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Management Board

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Contractor's Report

To The Board

Feedstock Conversion Project Report

Produced Under Contract by:

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Introduction

This report summarizes the Feedstock Conversion Project. The California Integrated Waste Management Board contracted with R.W. Beck to conduct this project as part of a broader contract to manage the Tire-Derived Product Business Assistance Program (TBAP). Feedstock conversion in the context of this project refers to efforts to encourage existing manufacturers to convert a portion of their current raw material feedstock needs to recycled tire rubber. The Feedstock Conversion Project is one of six "industry and sector wide projects" under the TBAP program, and has the goal of increasing and diversifying demand for California-produced ground rubber. This is part of a broader strategy to strengthen scrap tire markets and achieve the Board's goal of a 90 percent scrap tire diversion rate by 2012. The main focus of the project is increasing and diversifying demand for fine ground rubber produced from passenger and light truck tires, as opposed to buffings derived from retread operations. While no California-based producers currently regularly produce fine ground rubber (i.e., 80-200 mesh and smaller), several have the potential to if demand were sufficient.

The project was undertaken from late 2008 through early 2009 by R.W. Beck, along with four subcontractors. Bottom Line Consulting provided expertise on rubber and plastic manufacturing practices, worked directly with candidate firms and drafted much of the technical analysis presented in this report. Outreach to candidate firms was conducted by DK Enterprises, Tinney Associates and the Corporation for Manufacturing Excellence, in addition to R.W. Beck.

The five sections of this report summarize the project activities and results including:

- A summary of outreach efforts to identified candidate firms;
- A description of feedstock conversion in the rubber manufacturing industry;
- A description of feedstock conversion in the plastics manufacturing industry;
- An overall assessment of California feedstock conversion opportunities and barriers, including an estimate of the market potential; and
- Conclusions and recommendations.

Outreach to Candidate Firms

The initial focus of the feedstock conversion project was to identify California firms that are candidates for feedstock conversion and to conduct outreach to them with the aim of: a) encouraging them to convert to use of ground rubber for all or a portion of their raw material needs; and/or b) encouraging them to apply to the TBAP program to receive technical assistance towards that goal and allow the TBAP team to both provide assistance and build capacity for future feedstock conversion efforts.

To develop the list of feedstock conversion candidates, R. W. Beck compiled contacts from a number of sources that identify California plastics and rubber firms, as shown in Table 1.

Table 1 Sources of Business Contact Information Consulted

Source Organization	Business List Description
CIWMB	Online Recycled Content Product Directory
Consulting Team	Lists of Firms Identified through TBAP Program Work and Other Activities
ThomasNet	Online Commercial Products Directory
Scrap Tire News	2008 Scrap Tire and Rubber Users Directory
Rubber Product News	Rubber Industry Directory
Rubber Manufacturers Assoc.	Membership List and Review of Online Scrap Tire Publications

R. W. Beck created a master list of companies located in California by consolidating the above sources. The amount and quality of information on each company varied from source to source.. Depending on the source, company's information varied from basic contact information to specific products the company manufactured and the manufacturing process used.

We initially added a broad range of companies from both plastics and rubber industry sectors. While not feedstock conversion candidates, we also included firms that already had received assistance through the TBAP program, or that were known to already be manufacturing products from tire derived rubber. This was done so that, as the project progressed and we came across company names as potential TBAP participants, we would be able to verify their status based on information already on file. We also added a few companies located outside of California to our contact list if, by personal referral, we were informed that they were interested in potentially opening a new location in California.

Certain types of plastics or rubber industry businesses were not added to the Feedstock Conversion project contact list. These companies manufacture products that are clearly not candidates for incorporating crumb rubber in the products made, such as medical device manufacturers or thin blown film applications.

Once we had an initial contact list compiled, we uploaded the data into a web-enabled client relations management and sales tracking database called SalesForce.com. While the total number of rubber and plastics firms in California was estimated at approximately 720, the initial compiled list (excluding some categories of firms that were not downloaded into the initial database) contained 546 contacts. The list was refined by excluding existing recyclers and multiple contacts for the same firm, resulting in a candidate list of 345 firms. The list was then portioned out and distributed to the outreach team (including sub-contractors Tinney Associates, DK Enterprises and Bottom Line Consulting) for further prioritization. The team was tasked with prioritizing the contact list by ranking certain business types higher than others if the products they made or processes used offered better opportunities for feedstock conversion. At this stage the analysis and prioritization process was limited by gaps in the database, limits on time and budget and a desire to cast a fairly wide net in order to investigate a wide range of feedstock conversion opportunities. For example, firms identified as priorities included: companies known to have an established interest or involvement in recycling or "green" products; medium sized firms with sales roughly between $20 - $75 million (i.e., firms that have sufficient resources to consider process adjustments and that may be particularly interested in identifying new marketing advantages) and firms with products or processes that appeared to be good candidates for feedstock conversion (this is discussed further in the remainder of this report).

