Science Scope

PUBLICATION OF THE CSIR
VOLUME 16 | NUMBER 1 OF 2020

science & innovation
Department:
Science and Innovation
REPUBLIC OF SOUTH AFRICA

CSIR
our future through science

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FOREWORD

IT MATTERS

The mandate of the CSIR ties us to work that truly matters. We are about supporting industrial development and competitiveness in the country, as well as the creation of a capable state. Simply put, we touch people's lives through innovation.

The people who choose to work at the CSIR are people who know why what we do matters and are motivated to make a difference. CSIR employees understand the importance of what we do for industries, communities and the country, and how their respective contributions fit into the bigger picture. In this edition of *ScienceScope,* you will read about CSIR researchers who are passionate about making open-pit mining safer, reducing toxicity when producing high-precision metal parts, providing energy solutions for communities that have no access to the national grid and many other impactful innovations.

What we do matters to both industry and the broader society. Our laser engineers have used laser technology to repair steam turbines for the Majuba Power Station in Mpumalanga, and our casting experts are helping a manufacturer of new-generation aircraft with specifications for component manufacture. Such undertakings matter – supporting our industries is vital to the wellbeing of the economy.

Sustainability, in all its facets, matters too. South African enterprises must remain sustainable, while preserving the natural resource base. This edition of *ScienceScope* also gives you insight into how the CSIR has helped to assess the state of the country's estuaries, and compiled a guidebook to help conservationists make decisions on technologies to counter poaching. In reading about the work done by the Southern Ocean Carbon and Climate Observatory over the last decade, you will gain an appreciation of how important the Southern Ocean's uptake of anthropogenic carbon dioxide is in slowing down the pace of global warming, and how important it is for us to understand the associated processes.

In every edition of *ScienceScope* we get to share a glimpse of the work we do. It is work that matters and we are proud to share it with you.

Dr Thulani Dlamini
CSIR Chief Executive Officer

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ON THE COVER

Cones on the walls and floor of an electromagnetic anechoic chamber, which is used to measure antenna performance. This is key in, for example, the design of radar systems. The chamber keeps out unwanted emissions, such as those from cell phones, during testing. (Full story on page 64)

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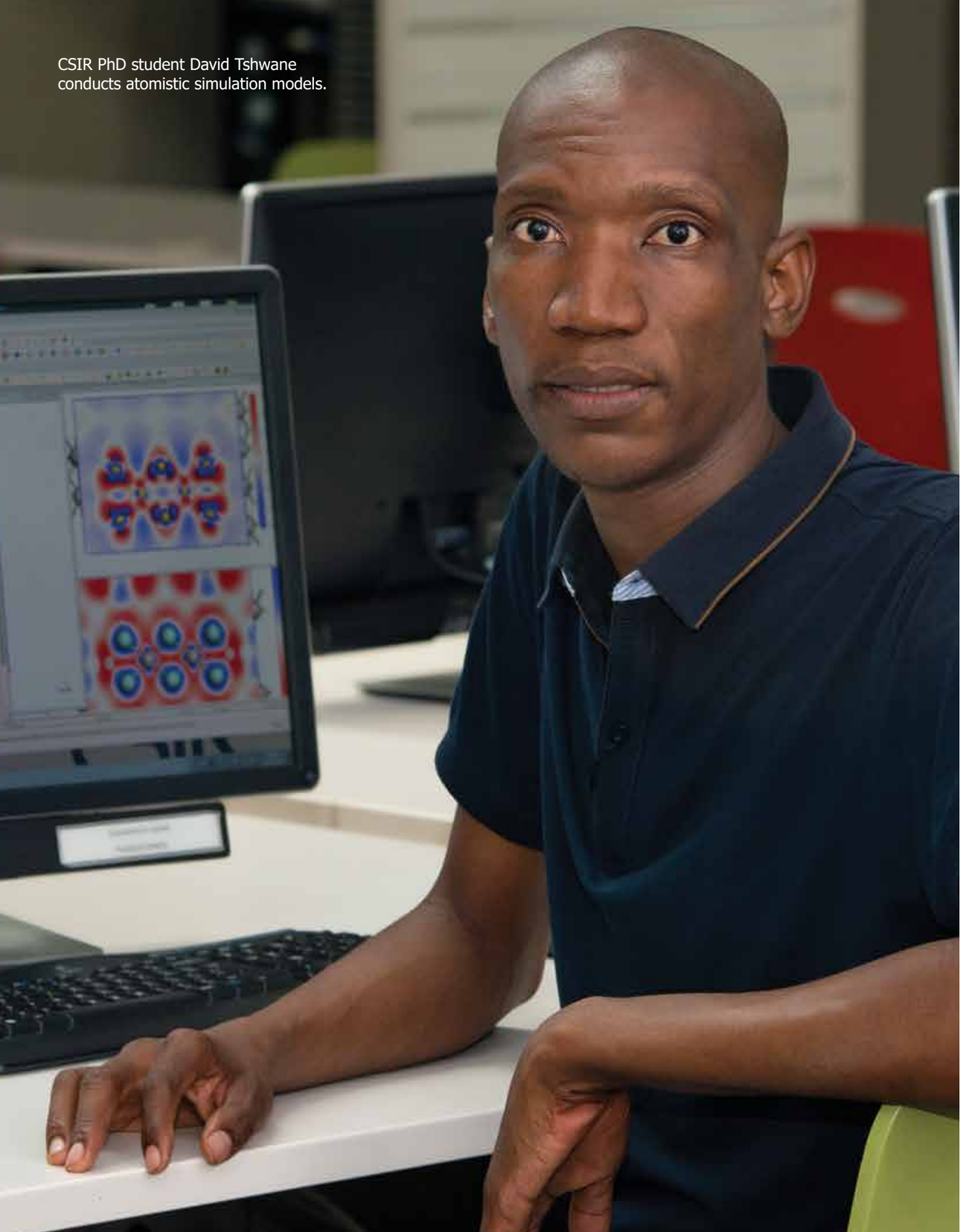
OUR PEOPLE

Lutendo Mamushiana, a CSIR candidate engineer conducting wind tunnel tests on an all-3D-printed model in the low-speed wind tunnel. Mamushiana completed her BSc Mech Eng degree at the University of the Witwatersrand and joined the CSIR as an intern on the Collaborative Programme in Additive Manufacturing, funded by the Department of Science and Innovation.



CSIR PhD student David Tshwane conducts atomistic simulation models.

Computer simulations employed to *reduce toxicity* in producing high-precision metal parts

CSIR PhD student David Tshwane uses computer simulations to investigate the behaviour and nature of materials. Tshwane's research focuses specifically on computational modelling and simulation of titanium metal surface etching.

Titanium and its alloyed components are used extensively in industries such as aerospace, automotive, medicine and energy storage. Etching is a highly accurate manufacturing surface process used to produce high-precision metal parts. However, these processes place workers at risk as they are toxic and dangerous, which makes it difficult to investigate the etching mechanisms experimentally or physically.

