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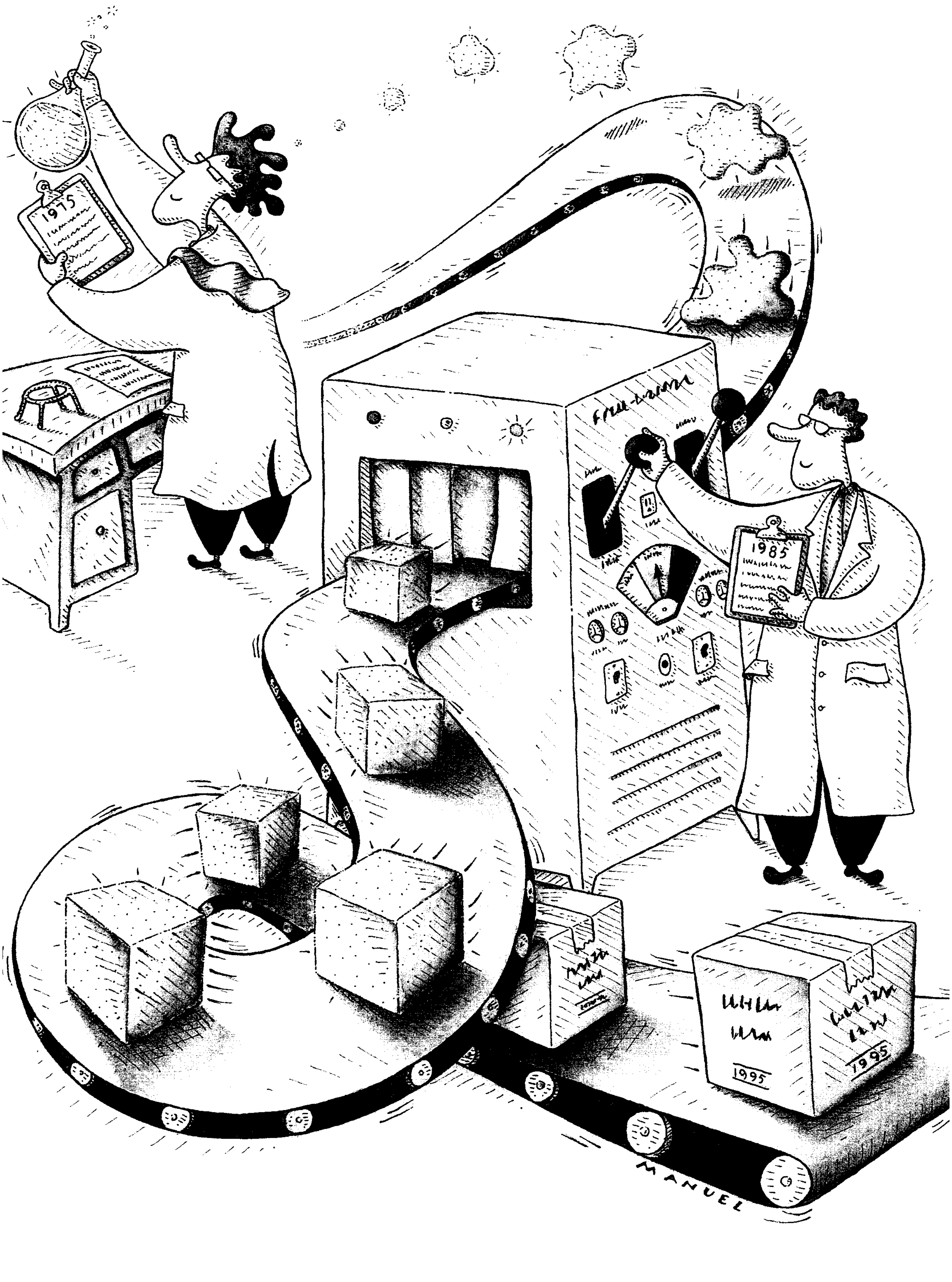

