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Investing in new materials: a tool for technology managers

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Abstract

A technology management tool has been developed to determine the attractiveness of a materials innovation by systematically assessing the technical and economic viability, along with the likelihood to capture profits created. The Investment Methodology for Materials (IMM) may prevent companies from pursuing investment strategies destined for failure. Small and medium sized enterprises (SMEs), often started by the inventor of a new material, have had particular difficulty in commercialising new materials—either due to the upfront and risky expense involved in displacing an incumbent material in a mature industry or due to the need for complementary innovations to enable a radical innovation.

IMM helps identify promising materials innovations at an early stage, helps to direct research and development in directions most likely to lead to successful exploitation, shortens the gestation time of materials substitution and guides investment strategy. 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 analysis*, *market assessment* and *value capture*. For SMEs this technology management tool would be most easily applied by an outside consultant over a period of approximately one month.

Keywords: Materials innovation; Methodologies for SMEs; Commercialisation of new materials; Seed capital investment; Viability analysis; Market assessment; Value capture

1. Introduction

1.1. Technology management methodologies developed for industry

The need to combine good technological and business judgement is the driver behind th0e development of most technology management tools. These are practical techniques, usually decision support processes, that assist managers of technology intensive firms in evaluating the many factors that need to be considered in coming to soundly based plans of action (Brady et al., 1997). Typical examples of such tools and techniques are technology strategy formulation processes (Stacey and Ashton, 1990), technology roadmapping methodologies (Phaal et al., 2000), R&D project selection techniques (Phaal et al., 2000; Neely, 1998) and new product introduction processes (Cooper, 2001; Gardiner et al., 1998). In recent years many such processes and tools have been published, as managers seek structured ways of dealing with these complex issues. The many factors that need to be integrated into such an approach result in a high information requirement, and an associated high demand on company resources to fully implement the approach. As a consequence, they are usually designed for use in larger corporations, in which project teams can be assembled drawing on a wide range of knowledge from the various functions represented in the business: manufacturing, engineering, R&D, marketing, sales, finance, purchasing, etc.

However as the contribution of small firms to innovation has grown, so has the interest in adapting technology management tools for use in small businesses. National Government programmes in the UK and more broadly in the European Community have specifically sought to provide support to small and medium sized enterprises (SMEs). For example, the recent Technology Foresight programme in

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the UK has had a particular focus on the small firm, and has developed methodologies which are relevant in this context (Future Markets–Future Business, 1998). SMEs are seen to be central to wealth creation; but have particular difficulty in accessing and applying many of these technology management tools and techniques. There are some particular characteristics of SMEs, including a narrow focus on very specific technologies, a limited infrastructure, and concentration of knowledge in the heads of a few key individuals, which make the application of these tools and techniques a challenge. Successful technology management techniques aimed at such firms need to allow for these characteristics and resource limitations.

2. Materials innovation: a technology management challenge

For the last two decades, new materials have been identified as a source of revolutionary technologies (Tidd et al., 2001; Coates, 1998; Wield and Roy, 1995). Yet the introduction of new materials innovations to the marketplace is a technology management challenge that has been poorly addressed to date, particularly among SMEs. The greatest barriers to rational technology management of new materials innovations have been: (1) the time period that has traditionally elapsed between the discovery of a new material and its successful introduction to the market embodied in a product, and (2) the very large cumulative investment that is usually necessary to develop the innovative material to the point at which it can be commercialised. Both these barriers mitigate against the small firm pioneering materials innovations, and there has been very little published that can help small businesses to overcome these barriers. The technology management tool developed in this paper provides support to businesses of all sizes in evaluating the potential of a materials innovation: however, special care was taken to ensure this technique could be useful to SMEs by limiting the employee time and resources needed to use the methodology and by clearly defining the procedure to be followed.

2.1. Slow adoption of new materials

Innovation in new materials[1] has been characterised by a long gestation period between the technical invention and the first commercial application, and a long substitution period between the first commercial application and the widespread use of the new material. Polyethylene, Sheet Moulding Compound (SMC), Metglasses (amorphous metals), Metal Matrix Composites (MMCs), and technical ceramics for mechanical applications (SiC, Si_3N_4) are all examples of new materials innovations which have gestation periods of 20 years and above (Maine, 2000).

