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Guide to commercialisation of research for South African university researchers

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Introduction

Nanotechnology has become the centre and the platform for development of new innovations and technologies for almost all industrial sectors. It has enabled the development of new products with unique properties and advanced functionalities consuming fewer raw materials and less energy. Many countries across the globe have already seen the introduction of nanomaterial-enabled products in their marketplaces.[1]

South Africa was among the first countries in the southern hemisphere to recognise nanotechnology (with nanomaterials being the bedrock of nanotechnology) as a key industrial sector towards realising sustainable economic growth and social development. The establishment of the South African Nanotechnology Initiative (SANi) in 2002 and the subsequent publication of the National Nanotechnology Strategy in 2005 by the Department of Science and Innovation (DSI) was an important milestone in South Africa's quest to use nanotechnology to address a wide range of social and economic challenges in the country.[2] Areas where South Africa can fully exploit the potential of nanotechnology include water, energy, health, chemical and bioprocessing, mining and minerals, and advanced materials. For example, nanomaterials can address the challenges of energy-efficient water purification such as removal of organic, inorganic and biological pollutants from contaminated water, including industrial waste.[3] Due to their unique properties, nanomaterials are central to improved energy conversion, storage and transmission.[4] Exploitation of nanomaterials would imply the translation of South Africa's research outputs into nano-products, and that would enhance the country's competitiveness in the marketplace. However, a lot of nanomaterials research output ends up in publications and a very small fraction has been successfully translated into nano-products.

Successful development and commercialisation of nanoscience has been hindered by a number of barriers such as immature manufacturing technology and infrastructure, immature market, lack of funding, and stringent regulatory requirements.[5] 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. The low percentage of collaborations amongst different stakeholders (e.g. between research institutions and manufacturing industries) along the nanotechnology value chain has led to research outputs that lack industrial applicability. The lack of commercial objectives in developing nanomaterials often results to nanomaterials that are not commercially viable from a cost point of view, which largely appeal to a small group of innovators and early adopters (customers) and not too early and late majority customers as described in Moore's technology adoption life cycle.[6] Therefore, the successful development and commercialisation of nanomaterials calls for conceited efforts and collaborations between public and private sectors, inventors and investors, and universities and industry to assess viability of the product in the marketplace. Generally, businesses will consider materials that will make them profitable by working towards the success of their business goals and product vision. Businesses are always looking for materials that will enhance their product's competitiveness in the marketplace.

