Advanced Materials Sector Report

Technology Roadmap Project

For the

CENTER FOR ECONOMIC GROWTH

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ADVANCED MATERIALS

Introduction

This summary provides an overview of advanced materials, in order to assist in the identification of a few sub sectors that are of greater interest to CEG. Due to the vastness of the materials field, a brief overview and definition of materials and advanced materials are offered. Next, alternative ways in which activity associated to materials can create value in the economy and region are described. This is followed by a brief description of a number of different sectors that, based on their position in product lifecycle, technological lifecycle, current market size and market potential, appear to be among the most attractive areas to focus on.

'Materials' is a very inclusive term, since it is the basic building block of all physical products. Materials are typically broken down into five groups: metals, polymers (thermoplastics and thermosets), ceramics, glasses and composites. This delineation offers insights into likely applications, since these materials have very different atomic and structural properties leading to very different properties and suitability for different applications and purposes. The most common ways in which materials are categorized [1] are: by industry (based on the compatibility with the requirements of a specific industry), by application (such as pressure vessels), or by a material subgroup (such as martenitic steel or low-density polyethylene). In the case of industry, examples of delineations are: medical materials (compatibility with human body), electronic materials (focus is on electronic and optical properties), and aerospace materials (focus is on low weight and characteristics that limit the likelihood of catastrophic failure).

Advanced materials can be defined in numerous ways; the broadest definition is to refer to all materials that represent advances over the traditional materials that have been used for hundreds or even thousands of years. From this perspective advanced materials refer to all new materials and modifications to existing materials to obtain superior performance in one or more characteristics that are critical for the application under consideration. A more insightful and focused approach to advanced materials is to consider materials that are early in their product and/or technology lifecycle. In other words, there is significant room for growth in terms of the improvement of the performance characteristics (technology lifecycle) and their sales volume (product lifecycle). The latter definition is what will be focused on here. Prior to considering the advanced materials, some brief comments are offered on materials as an industry to demonstrate size and pervasiveness.

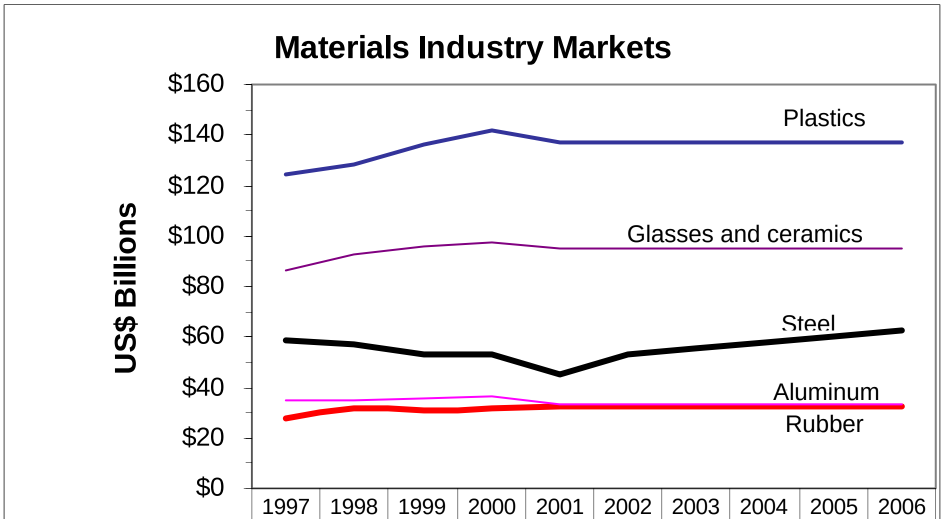
1. Market size

Market size figures are available for traditional materials, but are usually unavailable for emerging technologies (see Figure 1 below). If values are available for emerging technologies they are often based on the opinions of experts, rendering the forecasts as more of a guidepost than a decision making tool [2]. However, the market size for traditional materials is important, since it offers an indication of the potential market for advanced materials that replace traditional

[1] See for example: ASM Handbooks, ASM International, Metals Park, Ohio.

[2] Linton, J. D., *Determining Demand, Supply and Pricing for Emerging Markets and Technologies*, Technological Forecasting and Social Change, Volume 71, Number 1/2, pp. 105-120, 2004.

materials. From the figure, one can see that the market for traditional materials is fairly flat in terms of $ sales. However, it is important to take into account the dematerialization of most products. Over time products are providing the same level of benefit and value through the use of less material. In some cases this is the result of better use of existing materials. In other cases, dematerialization is driven by the use of smaller quantities of more expensive (on a per unit basis) advanced materials.