The resulting refined list of candidate firms contained 260 companies, approximately 220 of which were called directly to discuss the use of ground rubber and to inform them about the TBAP assistance services and the upcoming solicitation. Of those, 48 were deemed to be "high priority" for the purposes of the project's outreach efforts, and received multiple follow-up calls. In three cases, technical consultations were arranged with Bottom Line Consulting, the project's manufacturing process expert.

In addition to the direct calling, R. W. Beck also conducted a mass mailing via email and regular mail. The outreach material consisted of an introductory letter from R. W. Beck which gave a high-level introduction to the benefits of using ground rubber, as well as general information about the TBAP grant program, similar to that which was distributed to all prospective TBAP applicants. The traditional mail was sent to over 300 companies (including some which had been eliminated from consideration for phone outreach) and the email was sent to 188 companies for which we had functioning email addresses.

As outreach was conducted, many of the firms contacted were categorized as "not interested" or otherwise filtered from the process further. The most common reasons for excluding at this point were:

- The company was not interested in using crumb rubber;
- The company was no longer in California or did not plan to be in California;
- The company did not believe rubber would work in their particular process; and
- They were strictly a product distributor or sales representatives.

Based on this process and the outreach conducted, 25 companies were identified that appeared to be good candidates and who specifically expressed an interest in exploring the opportunities further. (The specific company names will be provided to CIWMB via separate, confidential memorandum.) The companies interested generally fell into the following groups:

- They currently use rubber, but not ground tire rubber;
- They are a plastic processor or converter who is interested in finding out if recycled rubber will add value or reduce costs;
- They are a manufacturer looking for new products or line extensions; or
- They are simply interested in growing their business with outside funding.

The main questions and concerns expressed by these firms were typically related to: a) The technical aspects of manufacturing with ground tire rubber; b) The availability of supply, especially issues of cost and quality; c) Any other ancillary risks or costs such as equipment replacement, or other issues that may impose a cost on their operations; and d) The potential for receiving funding or support from the Board.

Of this list, seven firms ultimately applied to the TBAP program during the April 30, 2009 cycle. Given the challenges inherent in feedstock conversion, this was considered a very positive result. At the time of writing this report, these firms were being assessed through the TBAP program to confirm eligibility and to determine the most appropriate services that will best achieve feedstock conversion and other firm-specific objectives.

Rubber Feedstock Conversion

Overview

Feedstock conversion has potential to diversify and expand markets for ground rubber. As shown in Table 2, R.W. Beck estimates that in 2008 approximately 22 percent of California scrap tires (just over 10 million passenger tire equivalents) were used to produce over 130 million pounds of ground rubber. Molded & extruded product accounted of 11 percent of the total market for ground rubber. While currently a relatively small portion of ground rubber use, the molded & extruded category is a broad category that could include a large number of "feedstock conversion" product types. Expanding and diversifying current demand for ground rubber through feedstock conversion is desirable because it can:

- Increase diversion rates through relatively high value end-products that strengthen overall scrap tire recycling economics;
- Use recycled rubber in well established products produced by long-standing, viable manufacturing businesses; and
- Provide synergistic benefits by demonstrating the wide range of potential uses, thereby further expanding demand and institutionalizing ground rubber as a mainstream manufacturing raw material.

Table 2
Estimated Ground Rubber Shipments by Market Category

Category	2007		2008	
	Pounds	Percent of Total	Pounds	Percent of Total
RAC & Other Paving	50,922,824	43%	56,204,040	43%
Turf & Athletic Fields	32,394,927	27%	31,742,828	24%
Loose-Fill Playground	7,330,652	6%	10,102,434	8%
Pour-in-Place Playground	3,432,920	3%	5,803,831	4%
Mulch/Bark	5,019,868	4%	4,839,672	4%
Horse Arena Materials	1,570,160	1%	1,056,600	1%
Molded & Extruded	13,213,736	11%	14,992,707	11%
Other	5,885,320	5%	5,925,098	5%
Total	119,770,407	100%	130,667,209	100%

Source: R.W. Beck, Inc.

The remainder of this section describes feedstock conversion opportunities in the California rubber industry. The next section covers opportunities for using ground rubber in the California plastics industry.

The Rubber Manufacturing Industry

The rubber manufacturing industry involves a series of processes from compounding of raw materials through product manufacturing. The first step is to soften the crude, virgin rubber raw materials. This is accomplished by subjecting the rubber to mechanical work, predominately in two-roll mills or high intensity mixers. This softening of the crude rubber allows uniform mixing of the various formulation ingredients. After all ingredients are properly mixed, the compounded "green stock" is tacky and thermoplastic. In this form, the stock can be formed to a desired shape by, for example, squeezing it between rolls (calendaring) or pushing it through a die to the desired shape or compression molding into a finished part. The shaped green stock is vulcanized to achieve full elastomeric properties. This is achieved by subjecting the part to high temperatures and pressure to form the desired cross-linked structure. This cross-linking of rubber is also referred to as curing because it converts raw materials into useful products.