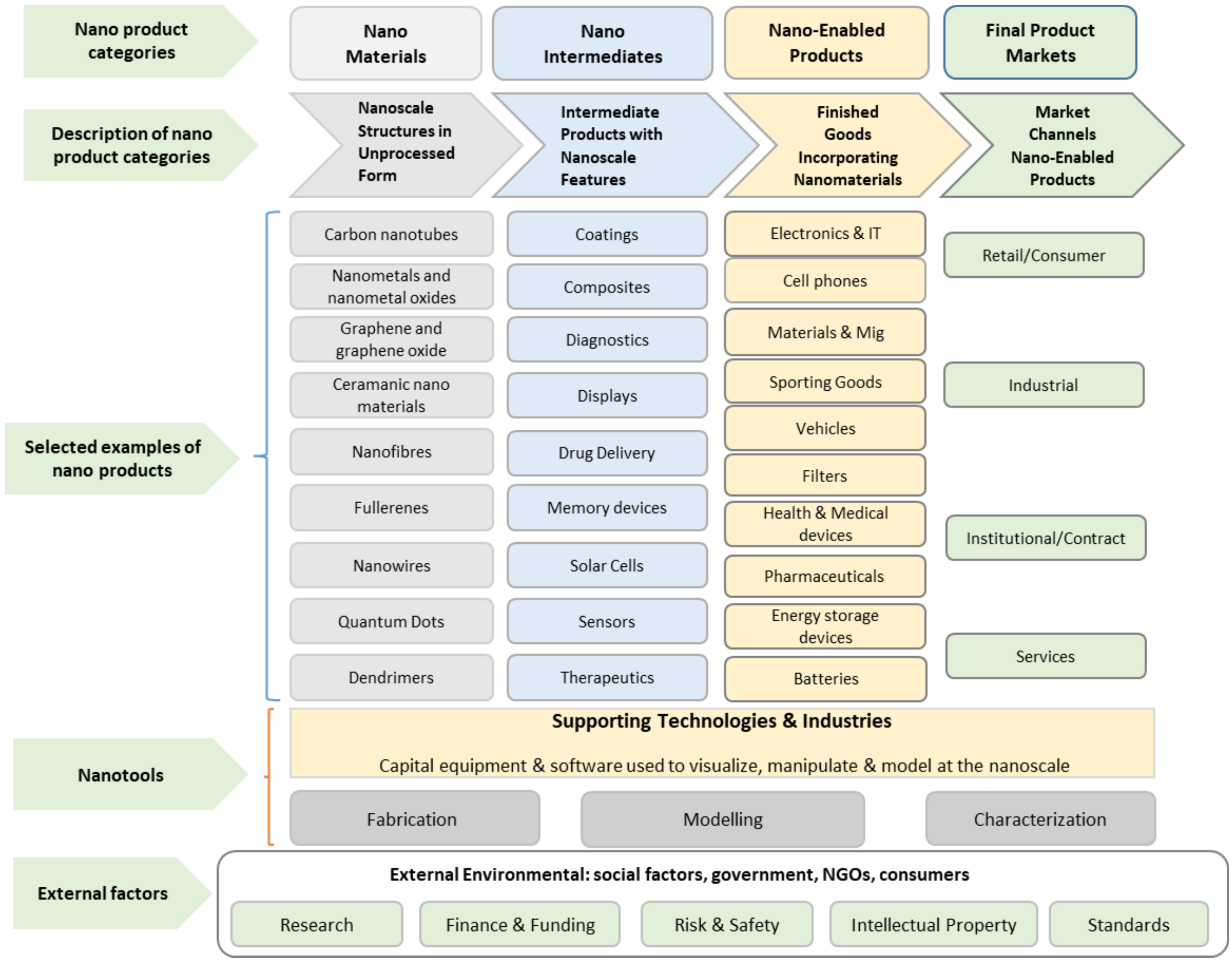
It is therefore the intention of this document to provide a guide for commercialising nanomaterials from a university perspective. The guide provides a two-dimensional approach which focuses on the simultaneous maturity of both the technology and business development. Having a clear grasp of overlapping 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 therefore largely focuses on stages of nanomaterials development and commercialisation, role of technology transfer offices, standards and regulations, intellectual property, funding instruments, commercialisation options and the role of nanotechnology innovation centres. The guide encompasses the commercialisation of raw nanomaterials such as carbon nanotubes, graphene, titanium dioxide, silicon dioxide, calcium oxide, and nanocellulose, and not necessarily nano-devices and technologies derived from nanomaterials.

An overview of nanomaterials and their important role in developing new products and technologies

Nanomaterials are, in most cases, synthetic forms of already known materials that can be found in the periodic table of elements. The difference between nanomaterials and their natural (bulk) counterparts is that they possess different and unique physicochemical properties (e.g. high surface area, quantum effect, electronic, optical, chemical reactivity, etc) than the same materials in bulk form.[7] The nanomaterials behave differently because of their nanoscale sizes; typically, with at least one dimension of the nanomaterial measuring less than 100 nanometres.[8] Depending on their application, nanomaterials can be developed and used as final products or as raw materials to develop other technologies (nanotechnologies). The global nanomaterials market size was valued to be around USD8.5 billion in 2019 and was expected to grow at a compound annual growth rate (CAGR) of 13.1% from 2020 to 2025.[9] This exponential growth can be attributed to the ongoing technological advancement and the wide application areas of nanomaterials in different industrial sectors.