	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Steel	58	57	53	53	45	53	56	58	60	62
Aluminum	28	31	31	32	33	33	33	33	33	33
Plastics	124	129	137	142	137	137	137	137	137	137
Rubber	35	35	35	36	33	33	33	33	33	33
Glasses Ceramics	86	93	96	97	95	95	95	95	95	95

Figure 1: Reported and predicted size of major US material markets [3]

The worldwide production of steel is about 780 million metric tons annually [4]. In 2002, the North American aluminum supply was 10 million metric tons (5.2% above 2001) [5] and the European aluminum market was about 7 million metric tons in 2003 [6]. The aluminum market is currently supplied by a mixture of secondary (metal from recycling) and primary (virgin material) production. Markets for polymers, both thermoplastics and thermosets, are large and continue to grow [7]. Since composites are a combination of other materials their volumes are included in the values reported above. Having given an indication of the size of the global

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[3] Sources: Data for 1997-2001: Statistics for Industry Groups and Industries 2001 Annual Survey of Manufacturers, US Census Bureau, Department of Commerce Economic and Statistics Administration, Washington DC, 2003; Steel Data 2002-2006: Steel Industry Profile Reference Code: 72-998, Datamonitor, New York, 2002.; Other Data 2002-2006: Forecast based on regression of earlier sales.

[4] Steel Works Industry Yearbook, Jan2001/2002 (Business Source Premier) United States Steel: Datamonitor Industry Profiles; 2002.

[5] The Aluminum Association (Hwww.aluminum.orgH).

[6] The Aluminum Association (Hwww.aluminum.orgH).

[7] Thermoset production grew from 8,003 Million lbs to 8,312 Million lbs and the thermoplastics production grew from 85,828 Million lbs. Source: APC Plastics Industry Producers' Statistics Group (PIPS), as compiled by VERIS Consulting, LLC.

materials markets, the manner in which economic value can be extracted from materials is considered.

2. Value chain - extracting economic benefit from materials

There are a number of different ways that economic growth associated to advanced materials can occur. The most common types of businesses are briefly considered below:

- Materials production. Materials production facilities tend to offer a mix of unskilled, semi-skilled and skilled labor. The facilities tend to be large.
- Supply equipment or services to materials producers and processors. Producers and processors of materials require supply of capital equipment, consumables, and services. This is especially the case for advanced materials that often require new capital equipment, services with high knowledge value-added, new test equipment for in-process monitoring and out-going quality control. These businesses tend to have a smaller workforce with a higher skill set, but usually have low environmental impacts.
- Processing of materials into high-value added niche applications. These businesses focus on the needs of specific industries and/or applications and select or develop materials to offer these benefits. These firms can be very attractive, since a niche might be too small to attract major competitors, but large enough to offer a stable and profitable market. These businesses are typically in between the above mentioned businesses in terms of their employee mix.
- Development of a new process for the manufacture of materials. Businesses have been based on the production of a material using a new process. If the new process is successful, the result is a transfer of economic activity from the firms that utilize the old processes to the firm(s) that are pioneering the new processes. New manufacturing processes can be protected not only with patents, but with the concentration of tacit knowledge at or near the firm's site. Examples of this for new processes for existing materials include the Pilkington tin float process [8] and mini-mills at Nucor and Chapparal steel [9]. The risk associated with a new process is that the novel process may not succeed, for example the failure of the float zone process for the production of semiconductor grade silicon. Even riskier, but with greater upside potential, is the production of a new material with a new process; for example nanotechnology which is examined in detail in another section.

Having addressed different ways in which economic value can be extracted from advanced materials, some advanced material sub sectors with high growth potential will now be briefly described [10].

3. Significance for economic development

So far the size, breadth and the complexity of the materials field has been described. With such scope to work from hundreds of advanced materials sub sectors can be identified. This section

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[8] Utterback James M., Mastering the Dynamics of Innovation: Haw companies can seize opportunities in the face of technological change, Harvard Business School Press, Boston MA, 1994.

[9] Linton, J.D. and Walsh, S.T. *A Theory of Innovation for Nanotechnologies and other Process-Based Innovations*, with Steven Walsh, IEMC-2003, Engineering Management Society of the IEEE, November 2003, Troy, NY.