Atomistic simulation models are used to probe what happens at the atomic scale in solids, liquids, molecules and plasmas. The size of a simulation model can take on thousands of atoms. These simulations have become possible with the increase of high-performance computing power, and offer new ways of investigating the properties of a material, whereby the simulator builds a model of a real system and explore its behaviour. Tshwane is able to generate large data sets and simulations through computational power provided by the CSIR's Centre for High Performance Computing.

"One can design, discover, characterise, manufacture and test materials in this way. Simulation studies share the same approach as an experimental investigation. Modelling and simulation predicts the properties of the material under simulated conditions, whereas actual experiments are costly, limited or more dangerous," says Tshwane.

Tshwane says that industries that embraced modelling and simulation have realised huge cost and time savings in getting their products to market.

Tshwane is a member of the CSIR's team for advanced materials and engineering, which develops, designs, manufactures and tests various metals parts for numerous sectors. He has a BSc degree (Physics and Chemistry), BSc Honours (Physics) and MSc (Physics) *cum laude*. He is currently enrolled for a PhD degree at the Materials Modelling Centre of the University of Limpopo.

His time at the CSIR has made him realise that he loves modelling and simulation, a direction that he never would have foreseen and a far cry from his high school intention of becoming a pilot.

Computer simulation offers an alternative way of investigating the properties of a material, using a computer, whereby the simulator builds a model of a real system and explore its behaviour.

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Developing the country's future ***energy*** experts

A school excursion to SciFest in Makhanda in the Eastern Cape changed the course of Jody Julies' life. It was the first time that he was introduced to research conducted at the CSIR, and when an opportunity to apply for a bursary to study engineering presented itself, he took it. Julies obtained his BEng in Mechatronics from Stellenbosch University and was the perfect candidate for the CSIR's new graduate in-training programme.

The CSIR's graduate in-training programme provides recent graduates with skills and relevant work experience to create a pool of competent professionals that is aligned to the organisation's strategy. The programme is designed with the requirements of relevant professional bodies in mind; in this case, the Engineering Council of South Africa and the South African Council for Natural Scientific Professions. The aim is to ensure that trainees are given enough exposure to as many functions of the CSIR operations as possible, through induction and rotation. The programme was designed to heed three components, namely induction, learning and development, and social innovation for impact.

As part of the programme, Julies was placed in the CSIR's Energy Research Centre where he has become a valued member of the team that undertakes wind energy research. "It's exciting to be at the forefront of providing solutions regarding energy, especially with the country's current energy crisis," he says. One of the most notable projects that he has worked on is designing the wind component of a mini-grid solution intended for a community in Upper Blinkwater in the Eastern Cape. Julies says working with data, and modelling the ideal energy solution for a community that would otherwise have no access to the national grid, has shown him how his work can have real-life impact.

An energy off-grid blueprint for South Africa's rural communities

Electrical engineers and researchers from the CSIR are leading the wind component of a mini-grid project to electrify a small village in the Eastern Cape. The remoteness of the village hampers access to electricity from the national utilities grid. The project relies on a hybrid approach in which wind turbines, a photovoltaic system, a battery source and a back-up diesel generator are used.

The Eastern Cape government, through the Department of Economic Development, Environmental Affairs and Tourism, is collaborating with the South Africa Wind Energy Project (SAWEP) to add the wind component to the Upper Blinkwater mini-grid project. SAWEP is supported by the United Nations Development Programme with resources from the Global Environment Facility, and implemented by the South African National Energy Development Institute on behalf of the Department of Minerals Resources and Energy and will fund the integration of small-scale wind turbines, between 21 to 24 kW capacity for Phase 2 of the project. The CSIR Energy Research Centre is leading the wind integration phase of the project and is responsible for the resource assessment, energy and power system modelling and knowledge transfer to the community. Researchers have set up specialised equipment, including an on-site wind measurement tool, using LiDAR and a temporary meteorological mast to take measurements over a six-month period and to use those measurements to propose a solution for the wind energy supply to the mini-grid.

The pilot project will inform the future roll out in similar communities in South Africa. The mini-grid will consist of a centralised renewable generation plant, with powerlines reticulated to households. A smart and prepaid meter will be installed in each household to control electricity supply.

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The CSIR's Jody Julies at the site of a wind mast erected to take wind measurements in Upper Blinkwater in the Eastern Cape.

Using **technology** to ensure ***safer*** open-pit mining practices

A simple 'what-if' question fuelled young CSIR researcher Shelley Haupt's doctoral study on the integration of multiplatform remote sensing techniques to monitor slope instability in open-pit mines. "What if there were a single early-warning system that could accurately predict when a slope is unstable, ensuring that our miners are safe?" Haupt contemplated.

South Africa is home to various open-pit mines, with the most famous being The Big Hole in Kimberley. Materials such as diamonds, copper and coal are among the primary minerals mined in open-pit mines. They contribute significantly to the country's gross domestic product and lead to the employment of thousands of people. However, mining in these mines is fraught with dangers. Slope failures in open-pit mines can occur without any visual warning. Ensuring safe and sustainable mining practices has become paramount for mining companies, and health and safety codes are regularly revised to help improve safety.

Haupt says there are various techniques available for monitoring potentially unstable slopes. These range from inexpensive short-term solutions to more costly long-term monitoring programmes. In her research, various slope-monitoring techniques are used to monitor slope stability in an operational open-pit mine. These include in-field inspections, optical techniques, ground-based interferometry and satellite interferometric Synthetic Aperture Radar (SAR). Previous research has shown that each technique can be successfully used to monitor slope stability. However, the integration of all these methods has been largely untested. The findings of this research will inform the design specifications of optimal monitoring instrumentation to address the legal compliance and monitoring requirements of monitoring in open-pit mines. Ultimately, this can contribute to the development of an early warning system.

A chance to become a pioneer

Haupt began her career at the CSIR in a Master's studentship position in earth observation science and information technology in 2016. She completed her Master's degree in geoinformatics, which entailed the use of SAR techniques to monitor backfill settlement in post-mining landscapes. She mainly works on Azimuth, the large-scale surface deformation monitoring system developed by the CSIR. This system is used to detect small-scale movement in areas undergoing natural geological processes and mining environments.

Haupt is completing her PhD at Stellenbosch University, where she first started her studies and completed her BSc Geoinformatics in 2014.

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CSIR researcher Shelley Haupt monitors slope stability during an in-field inspection.

Young **researchers** ***prove*** their mettle in advanced materials

The CSIR demonstrated its prowess in advanced materials when a group of CSIR student researchers, namely Ntsoaki Mathabathe, Khodani Ramabulana, Nicolene Roux and Ntswaki Nyakane, dominated the awards session at the annual Conference of the South African Advanced Materials Initiative.

