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INTERNATIONAL UNION OF MATERIALS RESEARCH SOCIETIES

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To inform and promote the enabling role of advanced materials for global progress

Volume 1, Number 4
October 2002

ISSN 1537-1654

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INNOVATION

An Investment Methodology for Materials

E. M. A. Maine and M. F. Ashby

Will a new material innovation succeed in the marketplace? Should time and money be invested in developing it? By whom? A methodology has been developed to address these questions. The Investment Methodology for Materials (IMM) is proposed to help identify promising materials innovations at an early stage, direct research and development in directions most likely to lead to successful exploitation, and guide investment strategy to achieve this goal. IMM adapts existing and emerging predictive software tools and business strategies to materials innovations, linking them to give a practical, comprehensive procedure. It consists of three interwoven strands:

- Viability assessment involves the analysis of technical suitability of the material for an application, an estimate of production cost, and the market trade-off between performance attributes and cost.
- Market forecasting involves gathering application-specific market preferences, estimating the technically and economically viable market size, and predicting the timing of industrial adoption by comparison with relevant historical precedents.
- Value capture analysis uses tools to assess industry structure, appropriability, and organizational structure.

The methodology was developed in response to perceived under-investment in new materials innovation. It has been validated through interviews with venture capitalists and materials industry experts. IMM is aimed in particular at small- and medium-sized enterprises (SMEs) that are attempting to commercialize a materials innovation.

> *"The methodology was developed in response to perceived underinvestment in new materials innovation."*

Overview of Investment Methodology for Materials

Innovations in the materials industry have been considered a high-risk investment and have been characterized by long gestation periods between invention and widespread market adoption. For these and other reasons, they have generally been driven by large enterprises and national governments. The proposed IMM could both reduce risk and shorten that gestation time. The risk can be lowered through early viability analysis, and the gestation time can be shortened, and thus the present value of expected revenues increased, through earlier and more effective information exchange. This methodology is designed to

(Methodology... continued on page 3)

EDUCATION

Educating Students and the Public about Polymer Science and Engineering

Richard S. Stein

Polymers serve an increasingly important role as materials—the volume in use today surpasses that of metals. The environmental implications of their production and disposal have concerned the public and legislators, and educational efforts are needed to ensure awareness of the issues involved.

One concern has been that polymers, which are produced primarily from petroleum, consume a nonrenewable resource. Yet polymer production consumes less than 5% of all petroleum produced; approximately 90% is used for fuel. By reducing the weight of vehicles, bottles, and containers, the use of polymers to replace heavier materials saves more petroleum than is used in their production. This factor complements other advantages, such as convenience, economy, and safety.

Renewable Feedstocks

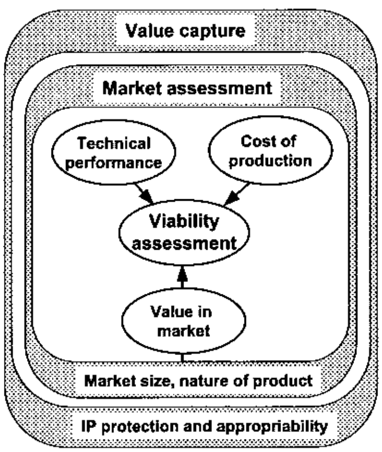
Efforts are being made to produce polymers from alternate feedstocks, mainly of renewable agricultural origin. Because of current oil prices, however, such processes have not generally proved economical. As oil inevitably becomes scarcer and more expensive, such an approach may prove more attractive, so research in this area is desirable in anticipation of future needs. However, at present it appears more cost-effective

(Polymer Science and Engineering... continued on page 6)

(Methodology... continued from page 1)

assist SMEs to commercialize new materials innovations in an industry previously dominated by large enterprises.

