 (16 documents published per month), 2Q-2010 (20 documents), 3Q-2010 (21 documents), 4Q-2010 (22 documents).
SpecialChem - Feb 1, 2011
http://www.specialchem4polymers.com/community-pulse/community-insight.aspx?id=5623

Ecolibrium Bio-Based Rubber Wall Base
Johnsonite's Ecolibrium Bio-Based Rubber Wall Base is manufactured with a new compound that includes 5.21 percent rapidly renewable materials (pine rosin, walnut shell and vegetable oil); 5.1 percent oyster shells; and 2.21 percent pre-consumer recycled materials as a by-product of the walnut industry in de-shelling.
Source: *Floor Covering Weekly,* April 4-11, 2011

Bio Based Rubber Tires Coming Down the Road
Genencor has engineered bacteria to efficiently convert sugars to isoprene and integrate fermentation and recovery processes to create a new route to make this important ingredient used to make synthetic rubber. Goodyear and other large tire manufacturers use isoprene to produce synthetic rubber for use in tires to supplement use of natural rubber. Nokian Tyres is the world's first tire manufacturer to have fully eliminated high-aromatic (HA) oils in its production.
Source: http://biomassenergyjournal.com/bio-rubber-tires/ March 26, 2010

Volatility and Uncertainty
Numerous issues are delaying a return to business as usual. By far the most serious are the high costs of raw materials and energy (more than 80% of respondents expressed concerns over this issue) and the volatility in energy and feedstock markets. This was viewed as the single most important factor contributing to the volatility and uncertainty in the chemical industry today, followed by consolidation among suppliers, overcapacity in emerging markets and regulatory changes.
Sources: Paul B. Jacek, Global Research Lead, Chemicals, Accenture
ICIS Chemical Business July 18-31, 2011
http://www.icis.com/Assets/GetAsset.aspx?ItemId=29104

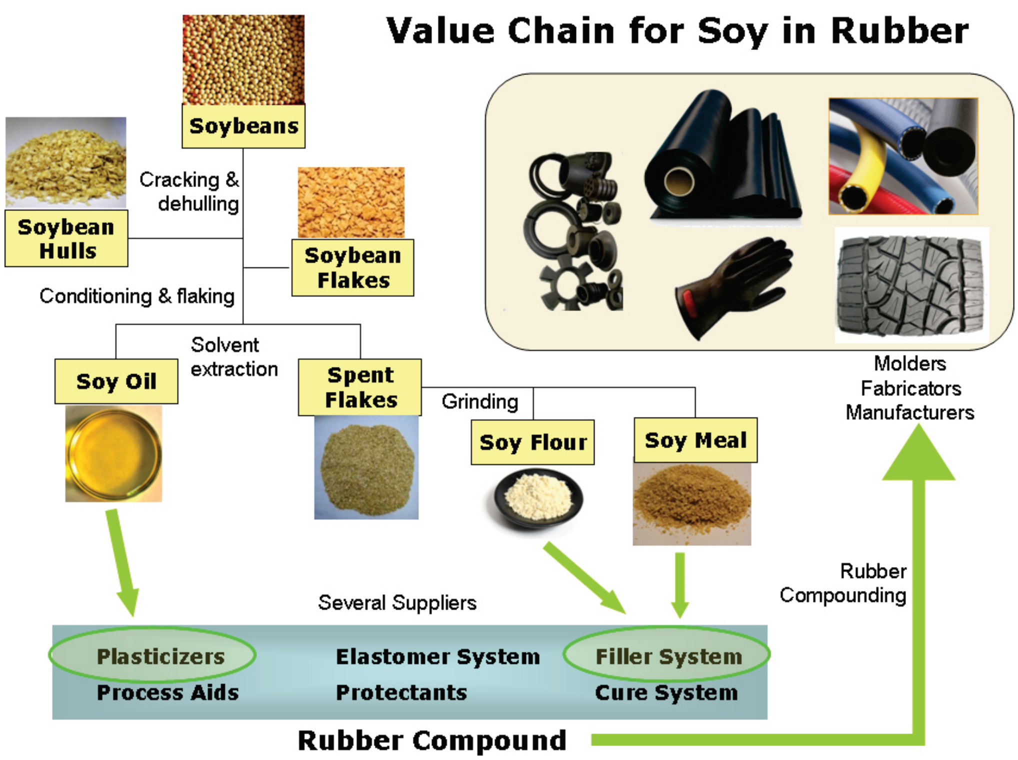
Commercialization Next Steps

Value Chain for Soy in Rubber

The soybean value chain from the field to a molded or extruded rubber part passes through several manufacturing processes, physical forms, suppliers, compounders, and fabricators. Rubber compounds are a multi-ingredient formulation and soy has potential use in oil, flake, flour, and meal forms.

To navigate opportunities along the value chain, additional formulation development and product testing will be required to improve materials to meet current requirements. By targeting specific applications, specific goals can be set for performance and processing. This will certainly involve collaboration with current and new members of the supply chain. While there are risks in implementing new technology, a disciplined approach to reducing uncertainty of critical issues before making significant investments in commercialization will increase the probability of success. With increasing volume, costs are typically reduced and the new technology becomes more widely adopted.

Figure 24



Product and Market Development Strategies for Soy Products in Rubber Compounds

In defining the market opportunities for soy products (oil, modified oil, flour, meal) in rubber compounds, Omni Tech International, Ltd. interviewed several people with extensive experience in the rubber industry and with developing rubber compounds. Considering the relatively early stage of development in the use of soy products in rubber compounds, discussions focused on defining the next steps for soy product suppliers and rubber compound developers to further develop and validate the technology for widespread commercial use.