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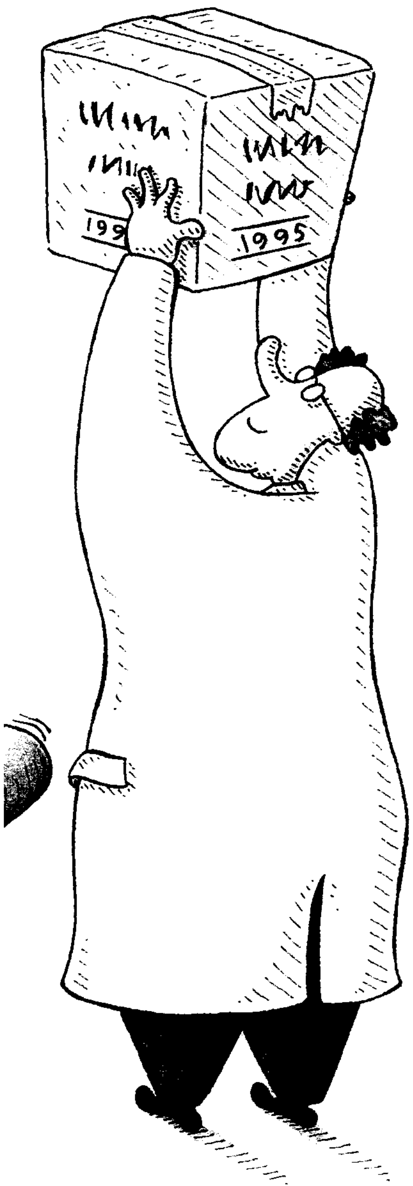
BY THOMAS W. EAGAR

Bringing New Materials to Market



The invention of a new material can signal the birth or death of an entire industry. Silicon chips replaced vacuum tubes; optical fibers decimated the copper telecommunications market. Many U.S. companies have invested in advanced materials in the hope of developing new and profitable businesses, but their efforts have met with mixed success. Although U.S. firms have invented the majority of materials introduced over the past half-century, they have failed to commercialize many of these innovations.

One of the most important obstacles has been the failure to recognize how long commercialization is likely to take. There has typically been a 20-year interval between invention and widespread adoption of a new material (*see the chart on page 45*). This delay is significantly longer than in most other industries and makes it very difficult for a company to recoup its investment. At an annual interest rate of 8 percent, a dollar invested today must yield a fivefold return 20 years from now for investors to break even. Most firms look for a return of 20 percent per year, which means each dollar invested would have to earn nearly $100!

Many companies give up if after 10 years of investing heavily they have not succeeded in developing new products. They either sell the invention or allow another firm to pick it up for free. The new firm may also have a 10-year horizon, but starting at the halfway point in the development process can mean success rather than failure. It is

Companies must form cooperative ventures to shorten—or at least transcend—the 20-year delay in commercialization.

ILLUSTRATIONS BY MANUEL KING

Product designers tend to use new materials in the same way as old ones, while materials engineers are often too optimistic about the utility of their inventions.

for this reason that Japanese companies were able to commercialize ceramic substrates, used to package semiconductors. Kyocera, the company that broke through after most U.S. companies abandoned the effort, gained more than half the world market and went on to become a multibillion-dollar business, and for several years was the most profitable company in Japan.

The 20-year time frame also limits the profitability of new materials. By the time a material comes to market, the patent protection afforded the original invention is at the end of its tenure and proprietary advantage is lost. What's more, products that incorporate new materials today have ever-shorter life cycles, so the period over which a company can recoup its investment is brief. For example, the life span of the phonograph was 70 years, that of magnetic tape 30 years, while compact discs may become obsolete within 20 years.

Fortunately, there are a number of steps producers and would-be users of new materials can take to cut the lag between development and commercialization. In particular, companies can take a more rational approach to investing in advanced materials by emphasizing cooperation rather than competition.

THOMAS W. EAGAR is a professor of materials engineering at MIT and codirector of its Leaders for Manufacturing Program, a partnership with U.S. companies that aims to educate modern technological managers.

Failure to Communicate

Poor communication between inventors of new materials and product designers who might use them is a key factor holding back commercialization of novel substances. One example of miscommunication occurred in the substitution of plastic panels for steel panels in the household refrigerator.

In the 1950s, both the inner and outer panels of refrigerators were made of painted steel. Shelves were bolted or welded to these panels. The refrigerators were very durable: I have a freezer in my garage of this vintage that continues to work fine.

