GEOSYNTHETICS: COASTAL MANAGEMENT APPLICATIONS IN THE GULF OF MEXICO

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None of the opinions or comments expressed in this study are endorsed by the companies mentioned or individuals interviewed. Errors of fact or interpretation remain exclusively with the authors. We welcome comments and suggestions.

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Cover photos courtesy of: (clockwise from top left) Fiberweb, U.S. Government, Apollo Environmental, U.S. Government, Apollo Environmental, U.S. Government

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[1] Click here to explore an online interactive map with the full list of firms identified in this report.

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I. Executive summary

The Gulf of Mexico is an ecosystem of critical social, ecologic, and economic importance. It is crucial to the region's unique culture and cuisine and is a vital resource worth billions of dollars to the energy, fishing, shipping, and tourism industries (Gordon et al., 2011). Regrettably, decades of manmade and natural stressors have altered the functional health of this ecosystem, pushing the Gulf Coast into a state of chronic degradation (Peterson et al., 2011). Rapidly accelerating land loss is now one of the most striking features of the Gulf Coast. Since 1932, the Louisiana coast alone has lost an astonishing 1,883 square miles of wetlands. Between 1985 and 2010, an area the size of a football field disappeared every hour (CPRA, 2012; Gordon et al., 2011).

To restore the ecosystem and improve its resilience to storms and sea rise, coastal planners are increasingly implementing projects to mitigate land loss and prevent floods. Projects to mitigate land loss include marsh creation, sediment diversion, shoreline protection, and erosion control. Flood prevention measures include building dikes, levees, and floodwalls.

Nearly all of these coastal management projects use geosynthetics – manmade, polymer-based materials used in engineering applications such as infrastructure (US Fabrics, 2012). Several attributes of geosynthetic materials make them suitable for many coastal engineering designs. They can improve structure performance, reduce project time and cost, and lessen environmental impact.

U.S. geosynthetics manufacturers have rapidly evolved into a well-organized, $2.1 billion industry (Freedonia Group, 2009). Many of these firms strategically located their manufacturing facilities in old textile mills in the rural Southeast, where there is abundant labor skilled in textiles (Adkins, 2012). The North American industry will employ approximately 12,000 people in 2012 (Aho, 2012).

As a follow-up to "Restoring the Gulf Coast: New Markets for Established Firms" (Lowe et al., 2011), this study examines how geosynthetics are applied in coastal management programs in the Gulf. It analyzes what impact these materials and project designs have on the region's environment and economy.

Government agencies and various stakeholder groups in Gulf Coast states are developing coastal restoration plans that call for dozens of projects worth billions of dollars. If sufficient funds are made available to fund Gulf Coast states' restoration plans, geosynthetics may play an increasing role, creating opportunities for the geosynthetics industry and the coastal engineering profession to grow and evolve.

This study analyzes 84 firms linked to geosynthetics and the coastal management projects in which they are applied. The analysis examines several types of firms across the value chain.

Five Key Findings:

1. **Coastal management projects using geosynthetics provide job opportunities in the Gulf Coast and 31 other states.** Of the total 192 employee locations nationwide, 72, or 38 percent, are in the five Gulf States of Texas, Louisiana, Mississippi, Alabama, and Florida. The Southeast States of Georgia, North Carolina, South Carolina and Tennessee have a concentration of 49, or 26 percent of total relevant employee locations identified.

2. **Most firms are small businesses.** According to SBA guidelines on number of employees, 73 percent of the firms in our sample qualify as small businesses. Nearly half the firms reporting data have fewer than 100 employees. Most geosynthetics firms are relatively new establishments. The average age of geosynthetics manufacturers is 22 years, and a quarter of firms identified in this study were established in the last decade.

3. **Distributors play a key role in the value chain.** As the intermediary between the manufacturer and end user, distributors must convey important product information to construction firms, and are thus in a position to influence product choice. In this value chain for new and evolving geosynthetic products and applications, distributors must have strong product knowledge, a well-founded understanding of product applications, and established relationships with clients. As manufacturers develop more products, and as coastal engineers learn of more applications, distributors will grow more important.

4. **Testing of geosynthetics is encouraged.** The U.S. Army Corps of Engineers (USACE) has led the way in testing geosynthetics in various coastal applications. The USACE provides a verification process that validates the safety and effectiveness of geosynthetics in various project designs. Coastal engineers rely on this verification process to know which materials and applications they can reliably incorporate. USACE testing has helped realize the many ways in which geosynthetics add value to coastal management. Further testing should be encouraged, especially for new products such as intelligent geotextiles – geocomposites fitted with fiber optics that can detect and warn of breaches in coastal structures before they occur.

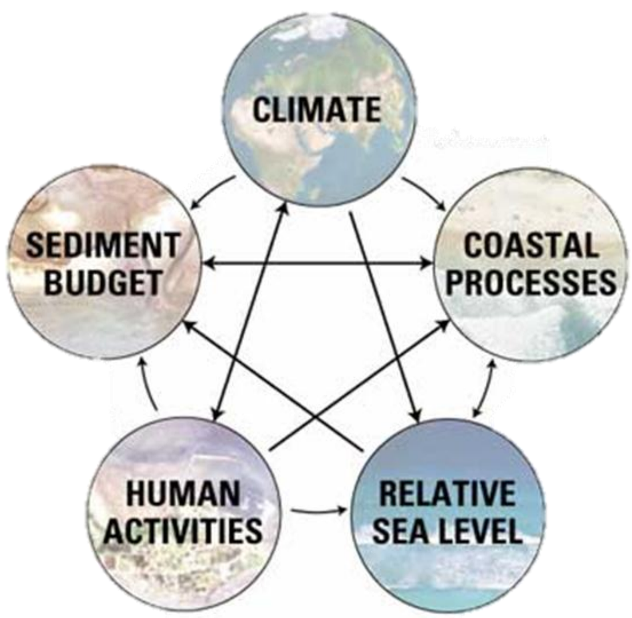
5. **Increased collaboration with coastal management practitioners will create opportunities for the geosynthetics industry and improve coastal management programs.** By facilitating collaboration with coastal engineering firms and the USACE, the geosynthetics industry would discover new opportunities for product development. As the USACE continues to test geosynthetics, and as a new generation of engineers familiar with geosynthetics transitions into coastal planning and design firms, the coastal management segment of geosynthetics is positioned to grow. Geosynthetics firms could better understand how to serve this growing sector by fostering communication and feedback loops with planning and design firms and the USACE. Shared insights may present opportunities for the geosynthetics industry to diversify and grow, and for coastal management programs to improve engineering designs, reduce project costs, and retain jobs.

II. Introduction

The Gulf of Mexico is an ecosystem of critical social, ecologic, and economic importance. It is important to the region's unique culture and cuisine and is a vital resource worth billions of dollars to the energy, fishing, shipping, and tourism industries (Gordon et al., 2011). Regrettably, decades of manmade and natural stressors have altered the functional health of this ecosystem and pushed the Gulf Coast into a state of chronic degradation (Peterson et al., 2011). Rapidly accelerating land loss is one of the most striking features of this degradation. Since 1932, the Louisiana coast alone has lost an astonishing 1,883 square miles of wetlands. Between 1985 and 2010, an area the size of a football field disappeared every hour (CPRA, 2012; Gordon et al., 2011).

The United States Geological Survey (USGS) names two distinct categories of land loss in the Gulf Coast: erosion and wetlands loss (USGS, 2004). Natural and human activities, along with climate change-related sea rise, create a cycle that accelerates relative coastal land loss in the Gulf (Figure 1). Some of the natural causes of land loss in the region are coastal processes such as waves, storms, currents, changes in the natural sediment budget from varying rainfall, and natural land subsidence (USGS, 2004). Human activities that contribute to land loss include coastal construction of roads, dredging for oil and gas pipelines, modification of natural waterways for navigation, and poorly planned flood control and diversion structures such as dams and levees (Ko & Day, 2004; USGS, 2004).

Figure 1. Cycle of factors that contribute to coastal land loss and vulnerability to sea rise[2]

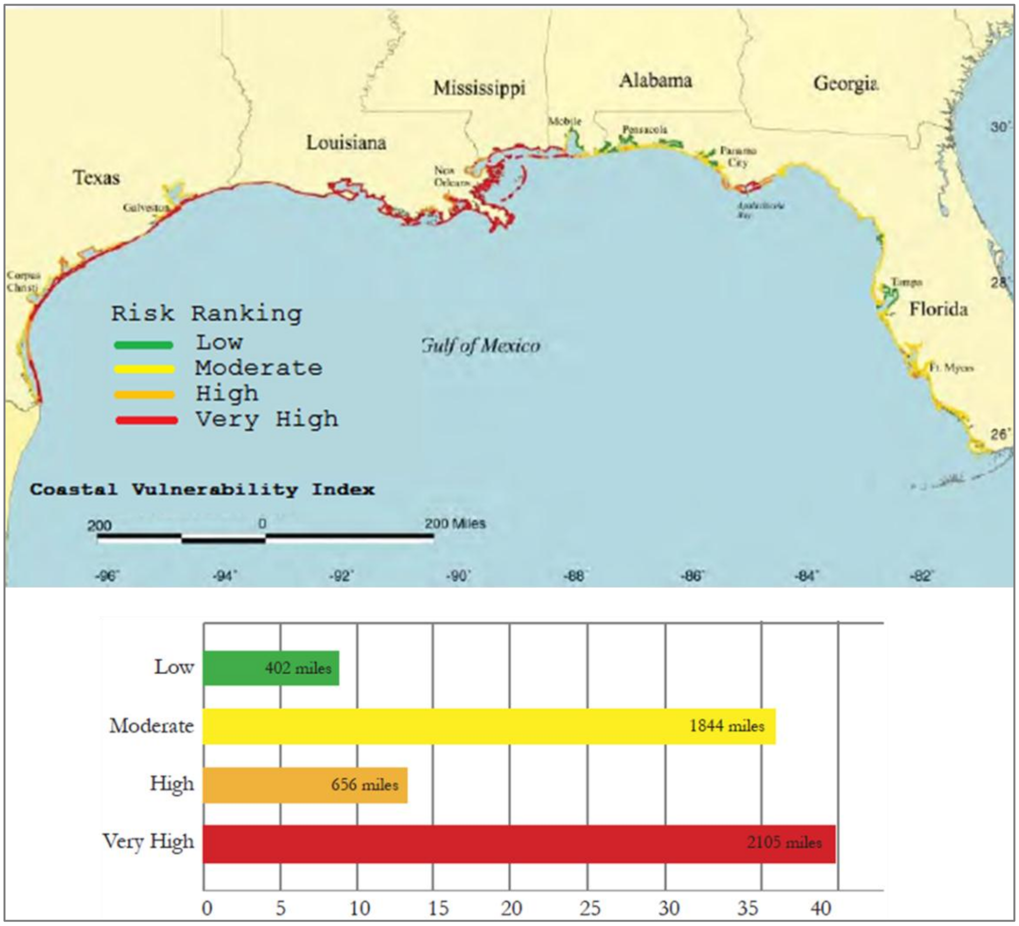


Source: (USGS, 2004)

[2] *Relative sea level rise accounts for movement of both water and land. For example, a rising land surface such as an accreting shoreline would experience a relative fall in sea level (Morton, 2004).*

This cycle of factors in the Gulf not only accelerates land loss, but as sea rise continues, also makes the coast increasingly vulnerable to flooding. Figure 2 shows the 5,007 miles of coastline vulnerable to sea rise across the five Gulf Coast states. More than half of this fragile coastline – almost 2,700 miles concentrated in Louisiana and Texas – is considered to be of either high or very high vulnerability (USGS, 2000).

Figure 2. Vulnerability to sea rise in the Gulf Coast



Source: (USGS, 2000)

To address this, coastal planners across the region have employed several approaches to restore the ecosystem and improve its resilience to storms and sea rise. Increasingly, these approaches incorporate geosynthetics. Geosynthetics are manmade – usually polymer-based – materials used in geotechnical earthen applications (US Fabrics, 2012). Though geosynthetics were developed for industries such as road construction, coastal engineers are discovering more geosynthetic applications in coastal management of ecosystem restoration, flood prevention and erosion control projects (PIANC, 2011). In most cases, engineers and project owners choose to use geosynthetics because they provide a comparable but lower-cost alternative to traditional materials such as rock, gravel and cement (O'Brien, 2012; PIANC, 2011). In cases such as levee construction, geosynthetics not only reduce costs, but also substantially improve structure performance (McConnell, 2012). Geosynthetics can reduce environmental damage to delicate shallow-water marshes by reducing the need for heavy machinery and barges used to transport and install rock (Moore, 2012; O'Brien, 2012).

Geosynthetics manufacturers belong to a well-organized, $2.1 billion industry with multiple professional associations, publications, and annual meetings focused on technologies and markets (Freedonia Group, 2009). The North American industry will employ approximately 12,000 people in 2012 (Aho, 2012). Many of these firms strategically located their manufacturing facilities in old textile mills in the rural Southeast, where there is abundant labor skilled in working with textiles (Adkins, 2012). This technical textile industry has helped retain a small portion of the traditional textile jobs that moved overseas (Aho, 2012).

While coastal management applications contribute to less than five percent of demand for geosynthetics, recent events suggest this demand will likely grow in the future (Adkins, 2012; Burran, 2012). Until recently, coastal engineering firms have been reluctant to use geosynthetics in project designs until the materials are proven successful elsewhere (Lothspeich, 2012; Thomson, 2012). The U.S. Army Corps of Engineers (USACE) has led the way by testing these products in coastal management (Aho, 2012; Lothspeich, 2012). Now that the USACE has tested and proved effective a substantial number of designs using geosynthetics, the market is positioned to grow, providing considerable opportunities for the geosynthetics industry to diversify and grow with it (Aho, 2012). Likewise, there are opportunities for coastal management programs to improve engineering designs, reduce costs, and retain jobs in the region.