Ntsoaki Mathabathe: Best oral presentation

Ntsoaki Mathabathe took honours in the oral award category and was named the overall conference winner for her presentation of her PhD research, which focuses on electron backscatter diffraction characterisation of the primary solidification phase in a titanium aluminide alloy. The research gives fundamental insight into phase transformation behaviour and describes microstructural evolution within the alloy.

She was thrilled and humbled by the recognition, "It is a great honour to win such an award, and I am grateful for the recognition," she says. She expressed her gratitude for the support of her supervisor, CSIR principal researcher Dr Sylvester Bolokang, who won the best supervisor award at the conference. Mathabathe has since obtained her PhD and graduated from the University of Pretoria in April 2020.

Khodani Ramabulana: Second place for best oral presentation

Khodani Ramabulana received the second prize in the oral award category for a presentation on work that forms part of a bigger project aimed at reducing the cost of titanium-based components, undertaken at the CSIR-hosted Titanium Centre of Competence.

"Generally, titanium-based components have been produced through the process of melting and casting, followed by other processes. To lower these costs, research efforts have been dedicated to an alternative manufacturing process called powder metallurgy," he says.

The young researcher proved that challenges could be stepping blocks if we allow them. Ramabulana tackled the project concurrently with his Master's degree.

Nicolene Roux: Third place makes it a clean sweep in the oral presentation category

A presentation on fragmentation in the titanium industry earned Nicolene Roux the third position in the category for oral presentations. Her PhD project investigates upstream and downstream aspects of the titanium value chain with the aim of producing a roadmap for the local industry. The research required close interactions with industry, "I interacted with many industry experts as my main data were collected from interviews. I spent hours discussing and learning all aspects of the titanium industry."

Ntswaki Nyakane: Best poster award winner

The best poster award went to Ntswaki Nyakane for a presentation titled, 'The development of TiNbZr biomaterials by spark plasma sintering'. The project seeks to assist the biomedical industry with the development of affordable, accessible and good implantable biomaterial alloys. The research was supervised by CSIR principal researcher Prof. Ronald Machaka and Linda Teffo of Tshwane University of Technology.

Nyakane says being part of team CSIR has been career changing. "Working with highly knowledgeable CSIR experts, and the opportunity to attend conferences to share and receive knowledge from specialists have been major highlights," she says.

About CoSAAMI

The annual Conference of the South African Advanced Materials Initiative (CoSAAMI) is an evolution of the advanced materials initiative (AMI) series of conferences that offers a platform for researchers and students from the AMI networks, Light Metals Development Network, Ferrous Materials Development Network, Precious Materials Development Network and the Nuclear Materials Development Network to share their research.

The annual conference provides researchers and students across all networks the opportunity to present their research on advanced materials. The 2019 conference focused on materials science, aimed at beneficiating South African minerals toward research and development-led industrialisation.

The CSIR will host the 2020 edition of the CoSAAMI conference in East London from 12 to 16 October 2020 – visit https://cosaami.co.za/. Manuscripts can be submitted until 15 June 2020.

OUR WORK

The CSIR's first all 3D-printed polymer aircraft model set up for testing in the CSIR's low-speed wind tunnel. Full story on page 22.

Laser welding could ***reduce*** downtime for Eskom

In December 2019, the same month that South Africans experienced Stage 6 load shedding for the first time, Dr Corney van Rooyen's laser engineering team were working overtime to help repair a steam turbine at Rotek Engineering for the Majuba Power Station in Mpumalanga. They piloted a new on-site laser welding technology that Van Rooyen believes could save companies like Eskom weeks of downtime – and hundreds of millions of rand.

Van Rooyen and colleagues have been developing laser-based welding repair technology for Eskom's steam turbine rotors in collaboration with Eskom Research, Testing and Development since 2010.

Van Rooyen joined the CSIR in 2001, and, in 2006, he became the CSIR's only internationally accredited welding engineer with the ability to sign off on the incredibly specialised welding work needed for turbines.

Nearly two decades later, his team loads their compact, 600 kg, mobile laser welding system onto a truck, bringing laser-cladding services straight to site to repair steam turbines and compressor rotors. They currently assist companies like Eskom, MAN Energy Solutions, Actom and SASOL.

The significance of this mobile solution for Eskom, for example, is that a welding fix to a turbine rotor that would usually take up to six weeks, could be done in just 10 days.

"Removing a rotor from its casing is a big mission. Typically, removing it and replacing it or sending it for repairs can take four to six weeks," he says. A laser can do the repair job *in situ* – without removing the rotor – because it generates heat for welding in a much more focused, precise way than, for instance, arc welding.

"Laser welding means less downtime for repairs and planned maintenance, which would ultimately help reduce loadshedding," says Van Rooyen.

Above: Laser welding produces better mechanical and corrosion properties in stainless steel overlays than arc welding.

Led by Van Rooyen, the CSIR's laser engineering service has been doing this kind of work for industry for five years.

He credits MAN Energy Solutions as the first industry partner that saw the benefit of the technology: "Our strategic relationship with MAN created the opportunity, for us to develop our technology further, and to test and refine our processes to the point where we could provide a reliable repair service for industry. At the same time we offered MAN the opportunity as first adopters to have access to this new advanced manufacturing technology that allowed refurbishment of complex components, not previously available to the local industry."

While building the team's skills and tailor-making solutions for companies, Van Rooyen had also been completing his PhD. "Doing work for commercial companies, establishing a new technology and doing a PhD at the same time was challenging," he admits.

Although it took a long time to complete, his doctoral finding that laser welding produces much better mechanical and corrosion properties in stainless steel overlays than arc welding, could have major industrial applications.

"A laser's heat input is 10 times less than arc welding – if you lower the heat input, solidification is more rapid, which creates better properties for the stainless steel overlays used to refurbish cast iron or cast steel. So, although lasers are expensive, producing such metals would be cheaper for the same integrity, and the total lifecycle cost is lower," he explains.

Above: Dr Corney van Rooyen is an internationally accredited welding engineer and has completed his PhD in this field.

"

There are so many potential applications. To me, laser is not necessarily an alternative, but a complementary technology, so it adds big value. That's exciting because different industries can join hands and solve problems, and that is what South Africa needs.

We should stop trying to exclude technologies; let's think like engineers, see what we have at our disposal and package it for synergy."

- Dr Corney van Rooyen

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CSIR assists with the **industrialisation** of an *aircraft engine* for ADEPT Manufacturing

Steel melting furnace for casting engine parts installed at the CSIR

CSIR experts in casting technology are assisting ADEPT Manufacturing, a manufacturer of new-generation aircraft engines, with aspects of engine manufacturing. In one of the milestones, a melting furnace was installed at the CSIR.

Following the introduction of its Airmotive engine and associated advanced aircraft engine technology to the market, ADEPT Manufacturing is setting up a manufacturing and supply chain network that is capable of meeting the international demand for modern, lightweight, efficient, high-performance general aviation engines.

