Strategic Business Insights

Explorer

Technology Map

Business Opportunities in Technology Commercialization

Smart Materials

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- Artificial Intelligence
- Biocatalysis
- Biomaterials
- Biopolymers
- Biosensors
- Collaboration Tools
- Connected Cars
- Connected Homes
- Engineering Polymers
- Flat-Panel Displays
- Fuel Cells
- Membrane Separation
- MEMS/Micromachining
- Mobile Communications
- Nanobiotechnology
- Nanoelectronics
- Nanomaterials
- Novel Ceramic/Metallic Materials
- Optoelectronics/Photonics
- Organic Electronics
- Pervasive Computing
- Photovoltaics
- Polymer-Matrix Composites
- Portable Electronic Devices
- Portable Power
- Renewable Energy Technologies
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- Robotics
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Technology Map

Smart Materials

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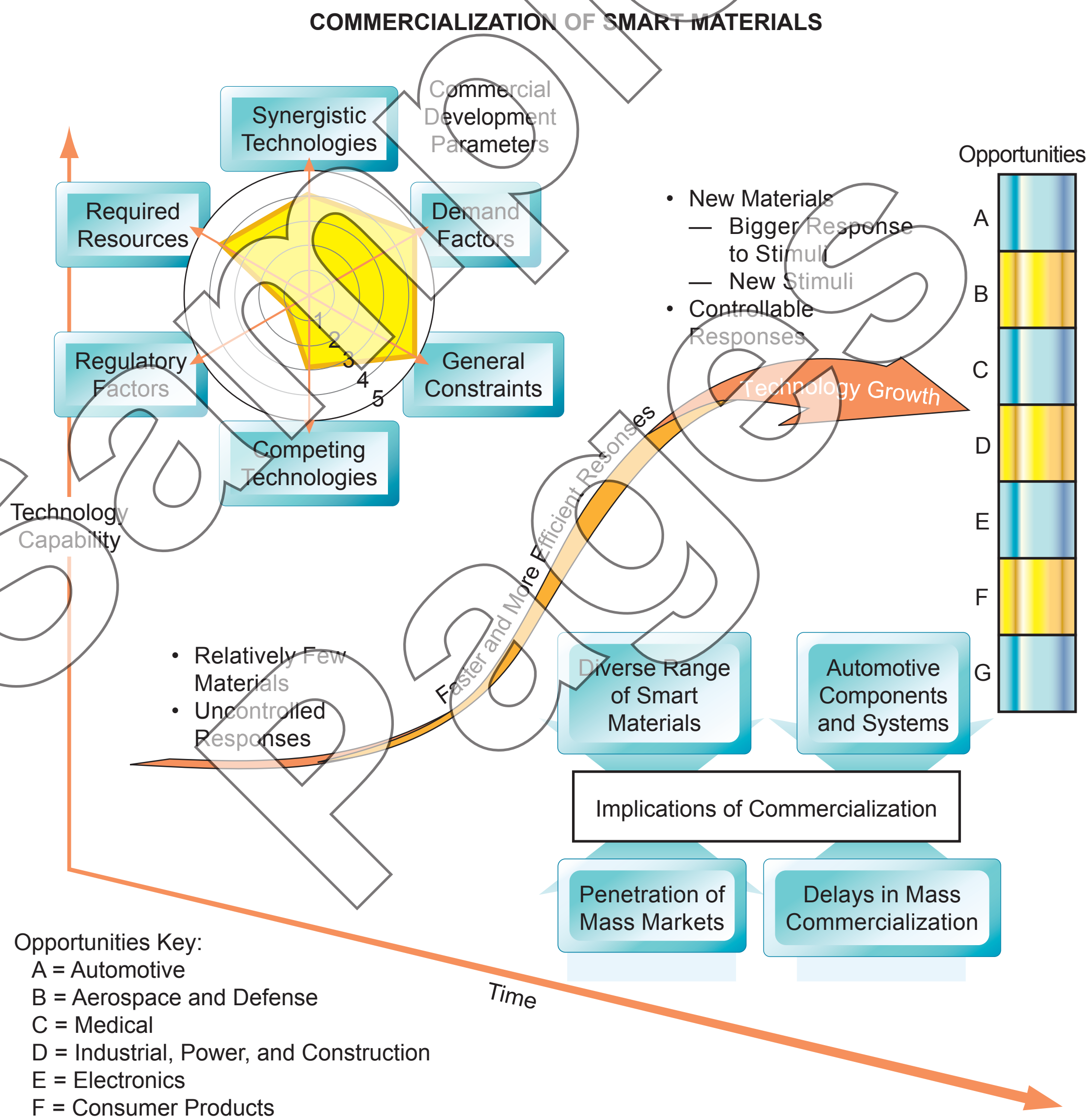


Opportunities Key:
A = Automotive
B = Aerospace and Defense
C = Medical
D = Industrial, Power, and Construction
E = Electronics
F = Consumer Products
G = Robotics

Source: SBI

SMART MATERIALS
DETAILED CONTENTS

Importance of the Technology

Smart materials produce direct, inherent physical responses to signals such as temperature, voltage, pressure, magnetic fields, light, and so on. Though the mechanical behavior of an SM actuator often is unimpressive in isolation, the ability to use a very simple device to produce specific mechanical action in response to specific conditions or signals can dramatically improve the overall performance of a device. Designers can use SMs to simplify products, add features, improve performance, or increase reliability with relatively little mechanical complexity.