[10] Due to the breadth and pervasiveness of materials it is not possible to offer a value chain at this level.

focuses on five areas that appear to have excellent potential. It is suggested that two areas be selected for further study. The areas to be considered are:

- Electronic materials
- Medical materials
- Nanomaterials
- Reprocessing of waste materials
- Superconductivity

The electronic materials sector is already a huge field with a large number of firms actively participating. This sector, however, offers tremendous potential since the field is undergoing rapid change to allow for continued miniaturization of components. This miniaturization provides new requirements for materials, processing and test equipment, consumables and services.

Medical materials have tremendous growth potential due not only to developed economy demographics, but due to its relatively primitive state. Historically, the most advanced medical materials were the domain of dentistry. However, greater attention has recently been focused on medical materials [11]. This attention considers the novel use of existing materials for medical purposes and hybrid methods which use new materials to assist the body in self repair. Medical materials typically are high value added, but regulatory requirements can create delays in commercialization and additional overheads associated with compliance to regulations.

The nanomaterials sector is worth considering separately from nanotechnologies, since it focuses on the development of a material while focusing on structure at the near atomic level. This offers the potential for materials with properties that are at their theoretical limit, thus able to vastly outperform existing materials and command a higher price. The industry is still young and there is a mixture of small, medium and large firms active in this area. This is an opportunity to target location of all sizes of firms, since the novelty of the material is such that firms will probably opt for Greenfield sites that provide some physical and intellectual distance from the manufacture of existing products and business units. Nanomaterials offer potential for all types of materials [12]. The domestic market is expected to be greater than US$ 1 billion, by 2007, as a result of the application of nanotechnology in many different types of materials for a wide range of product applications [13].

Superconductivity, the ability to transfer electricity across great distance without losses through resistance, was the focus of tremendous interest in the mid to late 1980’s, due to a string of discoveries. These discoveries found that materials based on oxides of rare-earth metals exhibited superconducting properties well above absolute zero. The premature hope was that a material would be found which is superconducting at room temperature. However, within the last

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[11] Interest has increased significantly recently. Consequently, the ASM held its first conference on Medical Devices in September of 2003. This is significant, since this is one of the major sectors that was not being directly addressed by materials associations meetings.

[12] For example see: Lowe, T., The Revolution in NanoMetals, Advanced Materials and Processes, pp. 63-65. January 2002.

[13] Freedonia Group, Nanomaterials to 2007 – Market Size, Market Share, Demand Forecast and Sales, Cleveland, Ohio, 2003.

year a new form of matter that has superconducting properties has been discovered. This discovery should accelerate research and eventual development of superconducting materials. This field has tremendous future potential, but is risky since it is still far from development and the timeline for development is not clear.

Reprocessing of waste materials is different from the other sub sectors that have been considered so far, since it is based on legislation in North America, Europe and Asia. In many Counties, States and Countries laws that encourage or require reprocessing of post consumer waste are in place, pending or under development. The most notable examples are the decade old German laws requiring the take-back and recycling of packaging materials and the more recent European Union requirement for all member countries to take-back and reprocess post consumer electronic waste. Similar regulations are enacted or under consideration in many US jurisdictions [14]. Reprocessing of post consumer waste can be in the form of remanufacturing (product recovery) or recycling (material recovery). These markets will continue to grow in the future due to legislative requirements. In the case of recycling, opportunities are expected to be co-located with the waste producing population since it is a low value added process and is greatly affected by the cost of transportation. However, remanufacturing (product recovery) can be high value added. Significant remanufacturing operations currently exist in the United States, but the industry is relatively invisible since it is not recognized as an industry [15]. Remanufacturing has been described as attractive for economic development, since it requires high levels of unskilled labor [16]. The coupling of future growth due to changes in legislation in the US and abroad with the high labor intensity makes this an interesting sector to consider further.

4. Summary

The field of materials has hundreds of sub sectors that constitute advanced materials. Five of these sub sectors have been briefly considered. As the potential of a sub sector increases, so does the risk since the market potential remains undeveloped and clear. From least risky to most risky (least potential to most potential economic development potential), the sub sectors are roughly in the order: electronic materials, reprocessing of waste materials, medical materials, nanomaterials, and superconductors.

[14] Linton, J.D., and Yeomans, J.S. *Materials Recycling and Industrial Ecology*, Nature Materials, Volume 3, Number 4, pp. 199-201, 2004.

[15] Participant firms are counted in the industry that their product is sold to. For example automotive remanufacturers are grouped with automotive component manufacturers. This has led to Robert Lund referring to it as a hidden giant, see Lund, R. *The Remanufacturing Industry: Hidden Giant*. Boston University, Boston MA. 1996.

[16] Lund, R. *Remanufacturing: United States experience and implications for developing nations*, The World Bank: Washington, DC. 1983.