Nanomaterials are applicable in almost any manufacturing industry including food, biotechnology, health, energy, electronics, transportation, mining, water treatment, building and construction, mining, etc. For example, there has been a growing adoption of nanomaterials in the aerospace sector with a key focus in improving the strength and durability of aircraft part.[10] There is an increasing consumption of nanoparticles in batteries, fuel cells, and photovoltaic film coatings. These are the few of the examples that demonstrate the increasing demand for nanomaterials in different industries. The ability to make nanomaterials with desired properties therefore makes it possible for researchers to develop innovative solutions or products and technologies with commercial value. For example, nanomaterials of carbon, copper, gold, silver, titanium, calcium, iron, zinc, sulfur, gallium, silicon, and many others have been developed by many researchers based at South African universities and research councils, but most remain as products of research documented in research papers and theses. Very few have reached the marketplace or have been translated into innovative products. For example, SabiNano (Pty) Ltd[11], a nanotechnology company, is among the few companies that were able to commercialise academic research. Supplementary figure 1 below demonstrates the importance of nanomaterials in nanotechnology. It is at the base of the nanotechnology value chain demonstrating its role in the development and advancement of many industries.

This guide seeks to make it easy for the entrepreneurial researcher to get their nanomaterials into the market for the benefit of themselves and the society at large. 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.



Source: Modified from S. Frederick, A Value Chain Approach to Understanding the Impact of Nanotechnology, Poster presentation for the Center for Nanotechnology in Society (CNS) Research Summit and NSF Site Visit, July 5, 2009

Supplementary figure 1: Nanomaterials are a fundamental base for a nanotechnology value chain.

Stages of nanomaterials development and commercialisation

The process of discovering and developing nanomaterials involves an integrated multi-stage process which includes: research and development; nanomaterials 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 speaks to human and environmental health from any detrimental effects that the nanomaterials may possess.

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).[12] Functionalisation is one of the key limiting factors towards the successful commercialisation of nanomaterials. Most of South African research in this front has focused on the synthesis and characterisation of nanomaterials and very little attention has been given to functionalisation. Researchers often neglect the importance of functionalisation to prove the competing abilities of the materials they produce. It is therefore advisable for research institutions to provide competitive advantages in one or more application areas compared to incumbent materials in the market before seriously pursuing scale up, private capital, etc.

Validation of nanomaterials refers to the process of testing and confirming the theoretical assumptions of the nanomaterials in a real-world environment. This is an important aspect in product development and commercialisation. From an investor perspective, the most valuable application data typically comes 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. Supplementary table 1 provides a picture of what is entailed in the innovation value chain for nanomaterials.

Basic research and development

Nanotechnology research and development involves the discovery, synthesis, characterisation and functionalisation of novel nanomaterials or development and improvement of manufacturing methods of nanomaterials. 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 the nanomaterial 'perfect' and not the potential end uses or industrial applications. This is often the classical approach of many researchers i.e. one that creates a very innovative solution but with no problem for it to solve or less knowledge about customer needs and requirements.

It is advisable for researchers to pay close attention to the real market needs and industrial application areas of their research output beyond academia. Therefore, the research questions must not only focus on the scientific problems but further look at the industrial challenges and the immediate needs of end users. Having a clear understanding of the industry challenges and future needs makes it is easy to streamline and direct the research focus on the most pressing needs of the industry and thus increased chances for industrial collaboration and adoption of researchers' innovations. The nanomaterials developed at this stage do not need to be perfect to have commercial value. A nanomaterial of lesser quality can be applicable in one industry but not another. For example, in the building and construction industry, the strength or surface area of a desired nanomaterial may be more important than its purity level, whereas the purity of a nanomaterial used in a health drug or product may be of paramount importance. Therefore, it is important to understand the need of the industry or market at an early stage of development. Understanding the market will enable the researcher to produce market ready products and research market relevant aspects - this drives commercialisation.