Ground rubber produced from tires can be used in rubber compounds by substituting it in the base formulation for crude, virgin rubber and adjusting the formulation of ingredients accordingly for the presence of a fully vulcanized rubber component. High intensity (efficient) mixing is critical to realizing optimum properties with the addition of recycled ground rubber. And, the ground rubber typically must be very fine, at least 200-300 mesh.

Examples of Rubber Products with Feedstock Conversion Potential

The manufacture of rubber products starts with a list of product specifications, desired pricing, and selection of the processing to be used. It is then the job of a trained engineer or chemist to develop the most cost effective formulation to meet the performance requirements. Most rubber compounds contain twelve or more ingredients and the recipes are highly customized and proprietary. A generalized rubber formula is presented in Table 3 below.

Table 3 Generalized Formula for Rubber Products

	Parts/Hundred of Rubber
Crude rubber	100
Filler	50
Plasticizer	5
Antioxidant	1
Stearic Acid	1
Zinc Oxide	5
Accelerator	1
Sulfur	2
Total	165

Each ingredient has a specific function, either in processing, vulcanization, or product end-use. The ingredients can be classified according to their specific function as follows:

- Crude rubber – the base non-vulcanized feedstock which in many cases is more than one type of rubber. Combinations of natural and synthetic rubbers are common and typically used to expand the balance of properties beyond that which can be achieved with a single rubber.
- Fillers are added to crude rubber in relatively large proportions primarily to make the finished product less expensive. There are two main categories of fillers used in rubber compounds: carbon blacks and non-black fillers. Examples of non-black fillers are clays, calcium carbonate, anhydrous silicas, and silicates.

- Plasticizers are incorporated for a number of purposes in rubber compounds. They are sometimes used to reduce product cost or as a processing aid or as a modifier for certain vulcanizate properties. Petroleum oils are the most widely used extenders and processing aids.
- Antioxidants are added to minimize degradation caused by aging, thus extending the life of the product. Various additives are used to protect the product form ultraviolet light, heat, cyclic deformation, radiation, or high humidity.
- Vulcanizing ingredients are incorporated into rubber compounds in order to insert cross-linkages between the polymer chains when the compound is heated to an appropriate temperature. Sulfur is the main vulcanizing agent for most crude rubbers, zinc oxide generally acts as a vulcanizing agent, and accelerators speed up the vulcanizing process.

There are a number of commercial products where the inherent properties of ground tire rubber may have added value compared to virgin rubber raw materials. A partial listing includes:

- Window and door seals/gaskets;
- Automotive mud flaps;
- Wheel well spray sealants;
- Floor mats;
- Carpet underlay;
- Flooring and tiles;
- Industrial belts and rollers;
- Vibration pads;
- Wheel chocks;
- Drains and downspouts;
- Soaker hose;
- Floating docks;
- Dock bumpers;
- Rubberized asphalt;
- Crack sealant;
- Sports/playground surfacing;
- Expansion joints;
- Sound barriers;
- Guard rail components; and
- Roofing shingles.

Table 4 below presents one estimate of the potential market nationally for certain categories of ground rubber.

Table 4
Estimated Demand for Ground Rubber in Bonded Rubber Products

Category	2007 Estimated Ground Rubber Demand (Million Pounds)	Estimated Annual Growth
Agriculture Stall/bed mats, pavers, trailer liners	150	4-6%
Automotive/Transportation Miscellaneous components, load securement, bed mats, car mats	60	3-5%
Construction/Indoor Sports/commercial flooring, mats, acoustics, underlayments, ballistics	85	6-8%
Construction/Outdoor Commercial surfacing, safety surfacing, roofing, marine, pour-in-place products	120	4-6%
Consumer Floor and door mats, bulletin boards, interlocking tile, mouse pads, shoes, etc.	28	12-14%
Total	**443**	

Source: Presentation by Art Dodge, President and CEO, ECore. Presented at the April 2009 conference of the Institute of Scrap Recycling Industries

Plastic Feedstock Conversion

Overview

The use of ground rubber in plastic products is growing nationally. As with rubber products, ground rubber of a very high quality and small size (ideally 200-300 mesh) can provide cost and performance advantages in certain circumstances. Coarser ground rubber can also be used in some applications.

The Plastics Manufacturing Industry

There are two main areas for feedstock conversion in the plastics industry that provide potential benefits, as well as one additional areas (fillers) that may be feasible, but offers less advantages. These are described below.

Modification

The largest potential for ground rubber use in plastics is as an impact modifier, displacing established rubbers. As an example, the type of synthetic rubber used in tires is styrene-butadiene rubber (SBR) and it is commonly used to improve the toughness of polystyrene. Properly sized, surface-treated ground rubber can be used as an alternative to SBR in certain grades of polystyrene.

Typically, an impact modifier is added to the base plastic material at levels ranging from 10 percent to 25 percent. The range of use is dependent on the desired or required product performance.

