Accelerating advanced-materials commercialization

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Long commercialization times, high capital costs and sustained uncertainty deter investment in innovation for advanced materials. With appropriate strategies, technology and market uncertainties can be reduced, and the commercialization of advanced materials accelerated.

Advanced-materials ventures, often spun out of universities, are of increasing importance for the creation and commercialization of new materials and processes[1,2]. As more multinational firms within the ambits of chemistry and materials move to open innovation models[3,4], these firms need to monitor and then buy or license radical innovation. Advanced-materials ventures focused on breakthrough technologies provide a window of opportunity for these large firms and are likely to be their source of radical innovation[1,5]. But these ventures are also risky businesses that face daunting challenges in their route from the lab to the market[2,5,6]. Innovations in advanced materials, which underlie new product development across many industries, typically take 5–15 years to turn into a commercial product[5,7], and can take far longer to penetrate multiple markets[8]. For example, Cambridge Display Technology (CDT) — a spin-out from the Cavendish Laboratory at the University of Cambridge that focused on making organic light-emitting diodes (OLEDs) — needed 10 years to commercialize their first product, an electronic shaver display[5]. Similarly, Hyperion Catalysis International, a nanomaterials venture in the Boston area, followed a 10-year lab-to-market timeline to commercialize their carbon-nanotube-reinforced polymer composites in automotive fuel lines[5]. Nanosphere — a spin-out from Northwestern University — needed 12 years to commercialize the world's first diagnostic test for sepsis[9]. NanoGram — a Silicon Valley start-up — took 8 years to commercialize a high-performance cathode material for medical implantable batteries[10]. In each of these examples of a company's first commercial products, overall market size slowly increased as more designers became familiar with the new material, as market applications in new industries were recognized or emerged, and as required complementary innovations occurred. Clearly, long time frames negatively influence the willingness of both investors and potential alliance partners to invest time and money in the commercialization of advanced materials[8,11]. Nevertheless, investors with relevant domain expertise continue to support materials start-up companies while optimizing their strategy to minimize market and technology uncertainties and to accelerate the time to market. In this Commentary, we discuss challenges in the commercialization of advanced materials and offer potential solutions. We draw on our academic and industrial experience, on the close observation and analysis of over 100 advanced-materials ventures, and on the output of an international summit on this topic[12].

The investment challenge

Why would venture capitalists and multinationals invest in advanced-materials ventures? Compared to software ventures, the investment is far more challenging, with materials ventures commonly facing high technology and market uncertainties over long periods of time, as well as high capital costs before the uncertainties are resolved. The commercialization costs, timelines and levels of technology and market uncertainties typically faced by advanced-materials ventures are broadly similar to those of biotechnology ventures, and contrast starkly with those faced by ventures in the software industry (Table 1). In the biotechnology sector, clinical trials involve high expenses and very high technology uncertainties, and involve the market risk of changes in the standard of care. For advanced-materials ventures, high commercialization costs involve the scale-up of process manufacturing as well as customized product design and development. Hence, as with biotechnology ventures that involve the development of a new drug, advanced-materials ventures developing a novel material often face high levels of uncertainty over a long period of time, and may require hundreds of millions of dollars to commercialize the product.

Technology uncertainty. The reasons for technology uncertainty are fairly clear. Even after key patents are granted, translating what works in the lab to a full-scale manufacturing process is not always feasible; and when it is, it may not be economically viable[13,14]. In addition, the material will typically need to be tailored to different industry applications, in which varying combinations of performance attributes are valued. For example, the proprietary nanomaterials manufacturing process of NanoGram — which produced small (5–200 nm), uniform, high-purity nanoparticles for a broad range of materials — had applications across the alternative energy, consumer electronics, biomedical and communications industries, all of which required the development of distinct prototype components. In particular, NanoGram's nanoparticle silver–vanadium-oxide cathode materials led to batteries with a higher energy density, which enabled the use of smaller and longer-lasting implantable medical devices. However, a different combination of component attributes are valued in automotive batteries, such as faster recharge rates, for which NanoGram's process could also be tailored. And different materials and product-attribute tailoring are needed to meet market needs in, for example, optical components for telecommunications and solar cells. The functionality of each different combination of materials and attributes needs to be proven at scale.

Table 1 | Commercialization time, costs and uncertainties for software, biotechnology and advanced-materials ventures.