A primary aspect of the manufacturing process is the casting of aluminium cylinder heads and crankcases for the engine manufacturing process. Casting technology has been developed in conjunction with development partners. It now needs to be applied and refined within a manufacturing environment and then industrialised.

The CSIR contribution

To ensure that the application of the technology is effectively migrated into a manufacturing environment, ADEPT sought the assistance of the CSIR. The CSIR's advanced metals engineering team is highly qualified and experienced in the optimisation of production specifications for casting technology and component manufacture. The team worked closely with the company on mould design and design for manufacture, as well as the installation of a furnace and crucible preparation. Casting of the first engine block and cylinder heads is set to start soon.

"ADEPT is leveraging the intrinsic skills and specialised facilities at the CSIR to help ensure that their engine is successfully commercialised. Our goal with the collaboration is to establish a high-quality repeatable and fully documented manufacturing process, capable of producing superior quality aluminium castings for ADEPT and other aerospace companies," says CSIR research group leader for advanced casting technologies, Dr Sagren Govender.

The furnace selected by ADEPT has a capacity of 100 kg aluminium or 300 kg steel. The CSIR is providing technical assistance with the furnace specifications and assisted in preparing the facility for installation. Expert advice on mould design and design for manufacture has been provided, and the installation of the furnace and crucible preparation has been completed.

"This is not a once-off project. While the work done supported the industrialisation phase of the Airmotive engine, and will lead to the production of four engine castings per month, the furnace can be used by the CSIR for other projects. The CSIR is responsible for maintenance of the furnace and ensuring that it is operational whenever ADEPT Manufacturing requires it," says Govender.

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CSIR senior engineer Dr Sylvester Bolokang with a part casted at the CSIR.

The CSIR is hosting the Light Materials Development Network of the Advanced Materials Initiative of the Department of Science and Innovation, and was responsible for the development of the South African Aluminium Industry Roadmap. One of the recommendations on how to grow the aluminium industry was to design and produce proudly South African products.

CSIR's ***first*** ever fully **printed** wind tunnel model is tested

The CSIR has successfully manufactured and tested its first fully 3D-printed polymer aircraft model in the organisation's low-speed wind tunnel.

The prototype, which was made possible under the Department of Science and Innovation's Collaborative Programme in Additive Manufacturing, was manufactured using various polymer materials and advanced manufacturing techniques. It was manufactured in collaboration with the Central University of Technology.

While all the parts constituting the outer mould line of the model were grown – built up one superfine layer at a time – the strength of the polymer material required internal metal bracing to strengthen the model.

The CSIR is investigating the use of additive manufacturing technology for the design of wind tunnel models, to determine whether the technology can reduce the manufacturing. This will enable the CSIR to be more competitive when pitching for wind tunnel testing contracts, particularly in the global market.

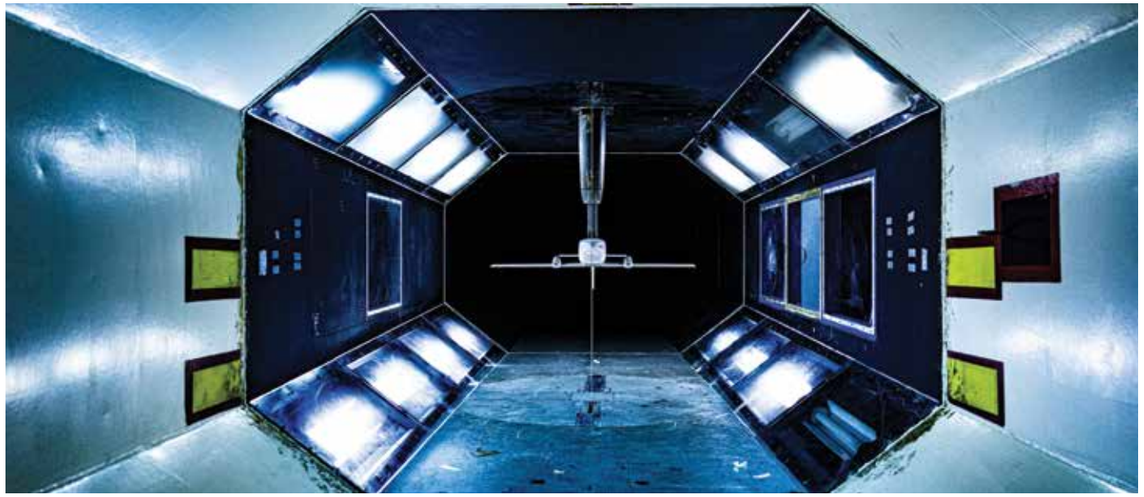
Additive manufacturing has features that need to be managed if the technology is to be used for wind tunnel models, for example, the surface roughness of the built part; the size of model that can be built in South Africa currently; and the differences in the design philosophy required with respect to the traditional manufacturing methods.

The advantages of the technology are the ability to manufacture complex parts; the potential reduction in part count; the ability to create internal spaces, which would be difficult or impossible to do with traditional methods; savings in material usage; and a potential decrease in manufacturing time.

The model's geometry is a high-wing, turbo-prop aircraft. "A commercial-type airframe was chosen so that there were no confidentiality concerns. It is also intended that this wind tunnel model, which is a 5.8% scaled model, can now be made available to engineering students for academic projects," says Charmaine Johnston, a CSIR senior engineer.

The first 3D-printed part was used in the CSIR's transonic medium-speed wind tunnel in 2007; this part was however non-loadbearing. Numerous 3D-printed parts have formed part of wind tunnel models in the interim, primarily metal 3D-printed parts.

The CSIR's suite of wind tunnels has provided a scientific research and experimental foundation to the aerodynamic design efforts of the South African aeronautics industry for many years. The suite was installed in the mid-1960s and has become a popular test capability in the Southern Hemisphere.



Above: The CSIR's fist first all 3D-printed polymer aircraft model set up for testing in the low-speed wind tunnel.

Left: Tufts on the upper surface of the wing, for visualisation of the flow over the wing.

Left bottom: Candidate engineer Lutendo Mamushiana testing the polymer aircraft model inside the wind tunnel.

A wide variety of airframes have been tested successfully in these facilities. This includes subsonic types such as gyrocopters, helicopters, unmanned aerial systems and military trainers, as well as transonic airframes, and supersonic airframes of high-speed missiles and projectiles flying at more than four times the speed of sound. Data collected at the facilities are used for airframe characterisation, aerodynamic design and to populate complex modelling and simulation environments for mission simulation, doctrine development and training.

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CSIR encapsulation **technology** solutions enhance ***health*** benefits in nutraceuticals

The CSIR is developing and commercialising encapsulation technologies that address shortcomings in the pharmaceutical market.

Imagine consuming a pharmaceutical such as a probiotic or vitamin with the expectation of getting its full health benefits, only to find that it is ineffective. According to research, probiotics on the market do not meet World Health Organization recommendations on the concentration of 10^7 colony-forming units per gram of viable probiotic bacteria, which is a requirement for a probiotic to have health benefits.