IMM assesses the technical and economic viability of the materials innovation and also the likelihood that a specific company could capture the value created by adopting the innovation. Specifically, IMM should provide a structured, informed procedure for assessing the attractiveness of investing in the scale-up required for commercial production of a new material. IMM can be divided into three segments: *viability, market forecasting,* and *value capture.* A material is *viable* in an application if the balance between its technical and economic attributes are favorable. Assessing viability involves technical modeling of the application, cost modeling of manufacturing, input from the market assessment, and value analysis. The *market assessment* uses techniques for identifying promising market applications and forecasting future production volume. Likelihood of *value capture* is assessed through an analysis of industry structure, organizational structure, intellectual property (IP) issues, appropriability, and the planned market approach. The history of materials development suggests that one or more of these three segments have typically been ignored or, at best, treated in isolation when a materials investment decision is made.



The Investment Methodology for Materials (IMM)

Viability Assessment

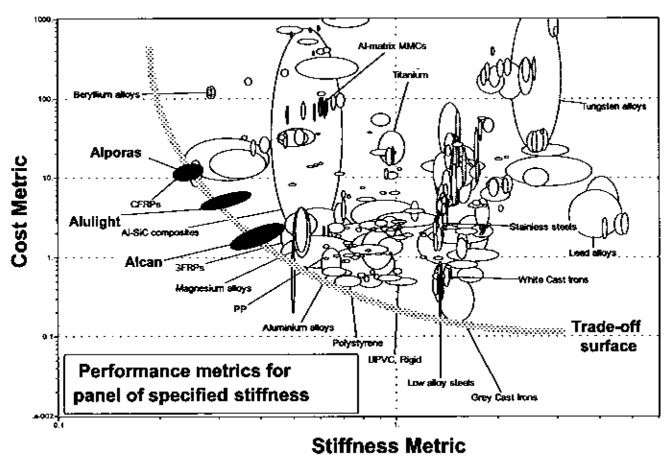
The viability of a new material in a given application depends on the balance among performance, cost, and value. There are three steps in its evaluation.

1. *Assessment of technical performance:* Performance metrics are identified and evaluated for competing solutions for the design. Each application can be modeled in this way to provide a basis for performance comparisons between new and existing solutions. This module takes as input the property profile of the new material so that it may be compared with the profile of existing materials in a range of potential applications. Contemporary software, typified by the Cambridge Engineering Selector, allows the retrieval and comparison of physical, mechanical, and thermal properties of thousands of materials. Comparison by function (as well as by simple property) is enabled by using material "indices" that characterize the performance of a material in a given function.
2. *Analysis of cost:* How much does it cost to achieve a given value of a performance metric? The quantity of material needed to meet constraints on stiffness, strength, energy absorption, etc., is calculated from straightforward technical models. The cost C of producing this quantity of material in the desired shape is the main output of the cost model. IMM uses Technical-Economic Cost Modeling to compare costs between functionally similar components or systems made with competing materials and processing methods. The inputs include technical properties of the new material, process information, estimated dimensions and key design features of the desired applications, and desired production volume range. The main output is a comparison between the cost of a part made of a new material and one made of an existing one. Additional outputs are a manufacturing cost estimate over a range of production volumes, cycle time estimates, limiting intermediate variables, costs broken down by accounting line item, and the results of sensitivity and scenario analyses.

"Some new materials solutions can be rejected..."

3. *Assessment of value:* Is the change in performance worth the change in cost? Balancing performance against cost and value is an example of multi-objective optimization. This module uses the profile of a new material, the economics of production (including scenario forecasting), knowledge of existing products and technologies, and measures of utility for the cost and/or performance attributes of the new material. Some new materials solutions can be rejected quickly because—in the words of optimization theory—they are *dominated* by other solutions: other solutions have better values of both (or all) the performance metrics. The solutions that cannot be rejected in this manner lie on a line called the *nondominated* or *optimum* trade-off surface and are known as the Pareto set of solutions.