	Development time (years)	Research and development costs* (US$ millions)	Commercialization costs† (US$ millions)	Technology uncertainty	Market uncertainty
Software	0–2	0–3	1–10	Low	Medium
Biotechnology	10–15	5–10	300–900	Very high	Medium
Advanced materials	5–15	2–20	50–500	High	High

The reported development times and research and development (R&D) costs are based on interviews and our experience, as well as on published case studies involving advanced materials[2,5,10,34,38], biotechnology[39–42] and software development[43–47]. *R&D costs refer to software development costs up to a first commercial release, to the cost of preclinical trials and to lab-scale R&D costs for a new material and its potential applications. †Commercialization costs refer to the necessary investment to commercialize an invention, which can involve pilot plants, iterative development, process scale-up, clinical trials, regulatory approval, marketing and distribution.

Market uncertainty. The distinctive marketing challenges faced by advanced-materials ventures are less well known. High levels of market uncertainty are linked to the upstream position of the ventures in their target industries' value chains (the set of activities and firms involved in making and distributing a product[15]), to the need for complementary innovations in emerging product applications, to the fact that potential end consumers usually can't observe or trial the invention, and to the multiple markets to which advanced-materials technology may be applied[5]. In what follows, we briefly explore the contribution of each factor.

Upstream position. Being far removed from the end consumer makes it difficult for a materials company to assess consumer needs and to manage market experimentation and feedback[8]. For example, in Hyperion Catalysis International's commercialization of an automotive fuel line made of carbon-nanotube-reinforced polymer composites (Fig. 1, left), typical customers are component suppliers (in this case, automotive suppliers) and original equipment manufacturers of assembled goods (in this case, an automotive manufacturer), who must be convinced and then helped to design products incorporating the innovation. The downstream designers in these manufacturing firms may not be familiar with a new material class and its design possibilities, or they may resist change that has the potential to undermine their current expertise[5,8]. In Hyperion Catalysis International's case, a large, experienced materials supplier worked with them and a Tier 1 automotive supplier in designing a composite fuel line with good static dissipation that had equivalent strength and stiffness, and required fewer forming steps than the steel fuel line that it replaced. The Tier 1 automotive supplier needed to alter the existing power train, add fasteners and make process changes in order to make the new material substitution compelling, and did so because of a strong relationship with the materials supplier. In the medical device industry, NanoGram Devices faced similar design and adoption challenges (Fig. 1, right).

Complementary innovation. The end-product redesign required for Hyperion Catalysis International to commercialize their polymer-composite fuel line is an example of complementary innovation (defined by the set of related advances required to make a product viable), which advanced-materials inventions usually require[5]. For instance, the significant adoption of carbon fibre was dependent on process innovations in polymer-composite manufacturing and required significant design changes in eventual marine, sporting equipment, automotive and aerospace applications. Similarly, the adoption of structural polymer composites in automotive and aerospace applications required design for the integration of parts in order to be cost-effective (a notable example is the fuselage of the Boeing 787 Dreamliner[16]). Proton exchange membrane fuel cells, long targeted at replacing the internal combustion engine in automobiles, are still waiting for the requisite infrastructure to utilize hydrogen as a fuel and for process innovations that reduce the cost of catalysts and that increase the durability of the membranes[17]. The need for such complementary innovations increases market uncertainty.

Unobservable innovation. The adoption of new materials requires recognition of the relative advantage that they offer. Marketing research on product adoption has shown that innovations are likely to be adopted more rapidly if they are compatible with existing practices and offer benefits that can be understood, observed and trialled[18,19]. However, materials innovations with the highest potential are often discontinuous and difficult for customers to understand or observe[20,21]. In fact, such innovations may not be observable by the end consumer even after a fully working prototype of the downstream product has been developed.

Multiple markets. Ironically, the very breadth of value creation that advanced materials provide may also increase market uncertainty. Advanced-materials ventures often target several industries (including automotive, aerospace, consumer electronics, biomedical devices, construction, power generation, telecommunications, sports equipment and defence applications) and must make early decisions on which target markets and applications to prioritize. This usually involves gathering information on customer utility for the performance attributes of applications in several different industries[13], learning about regulatory or infrastructure barriers, and attempting to engage alliance partners[2,5]. The selection of an initial target market — that is, technology–market matching — is of much higher priority than for software ventures which, although they also develop generic technology, can pivot quickly and easily[5,8].