This report sets out to describe the geosynthetics market and its relevance to coastal management programs in the Gulf of Mexico. The analysis will provide the following:

Overview of the geosynthetics industry and how geosynthetics materials and products apply to coastal management

Value chain analysis of the firms involved

Firm-level analysis of lead firms in the most significant categories of the value chain

Discussion of the types of jobs and geography of jobs in the geosynthetics value chain

The intent of this analysis is to examine the impact of using geosynthetics in coastal management programs, and to provide an understanding of how geosynthetics manufacturers and coastal planners might find areas of mutual opportunity to grow and improve the quality of their respective products and services.

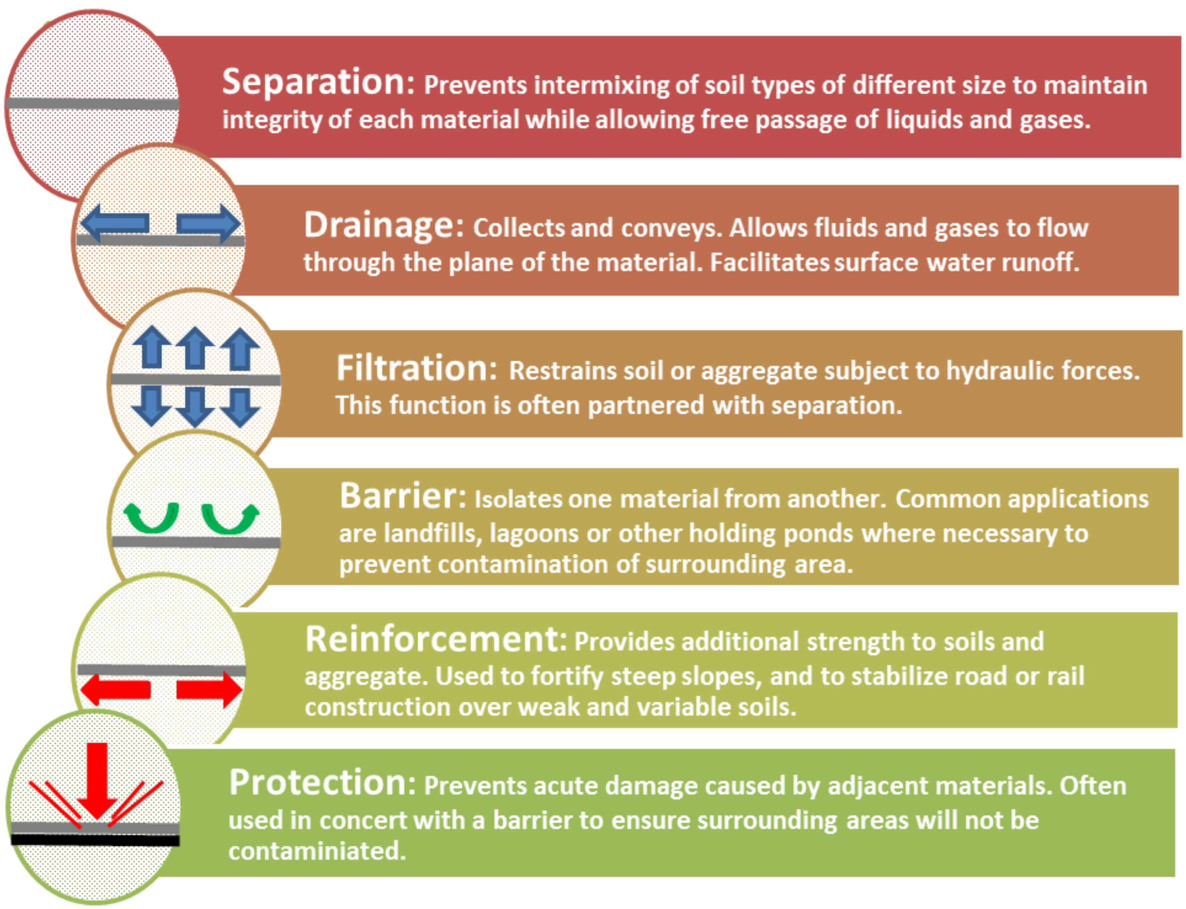
III. What are Geosynthetics?

Geosynthetics are plastic materials used in in engineering applications such as infrastructure. Most geosynthetics are fabrics or sheets of various sizes, strengths, and textures. They are generally made of plastics such as polypropylene, polyethylene, and polyester (Koerner, 2012b; US Fabrics, 2012). The geotechnical engineering applications that create the highest demand for geosynthetics are infrastructure projects such as roads and railways, landfills, and containment ponds for mining operations (Durham, 2012; Heins, 2012; Jones, 2012).

Principal Functions and Applications

The functions of geosynthetics in engineering fall into six primary categories (see Figure 3): separation, drainage, filtration, barrier, reinforcement, and protection (Shukla & Yin, 2006). In many instances geosynthetics perform two or more of these six functions in the same application.

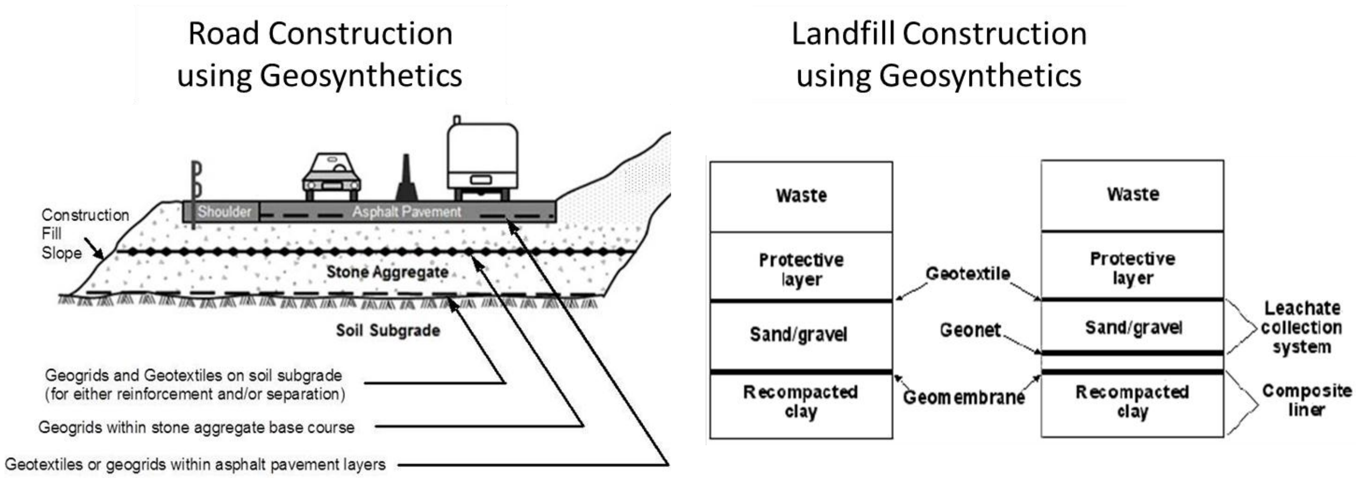
Figure 3. Six primary functions of geosynthetics



Source: CGGC Staff, adapted from (GEOfabrics Limited, 2012)

The applications that create the most demand for geosynthetics such as roads and landfill construction take advantage of their multiple functions. Geosynthetics are used in road construction to separate soil from gravel, facilitate drainage away from the road, and reinforce the ground beneath to displace pressure that would otherwise create potholes (see Figure 4). When used in landfills, geosynthetics provide both a barrier to keep harmful contaminants from entering the soil, as well as a durable protective layer to prevent objects from puncturing the barrier.

Figure 4. Multiple functions of geosynthetics in road construction and landfills

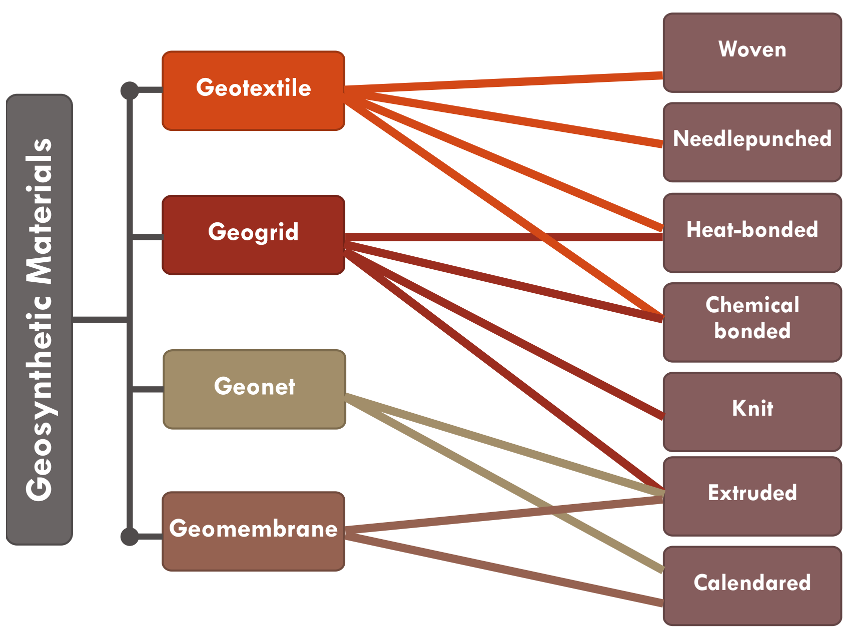


Source:(Koerner, 2012a), Ohio State University

Types of Geosynthetic Materials

The general category of geosynthetics is further broken down according to the nature of the manufactured geosynthetic material (see Figure 5). The following provides a brief description of those materials most commonly used in the coastal applications covered in this report.

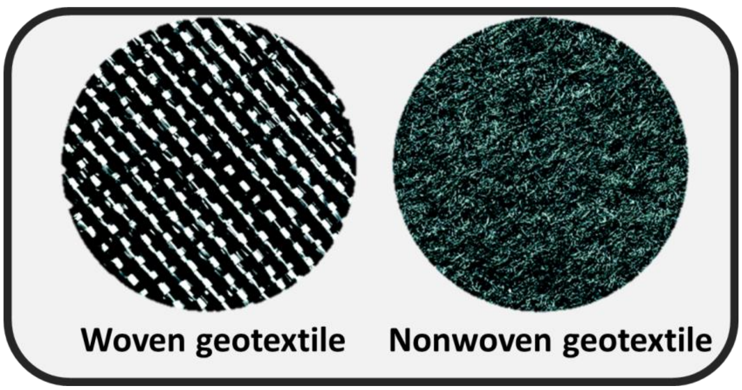
Figure 5. Types of geosynthetic materials, by manufacturing process



Source: CGGC staff based on (FHWA, 1998; GMA, 2009; P. R. Rankilor, 2000; TenCate, 2012; US Fabrics, 2012)

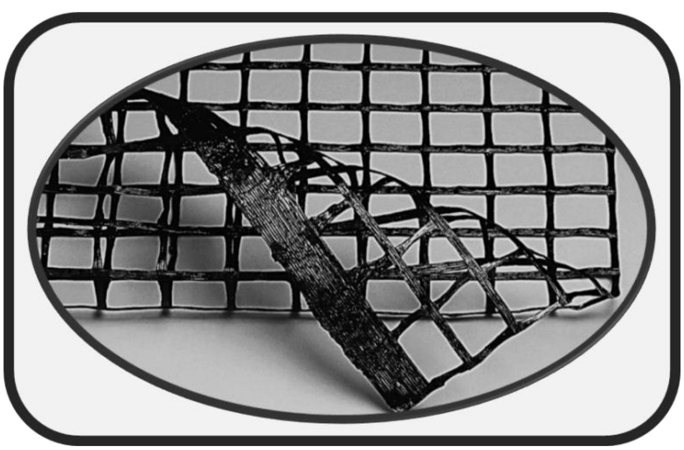
Geotextiles are composed of fibers and fall under two main categories: woven and nonwoven. The woven geotextiles are made of polypropylene yarns using textile looms. Non-woven geotextiles can be made like felts, where a conveyer belt takes a mass of fibers through a machine that binds them into a single fabric. The machines may join the fabrics by passing barbed needles through the fabrics to entangle their fibers (needle-punch), by chemical bonding, or by heat-bonding (GMA, 2012b).

Most geotextiles are permeable sheets made from polypropylene, polyethylene, and polyester (P. Rankilor, 2000). Some geotextiles are natural fiber fabrics, rather than geosynthetics. These materials last a few years and can cost a fraction of what synthetics do (Pritchard et al., 2000).



Photograph courtesy of Propex

Geogrids have visible apertures, big enough for the soil above and beneath the geogrid to touch. By definition, geogrids are used for reinforcement applications. Geogrids can be made by punching holes in a plastic sheet, by bonding straps together to form a grid, or by joining woven or knitted yarns. Geogrids may have a coating to provide a desired stiffness (GMA, 2009; Koerner, 2000).



Photograph courtesy of TenCate

Geonets are made of bonded layers of polyethylene strands. The geosynthetic will have ribs going in one direction on the bottom fused to ribs going in another direction on the top, forming a net. Geonets are by definition used in drainage applications, and they are almost always covered with geotextiles. (GMA, 2009; Koerner, 2000).

Photograph courtesy of Robert Koerner

Geomembranes are relatively impermeable plastic sheets, and they can be extruded or calendared. An extruded geomembrane is made of resin that is melted and then forced through a die to the required length, width, and thickness. As the sheet is extruded, a conveyer belt passes it through rollers, which can be designed to give the membrane a particular texture. To make calendared geomembranes, molten resin is passed through rollers that work it to the desired thickness (GMA, 2009).