The length of the gestation and substitution periods of new material innovations are as long as they are due to many factors, often including an initially high cost invention, cost barriers to materials substitution from entrenched materials, and insufficient knowledge of market applications by inventors. We surmise that this long gestation period is partly due to a mismatch between designers' and entrepreneurs' understanding of market needs and the development of new materials for various applications. This mismatch is exacerbated by the many layers of separation between material and end consumer. Freeman likens the market push and technology pull of technological innovations to a pair of scissors (Freeman, 1982): together, the parts work efficiently; separately, they do not work at all. Assuming this matching process is a bottleneck in the diffusion of a materials innovation, a methodology to facilitate the matching of technical possibilities with the market could directly shorten the gestation period of materials innovation and substitution.

Adoption of new materials innovations is also slowed by strategic corporate decisions at the firm level. Much of innovation in materials industries has been developed and commercialised by large enterprises with structured R&D strategies. These organisations generally follow some sort of portfolio management system in order to diversify risk in the R&D projects that they fund and develop. However, due to flawed R&D valuation methodologies, the desire to match R&D tightly with current core competencies, and the reluctance to cannibalise current business, some potentially profitable materials innovations are passed over by large enterprises (Neely, 1998). Small enterprises escape some of these constraints, but have faced financial barriers to entry in commercialising a materials innovation over the past several decades, since long-term R&D investments, manufacturing equipment investments, market information, and distribution channels all benefit from the scale economies of large materials companies.

2.2. Need for materials investment analysis tool

One of the main barriers to smaller firms commercialising materials innovation has been access to capital for 'risky, long-term development' (Wield and Roy, 1995). Empirical evidence suggests that connectivity and the trend towards collaborative research are making access to capital less difficult (Maine, 2000). If the gestation time of a materials innovation can be shortened by these forces and technology and market risks can be lowered by tools and methods of research enabled by IT, the risk/reward position of materials

[1] This paper concerns innovation and adoption of new materials. In it, reference is often made to the 'materials industry', by which is meant the sector involved in the development and commercialisation of new materials. Factors common to companies in the materials industry include: high knowledge intensity; significant R&D expenses; production of an intermediate, non-assembled product; need for substantial investment in production facilities; need to interact with designers of downstream companies; ability to protect innovations with patents; economies of scale; and, in many cases, common buyers.

innovation by SMEs will be considerably improved. The potential reward is higher, as the returns are expected sooner. The technology risks are lowered by utilising viability assessment for early stage vetting of a materials innovation. The marketing risks are lowered by the use of relevant precedents for market forecasts, by earlier stage access to information about consumer needs, and by predictive tools used to create materials in response to consumer needs.

Venture capital is the traditional source of financing for risky, early stage ventures. Currently, ideas for materials innovations are assessed by venture capitalists in precisely the way that non-technological business ideas are assessed.[2] Without assessing the technical and economic viability of the materials innovation, investors are either assuming unnecessary risk or missing worthwhile investment opportunities. A better investment assessment methodology for materials innovations is outlined in Section 3.

Additionally, materials innovating SMEs need to become aware of the strategic positioning of their innovation and of the best paths for commercialisation. The methodology allows the predominantly science-biased entrepreneurs driving materials innovation in SMEs to make strategic decisions at an earlier stage of development. In summary, this methodology is meant as a tool for venture capitalists, an accepted method of vetting a materials innovation, and a learning mechanism for materials innovators.

3. Tool for materials investment analysis

3.1. Overview of investment methodology for materials (IMM)

Here, we propose an investment methodology for new materials (IMM) to reduce risk and shorten gestation time. Risk can be lowered through early *viability analysis* and gestation time could be shortened, and thus the present value of expected revenues increased, through earlier and more effective information exchange. 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 adoption of the innovation. Specifically, it is envisioned that IMM should provide a structured, informed procedure for assessing the attractiveness of investing in the industrial scale-up of the production of a new material.

IMM can be divided into three segments: *viability*, *market assessment*, and *value capture* (see Fig. 1). A material is viable in an application if the balance between its technical and economic attributes are favourable. Assessing viability involves: technical modelling of the application, cost modelling of manufacturing, input from the market

[2] Interviews with Cambridge Research and Innovation Ltd, Arthur D. Little, 31, Scientific Generics, and St John's Innovation Centre.