Information a rubber compounder or rubber parts producer would want to know before considering the use of soy products in rubber compounds:

1. Information comparing the experimental compound containing soy oil and/or flour utilizing state-of-the-art formulation which is typical of the application.
2. Evaluate the effect of soy oil as plasticizer on mechanical properties such as hardness, stress-strain relationships, elastic recovery after deformation under tension or compression, resistance to aging in heat, oxidation, UV or weathering environs, chemical stability or compatibility, other special features depending on the end-use; from a manufacturing perspective, processing issues include mixing the compound, rheological and flow behavior, adaptability to shaping equipment, vulcanization and cure performance
3. Effect of flour as filler on its reinforcement capacity and dispersion in rubber, processing and mechanical properties as outlined above.
4. For small scale, there are established and certified laboratories that perform both compounding and testing to compare experimental ingredients, i.e., soy products versus the materials being replaced. The importance of having comparative data evaluations before proceeding with larger scale trial should be emphasized.
5. Larger scale feasibility studies could be pursued through a custom compounding facility to generate material for part fabrication trials. Molding and extrusion trials to demonstrate and evaluate the experimental compounds are an important next step. Develop a plan of work in collaboration with the custom compounder and the tier-one end-use fabricator.
6. It is useful to show side-by-side comparisons (performance properties and economics) of soy filler (carbohydrate and protein) versus commercial control formulations (talc, clay, carbon black, silica).
7. Other considerations:
    a) What is the anticipated cost of soy products and long term availability of supply? If priced higher than typical hydrocarbon process oils, is there some benefit or value added to offset higher price of soy?
    b) Rubber factory process operations encompass a broad range of materials handling equipment including silos for fillers, weighing capability, tanks and pumps for metering fluids, ingredient storage often in broad ambient temperatures, i.e., cold winter, hot summer.

c) Consider the microbial influence in compounds containing natural/vegetable products. Polymers, including elastomers, are generally thought to be immune from microbial contamination. However, microorganisms can obtain suitable nutrients from decayed organic matter and dirt. Rubber compounds may be particularly vulnerable to microbial contamination due the presence of various ingredients in the formulation. Plasticizers, hydrocarbon oils, processing aids, and stearates provide an ideal source for microbial proliferation.

How would a rubber compounder or rubber parts producer go about testing /qualifying a modified rubber compound?

The initial approach is to select one or two EPDM applications to evaluate soy products using testing methods and qualification as outlined above. ASTM and ISO standards should be followed to assess properties of both the compound as well as the end-use product.

Define an appropriate industry application based on market volume, technical need, and government regulatory issues; demonstrate or emphasize "go green" concept. Screening in industrial hose and/or roof sheeting compounds where the respective formulations contain quantities of plasticizer and inorganic filler is suggested as the initial approach. Generate compound data via laboratory scale mixing and testing trials.

Where should soy solid products find the best fit in rubber compounds as fillers?

Key properties of fillers for rubber compounds are particle size, particle surface area, particle surface activity and particle shape. Reinforcement is characterized by particle size:

- Fully reinforcing (0.01 to 0.1 micrometer)
- Semi-reinforcing (0.1 to 1 micrometer)
- Diluent or extending (1 to 10 micrometers)

Larger filler particles (> 10 micrometers) introduce areas of localized stress which contribute to elastomer polymer chain rupture on flexing or stretching. The inherent characteristics of soy products should largely determine their utility in rubber compounds.

What non-mechanical property issues might be considered in using soybean oil?

Key properties of soy oil that will be considered in compound processing are viscosity, volatility, and pour point. Other considerations include: can the fluid be pumped, does the hot batch smoke when dumped from the mixer, and will the oil bleed in cold climate?

What are the most likely / least likely applications for using soy products?

EPDM rubber compounds could be a viable market for soy products because they contain significant quantities of paraffinic process oils (typically 18-25% by weight). Other hydrocarbon elastomers such as SBR, polyisoprene, butyl are possibilities. More polar polymers such as NBR, neoprene, acrylate, epichlorohydrin and others may show tendency for incompatibility with soy oil.

What is the market opening for soybean derivatives as ingredients in rubber compounds and how might a soybean supplier approach the market?

Within the rubber enterprise, technologists become interested when there are cost and/or performance benefits. Regulatory issues associated with work-place health and safety might induce interest in exploring natural oils as well as the ban on high polyaromatic process oils in Europe for tires. Tight supplies of natural rubber should provide opportunities to use factice. Tier-one competitors marketing "green" rubber products may also get the attention of the technologist.

What existing applications for soy products can be promoted or expanded?

Established uses of soy products in rubber compounds include epoxidized soybean oil as an acid scavenger in butyl rubber compounds and vulcanized soybean oil as an extender in natural rubber compounds.

Resources

Patents and Patent Applications

[US 2011/0144261 A1 Soy-Based Rubber Composition and Methods Of Manufacture And Use (16-Jun-2011)]

In at least one embodiment, a composition includes a thermoplastic resin and a softened rubber. The rubber ranges from 5 wt. % to 75 wt. % of the resin. The softened synthetic rubber comprises a rubber, a paraffinic oil, and a fatty-acid-containing material. The paraffinic oil ranges from 15 wt. % to 40 wt. % of the rubber. The fatty-acid-containing material ranges from 5 wt. % to 16 wt. % of the weight of the rubber.

Inventors: Flanigan, Cynthia Mowery; Mielewski, Deborah Frances; Perry, Christine

Assignee: Ford Global Technologies, LLC

[US 2011/0184093 Rubber Compositions Containing an Oil Blend of a Petroleum Oil and a Biobased Oil and Methods of Making the Same (28-Jul-2011)]

According to at least one aspect of the present invention, a rubber composition is provided. In at least one embodiment, the rubber composition comprises a rubber, an oil blend of a petroleum oil and a bio-based oil, the bio-based oil being non-hydroxyl-functionalized, hydroxyl-functionalized, or combinations thereof; and a filler. In certain instances, the bio-based oil includes a soy oil. In certain other instances, the soy oil is hydroxyl-functionalized having a hydroxyl number of from 10 to 350 KOH/g, 40 to 150 KOH/g, or 25 to 200 KOH/g. According to at least another aspect of the present invention, there is provided a method comprising providing a rubber composition as described herein and molding the rubber composition to form the rubber article.

Inventors: Perry, Christine; Flanigan, Cynthia Mowery

Assignee: Ford Global Technologies, LLC

[US 2005/0131112 A1 Oil extended rubber and composition containing low pca oil (16-Jun-2005)]

The invention is directed to an oil extended rubber and composition comprising: a solution polymerized elastomer derived from isoprene and optionally at least member of the group consisting of conjugated dienes and vinyl aromatic monomers; and from about 5 to about 70 parts by weight, per 100 parts by weight of elastomer (phr), of a process oil having a glass transition temperature of from about −80° C. to about −40° C. and a polycyclic aromatic content of less than 3 percent by weight as determined by the IP346 method.