Photograph courtesy of TenCate

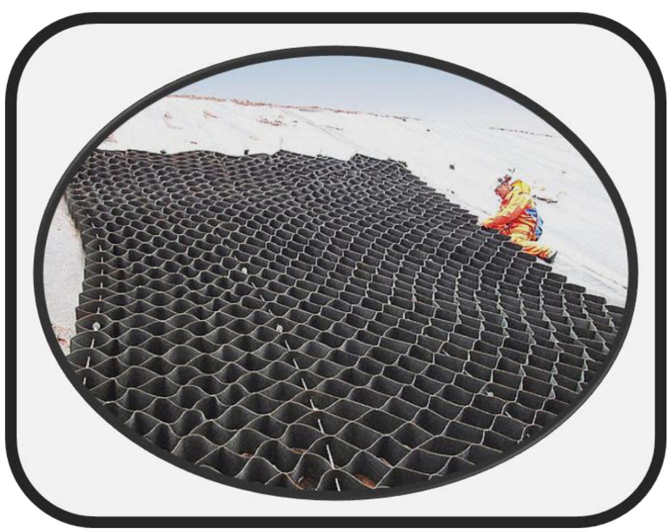
Types of Geosynthetics Products

Once manufactured, geosynthetic materials can be fabricated to make a variety of products for coastal restoration. When manufacturers combine two or more types of geosynthetics, the products fall under a special category called geocomposites. Combining geosynthetic materials takes advantage of their various functional characteristics. The following paragraphs outline geosynthetic products commonly used in the Gulf Coast.

Geotextile tubes are usually composed of high-strength woven geotextiles sewn together into tubes. Fabricators then close the ends to make pouches and attach ports for filling the inside with sand or sediment. The pouches have a circumference of up to 120 feet and can be hundreds of feet long, depending on the specifications (Ginter, 2011). For smaller geotextile tubes that require less strength but increased flexibility, fabricators may use a combination of woven and nonwoven geotextiles.

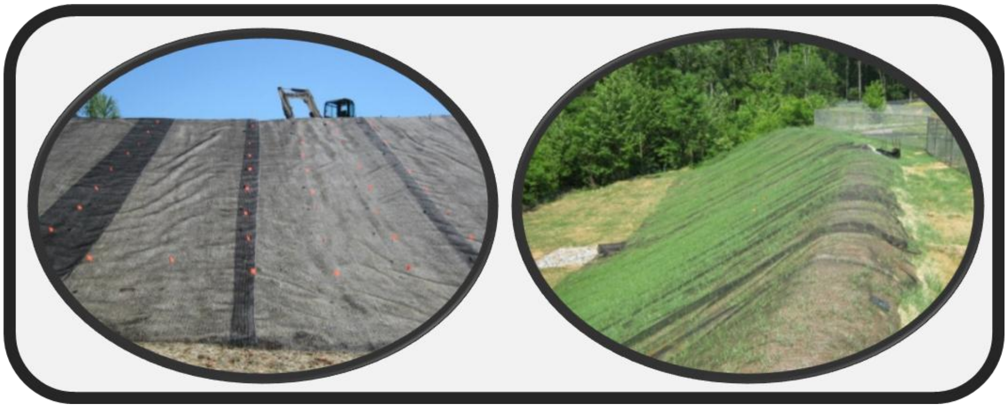
Photograph courtesy of TenCate

Geocells are made from nonwoven geotextiles or geogrids, fabricated so they expand into a three-dimensional honeycomb. The U.S. Army Corps of Engineers designed geocells for protection and stabilization purposes (Aho, 2012). The cell compartment areas range in size from approximately 14 to 450 inches squared (GMA, 2012a).



Photograph courtesy of Fiberweb

Rolled Erosion Control Products (RECP) and bank stabilization systems are seeded blankets designed to facilitate plant growth and protect steep slopes from erosion (Allen & Leech, 1997) (Lancaster & Austin, 2003). RECPs can be degradable or nondegradable, depending on the project objectives. Degradable RECPs are often made of natural fiber geotextiles such as coconut coir, and they are designed to decompose once they have facilitated plant growth. Nondegradable RECPs are generally synthetic geotextiles meant to facilitate plant growth indefinitely. Bank stabilization systems require building the slope by alternating geogrids or geomembranes and dirt in layers parallel to the ground (Dendurent & Woodward, 2009a, 2009b).



Photograph courtesy of Huesker

Foundations[3] use woven geotextiles and geogrids beneath heavy structures and within slopes to prevent the structure from sinking or the slope from eroding. Foundations displace and distribute the weight of a structure and strengthen the weak ground beneath.

Marine mattresses are large, rectangular geogrid pouches filled with rocks. They are used to support structures and control erosion.

Photograph courtesy of Shawn Stokes

[3] For this report, we do not use the term foundation in the traditional sense, but rather to describe any application that uses geosynthetics as a base to support a heavy structure.

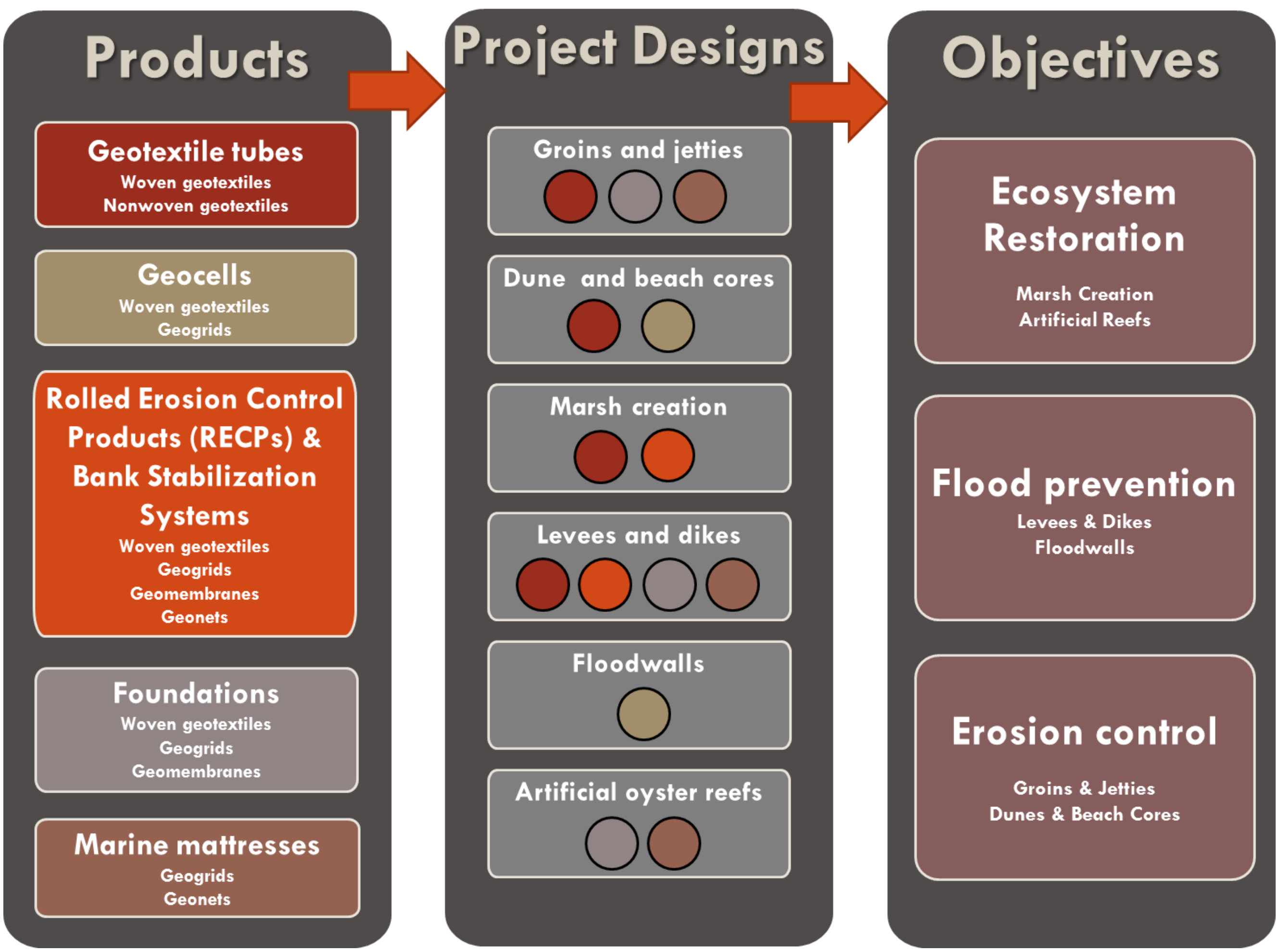
IV. Geosynthetic applications in the Gulf Coast

Geosynthetics have several applications that could be especially important for coastal management programs in the Gulf Coast. In this report, we concentrate on environmentally sound uses of geosynthetics in projects used to meet three objectives in the Gulf Coast: environmental restoration, flood prevention, and erosion control.

Geosynthetics across three coastal management objectives

In Figure 6, we show how products made from geosynthetic materials are used in project designs for the three Gulf Coast objectives covered in this study. There is significant overlap in terms of how geosynthetic products are implemented in these projects. Among geosynthetics, the materials that play the biggest role are geotextiles and geogrids. Geotextile tubes are among the most versatile products. The following paragraphs describe in more detail how geosynthetics are used in environmental restoration, erosion control, and flood prevention.

Figure 6. How geosynthetics meet Gulf Coast engineering objectives



Source: CGGC staff based on (FHWA, 1998; GMA, 2009; P. R. Rankilor, 2000; TenCate, 2012; US Fabrics, 2012)

Many of the projects discussed below of those outlined in the Louisiana Master Plan. We refer to the Master Plan because the project types it lists will likely have funding in the near future (CPRA, 2012). Geosynthetics have been used for all of these project types, whether as the main structural material or—as with artificial oyster reefs—a small but still important element of the project.

Ecosystem restoration projects include marsh creation projects, breakwaters, shoreline protection barriers, and oyster reef restoration projects.

1. **Geotextile tubes** may also serve as artificial shorelines to restore marsh ecosystems. When applied this way, the project design calls for the area landward of the geotextile tube perimeter to be filled with sediment and sown with plants. Geotextile tubes are also used to create breakwaters—structures placed in the water parallel to shore. Breakwaters are designed to dissipate wave energy so that waves are smaller and cause less erosion when they reach the shore, allowing sediment to build up behind them (USACE, 1998).
2. **Foundations** provide support for a number of ecosystem restoration projects. Most often, woven and nonwoven geotextiles are installed under structures such as rock walls used in shoreline protection barriers to prevent the rocks from sinking into the soft undersea floor (GEOfabrics Limited, 2005). Other times, geogrids may be used as well (Thomson, 2012).
3. **Marine mattresses** are used in oyster reef restoration projects. The marine mattresses serve as a foundation under heavy artificial reef structures to keep them from sinking (Ortego, 2012).

Flood prevention projects include levees, dikes, floodwalls, and similar structures designed to prevent rising water from ruining livelihoods and infrastructure.

1. **Geotextile tubes** play a role in supporting and stabilizing earthen structures like levees and dikes. They may be constructed within the core of an earthen structure to provide strength, or at the foot to prevent waves from eroding the base. They may also be placed at the top, giving the structure extra height and preventing floodwaters from flowing over the top and weakening the entire structure (Bezuijen & Vaastenburg, 2008; Fowler, 1996).
2. **Bank stabilization systems** using geogrids, geocells, and geomembranes fortify the core of levees, while geotextiles (usually erosion control blankets) protect the steep slopes of levees and dikes from erosion (Aho, 2012).
3. **Geocells** with deep compartments can be used as floodwalls and may serve as a substitute for sand bags (TERRAM, 2012). These are exceptionally large, up to 2 feet tall and 3 feet deep, and may be stacked on top of one another to gain additional height.

Erosion Control projects include coastal armoring techniques, breakwaters, groins, jetties, and similar structures to slow or prevent shoreline loss.

1. **Geotextile tubes** are often constructed near shorelines as retaining structures. In some applications, they are laid level with the natural beach then covered with sand to form a "beach core." Similarly, they may be incorporated into dunes. Retaining structures and dune cores are designed to be an erosion barrier of last resort, so that they prevent erosion only once storms have washed or blown the other sand away (Titus & Gill, 2009). Geotextile tubes used as breakwaters dissipate wave energy and reduce erosion. Finally, short groins, or structures perpendicular to shore, can use geotextile tubes to mitigate erosion in hot spots. Over time, coastal engineers have found that short strategically placed groins are the best (Fontaine, 2012; Thomson, 2012). When used in coastal restoration applications, geotextile tubes often come with scour aprons and smaller anchor geotextile tubes, so that the main geotextile tube will not roll out to sea when the sediment beneath it washes away (USACE, 1998).
2. **Geocells** have compartments that are filled with ballast – often soil and plants that provide additional stability – and then installed along a slope to prevent erosion (Aho, 2012).
3. **Rolled Erosion Control Products (RECP)**, also called erosion control blankets, are geotextiles designed to facilitate plant growth. They can be an alternative to armoring with rock (Lancaster & Austin, 2003).
4. **Marine mattresses** may be used as revetments on slopes or as scour mats to prevent erosion in high wave energy environments (Hughes, 2006).
5. **Foundations** made of geogrids may be placed under armor stone used in shoreline protection designs. The geogrids displace pressure and prevent the heavy stone from subsiding into the underwater floor (Thomson, 2012).

Advantages of using geosynthetics in coastal management

While geosynthetics are not the optimal solution for every coastal challenge, in many cases various attributes of geosynthetic materials make them a superior choice. Depending on the application, geosynthetics may improve project design, reduce costs and time, and benefit the environment. Below we outline some of the advantages – and caveats – of using geosynthetics in ecosystem restoration, flood prevention, and erosion control designs, and provide some examples of coastal projects in which they were used (Figure 7).