Supplementary table 1: An overview of the innovation value chain for nanomaterials: discovery to commercialisation

Discovery			Development and pre-commercialisation				Commercialisation		
Basic research	Applied research	Experimental proof of concept	Lab demonstration	Lab validation (early prototyping)	Demonstration in relevant environment	Piloting and/or demonstration in the operational environment	System completed and qualified	System proven and operational	
		Demonstrate the feasibility of the newly developed technique or process innovation.		Transitioning from the lab-scale manufacturing process into pilot (small) scale development system.		Small-scale manufacturing.	Full-scale nanomaterial production. Competitive manufacturing process in full scale operation.		
		Nanomaterials are produced in a timely and cost-effective manner.		Design quality control and assurance parameters.			Nanomaterial/s		
				Identifying and mapping operating zones for nanomaterials, process conditions, and inputs.			Quality control		
			Manufacturing process - synthesis for improved quality and quantity.						
		Determining and validating chemical and physical properties (purity level, particle size distribution, shape/morphology; crystallinity and assemble structure of the nanomaterials). Consideration for intellectual property (IP) assessment and registration.							
	Market viability assessment		Market testing and validation			Market entry and launch		Business development	
TRL 1	TRL 2	TRL 3	TRL 4	TRL 5	TRL 6	TRL 7	TRL 8	TRL 9	TRL 10

Researchers may seek assistance from their technology transfer offices (TTOs) with regards to basic market analysis. Commercial viability assessment seeks to investigate whether there are commercial opportunities or not before substantial amount of money is 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. The goal is to ascertain that innovation solves a real market problem and that the proposed solution outcompetes its counterparts. Basic market viability assessment would assist in determining the key market players and potential validation partners. It is important to start contacting and engaging validation partners during the early stages of development. Working with end-users assist in developing a product that best meet their needs and can determine areas that requires change and/or attention. In cases of nanomaterials, one of the key important requirements is determining the competing properties of the materials over existing ones as well as their application areas. This determines whether the nanomaterial is a viable 'product' that can be sold to someone for profit or not. Market viability assessment can be used as the key decision-making tool in deciding whether to spend resources and time in the project or not.

The interaction between scientists with different disciplines will undoubtedly lead to the production of novel nanomaterials with tailored properties. The success of nanomanufacturing depends on the strong cooperation between academia and industry to be informed about current needs and future challenges, to design products directly transferred into the industrial sector.

Nanomaterial manufacturing in the lab

At this stage, basic research has shown promising results and industrial applications of the materials have been identified or are known. Technologies show great potential but with little established commercialisation pathways and this would be the perfect time to start deliberating on commercial opportunities for the technology under development. The principal investigators are required to ensure 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. The production methods must show that they outperform existing methods in terms of scale, time and cost of production. 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. The purpose is to demonstrate that a product concept (product prototype) is both functional and can be developed in the real world.

In the process, special attention is given to parameters for 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. The manufacturing process should be designed, areas of collaboration, skills and capabilities required must be identified. Potential areas of risk and issues that might need to be solved upfront need to be identified. Special attention must be paid to the manufacturing process and potential areas of change in the process must also be identified.

Transitioning from the lab to pilot manufacturing process

Transitioning from the lab scale manufacturing process into pilot (small) scale development system requires special attention and significant amount of financial investment. This process includes optimising the manufacturing process of nanomaterials with the goal of improving the quantity, quality, precision and reducing time and cost of production. During the process, quality control and assurance parameters are designed, to ensure a smooth transition from the lab to the pilot scale. Careful attention is given to the manufacturing process, identifying and mapping operating zones for materials, process conditions, inputs, raw materials, etc. At this stage it is advisable to engage and involve engineers and key industry players and work on iterative product development to ensure that the product meets the customer's needs.

The goal is to produce the nanomaterial samples and distribute to customer representatives for validation. Validation partners assist in investigating and confirming the chemical and physical properties of nanomaterials produced such as purity level, particle size distribution, shape/morphology; crystallinity and assemble structure of the nanomaterials. The information obtained from validation partners should be used to customise the production process to improve the quality and precision of the produced nanomaterials. Based on the customer feedback, the iteration process would take place, otherwise the manufacturing process proceeds towards industrial manufacturing scale. Researchers are advised to also produce materials safety data sheet (MSDS) documentation for the nanomaterials under development.

