

The Rationale for Transforming Sunflower into a Rubber-Producing Crop

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Natural Rubber (NR) is a biomaterial essential for our modern standard of living. Natural rubber is a highly important product in commerce and industry, but it is also a critical strategic material as noted by the US Congress in Public Laws 95-592 and 98-284. Although not well understood, it is thought that plants produce NR as a secondary product for a defense and protective mechanism to prevent fungal and bacterial invasion when plants are wounded (Kush 1994).

Nearly all NR used in commerce comes from a single plant species, the Brazilian rubber tree (*Hevea brasiliensis* Muell. Arg., Euphorbiaceae). High quality, NR is a long chain polymer with a high molecular weight of approximately 1 million g/mol synthesized in the plant via a simple side-branch of the ubiquitous isoprenoid pathway (Chappell 1995).

Natural rubber from *Hevea* exhibits performance characteristics that cannot be readily or economically matched by synthetic rubber made from petroleum. This is because of the superior properties of NR (Mooibroek and Cornish 2000; Rodgers et al. 2005). Natural rubber has excellent resilience, which promotes products made from NR to return to their original shape when external force is applied and then released. The abrasion resistance of NR is excellent, as is its impact resistance. Natural rubber is responsive to a wide range of temperatures. Heat that accumulates under use readily dissipates from NR. At cold temperatures NR maintains much of its malleability. Surface quality of NR is such that it resists absorption of liquids, while at the same time other compounds do not readily adhere to its surface. Tensile and tear strength of NR are high.

The many positive characteristics of NR far outweigh negative factors. The weaknesses of NR are its moderate susceptibility to environmental factors of heat, light, and ozone, which promotes degradation of this biomaterial.

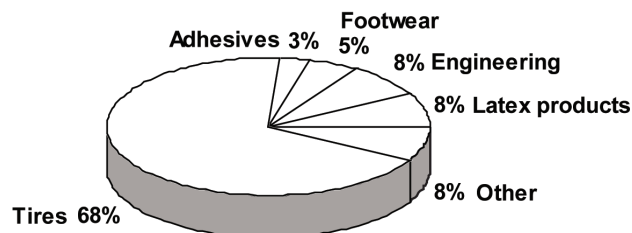
More than 40,000 products contain NR. These products cover a wide range, many of which are part of everyday life. By far, the single largest use of NR is the tire industry, commanding nearly 70% of the total consumption (Fig. 1). Other major categories containing NR are adhesives, footwear, various latex products, and engineering applications. As a major ingredient in tire formulations, NR provides several essential traits for superior tire performance. Natural rubber has high green strength, tack, and cohesive properties which are important for tire uniformity and stability during the manufacturing process. Tires made with NR have low rolling resistance, low heat generation, have excellent traction under a wide range of environment conditions, and have excellent resistance to cutting, chipping, and tearing (International Rubber Research and Development Board 2006).

In the tire industry, there is limited ability to switch from NR to synthetic rubber. Manufacturers can change a tire formulation by 5% to 7% from NR to synthetic rubber in an attempt to offset increased costs. One manufacturer has claimed a 15% formula replacement from NR to synthetic rubber without sacrificing tire performance.

NATURAL RUBBER PRICES

More than \$2 billion of NR is imported into the United States each year. When manufactured into finished products the value of this rubber increases to \$28 billion, making NR one of the most important biomaterials in the world.

Fig. 1. Percentages of natural rubber manufactured into major use product categories. Source: The International Rubber Research and Development Board. www.irrd.com, (verified 31 Jan. 2007).



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Prices of NR declined during the last half of the 1990s and early 2000s (Fig. 2). During 2001, NR prices hit a low at \$0.50/kg. Prices began to rise over the next 4 years and in late November 2005 NR prices had risen to \$1.59/kg and by mid-May 2006 prices were at a 20-year high at \$2.16/kg. On June 12, 2006, NR prices reached \$2.89/kg, but by late August 2006 prices had fallen by 20%.

During early 2006, production deficits had been forecast but as prices continued to rise NR growers foresaw a greater profit potential and responded by using better production management practices to increase yields from rubber trees. These management practices used by farmers included improved fertility practices on their trees, using better tapping techniques, and applying ethylene compounds to improve the flow of NR in trees.