Figure 7. Geosynthetic advantages in coastal management applications

Project Objective & Examples		Improved Design	Cost Savings	Time Savings	Environ-mental Benefit	Caveats
Ecosystem Restoration	**GT tube marsh creation** Shamrock Island, TX; Jumbile Cove, TX; Starvation Cove, TX		●	●	●	- GT tube design must not prevent marine life from having easy. access into and out of the marsh. - Damage to GT tubes from sun, boats, and vandalism.
	Oyster reef restoration Rockefeller Refuge, LA; Lower James River, VA	●				
Flood Prevention	**Levees** Red Eye Crossing, LA; Hero Canal Levee, LA		●	●		
	Floodwalls Smithland, KY		●	●		- Geocell floodwalls have only been tested in small projects in the Gulf, but have the potential to be widely used.
Erosion Control	**Dunes & Beachcores** Walton County, FL		●	●		- Geotextile tubes must be buried deep enough to avoid interfering with sea turtle nesting. Structures must be secured against storm surge. If punctured, tubes will fail, and property will be damaged.
	Groins and jetties Hillsborough County, FL; Longboat Key, FL; Manatee County, FL; Upton Beach, FL	●	●	●	●	- Structures may move erosion problem down coast. Engineers should carefully evaluate project site, and incorporate a minimalist, strategic approach to project design

Source: (Elko & Mann, 2007; EPA, 2012; EPA & USACE, 2007; FLDEP, 2008; O'Brien, 2006; Ortego, 2012; Propex, 2010; Siwula & Breen, 2008)

Ecosystem restoration projects can incorporate geosynthetics in a variety of ways. One of the most common uses geotextile tubes instead of rocks as a perimeter for wetland creation. Wetland projects are frequently located in distant, hard-to-reach, shallow areas of water. Machinery used to transport heavy rock overland and across water is expensive, time consuming, and potentially harmful to the delicate wetland environment. Geotextile tubes are lightweight and can be filled quickly on site using a dredge positioned far away from the placement site, saving time, money, and resources. Engineers should ensure the geotube perimeter does not restrict marine life from entering and exiting the marsh area. Also, experience has shown that geotextile tubes placed low in an intertidal zone, rather than fully exposed, can reduce damage caused by boats, sun exposure and vandalism (O'Brien, 2012).

Oyster reef restoration projects provide another opportunity to use geosynthetics in ecosystem restoration. Prefabricated concrete oyster reef structures can weigh up to 2,000 pounds each (Ortego, 2012). Without proper support, these heavy structures sink quickly in the soft

Mississippi Delta mud. Placing rock-filled marine mattresses made of geogrids under the concrete structures provides a solution (CWPPRA, 2011).

Flood Prevention measures such as levees and floodwalls provide ideal opportunities to incorporate geosythetics. Not only do geosynthetics strengthen levees, they also provide several cost-saving benefits. Two of the most challenging constraints to building levees are having sufficient earthen material to build with and acquiring right of way (ROW) from private landowners. ROW is especially difficult, as it is expensive and can delay project completion. Because using geosynthetics allows for a smaller lateral base at the levee foundation, levees with geosynthetics require less material and less ROW. Incorporating geosynthetics into the Hero Canal levees in Louisiana saved 30 acres of ROW and over 11,500 cubic meters of borrow material (Siwula & Breen, 2008).

Coastal planners have yet to use geocells as floodwalls extensively in the Gulf, though manufacturers such as Fiberweb have carried out demonstration projects (Whitaker, 2012). Large geocells are a quick and inexpensive alternative to sandbag floodwalls. Work crews expand these accordion-like structures along river banks and shores and then fill the deep cells with sand using a front-end loader. The time savings not only reduce costs, but protect lives and property. When rivers in Smithland, KY flooded in 2011, crews of three laborers – two people installing and one operating a front-end loader – constructed a mile of Fiberweb Defencell barriers in 37 hours (Whitaker, 2012).

Erosion Control designs that use geotextile tubes to create dunes, beach cores, groins, and jetties present opportunities to reduce costs and time, improve design, and lessen environmental damage. These structures typically replace traditional erosion-control structures such as rock jetties and groins. Since rock is expensive to transport and requires more time and heavy machinery to install, geotextile tubes are often the preferred design.

However, geotextile tube structures are among the most contentious for coastal engineers. Disagreement persists on whether chronic erosion can be fixed or whether preventing erosion in one location simply transfers it to another location (Fontaine, 2012; Thomson, 2012). However, because these structures typically replace traditional rock structures, the question is not whether to use geosynthetics but whether to use any structure at all. The alternative is to rely entirely on regular cycles of expensive beach nourishment. Therefore, geosynthetics improve traditional project design that uses rocks by serving as a less expensive, less permanent structure. If project owners find the design is not acting as expected, it is much easier for them to alter or completely remove the geotextile tubes than it would be for rock structures (Fontaine, 2012; Thomson, 2012). As coastal engineers have had more time to use geotextile tubes for erosion control, they have learned that taking a strategic approach using short geotextile tube groins in precise locations can be very effective (Fontaine, 2012; Thomson, 2012).

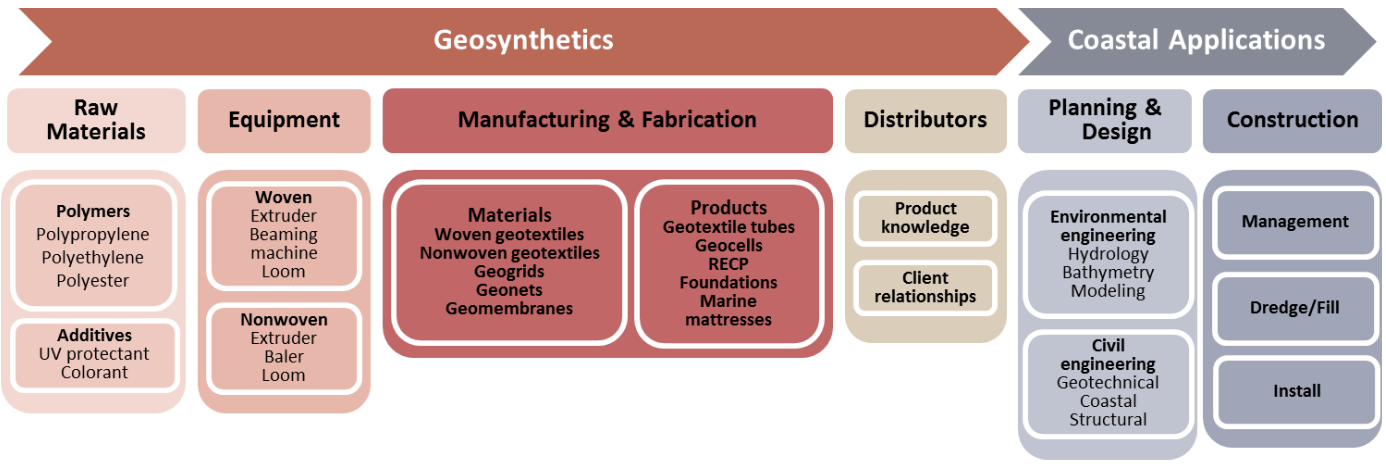
V. U.S. Value Chain

The value chain for geosynthetics as used in coastal management applications is found in Figure 8. Our depiction of the value chain includes a range of raw materials, equipment, and services. Firms in these value chain segments engage with one another in a project cycle explained in our previous report (Lowe et al., 2011). The analysis that follows will map out the major players and organize them across six categories.

Six value chain categories

For this study, we have divided the value chain into two main sections: Geosynthetics (in red), and Coastal Applications (in blue). Broadly, the four columns under Geosynthetics (raw materials, equipment, manufacturing, and distributors) serve as inputs to the two columns under Coastal Applications (planning & design, and construction). Each category is described below.

Figure 8. U.S. value chain for coastal restoration projects



Source: CGGC based on industry interviews.

1. Raw Materials

The raw materials used to make geosynthetics include polymers and additives. Polymers – plastics made from petrochemicals – are the main raw material input to manufacturing geosynthetics. Most geosynthetics are made from polypropylene. Other polymers such as polyethylene, polystyrene and polyester may also be used (Dean, 2012). Geosynthetics manufacturers purchase these plastics in the form of resin pellets – up to 100 million pounds per year – most often from subsidiaries of oil companies (Jones, 2012). Firms commonly cited in this study included Conoco Phillips, Dow Chemical, Exxon Chemical, and Formosa (Heins, 2012; Jones, 2012). Raw materials make up roughly 65 percent of geosynthetics firms' variable costs, and this cost fluctuates directly with the price of oil (Jones, 2012). A shortage of resin exacerbates price variability. More resin manufacturing plants would help reduce spikes in price (Aho, 2012).

Additives used to make geosynthetics include ultraviolet ray (UV) protectants and colorants. UV protectants prolong the life of geosynthetics exposed to the sun by reducing damage from ultraviolet rays. Also derived from petrochemicals, UV protectants contain a polyurea base that creates a protective shell. Most geosynthetics are black, as they are usually buried underground. However, geosynthetics manufacturers sometimes use colorants to create products of various colors. Because many coastal applications designs leave geosynthetics exposed, engineers consider various aesthetic concerns such as ensuring geotextile tubes match the color of beach sand (Jones, 2012). Ampacet, Premier Color Group, and Sherwin Williams are some firms that manufacture additives used in geosynthetics (Heins, 2012; Jones, 2012; Trainer, 2012).

2. Equipment

Most firms that provide geosynthetics-manufacturing equipment are based in Europe. Equipment differs for woven versus non-woven assembly lines. Equipment used to make woven geotextile includes extruders, beaming machines, and looms. Extruders melt the polymer resins, press them through a die, and spin them into yarn. A beaming machine then winds the polypropylene yarns onto beams. Finally, a loom very similar to a traditional textile loom weaves the yarn from the beams into textiles. Itema is one of the most commonly-cited firms that manufacture woven line equipment (Adkins, 2012; Jones, 2012).

Nonwoven geosynthetic lines have an extrusion process and a pressing process (Burran, 2012). The extrusion process uses an extruder to melt resin and form fibers, then a baler to compress and bind the fibers. The pressing process uses nonwoven textile looms to achieve a variety of different material characteristics such as size, texture and permeability (Adkins, 2012; Burran, 2012). Some firms that manufacture nonwoven textile equipment include Dilo and NSC machinery (Adkins, 2012).

3. Manufacturing & Fabrication

For this study we use the terms “manufacturing” when referring to geosynthetic materials and “fabrication” when referring to geosynthetic products. Because so many firms do both, we bring manufacturing and fabrication together under one segment of the value chain. Firms in this segment belong to a well-organized, billion-dollar industry with multiple professional associations, publications, and annual meetings focused on technologies and markets (Aho, 2012). Estimated demand for geosynthetics suggests the North American industry will employ 12,000 people and produce 900 million square yards of geosynthetics in 2012 (Aho, 2012; Freedonia Group, 2009). Most of these firms’ manufacturing facilities are strategically located in either the Gulf Coast states where they have easy access to petroleum-based inputs, or the Southeast where they moved into old traditional textile mills (Aho, 2012). The Southeast also provides easy access to deep water ports in Savannah, as well as abundant labor skilled in working with textiles in rural areas (Adkins, 2012). Larger manufacturing plants such as those operated by Propex in Nashville, GA and Ringgold, TN employ approximately 400 people (Durham, 2012). Demand for geosynthetics fluctuates seasonally with construction work during summer months. During peak productivity – from June to September – firms will add additional shifts to meet demand, often operating 24 hours a day (Durham, 2012).While coastal applications covered in this study only make up approximately 5 percent of total demand for geosynthetics, that demand is increasing as more engineers look for cost-effective and reliable solutions to fit their needs (Aho, 2012; Burran, 2012).

4. Distributors

Many representatives from the construction industry consider geosynthetic products equal to each other in quality and performance, so long as the product meets specifications. As the intermediary between the manufacturer and end user, distributors must convey important product information to the construction firms. This is an important role that is relatively unique to this industry. In value chains for consumer products, distributors are seldom in a position to influence which product the consumer chooses to purchase. However, because this is a practitioner value chain for products that are somewhat new to the construction firms that build coastal management projects, distributors must have strong product knowledge and a well-founded understanding of product applications. As manufacturers develop more products, and as coastal engineers learn of more applications, distributors will grow more important.

5. Planning and Design

This report limits its discussion on planning and design firms to their role in selecting geosynthetics for coastal applications. For a full description of how planning and design firms work in coastal restoration projects, see “Restoring the Gulf Coast: New Markets for Established Firms” (Lowe et al., 2011).

Planning and design firms create the most demand for geosynthetics used in coastal applications. Coastal engineers work with project owners – usually a public entity such as a state government agency – to consider various project designs using geosynthetics (Moore, 2012; O'Brien, 2012). The project owner asks planning and design firms to put together a few different designs. Most often, owners chooses the design with geosynthetics because it meets the same performance as rock, but at a lower cost (O'Brien, 2012). The role of planning and design firms in the value chain is discussed in more detail below.

6. Construction

This report limits its discussion on construction firms to their role in working with geosynthetics in coastal applications. For a full description of coastal restoration projects and how construction firms build them, see “Restoring the Gulf Coast: New Markets for Established Firms” (Lowe et al., 2011). In most cases, adding geosythetics to a project design requires little change to the overall construction process. For example, a levee designed with geosynthetics requires that the construction firms simply alternate layers of geogrids into the levee.

