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HOW TO CITE:
Dikweni S, Makgabutane B, Mhlanga SD. Lab-to-market guide for commercialisation of nanomaterials: A South African university perspective. S Afr J Sci. 2023;119(1/2), Art. #14912. https://doi.org/10.17159/sajs.2023/14912

ARTICLE INCLUDES:
☐ Peer review
☒ Supplementary material

KEYWORDS:
nanomaterials, nanotechnology, nano-products, commercialisation, research innovation, technology transfer

PUBLISHED:
31 January 2023

Lab-to-market guide for commercialisation of nanomaterials: A South African university perspective

Significance:

This Perspective presents a unique guide for South African university researchers on how to successfully commercialise their research, especially nanomaterials. The commercialisation of nanomaterials has been a challenge for many researchers in South Africa because of a lack of information that can serve as a guide. The guide presented here is applicable across many disciplines of science, engineering, and technology, where nanomaterials are a subject of research and innovation. The full guide is included as supplementary material for reference.

Introduction

Nanotechnology has become an integral platform for the development of new innovations and technologies for almost all industrial sectors. As such, the commercial exploitation of nanotechnology has become the key focus in many jurisdictions with universities and research institutions leading the discovery of nanomaterials, which are the foundational building block of nanotechnology. Many countries across the globe have already seen the introduction of nanomaterial-enabled products in their marketplaces.[1] However, in many other countries, the successful commercialisation of nanomaterials and nanotechnologies has proven to be rather a difficult or an impossible task. In these jurisdictions, nanomaterial research output ends up in publications and a very small fraction has been successfully translated into nano-products.

It has become evident that successful development and commercialisation of nanoscience has been hindered by a number of barriers, such as immature manufacturing technology and infrastructure, immature markets, lack of funding, and stringent regulatory requirements.[2] Moreover, the weak link between research institutions and the industry has immensely contributed to the slow translation of research output from the lab to the market. It is worth noting that such jurisdictions are missing out on a very lucrative market with an estimated value of around around USD8.5 billion and bolstered by a compound annual growth rate of about 13%.[3] This exponential growth can be attributed to the ongoing technological advancement and the wide application areas of nanomaterials in different industrial sectors. Thus, there is an urgent need to develop practical materials to guide different institutions in the process of nanotechnology development and commercialisation.

It is therefore the intention of this Perspective piece to provide a guide for commercialising nanomaterials from a university perspective. The guide provides a two-dimensional approach which focuses on the simultaneous maturity of both the technology and business development. Having a clear grasp of overlapping development areas between technology maturity and business development makes it easy to manage the project and plan development milestones that entail concurrent validation of both technology and commercial opportunities of the nanomaterials. The guide largely focuses on the stages of nanomaterial development, the role of technology transfer offices, standards and regulations, intellectual property, funding instruments and the commercialisation options for nanomaterials.

Research and development of nanomaterials

The process of discovering and developing nanomaterials involves an integrated multi-stage process which includes research and development; manufacturing design in the lab; functionalisation and validation of nanomaterials and transitioning from the lab scale to manufacturing process; piloting and industrial manufacturing. Key to the successful development and commercialisation of nanomaterials is compliance with national and international standards of regulations, which seek to protect human and environmental health from any detrimental effects that the nanomaterials may have. Another important element is the clear understanding of the commercial value of the nanomaterials. Without clear understanding of the market needs and value proposition offered by the new materials, it becomes very difficult to realise successful commercialisation of such materials.

University research has been solely influenced by following technological trends and proving scientific principles with little to no attention paid to industry market needs. The focus has been limited to research problems and sometimes on getting a publication or making a synthesis process or making the nanomaterial 'perfect' without considering the potential end uses or industrial applications. In the process, market development has been neglected and that has significantly contributed to innovations that could not be realised in the marketplace. Universities have, however, realised the need to marry research with market and business development to speed up the process of translating research output from the lab to the market. For that, universities have since established Technology Transfer Offices (TTOs) tailored to strengthen the relationship between the universities and industry. These offices act as the bridge between university research units and industry, facilitating the management and the transfer of university intellectual property to the market. Researchers are given space to do what they are good at, which is research and development, whilst technology transfer professionals focus on identifying market opportunities for the research output. TTOs investigate commercial opportunities for innovations brought about by university researchers before a substantial amount of money can be invested in the project. This process focuses on the key market needs and challenges, competitor profiling and identifying key industry players, innovation revenue streams, market size, key market drivers and barriers to market entry.