An increase in the NR supply had an effect, albeit small, on market conditions. Historically, the price of crude oil has had a major impact on NR prices. However, large price fluctuations in the NR market have been largely due to external factors not associated with typical supply/demand economics or even the price of crude oil. These price fluctuations of NR are a fairly recent phenomenon mainly caused by fund managers who began using NR futures market as an investment tool. Historically, the NR market has followed a fairly reliable 7-year cycle of highs and lows which have coincided with the replanting cycle of 10% to 15% per year. New trees require 6 to 7 years before they can be tapped for NR. From 1999 to early 2002, NR prices flattened out at a 30-year low and then gradually climbed until 2004 when fund managers entered the NR market scene. As demand grew and a larger than expected shortfall was predicted, fund managers invested more and more speculative dollars into futures markets making quick and tidy profits. This speculative element fueled the rapid price rise during the first half of 2006. The last half of 2006 has been met with an equally rapid fall because fund managers have liquidated their holdings and decided to regroup as a result of the defaults of NR purchases in some foreign countries (D. Thomas Marsh, President, Centrottrade Rubber USA, Inc., pers. commun., 2006).

In a rising market, buyers have been known to default on supply contracts so in a falling market these foreign buyers returned the “favor.” Once under contract to sell and now defaulted on, NR goes back on the open market and the sellers scramble to resell their NR in order to avoid further losses given they paid top dollar for the raw product. These price swings are dangerous and contribute to a “whipsaw” effect that hurts both consumers and suppliers alike. As prices fall, fund managers begin to re-enter the market and buy forward, pushing the price up and beyond the market’s normal level and the cycle repeats itself. Thus, NR price fluctuations are compounded because of influences beyond simple supply and demand economics. Prices have now become more complicated by using NR as an investment tool (D. Thomas Marsh, President, Centrottrade Rubber USA, Inc., pers. commun., 2006).

PRODUCTION AND CONSUMPTION OF NATURAL RUBBER

The United States is completely dependent on imports of NR from foreign sources. Production of NR is concentrated in southeast Asia (Fig. 3). Most NR is grown in tropical environments between 15°N and 10°S

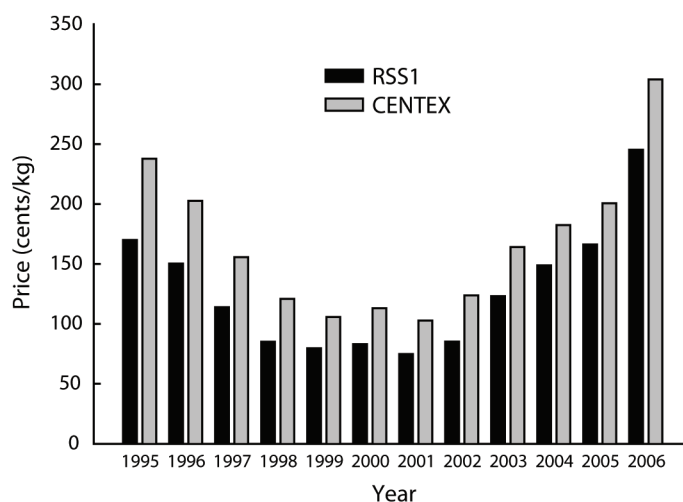


Fig. 2. Prices of two grades (ribbed smoked sheets and Centrex) of natural rubber during the period from 1995 to 2006. Data provided courtesy Centrottrade Rubber USA, Inc.

latitude. Thailand, Indonesia, Malaysia, Vietnam, India, and Sri Lanka are the top, NR-producing countries and together they are responsible for most of total world production. Recently, a small amount of NR is being produced commercially in the US from guayule (*Parthenium argentatum*, Gray, Asteraceae) by the Yulex Corporation. This NR is targeted at some of the high end medical uses, particularly markets related to non-allergenic uses.