Projects with geotextile tubes are the most distinct from traditional coastal designs, requiring specialized firms (hydraulic dredging companies) or equipment (eductor pumps) in order to fill the tubes with a slurry of sediment and water. Because construction teams cannot partially fill a tube and leave it overnight to be finished the next day, firms order segments of geotextile tube that can be completed within a day's time. Depending on the diameter of the tube and the dredge or pump capacity used to fill it, construction firms specify the number and location of ports for filling the tubes, and as a general rule the tubes be between 200 and 400 feet long (Moore, 2012). Construction firms are more likely to buy geotextile tubes from the firms that can meet specifications on time (Moore, 2012).

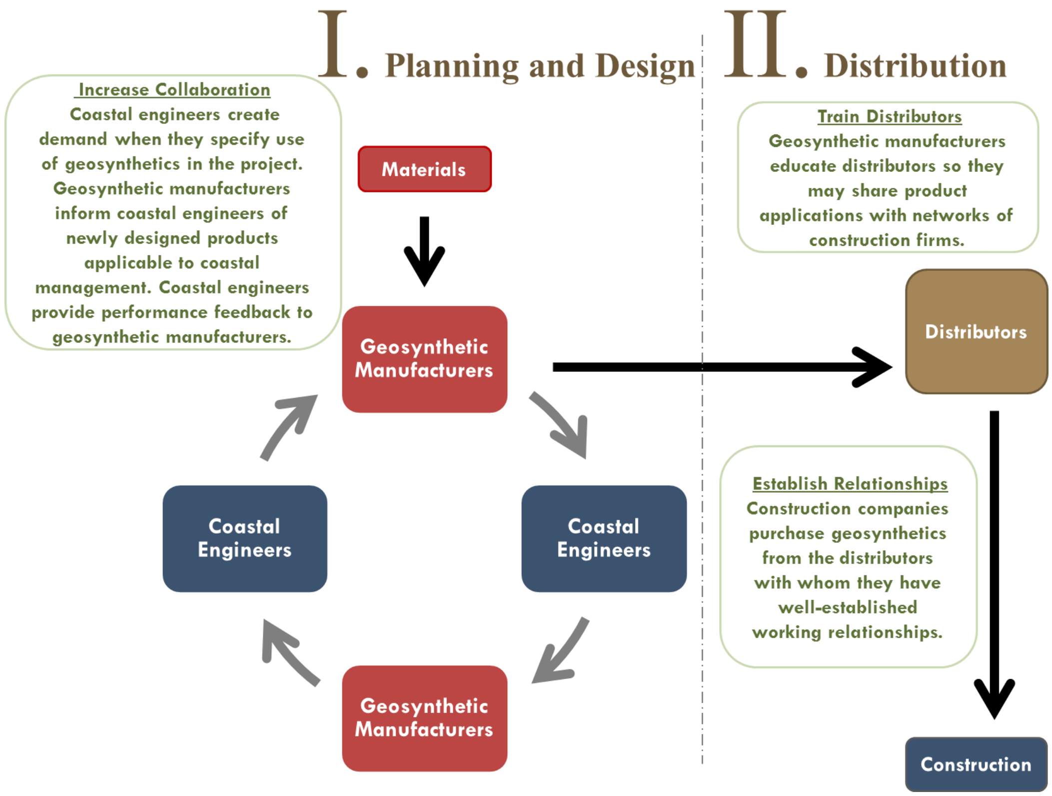
Areas of opportunity

As the use of geosynthetics in coastal applications increases, geosynthetics manufacturing and fabrication firms are looking for opportunities to improve and grow. Many representatives from the construction industry consider geosynthetic products equal to each other in quality, so long as the product meets specifications. This section identifies two areas of the value chain – planning and design, and distribution – in which firms may find opportunities to improve product performance and identity.

Figure 9 depicts an alternative view of the value chain, divided into two areas of opportunity, planning and design (coastal engineers) in area I, and distributors in area II.

Increased collaboration between geosyntetics manufacturers, planning and design firms and other coastal engineers may create opportunities to develop or improve products for coastal applications. Coastal engineering firms have been reluctant to use geosynthetics in project designs until the materials are proven successful elsewhere (Lothspeich, 2012; Thomson, 2012). The U.S. Army Corps of Engineers (USACE) has led the way by trying out geosynthetics in coastal management (Aho, 2012; Lothspeich, 2012). As the USACE continues to test and prove effective a substantial number of geosynthetics, and as a new generation of engineers familiar with geosynthetics transitions into coastal planning and design firms, the market segment is positioned to grow (Aho, 2012). Geosynthetics firms could better understand how to accommodate this growing sector by facilitating communication and feedback loops with planning and design firms and the USACE. Mutually shared insight may present opportunities for the geosynthetics industry to diversify and grow, and for coastal management programs to improve engineering designs, reduce project costs, and retain jobs.

Figure 9. Areas of opportunity within two segments of the value chain



Source: CGGC based on industry interviews.

Distributors play an important role in geosynthetics manufacturers' growing presence in coastal applications and help establish product differentiation. We asked representatives from construction firms to indicate what factors they consider when selecting a particular geosynthetic manufacturer. While they almost always mentioned price, many said their relationship with distributors was more important (McConnell, 2012; Moore, 2012). Since many of these respondents considered geosynthetic products from most manufacturers to be homogenous, well-informed distributors adept in networking can provide opportunities to grow in the coastal applications market.

VI. Firm Level Analysis

This section analyzes the different types of firm that produce geosynthetics and apply them in coastal management projects. Our selection of firms concentrates on U.S. geosynthetic manufacturers, the most relevant materials, equipment, and dredging firms that industry leaders identified during our research. Not included in this analysis are firms from the planning and design and construction segments of the value chain, as these were covered in the first study of the series. For a list of these companies and firm level analysis, see the first study in the three-report series, "Restoring the Gulf Coast: New Opportunities for Established Firms" (Lowe et al., 2011).

The full list of 82 firms and their characteristics is on page 37. Our analysis of these firms yielded useful observations about the size of firms and the newly established state of the growing geosynthetics manufacturing industry.

Size of firms

Most firms in the geosynthetics value chain are small businesses (see Figure 10). The U.S. Small Business Administration (SBA) provides varying definitions of small businesses according to the characteristics of a given industry. For example, for a dredging firm to qualify as a small business, its annual income may not exceed $33 million. However, for a textile firm to qualify, annual income is irrelevant so long as its number of employees does not exceed 1,000 (SBA, 2012).

More than 61 percent of firms in this study meet the income requirements to be considered small businesses. In terms of number of employees, 73 percent of firms in this study qualify to be small businesses. Nearly half the firms reporting data have fewer than 100 employees. There are some outliers with 10,000 or more employees— large oil companies that produce plastic raw material inputs. These are not typical of the firm size associated with this value chain.

Figure 10. Distribution of Firms by Size and Category

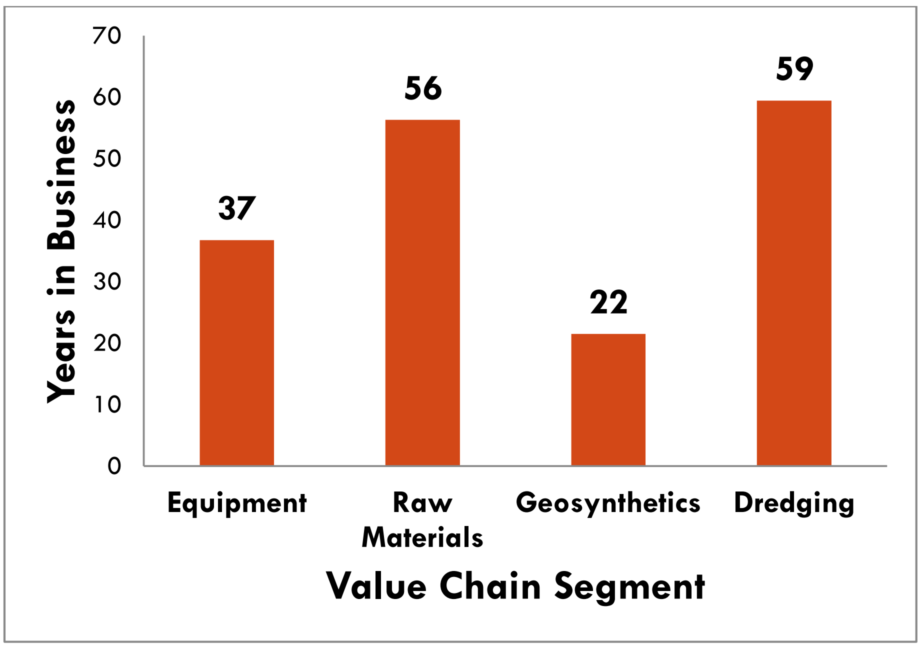
Source: CGGC, based on industry interviews, company websites, Hoover's database, and OneSource database.

A newly established and growing geosynthetics manufacturers industry

Firms in the geosynthetics manufacturing segment of the value chain are much less established than firms in other segments. Nearly half of the 79 firms we identified in this study are geosynthetics manufacturers. While firms in the materials and construction industries were established an average of almost 60 years ago, the average geosynthetics firm was established just 22 years ago (Figure 11).

More interesting is our finding that almost a quarter of geosynthetics manufacturing firms cited were established in just the last 10 years. As the value of the total industry nearly tripled from $786 million in 1993 to $2.1 billion today, many new firms emerged (Freedonia Group, 2009; Waste360, 1993). These new firms anticipate that growth for geosynthetics will continue as opportunities open up in new sectors such as coastal management.

Figure 11. Average age of firms by value chain activity



Source: CGGC, based on industry interviews, company websites, Hoover's database, and OneSource database.

VII. Geosynthetics and Jobs

In this section we consider jobs related to manufacturing and fabricating geosynthetic products for use in coastal restoration applications. This section will address types of jobs and employee locations.

Types of jobs

For this study, we focused on the types of jobs directly related to manufacturing and fabricating geosynthetics products. The number of jobs in the geosynthetics industry as a whole also includes sales and marketing positions, transportation work, and a number of other categories. These are spread across several markets, including coastal management.

Table 1: U.S. Median Wages of Geosynthetics Jobs

Occupation	Median Hourly Wage (USD)
Manufacturing	**$ 16.41**
Labor	$11.42
Operators--textile cutting machine	$12.20
Operators--knitting and weaving machine	$12.86
Doffer (Machine feeders and offbearers)	$12.98
Operators--cutting, punching, and press machine	$14.97
Inspectors	$15.31
Operators--extruding machine setters	$15.43
Extruder operators	$16.40
Operators--multiple machine tool setters, operators, and tenders	$16.61
Forklift driver (material moving workers)	$16.90
Fixers (Mechanics)	$21.38
Head fixers (First-Line Supervisors of Helpers, Laborers, and Material Movers, Hand)	$21.43
Electricians	$25.44
Planning and design	**$ 27.56**
Industrial Engineering Technicians	$24.93
Drafting engineer (Drafters, All Other)	$21.92
Environmental Engineering Technicians	$23.51
Civil Engineering Technicians	$27.42
Geological and Petroleum Technicians	$27.81
Engineer, Civil	$39.76
Average	**$19.91**

Source: (BLS, 2010)

Manufacturing

As outlined in Table 1, median wages for geosynthetics manufacturing and fabrication jobs are $16.41per hour. Some of these jobs require years of experience in lower positions (Burran, 2012; Jones, 2012). The payment ranges from a median hourly wage of $11.42 to $25.44.

During the manufacturing process, some geosynthetic types require much more labor than others. In particular, woven geotextiles require more equipment, more material, and more labor (Burran, 2012). For example, Chattanooga, Tennessee-based Propex meets their demand for nonwoven geotextiles with three to eight production lines. To produce wovens, however, they employ hundreds of workers to man and repair their 300 looms (Burran, 2012).

Fabrication

During the fabrication phase, where a geosynthetic product is created from geosynthetic materials, firms hire more machine operators. They often employ sewing machine operators and other workers to cut the fabric or install ports on geotextile tubes (Jones, 2012; Trainer, 2012).

TenCate and Propex have not had much trouble hiring or retaining workers in geosynthetic manufacturing and fabrication (Burran, 2012; Jones, 2012). Propex has plants in relatively remote areas, and they are a major employer in towns where they have manufacturing locations (Burran, 2012).

Planning and design

For planning and design jobs—those for the people who design geosynthetic products into coastal applications—the average wages are much higher. A worker in one of these jobs will earn an average median hourly wage of $27.56. Depending on the position, the payment ranges from a median hourly wage of $24.93 to $39.76. Some of these job positions are at geosynthetic manufacturers (Jones, 2012). Others are at separate design firms.