Cross-linked rubber from recycled tires offers several advantages as an impact modifier or compounding ingredient in plastics. The cross-linked structure inherently provides improved cushioning, toughness, resiliency, abrasion resistance; chemical, thermal, and ultraviolet light stability, and low slip.

This allows the plastic material to be used in higher-valued durable applications where long-term product performance is essential. Unfortunately, there are some tradeoffs. Impact modifiers (whether they be ground rubber or other soft materials) can reduce the strength, stiffness, and hardness of plastics.

Plastic/rubber properties are tailored for specific product needs by carefully adjusting the ingredients and/or formulation. This balancing of the strength and toughness characteristics of rubber in plastics results in optimum properties at lowest cost.

Thermoplastic Elastomers (TPEs)

TPEs are combinations of single plastic resins, such as polypropylene, polyethylene, polystyrene, thermoplastic polyurethanes, or polyesters with natural or synthetic rubbers. Typically, the rubber content is about 75%. These natural or synthetic rubbers can be virgin or recycled materials.

The dominant rubber constituent has been synthetic materials such as ethylene propylene dimer (EPDM) and styrene butadiene rubber (SBR). However, the use of tire-derived crumb rubber in TPEs is an emerging and proven market for value-added opportunities.

The resulting combination maximizes the synergy between strength and processing characteristics of plastics and the ductility of rubber. Primary markets for TPEs include automotive, industrial, appliances, lawn and garden, electronics, power tools, and sporting goods.

Fillers

The use of ground rubber as filler in various plastic compounds was initially investigated. The main purpose of fillers is to reduce cost and displace more expensive plastic. A secondary benefit is they add stiffness to the plastic matrix.

There are a number of commercial fillers available, most notably talc, calcium carbonate, and mica. These minerals are widely available in very fine particle sizes and, as a result, market prices are quite low.

Unfortunately, most fillers are sold at prices <$0.10/pound and therefore ground rubber which is typically sold at or above this price does not provide any cost advantage. There are some ultra-fine coated grades that are marketed at prices near $0.20/pound. Our initial investigation concluded that this market does not offer value added opportunities for ground rubber and should not be considered for feedstock conversion.

Examples of Plastic Products with Feedstock Conversion Potential

Incorporating recycled ground rubber into commercial plastic product can add performance benefits and replace virgin material.   In rigid plastics ground rubber improves the durability and toughness and in elastomeric plastic ground rubber can replace natural and synthetic virgin rubber with similar or better performance. In a number of these products, the benefit to using ground rubber can include reduced material cost, enhanced product performance, and competitive market advantages from incorporating recycled-content. A partial listing of top candidates for feedstock conversion includes:

- Composite roof tiles;
- Roofing membranes;
- Solar panel framework;
- Basement foundation water proofing material;
- Soft feel handles for hand tools and garden products;
- Automotive bumpers strips, bumper pads, wheel flares, and step pads;
- Automotive soft interior trim;
- Truck cargo box side rails and tailgate covers;
- Tool and tackle boxes;
- Insulating strips for automotive and household use;
- Landscape edging and boards;
- Acoustical office panels;

- Soft components in household appliances;
- Thermoformed pallets and component shipping containers;
- Tractor and RV roof panels and running boards;
- Composite lumber;
- Loading dock bumpers;
- Marine docks and bumpers; and
- Office products.

Feedstock Conversion Opportunities and Barriers

Overview

This section summarizes opportunities for promoting feedstock conversion, beginning with a description of the highest potential areas grouped by manufacturing process, raw materials and types of companies. Next, advantages and barriers to using ground rubber as manufacturing feedstock are presented. The last part of this section estimates the potential demand for ground rubber via feedstock conversion in California.

Manufacturing Processes with the Highest Potential

Suitable manufacturing processes for use of ground rubber/polymer compounds or rubber compounds would be ranked as follows:

1. Injection molding
2. Industrial sheet extrusion and thermoforming
3. Profile extrusion and pultrusion
4. Compression molding
5. Structural foam molding

Compression molding is the most ground rubber friendly process but is becoming less widely used and is limited in California. Therefore, it is not rated higher.

Certain manufacturing processes eliminate the potential for ground rubber as a feedstock. Due to the nature and particle size of ground rubber, it cannot be used in thin products or products requiring hot melt strength. This eliminates blown and cast film, many thermoformed and blow molded products, and thin-walled injection molding. Rotationally molded parts should not be considered as the flow properties of ground rubber/polymer compounds are not sufficient for this process.

Following is a brief summary of the manufacturing processes that are suitable for ground rubber use, as well as three others not recommended for feedstock conversion. Among the processes included, extrusion, compression molding, and reaction injection molding (a form of injection molding) are most commonly used in the rubber industry, while all of these processes are used in the plastics industry.

Injection Molding

The most common method of producing plastics parts of most any shape is injection molding. The ingredients are melted and homogenized inside the molding machine, which is similar in many ways to an extruder, except it is typically shorter. A measured amount of material is injected under high pressure into a mold. Cooling channels in the mold reduce the temperature of the part to a point where it will hold its shape. The part is then ejected, the mold closes, and the cycle begins once again. An abbreviated product list of injection molded parts would include phone, appliance, computer, and speaker housings, compact discs, tool boxes, office products, solar cookers, remote controls, automotive bumpers, and recycling bins.