World production and consumption of NR has continued to increase since 1990 and the projections for 2007 and 2008 remain the same (Fig. 4). Over this 17-year period there have been some years when surpluses occurred and some years when deficits occurred. In 2005 and 2006, deficits have occurred and are projected through 2008. Until recently, the US was the largest user of NR at 20% of the total world supply. Currently, China is the largest consumer of NR at 20% of total world supply and the US is second using 14% of the world supply. The industrialization of China and India is likely to increase demands and tighten the supply of world NR. This will likely force NR prices to increase. Other regions of the world such as Eastern Europe may increase their consumption of NR. Given the current and projected demand worldwide, the likelihood for Hevea to meet the increased needs of NR is questionable.

NATURAL RUBBER HISTORY

There are at least 2,500 plant species that produce latex (Bowers 1990). Most of these species are tropical, produce low quality and small amounts of NR. They are wild and not domesticated. Little scientific and technical information is known about them. Nevertheless, there are some plant species that do produce high quality rubber similar to Hevea (Buranov et al. 2005), but are not domesticated to the point they are suitable for mechanized agriculture. Domesticating wild plant species requires a large scientific investment in research and development, is expensive, requires a long term commitment, and is risky.

Periodically throughout the 20th century there have been concerns about having a sufficient NR supply to meet US needs. During WWI, difficulties with shipping during wartime and limited supplies of NR in the

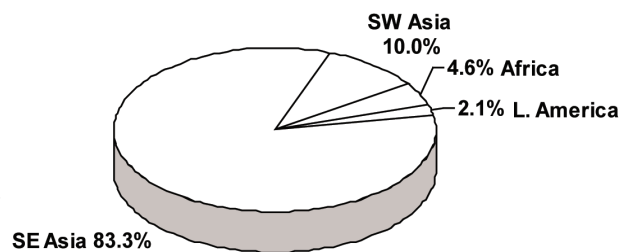


Fig. 3. Production percentages of natural rubber in various regions of the world. Source: International Rubber Study Group, Rubber Statistical Bulletin, July/August 2005.

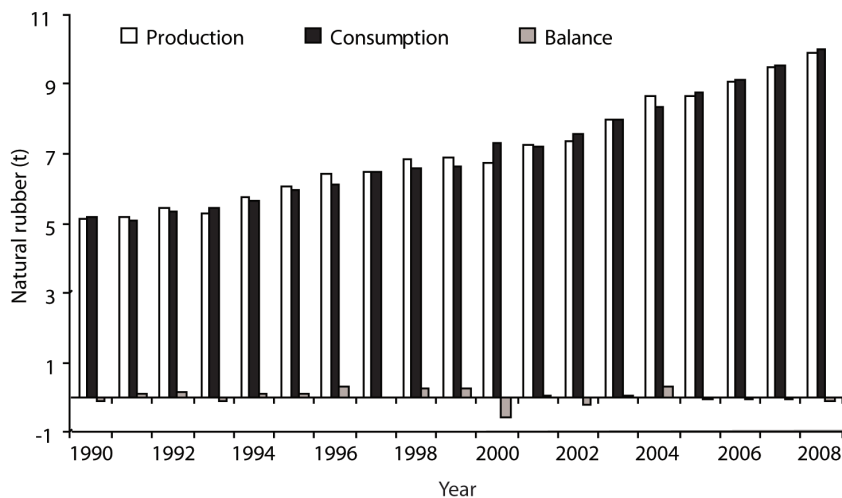


Fig. 4. Production and consumption of natural rubber from 1990 and projected through 2008. Surpluses and deficits are also shown for each year. Source: Weber & Schaer, Market Report 3/2006, Issue: 07.06.2006.