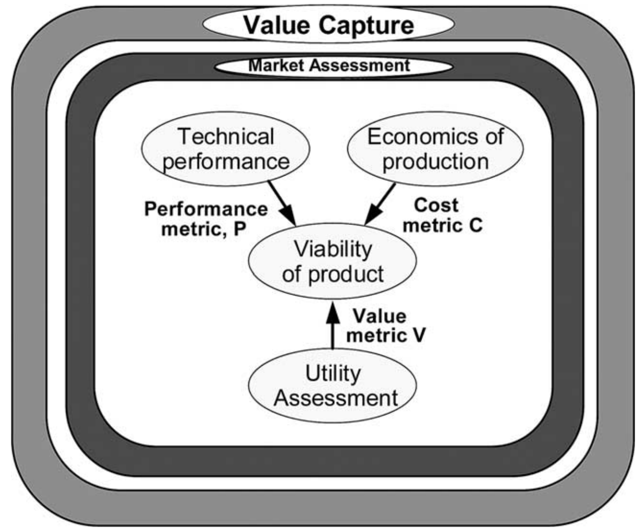

Fig. 1. Investment methodology for materials (IMM).

assessment, and value analysis. The market assessment consists of techniques for identifying promising market applications and for forecasting future production volume. Likelihood of value capture is assessed through an analysis of industry structure, organisational structure, IP issues, appropriability, and the planned market approach.

If the two metrics of size of viable markets and value capture are used to characterise materials, it is clear that the most desirable investment opportunities lie in the upper right-hand quadrant of Fig. 2. The position of a not-yet-commercialised structural material on these two axes is not easy to predict—polyethylene, at the top left, was at first thought to have only a tiny potential market. Control of intellectual property is a key to value capture in the materials industry (as elsewhere), as the positions of Kevlar™ and of Gore-tex™ indicate. With functional materials, of which LEPs are an example, the positioning

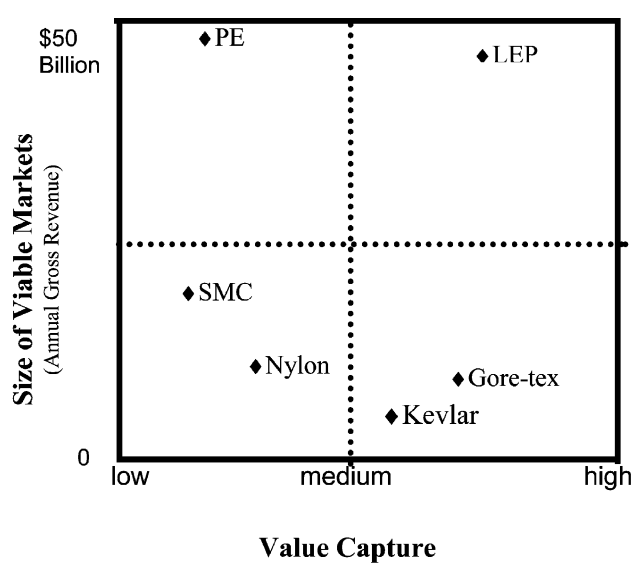

Fig. 2. Decision to invest in a materials innovation.

on the figure may be more certain, though still an informed guess rather than a certainty.

There exists a substantial body of literature and experience on each of the topics listed above, each corresponding to a segment of Fig. 1 and a module of this methodology. The novelty of the methodology proposed here lies in their integration into a concurrent procedure. It may be thought that this step is an obvious one, but the history of materials development suggests that the modules, or the groupings shown in Fig. 1, are frequently treated in isolation, compromising the effectiveness of the analysis.

The rest of this paper explains the methodology from a user's perspective. Each segment of Fig. 1 corresponds to an analysis module of the methodology. The inputs and outflow of information from each module are elaborated on in the following.