During the 1960s and 1970s, appliance manufacturers began to replace the steel inner panels with plastic panels, which were less expensive to produce. However, they still used bolts to attach the shelves, as they had with the steel panels, failing to recognize that because plastic has less inherent strength and stiffness, the panels were apt to crack more easily around the bolt holes. I purchased four or five new refrigerators over a 20-year period, not because the compressor failed, but because the shelves broke and repairing the cracked plastic panels was too difficult.

During the 1980s, as product designers gained more experience with plastic, they learned that they could mold the shelf support directly into the plastic panel and build in ribs to make the panel stiffer. These redesigned panels and shelves are as strong as the old steel inner panels and shelves, less expensive to assemble and manufacture, more resistant to corrosion, and easier to clean. But it took decades of product failures and changes for designers to learn how to use the plastic most effectively.

Product designers tend to use new materials in the same ways as the old materials. As a result, early designs with new materials rarely demonstrate their full potential. Designers may then develop a bias against the new material, delaying commercialization further.

For their part, materials engineers are often too optimistic about the usefulness of their inventions. Many new materials are developed to maximize a specific property, such as strength. Engineers may ignore secondary requirements, such as corrosion resistance, ease of fabrication and repair, or recyclability. After all, it is not easy to develop a material that meets or exceeds a dozen disparate design goals. Unfortunately, failure to meet these secondary requirements can prevent the adoption of the new material.

The design of new high-temperature superconductors (HTSCs) illustrates this problem. In early 1987, scientists announced that they had developed ceramic materials that retained their superconductivity at temperatures more than five times higher than other materials, an extraordinary—and unexpected—accomplishment. And unlike earlier materials, the new ceramics conducted a small amount of current even when subjected to powerful magnetic fields. There was hope that these materials could be used to develop powerful magnets that could lift trains above their tracks for frictionless travel, for example, or reduce the size and increase the efficiency of many types of equipment, from electric generating plants to transmission lines.

However, ceramic HTSCs did not have all the properties required for use in such a powerful magnet. They have very low "critical current density": when enough current is run through the coils of ceramic wire to create a high-intensity magnetic field, the ceramic loses its superconductivity. The highest currents that the earliest HTSCs could tolerate were 10,000 times lower than those needed to generate the desired magnetic field. The coils of a high-field magnet must also withstand stresses powerful enough to snap steel bands. Ceramic HTSCs are very brittle; they just cannot stand up to this much stress. Even today, ceramic HTSCs are orders of magnitude away from commercial success.

Communication barriers like these can be overcome only if materials development engineers work closely with product designers. The researchers developing new materials need to be aware of the design requirements of potential users. Product designers, in turn, must work closely with materials engineers to modify existing designs to ensure that they capture the advantages of the new material.

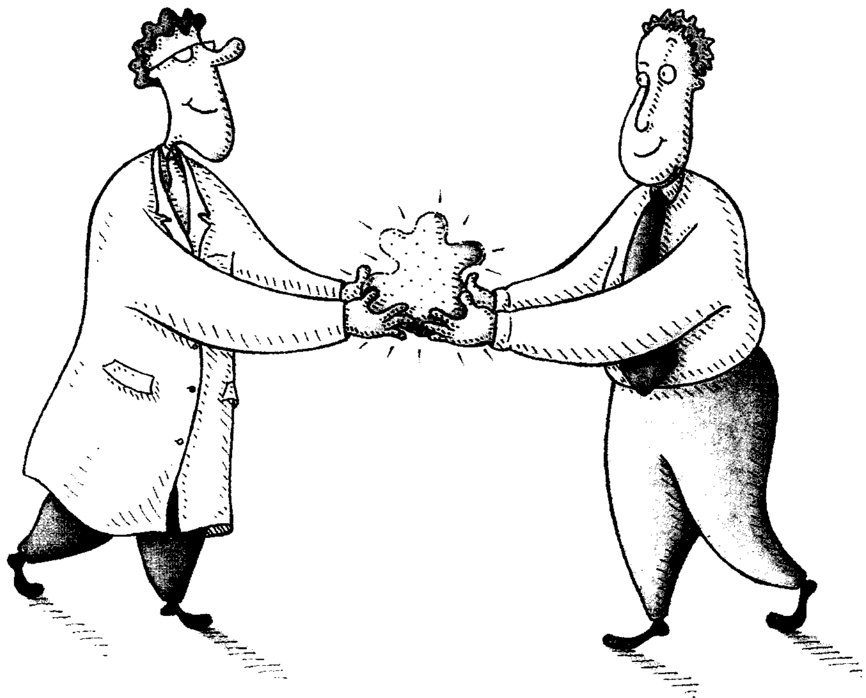
Materials suppliers in most industries do have applications teams that can serve as liaisons with product designers. Plastics companies in particular excel in helping product designers choose which plastic best suits their application, because this strategy helps them compete with steel and aluminum manufacturers. In most industries, however, applications teams work only with the largest clients, such as the automotive industry; and in most firms, those teams involve only a handful of engineers compared with the thousands involved in research. To bring their innovations to market more quickly, materials suppliers should devote a much larger share of their resources to creating and supporting applications teams, and should ensure that these teams work closely with companies in smaller markets as well as large ones.