Sheet, Extrusion and Thermoforming

Sheets products are basically flat in shape with thicknesses of 0.01 inch to 0.5 inch and widths at least up to 10 feet. End-products include slip sheets, window glazing, semi-truck trailer sidewalls, and an intermediate product for thermoforming.

One California company uses an extrusion process combined with a compression molding process to manufacture customized drains used in road construction and other applications. The process uses both ground rubber and recycled plastic, mainly agricultural film. In an extruder, heat and pressure are used to melt thermoplastic materials and force the melt through a die to the desired shape. Once through the die, the product, in most cases is cooled by water, either by water spray or water bath or a combination of both. The process is continuous and is best suited for producing parts with a uniform linear shape. There are three major categories of products produced by extrusion. Formed profiles are a large subset of extrusion, with products ranging from house siding, fencing, and pipe, to decorative moldings, decking lumber and rails, landscape edging and boards, and automotive bumper strips.

Thermoforming is a plastics manufacturing process that involves raising the sheet temperature to a point near its glass transition temperature where molecules can move but are not in a liquid state yet. Pressure (or vacuum) is applied once the sheet has uniformly reached its thermoforming temperature. This forces the sheet into a cold mold of the desired product shape. Products made by thermoforming include refrigerator liners, in-house material handling trays, yogurt tubs, fruit containers, egg crates, blister packaging and clamshells, and scanner lids.

Pultrusion

This is a specialized process used to make continuous lengths of high strength, typically glass-reinforced, profiles. The plastic resin, ground rubber and reinforcing material are combined in the extruder then pulled through the shaping die to form the part and orient the fibers. Examples of products include platforms, handrails, stair steps, beams, building panels, industrial tool handles and snow markers.

Compression Molding

Several California and national firms use compression molding to manufacture mats, dock bumpers and other products from ground rubber, as well as from virgin rubber. This is an older process initially developed to manufacture parts from thermosetting materials, such as urethanes, epoxies, melamine, and rubber. Thermosetting resins become finished parts as a result of an irreversible chemical reaction between the ingredients. Unlike thermoplastic materials, that can be remelted and reshaped repeatedly, thermoset parts are chemically bonded or cross-linked and do not melt. The process of compression molding is quite simple. The ingredients are placed or fed into a heated mold cavity, the top cavity is closed, and the combination of pressure, catalyst, and temperature promotes the chemical reaction and the part sets up. Large housings and industrial components are typically compression molded, many for automotive, aerospace, rapid transit, and furniture applications.

Structural Foam

This process is essentially an extension of injection molding, used in plastics manufacturing. The main difference is that a blowing agent is added to the formulation to produce a uniform cellular structure rather than the solid structure of injection molded parts. This extends the application for injection molding to much larger parts. Another advantage of structural foam is it allows the production of a thicker less dense part. Thicker parts achieve higher stiffness because part rigidity is related to part thickness to the third power. Products made by the structural foam process include large electronic panels, tool boxes and storage bins, and automotive components.

Blow Molding

This is a process best suited for hollow parts such as plastic bottles, blow molding is primarily accompanied by melting and mixing the resin, ingredients, and additives in an extruder, then forcing the molten material through a die. The molten material is allowed to sag at a controlled rate basically forming a hollow cylinder called a parison. The blow mold automatically clamps around the parison and air forces the molten material into the mold shape. After cooling the part is ejected. A two-step process is used for some applications, most notably PET soda and water bottles. This involves injection molding a preform (looks like a test tube with threads) and then indexing the preform to a blow station where it is blown into the mold shape. Most plastic bottles are produced by blow molding as well as large industrial drums and some electronic housings.

Blown Film

Most all plastic bags are produced by a process that in many ways is similar to blow molding. The resin, ingredients, and additives are fed into an extruder for melting and mixing, then forcing the material through the appropriate die shape. Many films are less than 0.001” thick so the process controls are extremely tight so that a uniform wall film is produced. The molten polymer exits the die as a very thin-walled upward flowing ring of material that is air cooled. Air is blown inside the ring of material to expand it to the desired diameter. Once cooling solidifies the polymer, the film is drawn vertically upward by a nip assembly, collected and prepared for further processing, such as shaping, creasing, or perforating. There are a number of other processes used to manufacture plastic and rubber products but these tend to be specialized and insignificant compared to those processes described above.

Raw Materials with the Highest Potential

The project team believes that manufacturing raw materials with the highest potential for substitution by, or combination with, ground rubber generally have one or more of the following characteristics:

- They are commonly impact modified;
- They are generally chemically receptive to the incorporation of a cross-linked material;
- They are established commercial materials; and
- They are used in higher-valued markets and applications.