Strategies for ventures

Investment timelines for advanced-materials ventures typically start with the breakthrough invention stage, and follow through the lengthy development stage, in which commercialization is attempted, until eventual product acceptance and the onset of revenues is achieved (Fig. 2). For example, Nanosphere, following a breakthrough invention from the lab of Professor Chad Mirkin and the receipt of four rounds of venture capital investment from 2000 to 2006 (ref. 22), and of public financing in 2007, did not achieve product revenues until 2012, when they commercialized the world's first diagnostic test for sepsis. Over those 12 years, Nanosphere required US$300 million in investment, and returned only US$5 million in product revenues[9]. Investors, however, want to invest either very early and take an exit when the firm achieves a liquidity event (an initial public offering or an acquisition), or after the firm achieves product revenues following the technology–market matching, development, process scale-up and regulatory hurdles of its development stage. Even after product revenues are achieved, market uncertainty remains if competitors develop novel substitute products. Nanosphere's commercialization timeline is not atypical: many advanced-materials ventures have similarly long commercialization phases[2,5].

How can the lengthy development stage be shortened, to everyone's benefit? Drawing on our analysis of advanced-materials ventures, and on the output of an international summit on the acceleration of the commercialization of advanced materials[12], we propose four strategies for ventures to overcome commercialization challenges: seeking out materials accelerator programmes, prioritizing target markets, strategic positioning in the value chain and creating effective alliance partnerships. These four strategies span the timeline from the lab through to market.

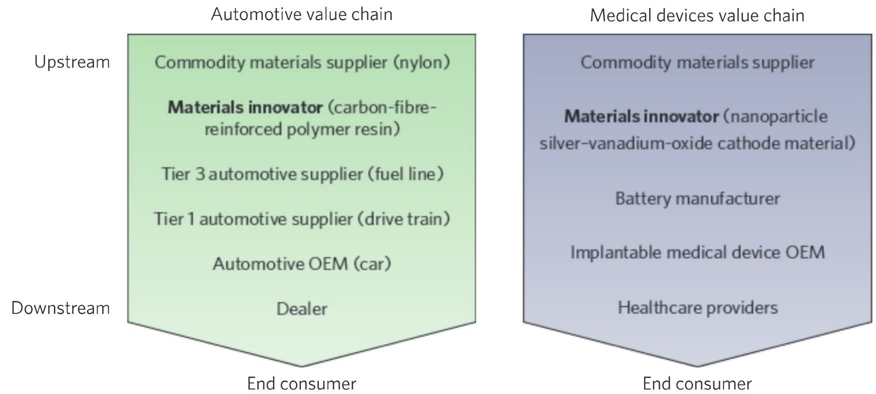

Figure 1 | Position in the value chain. In the value chains of many industries (here exemplified by the automotive and medical device industries), the materials innovator is commercializing their technology from an upstream position (further away from the end consumer), which increases market uncertainty and complicates the adoption of the technology. The original equipment manufacturer (OEM) is rarely the initiator of materials innovation.

Innovative materials accelerators. Accelerator programmes — such as those of Y Combinator in Silicon Valley — have become increasingly popular. Most accelerators, however, accept start-ups with a short commercialization phase and focus on networking, marketing and business mentoring. Cleantech and materials accelerators are a much more recent phenomenon, addressing the investment challenge of materials ventures. They accept start-ups with longer commercialization phases and generally include access to technical facilities and expertise[23]. Advanced-materials ventures can leverage such novel accelerators to mitigate technology and market uncertainty.

For example, the innovative accelerator Cyclotron Road — a joint initiative between the Lawrence Berkeley National Laboratory and the US Department of Energy — gives a cohort of scientist-entrepreneurs the chance to spend up to two years reducing the technology uncertainty of their cleantech innovation ideas, leveraging the world-class equipment and scientific expertise of the Lawrence Berkeley National Laboratory, being mentored by experienced scientist-entrepreneurs, and supported by postdoctoral funding[11,24]. And in Geleen, the Netherlands, the equipment and expertise of the chemical multinational firm DSM and of the University of Maastricht have been leveraged in the newly created Startupbootcamp for Smart Materials[25], a triple-helix model of advanced-materials commercialization[26], where cooperation between the university, industry and government strengthens the innovation ecosystem. The focus at the Startupbootcamp for Smart Materials is on mentoring scientist-entrepreneurs, and on matching them and their technologies to potential alliance partners and customers. Six months of office space, some funding and access to process equipment and scaled-up production facilities are provided[25]. Non-dilutive financing — such as through the Small Business Innovation Research (SBIR) programme[27], the Defense Advanced Research Projects Agency (DARPA; ref. 28), or the Advanced Research Projects Agency-Energy (ARPA-E; ref. 29) in the US and the Sustainable Development Technology Canada (SDTC) Tech Fund[30] in Canada — can also help advanced-materials ventures develop a prototype product, reduce technology uncertainty and become more attractive to potential partners and investors.