Both the materials supplier and the user must also be more willing to share proprietary information, with the supplier describing the strengths and weaknesses of the material and the user discussing in detail plans and strategies for product development. A high level of trust is needed to offset the risks of sharing such sensitive information. Some firms might rely on a handshake between CEOs; others might require a strongly worded confidentiality agreement. Whatever route they take, in the end, both suppliers and users stand to gain by negotiating this kind of partnership.

Twenty years from Invention to Commercialization

MATERIALS TECHNOLOGY	INVENTION	WIDESPREAD COMMERCIALIZATION
Vulcanized rubber	1839	late 1850s
Low-cost aluminum	1886	early 1900s
Teflon	1938	early 1960s
Titanium (used as a structural material in the aerospace industry)	mid 1940s	mid 1960s
Velcro	early 1950s	early 1970s
Polycarbonate (used in bulletproof "glass")	1953	about 1970
Gallium arsenide (used in semiconductors)	mid-1960s	mid-1980s
Diamond-like thin films (used to coat hard disk drives)	early 1970s	early 1990s
Amorphous soft magnetic materials (used in transformers)	early 1970s	early 1990s

Although the time lag between invention of a material and common use is typically two decades, companies can take a number of steps to reduce the barriers to faster commercialization.



Materials suppliers and users need to create partnerships that will permit them to share the risks–and the profits–of bringing new products to market.

to be held hostage by suppliers who may not keep prices stable over the life of the product. As long as a substitute is available, even if it is inferior, designers will avoid the risk of selecting a material that is priced monopolistically; they will delay introduction of the new material until the monopoly afforded by patent protection expires.

Large-scale users commonly solve this problem by requiring multiple suppliers. But this strategy can create excess capacity in the new industry. If each plant must produce, say, a million pounds of a given material in order to operate efficiently, suppliers may be left with unused capacity. Requiring multiple suppliers can also discourage materials development, because investors may decide that the profit potential is too low to justify the risk of the venture.

To overcome this problem, materials suppliers and users may need to create partnerships or joint ventures that will permit them to share the risks—and the profits—of bringing new products to market. With a commitment in hand, materials developers can go to the bank and get the backing they need to increase production levels. Users in turn can be assured of an adequate supply and stable prices. To create these kinds of agreements, however, firms must achieve a level of trust and commitment that has historically been lacking among U.S. companies. Until now, they have had little incentive to combine their efforts; but as the time, costs, and risks of bringing materials to market have increased, companies are beginning to find that the rewards of cooperation far outweigh the costs.

Building Production Capacity

The fact that new materials are usually produced in limited quantities also slows their adoption. In large industries, such as the automotive industry, the volume requirements of even a modest-scale adoption may be several times greater than the suppliers' production capacity. The problem of low capacity may be amplified by mutual mistrust. Product designers are wary of incorporating new materials into their processes unless they are sure there will be an adequate supply, while suppliers hesitate to invest in major new facilities unless there is a guaranteed market for the new material.