The following six materials were identified as examples of manufacturing raw materials that meet some or all of the above criteria, and therefore are potentially suitable for being substituted with, or combined with ground rubber in manufacturing processes.

- Thermoplastic elastomers (TPEs);
- Virgin rubbers;
- Polystyrene;

- High density polyethylene;
- Thermoplastic polyesters; and
- Polyurethanes.

Types of Companies with the Highest Potential

Based on the project team's research and experience in feedstock conversion, the following profile was developed for companies with the highest potential to use ground rubber in rubber, rigid plastic or elastomeric products.

- *Captive Manufacturers* – These are companies that market products directly to consumers and manufacture them on-site or at company-owned manufacturing locations. Captive manufacturers are in total control of the decision making process and can act quickly to meet changing market demands. Therefore, changes in materials to incorporate recycled-content or performance testing of those new materials can be quickly implemented. These companies are quite innovative and continually strive for competitive marketing advantages that feedstock conversion offers.
- *Consumer Product Companies and Original Equipment Manufacturers (OEMs)* - These companies know the pulse of the marketplace and respond rapidly to new developments, such as feedstock conversion. They outsource plastics production to regional custom processors. A motivated consumer product company or OEM provides the driving force and pressure on their suppliers to respond to change. In some cases, these companies will work with supplier(s) to develop new recycled-content products. Once the product is commercial, there is an established captive market for its use.
- *Innovative Custom Processors* - Some forward thinking custom processors recognize the value of recycled-content and sustainability. Their business model sets targets that must be met. They are motivated to develop environmental products for their own competitive market advantages. These products are typically marketed to their customers but, in some cases, have become their own product brand.
- *Mid-Sized Companies* – Companies with annual sales of $20-$75 million are often more innovative and willing to put people and financial resources into commercializing new products that give them a competitive advantage over their larger competitors. Smaller companies tend to be in a survival mode and are focused on short term profit targets rather than long-term growth.
- *Green Companies* – Companies with a demonstrated commitment to manufacturing with recycled materials or otherwise pursuing "green" strategies are often more open to consideration of new concepts such as feedstock conversion.

Potential Advantages of Ground Rubber as Manufacturing Feedstock

Cross-linked rubber from recycled tires offers a number of advantages as an impact modifier or compounding ingredient in plastics and rubber products. The cross-linkages chemically bind rubber molecules together into a thermoset structure providing excellent toughness, stability, and structural properties. The main performance benefits of incorporating ground rubber are:

Toughness – The rubbery nature of ground rubber allows it to perform extremely well as an impact modifier in certain plastics. As mentioned, polystyrene is particularly suited to rubber modification. Crystal polystyrene is the stiffness and strongest grade of non-reinforced polystyrene. As is the case with most plastics, the higher strength offered by a highly crystalline (ordered) structure comes with one major trade-off. The plastic is brittle and must be impact modified if used in tough durable products. Virgin resin companies use several synthetic rubbers to modify virgin polystyrene during its manufacture. The most common is styrene-butadiene rubber (SBR). Surface-coated ground rubber, which contains SBR, can be compounded into crystal polystyrene and achieve a similar effect.

Cushioning – Another benefit of incorporating ground rubber is it softens plastics and induces a cushioning property. This is especially true as the rubber content becomes the major component and the product is referred to as a thermoplastic elastomer.

Resiliency – The ability to withstand shock without permanent deformation is another important feature of rubber. It does recover from most impact blows and conveys that property to the material it is incorporated with.

Abrasion Resistance – The thermoset structure and toughness of rubber provide good resistance to surface wear or grinding by friction. Proper formulation and surface coating are critical to achieving acceptable wear resistance.

Low slip – An inherent property of rubber is its surface characteristic of being non-slippery. This property prevents sliding and is particularly valuable in flooring, conveyor belts, and truck running boards and bed liners. Improved chemical and thermal resistance – thermoset materials, such as rubber, generally have better chemical and thermal stability than thermoplastics. This is because the cross-linked structure cannot be dissolved or penetrated by chemicals and, essentially, there is no melting point.

Ultraviolet Light Stability – Passenger and truck tires typically contains 25-30 percent carbon black. Carbon black is an extremely effective ultraviolet light stabilizer and commonly used in plastics for that purpose. When incorporating recycled ground rubber in plastics, the actual benefit is dependent on the amount and type of carbon black contained in those tires as well as the percent incorporation.

Sustainability – Extending the life of our limited resources is a national goal and recycling used tires into long-term durable products can make a significant contribution to that goal. Competitive market advantages can be developed by companies providing recycled-content products to proactive environmental customers.

Cost Savings – The value for ground rubber in rubber/plastic products and compounds is set by the marketplace and strongly affected by supply/demand, quality, competition, and purchase quantities. In the past, ground rubber suppliers have not been particularly adept at providing their product in the proper form or with the proper surface coating to potential customers. Ground rubber sold into plastic or elastomeric applications must be "fine grind rubber" meaning a particle size no greater than 80 mesh and, in some cases, 200 mesh or finer.