Role of technology transfer offices

The goal of TTOs at public institutions is to translate research innovations such as new nanomaterials produced by researchers into commercially viable products. In this case the focus would be on the novelty aspects of the nanomaterials (IP), monetisation of nanomaterials, 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; fund-raising for technology development, assisting in project planning and management; identifying market opportunities and promoting the university developed technologies to the industry and/or the market.

Following the disclosure of the invention, TTOs will assist in conducting novelty, and prior art searches to determine the uniqueness of the innovation over competing and/or existing methods of producing nanomaterials in the case of new nanomaterials. This also assist in determining if there is any scope of IP protection for the proposed nanomaterials manufacturing process or not. TTOs provide funding for protecting intellectual property emanating from university research and development activities, and also drive the process of filing for IP protection. IP protection plays a key role in the process of commercialisation. It fosters innovation and competitiveness as it provides monopoly over the use of such IP rights. It enables owners to stop and/or prohibit others from using, making, selling or importing it without their consent. It gives owners time to fully exploit and reap their returns on investment over the development of such IP. Intellectual property protection may form essential part of marketing or branding.

Different IP management strategies may be employed based on the nature of the new nanomaterials manufacturing process, market opportunities as well as the route to market strategy. Some researchers may decide to keep their process innovation as know-how or trade secrets, whilst others may opt for filing patent applications. Protection of intellectual property is very necessary in today's business landscape but deciding on which IP strategy to devise is equally important. It is accompanied by a comprehensive knowledge of how such IP will be devised towards the successful commercialisation of the newly developed technology. Moreover, a careful and calculated consideration to the timing of your filing for IP protection is even more important. Often, universities file too early, and this may be attributed to the pressure for researchers to publish. It is advisable to ensure that your process innovation has been optimised and all the operating parameters has been identified or wait until the process innovation has been fully developed, tested and proven to be able to produce the nanomaterials in a real-world environment.

In addition to the above, TTOs can assist with Technology Economic Evaluation (TEA) to assess the economic viability of new products, service or process developments. This process is often outsourced due to skills shortages in South African technology transfer offices. This is a process in which the market size and input cost of production information are combined in order to determine and forecast future cash flows and thus return on investment. This process takes account of the whole value chain for the innovation at hand. Understanding all the key activities, primary and secondary key inputs that work towards the success of the product is of paramount importance.

Together with the principal investigators, TTOs work on gathering all the necessary information in order to fast track the process of TEA. The most relevant information that is required for TEA to proceed includes but not limited to the product and/or process and the market it seeks to serve; understanding and identifying the route to market strategy; investigating the availability and supply of raw materials; operating costs (direct and indirect cost); as well as the capital required for the pilot plant. Investigating the raw materials looks at the cost of procuring the materials; delivery and timelines, including any shipping and/or custom requirements if there is any and most importantly the purity of the raw materials and the process of purifying them if need be.

After investigating the raw materials and input, the manufacturing process must be investigated. This exercise serves to answer questions such as: Is the manufacturing process optimised and can it support industrial manufacturing? Is there expertise that will be required externally? What are the operating costs? What does the process safety look like? What labour is required, shifts required, opportunities for automation, etc. All the technical risks that may arise are identified and rated. The risks may exist in relation to cost, quality control and tolerance of the nanotechnology in the manufacturing, including occupational and environmental health and safety considerations. This process is one of the key decision-making criteria for transitioning from pilot-scale manufacturing to industrial manufacturing.