Moreover, while the potential for monopolistic profits is exactly what drives suppliers to develop new materials, it can deter their adoption. Adopters do not want

Inflexible Codes and Standards

Another barrier to the commercialization of new materials is the lack of flexibility in the codes and standards governing the construction of buildings, bridges, pressure vessels, transportation systems, and the like. These guidelines are usually written by committees of professional or trade associations, such as the American Society of Mechanical Engineers (ASME), which writes codes for pressure vessels, or the American Petroleum Institute, which sets standards for pipelines. The National Institute of Standards and Technology, part of the Department of Commerce, performs research to generate performance and safety data. State and local governments then use these codes as the basis for their own regulations.

Many codes and standards, particularly those formulated in the first half of the century, specify the kinds of materials that can be used in each setting. New materials are automatically excluded from use. Most building codes, for example, often specify copper rather than aluminum electrical conductors for household wiring—in part because of safety problems that occurred 25 years ago when contractors and builders began to substitute aluminum for copper without redesigning the connectors.

Trade associations have recently begun to establish codes and standards based on product performance rather than specific materials. For instance, plumbing codes for new piping may specify criteria for properties such as corrosion resistance, rigidity, and the ability to withstand pressure. This allows suppliers to choose among a variety of materials—copper, plastic, and galvanized steel—that meet these requirements.

It can take a long time—and a lot of money—for manufacturers to accumulate enough experience to demonstrate that new materials can meet performance-based criteria. In some cases, the new codes create a catch-22: we can't use the material until we have generated the performance data, but we can't generate the performance data because we can't use the material. As a result, contractors and builders continue to use otherwise inferior materials simply because they have more experience with them.

One factor driving up the costs of experimenting with new materials is risk assessment. The Boiler and Pressure Vessel Code is an excellent example. Written by ASME and adopted, with some variations, in all 50 states, the code governs machinery used in any process that involves gases or liquids operating under pressure: electricity generated as water is turned to steam, for instance, or many chemical processes. The code was formulated during the early part of the century to prevent catastrophic failures and explosions. Contained in many volumes occupying several feet of shelf space, it spells out in detail the types of materials that may be used and the performance specifications a new material must meet. The materials specifications are nearly the same as they were 50 years ago, despite the fact that much stronger, more fracture-resistant steels are now available. This is because the performance criteria are so stringent that it would take tens of millions of dollars to prove that a new material could perform equally well. No one company can afford to underwrite such extensive tests. But the costs of failure are so high that no one wants to risk changing the standards.

To lower the cost of adopting new materials, codes specifying performance criteria for new materials should recognize different categories of risk. The code for pipeline construction already does this. A natural gas pipeline that passes through a densely populated area must meet more stringent performance standards than one located in open land. Similarly, a large pressure vessel located in a highly populated area should be built with a high degree of conservatism, but a smaller vessel containing a less hazardous substance (like water or oil, rather than natural gas) located far from most people or buildings should be allowed to incorporate new designs and materials. Instead of serving as a barrier to innovation, properly written codes and standards can encourage it.

It will take a long time to develop more flexible codes and standards, since trade associations review them on a case-by-case basis. Firms that develop new materials can speed their acceptance by assigning representatives to join the relevant trade association committees and lobby for changes that will give builders and contractors greater freedom to choose among materials.

Lowering Production Costs

Even if all other barriers can be overcome, a new material must be cost-effective to produce if it is going to be widely used. But production processes are likely to be inefficient in the early stages of the learning curve and yields relatively low. This forces developers to keep prices high to recoup their investment.

The industries most likely to lead in introducing new materials are those that can demonstrate the greatest savings by doing so. For example, the aerospace and aircraft industries have successfully adopted high-performance, lightweight composite materials, some of which are very expensive. They can afford to do so because the value of weight saved over the life of a spacecraft can be $20,000 per pound; in commercial aircraft it is $200 per pound. By contrast, in an automobile the equivalent figure is $2 per pound. (Indeed, most of the heaviest components in a modern automobile are composed of materials whose cost in bulk form is one dollar per pound or less.) Thus it is unlikely that the automotive industry will benefit by using these expensive lightweight materials until the cost comes down. It is not that the aerospace industry is necessarily more progressive than the automotive industry; it's just that those companies can afford to pay a higher price for improved performance.