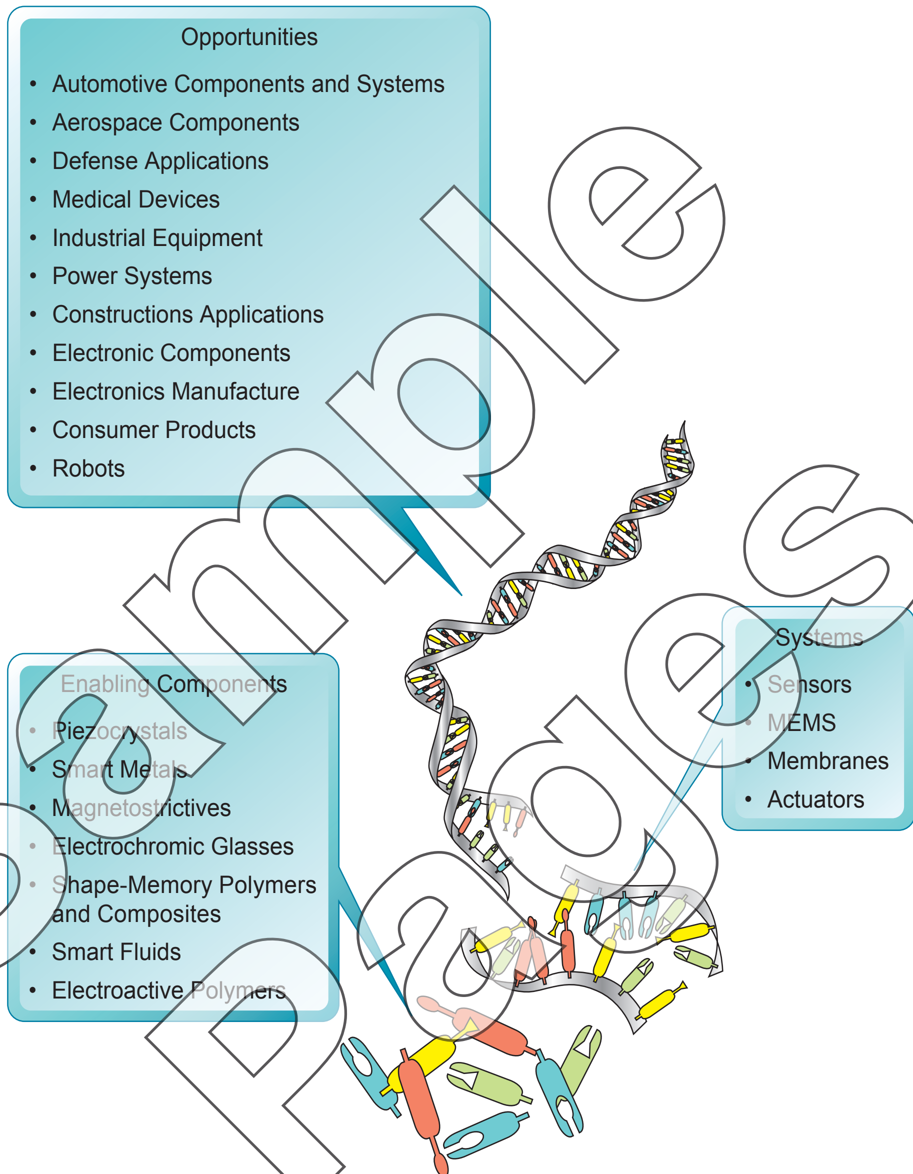
Most SM markets and technologies are young and remain largely unexplored (piezoelectric materials are a notable exception), with only a few simple, derivative products on the market. Fortunate combinations of technology and market conditions can bring explosive growth in commercial activity, however, as medical applications of shape-memory alloys have shown in recent years. Most SM technologies will slowly enter the market as suppliers and technologies mature and as users gain familiarity with the materials. Several SM technologies have just begun to enter or approach the market, and might find strong early sales in a few niches. Rapid advances in electronic control technology will continue to reduce the cost and increase the benefits of SM use. Existing SM applications are surprisingly numerous and diverse. Examples include simple piezoelectric speakers, card-eject mechanisms for laptop computers, tip positioners on scanning microscopes, self-expanding stents to hold coronary arteries open after angioplasty, a snow ski that actively damps harmful vibration frequencies, self-dimming automobile mirrors, medical imaging devices, autofocus motors for cameras, active noise control for electric transformers, and electronically controlled resistance units for home exercise equipment.

Development of SM fields will benefit companies that use SM components to add value to products and services, companies skilled in using SMs to design new products and services, and materials processors that add value to raw materials. The small volumes of SM consumption likely will have little impact on raw materials suppliers. Near-term returns on investments by SM suppliers generally will be modest, because most SM fields still are building infrastructure and knowledge bases for efficient and effective production, marketing, and use of SMs. The specialized knowledge necessary to produce SMs and to incorporate them effectively into products will slow the spread of SM use, but it also has led to high market valuations for companies developing products for high-value applications. Smart structures, which fully integrate structural and mechatronic components, represent the most refined use of SMs and might eventually enjoy very large SM markets. Only a very simple SM-based smart-structure product is in commercial use today. Other important areas of opportunity include applications in which designers desire performance improvements or new features but are unwilling to accept the compromises necessary to use conventional mechanisms and products (including nonmechanical devices) that must operate in a variety of conditions but have rigid designs optimized for a single operating point. Though improvements in SM performance would increase the range of possible applications, the major barriers to widespread SM use are users' lack of familiarity, the need for low-cost, robust production processes, and the need for improved design tools to enable nonexperts to use the materials with confidence.