Inventors: Henning, Steven Kristofer; Weydert, Marc; Thielen, Georges Marcel Victor; Johnson, Edward Lee; Kerns, Michael Lester

Assignee: Goodyear Tire & Rubber

[US 2007/0037917 A1 Rubber prepared with precipitated silica and carbon black pellet composites of controlled hardness and tire with component derived therefrom (15-Feb-2007)]

This invention relates to a rubber composition prepared with reinforcement comprised of a combination of precipitated silica aggregates and pelletized rubber reinforcing carbon black

composites of carbon black and organic binder of a controlled hardness and to a tire with at least one component comprised of and derived from such rubber composition in which said carbon black pellet composites are disintegrated (fragmented) in situ within said rubber composition in the presence of particulate precipitated silica and silica coupling agent. In one aspect the invention relates to a tire having a component of a rubber composition comprised of at least one conjugated diene-based elastomer and reinforcing filler comprised of a combination of precipitated silica, silica coupling agent and fragmented rubber reinforcing carbon black pellet composites, said pellets having a controlled hardness value.
Inventor: Sandstrom, Paul Harry
Assignee: Goodyear Tire & Rubber

US 6448318 B1 Method of processing rubber compositions containing soya fatty acids, sunflower fatty acids and mixtures thereof (10-Sep-2002)
There is disclosed a method of thermomechanically mixing of a rubber composition containing a fatty acid selected from the group consisting of soya fatty acid, sunflower fatty acid and mixtures thereof.
Inventor: Sandstrom, Paul Harry
Assignee: Goodyear Tire & Rubber

US 2006/0125146 A1 Tire curing bladder of EPDM rubber and use thereof (15-Jun-2006)
The invention relates to expandable rubber bladders comprised of EPDM rubber for shaping and curing articles of conjugated diene-based elastomers such as pneumatic tires. The bladders are of a rubber composition comprised of resin cured EPDM rubber composition as a terpolymer of ethylene/propylene and a minor amount of a non-conjugated diene. The bladder composition may also contain castor oil, corn oil and/or soya-bean oil. The bladder composition may also contain at least one of graphite and polytetrafluoroethylene powder. Alternately, the EPDM-based bladder rubber composition may also contain a minor amount of a butyl-type of rubber. The invention also relates to a method of curing pneumatic rubber tires by utilizing such EPDM-based expandable rubber tire curing bladder in a tire curing press.
Inventor: Sandstrom, Paul Harry
Assignee: Goodyear Tire & Rubber

US 7285584 B2 Tire with component comprised of rubber composition containing hydrophobated, pre-silanized silica (23-Oct-2007)
The invention relates to a tire having at least one component comprised of a rubber composition which contains a hydrophobated, pre-silanized silica, namely a pre-silanized silica hydrophobated with an epoxidized soybean oil and/or epoxidized rubber tree seed oil in situ within said rubber composition. Such tire component may be, for example although not limited to, a tire tread, sidewall and/or sidewall insert.
Inventors: Hsu, Wen-Liang; Futamura, Shingo; Hua, Kuo-Chih; Bates, Kenneth Allen; Zhang, Ping
Assignee: The Goodyear Tire & Rubber Company

US 7473724 B2 Preparation of silica reinforced polyisoprene-rich rubber composition and tire with component thereof (06-Jan-2009)

This invention relates to the preparation of a cis 1,4-polyisoprene rubber-rich rubber composition containing precipitated silica which has been pre-treated with a fatty alcohol and/or epoxidized soybean oil together with an organosilane containing polysulfide coupling agent and to tires having at least one component comprised of such rubber composition. The invention particularly relates to a process of (a) preparing a natural rubber-rich rubber composition comprised of pre-treating precipitated silica aggregates prior to blending with, or in the presence of, dry natural rubber with a fatty alcohol and/or epoxidized soybean oil to the exclusion of sulfur curative for the natural rubber, mixing an organalkoxysiloxane based polysulfide coupling agent with said dry natural rubber coincidentally with or subsequent to said precipitated silica aggregate fatty alcohol and/or epoxidized soybean oil pre-treatment to form a composite thereof, to the exclusion of sulfur curative, followed by (b) mixing the resulting rubber mixture with sulfur curative and (c) curing the resulting rubber composition.
Inventors: Hsu, Wen-Liang; Futamura, Shingo; Bates, Kenneth Allen; Halasa, Adel Farhan; Hua, Kuo-Chih; Hahn, Bruce Raymond
Assignee: The Goodyear Tire & Rubber Company

EP 1 288 022 A1 Eco Tire 05.March.2003
An earth-friendly tire using raw materials derived from non-petroleum resources instead of all or part of raw materials derived from petroleum resources currently used for tires. The tire is prepared by using a natural rubber instead of a synthetic rubber; an inorganic filler and/or a biofiller instead of carbon black; vegetable oil instead of petroleum oil; and natural fiber instead of synthetic fiber so that the tire comprises a non-petroleum raw material in an amount of at least 75 % by weight based on the total weight of the tire.
Inventors: Kikuchi, Naohiko; Kobe-shi, Hyogo-ken; Hochi, Kazuo; Kobe-shi, Hyogo-ken; Horiguchi, Takuya; Kobe-shi, Hyogo-ken
Assignee: Sumitomo Rubber Industries, Ltd.

US 7863371 B2 Rubber composition for inner liner and tire comprising the same (04-Jan-2011)
A rubber composition for an inner liner improving rolling resistance performance of a tire and further improving processability is provided. A rubber composition for an inner liner comprising at least 30 parts by weight of silica having a BET specific surface area of less than 150 m2/g and at most 5 parts by weight or less of carbon black based on 100 parts by weight of a rubber component comprising a natural rubber and a tire having an inner liner comprising the same.
Inventors: Hirayama, Tomoaki; Wada, Takao; Uchida, Mamoru
Assignee: Sumitomo Rubber Industries, Ltd.

US 2007/0232745 A1 Preparation process of oil extended rubber for tire, oil extended rubber for tire, and rubber composition and tire using the same (04-Oct-2007), EP 1840161 B1 (14-Jan-2009), EP 1840161 A1 (03-Oct-2007)
The present invention provides a process for preparing an oil extended rubber, in which an effect on environments can be taken into consideration, provision for the future decrease of petroleum supply can be satisfied, and further, strength is excellent without molecular breakage, an oil extended rubber obtained by the preparation process, and a tire using the oil extended rubber. A process for preparing an oil extended rubber, comprising (a) a step of preparing an oil-in-water

type emulsion by emulsifying a vegetable oil having an iodine value of not less than 135 with a surfactant, (b) a step of mixing said emulsion and a modified natural rubber latex, and then aging the mixture, and (c) a step of coagulating the mixture obtained in the step (b) to obtain a lump of a rubber, an oil extended rubber obtained by the preparation process, and a rubber composition for a tire and a tire which use the oil extended rubber.
Inventors: Sakaki, Toshiaki; Ichikawa, Naoya; Hattori, Takayuki; Ho, Chee-Cheong; Hean, Choong Dick
Assignee: Sumitomo Rubber Industries, Ltd.