In some South African universities, independent companies owned by the university exist to ensure successful commercialisation of their innovations and this can be effective in commercialisation of nanomaterials and nanotechnologies. One example is the University of Johannesburg's UJInvnt (https://www.ujinvnt.com/) which is an IP holding company for subsidiary and spin-off companies of UJ. Its activities involve the acquisition, exploitation, licensing or sublicensing of innovative technologies emanating from UJ's research activities. Other examples are the University of the Witwatersrand's Wits Enterprise (https://wits-enterprise.co.za/), Nelson Mandela University's Innovolve (http://innovolve.co.za/) and Stellenbosch University's Innovus (https://www.innovus.co.za/), to name a few.

Standards and regulations

With the fast-growing and increasing interest globally, on 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 health, safety and environment hazards that they may pose. As such, the handling, use and disposal of nanomaterials in places of work including research laboratories and industrial enterprises needs to be safeguarded and effectively regulated.

As part of the safeguarding and regulation of nanomaterials and nanotechnologies usage, guidelines have been established amongst several others standards, wherein guidance on what organisations can do to demonstrate responsible governance on the production, research, disposal of materials containing nanomaterials is given.[13,14] The responsible nano code was designed to be adopted by organisations of all sizes, in all countries under any regulatory regime. Moreover, it is founded on seven principles that are core to the responsible development nanomaterials and nanotechnologies, which include 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) engaging with business partners, 7) transparency and disclosure (Supplementary table 2).

Supplementary table 2: The seven principles of the responsible nano code[14]

Principle number	Principle name	Principle description
1	Board accountability	Each organisation shall ensure that accountability for guiding and managing its involvement with nanotechnologies resides with the board or is delegated to an appropriate senior executive or committee.
2	Stakeholder involvement	Each organisation shall identify its nanotechnology stakeholders, proactively engage with them and be responsive to their views.
3	Worker health and safety	Each organisation shall ensure high standards of occupational health and safety for its workers handling nanomaterials and nano-enabled products.
4	Public health, safety and environment	Each organisation shall carry out thorough risk assessment and minimise any potential public health, safety or environmental risks relating to its products using nanotechnologies. It shall also consider the public health, safety and environmental risks throughout the product life cycle.
5	Wider social, environmental, health and ethical implications and impacts	Each organisation shall consider and contribute to addressing the wider social, environmental, health and ethical implications and impacts of their involvement with nanotechnologies.
6	Engaging with business partners	Each organisation shall engage proactively, openly and co-operatively with business partners to encourage and stimulate their adoption of the Code.
7	Transparency and disclosure	Each organisation shall be transparent about its involvement with and management of nanotechnologies and report regularly and clearly on how it implements the Responsible Nano Code.

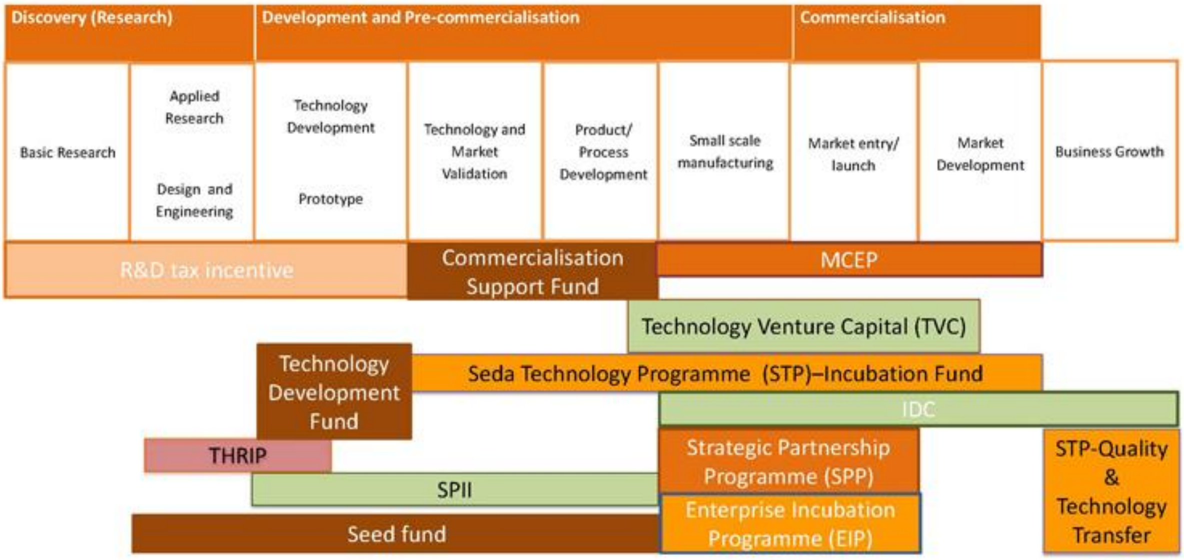
In South Africa, it is recommended that anyone working/doing research with this product or nanomaterials in general should adhere to the Nanosciences and Nanotechnologies Code of Conduct, which is an integral part of the implementation of the National Nanotechnology Strategy. It is recommended that any person handling or working with nanomaterials should apply appropriate standards such as the ASTM E2535-07(2018) Standard Guide for Handling Unbound Engineered Nanoscale Particles in Occupational Settings.[15]