Installation

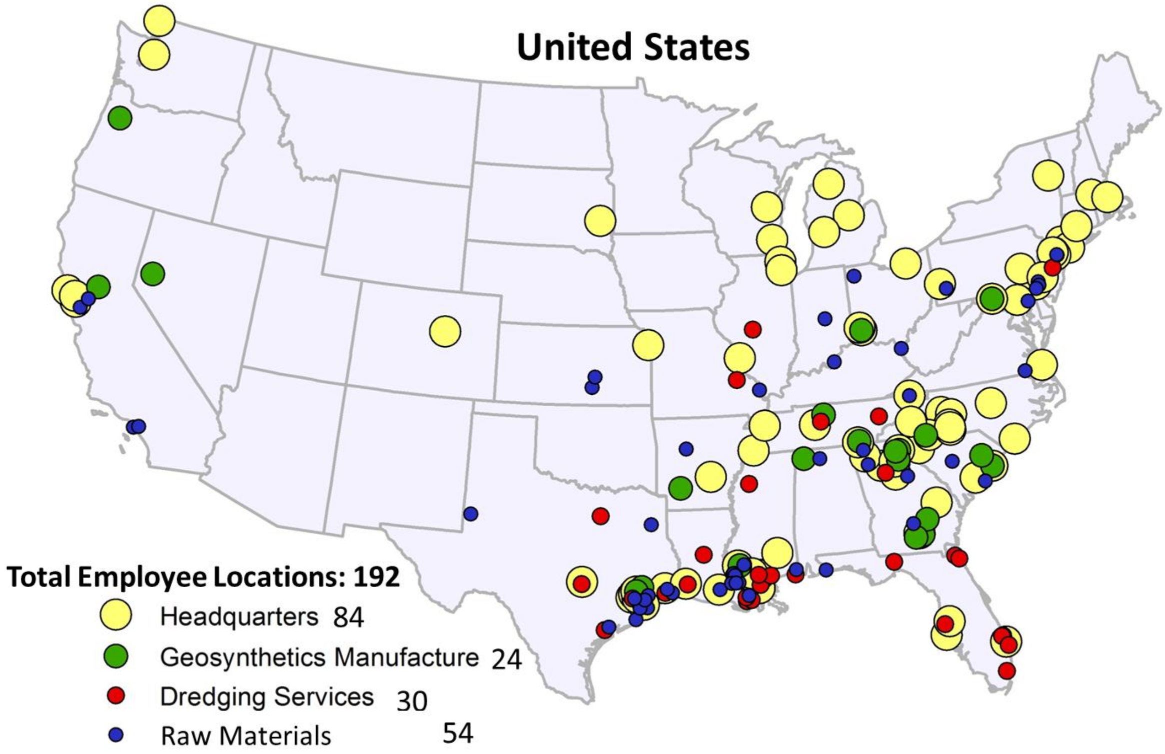
CGGC has outlined other jobs related to geosynthetic restoration work in the previous study, "Restoring the Gulf Coast: New Markets for Established Firms." Occupations listed in "Restoring the Gulf Coast" apply to the construction and deployment phases of geosynthetic applications. In particular, geotextile tube jobs require Mobile Heavy Equipment Mechanics, Construction and Related Workers, and Dredge Operators (Moore, 2012). These workers place the geotextile tube, smooth it out, and operate the pumps, backhoes, and forklifts that are often part of the process. A geotextile tube installation takes about two weeks and employs 8 to 12 people (Moore, 2012).

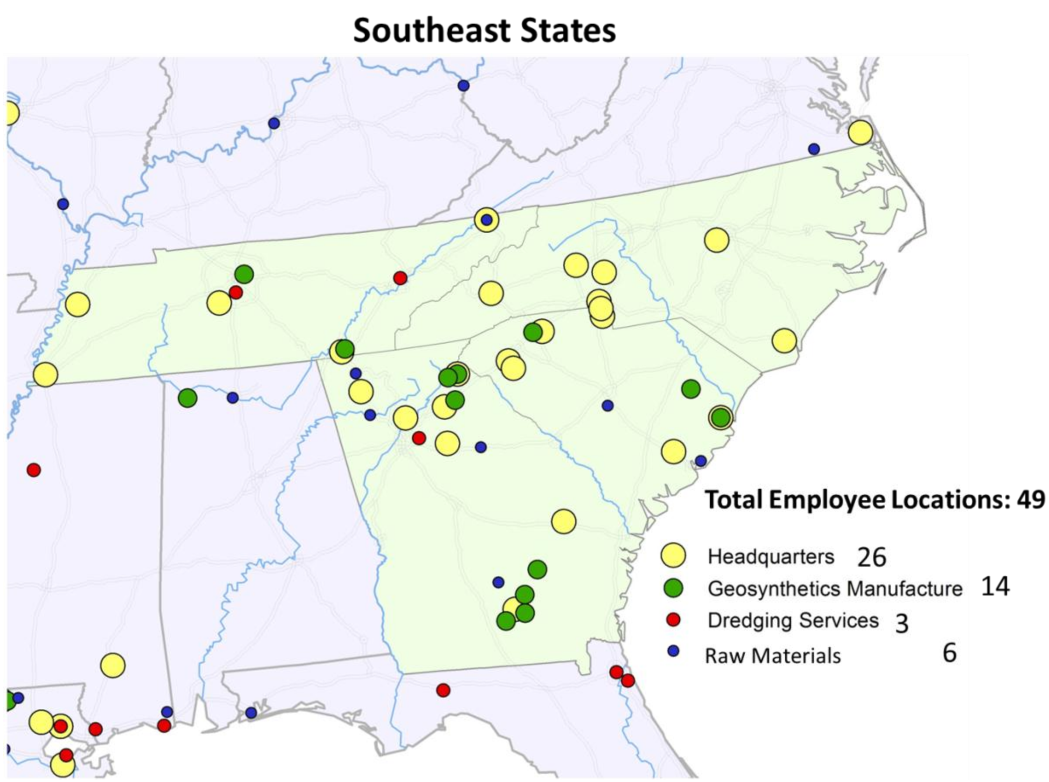
The installation phase for geosynthetic products such as Rolled Erosion Control Products and geogrids does not require extensive training for laborers, although the geosynthetics manufacturer may send someone to help with instructions and quality control (McConnell, 2012).

Geographic distribution of jobs

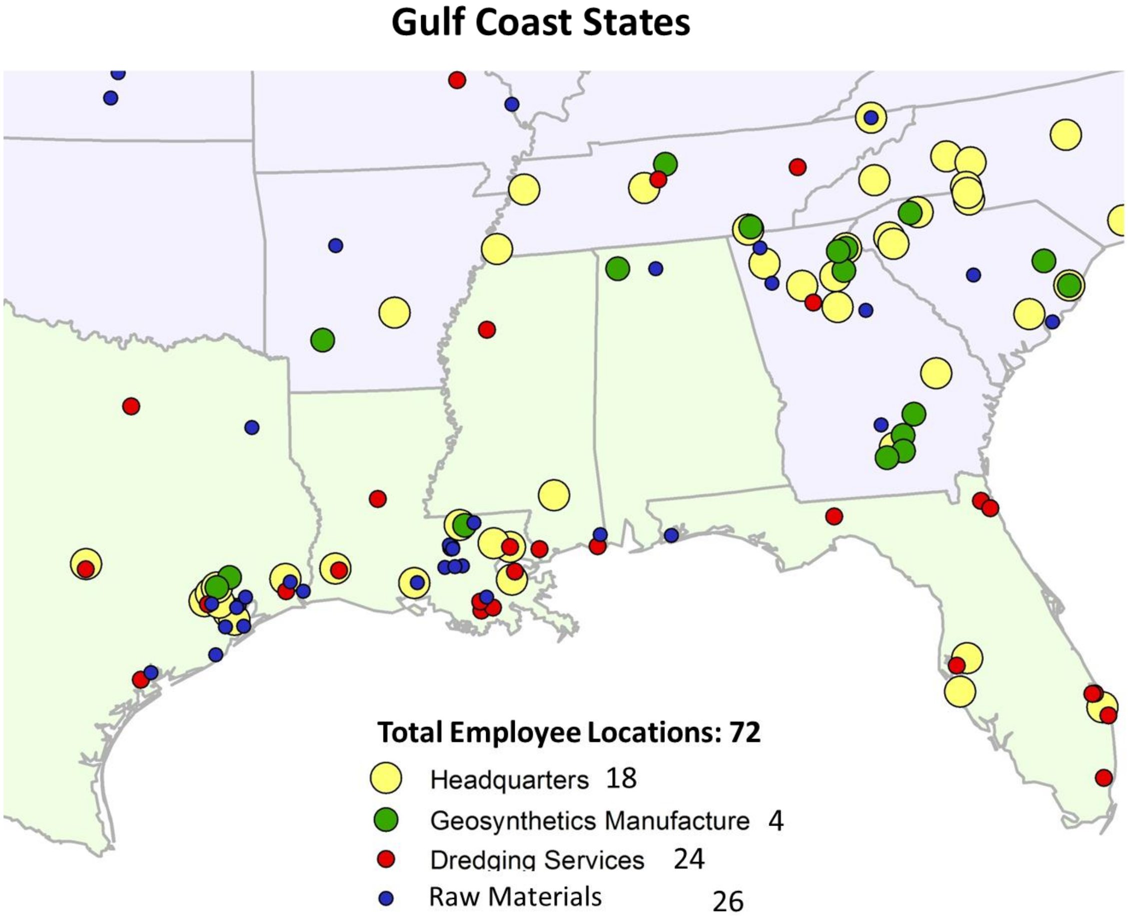
Maps of relevant employee locations of firms linked to geosynthetics & coastal management are presented in Figure 12. This analysis identified 84 relevant firms in the value chain, and a total of 188 relevant employee locations. The Gulf Coast states represent 72 of the 192 employee locations, and 51 are in the Southeast states. We identified relevant employee locations in 36 U.S. states (see Table 2 and Table 3). Among the 84 firms identified, 37 manufacture or fabricate geosynthetics, 23 supply the geosynthetics manufacturers with the raw materials that will become geosynthetics, and four supply the geosynthetics manufacturers with equipment such as looms. We identified 20 dredging companies with experience using geosynthetics for coastal management projects in the Gulf.

Figure 12. Relevant employee locations of firms linked to geosynthetics & coastal management





Source: CGGC, based on industry interviews, company websites, Hoover's database, and OneSource database.



Source: CGGC, based on industry interviews, company websites, Hoover's database, and OneSource database.

Geosynthetics firms are concentrated in the Southeast states. Just four states – Georgia, North Carolina, South Carolina, and Tennessee – represent more than half of geosynthetics firm headquarters (19 of 37), and almost two thirds of geosynthetics manufacturing locations (14 of 24).

We have categorized the firms that supply geosynthetics manufacturers with resin and pigments as Raw Materials Firms. Through phone interviews with industry representatives, we identified only those locations that make raw materials used to manufacture geosynthetics materials. Nearly half the materials manufacturing locations (26 of 54) are in the Gulf Coast states, the majority of which are located in Texas (14) and Louisiana (9).

This study identified 20 firms with experience placing and filling geotextile tubes used in coastal management projects. Nearly half the dredging firm headquarters (9 of 20), and 80 percent of dredge service locations (24 of 30), are concentrated in the Gulf Coast states.

Geosynthetics manufacturers have few choices for U.S. equipment suppliers. The looms and other equipment come from only about four subsidiaries in the United States: Dilo, N.

Schulmberger, Itema, and NAEF Press & Dies Inc. The global headquarters and manufacturing locations of these firms are in Europe.

Table 2. Employee Locations by General Location Type

	Employee locations	HQ	Other relevant employee locations
Total	**192**	**84**	**108**
No. of states with employee locations	**36**	**27**	**25**
Top regions			
Gulf Coast	**72**	**18**	**54**
Alabama	2	0	2
Florida	12	3	9
Louisiana	24	6	18
Mississippi	5	1	4
Texas	29	8	21
Southeast	**49**	**26**	**23**
Georgia	22	8	14
North Carolina	7	7	0
South Carolina	11	6	5
Tennessee	9	5	4

Source: CGGC, based on industry interviews, company websites, Hoover's database, and OneSource database.

Table 3. Employee Locations by Firm and Location Type

	Materials HQ	Materials manufacturing locations	Equipment HQ	Geosynthetics HQ	Geosynthetics manufacturing locations	Dredging HQ	Dredging service locations
Total	23	54	4	37	24	20	30
No. of states with employee locations	15	22	3	17	12	14	9
Top regions							
Gulf Coast	3	26	0	6	4	9	24
Alabama	0	1	0	0	1	0	0
Florida	0	1	0	1	0	2	8
Louisiana	0	9	0	2	1	4	8
Mississippi	0	1	0	0	0	1	3
Texas	3	14	0	3	2	2	5
Southeast	4	6	3	19	14	1	3
Georgia	1	4	0	7	9	0	1
North Carolina	0	0	1	6	0	0	0
South Carolina	1	2	2	4	3	0	0
Tennessee	2	0	0	2	2	1	2

Source: CGGC, based on industry interviews, company websites, Hoover's database, and OneSource database.

VIII. Future of geosynthetics in coastal management

The geosynthetics industry is projected to grow at an annual rate of 6.8 percent through 2015 and the share of geosynthetics for coastal management is expected to grow at a similar rate (Aho, 2012; Freedonia, 2011). While most growth in the coastal management sector will come from the geosynthetic applications covered above, some new products or applications may create additional demand. We identified two such applications that coastal planners and engineers may consider adopting in the future: dewatering and intelligent geoetextiles.

Dewatering is a process that uses geotextile tubes to remove pollutants from contaminated soil or effluent. Environmental remediation firms use this technology to clean toxic areas such as EPA superfund sites (Geosynthetics, 2006). To do so, they pump effluent or soil as slurry into the geotextile tubes, and add a flocculent to help bind the solids. The contaminated solids stay in the geotextile tube while the clean water passes through the textile. Once the solids are completely dry the firms then dispose of them in an approved facility.

Because dewatering with geotextile tubes can effectively remove excess nitrogen from animal waste at large animal feeding operations, this technology could help restore the Gulf (EnviroWaste, 2009). Excess nitrogen is what creates the oxygen-starved dead zone in the Gulf, and animal feedlots along the Mississippi River are one of the principal sources of excess nitrogen (Goolsby et al., 1997). Therefore, dewatering technology using geotextile tubes is a viable means to reduce the dead zone.

Intelligent geotextiles are geocomposites fitted with fiber optics that can detect strain and changes in temperature, and can improve the safety of structures such as dikes or levees by detecting and warning of a structural breech before it happens (Ginter, 2011). TenCate developed one of the first lines of intelligent geotextiles, called GeoDetect, which China and the Netherlands are using monitor their coastal structures (DWS, 2012). Intelligent geotextiles have not yet been implemented in the United States. In the future they could improve the safety of new coastal projects, as well as much of the aging and deteriorating U.S. coastal infrastructure such as dams, dikes, levees, bridges, and wastewater treatment plants that are in poor condition (Cooper, 2009; Vergun, 2012).