United States stimulated a number of new investigations on NR (Anon. 1942). Thomas A. Edison recognized the importance of NR to the modern society and during the final years of his life he, with the financial support and encouragement from his friends, Henry Ford and the Ford Motor Company and Harvey Firestone and the Firestone Tire & Rubber Company, dedicated his efforts toward creating a domestic source of NR by working with the plant species *Solidago* spp., Asteraceae (Josephson 1959). Unfortunately, these efforts ceased with Edison's death. During WWII, the Japanese seized rubber plantations in southeast Asia and disrupted the supply of NR to the US and her allies. This action resulted in NR being the first nonfood item to be rationed in the US (Wright 1998). The OPEC embargo that occurred in the 1970s raised public awareness about the long-term availability of petroleum to meet future consumer and industrial needs. This concern about adequate supplies of petroleum has continued to the present with its ups and downs mainly related to the price of transportation and home heating fuels. At the beginning of the 21st century the public expressed renewed concern about sustainability and some segments of society also were concerned about the long term viability of agriculture. Present concerns about prices and availability of petroleum have permeated every aspect of society, creating widespread apprehension among the population about energy availability and cost. Current and projected world petroleum and NR prices and supplies are likely to impact the US military and cause some uneasiness regarding national security. The concern about the future of petroleum has direct impacts on NR and draws attention once again to the importance of a domestic source of NR in the United States.

SUNFLOWER AS A RUBBER-PRODUCING CROP

Over the years, a number of researchers have investigated the potential of identifying plant species that would be suitable for NR production in the United States. Buchanan et al. (1978) evaluated 100 plant species found in Illinois for their potential as hydrocarbon and rubber-producing crops. Based on their findings they concluded that "*It appears technically and economically feasible to develop a US crop that is as productive in hydrocarbons as the Hevea tree currently is in southeast Asia.*" More specifically, Adams and Seiler (1984) studied 48 accessions representing 39 taxa of sunflower (*Helianthus annuus* L., Asteraceae) to determine their potential for producing various compounds including NR. They concluded that "*several sunflower species appear to offer an opportunity for the development of a whole-plant utilization crop based on multiple products such as hydrocarbons, rubber, specialty carbohydrates and livestock feed.*"

The sunflower genus *Helianthus* has 69 species and subspecies native to the US. Leaves of sunflower produce a small amount of rubber, and, of the 53 species and subspecies of sunflower analyzed, 14 produced more than 0.93% NR (Stipanovic et al. 1982; Seiler et al. 1991). Those researchers postulated there is a high genetic potential for increasing the NR content of cultivated sunflower. Twenty-eight taxa of sunflower were evaluated by Seiler et al. (1991) and of the 13 species of wild sunflower that yielded at least 0.4% hydrocarbon and were further analyzed, all were found to contain NR. The molecular weight of the NR in sunflower was found to be low, but these researchers surmised that this low molecular weight NR might have potential use in various specific commercial applications and as a feedstock for the synthesis of polyisoprenes. Numerous species of sunflower were evaluated in Texas for their NR content (Stipanovic et al. 1980). These researchers found two species of sunflower that contained 1.6% NR. The researchers concluded a potential exists to increase NR produced within the plant through genetic improvement using plant breeding. It also may prove possible to increase the molecular weight of sunflower rubber through biotechnological approaches.

The ideal NR-producing crop plant would have several important characteristics. Such a crop plant would be fast-growing with a high biomass and partition a high percentage of its dry matter into the plant part that contains NR. Preferably, the crop plant would be an annual species that could be planted or rotated with other crops to meet changing market needs and conditions, along with meeting the specific needs of a given farming operation. The ideal NR-producing crop plant would be well suited to mechanized agriculture. The agronomy such as planting, harvesting, soil fertility, pest control, and water requirements of the crop would be well known and farmers would be acquainted with the production requirements of the crop. A NR-producing crop would be adapted to a wide range of environments to spread production risks related to the weather and other potential environmental problems and to provide farmers in many areas with an opportunity to grow the crop. Furthermore, a useful NR-producing crop for the US would need to be grown on a relatively large area to meet most, if not all, of the United States NR needs. This would require the crop to be adapted to many of

the northern climates (Buchanan et al. 1978).

Rather than relying on one plant species to meet the global demands for NR, multiple NR crops would reduce risk and widen the production of NR while allowing for greater flexibility to meet changing market conditions. Sunflower appears to be an excellent candidate as a potential source of cultivated rubber because: Sunflower (1) already makes rubber which means it can compartmentalize this secondary product and the plant will likely do the same with larger endogenous amounts; (2) is adapted for agronomic production in many parts of the United States as an annual crop; (3) produces high biomass per hectare; (4) agronomy is well understood and would likely need only minor adjustment for it to be grown for rubber across the country; (5) is adapted for mechanized agriculture; and (6) is a close relative of guayule, a plant in which the biochemical regulation of rubber yield and quality has been extensively studied. As a rubber-producing plant, sunflower would be able to meet the US rubber needs and allow for marketing of high quality manufactured rubber products in international trade.