✦ For a review of recent activity, see the Viewpoints in this Explorer technology area.

The Technology in Brief

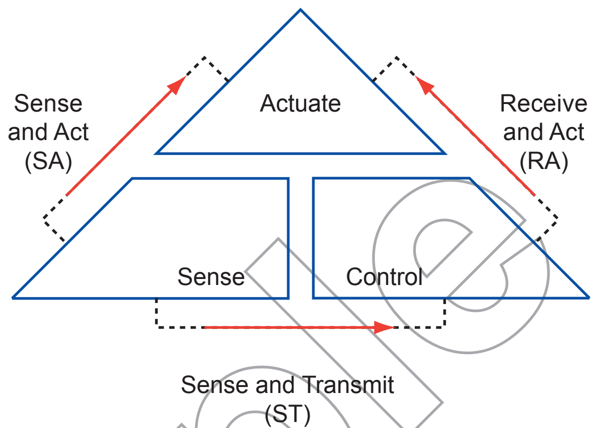
BUILDING BLOCKS OF THE TECHNOLOGY



Source: SBI

Many materials can change their shape, color, form, phase, electric properties, magnetic properties, optical properties, or other physical characteristics in response to stimuli from a control system or the environment. Smart materials respond rapidly and dramatically to changes in their environment, and in that capability lies their interest. Figure 1 represents the capabilities of smart materials. They can react to an environmental stimulus with an action or a signal; they can also do the reverse, receive a signal and act upon it.

Figure 1
FUNCTION COMBINATIONS IN SMART MATERIALS



Side SA = sense + act
Side RA = receive + act
Side ST sense + transmit

Source: SBI

For example, Side SA (sense and act) of the figure represents the ability of a smart metal to respond to a change in temperature by abruptly changing its volume or a magnetostrictive material's ability to react to a magnetic field by changing its length. Most products that follow the SA path use smart metals: medical implants and devices, thermostats, pipe couplings, to name a few.

Side ST (sense and transmit) represents a piezoelectric material that can convert a pressure change into electricity, which in turn can lead to the output of a signal. Examples of side ST are piezocrystals: vibration dampers and strain gauges. Solar cells receive light and emit current.

Side RA (receive and act) represents the conversion of an electric current or light signal into an action, such as the quartz crystals of a watch, which beat to an electric pulse. Piezocrystals that find use in watch motors and pacemakers comprise one RA category. Magnetoresistors—MR and GMR heads in magnetic storage devices—and chromogenic glasses, which dim upon receiving an electric signal, are other RA examples. The path alongside RA is the inverse of ST.

One can easily envision converting an electric current generated on the ST side of the triangle into a signal to drive an actuator alongside RA. A solar cell responds to incoming sunlight by transmitting a current (ST) to a chromogenic glass that dims upon receiving the current (RA) thus shading a room against the sunlight.

The general term for a device that receives one form of energy as input and produces a second form as output is *a transducer*. An SM transducer acts as an actuator when the output is force or motion and as a sensor when the output is a useful signal; several SMs allow a single component to function as both a sensor and an actuator. This Technology Map emphasizes actuator applications. Designers can harness an SM's ability to respond automatically to an environmental change, produce a specific mechanical response to a control signal, or produce a useful signal in response to a change in the operating environment. The response of an SM often is not impressive in isolation, but an SM can allow impressive improvements in the overall performance of a system. A piezoelectric transducer, for example, can shrink or expand by just one part in a thousand, but the ability to make that change rapidly and reliably in response to a control system allowed one designer to improve the diameter tolerance (variation from the desired size) of a spring winder by a factor of ten.

Commercial Development Parameters

COMMERCIAL DEVELOPMENT PARAMETERS

Note: Numbers indicate importance of commercial development parameters relative to each other.
1 = low relative commercial importance; 5 = high relative commercial importance.

Source: SBI

DEMAND FACTORS

Factors that contribute to demand for SMs come both from important general industry trends and from deliberate efforts to seek unique or advanced technologies. General trends that benefit SMs include the spread and improvement of electronic control systems; pressure on suppliers to pack new features into components, continuing efforts to package performance improvements into ever smaller volumes, and pressure to simplify systems to reduce manufacturing cost and improve reliability. OEM suppliers in several industries report pressure to increase the sophistication and performance of their products so that components such as switches become systems with capabilities that enhance the performance or simplify the design and manufacture of the end products. Medical applications for SMs have increased substantially as the use of minimally invasive procedures has spread.

Introducing SMs into articles such as skis and baseball bats taps into the huge market for consumer applications, which, unlike most other markets for SM products, are susceptible to manipulation via advertising campaigns. Each of these products also consumes more SMs than sensors do. Similarly, the automobile market offers immense room for SMs, because the world's manufacturers build tens of millions of automobiles each year.