It is no different for nutraceuticals for human or animal health. Currently, probiotics on the market are said to have insufficient health benefits due to poor stability, low absorption or ineffective release profiles.

This is because active probiotics typically die during manufacturing, transport or storage. In addition, a host of studies show that, on average, approximately 90% of viable probiotics consumed are degraded in the acidic gastric juices before they reach the intestines.

However, a team of CSIR experts has been steadily building a track record in developing and commercialising encapsulation technologies that address these shortcomings in the market. They have been able to do so through world-class supercritical fluid-based infrastructure. Several other encapsulation techniques have been developed to deliver the active compound in a controlled fashion and sometimes directly at the site of interest.

Above: An active protected through microencapsulation.

What is encapsulation technology?

Encapsulation is a technology that has been used in the pharmaceutical, food and feed sectors to enclose active ingredients, providing an effective barrier against environmental parameters such as oxygen, light, stomach acids and free radicals, or to mask an unpleasant taste. The process involves the entrapment of one or several substances (active agents) into beads of sizes ranging from nanometer to micrometer or millimeter scale. In addition, the characteristics of the wall material can be selected to enhance the aqueous solubility of hydrophobic actives, thus enhancing their bio-accessibility.

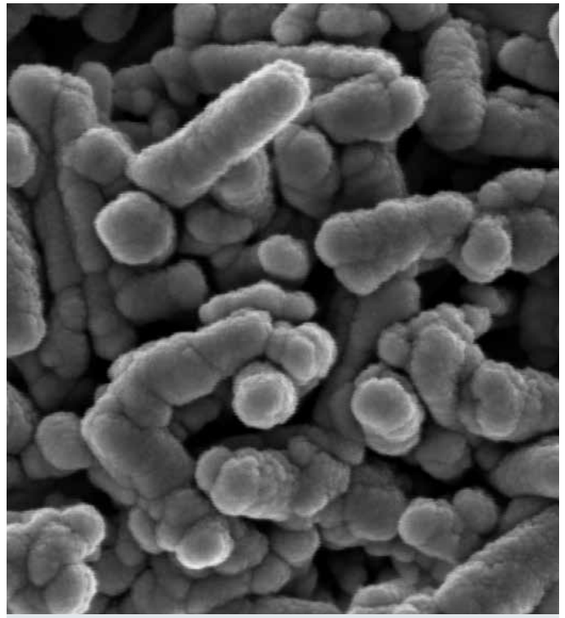
The value of the CSIR's encapsulation technologies

Supercritical CO_2 encapsulation

Conventional encapsulation processes, such as extrusion, spray drying and prilling require the use of one or a combination of organic solvents, water, high temperatures and high shearing – all which can degrade sensitive actives used in nutraceuticals for human and animal health. These actives include probiotics, phytochemicals, vitamins and enzymes. The CSIR has a novel encapsulation facility that only uses supercritical CO_2 as a process medium. It has the following value characteristics over conventional encapsulation processes:

- No organic solvents or water required;
- The final product contains no residual organic solvents;
- Anaerobic processing is used, which is ideal for oxygen-sensitive actives;
- Most materials are processed well below actual melting point, which is ideal for thermolabile actives and energy saving;
- No or minimal activity loss of sensitive bioactive compounds during encapsulation; and
- Natural and environmentally friendly (green) encapsulation process.

The unique benefits of the technology have allowed the CSIR to develop, patent and commercialise a probiotic encapsulation technology. The organisation has demonstrated the ability to encapsulate antibiotics, vitamins and phytochemicals for improved stability and bio-accessibility without jeopardising their activity.

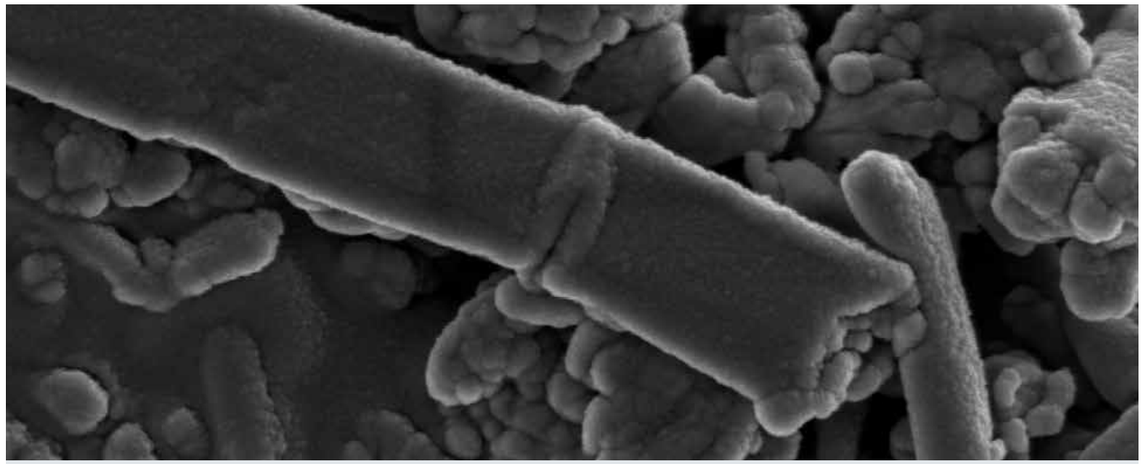


Above: Nanoclay tubes as seen using a scanning electron microscope.

As a result of significant industry interest in the novel encapsulation process, the CSIR has initiated a process for the establishment of a pilot facility, which will be the first of its kind in Africa. The pilot facility will enable the local development of innovative, technology-based products for the South African human and animal nutraceutical markets. In particular, the facility will focus on the development of innovative encapsulation technologies for sensitive actives (including phytochemicals, vitamins, enzymes, vaccines and probiotics), scale-up, toll manufacturing, and market trials of these products, which will be undertaken together with industry partners.

"We anticipate that, through this facility, new innovative products for the human and animal nutraceutical sectors will be developed. These products will have greater stability and activity, and thus enhanced health benefits," says Dr Philip Labuschagne.

(continued on page 26)



Above: Images of natural nanoclay tubes obtained through the use of a scanned electron microscope.

Natural nanoclay-based encapsulation technology

While feed processing is used to increase the overall quality of feed ingredients, generally micro-ingredients, such as vitamins, tend to be damaged by these processes. Therefore, often higher levels of the required active ingredients or overages are added to compensate for expected losses in vitamin potency that occur during processing and storage.

The CSIR has developed a delivery system, utilising natural nanoclays as the encapsulation medium, to protect and improve the thermal stability of biological active ingredients during animal feed processing. The physical loading of vitamins into the nanocontainers is a low-energy, environmentally friendly process.