New NR-producing annual crops are needed to meet the demands of the large US market (Table 1). Also, US-produced NR could potentially supply a large export market (Table 1). In 2006, sunflower was produced on 1.8 million acres in the United States (USDA 2006). There are slightly more than 122 million ha of harvested cropland in the US. In comparison to sunflower, soybeans, and corn for grain were produced on 30 and 29 million ha in the US in 2006, respectively (USDA 2006). Considerable potential exists to expand the production of sunflower to produce NR.

Commercial production of NR-producing crops in the United States would have huge benefits to agriculture, industry, and the American people. Such crops would contribute to diversity in agriculture, industry, and business. Renewable industrial resources, such as those from NR, would contribute sustainability, stability, and productivity in the following ways: (1) NR crops would improve national security; (2) NR crops would increase the effective use of resources, reduce environmental pressure, and contribute to sustainable intensification; (3) NR crops and their co-products would provide more and novel raw materials for medicines, industrial materials, cosmetics, construction materials, etc., spawn new businesses, and promote rural development; (4) Environmentally-sound, productive, and profitable NR crops would add stability to US agriculture; (5) An array of new crops in agriculture may be environmentally enhancing by decreasing exploitation of the environment for needed resources; (6) NR crops with a diverse genetic base could be grown in new crop rotations that may reduce external inputs and conserve nonrenewable resources; and (7) US rubber could be exported and contribute to decreasing US trade deficits.

A collaborative research project was initiated in 2001 to transform sunflower into a rubber-producing crop. The overall objectives of this research project on sunflower were to: (1) insert genes to optimize rubber synthesis into sunflower; (2) develop the agronomy for genetically-engineered, rubber-producing sunflower; (3) evaluate genetically-engineered, rubber-producing sunflower for insect and disease pests when grown under cultivated conditions; (4) develop crop enterprise budgets, and processing and product analysis for genetically-modified, rubber-producing sunflower; and (5) identify and partner with agribusinesses, farmer organizations, and private industries for crop production, processing, and utilization of rubber and co-products produced from

Table 1. US farmland needed using annual crops for domestic and potential export markets.

Type of rubber consumed	Production (t)	Hectares (acres) × 1,000 required to meet production ^z
US natural rubber used for manufacturing	349,000	389 (961)
Total US natural rubber consumed	1,157,000	1,291 (3,188)
Total world natural rubber consumed	6,607,000	7,372 (18,202)
Total US synthetic rubber consumed	2,354,000	2,627 (6,485)
Total world synthetic rubber consumed	9,857,000	10,998 (27,156)
Total world rubber consumed	16,464,000	18,381 (45,385)

^zAssumes dry matter production at 8,950 kg/ha (8,000 lbs/acre) and 10% rubber content.

rubber-producing sunflower. Successful completion of these research objectives leading to eventual commercial production of a rubber-producing sunflower would have enormous benefits to society.

SUMMARY

Natural Rubber is an important biomaterial needed for our modern standard of living. Production of NR is concentrated in Southeast Asia with most of total world production coming from five countries in that region. The United States is dependent on imports of NR. Given the current and projected demand worldwide, the overall situation for NR in the near and long-term future appears volatile. For more than 100 years there have been concerns about having a sufficient NR supply to meet US needs. Commercial production of NR-producing crops in the US would have huge benefits to society. A number of researchers over the years have investigated the potential of identifying plant species that would be suitable for NR production in the United States. They concluded that it appears feasible to develop a United States NR crop. The ideal NR-producing crop plant would have several important characteristics and have been noted in this paper.

Leaves of sunflower produce a small amount of low quality NR. Sunflower appears to be an excellent candidate as a potential source of cultivated rubber for six major reasons as noted above. Several researchers have postulated there is a high genetic potential for increasing the NR content of cultivated sunflower. As a rubber-producing plant, sunflower has the potential to meet the US rubber needs and for marketing high quality manufactured rubber products in international trade.

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