US 7776951 Rubber composition and tire comprising thereof (17-Aug-2010)
There is provided a rubber composition in which strength and weather resistance are improved and the use of petroleum resource is suppressed as much as possible, and a tire comprising thereof. A rubber composition comprising 3 to 12 parts by weight of a pigment derived from resources other than petroleum, 10 parts by weight or less of carbon black and 30 parts by weight or more of silica based on 100 parts by weight of rubber components comprising an epoxidized natural rubber and/or a natural rubber.
The rubber composition of the present invention can contain oil as a softener. As the oil, a process oil, a plant oil and fat, and a mixture thereof may be used. The process oil includes specifically, paraffin process oil, naphthene process oil, aromatic process oil and the like. Further, the plant oil and fat includes specifically ricinus oil, cotton seed oil, linseed oil, rape seed oil, soy bean oil, palm oil, coconut oil, peanut oil, rosin, pine oil, pine tar, tall oil, corn oil, rice oil, saffron oil, sesame oil, olive oil, sun flower oil, palm kernel oil, camellia oil, jojoba oil, macadamia nut oil, safflower oil, wood oil and the like.
Inventors: Hirayama, Tomoaki; Wada, Takao; Uchida, Mamoru
Assignee: Sumitomo Rubber Industries, Ltd.

JP 2008-56802 Rubber composition and tire with specific component using the same (13-Mar-2008)
To provide a rubber composition gentle to the environment and preparing for the reduction of petroleum supply in the future, excellent in rubber strength and weather resistance, and to provide a tire having specific component using the same. The invention relates to the rubber composition comprising 100 pts.wt. of a rubber component, more than 30 pts.wt. of silica and 1-100 pts.wt. of carbon black with less than 100 nm of average particle size obtained not from petroleum but by burning fats and oils selected at least one kind from a group comprising castor oil, cotton seed oil, linseed oil, rapeseed oil, soy bean oil, palm oil, peanut oil, cone oil, rice oil, safflower oil, sesame oil, olive oil, sunflower oil, camellia oil and wood oil. The invention relates to the tire having a specific component using the same.
Inventors: Hirayama, Tomoaki; Wada, Takao; Uchida, Mamoru
Assignee: Sumitomo Rubber Industries, Ltd.

US 7649036 B2 "Green" materials from soy meal and natural rubber blends (19-Jan-2010) , US 2006/0041036 A1 (23-Feb-2006), US 2007/0155863 A1 (05-Jul-2007)
Blended compositions and methods for the production of thermoset compositions of soy meal, which has been treated to remove non-thermoplastic materials associated with soy beans, and

natural rubber. Also provided is a method for the preparation of a prepared granular soy meal by blowing a gas through a stream of granular natural soy meal to remove hulls and cellulose fiber materials which are lighter than the granular soy meal to provide the prepared granular soy meal for the compositions. The compositions are elastic and can be used in place of rubber bands and the like.
Inventors: Mohanty, Amar K.; Wu, Qiangxian; Selke, Susan
Organization: Board of Trustees of Michigan State University

US 7196124 B2 Elastomeric material compositions obtained from castor oil and epoxidized soybean oil (27-Mar-2007)
Elastomers are formed from castor oil and/or ricinoleic acid estolides and a polyester formed from an epoxidized vegetable oil such as ESO and a polycarboxylic acid such as sebacic acid, optionally in the presence of a peroxide initiator, or include crosslinked reaction products derived from ricinoleic acid or castor oil estolides, epoxy group-containing compounds such as epoxy resins and/or epoxidized vegetable oil, epoxy hardeners such as polyamine and polycarboxylic acid hardeners, thermally activated free radical initiators such as peroxides, and optionally but preferably include fillers such as limestone or wood flour. The elastomers can be prepared using a two-step, solvent-less procedure at elevated or ambient temperatures. These predominantly "all-natural" elastomers have physical properties comparable to conventional petroleum-based elastomers and composites and exhibit good flexibility, resiliency, abrasion resistance and inertness to hydrolysis. The resulting elastomers display good mechanical strength and resiliency, are resistant to abrasion and hydrolysis, and can be processed into sheet materials, which makes them attractive as floor covering components.
Inventors: Parker, Harry W.; Tock, Richard W.; Qiao, Fang; Lenox, Ronald S.
Assignee: Texas Tech University

US 7211611 B2 Rubber compositions with non-petroleum oils (01-May-2007)
Non-petroleum based oils replace traditional process oils used in rubber compositions in general and specifically in footwear applications. The replacement oils, derived from plant or animal sources, represent a renewable resource and provide other advantages. The oils contain a sufficient level and distribution of fatty acid side chains to partially incorporate into the rubber at low levels, and to act as internal plasticizers at higher levels. Other compositions are free of silane coupling agents and additives that generate carcinogenic nitrosamines.
Inventors: Wilson, III, Thomas W
Assignee: Nike, Inc.

US 7902285 B2 Rubber mixture and tires (08-Mar-2011)
Sulfur-vulcanizable rubber mixture without aromatic process oils, in particular for the tread rubber of vehicle pneumatic tires, containing at least one diene rubber, carbon black, mineral oil plasticizer, and resin. A vehicle pneumatic tire with a tread rubber that is composed at least partially of a rubber mixture of this type vulcanized with sulfur is also disclosed. To improve the chipping and chunking behavior, the rubber mixture can contain at least one diene rubber, 5-100 phr of at least one carbon black with an iodine adsorption number of 100-180 g/kg and a DBP number of 100-150 cm3/100 g, 5-80 phr of at least one mineral oil plasticizer that has a content of

polycyclic aromatic compounds determined with the DMSO extract according to the IP 346 method of less than 3% by weight relative to the total weight of the mineral oil plasticizer, and 5-30 phr of at least one resin with an average molecular weight determined with GPC of less than 400 g/mol and a softening point (ring and ball according to ASTM E 28) of less than 40° C.
Inventors: Dumke, Joachim: Soehnen, Dietmar; Stark, Annette; Struebel, Christian; Weinreich, Hajo
Assignee: Continental Aktiengesellschaft