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 in helping you, or anyone you supply, to make the workplace safe and to protect the environment. More specifically, a MSDS contains information to help you make 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

Funding is a critical component for the successful commercialisation of nanomaterials. The South African government has a wide range of funding institutions that are focused on providing 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

(TRLs) which helps in understanding the maturity of a technology during its acquisition phase. A technology or product such as a nanoproducts or technologies 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 TRLs will most likely secure innovation and/or seed type of funding whereas those that are highly mature can secure loans and venture capital funding. Supplementary figure 2 depicts 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 (DTIC).[16]



MCEP = Manufacturing Competitiveness Enhancement Programme; THRIP = Technology and Human Resources for Industry Programme; Seda = Small Enterprise Development Agency

Supplementary figure 2: Innovation and technology funding instruments by the Department of Trade, Industry and Competition (DTIC), South Africa.[16]

In the case of South African university researchers, basic research is usually funded by the National Research Foundation. Proof of concept and prototyping can be funded by TIA's Seed funding and/or other international funding donors. Technology Development and Commercialization Support Fund Development Funding can be leveraged for developments that are past the proof-of-concept stage. The purpose of Technology Development Fund is to advance developments from proof of concept to product prototyping and demonstration thereof in an operating environment. Furthermore, Pre-Commercialisation funding can be leveraged for market validation and testing. Large companies have also been active in helping commercialise nanotechnology products, including by funding academic research and by collaborating with universities and/or small companies. Supplementary table 3 presents a list of relevant government funding entities and the type of funding they provide to start-ups and established businesses.

To secure funding for a nanomaterials/nanotech startup, the funder or investor will consider several key factors that would normally be presented in the form of a business plan. The inventor or entrepreneur should perform a due diligence on several elements of the business plan that can impact the success of a funding application such as those given in Supplementary figure 3. This will assist the funder to measure the business and market readiness level of the company.

Supplementary table 3: South African government entities that provide funding to businesses producing nanomaterials and nanotechnologies

Government funding entity	Type of funding offered	Website link
Department of Trade, Industry and Competition (DTIC)	Incentive/grant funding, e.g. for development of innovative products and/or processes	http://www.thedtic.gov.za/
Industrial Development Corporation (IDC)	Development funding in the form of a loan or equity	https://www.idc.co.za/
Technology Innovation Agency (TIA)	Seed funding, technology development funding and pre-commercialisation support funding	https://www.tia.org.za/
Small Enterprise Finance Agency (SEFA)	Business loans	http://www.sefa.org.za/
National Empowerment Fund (NEF)	Business loans and equity	https://www.nefcorp.co.za/
The Small Enterprise Development Agency (SEDA)	Grant funding	http://www.seda.org.za/

Supplementary figure 3: Key elements for a successful business plan.