The trade-off surface identifies the subset of solutions that offers the best compromise between the objectives, but it does not distinguish between them. Two strategies are then possible. The

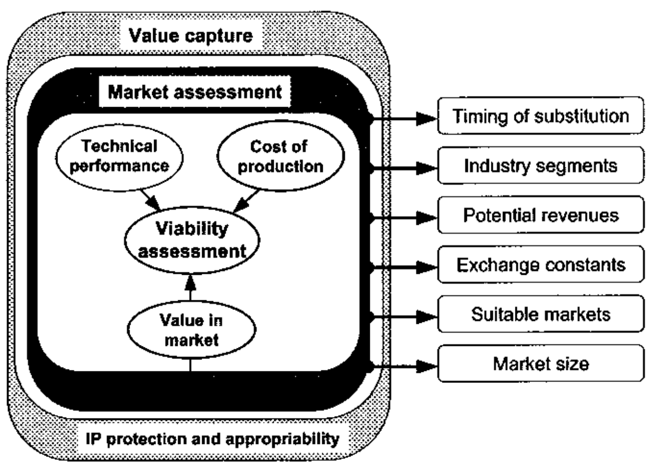


Performance-cost trade-off example of a light, stiff panel. A cost metric (cost per unit stiffness) is plotted along the vertical axis and a performance metric (mass per unit stiffness) is plotted on the horizontal axis. The open ovals show the range of cost and performance offered by conventional materials. The trade-off surface is the lower envelope of materials on this plot. Three unconventional materials—aluminum foams (labeled Alporas, Alulight, and Alcan, products of three different suppliers), shown in solid black—lie outside this trade-off surface. It is clear that the foams are attractive candidates for stiffness-limited structures when the value associated with weight savings is high. Dominated solutions (those above and to the right of the trade-off surface) are uncompetitive on the grounds both of cost and of performance.

simplest is to examine the trade-off surface, using intuition to select one or more nondominated solutions for further consideration. The alternative—one that requires more information—is to construct a composite objective function or value function *V*; the solution with the minimum *V* value is the overall optimum. This method allows true multi-objective optimization but requires more information.

Market Assessment

Science-based innovations require an early market assessment to link the worlds of engineering and finance. Market assessment involves both the technical inputs of performance metrics and the market inputs of customer requirements and emerging opportunities. Desired outputs include information to direct technical development, such as suitable markets on which to concentrate development and exchange constants for value analysis; and information to guide business decisions, such as the market segments that offer the greatest promise, sizes of those markets, and anticipated timing and amount of potential revenue flows. The overall goal is to link the technological innovation's characteristics with the market dynamics of the industries in which the applications are targeted.

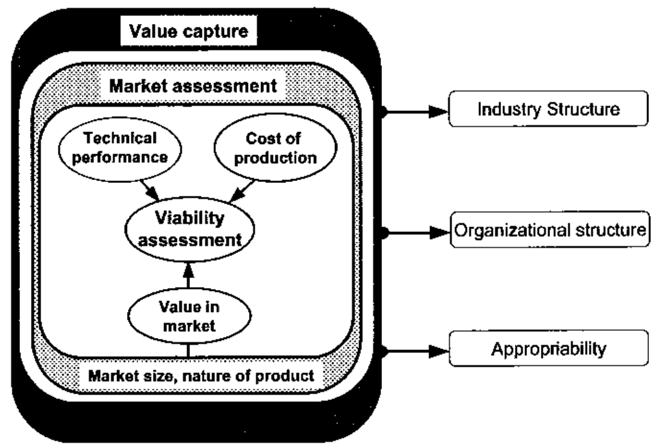


Market Assessment Information Flow

The current or potential revenues of all the markets in which the materials innovation is viable determine the total market size. The timing of realizing these revenues can be estimated by matching the materials innovation to a comparable historical example and using performance and cost characteristics to forecast penetration rates of the material into the targeted markets. Lower cost/lower performance innovations serve the minimum requirements of customers for the application. For substitution to occur, this lesser functionality must be provided at a reduced cost. Oriented strand-board substituting for plywood in furniture is an example of this type of substitution. An example of technological innovation allowing for performance enhancements but at (initially) higher cost is carbon-fiber-reinforced plastic boat hulls substituting for wood hulls. If the materials innovation enables entirely new applications, it does not need to be compared with an existing product or technology but rather with assessed customer requirements and safety standards. Thus, the market penetration rate for the materials innovation under consideration can be estimated with historical substitution curves for materials with similar performance and cost characteristics.