Research and development of nanomaterials focuses on developing methods for synthesising novel materials with nanoscale dimensions, as well as their purification, functionalisation and characterisation. Functionalisation includes modifying the newly discovered and/or developed nanomaterials to possess desired properties (e.g. solubility, electrical conductivity, thermal stability).[4] Functionalisation is one of the key limiting factors towards the successful commercialisation of nanomaterials. The process enables researchers to demonstrate the competitive advantages of the newly formed nanomaterials in one or more industrial applications compared to incumbent materials.

This process is followed by validation which is an important aspect in the development and commercialisation of nanomaterials. From an investor perspective, the most valuable application data typically come from third parties who can independently vouch for the quality or value of the materials. Often, universities overlook this important step and focus solely on developing methods for manufacturing and producing nanomaterials. The validation of nanomaterial products is an institutional void in South Africa. There is therefore an opportunity for local institutions and businesses to provide this service to aspiring entrepreneurs and existing businesses wanting to adopt the use of nanomaterials at a commercial scale.

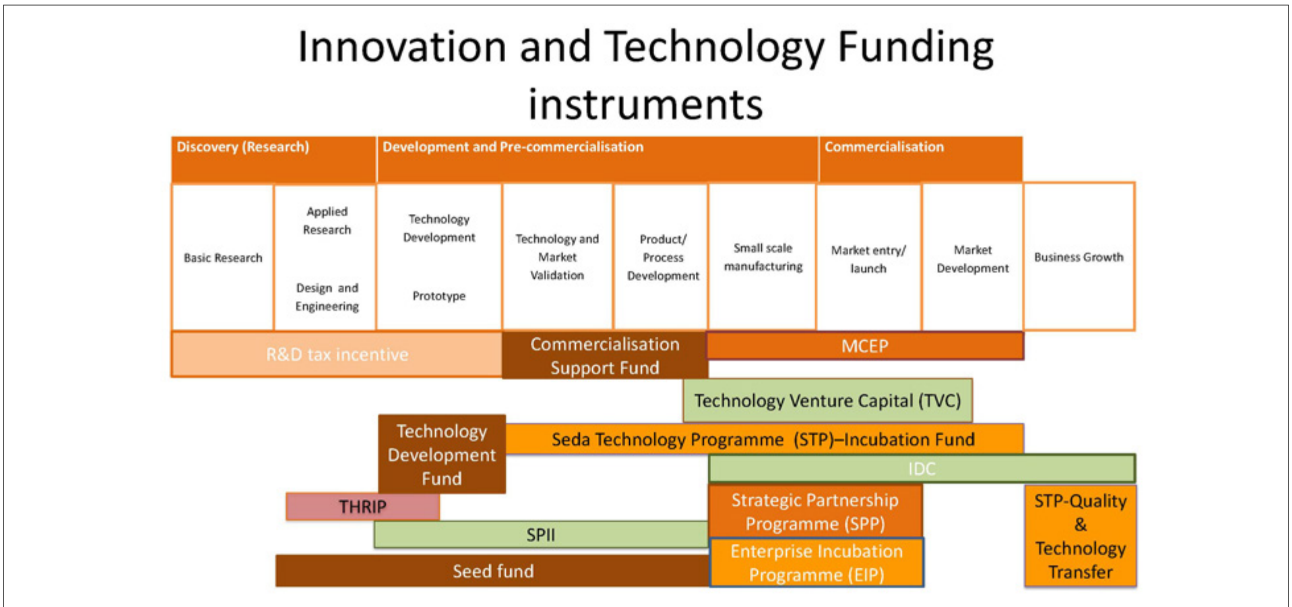
As the research transitions from concept to lab scale, researchers need to demonstrate that the identified and/or discovered nanomaterials are manufacturable in a timely and cost-effective manner. In cases of process innovation, researchers need to show and prove the competence of their innovations over existing methods. Therefore, the focus should be on proving the concept, i.e. to demonstrate the feasibility of the newly developed technique or process innovation in real-world applications. In the process, special attention is given to parameters for the manufacturing environment as well as the whole manufacturing value chain for nanomaterials. The value chain refers to a set of activities, processes and raw materials, suppliers, key resources and equipment required to get the product ready. Once the parameters for manufacturing have been determined, and the concept has been proven in the lab, the project can transition into small-scale manufacturing (piloting) and production of market samples. Whilst the researchers are busy with proof-of-concept, university TTOs would focus on the novelty aspects of the nanomaterials (IP), monetisation, identifying different revenue streams and assisting in taking the research from the lab to the market. To this effect, university TTOs provide support by facilitating IP protection; fundraising for technology development, assisting in project planning and management; identifying market opportunities and promoting the university developed nanomaterials to the industry and/or the market.