3.2. Viability analysis

3.2.1. Modelling technical feasibility

Before recommending a new material to a designer, or investing in manufacturing equipment to industrially produce a new material, it is essential that the new material be well understood from a technical perspective. The first module (upper left oval of Fig. 1) of the analysis takes as input the property profile of the new material, allowing its comparison with the profile of existing materials in a range of potential applications. Contemporary software, typified by the Cambridge Engineering Selector (CES), 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 characterise the performance of a material in a given function (Ashby, 1997). Material and first-order processing costs are also captured, as well as some environmental information.[3]

The use of software of this sort, illustrated in later chapters, is the initial, scoping, step in establishing technical merit. Almost always this must be supplemented with more detailed analysis, identifying performance metrics, for which we shall use the symbol P, that measure technical excellence and comparing those of the new material with those of existing materials. The output of the technical assessment is a tabulation of these metrics for new and incumbent materials. It is worth emphasising that viability does not necessarily require greater technical excellence, since it is the balance between this and cost (to which we now turn) that determines viability.

3.2.2. Modelling cost

The second step in exploring the technical viability of a materials innovation is that of establishing the material production and secondary processing costs. Most models to predict manufacturing cost as a function of production volume rely on historical data for existing processes. It is common to crudely approximate costs when the process has not been developed past pilot scale, the manufacturing method is untried, and the potential for technical advances exist. Such approximate estimates can be useful, but a predictive cost model which allows for sensistivity analysis on technical uncertainties is better. This is made possible by Technical-economic Cost Modelling (TCM) (Clark et al., 1997).

TCM enables a cost comparison between functionally similar components or systems made with competing materials and processing methods. Developed at the Massachusetts Institute of Technology over the past two decades, TCM has emerged as an accepted metric for material and process comparison for automotive manufacturers and suppliers. TCM can facilitate credible communication with design engineers about new material innovations and enable the development of product cost scenarios that are based on potential technological changes (Clark et al., 1997; Han, 1994).

The upper right oval in Fig. 1 represents a technical cost modelling module. The inputs into this module 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, C, 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 analysis.

3.2.3. Value analysis

If the materials innovation delivers products with better performance at lower cost than existing solutions, the innovation is viable. Barriers to entry may delay the substitution, but, eventually, it will occur. Nothing more needs to be considered in this sector. However, it is commonly the case that a new material that is proposed for substitution into a particular application has enhanced performance, but costs more, or is cheaper, but has lower performance than existing solutions. The new material may have a viable market niche, but, to establish this, more information is needed about how the market values performance. The lower oval in Fig. 1 represents a module for exploring trade-offs and assessing value. It utilises 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.

Here, we have a classic example of the problem of finding a compromise between two conflicting objectives—that of maximising performance at the same time of

[3] CES Software, Granta Design Ltd, 20 Trumpington Street, Cambridge CB2 IQA, UK. www.grantadesign.com

minimising cost. When a design has two or more objectives, solutions rarely exist that optimise all objectives simultaneously. The objectives are normally non-commensurate, meaning that they are measured in different units, and in conflict, meaning that any improvement in one is at the loss of another (Ashby, 2000). However, some solutions can be rejected quickly because they are dominated by other solutions, meaning that other solutions exist that 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 *non-dominated* or *optimum* trade-off surface (Sawaragi et al., 1985; Hansen and Druckstein, 1982). The values of the performance metrics corresponding to the non-dominated set of solutions are called the Pareto set.

The trade-off surface identifies the subset of solutions that offer the best compromise between the objectives, but it does not distinguish between them. Three strategies are available to deal with this: use of intuition, reformulation of 'secondary' objectives as constraints, or the formulation of a *value function*. A value function is a mathematical expression, composed of performance metrics and exchange constants, that allows for true multi-objective optimisation. In cases where the data can be gathered (through structured interviews, lifecycle costing, or historical pricing data) the value function is the preferred approach for conducting value analysis.

3.2.4. Market assessment

Science-push innovations require an early stage market assessment to link the worlds of engineering and finance (Williams, 1993). Market assessment involves both the technical inputs of performance metrics and the market inputs of customer requirements and emerging opportunities. Desired outputs include: further information to direct the technical development effort, such as, suitable markets on which to concentrate development, and exchange constants for utility analysis; and information to guide business decisions, such as, segments of the market which are most attractive, sizes of those markets, and anticipated timing and amount of potential revenue flows.