US 2007/0161733 A1 Defatted soy flour/natural rubber blends and use of the blends in rubber compositions (12-Jul-2007)
There is disclosed a composition comprising defatted soy flour and a natural rubber in aqueous or dried form. There is also disclosed rubber compositions comprising the compositions comprising defatted soy flour and a natural rubber. There is further disclosed use of the compositions comprising defatted soy flour and a natural rubber, as well as use of rubber compositions including the compositions comprising defatted soy flour and a natural rubber, in the production of various products such as pneumatic tires and tire components, and the like.
Inventors: Hogan, Terrence E.; Hergenrother, William L.; Robertson, Christopher; Tallman, Maria
Assignee: Bridgestone Americas Holding

US 2008/0108733 A1 Method and formulation for reinforcing elastomers (08-May-2008), CA 2667239 A1 Method and formulation for reinforcing elastomers using soy protein and a silane coupling agent (15-May-2008), PRC 101573660 (04-Nov-2009)
A rubber composition has a base rubber, a filler which is a protein, including soy protein, derived from byproducts resulting from the manufacture of biodiesel fuel and a coupling agent.
Inventors: Colvin, Howard A.; Opperman, Jeffery M.
Assignee: Cooper Tire & Rubber Co.

US 7645818 B2 Material compositions for reinforcing ionic polymer composites (12-Jan-2010), US 2008/0004376 A1 (03-Jan-2008), US 2006/0094800 A1 (04-May-2006)
The invention is related to the preparation of an ionic polymer composite material comprising a protein and carbohydrate-containing vegetable material component that serves as a reinforcement agent for the composite. In preferred embodiments of the invention, the vegetable seed component is selected from the group of soy spent flakes, defatted soy flour, or soy protein concentrate with ionic polymers and the ionic polymer is carboxylated poly(styrene-butadiene). The composites have a significantly higher elastic modulus when compared with base polymer.
Inventors: Jong, Lei
Assignee: The United States of America as represented by the Secretary of Agriculture

US 2010/0206444 A1 Rubber composition for tire and pneumatic tire (19-Aug-2010)
There are provided a rubber composition for tire including a rubber component containing at least one selected from the group consisting of natural rubber, epoxidized natural rubber and deproteinized natural rubber; silica; and a silane compound represented by the following general formula $(X)_n—Si—Y_{(4-n)}$ (wherein X represents a methoxy group or an ethoxy group, Y represents a phenyl group or a straight-chain or branched alkyl group, and n represents an integer of 1 to 3),

and a pneumatic tire using the same. The rubber composition for tire can be suitably used for manufacturing bead apex rubber and base tread rubber of tire
Inventors: Kawasaki, Satoshi

02325255/EP-A1 Biodegradable product obtained from compositions based on thermoplastic polymers (25 May 2010)
A biodegradable product obtained from compounds of thermoplastic polymers is described, comprising: a styrenic block copolymer, a plasticizer, and a biodegradation catalyst, in which the plasticizer is a natural oil and the biodegradation catalyst is a yeast.
Inventors: Cardinali, Bruno
Assignee: Tecnofilm S.p.A

CN 201010283336 Preparation method of soy protein-strengthened rubber composite material (16-Sep-2010) Identifying No. 101967239 A (09-Feb-2011)
The invention discloses a preparation method of a soy protein-strengthened rubber composite material, relating to a preparation method of a rubber composite material. The rubber composite material comprises the following components in parts by weight: 0-10 parts of soy protein isolate, 1-1.5 parts of accelerating agent, 1-4 parts of anti-aging agent, 3-5 parts of zinc oxide, 0-3 parts of coupling agent, 2-4 parts of stearic acid, 1-3 parts of sulfur, 40-50 parts of carbon black and 100 parts of unsaturated rubber. The protein content in the soy protein material is 65-95 percent, and the soy protein material is dried for 24h at 60-80 DEG C. In the invention, soy protein molecules have more functional groups and stronger surface reaction ability, can take effect with a rubber matrix more easily and are beneficial to improving the processing property and the mechanical property of the rubber composite material. The 1-3 parts of rubber composite material made from a reinforcing agent increases tensile strength compared with the pure carbon black-strengthened rubber composite material, increases 300 percent stress at definite elongation and reduces abrasion volume, therefore, the invention has higher popularization and application values.
Inventors: Fang Qinghong; Li Tianyu
Organization: Shenyang University of Chemical Technology

TABLE OF COMMON SYNTHETIC RUBBERS

ISO 1629 Code	Technical Name	Common Names
ACM	Polyacrylate Rubber	
AEM	Ethylene-acrylate Rubber	
AU	Polyester Urethane	
BIIR	Bromo Isobutylene Isoprene	Bromobutyl
BR	Polybutadiene	Buna CB
CIIR	Chloro Isobutylene Isoprene	Chlorobutyl, Butyl
CR	Polychloroprene	Chloroprene, Neoprene
CSM	Chlorosulphonated Polyethylene	Hypalon
ECO	Epichlorohydrin	ECO, Epichlorohydrin, Epichlore, Epichloridrine, Herclor, Hydrin
EP	Ethylene Propylene	
EPDM	Ethylene Propylene Diene Monomer	EPDM, Nordel
EU	Polyether Urethane	
FFKM	Perfluorocarbon Rubber	
FKM	Fluoronated Hydrocarbon	Viton, Kalrez, Fluorel, Chemraz
FMQ	Fluoro Silicone	FMQ, Silicone Rubber
FPM	Fluorocarbon Rubber	
HNBR	Hydrogenated Nitrile Butadiene	HNBR
IR	Polyisoprene	(Synthetic) Natural Rubber
IIR	Isobutylene Isoprene Butyl	Butyl
NBR	Acrylonitrile Butadiene	NBR, Nitrile rubber, Perbunan, Buna-N
PU	Polyurethane	PU, Polyurethane
SBR	Styrene Butadiene	SBR, Buna-S, GRS, Buna VSL, Buna SE
SEBS	Styrene Ethylene Butylene Styrene Copolymer	SEBS Rubber
SI	Polysiloxane	Silicone Rubber
VMQ	Vinyl Methyl Silicone	Silicone Rubber
XNBR	Acrylonitrile Butadiene Carboxy Monomer	XNBR, Carboxylated Nitrile
XSBR	Styrene Butadiene Carboxy Monomer	
YBPO	Thermoplastic Polyether-ester	
YSBR	Styrene Butadiene Block Copolymer	
YXSBR	Styrene Butadiene Carboxy Block Copolymer	

In addition, the term gum rubber is sometimes used to describe the tree-derived *natural rubber* (code NR), and to distinguish it from synthetic *natural rubber* (code IR).
http://en.wikipedia.org/wiki/Synthetic_rubber

Rubber Industry Terminology

Definitions of rubber industry terms used in this report are listed below. In addition, there are a several glossaries available on the rubber industry.