Mesh sizing is defined as the number of holes in a one inch standard wire screen; the higher the number the smaller the particle size. The largest particles that would go through an 80 mesh or 200 mesh screen are, respectively, 0.007” and 0.0029”.

Low cost ground rubber is readily available and inexpensive. However, the most common particle size is 10-30 mesh, which means the particles are as big if not bigger than the wall thickness of many plastic parts. Plastics industry experience has proven that adding these larger rubber particles to plastics actually reduces the toughness and impact strength of the parts. The large particles act as stress concentrators and embrittle the molded or extruded parts.

Cost savings are there for proactive companies willing to implement programs where ground rubber is used as a lower cost alternative to an existing impact and/or property modifier. These value added products are typically sold at $0.35 to $1.25 per pound. However, if the property benefits of ground rubber exceed those of the existing modifier, then there is value added benefit to the company. These are not commodity applications where the only consideration is cost.

Barriers to Using Ground Rubber as Manufacturing Feedstock

Some of the main barriers to promoting feedstock conversion include:

Ground Rubber Quality – There is a perception in the industry, rightly or wrongly, that the quality of ground rubber is poor and inconsistent. Suppliers have not invested in newer technology to automate and improve quality, partly because margins are so slim they cannot afford to do so. Most current markets are commodity applications where customers make purchase decisions solely on price. Feedstock conversion markets require higher quality and consistency in ground rubber. By the nature of the product, purchasing decisions are based on the combination of price *and* performance. Ground rubber quality must be very high to allow penetration into feedstock conversion markets.

Particle Size – The finer particle sizes (≤ 80 mesh), smoother surface, and narrower particle size distribution required for feedstock conversion are currently not available from California suppliers. Fine ground rubber must currently be shipped to California from the Midwest or east coast. These shipping costs are significant and may cause some projects to be too costly to implement. Pricing, in the short term can be high for fine particle size ground rubber due to the limited supply of the fine particle sizes. As demand increases due to increased market development efforts, new supplies will be started up and the raw material shortage will subside. CIWMB has adopted a policy that firms receiving assistance through the Tire-Derived Product Business Assistance Program may receive a temporary exemption from the requirement to use California generated ground rubber if it is not available in state. This is intended to facilitate the Board’s efforts to promote feedstock conversion.

Color – Like the Model T, ground rubber comes in any color you want as long as it is black. This certainly limits its use in many consumer product and distinctive color applications. This is not a major barrier to feedstock conversion but must be recognized as a limitation. New equipment to handle cross-linked rubber – as discussed in this report, the cross-linked structure of ground rubber provides many of its value-added properties. However, this structure also means that conventional processing equipment used in the plastics industry, which is highly based on simple melting/mixing of the raw material will have to be augmented with additional equipment. In many cases the added value of ground rubber will support this expenditure. There other cases where new capital costs is not under consideration.

Regulations – In some cases the Food and Drug Administration (FDA) has set some very stringent requirements for the use of post-consumer content in food, drug, and medical applications. Some certifications, such as NSF, still specify that only virgin materials be used in products submitted for their approval.

Odor – There have been some cases where molded or extruded products retain and emit a burnt rubber odor. This is likely due to overheating ground rubber during the grinding and manufacturing steps or contaminated material. In either case, this would obviously prevent ground rubber from being used in many feedstock conversion markets.

Estimated Market Potential

The project team developed a rough estimate of the potential demand for ground rubber through feedstock conversion in California, based on statistics on California manufacturers and assumptions about raw material supplies, costs and the potential for conversion to ground rubber. The approach relies heavily on the project team's industry experience, research, and knowledge of the markets and firms in California. While this is the best estimate available at this time, it is also subject to much uncertainty and should be considered as a rough estimate for illustration purposes.

The estimate is based on data on California manufacturers contained in ThomasNet (www.thomasnet.com). While this is the same source that was used to develop the initial database of firms used for feedstock conversion outreach activities (as described above), this was a separate exercise conducted independently of that previous task.

Following is a brief description of the estimation process and results.

1. We completed an initial review of the company profiles available within ThomasNet to confirm that it was reasonable and would be useful as the baseline for our market potential estimate.

2. We searched ThomasNet for plastics and rubber companies in California, and then to the extent possible with accessible information narrowed the search to those materials, processes, and products that representing the bulk of feedstock conversion opportunities.

3. We eliminated major duplications and some obvious errors in the resulting listing of firms. This resulted in a list of 718 firms.

4. We developed a rough estimate of the average number of pounds of raw material used by the 718 companies based on their average dollar sales. ThomasNet provided average company sales for each firm in ranges. The project team used midpoints of these annual sales and computed an overall firm average of $8 million. We assumed that raw materials represent approximately 33 percent of annual sales values, and an average market value of feedstock conversion raw materials as $0.60 per pound. Therefore, the total raw material usage is roughly $2.64 million divided by $0.60 per pound or 4.4 million pounds per firm, or a total of 3.2 billion pounds.