Release kinetics of actives from the nanocontainers is controllable, ranging from minutes to hours. The nanoclay encapsulation technology protects vitamins against various physical and chemical feed processing stress factors, including heat, pressure and redox reactions. The final products are dry, free-flowing powders with excellent handling and processability properties. The technology is flexible in that both water-soluble and fat-soluble vitamins can be encapsulated, a major advantage for homogeneous distribution in the feed matrix. Further ongoing developments include other feed additives, such as phytochemicals against thermal degradations.

Emulsion and spray-drying technologies

The team has extensive experience with emulsions and spray-drying techniques to produce nanoparticles for the encapsulation of hydrophilic (water-loving) and hydrophobic (water-hating) active compounds (such as drugs) within different carriers (polymers or lipids).

The spray-drying technology enables the production of dry powders from a fluid by atomisation into a hot-drying gas medium (air or nitrogen). The process is rapid, continuous, cost-effective, reproducible and scalable. The solid particles obtained present relatively narrow-size distribution. The team has developed several novel and patentable spray-drying-based formulations and processes for the production of free-flowing powder with particle sizes ranging between 100 and 500 nm by using the Buchi B-290 spray dryer. Applications include therapeutics (drug nanoparticles for effectively treating infectious diseases such as tuberculosis, HIV and malaria, as well as radiopharmaceutics for the detection and therapy of cancer), nutraceuticals for human and animal health, as well as agriculture, cosmetic and food applications.

CSIR encapsulation technology success stories

Supercritical CO_2 encapsulation

Probiotic encapsulation

The CSIR developed, patented and recently commercialised a novel encapsulation technology to enhance the stability and bioavailability of probiotics. The technology is based on the combination of two novel ideas, namely the encapsulation of the probiotic in a pH-responsive interpolymer complex and an encapsulation process occurring in an anaerobic supercritical CO_2 environment. An interpolymer complex is a pH-responsive system in that the complex will remain intact, and thus protect the probiotic when passing through the stomach while dissolving, thereby releasing the probiotic in the small intestines.

Independent studies showed significant improvement in shelf stability, protection in simulated gastric fluids and improved intestinal colonisation compared to non-encapsulated probiotics.

Phytochemical encapsulation

Phytochemicals are natural bioactive compounds that are derived from plants and incorporated into animal feed to enhance productivity and health status. Some of the main bioactive compounds of the phytochemicals are polyphenols and flavonoids. Although the health benefits of hydrophilic phytochemicals are well studied, it is believed that many beneficial components are contained in hydrophobic phytochemicals. However, the poor bioaccessibility and thus absorption of these hydrophobic compounds limit the full potential of the health benefits that they can impart. The CSIR developed an encapsulation technology to maximise the delivery and absorption of both hydrophilic and hydrophobic phytochemical compounds. An independent trial on poultry has shown that consumption of the encapsulated phytochemical leads to improved meat quality and stronger bone structure.

Animal vaccine encapsulation

One of the drawbacks in the use of vaccines, specifically in the animal health sector, is the requirement for both a prime and boost vaccination, adding to the labour and product costs. The CSIR, in collaboration with the University of Pretoria, developed a novel delivery system that allows single-dose administration of the vaccine. Animal trials have shown that a single dose of vaccines encapsulated in the delivery system developed by the CSIR generates similar antibody responses as two doses of a non-encapsulated vaccine.

The CSIR continues to develop and optimise suitable encapsulation technologies for the pharmaceutical, food and feed sectors. The organisation has technology solutions for unique application in the form of contracting or co-development.

Above: CSIR researcher Andri Swanepoel adjusts settings on the Supercritical Carbon Dioxide System.

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Alternatives to **non-biodegradable** plastic products give ***hope*** in the battle against plastic pollution

New technology is making it possible to use sustainable biodegradable materials for plastics as an alternative to conventional non-biodegradable plastics, which are a major pollution concern.

The CSIR is developing eco-friendly plastics that will help reduce the environmental burden of plastic pollution at landfill sites. "More than eight million tons of single-use plastics are dumped in landfill sites or oceans every year. These plastics are non-biodegradable and harmful to many living organisms. As a result, many countries have outlawed the use of single-use disposable plastic items, which include thin carrier bags, cutlery and straws," says CSIR senior researcher Dr Sudhakar Muniyasamy.

The current conventional plastic is not only creating plastic pollution issues, it is harmful to aquatic and terrestrial habitats, particularly microplastics, which pose a risk to human health. To address these issues, it has become a worldwide priority to develop biobased materials from renewable resources to ensure that the next generation of sustainable materials meet ecological and economic requirements.

Muniyasamy says that in South Africa and other African countries, there are lot of opportunities to fully utilise local biomass and develop sustainable biobased polymeric materials from various agricultural by-products, forestry and organic waste for use in various manufacturing sectors. He says that according to a report by the Institute for Bioplastics and Biocomposites, in Germany, European Bioplastics estimates that biobased plastics currently originate from less than 0.02% of agricultural land. "There is no real competition with food and feed production," he says.

The CSIR-developed bioplastics technology has good mechanical properties, similar to conventional plastics. Conventional processing equipment can be used to produce flexible film applications, such as plastic carrier bags and packaging products. It is highly suitable to address the plastic waste disposal problem because it is made from a renewable resource, is non-toxic and biodegradable in soil, compost and water.

> "The bioplastic sector will have a positive social, environmental and economic impact. It will stimulate agricultural production, contribute to agro-industrial value chains and create new work opportunities. It is set to contribute to rural development for biomass sourcing, increase the sustainability and greening of the chemical industry, as well as improve workforce health and safety."
>
> - Dr Sudhakar Muniyasamy

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CSIR senior researcher Dr Asanda Mtibe working on the blown-film extruder equipment used to produce biodegradable plastic bags.

Local mining industry to receive a boost with two new high-tech **rock drills**

The Mandela Mining Precinct has unveiled two new high-tech rock drill prototypes that will enhance drilling operations, reduce the exposure of operators to dangerous conditions and immediately contribute to zero harm. The prototypes are the culmination of an open innovation challenge launched in 2018 to develop a new rock drill for the South African mining industry.

"The Isindingo Drill Design challenge was launched with specific industry criteria detailing what is needed to improve efficiencies and reduce harm at the mining face, hence the name Isidingo," says Mandela Mining Precinct programme manager, Martin Pretorius.

Drilling is the primary and most important part of the mining cycle, and, in its role of advancing the mining sector, the Mandela Mining Precinct saw the opportunity to develop a new locally manufactured rock drill for the industry. The challenge adopted a three-phased approach. Phase 1 entailed the introduction of a new and innovative rock-drill concept design; followed by Phase 2, which involved the prototype construction associated with testing and monitoring, while Phase 3 will entail manufacturing and underground performance testing.