Abrasion Resistance
The ability of a rubber compound to resist surface wearing by mechanical action

Aging
The change in physical and chemical characteristics of an elastomer that has been exposed to a particular environment over time

Antioxidant
Any organic compound that slows the process of oxidation

Antiozonant
Any substance that slows the severe oxidizing effect of ozone on elastomers. Exposure to ozone typically causes surface cracking in many rubbers

Compression Molding
A molding process in which the uncured rubber compound is placed directly into the mold cavity, and compressed to its final shape by the closure of the mold

Compression Set
The permanent deformation experienced by a rubber material when compressed for a period of time. The term is commonly used in reference to a test conducted under specific conditions wherein the permanent deformation, expressed as a percentage, is measured after a prescribed period of time. A low compression set is desirable in molded rubber parts such as seals and gaskets, which must retain their dimensions to maintain an effective seal.

Cross-linking Agents
A chemical or chemicals that bond the polymer chains of a rubber together during the molding process

Cure
A) One complete cycle. B) The thermo process that causes a chemical change in the raw stock, turning it into the finished rubber part

Cure Time
The preset time needed to complete the curing process

Durometer
One of several measures of the hardness of a material. Hardness may be defined as a material's resistance to permanent indentation

Elasticity
A rubber's ability to return to its original size and shape after removal of the stress causing deformation such as stretching, compression, or torsion. It is the opposite of plasticity. The term elasticity is often loosely employed to signify the "stretchiness" of rubber

Elastomer
Any of various polymers having the elastic properties of rubber

Elongation
Generally referred to in terms of tensile (pull apart) testing, elongation is the increase in length of a test specimen, expressed as a percentage of its original (unstretched) length... relative to a given load at the breakpoint

Extrusion
When part or all of a component is forced from its groove by high continuous or pulsating pressure

Hardness
A measurement of the resistance to penetration of a rubber sample by an indenter. High values indicate harder materials while low values indicate softer materials.

Injection Molding
A molding method in which a rubber or plastic material is heated and forced under pressure into the mold cavity

Mooney viscosity
A measure of the plasticity of a polymeric compound determined in a Mooney shearing disc viscometer

Modulus
A measure of resistance of a material to deformation. It is measured by the force required to reach a predetermined compression or extension

Oil Resistant
Ability of vulcanized rubber to resist swelling and other detrimental effects of exposure to various oils

Plasticize
To soften a material and make it plastic or moldable, either by means of a plasticizer or the application of heat

Plasticizer
A chemical agent added to the rubber compound batch mix to soften the elastomer for processing, as well as to improve physical properties of the compound product (i.e., increase elongation, reduce harness, improve tack)

Polymer
A long molecular chain material formed by the chemical combination of many similarly structured, small molecular units

Resilience
The capability of returning to original size and shape after deformation

Rubber
A common name for both naturally occurring and synthetically made elastomers

Scorching
Premature curing of compounded rubber stock during processing or storage, with the potential for adversely affecting material flow and plasticity during subsequent shaping and curing processes

Shore Hardness
A durometer or hardness test that measures the depth of an indentation in the material created by a given force on a standardized presser foot. The two most common scales are ASTM D2240 type A and type D scales. The A scale is for softer plastics, while the D scale is for harder ones

Tear Resistance
Resistance to the growth of a cut in the seal when tension is applied

Tear Strength
The force required to rupture a sample of stated geometry

Tensile Strength
The extension force per cross-sectional area required to fracture a material specimen

Terpolymer
A polymer resulting from the chemical combination of three monomers

Thermoplastic
A material which when thermally processed undergoes a reversible phase change to become plastic and capable of being molded to a desired shape. Upon cooling, the material reverts to its original properties

Thermoplastic Elastomer (TPE)
A material which combines the processing characteristics of a plastic but displays rubber-like properties upon completion of processing

Thermoset
A material, either an elastomer or plastic, which when thermally processed undergoes an irreversible chemical reaction to achieve its final material state

Toughness
Property of resisting fracture or distortion. Usually measured by impact test, high impact values indicating high toughness

TPE
Thermoplastic Elastomer combines the rubber-like performance of elastomers with the processing advantages of plastic. Scrap material can be recycled without significant loss in physical properties, unlike thermoset materials

Viscosity
The measurement of the resistance of a material to flow under stress

Vulcanization
The thermally initiated, irreversible process whereby polymer chains are cross-linked to form the final physical and chemical state of a rubber

Online Glossaries of Rubber Terms

ASTM D1566 - 10e1 Standard Terminology Relating to Rubber
http://www.astm.org/Standards/D1566.htm

Akron Rubber Development Laboratory
http://www.ardl.com/Public/Resources/Educational/glossary.html

Association of the Rubber Lining Industry
http://www.rubberlining.de/1glossary.htm

Atlas Supply
http://www.atlassupply.com/rubber-glossary.htm

Babylon
http://www.babylon.com/free-dictionaries/business-economy/tools-materials/Rubber-Glossary/12093.html

Blair Rubber
http://www.blairrubber.com/pdf/Glossary.pdf

Brenntag Specialties, Inc.
http://www.brenntagspecialties.com/en/downloads/Literature/Glossary_Rubber.pdf

Columbia Engineered Rubber
http://www.columbiaerd.com/glossary.html

Darcoid
http://www.darcoid.com/html/rubber-glossary.html

Delford Industries
http://www.delford-industries.com/glossary.html

Ericks
http://rubbertechnology.info/en/tools/glossary-of-rubberterms/

Harboro
http://www.harboro.co.uk/glossary_of_terms.html

KDL Precision Molding
http://www.kdlprecision.com/gloss.htm

Minnesota Rubber & Plastics
http://www.mnrubber.com/About_Us/Glossary_of_Terms.html
O-Rings, Inc.
http://www.oringsusa.com/html/glossary.html

Regional Rubber
http://www.regionalrubber.com/Glossry%20of%20Rubber%20Terms.htm

Robinson Rubber Products
http://www.robinsonrubber.com/pdfs/DesigningWithRubber.pdf