IX. Conclusion

Decades of natural and manmade stressors have pushed the Gulf Coast into a state of chronic degradation. Rapidly accelerating land loss now threatens the ecology and economy of this vital resource. To prevent future land loss, restore the coast, and protect valuable lives and infrastructure against flooding, Gulf Coast states are implementing a series of coastal management projects. Projects increasingly incorporate geosynthetics for their various attributes that can improve structure design, reduce project time and cost, and lessen environmental impact of heavy machinery used in restoration.

The geosynthetics industry is growing and evolving rapidly as it finds more applications for its products. Coastal management programs across the Gulf Coast states are growing as well, developing plans worth billions of dollars for ecosystem restoration, flood prevention, and erosion control. With geosynthetics playing an increasing role in coastal management, this convergence of events presents an opportunity for geosynthetics manufacturers to diversify and grow, and for coastal engineering to evolve and improve.

To fully take advantage of this opportunity, industries in key segments of the value chain can concentrate on three key areas– validation, collaboration, and information. Validating new coastal applications through continued testing is essential for verifying the proper use of geosynthetics. Collaborating with coastal planners will open lines of communication that can improve overall performance and quality. Informing construction firms of different products, applications, and manufacturing capabilities can help increase awareness of what is available to them, and make their work more efficient.

As government agencies and various stakeholder groups in Gulf Coast states develop coastal restoration plans with dozens of projects worth billions of dollars, geosynthetics will play an important role in how these projects perform, and will be an important and growing piece of the effort to help restore the Gulf Coast to a more resilient state.

Appendix: Full Set of Firm-Level Data

Employees		Annual Sales ($U.S. millions)	
1-25	☺	0-1	$
25-100	☺☺	1-4.5	$$
101-500	☺☺☺	4.5-33	$$$
501-1,000	☺☺☺☺	33-100	$$$$
1,001 or more	☺☺☺☺☺	100-1,000	$$$$$
		1,000 or more	$$$$$$

Company name (Year Founded)	U.S. Headquarters		Other employee locations		Company Size (sales | # of employees)	
Raw Materials						
Ampacet 1937	Tarrytown	NY	Cartersville	GA	$$$$$	☺☺☺☺
Bamberger Polymers, Inc. 1967	Jericho	NY			$$$	☺☺
BASF 1952	Florham Park	NJ	Geismar	LA	$$$$$$	☺☺☺☺☺
			Freeport	TX		
			Port Arthur	TX		
BP 1947	Decatur	AL	Cooper River	SC	N/A	N/A
			Texas City	TX		
Braskem 1979	Philadelphia	PA	Marcus Hook	PA	$$$$$	☺☺☺☺☺
			La Porte	TX		
			Kenova	WV		
ConocoPhillips Bayway Refinery	Linden	NJ			N/A	☺
DuPont 1802	Wilmington	DE	Pascagoula	MS	$$$$$$	☺☺☺☺☺
			Carneys Point	NJ		
Eastman 1920	Kingsport	TN	Indianapolis	IN	$$$$$$	☺☺☺☺
			Chestertown	MD		
			Jefferson Hills	PA		
			Columbia	SC		
			Kingsport	TN		
			Longview	TX		
			Texas City	TX		
			Franklin	VA		
Exxon Mobil Chemical 1882	Houston	TX	Pensacola	FL	N/A	☺☺☺☺
			Baton Rouge	LA		
			Plaquemine	LA		
			Bayway	NJ		
			Baytown	TX		
			Beaumont	TX		
			Mont Belvieu	TX		

Company name (Year Founded)	U.S. Headquarters		Other employee locations		Company Size (sales | # of employees)	
Raw Materials						
Formosa Plastics 1978	Livingston	NJ	Delaware City	DE	$$$$$	☺☺☺☺
			Baton Rouge	LA		
			Point Comfort	TX		
Fox Industries 1969	Baltimore	MD			$$$	☺
INEOS 1998	League City	TX	Long Beach	CA	$$$$$	☺☺☺☺
			Hobbs	NM		
			Alvin	TX		
			La Porte	TX		
Integra Plastics 1991	Madison	SD			$$$	☺
Modern Dispersions, Incorporated (MDI) 1967	Leominster	MA	Fitzgerald	GA	$$$	☺
Nova Chemicals 1994	Pittsburgh	PA			$$$$$$	☺☺☺☺
Osterman & Company, Inc. 1976	Cheshire	CT			$$$	☺
Premier Color Group	Williamston	SC			$	☺
Prime Colorants 1975	Franklin	TN			$$$	☺
Sherwin Williams 1866	Cleveland	OH			$$$$$$	☺☺☺☺☺
Spartech 1960	Clayton	MO	Wichita	KS	$$$$$$	☺☺☺☺
			Cape Girardeau	MO		
Standridge Color Corporation 1973	Social Circle	GA	Dalton	GA	$$$$	☺☺
			Greensboro	GA		
			Newton	KS		
			Defiance	OH		
The Dow Chemical Company 1897	Midland	MI	Russellville	AR	$$$$$$	☺☺☺☺☺
			Hayward	CA		
			La Mirada	CA		
			Pittsburg	CA		
			Louisville	KY		
			Greensburg	LA		
			New Iberia	LA		
			Plaquemine	LA		
			St. Charles	LA		

Company name (Year Founded)	U.S. Headquarters		Other employee locations		Company Size (sales | # of employees)	
Raw Materials						
Total Petrochemicals & Refining USA, Inc. 1956	Houston	TX	Carville La Porte Pasadena	LA TX TX	$$$$$	☺☺☺☺
Equipment						
Dilo 1983	Charlotte	NC			$	☺
Itema 1983	Spartanburg	SC			$$	☺
N. Schulmberger (NSC Groupe) 1979	Fort Mill	SC			$$	☺
NAEF Press & Dies Inc. 1988	Bolton Landing	NY			$	☺
Geosynthetics						
Aer-Flo Canvas Products, Inc. 1981	Bradenton	FL			$$$	☺
Agru America Incorporated 1988	Georgetown	SC	Fernley Georgetown	NV SC	$$$	☺☺
Belton Industries, Inc. 1916	Belton	SC	Salem Duluth	OR GA	$$$	☺☺
Carthage Mills 1958	Cincinnatti	OH	Cincinnatti	OH	N/A	N/A
Colbond 2005	Enka	NC			$	☺
Colorado Linings International 1978	Parker	CO	New Caney	TX	$$$	☺
CONTECH Construction Products Inc. 1986	West Chester	OH			$$$$$	☺☺☺☺
Crown Resources 2010	Toccoa	GA	Toccoa	GA	$	☺
Dalco Nonwovens 2004	Conover	NC			$$	☺
Deltalok 1990	Ferndale	WA			$$$$	N/A
East Coast Erosion Control Blankets, LLC 2002	Bernville	PA	Lake City	SC	N/A	N/A

Company name (Year Founded)	U.S. Headquarters		Other employee locations		Company Size (sales | # of employees)	
Geosynthetics						
Environmental Protection, Inc. (EPI) 1980	Mancelona	MI			N/A	N/A
Fiberweb 1989	Simpsonville	SC	Old Hickory	TN	$$$$	☺☺☺
Firestone Building Products 1982	Indianapolis	IN	Tuscumbia Prescott Wellford	AL AZ SC	$$$$	☺☺☺☺
Flint Industries 1995	Metter	GA			$$$	☺
Fuquay 1985	Austin	TX				☺
Geocell Systems, Inc.	San Francisco	CA			N/A	N/A
GeoProducts, LLC 2000	Houston	TX			$$	☺
Geostar Technologies 2007	Memphis	TN			$	☺
Geo-Synthetics, LLC 1971	Waukesha	WI			$$$$	☺☺
GSE Holdings 1995	Houston	TX	Houston	TX	$$$$	☺☺☺
Hesco Bastion Environmental Inc. (HBEI) 2003	Hammond	LA			N/A	☺
Huesker 1991	Charlotte	NC			$$$	☺
L & M Supply Company 1994	Willacoochee	GA	Douglas Nashville Pearson	GA GA GA	N/A	N/A
Maccaferri	Williamsport	MD	Williamsport West Sacramento	MD CA		N/A
Mattex 1996	Calhoun	GA			$	☺
PacTec 1989	Clinton	LA	Clinton	LA	$$$	☺
Presto Geosystems 2010	Appleton	WI			$	N/A
Profile Products LLC 1997	Buffalo Grove	IL			$$$$	☺☺
Propex 2009	Chattanooga	TN	Hazlehurst Nashville Chattanooga	GA GA TN	$$$$$	☺☺☺☺

Company name (Year Founded)	U.S. Headquarters		Other employee locations		Company Size (sales | # of employees)	
Geosynthetics						
Tencate 1995	Pendergrass	GA	Commerce Cornelia	GA GA	$$$$$	☺☺☺
Tensar 1988	Alpharetta	GA			$$$	☺☺
Texel (ADS Inc.) 1995	Apex	NC			$	☺☺
Thrace-LINQ 1972	Summerville	SC			$$$	☺
U.S. Wick Drain 1994	Leland	NC			$	☺
Vantage Partners	Mooresville	NC			N/A	N/A
Willacoochee Industrial Fabrics	Willacoochee	GA			N/A	N/A
Construction/Dredging Firms						
American Shoreline Restoration	Palm Beach	FL			$	☺
Apollo Environmental Strategies, Inc. 1992	Beaumont	TX	Beaumont Irving	TX TX	$	☺
Bertucci Industrial Services, LLC 1993	Jefferson	LA			$$$$	☺
Dixon Marine Services, Inc.	Inverness	CA			N/A	N/A
DQSI 1998	Covington	LA	New Orleans Stennis Space Center	LA MS	$$	☺
Dredge America	Kansas City	MO			N/A	[illegible]
Dutra Group 1972	San Raphael	CA			$$$$$	☺☺
Great Lakes Dredge and Dock 1890	Oak Brook	IL	Pascagoula	MS	$$$$$	☺☺☺☺
Infrastructure Alternatives (IAI Holdings, Inc.) 2000	Rockford	MI			$$$	☺
Inland Dredging Company 1997	Dyersburg	TN	Swan Lake	MS	$$$	☺
Javeler Construction Company 1968	New Iberia	LA			$$	☺

Company name (Year Founded)	U.S. Headquarters		Other employee locations		Company Size (sales | # of employees)	
Construction/Dredging Firms						
Jay Cashman, Inc. 1994	Quincy	MA	Stuart	FL	$$$$	☺☺☺☺☺
L&A Contracting Company 1947	Hattiesburg	MS			N/A	N/A
Manson Construction/ Manson Gulf 1905	Seattle	WA	Jacksonville	FL	$$$$	☺☺☺
			Houma	LA		
Mike Hooks, Inc. 1946	Westlake	LA			$$$$	☺☺
Norfolk Dredging Company 1899	Chesapeake	VA	Stuart	FL	$$$	☺☺
Orion Marine Group 1994	Houston	TX	Tampa	FL	$$$$$	☺☺☺
			Lake Charles	LA		
			Port Lavaca	TX		
Pine Bluff Sand & Gravel Company 1913	Pine Bluff	AR	Alexandria	LA	$$$$	☺☺
			Baton Rouge	LA		
Weeks Marine, Inc. 1919	Cranford	NJ	Bourg	LA	$$$$$	☺☺☺☺
			Covington	LA		
			Houma	LA		
			Houston	TX		
WRS Infrastructure & Environment, Inc. , 1985	Tampa	FL	Jacksonville	FL	$$$$	☺☺
			Miami	Fl		
			Tallahassee	FL		
			West Palm Beach	FL		
			Stone Mountain	GA		
			Springfield	IL		
			Desloge	MO		
			Hamilton	NJ		
			Brentwood	TN		
			Knoxville	TN		
			Austin	TX		

References cited

Adkins, Chastity. (2012). Product Engineering Manager, Propex. Personal communication with CGGC research staff. February 23, 2012.

Aho, Andrew. (2012). Managing Director, Geosynthetic Materials Association (GMA). Personal communication with CGGC research staff. March 15, 2012.

Allen, Hollis H. and James R. Leech. (1997). Bioengineering for Streambank Erosion Control. Vicksburg, MS: United States Army Corps of Engineers. pp. 90. http://www.engr.colostate.edu/~bbledsoe/CIVE413/Bioengineering_for_Streambank_Erosion_Control_report1.pdf.

Bezuijen, Adam and Erik Vaastenburg. (2008). Geosystems, Possibilities and Limitations for Applications. Netherlands: Delft Cluster. http://www.delftcluster.nl/website/files/geosystems.pdf.

BLS. (2010). May 2010 National Industry-Specific Occupational Employment and Wage Estimates. *Bureau of Labor Statistics: Occupational Employment Statistics* Retrieved January 20, 2012, 2012, from http://www.bls.gov/oes/current/oessrci.htm.

Burran, Andy. (2012). Lead Applications Engineer, Propex. Personal communication with CGGC research staff. February 23, 2012.

Cooper, Michael. (2009). U.S. Infrastructure Is in Dire Straits, Report Says. *New York Times*. January 28, 2009, p. A16. from http://www.nytimes.com/2009/01/28/us/politics/28projects.html.

CPRA. (2012). Louisiana's Comprehensive Master Plan for a Sustainable Coast: Committed to our Coast. Baton Rouge, LA: Louisiana Coastal Protection & Restoration Authority. http://www.coastalmasterplan.louisiana.gov/2012-master-plan/final-master-plan/.

CWPPRA. (2011). Bio-Engineered Oyster Reef Demonstration (LA-08). *Coastal Wetlands Planning, Protection and Restoration Act - Projects* Retrieved April 30, 2012, from http://lacoast.gov/new/Projects/Info.aspx?num=la-08.

Dean, Ellyn. (2012). Applications Engineer, Propex. Personal communication with CGGC research staff. February 23, 2012.