After a robust evaluation, two local companies were identified to develop prototypes, which were tested at the Mandela Mining Precinct. The tests successfully illustrated the adherence of Novatek and HPE to the primary criteria that will enhance the performance of the drill, reduce the exposure of operators to dangerous conditions and immediately contribute to zero harm. Phase 3 will take place at a mine to be announced closer to the time.

Both finalists found the balance between weight and robustness to be the most challenging. "We needed the drill to be as light as possible, but still robust, and this was not easy," says Novatek Managing Director, Julian Wills. "Our strengths lie in hydropower and stope drilling rigs and we are guided by the development of appropriate technology. This is part of our internal value system, advocating for technology that must be appropriate to the type of mining, the infrastructure, the resources and the skills of the end user."

HPE Director, Ulrich Kienle, explains that the development of their drill was a company-wide effort that adopted the HPE way of product development, whereby over a dozen concepts were considered and finally reduced to three viable ones.

HPE presented a versatile drilling system. "With our new offering, drilling is now possible in three ways, namely with a novel new hole guide puller, a stope drill jig or in a conventional manner with a thrust leg," says Kienle, adding that their drilling system is suitable for any angle and application. "Once the first hole has been drilled, the hole guide puller repeats the process and guarantees correct burden spacing, parallelism and in-line thrusting."

Pet named *the Buffalo*, Novatek's drill incorporates a spring, shaped like a buffalo's horns, and embodies strength, accuracy and speed. "What we delivered meets some of the criteria really well. In our early tests, we managed to improve on the noise levels, which we were not able to replicate but we are eager to continue working thereon for the next phase," says Wills.

The Mandela Mining Precinct is a public-private initiative between the Department of Science and Innovation and the Minerals Council of South Africa, and is working towards the revitalisation of mining research, development and innovation in South Africa to ensure the sustainability of the industry. The Mandela Mining Precinct is hosted and managed by the CSIR.

Left: HPE demonstrating the company's prototype rock drill as part of Phase 2 of the Isidingo Drill Design challenge. The HPE drill has 90 unique parts, which are all locally manufactured.

Left: CSIR Group Executive: Business Excellence and Integration, Khungeka Njobe; and Minerals Council South Africa Senior Executive: Modernisation and safety, Sietse van der Woude inspecting one of the many 3D-printed prototypes produced by HPE in their development process.

Left: Novatek's Buffalo rig demonstrates a people-centric approach to technology design. The prototype strikes a balance between weight and usability.

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Drones or dogs? Report on best **technology** options in ***anti-poaching*** available

Conservationists and other keepers of rhinos can now benefit from technology evaluations and lessons learnt in effective counter poaching efforts through a guidebook compiled by the CSIR on behalf of the Department of Environment, Forestry and Fisheries. The report-form publication, titled ***Guidelines to Inform the Establishment of Anti-Poaching Related Systems and Services,*** was funded by USAID, through the World Wildlife Fund South Africa, and contains contributions from a significant range of organisations involved in nature conservation, security technologies and countering wildlife crime specifically.

The new anti-poaching guide is aimed at any organisation faced with the need to establish an anti-poaching capability, regardless of scope or size. It covers higher-level design concepts, governance and organisation, as well as the practical aspects of staffing, facilities and operational teams – human and animals (dogs and horses). Substantial coverage is given to technical systems, such as perimeter security, access control, connectivity and mobility; the integration of technologies, such as sensors or optronics and situational awareness with response teams; and the sustainment of such a capability.

Contributors include the CSIR, the South African National Parks (SANParks), the SA Wildlife College, Ezemvelo Kwa-Zulu Natal Wildlife, the Greater Kruger Environmental Protection Foundation, the Private Rhino Owners Association, the Peace Parks Foundation and the Department of Environment, Forestry and Fisheries (Law enforcement division). The publication is available from the department at no cost.

Charl Petzer, Programme Manager: Environmental Asset Management at the CSIR provides context, "Rhino poaching received much media attention and subsequently a flood of offerings from technology vendors who claimed to have the ideal solution," he says.

"For example, drones received a lot of hype initially, but you have to consider endurance, terrain for take-off and landing, cost of ownership and stealth capabilities," he continues.

"The key is to properly understand the operational concept on the ground – the causes, *modus operandi*, limitations, environmental conditions, and so forth – and to design an integrated capability, not loose-standing components. Operations should also be conducted within the ambit of the applicable governance structure – you can't break the law to enforce the law," he says.

Different reserves have different challenges and resources. "We have found that not all expensive technology is good, and not all good technology is expensive," Petzer says. "Over the years, we could see the effect of making the right choices and we got a lot of positive feedback. However, at the end of the day, technology makes it possible, but *people* make it happen; we must understand the societal context of criminality and not ignore the integrity management of guardians."

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Above: Silent testimony: Horns, confiscated during counter-poaching operations, are examined and used as evidence in prosecution.

Technology interventions in the Kruger National Park

A large part of the CSIR's involvement in anti-poaching is based on a longstanding collaboration with SANParks in the Kruger National Park, where the world's largest rhino population is found. Over the past five years, several technologies were defined, designed, tested and rejected or deployed in the Park. These range from radar and optronic detection systems, secure communication networks, pattern recognition systems at access points, predictive modelling, managing technology uptake and developing operational doctrines, including air assets and canine unit optimisation.

In 2014, a Mission Area Joint Operational Command Centre was established at the SANParks offices near Skukuza camp as a nerve centre to a combined special counter poaching unit. The backbone of this operation was a collaboration software platform that provided a way of capturing incidents of different types, collected from different sources to give one real-time view of happenings in the Park – be it intrusions, gunfire, tracks detected, crime scenes, etc. This view on the worst-hit zone gave response teams the information to respond fast and on target.

It also became a means of analysing captured data to form scientific predictions of attacks. This way, squads can be deployed to hotspots pro-actively to foil attacks before animals are harmed. The system has since been rolled out to 28 reserves nationwide, where it is actively used in anti-poaching activities.

Transforming the South African human settlement *landscape*

The Neighbourhood Planning and Design Guide, also known as the Red Book, outlines the qualities that should be sought in South African settlements and neighbourhoods and provides practical guidance on how these qualities can be achieved. It is available electronically and as a printed document.

Above: CSIR senior researcher Engela Petzer (left) and principal researcher Tinus Kruger with the latest edition of *The Neighbourhood Planning and Design Guide.*

> "The *Red Book* encourages integrated settlement and neighbourhood development, promotes sound urban planning and design principles, and assists in improving the efficiency of engineering services and infrastructure."
>
> - Tinus Kruger

Left: The Minister of Human Settlements, Water and Sanitation, Lindiwe Sisulu (left) with CSIR Chairperson Prof. Thokozani Majozi at the launch of *The Neighbourhood Planning and Design Guide.*

The Neighbourhood Planning and Design Guide provides practical information related to the planning and design of the range of services and infrastructure typically provided as part of a neighbourhood development project. These include layout, water supply, sanitation, stormwater management, electrical energy, roads, transport, public open spaces, housing and crime prevention through environmental design.