Assessment of Probability of Value Capture

Viability assessment and market assessment may demonstrate that the innovation under consideration has the potential to create enormous value, but this alone is not sufficient to guarantee investment. The investor must be convinced that he will be able to capture a significant portion of this value. The probability of value capture is determined through an analysis of industry structure, organizational structure, and appropriability—the level of IP protection and the likelihood of capturing the bulk of the profits generated by an innovation. For this segment of the analysis, the company commercializing the materials innovation is examined.



Overview of Value Capture Analysis

Michael Porter's Five Forces methodology is used for assessing industry attractiveness (a proxy for profitability) to provide an interindustry attractiveness rating ranging from low to high. The Five Forces considered are the rivalry of competitors in the industry, supplier power, buyer power, barrier to new entrants to the industry, and the threat of substitute products. Additionally, the organizational strength of the innovating company is rated by assessing the entrepreneurial experience of management, the presence or absence of a visionary deal-maker, the flexibility of the organization, and the level of operational efficiency. For more in-depth assessment, Tidd et al. propose a list of strategic tasks necessary for organizations to innovate successfully. The appropriability of the innovation is assessed through patent or trade secret strength, asset type, and the type of innovation. The likelihood of value capture is assessed through these three criteria.

Conclusions and Investment Strategy

The key go/no-go questions of investment in the materials innovation or company can be answered by the three main parts of the IMM:

- *Viability*: The viability assessment consists of two predictive models—the first for performance, the second for cost—and a method for examining the trade-off between the two, determining whether customers will judge the product to be good value for the money. Only if the material is technically and economically viable is an investment justified, but viability assessment is not enough; the market forecast is also essential.
- *Market Assessment*: Investment is justified only if potential market size is sufficiently large. The market

forecast feeds back into the viability assessment by identifying promising market segments and the value consumers attach to them, and it assesses the size of the market that is likely to adopt the innovation. Historically relevant innovations are used as a basis for the forecast.

- *Value Capture*: Investment is justified only if the likelihood of capturing the value created by the material innovation (after considering potential collaborations) is high. The value capture assessment uses three established strategy tools: industry analysis, appropriability, and organizational assessment. A unique feature of the methodology is the incorporation of this essential component of business analysis into the viability assessment of a material innovation at an early stage.

This methodology also provides some insight into the type of organization most likely to find investment attractive. Logistics curves can help in estimating the length of payback on an initial investment. In the case of long-term payback, a public organization or a very large corporation may be the only interested investor. Conversely, in the case of a staged investment with a five-year payback, the potential of a buyout, and large "upside" profit, appears an attractive one to venture capitalists.

"...that the innovation under consideration has...enormous value...is not sufficient to guarantee investment."

Given the decision to invest, market approach is the key to managing cash flow. A new material can first be exploited in small-volume, high-value-added applications (such as sports equipment) to gain credibility and brand name recognition and to provide initial cash flow. Smaller companies can gain from joint ventures with suppliers, customers, and distribution channels, because such collaborations provide financing opportunities, faster market penetration, and a more detailed understanding of the market.

Further Reading

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Acknowledgments

We wish to acknowledge the support of the Cambridge Canadian Trust, the Körber Foundation, the UK EPSRC through the Engineering Design Centre at Cambridge, and Granta Design, Cambridge, who developed the software illustrated in this article.

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URL: *www-edc.eng.cam.ac.uk/people/mfa2.html*

U\links

Useful materials-related links on the World Wide Web

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- The NIST Materials Data Program provides evaluated data on phase equilibria, structure and characterization, and performance properties. *www.nist.gov/srd/materials.htm*
- A free online materials information resource with properties data on over 15,000 materials (premium service available for a fee). *www.matweb.com*