With the fast-growing and increasing interest in the use of nanomaterials and/or nanotechnologies for research and industrial purposes, it is essential to prioritise the minimisation of the risks (known and unknown) associated with the use of nanomaterials, in terms of the health, safety and environmental hazards that they may pose. As such, the handling, use and disposal of nanomaterials in places of work, including research laboratories and industrial enterprises, need to be safeguarded and effectively regulated. As part of the safeguarding and regulation of the use of nanomaterials and nanotechnologies, the Responsible Nano Code was established amongst several other standards, wherein guidance is provided on what organisations can do to demonstrate responsible governance on the production, research, and disposal of materials containing nanomaterials.[5,6] The code was designed to be adopted by organisations of all sizes, and in all countries under any regulatory regime. Moreover, it is founded on seven principles that are core to the responsible development of nanomaterials and nanotechnologies: (1) board accountability, (2) stakeholder involvement, (3) worker health and safety, (4) public health, safety and environmental risks, (5) wider social, environmental, health and ethical implications and impacts, (6) engagement with business partners, and (7) transparency and disclosure.

Every nanomaterial produced for sale must be accompanied by a materials safety data sheet (an MSDS) that must be provided by the manufacturer at any given time. MSDSs are important to manufacturers and those they supply to ensure that workplaces are safe and to protect the environment. More specifically, a MSDS contains information that enables a risk assessment as required by regulation. Researchers developing nanomaterials can partner with institutions such as the National Institute of Occupational Health (NIOH) in South Africa and various universities that conduct research on toxicity and exposure of nanomaterials.

Funding opportunities

Funding is a critical component for the successful commercialisation of nanomaterials. The South African government has a wide range of institutions that provide funding for business ventures that can make a difference to the country's economy. The funding can be in the form of innovation (product development), seed, or loan funding. The type of funding that one can secure is also determined by the maturity of a technology or product. Funders typically use a method of Technology Readiness Levels which help in understanding the maturity of a technology during its acquisition phase. A technology or product such as a nanoproduct or nanotechnology will undergo different phases including early stages of its discovery (research phase), its validation (development phase), and, finally, its full-scale commercialisation (deployment phase). Products and technologies at the lower spectrum of the Technology Readiness Levels will most likely secure innovation



Source: South African Department of Trade, Industry and Competition[7]

Figure 1: Innovation and technology funding instruments.

and/or seed funding, whereas those that are highly mature can secure loans and venture capital funding. Figure 1 depicts a funding instrument that can be accessed by nanomaterial producers based on the stage of development. The figure has been sourced from the South African Department of Trade, Industry and Competition's website.[7]

Commercialisation options

Commercial adoption of nanomaterials is accelerated by having a clear understanding of the characteristics of the nanomaterials produced as well as their correlation to application areas in different sectors. Having a clear understanding of the application areas of nanomaterials and their ability to improve the competitiveness of the customer's products in the market is of utmost importance. For example, the produced nanomaterial may be both lightweight and conductive, making it suitable for conductive composites, electromagnetic shielding, thermal management, thermal detectors, and optical devices. But who needs lightweight and conductive materials and for what? That is the question university researchers must continuously ask themselves throughout the development of these materials. Answers can only be obtained by working in close collaboration with industry players as they know which materials would enhance their nano-based products and thus their competitiveness in the marketplace. Nanomaterials are an ocean that you cannot finish by swimming. Researchers need to concentrate on a specific topic or topics in the nanomaterial/s of interest and make a risk assessment for the commercialisation of that specific technology or product. The target customer segments need to be identified with their risks, opportunities and threats. Lack of attempts to understand market behaviour drives sellers to produce goods that do not fit market needs, which creates a disequilibrium in the supply demand function.