An early stage, new material-market assessment (Fig. 3) involves the following two strategies:

Strategy A. The search for new markets or applications created by the new material. This search is based on the performance attributes of the new material or the new material process and relies on satisfying a consumer desire that is not currently met. Examples of the above include the novel processing of PTFE to create Goretex™ offering performance in combined winter/rain/sports/casual jackets; the development of cobalt-samarium magnets, which enabled ultra lightweight earphones and small DC motors; the advances in silicon wafer manufacturing which have contributed to the development of the computer chip industry; and the development of light emitting polymers into diodes. Success here is difficult to achieve but the potential payoff is large.

Strategy B. An exploration of substitution into existing markets. This strategy involves six broad steps:

1. Potential markets are identified by comparing the properties of the new material with those of existing materials and noting the most promising property combinations of the new material. The established applications of existing commercial materials with similar property profiles are explored as a first estimate of potential markets.
2. The sizes of potential markets for the new material are determined through public information sources (WWW, electronic news search services, etc.).
3. The above markets are prioritised according to market size and estimated type of substitution. This initial prioritisation step provides input for the technical assessment, cost modelling, and value analysis modules. Market size estimation is an iterative process, with refined estimates becoming possible only after value analysis is performed.

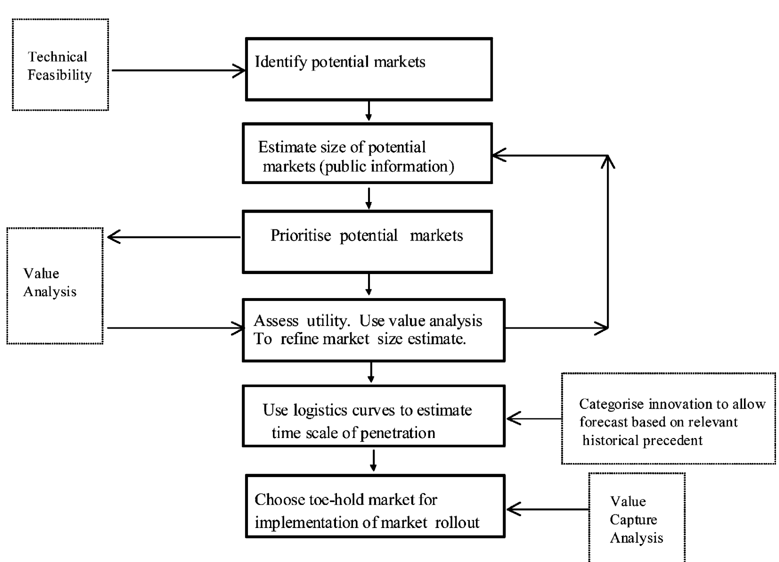

Fig. 3. Steps of market assessment (Strategy B).

4. The utility of different markets and/or applications for the performance-cost attributes of the new material is assessed. Utility analysis provides an input (exchange constants) into the value function, which enables material selection based on a combination of cost and performance metrics.
5. Logistics curves (Fisher and Pry, 1971) and assessed performance-cost attributes are used to estimate penetration into identified markets and applications. An Implementation Plan is created for the order of markets to be entered. Finding an entry market with minimum risk is most important for an SME.

Market demand estimates are always uncertain. If the innovation is deemed viable, performance and cost characteristics can help in estimating penetration rates of the material into the defined markets. This is accomplished by forecasting the penetration rates for the new materials innovation based on a historical material substitution curve of a material with similar performance and cost characteristics (Maine, 1997). 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 and construction applications is an example of this type of substitution. An example of technological innovation allowing for performance enhancements but at higher cost is carbon fibre 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.

By following the procedure outlined in Fig. 3, answers to guide further technical and business assessment can be reached. Market assessment is seen here as an interim step, but a vital step in reaching an investment decision. The overall goal is to ensure that the assumptions on which market forecasts are based are sound, and to integrally link the technological innovation's strengths and weaknesses with the market dynamics of the industries in which the applications are targeted.