In rare cases, high-volume users have even stepped in to bring down the cost of new materials. When General Motors Research Labs invented iron-neodymium-boron magnets, GM managers were eager to use these high-strength, permanent magnets in small automobile motors, such as those that operate windshield wipers and power windows. There may be 30 to 40 such motors in one vehicle; since a smaller magnet could be used to generate the necessary field, these motors could be made smaller, lighter, and more efficient. But the price of metallic neodymium was prohibitively high—not because the ore was rare, but just because the metal had never had any significant commercial utility. To commercialize its own invention, GM researchers set out to find ways to process neodymium ore more cheaply. When it became apparent that these efforts were bearing fruit—GM actually invented and patented a process for refining neodymium ore into metal—existing neodymium processors swiftly lowered their prices. As a result, GM postponed its plans to produce its own supply. But by achieving its intended result—lowering the price—the automaker significantly reduced the usual 20-year lag from conception to widespread commercial use of a new material. GM is now threatening to use the same strategy to lower the price of magnesium, a very lightweight substitute for aluminum or plastic.

The longer it takes to bring down the costs of a new material, the slower the commercial payoff will be—and the less time will be left before the patent on the invention expires. The solution is for companies to invest as much (or more) in the process for producing a new material as in developing it—and to control the process technology, rather than the product technology.

A successful example is Lincoln Electric Co., the world's largest manufacturer of welding electrodes—the metal wires through which current passes to create an arc of electricity. In the 1950s, the company developed a steel welding electrode that did not have to be surrounded by a shield of argon or carbon dioxide to prevent the metal from reacting with nitrogen in the air. The firm also developed a very efficient process for producing this self-shielding electrode. The company patented the product and held the process technology as a trade secret. While its competitors soon copied the product and engineered around the patent protection, the proprietary process enabled Lincoln Electric to sell its electrode at prices below competitors' production costs. Today, though the electrode's patent has expired, Lincoln Electric still enjoys an effective monopoly. It is the process technology that makes this product a winner for them.

Investment in process technologies by both government and industry could speed commercialization by increasing yields, improving reliability, and reducing the cost of new materials. But numerous studies show that U.S. industry spends far too little on process-oriented research: 70 percent of R&D funding goes to product development (including basic research) and 30 percent to process development. In Japan, these percentages are reversed.

Much of the emphasis on product development comes from the U.S. government, which funds about half of the nation's R&D. Ninety-five percent of federal R&D funding is devoted to product development. In recent years, however, the government has begun to recognize the importance of investing more in process technologies.

For instance, there is some evidence of a shifting emphasis toward process development in the new Advanced Technology Program (ATP) under the Department of Commerce. A public venture-capital fund for private business, ATP represents the fastest-growing segment of the federal research budget. The program has always required that participating companies provide a commercialization plan. Initially, this provision was interpreted to mean a marketing plan for a new product. More recently, the government has encouraged companies to develop new manufacturing processes and show how they plan to implement them. This is a small but potentially significant step toward redressing the imbalance between product- and process-oriented research funding.

Beyond the Barriers

There are limits to how much companies can do to speed the process of commercializing new materials. For instance, the length of the investment cycle in certain industries may delay large-scale production of a new material. This problem is particularly common in industries such as steel and chemicals, where the costs of a unit of production capacity are high and the productive lifetime of the equipment is several decades or greater. One cannot discard a long-term investment merely because a new alternative becomes available.