R. L. Hudson & Company
http://www.rlhudson.com/O-Ring%20Book/glossary-gloss.html

RPI Rubber & Plastics
http://www.conveyorbelt.com/resources_guide.php?p=glossary

R T Dygert International
http://www.rtdygert.com/technical/rubber_terms.cfm

Rubberlite
http://www.rubberlite.com/products/glossary/

Sante Fe Rubber
http://santaferubber.com/glossary.htm

Stockwell Elastomerics
http://www.stockwell.com/pages/technical_glossary.php

S W Jagels Materials and Technology, LLC
http://www.swjagels.com/uploads/Glossary_of_Rubber_and_Polymer_Terms_and_Abbreviations.pdf

The Rubber Economist
http://www.therubbereconomist.com/The_Rubber_Economist/Glossary_of_rubber_terms.html

Timco Rubber
http://www.timcorubber.com/rubber-resources/glossary.htm

Trelleborg
http://www.trelleborg.com/en/Infrastructure/Technology/Polymer-glossary/
http://www.trelleborg.com/en/Career/The-Polymer-School/Polymer-Glossary/

References

The Vanderbilt Rubber Handbook, Fourteenth Edition, R.T. Vanderbilt Company, Inc., 2010

An Introduction to Rubber Technology, Andrew Ciesielski, Rapra Technology Ltd., 1999

Factice – A Unique Additive, Mary E. Velka, Harwick Chemical Corporation, Rubber Technology International '97

Handbook of Specialty Elastomers, edited by Robert C. Klingender, CRC Press, 2008

ICIS, Reed Business Information (RBI), a division of Reed Business and a member of Reed Elsevier plc

Rubber World magazine

North American Industry Classification System (NAICS) - Rubber Product Manufacturing

The North American Industry Classification System was developed as the standard for use by Federal statistical agencies in classifying business establishments for the collection, analysis, and publication of statistical data related to the business economy of the United States. NAICS was developed under the auspices of the Office of Management and Budget (OMB), and adopted in 1997 to replace the old Standard Industrial Classification (SIC) system. It was also developed in cooperation with the statistical agencies of Canada and Mexico to establish a 3-country standard that allows for a high level of comparability in business statistics among the three countries.

3262 Rubber Product Manufacturing
This industry group comprises establishments primarily engaged in processing natural, and synthetic or reclaimed rubber materials into intermediate or final products using processes such as vulcanizing, cementing, molding, extruding, and lathe-cutting.

32621 Tire Manufacturing
This industry comprises establishments primarily engaged in manufacturing tires and inner tubes from natural and synthetic rubber and retreading or rebuilding tires.

326211 Tire Manufacturing (except Retreading)
This U.S. industry comprises establishments primarily engaged in manufacturing tires and inner tubes from natural and synthetic rubber. This includes:

- Aircraft tire manufacturing
- Camelback (i.e., retreading material) manufacturing
- Inner tubes manufacturing
- Motor vehicle tires manufacturing
- Retreading materials, tire, manufacturing
- Tire repair materials manufacturing
- Tires (e.g., pneumatic, semi-pneumatic, solid rubber) manufacturing
- Tread rubber (i.e., camelback) manufacturing

326212 Tire Retreading
This U.S. industry comprises establishments primarily engaged in retreading, or rebuilding tires.

32622 Rubber and Plastics Hoses and Belting Manufacturing

326220 Rubber and Plastics Hoses and Belting Manufacturing
This industry comprises establishments primarily engaged in manufacturing rubber hose and/or plastics (reinforced) hose and belting from natural and synthetic rubber and/or plastics resins. Establishments manufacturing garden hoses from purchased hose are included in this industry. This includes:

- Belting, rubber (e.g., conveyor, elevator, transmission), manufacturing
- Conveyor belts, rubber, manufacturing
- Fan belts, rubber or plastics, manufacturing
- Garden hose, rubber or plastics, manufacturing
- Hoses, reinforced, made from purchased rubber or plastics manufacturing
- Hoses, rubberized fabric, manufacturing
- Hydraulic hoses (without fitting), rubber or plastics, manufacturing
- Motor vehicle belts, rubber or plastics, manufacturing
- Motor vehicle hoses, rubber or plastics, manufacturing
- Plastics and rubber belts and hoses (without fittings) manufacturing
- Pneumatic hose (without fittings), rubber or plastics, manufacturing
- Radiator and heater hoses, rubber or plastics, manufacturing
- Rubber and plastics belts and hoses (without fittings) manufacturing
- Timing belt, rubber or plastics, manufacturing
- Transmission belts, rubber, manufacturing
- Vacuum cleaner belts, rubber or plastics, manufacturing
- V-belts, rubber or plastics, manufacturing
- Water hoses, rubber or plastics, manufacturing

32629 Other Rubber Product Manufacturing
This industry comprises establishments primarily engaged in manufacturing rubber products (except tires, hoses, and belting) from natural and synthetic rubber.

326291 Rubber Product Manufacturing for Mechanical Use
This U.S. industry comprises establishments primarily engaged in molding, extruding or lathe- cutting rubber to manufacture rubber goods (except tubing) for mechanical applications. Products of this industry are generally parts for motor vehicles, machinery, and equipment. This includes:

- Extruded, molded or lathe-cut rubber goods manufacturing
- Mechanical rubber goods (i.e., extruded, lathe-cut, molded) manufacturing
- Rubber goods, mechanical (i.e., extruded, lathe-cut, molded), manufacturing

326299 All Other Rubber Product Manufacturing
This U.S. industry comprises establishments primarily engaged in manufacturing rubber products (except tires; hoses and belting; and molded, extruded, and lathe-cut rubber goods for mechanical applications) from natural and synthetic rubber. This includes:

- Balloons, rubber, manufacturing
- Bath mats, rubber, manufacturing
- Birth control devices (i.e., diaphragms, prophylactics) manufacturing
- Brushes, rubber, manufacturing
- Combs, rubber, manufacturing
- Condom manufacturing
- Curlers, hair, rubber, manufacturing