5. We assumed that one-third of these companies could realize advantages through feedstock conversion, whether cost reduction, performance enhancement or green marketing advantages, bringing the potential to 1.04 billion pounds.

6. We then assumed that on average 25 percent of products made by these companies have potential to use ground rubber, bringing the potential down to 260 million pounds.
7. We further assumed that the average commercially viable potential ground rubber content in these products is 20 percent, bringing the market potential estimate down to 52.1 million pounds per year.

Thus, based on the assumptions above, the project team developed a rough estimate of the potential demand for ground rubber through feedstock conversion in California of about 52.1 million pounds, or about a 40 percent increase over current ground rubber production that would push California ground rubber from 22.4 percent of scrap tire use to about 33.1 percent.

This estimate of feedstock conversion market potential is very rough and subject to much uncertainty. However, it does indicates that there is potential for significant ground rubber demand through this strategy, possibly sufficient demand to encourage an existing or new California ground rubber producer to invest in the capability to supply large quantities of high quality fine mesh ground rubber in the 200-300 mesh range.

On the other hand, the above analysis and estimation also indicates that there are many challenges involved, and while feedstock conversion in California could yield a significant increase in ground rubber production over current levels, it is not likely to increase demand to a level where most California scrap tires could be recycled as ground rubber.

Conclusions and Recommendations

The Feedstock Conversion Project is one of only a handful of efforts to systematically explore the potential for replacing "virgin" feedstocks with recycled rubber in a range of manufacturing environments, and the first in California.

The key conclusions of this effort are:

- Feedstock conversion is extremely challenging and time consuming. This is because of the time and expense required to contact multiple firms, and their understandable reluctance and constraints in considering critical changes to their established manufacturing processes and formulations.
- Despite the challenges, the project team was surprised to encounter a significant amount of interest in feedstock conversion. This was probably due in part to the extreme spike in petroleum based raw materials during the middle of 2008. Although the spike had subsided when outreach was conducted, manufacturers were well aware that it could return, and their interest in identifying cost saving raw material changes was very strong, especially when there is potential for performance enhancements and green marketing advantages.
- Most firms will require a significant amount of time and effort to investigate feedstock conversion opportunities. State support could be a critical factor in helping them to make the commitment and ultimately to make the conversion.
- The long-term potential for feedstock conversion could be in the range of 52 million pounds per year of ground rubber, although this estimate is very rough. This would represent a 40 percent increase over California ground rubber production in 2008. While this is a significant amount, it would increase the use of California scrap tires in ground rubber from about 22.4 percent of all scrap tires to about 33.1 percent, suggesting that feedstock conversion may not be the "silver bullet" for scrap tire recycling rates that some might hope for.
- While the State of California is not likely to have the resources available to conduct outreach and provide technical assistance to a large percentage of the state's potential feedstock conversion firms, anecdotal evidence suggests the high potential for a "snow ball" effect if a number of firms can demonstrate success. Since feedstock conversion offers the promise of reduced costs, enhanced performance and green marketing advantages, word of mouth within industry circles may ultimately be the best promotion strategy.
- To build on the lessons learned in this project, the Board could consider a range of options, including:
    1. A systematic effort targeting select industries and manufacturers that seeks to demonstrate demand for recycled content products in business-to-business transactions where tire-derived products are used by other manufacturers (e.g., automotive, mining, agricultural and other industries).
    2. A systematic effort to explore the expanded use of ground rubber in consumer products, including exploration of supply chain leverage via outreach to retailers.
    3. Research and information dissemination to raise awareness of the potential benefits of ground rubber as a raw material.

4. Incentives to promote feedstock conversion such as grants or incentive payments to: processors (to encourage production of efficient, high quality fine grind crumb rubber); manufacturers of tire-derived products (to encourage investments in equipment and research needed to commercialize feedstock conversion opportunities); and to large manufacturers and retailers who are purchasers of tire-derived products. Incentive payments could be structured in a wide variety of ways, including payments per pound of product, a percentage of total cost, a one time payment for production changes or a rebate system.

Although challenging, feedstock conversion holds promise for expanding and diversifying the markets for recycled tire rubber in a wide range of products currently produced in California. In the latest application cycle for the Board's Tire-Derived Product Business Assistance Program in Summer 2009, several feedstock conversion firms applied for assistance services with the intent of exploring the use of ground rubber in their product lines. These firms produce products mainly for the construction industry but are also targeting other industries. The TBAP program also is considering a follow-up project that would explore the potential for promoting feedstock conversion through supply chain strategies. For example, such strategies could involve working with regional or national retailers to encourage sales of tire-derived products, or conducting outreach to key firms in select industries like agriculture or consumer products to encourage them to investigate specifying tire-derived products from their suppliers.

While feedstock conversion has the potential to significantly increase current levels of ground rubber production through sales to relatively high value markets, it may not have the potential by itself to divert the majority of California's annually generated scrap tires. However, the market place is constantly changing and new opportunities may open up as technologies, raw material pricing and consumer preferences continue to evolve.