3.3. Likelihood of capturing created value

Viability assessment and market assessment may demonstrate that the materials innovation under consideration has the potential to create enormous value. However, a company may be persuaded of this assessment and still decide not to invest. In order to invest, a company must be convinced that they will be able to capture a significant portion of the value created by the innovation. The concepts of appropriability, industry structure, competitive advantage, and organisational structure are utilised to predict the likelihood of capturing value.

3.3.1. Industry structure

Michael Porter's methodology for assessing *industry attractiveness* provides an inter-industry attractiveness rating, ranging from low to high. Porter assesses the attractiveness, or potential for profitability, of an industry by examining the rivalry of competitors in the industry, supplier power, buyer power, barrier to new entrants to the industry, and the threat of substitute products (Porter, 1985). Technological innovation can alter the attractiveness of an industry by changing one of the above factors, for example, by raising or lowering the barriers to new entrants to the industry. Porter's well-known method is used in this methodology to provide an initial indicator of the liklihood of value capture in specific applications.

3.3.2. Appropriability of profits

Ownership of Intellectual Property (IP) is of high importance in extracting value from commercialising a materials innovation. Without patent or trademark protection, it is difficult to maintain a profit margin in mass production of any product. The concept of *appropriability* was developed to measure the degree of IP protection and, further, the ability of the innovating firm to capture the profits from commercialising a new technology (Teece, 1987). Teece divides appropriability regimes into tight, where strong patent or trade secret protection, asset type, and the type of innovation combine to enable the capturing of innovation profits, and weak, where information about the innovation is not well protected and the innovator has difficulty capturing innovation. Tight appropriability regimes are very desirable as they allow for monopoly conditions for a period of time.

Categorising past innovations can provide a method for selecting relevant historical precedents to help with predicting market substitution and appropriability. Abernathy and Clark's framework for innovation provides such a categorisation. Innovations can be divided into one of four quadrants, shown in Fig. 4 (Abernathy and Clark, 1985). *Regular innovation*, found in the bottom left quadrant, refers to incremental technical change that builds on established technical and production competence and that is applied to existing markets and customers. This type of innovation

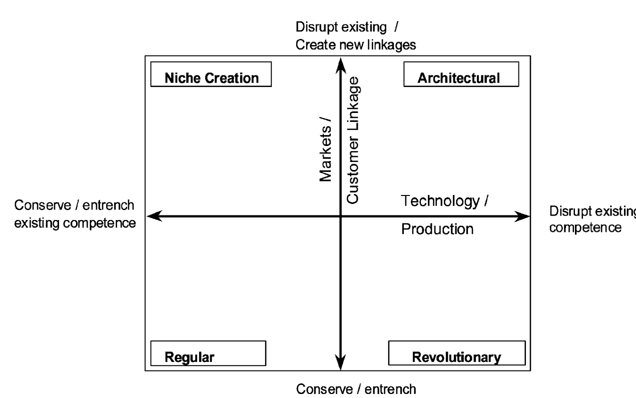

Fig. 4. Abernathy and Clark's transilience map.

Table 1
Appropriability guide

	Tightening appropriability			
IP/Trade secret protection	High	Medium	Low	None
Specialised assets	High	Medium	Low	None
Lead time (before competitors could imitate)	Long	Medium	Short	None
Innovation type	Architectural	Niche Product	Revolutionary	Regular
New product cycle time	Slow	Medium	Fast	Continuous
Is the industry protectable?	High	Medium	Low	No

incrementally reduces cost, improves performance or improves reliability, while strengthening existing technological and marketing competencies and linkages. *Revolutionary innovations*, such as transistors replacing vacuum tubes and jet engines replacing reciprocating engines in aircraft, are innovations that overturn established technical and production competencies, but allow a manufacturer to sell to their existing markets and customers. *Niche Creation innovation* is the application of existing technologies to new market applications. Lastly, *Architectural innovation* involves new technology that disrupts existing competencies and a product that disrupts existing market and customer linkages. Examples of architectural innovation include the creation of the radio and the development of the Ford Model T. Abernathy and Clark use these four types of innovation to mark the extremes of what they term a Transilience Map (Fig. 4). Transilience is defined as "the capacity of an innovation to influence the established systems of production and marketing (Abernathy and Clark, 1985)." Categorising the type of materials innovation under consideration according to this Transilience Map can help in locating an appropriate historical substitution on which to base both market forecast and appropriability comparisons. For more guidance on assessing the appropriability of an innovation, we have developed Table 1.