GENERAL CONSTRAINTS

SMs face the same barriers to adoption that most new materials face, with additional complications arising from the fact that SMs are conceptually very different from structural materials and conventional mechanisms. One observer groups the barriers to new material adoption into four categories: inadequate communication between developers and users, difficulty in establishing volume production, high early costs, and inflexible codes and standards. Establishment of adequate communication is expensive and time consuming, but vital. SM commercialization will proceed very slowly without such communication. Many potential users are not aware of SMs, and awareness is only a small step on the path toward adoption. Potential users need to learn how to evaluate the benefits of SM materials and devices (for the user and the user's customers), learn how to use the materials and devices in products and systems, and gain confidence in the reliability of SMs and SM suppliers. Suppliers, in turn, must become familiar with the needs and concerns of potential customers and will bear the primary responsibility for identifying entirely new business opportunities possible with SM use. Though one easily can identify existing market demand for the benefits that SMs provide, SMs are unlikely to benefit automatically from the forces of market pull. Such forces tend to follow pathways through established supply infrastructures and serve more to encourage improvements in commercial technologies than to encourage radical new approaches and technologies.

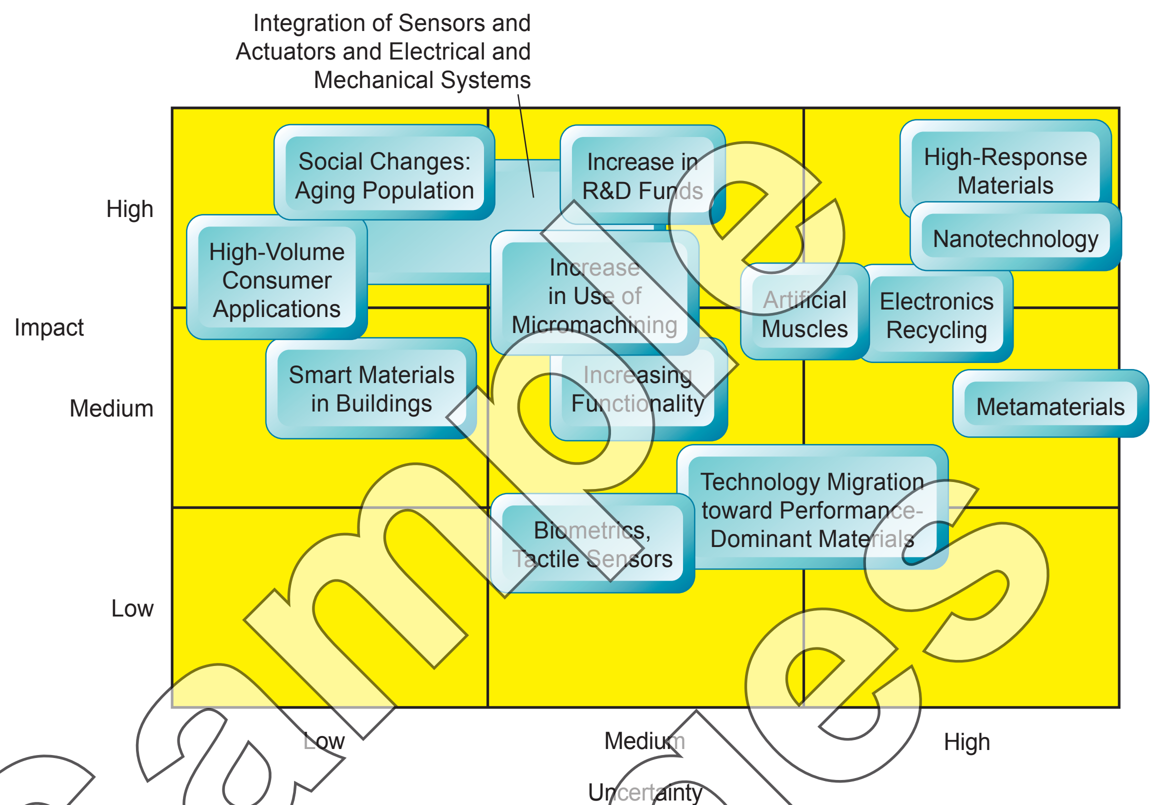
Most applications require design changes to take full advantage of SM properties, but relatively few designers and engineers are currently familiar with SMs (other than piezoelectric materials). This factor will slow adoption of SMs. Though a few knowledgeable designers can create a significant market in a high-volume application, such applications attract many competing technologies. Until SM users begin to play a significant role in designing applications, SM suppliers must divert resources from product development to applications development. The limited supply of SM expertise will restrict sales growth until design aids—software and material databases—allow nonexperts to use the materials easily and confidently.

Conservative users may hesitate to use SMs because they are markedly different from familiar technologies, have a brief history of commercial use, and often are available only from small companies. The interaction between an SM and its environment or control system appears less obvious and predictable than in the case of conventional mechanical systems. SM devices can blur the distinction between software and hardware. Designers "program" SMs in the design stage, distributing some or all of the control functions to the SM rather than retaining them in an electronic control system. Some users may be uncertain how to certify the quality of purchased SM components and the quality of products incorporating those components. These concerns may come into play in applications subject to regulatory codes or industry standards. Such codes and standards often delay or complicate initial use of new materials. Furthermore, SM materials and devices may not meet some codes simply because they are so different from the technologies the writers envisioned.