Dendurent, Jody and Mark Woodward. (2009a). Geotextiles in Levees: History, Performance, and Design of Geotextiles in Levees: A Report from New Orleans (Part 1 of 2). *Geosynthetics* Retrieved March 20, 2012, from http://geosyntheticsmagazine.com/articles/0409_f5_levees.html.

Dendurent, Jody and Mark Woodward. (2009b). Geotextiles in Levees: History, Performance, and Design of Geotextiles in Levees: A Report from New Orleans (Part 2 of 2). *Geosynthetics* Retrieved March 20, 2012, from http://geosyntheticsmagazine.com/articles/0609_f4_levees.html.

Durham, Andy. (2012). Stormwater Specialist, Propex Operating Company, LLC. Personal communication with CGGC research staff. February 23, 2012.

DWS. (2012). TenCate Geosynthetics Project Partner in Yellow River Dike Monitoring. *Dutch Water Sector* Retrieved May 2, 2012, from http://www.dutchwatersector.com/news/news/2012/03/tencate-geosynthetics-project-partner-in-yellow-river-dike-monitoring/.

Elko, Nicole A. and Douglas W. Mann. (2007). "Implementation of Geotextile T-Groins in Pinellas Country, Florida." *Shore & Beach, 75*(2): 1-10.

EnviroWaste. (2009). Swine Manure: High Volume Geotextile Dewatering: Farm Pilot Project Coordination, Inc. (FPPC). http://www.fppcinc.org/pdf/reports_envirowastetechnologies.pdf.

EPA. (2012). Chain O'Lakes and Fox River Selected for Streambank Protection Project. *Environmental Protection Agency - Illinois* Retrieved April 18, 2012, from http://water.epa.gov/polwaste/nps/success319/IL.cfm.

EPA and USACE. (2007). Identifying, Planning, and Financing Beneficial Use Projects Using Dredged Material. Washington, DC: Environmental Protection Agency and U.S. Army Corps of Engineers. http://glc.org/dredging/benuse/documents/BeneficialUseManual002.pdf.

FHWA. (1998). Federal Highway Administration Geosynthetic Design and Construction Guidelines. *Definitions, Manufacturing Processes, and Identification* Retrieved April 19, 2012, from http://www.lrrb.org/geosynthetics_design_cd/internetexplorer/htmlsections/chapter1FHWA/1-3.html.

FLDEP. (2008). Strategic Beach Management Plan for the Southwest Gulf Coast Region: Florida Department of Environmental Protection: Bureau of Beaches and Coastal Systems.

http://www.dep.state.fl.us/beaches/publications/pdf/SBMP/Southwest%20Gulf%20Coast%20Region.pdf.

Fontaine, Tem. (2012). Professional Engineer at Coastal Tech. Personal communication with CGGC research staff. March 1, 2012.

Fowler, Jack. (1996). Proposed Alternative for Raising Mississippi Levees Using Geotube Technology Developed Under the Corps of Engineers' Construction Productivity Research Program (CPAR). Vicksburg, MS: Geotech Associates. http://www.geotec.biz/publications/raisinglevees.pdf.

Freedonia. (2011). Geosynthetics to 2015 Retrieved May 4, 2012, from http://www.freedoniagroup.com/Geosynthetics.html.

Freedonia Group. (2009). Freedonia in the News. Retrieved February 13, 2012, from http://www.freedoniagroup.com/InTheNewsDisplay.aspx?DocumentId=435525.

GEOfabrics Limited. (2005). Designing Rock & Rip-rap Structures with Geotextiles. Leeds, West Yorkshire. http://www.geofabrics.com/downloads/downloads.htm?category=21&back=3.

GEOfabrics Limited. (2012). An Introduction to Geosynthetics. Leeds, UK: GEOfabrics Limited. pp. 8. http://www.geofabrics.com/docs/Geosynthetics%20guide.pdf.

Geosynthetics. (2006). Geotube dewatering containers help in cleanup of the Fox River. Retrieved May 2, 2012, from http://geosyntheticsmagazine.com/articles/0806_f4_geotube_dewatering.html.

Ginter, Vicki. (2011). Regional Marketing Manager. Personal communication with CGGC research staff. November 4, 2011.

GMA. (2009). Handbook of Geosynthetics. Roseville, MN: Geosynthetic Materials Association. pp. 72. http://geosyntheticsmagazine.com/articles/wp7_handbook.html.

---. (2012a). Geocells Product Data. *Geosynthetic Materials Association* Retrieved April 9, 2012, from http://geosyntheticsmagazine.com/repository/2/13305/geocells_specguide2012.pdf.

---. (2012b). How Geosynthetics Benefit our Nation's Infrastructure: Geosynthetics Materials Association. https://secure.ifai.com/gmanow.com/repository/8/2315/infrastructure_geosynthetics.pdf.

Goolsby, Donald A., William A. Battaglin and Richard P. Hooper. (1997). Sources and Transport of Nitrogen in the Mississippi River Basin. Atlanta, GA: USGA. http://co.water.usgs.gov/midconherb/html/st.louis.hypoxia.html.

Gordon, Kate, Jeffrey Buchanan and Phillip Singerman. (2011). Beyond Recovery: Moving the Gulf Coast Toward a Sustainable Future. Washington, DC: Center for American Progress and Oxfam America. pp. 80. http://www.americanprogress.org/issues/2011/02/beyond_recovery.html.

Heins, Ernie. (2012). Project Technical Manager, Agru America. Personal communication with CGGC research staff. February 28, 2012.

Hughes, Steven A. (2006). Uses for Marine Mattresses in Coastal Engineering. Vicksburg, MS: United States Army Corps of Engineers. http://chl.erdc.usace.army.mil/library/publications/chetn/pdf/chetn-iii-72.pdf.

Jones, David. (2012). Director of Product and Application Development, TenCate. Personal communication with CGGC research staff. March 9, 2012.

Ko, Jae-Young and John W. Day. (2004). "Wetlands: Impacts of Energy Development in the Mississippi Delta." *Encyclopedia of Energy, 6*: 397-408.

Koerner, Robert M. (2000). A Brief Overview of Geosynthetics and Their Major Applications: United States Universities Council on Geotechnical Education and Research. http://www.ce.ncsu.edu/usucger/Teaching%20Aids.html.

Koerner, Robert M. (2012a). *Designing with Geosynthetics* (6th ed. Vol. 1). Bloomington, IN: Xlibris Corporation.

Koerner, Robert M. (2012b). Emeritus Director, Geosynthetic Institute. Personal communication with CGGC research staff. May 9, 2012.

Lancaster, Tim and Deron N. Austin. (2003). Classifying Rolled Erosion-Control Products: A Current Perspective: Erosion Control Technology Council. http://www.ectc.org/resources/Classifying%20RECP%2004.pdf.

Lothspeich, Steven E. (2012). President, Huesker. Personal communication with CGGC research staff. April 25, 2012.

Lowe, Marcy, Shawn Stokes and Gary Gereffi. (2011). Restoring the Gulf Coast: New Opportunitities for Established Firms. Durham, NC: Duke University Center on Globalization, Governance & Competitiveness. pp. 56. http://cggc.duke.edu/pdfs/CGGC_Gulf-Coast-Restoration.pdf.

McConnell, Casey. (2012). Chief Estimator, The DRC Group. Personal communication with CGGC research staff. April 23, 2012.

Moore, Tina. (2012). Engineer, Apollo Environmental. Personal communication with CGGC research staff. April 27, 2012.

Morton, Robert A. (2004). Physical Agents of Land Loss: Relative Sea Level. *An Overview of Coastal Land Loss: With Emphasis on the Southeastern United States* Retrieved May 2, 2012, from http://pubs.usgs.gov/of/2003/of03-337/sealevel.html.

O'Brien, Cherie. (2006). Texas Parks and Wildlife Department Restoration Projects Overview. Dickinson, Tx: Texas Parks and Wildlife Department, Coastal Conservation Program. http://www.swg.usace.army.mil/OD/2006DC/Cherie%20O'Brien%20-%20TPWD%20-%202006%20Dredging%20Conference.pdf.

O'Brien, Cherie. (2012). Coastal Ecologist and Project Leader, Texas Parks and Wildlife Department. Personal communication with CGGC research staff. April 25, 2012.

Ortego, Tyler. (2012). President, ORA Engineering. Personal communication with CGGC research staff. January 12, 2012.

Peterson, Charles H., Felicia C. Coleman, Jeremy B.C. Jackson, R. Eugene Turner, Gilbert T. Rowe, Richard T. Barber, Karen A. Bjorndal, Rober S. Carney, Robert K. Cowen, Jonathan M. Hoekstra, James T. Hollibaugh, Shirley B. Laska, Richard A. Luettich Jr., Craig W. Osenberg, Stephen E. Roady, Stanley Senner, John. M. Teal, and Ping Wang. (2011). A Once and Future Gulf of Mexico Ecosystem: Restoration Recommendations of an Expert Working Group. Washington, DC: Pew Environment Group. pp. 112. http://www.pewenvironment.org/uploadedFiles/PEG/Publications/Report/Petersonetal-GOM-report.pdf.

PIANC. (2011). The Application of Geosynthetics in Waterfront Areas. Brussels, Belgium: The World Association for Waterborne Transport Infrastructure. pp. 111. http://books.google.com/books?id=aq7Z6H4jpIAC&printsec=frontcover#v=onepage&q&f=false.

Pritchard, Martin, Robert W. Sarsby and Subhas C. Anand. (2000). Textiles in Civil Engineering. Part 2 - Natural Fibre Geotextiles. In A. R. Horrocks & S. C. Anand (Eds.), *Handbook of Technical Textiles* (pp. 372-406). Cambridge: Woodhead Publishing Limited in association with The Textile Institute.

Propex. (2010). Case Studies: Penn and DeCamp Street Levees - Jefferson Parish, South Louisiana. *Armormax Levee Armstrong* Retrieved April 18, 2012, from http://armormax.geotextile.com/case-studies.aspx.

Rankilor, Peter. (2000). Textiles in Civil Engineering. In A. R. Horrocks & S. C. Anand (Eds.), *Handbook of Technical Textiles* (pp. 358-371). Cambridge, England: Woodhead Publishing Limited in association with The Textile Institute.

Rankilor, Peter R. (2000). Textiles in Civil Engineering. Part 1 - Geotextiles. In A. R. Horrocks & S. C. Anand (Eds.), *Handbook of Technical Textiles* (pp. 358-371). Cambridge: Woodhead Publishing Limited in association with The Textile Institute.

SBA. (2012). U.S. Small Business Administration Table of Small Business Size Standards. Washington, DC: U.S. Small Business Administration. http://www.sba.gov/sites/default/files/files/Size_Standards_Table.pdf.

Shukla, Sanjay Kumar and Jian-Hua Yin. (2006). *Fundamentals of Geosynthetic Engineering*. Leiden, The Netherlands: Taylor & Francis/Balkema.

Siwula, John M and Scott A. Breen. (2008). A Case Study: Levee Geotextile Reinforcement to Reduce ROW Acquisistion and Borrow Quantity. In K. R. Reddy, M. V. Khire & A. N. Alshawabkeh (Eds.), *Geosustainability and Geohazard Mitigation: Proceedings of Selected Sessions of Geocongress 2008*. New Orleans, LA: American Society of Civil Engineers.

TenCate. (2012). Geosynthetics North America. *Glossary* Retrieved March 6, 2012, from http://www.tencate.com/2588/TenCate/Geosynthetics/Region-North-America/en/en-Geosynthetics---Geotextiles/Tech-Info/Glossary.

TERRAM. (2012). Flood Defence. *Terram Geosynthetics* Retrieved March 29, 2012, from http://www.terram.com/applications/flood-defence.html.
Thomson, Gordon. (2012). Director, Coastal Planning & Engineering. Personal communication with CGGC research staff. March 14, 2012.
Titus, James G. and Stephen K. Gill. (2009). Coastal Sensitivity to Sea-Level Rise: A Focus on the Mid-Atlantic Region: Societal Impacts and Implications. Washington, DC: U.S. Climate Change Science Program. pp. 85-138. http://www.epa.gov/climatechange/effects/coastal/pdfs/ccsp_part2.pdf.
Trainer, Ed. (2012). Marine Market Manager, TenCate. Personal communication with CGGC research staff. February 9, 2012.
US Fabrics. (2012). Glossary of Geosynthetic Terms and Definitions. Retrieved March 6, 2012, from http://www.usfabricsinc.com/resources/geosynthetics-glossary.
USACE. (1998). Geotextile Tube Structures for Wetlands Restoration and Protection. Vicksburg, MS: United States Army Corps of Engineers. http://el.erdc.usace.army.mil/elpubs/pdf/hsrs3-2.pdf.
USGS. (2000). National Assessment of Coastal Vulnerability to Sea-Level Rise: Preliminary Results for the U.S. Gulf of Mexico Coast. *U.S. Geological Survey Woods Hole, Massachusetts* Retrieved April 29, 2012, from http://geology.uprm.edu/MorelockSite/morelockonline/3_image/cstvulnGoM.htm.
---. (2004). An Overview of Coastal Land Loss: With Emphasis on the Southeastern United States. *U.S. Geological Survey* Retrieved April 29, 2012, from URL: http://pubs.usgs.gov/of/2003/of03-337/intro.html.
Vergun, David. (2012). Aging Infrastructure Threatens U.S. Security, says USACE Nominee. *U.S. Army: Official Homepage of the United States Army* Retrieved May 3, 2012, from http://www.army.mil/article/73510/Aging_infrastructure_threatens_U_S__security__says_USACE_nominee/.
Waste360. (1993). Study Reports Growth in Geosynthetics. Retrieved April 30, 2012, from http://waste360.com/mag/waste_study_reports_growth.
Whitaker, Brian. (2012). Technical Sales Manager, Fiberweb. Personal communication with CGGC research staff. May 1, 2012.