Matching technologies to markets. Greater priority needs to be given to early-stage, technology–market matching decisions[5,8]. At large, incumbent firms, this could be done by in-house teams engaged in viability testing through strategic market segmentation, customer interviews and subsequent market selection[13]. Because small ventures have fewer resources, experience and networks for the processes leading to such matching decisions, they could take advantage of mentorship and networking activities at advanced-materials accelerators. The president of the Massachusetts Institute of Technology (MIT), Rafael Reif, has proposed to establish 'innovation orchards' — materials accelerators that are analogous to the triple-helix model but can also include not-for-profit organizations — to help match technologies to markets and accelerate the adoption of the technologies, and to further educate scientist-entrepreneurs about commercialization strategies[7]. MIT scientist-entrepreneurs such as Robert Langer have developed strong capabilities in technology–market matching[31], and these may be able to be taught more broadly. Governments can also play a role in facilitating technology–market matching through sponsorship of networking events and through funding programmes[5,32]. Some grant programmes (such as SDTC's Tech Fund) purposefully require an industry partner that could eventually become an alliance partner or customer of the venture[30]. Ventures are more likely to create value if they prioritize an initial industry and market application with customer utility for the attributes of their technology, a favourable industry ecosystem and an alliance partner with complementary assets[2,5]. Start-up companies developing undifferentiated products or failing to match their technology to a compelling initial application face a long, tough road in the commercialization cycle. Instead, companies solving big, urgent problems for customers that are ready to pay for such solutions are essentially creating the needed market pull.

Cnano Technology — a spin-out company from Tsinghua University in Beijing — provides a good example of success linked to such market pull. With its process innovation enabling the fabrication of low-cost, high-performance multiwall carbon nanotubes, Cnano Technology was able to address the need for better and cheaper conductive additives in lithium-ion battery electrodes. Partnering with battery manufacturers and moving up the value chain with value-added paste products, the company reached multimillion dollar sales in 2011, just four years after it was founded.

Value-chain positioning. Materials technologies represent upstream innovation, and the firms that

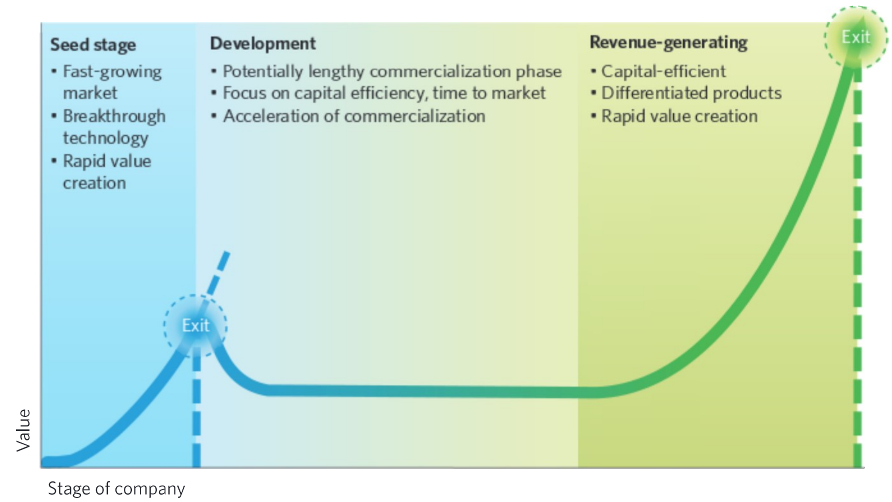

Figure 2 | Stages of venture capital investment for advanced-materials ventures. Financial investment in the seed stage allows investors to exit relatively quickly, before extensive development, or to realize the potential value of the breakthrough technology in the longer term. The development stage, involving market prioritization, manufacturing scale-up, regulatory approval and complementary innovation, can span many years, during which ventures may run out of funds. Often, the development stage of advanced-materials ventures exceeds the length of the typical venture capital investment. Once a venture reaches first-product revenues, it is poised for rapid growth and may represent an attractive investment proposition. Image courtesy of Chris Erickson, Pangaea Ventures.