Smart materials are expensive because they have low sales volumes, use expensive raw materials, or require complex manufacturing processes. Design expenses add to the cost of SM use. Most SM applications require very little material, so near-term demand for SM materials may be too low to push down manufacturing costs significantly or to encourage suppliers to improve raw material supplies and prices. Some developers are investigating substitute materials to lower the raw material

Areas to Monitor

ISSUES AND UNCERTAINTIES



Source: SBI

HIGH-VOLUME APPLICATIONS

The initial use of an SM in a high-volume application brings a number of important benefits, including a revenue base, market exposure, and volume increases that help reduce costs for all users. The catch is that high-volume applications can attract stiff competition. Several SM companies have succeeded with simple products that provide a unique benefit. SMAs, for example, built a good volume of material sales with such products as eyeglass frames, brassiere underwires, and orthodontic arch wires. A creative application was the installation of large piezocrystals into skis and water skis, which took out the vibrational energy of the skis and enhanced the athlete's performance. Though such products might lead some observers to conclude that an SM has limited usefulness and no practical applications beyond a few niches, the products might instead represent a necessary precursor to advanced applications. The successful introduction of the smart ski led Active Control eXperts to follow up with a smart baseball bat and a smart mountain bike, which also incorporated piezocrystals. One of the major barriers to high-volume commercialization of shape-memory materials is the current high cost of these materials. In the past decade, a number of researcher teams have reported developments in very low-cost SMPs (some report materials that could cost about 10% of the cost of existing SMPs), but these efforts have yet to result in any useful commercial products.

MICROMACHINING AND MICROELECTROMECHANICAL SYSTEMS

Researchers borrowed production technology from the integrated circuit industry to "micromachine" a fascinating array of micron-scale structures and electromechanisms. The technology quickly grew from a curiosity to an important new business with hundreds of research groups and commercial developers worldwide. Sensors are the most common application today, but developers have created many other types of devices as well. Though SMA developers already have begun to integrate SMA thin films with micromachined structures at the larger MEMS sizes, SMs likely will always play a minor role in MEMS. Similarly, SM/MEMS devices likely will account for a small portion of SM activity. The impact of MEMS on the SM field, however, might be significant. Work in the MEMS has increased understanding of the potential applications of very small mechanisms. Some researchers and funding agencies have begun to discuss R&D on mechanisms that would bridge the size gap between MEMS and conventional technologies. Such millimeter-scale devices might offer a great opportunity for SMs. SMs would have some competitive advantages at that scale and would not face the difficult challenge of displacing an existing technology. Present automotive technology relies heavily on sensor technology, and this application will continue to expand for a long time to come. Sensors can initiate actuators, air bags, or ABSs, among other applications.

TECHNOLOGY MIGRATION BETWEEN PERFORMANCE-DOMINANT AND COST-DOMINANT MARKETS

Technology frequently migrates from performance-dominant markets (such as aerospace) to cost-dominant markets (such as consumer electronics), but technology also can travel in the opposite direction. Migration in either direction has implications for SMs. A number of SMs started in performance-dominated fields and might gain access to large new markets as cost-dominant civilian industries adopt elements of high-performance technology. SM technology can either be at the core of the adopted technology (as in the case of magnetostrictive sonar units) or play just a supporting role. In either case, SMs can use the exposure and experience in the cost-dominant market as a base for further expansion. Technology migration in the opposite direction may allow the cost-dominant markets to define the technology and process standards for the high-performance market. Indeed, this process might be at work in the composites market. *Aerospace America* noted that "The auto industry appears on the edge of developing an entirely new infrastructure dedicated to the production of low-cost, high-performance composites," promising aerospace engineers "a wider choice of products, suppliers, and processes in the future." That scenario has important implications for smart-composites development, favoring techniques that are compatible with the processes developed for the automobile industry. Technology migration from commercial markets to high-performance markets is not a new phenomenon but might increase as military and aerospace procurement policies increasingly allow commercial-grade products.

TACTILE SENSATION FOR HUMAN-MACHINE INTERFACES

The sense of touch—tactile sensation—is well developed in humans, but most electronic equipment has only visual and audio interfaces with humans. In most applications, sight and sound are sufficient. Fields such as virtual reality, telepresence, and simulation, however, need additional interface "channels." Designers of military aircraft would like new methods of delivering information to pilots, who already complain of an overload of visual and audio information. Control of the tactile interface also could be valuable in many common applications (keyboards, for example). Researchers have confirmed that electronically controlled tactile devices can provide valuable benefits. The challenge will be to create a system of actuators and controls that is cost-effective and easy to use. SMs provide a variety of actuation and sensing technologies and can be especially useful in devices that must be very small and light.

Implications of Commercialization

POTENTIAL IMPLICATIONS OF CHANGE

- Greater Academia and Industry Links
- Development of High-Response Materials
- Advances in and Convergence of Synergistic Technologies
- Increased Military and Industry Demand for Advanced Materials
- Increased R&D Funding
- Variable Raw Materials and Fabrication Costs

A
Diverse Range of Smart Materials

- Increased Automotive Industry Demand for Low-Cost, High-Performance Materials
- Regulatory Push for Materials Recycling
- Increased Lifetime Requirements for Components and Systems
- Improved Economies of Scale
- Increased Emissions Legislation
- Greater Demand for Lower Energy and Fuel Costs

B
Automotive Components and Systems

Consequences of Change

A	Smart materials in the marketplace lead to new business and design strategies.
A+C	Smart materials penetrate various mass-market applications, offering some environmental benefits. Ultimately, advances lead to the era of autoadaptive structures and components.
A+D	A wide range of smart materials and a fragmented market prompt many companies to produce smart materials for internal use only. As a result, niche applications dominate and developments are technology driven, not market driven for the near to midterm.
B	The automotive industry represents a multi-million-dollar per annum market for smart materials, displacing conventional materials technologies.