Commercialisation options

Commercial adoption of nanomaterials will be 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 customer's products competitiveness in the market is of utmost importance. For example, the produced nanomaterials 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. You need to concentrate on a specific topic or topics in nanomaterial 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 behavior drives sellers to produce goods that are not fitting the 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 a number of factors such as the strength of the technology; market opportunity; resource availability; etc. Often times 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. We provide a brief description of the key commercialisation strategies that can be used to commercialise nanomaterials from a university perspective.

Licensing option

Licensing can be defined as a process of leasing out the intellectual property to the second party in return for money usually in royalty payments. Licensing can be on an exclusive or a non-exclusive basis. An exclusive licence is an option in which the IP is licensed to one party for a certain period. This can be limited to a certain industry, or a region and/or countries. A non-exclusive licence is an agreement in which different companies have access to the IP over a certain period. In the case of nanomaterials, the process and method of manufacturing and synthesising the novel nanomaterials can be licensed to an existing company on an exclusive or non-exclusive basis depending on the needs of the company. More often than not, process innovations are licensed on an exclusive basis. Exclusivity may be limited to a specific industry, application, or country.

IP Assignment

An IP assignment is an option on which IP is assigned to an existing company or a new company in exchange for money. This includes a single payment when parties sign the contract of transferring the ownership of intellectual property to the other party. Sometimes, milestone payments are negotiated based on the stage of technology development. This option takes control of this IP over the IP owners and/or creators.

Spin-off Creation

Spin-off creation is the establishment of a new company for the very purpose of taking the nanomaterials to the market. Researchers may be interested in establishing their own company. This is however, highly dependent on the capacity, resource availability and most importantly the strength of intellectual property and market entry requirements. Formation of a new venture creation may be capital intensive which may not be readily available at the institution and that would call for fund raising. The success to raise funds for the new venture creation is highly dependent on the robustness of the innovation, the market conditions which would include but not limited to competition, barriers to entry, market size and growth projections, customer requirements, etc.

After the decision has been taken to establish spin-off company as a purpose vehicle to get to the market, the team must determine their business model. There are two models that one has to consider in the process of commercialising nanomaterials. It's either the researchers follow 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 distribute 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 to electronics company where they will produce nano-based electronic devices. Business to Business (B2B) model is easy to manage for a university spin-off company as there are not a lot of barriers in the marketplace compared to B2C model. The B2C model is characterised by high infrastructure costs and barriers to market entry. It requires a strong market brand and reputation and that may present challenges for a newly established university spin-off. For that, it is 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 manufacturing process of 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 bucky-balls. 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 in order to produce critical nanomaterials such as carbon nanotubes (CNT) and Graphene and create a market on these materials. After the successful production of various types of CNTs, they began to study on the applications of different nanomaterials including nanotubes, metal oxides, carbides, clay 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 in order 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 the spin-off creation model, the IP is owned by the funder (university) and the inventor (researchers). The commercial benefits are shared between them. In other instances, other shareholders such as investors to the spin-off company may have a share of the commercial benefits.

Nanotechnology Innovation Centres

In 2007 the Department of Science and Innovation established two national nanotechnology innovation centres (NICs) at the CSIR and Mintek. While the NICs have their own research projects involving the research and development of various nanomaterials for various applications, they have a wide range of state-of-the-art facilities including nanomaterials characterisation instruments that are accessible to the public at a cost. Inventors can partner with these organisations in characterising or validating their nanomaterials or nano-enhanced products. The NIC at Mintek has clean room facilities that can be used to manufacture nanoproducts that are sensitive to environmental conditions. The NIC at the CSIR has a Nanomaterial Industrial Development Programme (NIDP) that focuses on the development of new and advanced materials through the incorporation of nanomaterials. The main objectives of the NIDP are to establish infrastructure and skills in polymer nanocomposites as well as nanoclay development, to stimulate the growth of the polymer industry and to create a nanostructure production industry. The NICs are all located in Gauteng and there is an opportunity for businesses to setup private centers that could provide characterization services in other provinces.

Conclusion

The success of nanoscience and nanotechnology innovation/research commercialisation needs collaborative efforts from all relevant stakeholders. The guide 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 and 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.

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