commercialize them are generally far removed from the end consumer (Fig. 1). Forward integration further down the value chain in one or more industries — for example, becoming an automotive component supplier, or even an automotive manufacturer, as Tesla Motors did — is highly capital-intensive. Many chemical multinationals are resistant to forward integration (because this would make them compete with their customers) and will only consider it in the form of a joint venture. An example is Automotive Carbon Fibers, the SGL Group's joint venture with the BMW Group to design and develop structural automotive parts made of carbon-fibre-reinforced polymer.

Advanced-materials ventures may need to forward-integrate to the manufacturing of components if there is technology uncertainty in the manufacturing process for the component. An example is CDT, who abandoned their manufacturing strategy after proving to Philips that they could manufacture organic light-emitting diodes[5]; in fact, a large multinational is usually better at process scale-up than a new firm. Joint ventures of advanced-materials ventures and multinational materials suppliers that combine the breakthrough technology of the venture with the vast expertise in process scale-up of the established materials company in order to build manufacturing plants is a proven risk-mitigating factor in getting products to market. Funded joint-product development is another useful approach in reducing market adoption cycle time. Focusing on specific products identified by the funding partner helps to minimize value-chain and regulatory issues, and develops a ready market if the product is successfully developed.

To balance the cost and rewards of forward integration down the value chain, an innovating firm can forward-integrate to the so-called decoupling point[33] — the point at which knowledge can be codified, and at which technology uncertainty in the process or product is no longer a limiting factor. The firm can adopt an organizational form that allows them to attract more financing and to diversify their risk, allowing them to pursue commercialization of their invention in more than one industry value chain[10,34]. Ventures can also form various strategic alliances to establish influence along the value chain and ensure timely feedback for optimal product development. Whether in a joint venture, a technology licensing arrangement or another form of strategic alliance, these partnerships need to be strategically managed.

Making alliance partnerships work. As multinational corporations move further towards open innovation and external corporate venturing, effective alliance partnerships are of high importance to both incumbent companies and advanced-materials ventures. Licensing intellectual property (IP) is a critical part of many such partnerships[35]. Potential strategies for win–win alliance partnerships include having the venture exclusively license broad materials IP to the multinational alliance partner by field of use, geographical region or for a specific period of time. Exclusivity results in a freer exchange of knowledge and tacit know-how between the firms. Limiting the license to a specific niche or time period helps to balance the power between the venture and the multinational, and better aligns their incentives. IP strategy is critical both to valuation and to good alliance partnerships[5,36]. Lessons can be learned from the biotechnology and pharmaceutical industry, in terms of the strategic timing of partnership and corporate-venturing practices[37]. Start-ups can also benefit by securing funded product development projects with established corporations. This is a great strategy to accelerate the time to market as the product will have a ready market if successfully developed.

Recommendations

Innovation in advanced materials enables broad value creation across many sectors of the economy. Although the general adoption cycle for novel advanced materials is lengthy and uncertain, there are proven strategies to accelerate the time to market. Our observations from case studies and the collective insights gathered at an international summit on accelerating advanced materials commercialization[12] lead us to provide four recommendations that span the continuum from lab to market. First, securing access to resources in a capital-efficient manner through the use of accelerators helps to quickly validate technology readiness and usefulness. Second, on validation of the technology, it is important to match the technology to an initial target market through consideration of customer utility, industry ecosystems and potential partnerships. Third, effective value-chain positioning includes balancing potential value capture and an innovator's tacit knowledge with the high capital requirements and incumbent resistance of moving down the value chain towards the end consumer; innovative organizational structures and forward integration to the decoupling point in an industry's value chain can help in attaining this balance. And fourth, market risks can be further mitigated by targeted strategic partnerships, managed through an IP strategy that aligns incentives. Policymakers can play a role in the creation of innovation orchards and of early-stage, non-dilutive funding to support broad IP protection and prototype development. ❐

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