C
Penetration of Mass Markets

- Greater Integration of Sensors and Actuators and Electrical and Mechanical Systems
- Low-Cost, Highly Reliable Systems
- Increased Demand from Various Markets and Industries
- Increased Social Changes and an Aging Population
- Increased Technology Migration from Performance-Dominant to Cost-Dominant Markets
- Regulatory Push for Materials and Products Recycling

D
Delays in Mass Commercialization

- High Industry Conservatism and Designers' Unfamiliarity
- Domination of Small Smart-Materials Companies
- Low Technology Transfer
- Long-Term Market Development
- Absence of Large-Scale Markets
- High Raw-Material and Manufacturing Costs
- Lack of Venture Capital and Investment
- High Materials Competition

Areas to Monitor identifies significant factors and events of change that will affect the roadmap for technology commercialization. This **Implications of Commercialization** Chart identifies possible ways in which particular combinations of such factors might unfold and combine in the future (the bullets), resulting opportunities or threats ( ), and some further downstream consequences.

Source: SBI

The implications of implementation of smart materials across a number of applications are diverse. SMs have already improved the performance of many processes, systems, and products across various industries and, however subtly, affected aspects of people's daily lives. Certainly, the development and large-scale commercialization of SM technologies could affect the way we live in the future.

DIVERSE RANGE OF SMART MATERIALS

Researchers and players are already developing a diverse range of smart materials. As **The Technology in Brief** highlights, players have already developed a number of categories of SMs, and researchers continue to improve the properties of these materials incrementally. Researchers are also actively looking to develop other, novel SMs (see **Areas to Monitor**), driven by military and industry demand for advanced materials. Governments across the world are supporting the development of new materials by funding R&D programs. Developments in synergistic technologies—such as nanomaterials, metamaterials, composites, electronics, and biotechnology—could result in the emergence of new SMs. In addition, SMs could converge with other technologies. Overall, the number of SMs available to component and product designers could accelerate.

AUTOMOTIVE COMPONENTS AND SYSTEMS

The automotive industry is a good example of an industry that could benefit extensively from SM technologies. Many of the improvements that smart materials can enable in current and future vehicles will remain subtle and essentially invisible to the end user. Indeed, smart materials already see use in several niche applications within the automotive industry, and automakers have already started developing large functional components such as smart radiator grilles (see **Opportunities**). Smart materials are emerging in automotive applications because of both technology push and market pull. Developers of smart materials are constantly looking for new applications for their materials and devices, and the automotive industry is often one of these developers' major targets. The automotive industry is also starting to create a market pull for smart materials. Driven by environmental issues (such as recycling legislation and emissions legislation) and ever-increasing consumer expectations, automotive players are constantly looking to improve the performance and efficiency of their vehicles. In addition to improving the performance and efficiency of vehicles, automakers are starting to look toward materials that could significantly improve the convenience, reliability, and functionality of vehicles. SMs could enable significant improvements in these areas.

PENETRATION OF MASS MARKETS

Apart from the automotive industry, which is likely to help drive demand for various smart-materials technologies in the coming years, other market sectors could also benefit from the commercialization of smart materials. These prime market sectors include health care, electronics, and consumer applications. Sporting goods like skis, rackets, and bats enhanced with SM devices could sell in the hundreds of millions. The development of smart clothing systems is poised to increase in the next few years, although a great deal of hype does pervade this application area. The use of SMs in health-care applications is set to increase: The growing prevalence of chronic illnesses and the aging populations in industrialized countries, in combination with consumers' growing motivation to play more active roles in their health-care management, will drive demand for both the development of and access to new enabling medical technologies. The electronics industry also represents a significant opportunity for smart-materials players. Indeed, the technological drive to develop ever-smaller electronic devices with greater functionality continues to gather pace, driving researchers to develop new and better high-performance materials. The aim for many developers is to make electronic devices not only smaller but also smarter. For example, the development of sensor systems that also comprise the ability to harvest energy is of particular interest. In addition, smart fasteners could enable the rapid disassembly of electronics and similar consumer products, facilitating recycling processes. Success in mass markets would not only produce sales but also stimulate and facilitate the introduction of novel goods: Mass-market products have a self-accelerating effect on the market. If SM technologies become acceptable

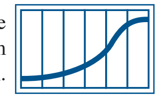
Opportunities

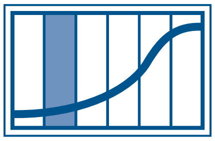
OPPORTUNITIES FOR SMART MATERIALS

Industry	Current Applications	Emerging Applications: Within 5 Years	Emerging Applications: 10 Years and Beyond
Automotive	Engine, Drive-Train, and Suspension Components; Smart Mirrors; Self-Repairing Coatings	Fasteners and Latches; EV and FCV Components; Light and Heat Control	Vibration Control; Self-Repair; Haptic Systems; Smart Tires; Color Control
Aerospace and Defense	Actuators; Structural Monitoring; Vibration and Noise Control; Smart Windows		Smart and Adaptive Structures
Medical	Minimally Invasive Surgery; Drug Delivery; Medical Analysis	Orthopedics and Prosthetics	Self-Powered Monitoring Devices
Industrial, Power, and Construction	Valves and Seals; Earthquake Dampers; Vibration Control; Heat Control; NDTE	Noise Control; Smart Windows; Motors and Actuators	Energy-Saving Systems; Smart Structures
Electronics	Manufacturing Systems; MEMS; Piezoelectric Components; Temperative Control	Self-Powered Devices	Self-Healing Electronics
Consumer Products	Sporting Equipment; Consumer Electronics; Domestic Appliances	Smart Clothing and Accessories	
Robotics	Piezoelectric Components	Smart Actuators	Tactile Sensors

Source: SBI

The shaded area indicates the maturity for each application, from research to market saturation.