- Diaphragms (i.e., birth control device), rubber, manufacturing
- Dinghies, inflatable rubber, manufacturing
- Doormats, rubber, manufacturing
- Erasers, rubber or rubber and abrasive combined, manufacturing
- Floor mats (e.g., bath, door), rubber, manufacturing
- Footwear parts (e.g., heels, soles, soling strips), rubber, manufacturing
- Fuel bladders, rubber, manufacturing
- Grips and handles, rubber, manufacturing
- Grommets, rubber, manufacturing
- Hair care products (e.g., combs, curlers), rubber, manufacturing
- Hairpins, rubber, manufacturing
- Hot water bottles, rubber, manufacturing
- Latex foam rubber manufacturing
- Life rafts, inflatable rubberized fabric, manufacturing
- Mattress protectors, rubber, manufacturing
- Mattresses, air, rubber, manufacturing
- Nipples and teething rings, rubber, manufacturing
- Pacifiers, rubber, manufacturing
- Pipe bits and stems, tobacco, hard rubber, manufacturing
- Prophylactics manufacturing
- Rafts, rubber inflatable, manufacturing
- Reclaiming rubber from waste or scrap
- Rods, hard rubber, manufacturing
- Rolls and roll coverings, rubber (e.g., industrial, paper mill, painters', steel mill
- Roofing (i.e., single ply rubber membrane) manufacturing
- Rubber bands manufacturing
- Sheeting, rubber, manufacturing
- Shoe and boot parts (e.g., heels, soles, soling strips), rubber, manufacturing
- Spatulas, rubber, manufacturing
- Sponges, rubber, manufacturing
- Stair treads, rubber, manufacturing
- Stoppers, rubber, manufacturing
- Thread, rubber (except fabric covered), manufacturing
- Tubing, rubber (except extruded, molded, lathe-cut), manufacturing

339991 Gasket, Packing, and Sealing Device Manufacturing
This U.S. industry comprises establishments primarily engaged in manufacturing gaskets, packing, and sealing devices of all materials.

- Coaxial mechanical face seals manufacturing
- Compression packings manufacturing
- Gasket, packing, and sealing devices manufacturing
- Gaskets manufacturing

- Grease seals manufacturing
- Molded packings and seals manufacturing
- Oil seals manufacturing
- Seals, grease or oil, manufacturing

www.census.gov/epcd/naics02/def/NDEF326.HTM

ASTM D 2000 • SAE J 200
Standard Classification System for Rubber Products in Automotive Applications

This classification system tabulates the properties of vulcanized rubber materials that are intended for, but not limited to, use in rubber products for automotive applications. The purpose of the classification system is to provide guidance in the selection of practical, commercially available rubber materials, and to provide a method for specifying these materials by the use of a simple "line call-out" designation.

Type and Class
Rubber materials are classified on the basis of type (heat resistance) and class (oil resistance). Type and class are indicated by letter designations as shown below

Type	Test Temperature			Class	Volume Swell, max %
A	70°C	(158°F)		A	no requirement
B	100°C	(212°F)		B	140%
C	125°C	(257°F)		C	120%
D	150°C	(302°F)		D	100%
E	175°C	(347°F)		E	80%
F	200°C	(392°F)		F	80%
G	225°C	(437°F)		G	40%
H	250°C	(482°F)		H	30%
J	275°C	(527°F)		J	20%
K	300°C	(572°F)		K	10%

Type is based on changes in tensile strength of not more than ±30%, elongation of not more than − 50%, and hardness of not more than ±15 points after heat aging for 70 hours at a temperature from the table above.

Class is based on the resistance of the material to swelling in ASTM Oil No. 3 after 70 hour immersion at a temperature determined from the same table. Limits of swelling for each class are shown above.

The letter designations are followed by a three-digit number to specify the hardness and the tensile strength—for example, 605. The first digit indicates durometer hardness, for example, 5 for 50 ± 5, 6 for 60 ± 5. The next two digits indicate the minimum tensile strength—for example, 05 for 5 MPa, 14 for 14 MPa.

Since the basic requirements do not always describe sufficiently all the necessary qualities, provision is made for deviation or adding requirements through a system of prefix grade numbers.

The suffix letters together with their meaning are listed below. Each suffix letter is followed by two suffix numbers. The first suffix number indicates the test method; the second suffix number indicates the temperature of test.

Meaning of Suffix Letter	
A	Heat Resistance
B	Compression Set
C	Ozone or Weather Resistance
0	Compression-Oefie.cbon
EA	Fluid Resistance (aqueous fluids)
EF	Fluid Resistance (fuels)
EQ	Fluid Resistance (oil and lubes)
F	Low-Temperature Resistance
G	Tear Resistance
H	Flex Resistance
J	Abrasion Resistance
K	Adhesion
M	Flammability Resistance
N	Impact Resistance
P	Staining Resistance
R	Resilience
Z	Any special requirement, as jointly agreed to buy producer and customer

A "line call-out," which is a specification, contains the documents names, the prefix letter M, the grade number, the material designation (type and class), and the hardness and tensile strength, followed by the appropriate suffix requirements.

Product and Market Development Strategy

In approaching a potential market opportunity for a new technology, the focus is on the key factors for a new product development success. That insight provides direction for managing product development and selection. Critical success factors identified in the Product Development and Management Association *Handbook of New Product Development* are having a superior and differentiated product with unique customer or user benefits. Dr. Robert G. Cooper lists characteristics of winning products:

- Feature good value for the customer's money, reduce the customer's total costs (high value in use), and excellent price and performance characteristics
- Provide excellent relative product quality relative to competitors' products and in terms of how the user measures quality
- Are superior to competing products in terms of meeting users' needs, offer unique features not available on competitive products, or solve a problem that the customer has with a competitive product
- Offer product benefits or attributes easily perceived as useful by the customer, and benefits that are highly visible
- The market should be large with the product type representing an essential component for the customer

Commercialization of new technology rarely proceeds quickly. Foundational research and discoveries often occurs years before the commercial potential is recognized and developed. Commercialization is an iterative process, branching several times with some branches withering while others find traction with early adopters.

To make the transition from technical potential to commercial reality there must be market openings or events that cause a specific set of needs to become relevant in the market today. This impetus causes industries to adopt new offerings and to a large extent determines the timing of the new product adoption. Market openings can occur with new regulations, the introduction in the value chain of a new process or new requirement that exceeds the limits of the current technology, gaps in new value chains created by technological innovation, and shifts in political, economic, or social trends. In the early stages, this may be evidenced by several industry participants and experts supporting what the new technology would offer. Lead users begin development programs to validate the new technology.

New product market development success comes at the intersection of market need, product technical capabilities, and favorable economics in use. The commercialization stage begins as customers make purchase commitments or include the new technology in design specifications that will drive sales of the new technology.