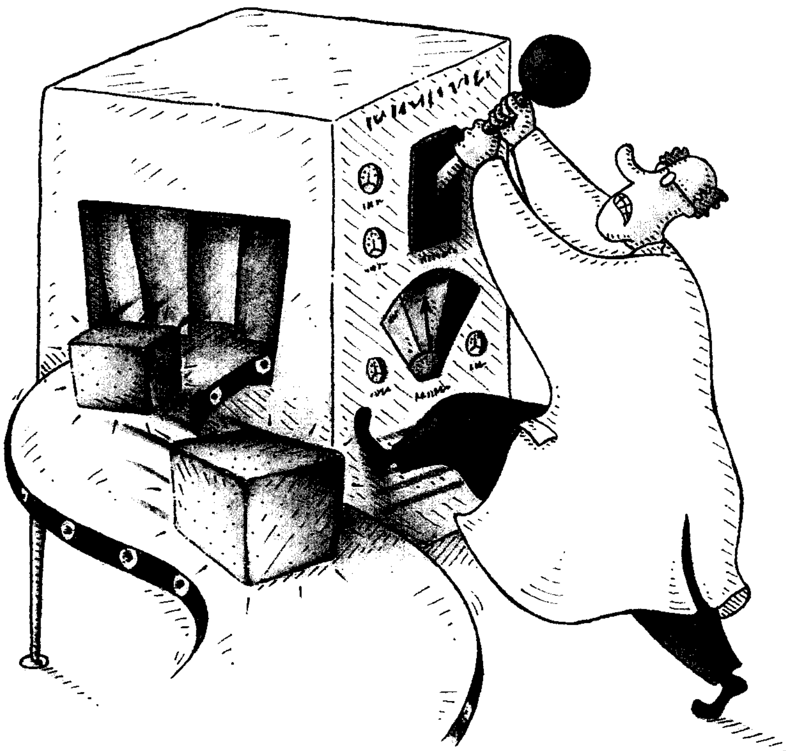
However, most of the barriers delaying commercialization of new materials can be overcome. And not every barrier will exist for every product. If managers begin to tackle potential obstacles early in the development process, they may be able to cut the time frame for commercialization of materials in half. But such a change is unlikely to occur overnight: managers have to develop the skills and mechanisms for speeding commercialization. Meanwhile, they must recognize the potential 20-year time frame and plan their research and investment strategy accordingly.

Since process technology is likely to be the key to a company's success in commercializing new materials, companies need to reevaluate the time and money they spend on developing new materials. In particular, they need to foster cooperative research in the early stages of materials development. This will free up the resources they need to focus on process research later in the game.

Competition in the early stages of materials research is duplicative and dysfunctional. Experience has shown that, given the 20-year window for commercializing new materials, no one will establish an insurmountable lead by running ahead of the pack at that stage of the race. Instead, it makes sense for companies to begin by sharing information so that everyone can progress faster.

Leadership in this kind of early intra-industry cooperation has to come from the top. Government-initiated projects like Sematech, a consortium aimed to improve process technology for manufacturing semiconductors, have already shown that firms that compete in the marketplace can cooperate in development. With half its funding from the military, Sematech has brought together a number of U.S. companies. Many were reluctant to commit their best people and resources and were unwilling to share proprietary information. Only after several years have managers come to realize that it is in their best interests to cooperate.

The government can also foster this more productive strategy by creating a climate that encourages rather than squelches international cooperation in materials research. Nearly every year, legislators in Congress introduce bills whose aim is essentially to classify government-funded research; the most recent was sponsored last year by Rep. John Dingell of Michigan. While no bill has yet been passed, funding agencies appear sensitive to potential criticism; there are direct or indirect pressures to restrict interaction among scientists from different countries.



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Government officials need to recognize that cooperative research augments a nation's investment—it does not squander it. The Council on Competitiveness recently found that the United States was behind or even with other countries in 18 of 21 key technologies. Clearly, American scientists need to tap a pool of knowledge that lies outside our borders. By participating in multinational joint research efforts, a company can maximize the return on its investment.

Finally, corporations must plan ahead to identify opportunities for developing a competitive advantage in their fields. Technology scouts—sophisticated scientists who can search the world for new ideas—can help at every stage of the research process. They can target knowledge for exchange with other researchers, find opportunities to form partnerships with other firms, identify the primary barriers to adoption of a new material, and lay the groundwork for commercialization. This information can help managers shape corporate strategy. AT&T and Corning used this approach when they joined forces to lay the foundations for the optical fiber industry: Corning commercialized the optical fibers, while AT&T developed lasers to send signals along them. AT&T scientists also helped Corning solve some problems with the process for making the fibers, recognizing that both corporations would profit from this knowledge.

In the past, most companies have tried to go it alone in developing and commercializing new materials. This strategy, however, is no longer effective: it is too slow, too expensive, and too unlikely to produce profitable results. Instead, companies must develop new mechanisms that foster cooperation in research, design, and strategic planning if society is to capture the benefits offered by new and advanced materials.