AUTOMOTIVE AND GROUND TRANSPORT

The automotive industry is already a major user of smart-materials technology, and the future is likely to hold may opportunities for these advanced materials. Automotive and ground-transport applications are attractive to developers of smart materials because a single product can generate very high sales volume. However, competition is strong, and the automotive market is extremely price competitive. SMs have many conceivable applications; those that improve comfort and convenience present the best current and near-term prospects. Table 4 highlights existing applications for SM technologies in the automotive industry

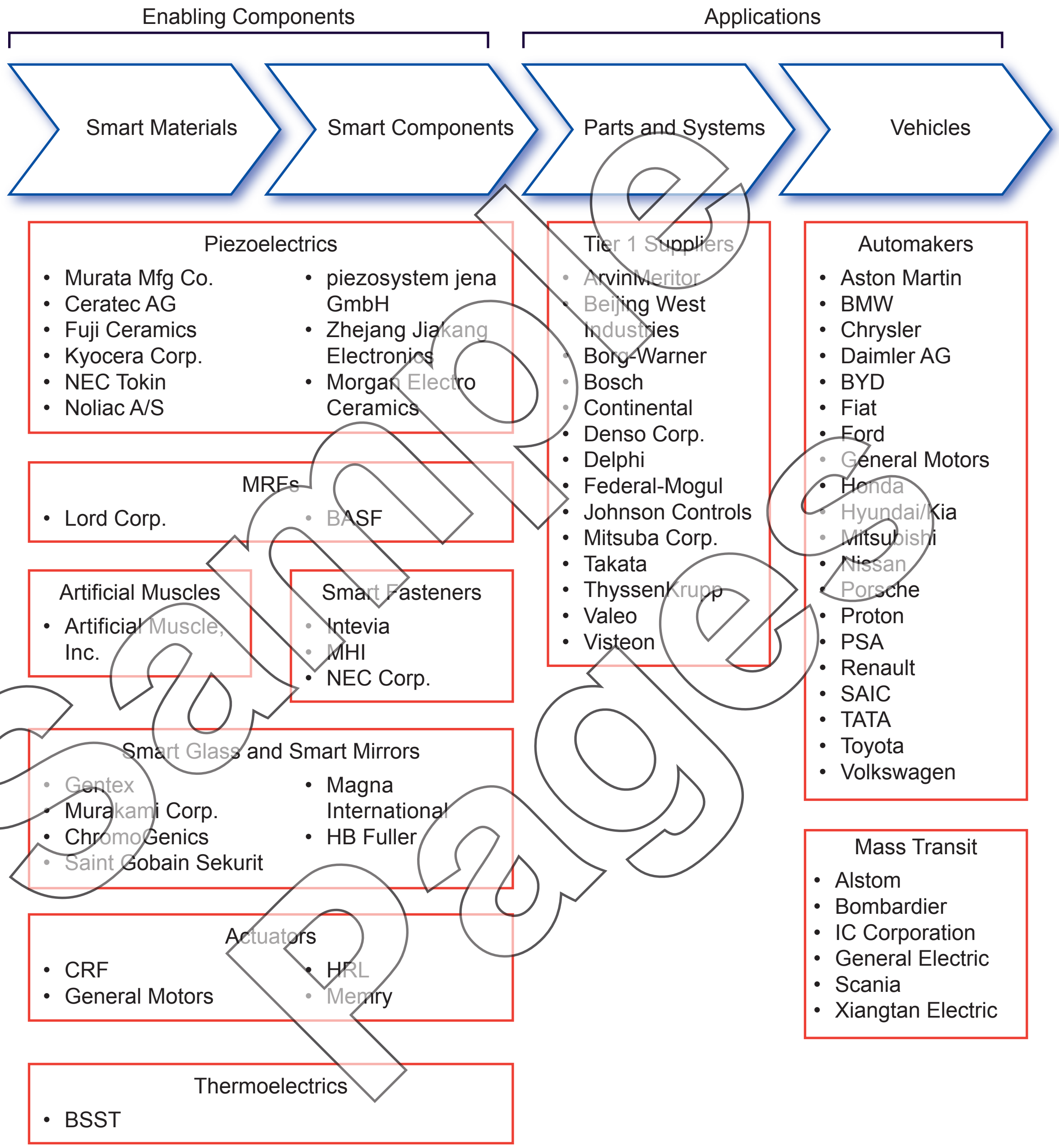
Table 4
CURRENT AUTOMOTIVE APPLICATIONS FOR SMART MATERIALS

Application	Systems	End Uses for Smart Materials
Engine, drivetrain, and structural components	• Fuel-injection systems	Piezoelectric actuators for fuel delivery
	• Torque transfer	MRF-based radiator-fan clutches
	• Suspension	MRF-based suspension systems
	• Vibration monitoring	Piezoelectric sensors for detecting engine knock
Exterior	• Paint and coatings	Self-repairing coatings
Interior	• Mirrors	Electrochromic self-dimming rearview mirrors