Generally, a tighter appropriability regime will exist to the left-hand side of the table.

3.3.3. Organisational structure

The most attractive innovation opportunity can be squandered through ineffective organisational structure (Amabile, 1998). In the materials industry in particular, organisational competencies are required to interchange knowledge across disciplinary fields, functional roles, organisational boundaries, and the marketplace. There is no one optimal organisational structure for the commercialisation of materials innovations. However, it is possible to use the academic literature on organisational structure to form a checklist of attributes to consider. For small firms, that checklist would include: the level of entrepreneurial experience of management, the presence and competence of a visionary dealmaker, level of demonstrated flexibility of the organisation, mechanisms for effective knowledge acquisition and management, and evidence of operational efficiency (Tidd, 1997; Amabile, 1998).

3.4. 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 methodology of Fig. 1:

- Viability—only if the material is technically and economically viable is an investment justified. The viability assessment is the most technical module of the three, but is nearly worthless if not tightly woven into the market forecast. The viability assessment consists of two predictive models and a value tradeoff. The models forecast technical performance attributes of a future product and production economics, and the value tradeoff predicts whether customers will buy the product.
- Market Assessment—only if the technically and economically viable market size is sufficiently large. The market forecast iterates with the viability assessment to identify promising market segments, obtain information about customer preferences, and forecast the size of the market which is likely to adopt the materials innovation. Historically, relevant innovations are utilised to as a basis for the forecast. Market forecasts are typically done very poorly by technology based SMEs and often not at all by technology research groups at universities. This methodology aims to simplify the steps of scenario planning through market and technology forecasts.
- Value Capture—only if the likelihood of capturing the value created from the introduction of this material innovation is high (after considering potential collaborations), is an investment justified. The value capture assessment utilises three strategy tools which are not unique to this thesis: those of industry analysis, appropriability, and organisational assessment. What is unique is the incorporation of this essential component of business analysis into the early stage viability assessment of a new materials innovation.

This methodology also provides some insight on the type of investing organisation 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 organisation or a very large corporation may be the only interested investors. Conversely, in the case of a staged investment with a five-year payback, the potential of a buyout, and large ‘upside’ profit, venture capitalists may be quite willing to provide financing for any company.

Given the decision to invest, market approach is the key to managing cash flow. For instance, a new material could first be exploited in small volume high value added applications such as sports equipment to gain credibility, brand name recognition, and to provide initial cash flow. Smaller companies in particular should consider collaborations with suppliers, customers, and distribution channels. Such collaborations can provide financing opportunities, faster penetration of the material, and a more detailed understanding of the market.

4. Discussion and conclusions

The attractiveness of a materials innovation can be determined by systematically assessing the technical and economic viability, along with the likelihood to capture profits created. This methodology may help match new materials innovations to market opportunities more quickly and may prevent some companies from pursuing investment strategies destined for failure. SMEs, often started by the inventor of a new material, have had particular difficulty in commercialising the new material—either due to the upfront and risky expense involved in displacing an incumbent material in a mature industry or due to the need for complementary innovations to enable a radical (or ‘architectural’) innovation. A methodology to facilitate the matching of technical possibilities with the market, through the systematic use of predictive software tools and forecasting techniques, was developed with the intention of shortening the gestation period of materials innovation and substitution. Any method of reducing the time period between invention, first commercial introduction, and significant marketplace adoption of a new material, would give the company driving the commercialisation of the new material many more financing options due to the shorter payback time.[4]

IMM is aimed at assisting materials SMEs in harnessing new predictive software tools and technology strategy methods to guide their strategy and prepare their business plans. In order to judge investments by a new material innovation’s credible positioning on a matrix such as that of Fig. 2, forecasting techniques must be employed. In the past, a large R&D department integrated with a large advanced marketing department would be required to attempt to position an early stage material’s innovation on such a matrix. Additionally, given the long gestation period of a new materials innovation, only a company with secure long-term financing would attempt to commercialise a new material. However, with changing organisational level forces in the materials industry (Maine, 2000), the opportunity exists for small companies to reasonably assess the potential of a new materials innovation and to drive the commercialisation process. The investment methodology for materials (IMM) has been designed to help identify promising materials innovations at an early stage. For SMEs, this technology management tool would be most easily applied by an outside consultant over a period of approximately one month. The cost of applying the IMM would be a very small fraction of any scale-up investment decision being made by the SME or venture capital company.