There are different commercialisation strategies that can be employed to take the product to the market. Deciding on which commercialisation strategy is influenced by several factors, such as the strength of the technology, market opportunity, and resource availability. Often universities license their intellectual property to well-established companies on an exclusive or non-exclusive basis. Alternatively, universities establish spin-off companies and take equity or assign the intellectual property to the new company or an outside company. There are also opportunities for collaborative arrangements with larger materials companies that would want to supplement their portfolios. The guide provides a brief description of the key commercialisation strategies.

After the decision has been taken to establish a spin-off company as a purpose vehicle to get to the market, the team must determine their business model. There are two models to consider in the process of commercialising nanomaterials. Researchers follow either the business to business (B2B) model or the business to consumer (B2C) model. The B2B model would imply that the university spin-off produces nanomaterials and distributes to different stakeholders for different applications and is not involved in the production of nano-based consumer products. For example, producing carbon nanotubes and selling them to an electronics company where they will produce nano-based electronic devices. The B2B model is easy to manage for a university spin-off company as there are fewer barriers in the marketplace compared to a B2C model. The B2C model is characterised by high infrastructure costs and barriers to market entry. It requires a strong market brand and reputation, which may present challenges for a newly established university spin-off. It is therefore common for a nanotechnology business to sail towards B2B; however, this must be controlled and fed by a substantial amount of B2C sales.

A few examples of nanomaterial-based university spin-off companies can be mentioned. These companies have been established based on new methods for cost-effective manufacturing nanomaterials. Oxford University has established a spin-off company based on a patented process for manufacturing carbon materials. The company, Designer Carbon Materials, uses their method and/or process to cost-effectively produce commercially useful quantities of the spherical carbon cage structures known as fullerenes or buckyballs. Investment in the company has been led by Oxford Technology and the Oxford Invention Fund. According to their website, Designer Carbon Materials Ltd is developing advanced nanomaterials for a range of applications, including energy harvesting, bio-sensing and quantum nanoelectronics.

NANOGRAFI Co. Inc. was established in 2011 as a nanotechnology start-up to produce critical nanomaterials such as carbon nanotubes and graphene and to create a market for these materials. After the successful production of various types of carbon nanotubes, they began to study the applications of different nanomaterials including nanotubes, metal oxides, carbides, and cellulose nanoparticles. It is worth noting that the value creation for nanomaterial companies is not solely based on the production of novel materials; they further develop new applications for nanomaterials to be sustainable. For example, General Nano LLC, a nanotechnology company formed by University of Cincinnati scientists, is working to transition its carbon nanotube sheet product to commercial scale. This material is both lightweight and conductive, making it ideal for conductive composites, electromagnetic shielding, thermal management, thermal detectors, and optical devices. These attributes can lead to enhanced performance of next-generation air vehicles. In South Africa, a private start-up company has commercialised nanomaterials like carbon nanotubes and related nanoproducts for industrial applications such as fertiliser production.

Conclusion

The success of nanoscience and nanotechnology innovation/research commercialisation requires collaborative efforts from all relevant stakeholders. The full guide (available as a supplementary file to this Perspective) provides an indication of the expertise and support that is required from both the public and private sector to drive commercialisation. Moreover, the way research is conducted needs to change; research should be tailored to serve the needs of the industry if the aim is towards the application of nanomaterials in commercial products. The establishment of successful start-up companies providing nanotechnology solutions to South Africa's grand challenges is an important success measure for the National Nanotechnology Strategy. It is also a key component for economic growth and global competitiveness.

Competing interests

We have no competing interests to declare.

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