Source: SBI

Piezoceramic actuators are replacing conventional solenoid valves to control fuel injection, particularly for diesel cars. These fast-acting piezoceramic valves meter out small amounts of fuel at precise moments, even repeatedly during a single stroke: Some of these systems use five injection events per engine cycle. Electrochromic mirrors, which automatically dim in response to headlight glare from trailing vehicles, have become popular in high-priced automobiles: Sales now exceed 10 million units per year. SM products are still emerging in demanding applications such as suspensions, hydraulic systems, and torque transfer. Automotive manufacturers are pursuing mechanisms for active-suspension systems, which adjust suspension stiffness and damping for optimal vehicle control and passenger comfort under a wide variety of conditions. Several companies have produced ERF- or MRF-based active-suspension systems, such as Beijing West Industries' MRF-based MagneRide system that General Motors has implemented. In general, automotive applications require components that need little maintenance and that can tolerate exposure to temperature extremes, dirt, oil, fuel, moisture, dust, and vibration. SMs have many potential advantages over traditional materials and components—particularly that they offer significant potential for parts consolidation.

Figure 4
VALUE CHAIN FOR SMART MATERIALS IN AUTOMOTIVE AND GROUND-TRANSPORT APPLICATIONS



Source: SBI

Opportunities

According to the International Organization of Motor Vehicle Manufacturers, global vehicle production declined in 2008—for the first time since 2001—to 70.5 million units. In 2009, global vehicle production fell again, to 61.7 million units. The industry has since rebounded: In 2010, total production of passenger cars, light commercial vehicles, coaches,

Updates

Recent changes in this Technology Map include:

- Links to relevant Viewpoints.

Opportunities

- This section features revision.

Viewpoints Features

Area	Date of Publication
2011: the year in review	December 2011/January 2012
Smarter piezoelectrics	November 2011
Smart-fluid patent activity	October 2011
Phase-change materials	September 2011
Nonstructural self-healing materials	August 2011
Cars and electronics in Japan	July 2011
Graphene and smart materials	June 2011
Self-healing plastics and rubbers	May 2011
High-temperature thermoelectric materials	April 2011
Living materials	March 2011
Piezoelectric IP	February 2011
2010: the year in review	December 2010/January 2011
Electroactive polymers	November 2010
Patent activity	October 2010
Wind power and piezoelectrics	September 2010

Note: Monthly Viewpoints provide our analysts' evaluation of any changes in technology, business, consumers, or any other external parameter that might have significance (positive or negative) to the commercialization of the technology. To view all past Viewpoints, go to www.strategicbusinessinsights.com/explorer/SM.shtml .

Abbreviations

The following abbreviations appear in this Technology Map.

AIST	National Institute of Advanced Industrial Science and Technology (Japan)
ANL	Argonne National Laboratory
BYD	Build Your Dreams
CNT	carbon nanotubes
CSIRO	Commonwealth Scientific and Industrial Research Organization
DARPA	Defense Advanced Research Projects Agency (United States)
EAP	electroactive polymer
EC	electrochromic
ERF	electrorheological fluid
ESP	electrostrictive polymer
EV	electric vehicle
FePd	iron palladium
FePt	iron platinum
FCV	fuel-cell vehicle
GaAs	gallium arsenide
GM	General Motors
GMR	giant magnetoresistive
HRL	Hughes Research Laboratories
IP	intellectual property
Li-ion	lithium-ion
MEMS	microelectromechanical systems
MIT	Massachusetts Institute of Technology
MPa	megapascal(s)
MR	magnetoresistive
MRF	magnetorheological fluid
MS	magnetostrictive
NASA	National Aeronautics and Space Administration (United States)
NDTE	nondestructive testing and evaluation
NiMnGa	nickel manganese gallium
NiTi	nickel titanium
nm	nanometer(s)
PE	piezoelectric
PEC	piezoelectric ceramic
PCM	phase-change material
psi	pounds per square inch
SBI	Strategic Business Insights
SFIT	smart fabrics and interactive textiles
SM	smart material
SMA	shape-memory alloy
SMP	shape-memory polymer
SRI	SRI International
T_{tr}	transformation temperature
TE	thermoelectric
TEC	thermoelectric cooler
UAV	unmanned aerial vehicle
UGV	unmanned ground vehicle
ZT	thermoelectric figure of merit

About Strategic Business Insights

Strategic Business Insights (SBI) works with clients to identify and map new opportunities based on emerging technology and market insights. We combine ongoing research with consulting services to create insights that affect customers, business, and technology.

With our help, leading organizations identify coming changes faster, separate hype from reality, and create strategy with a greater awareness of what the future may bring.

SBI stands apart from our competitors in our staff's ability to integrate all pieces of the puzzle necessary to manage the future: the technology developments that will determine commercial opportunities, the forces that will define the business environment, and the shifts in consumer demand that will shape the marketplace.

SBI is the former Business Intelligence division of SRI International that has worked with clients on opportunities and change since 1958. Headquartered in Silicon Valley—with offices in Japan, the United Kingdom, and New Jersey—we have a global reach and work across a wide range of government and business sectors, including electronics, health care, energy, and financial services.

CFD — The standard in consumer financial-services research, strategy, and insight

Explorer — Continuous evaluation of opportunities in technology commercialization and applications

Scan™ — Organizational radar to identify signals of change

VALS™ — Consumer insights that drive market innovation

Consulting Services — Leveraging of our research expertise and proprietary methods

- Scenario planning
- Opportunity discovery
- Strategic roadmapping
- Customer assessment
- Intelligence systems

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