[4] Private discussions with representatives from Arthur D. Little, Cambridge Research and Innovation Ltd, and 3i.

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References

Abernathy, W.J., Clark, K.B., 1985. Innovation: mapping the winds of creative destruction. Research Policy 14, 3–22.
Amabile, T., 1998. How to kill creativity. Harvard Business Review.
Ashby, M.F., 1997. Materials selection and design. In: ASM Handbook, 20. ASM International, Materials Park, OH, pp. 281–290.
Ashby, M.F., 2000. Multi-objective optimisation in material design and selection. Acta Materials 48, 359–369.
Brady, T., Rush, H., Hobday, M., Davies, A., Probert, D., Banerjee, S., 1997. Tools for technology management: an academic perspective. Technovation 17 (8), 417–426.
Clark, J.P., Roth, R., Field, F.R., 1997. Techno-economic issues in material science. In: Materials Selection and Design, ASM Handbook, 20. ASM International, Materials Park, OH.
Coates, J., 1998. The next twenty-five years of technology: opportunities and risks. 21st Century Technologies. OECD.
Cooper, R., 2001. Winning at New Products, third ed. Perseus Publishing, Cambridge, MA.
Fisher, J.C., Pry, R.H., 1971. A simple substitution model of technical change. Technical Forecasting and Social Change 3, 75–88.
Freeman, C., 1982. The Economics of Industrial Innovation. Frances Pinter Publishers Ltd, London, UK.
Gardiner, G., Ridgman, T., Gilmour, C., 1998. Speeding new products to market: a practical workbook. Centre for Technology Management, University of Cambridge, UK.
Han, H.N., 1994. PhD Thesis, The Competitive Position of Alternative Automotive Materials, MIT.
Hansen, D., Druckstein, L., 1982. Multi-objective Decision Analysis with Engineering and Business Applications. Wiley, New York.
Maine, E., 1997. Future of Polymers in Automotive Applications, Dissertation for Master’s of Science in Technology and Policy, MIT.
Maine, E., 2000. PhD Thesis, Innovation and Adoption of New Materials, University of Cambridge.
Neely, J.E., 1998. Improving the Valuation of Research and Development: A Composite of Real Options, Decision Analysis and Benefit Frameworks, PhD Thesis, MIT.
Phaal, R., Farrukh, C.J.P., Probert, D.R., 2000. Fast-Start Technology Roadmapping. Presented at IAMOT Conference, February 2000, Orlando, FL.
Porter, M.E., 1985. Competitive Advantage: Creating and Sustaining Superior Performance. Harvard Business School Press, Boston, MA.

Sawaragi, Y., Nakayama, H., Tanino, T., 1985. Theory of Multiobjective Optimisation. Academic Press, New York.

Stacey, G., Ashton, W., 1990. A structured approach to corporate technology strategy. International Journal of Technology Management 5 (4), 389–407.

Teece, 1987. Profiting from technological innovation: implications for integration, collaboration, licensing and public policy, Berkeley, CA.

Tidd, J., Bessant, J., Pavitt, K., 2001. Managing Innovation: Integrating Technological, Market and Organizational Change, second ed. Wiley, Chichester, UK.

UK Government Foresight website, 1998. Future Markets–Future Business, June, http://www.foresight.gov.uk/default1024ns.htm

Wield, D., Roy, R., 1995. R and D and corporate strategies in UK materials-innovating companies. Technovation 15 (4), 208.

Williams, J.C., 1993. Commericalization of new materials for a global economy. National Academy Press, Washington, DC. Chairman of the National Materials Advisory Board. p. 16.

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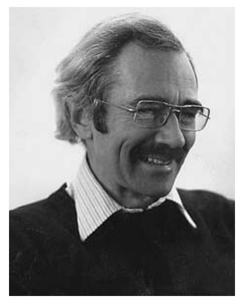

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