The *Red Book* provides decision-making support to built environment professionals and practitioners – including public and private sector engineers, town planners, urban designers, architects and landscape architects – as well as community groups involved in people-driven housing developments. The guide also contains useful information for students, lecturers and decision-makers, such as local government councillors.

Creating sustainable human settlements

The Department of Human Settlements appointed the CSIR to manage the process of developing the new *Red Book*, coordinate the various contributors and prepare the final document. This new version of the *Red Book* is a comprehensively updated and revised version of its predecessor, the *Guidelines for Human Settlement Planning and Design*, published in 2000. Factors that have influenced the nature of the revised guidelines include climate change, specifically its relation to the built environment, local realities such as poverty, inequality, rapid urbanisation and informality, current theoretical approaches to settlement-making, and the latest research as reflected in various government policies, programmes, frameworks and strategies.

The application of the guidelines should ultimately result in the delivery of infrastructure and services that are effective and efficient and that contribute to the creation of vibrant, safe, integrated and inclusive neighbourhoods, towns and cities.

"Over time, the *Red Book* will assist in transforming the South African human settlement landscape to reflect the qualities and objectives outlined in, for instance, the National Development Plan and the Integrated Urban Development Framework. It will also play a role in supporting the global Sustainable Development Goals and will ultimately contribute to improving the living conditions of all South Africans," says CSIR researcher Tinus Kruger, who managed the project.

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CSIR completes **3D model** studies for a proposed ***tidal pool*** in Port St Johns

Some of the biggest and busiest ports in the world have been tested at the CSIR's coastal and hydraulics laboratory in Stellenbosch. Recently, the team undertook the modelling of a project of a different nature, but one with real impact for the remote coastal community of Port St Johns in the Eastern Cape.

The Department of Environment, Forestry and Fisheries contracted the CSIR to undertake physical modelling studies of a proposed new tidal pool in Port St Johns. While the area was one of the most popular recreational swimming and surfing spots on the Wild Coast for many years, the town has suffered a loss of visitors in recent years.

The Department's Mavick Matutu, Programme Manager: Coastal Infrastructure Development says that starting from about 2004, Port St Johns experienced a number of high-profile shark attacks. "The perception of danger that came with that, scared people and tourism was impacted, companies went bankrupt and jobs were lost. The task that faced us as government was to invigorate and catalyse tourism in the area."

The CSIR constructed a small-scale replica of the tidal pool that is planned for the Port St Johns Second Beach community at its coastal and hydraulics laboratory. The model was constructed to the full detail of what is planned, so it was based on the drawings given to the CSIR by the consulting engineers.

"We then generated oceanic conditions that are similar to those found in reality to see how the structure behaves in those conditions and how it affects the surrounding area," says CSIR researcher Carl Wehlitz.

In constructing physical models such as this one, engineers use the data from surveys to replicate the actual sea floor conditions, which contribute to how waves are formed.

"We tested three aspects. The first was the wave climate both inside and outside the tidal pool, ensuring that the waves inside the tidal pool are small enough and safe enough for people to swim. The second aspect was overtopping, where we quantified the water that is washed over the wall and into the pool and thirdly we looked at flushing – how different water currents forming inside the pool behave and how water is evacuated out of the pool," says Wehlitz.

The testing was completed in November 2019 and the results have been handed over to the consulting engineers for consideration in terms of their design.

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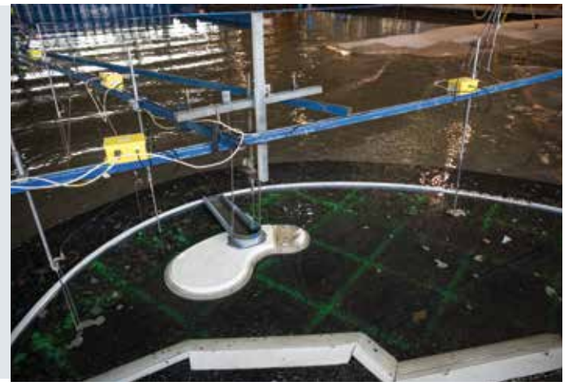

Above and right: A model of the proposed tidal pool for Port St Johns. Waves from offshore spill over the pool wall and the water height is kept constant by water draining through the evacuation area to the side of the pool. A small artificial island has been constructed in the centre, where bathers can swim without being exposed to the harsher waves offshore.

Left: Mavick Matutu of the Department of Environment, Forestry and Fisheries (left) discuss the progress of the 3D model testing with the CSIR's Carl Wehlitz.

Estuaries – **super-ecosystems** under *threat*

The findings of the latest National Biodiversity Assessment

South Africa's estuaries are at risk. In fact, it is the biodiversity realm that is most under threat, with 99% of the country's total estuarine area threatened. Researchers say that multiple interventions are required to avoid a further decline in health. Their findings were included in the National Biodiversity Assessment, led by the South African National Biodiversity Institute. The assessment was undertaken between 2015 and 2019. CSIR senior researcher Dr Lara van Niekerk led the team of national estuarine experts from more than 15 organisations who compiled the report.

South Africa has 290 estuaries and 42 micro-estuaries, which have been classified into 22 estuarine ecosystems and three micro-estuary types. Estuaries cover only about 2% of South Africa's extent, but they contribute roughly R4 billion per annum to the country's income, of which about R1 billion is from fishing both in the estuary and the near-shore marine environment. Estuaries also have high social value, sometimes less well quantified in the monetary sense.

"Estuaries are often described as 'super ecosystems'. They are high-retention environments. Therefore, unlike rivers and the sea, which are open environments, the area where the seawater and the fresh water meet, is an incredibly highly productive environment, with a lot of primary production (e.g. micro-algae and plants) and fewer predators. Species that live in the ever-changing environment of estuaries, basically thrive," says Van Niekerk.

Despite the very real threat, Van Niekerk says it is not all doom and gloom. She indicates that estuaries are resilient environments that have the ability to rapidly recover from pressures with the right interventions.

"If, for example, you remove nutrient enrichment from wastewater or urban stormwater runoff in an estuary, after the first flood, you will have a system that functions very close to its natural processes. Interventions can have very good results," she says. She cites the Sandvlei Estuary as an example of a success story. The City of Cape Town is managing the estuary mouth better through an artificial solution and, through that, they have increased the salinity. "The system is actually in a better state now than 10 years ago, it supports more fish, has less algae and is an all-round example of a success story."

Compiling the assessment of South Africa's estuaries was a mammoth task. The data collection started more than five years ago. It looked at the pressures on estuaries, for example how much wastewater was flowing into estuaries, as well as the pressures on fisheries, based on, for example, information from illegal gill netting. A group of estuarine specialists compiled an assessment for every one of the 290 estuaries in South Africa. This information was grouped into types of estuaries to draw conclusions on how the different types of estuarine ecosystems in South Africa were doing. The recommendation from the team was that South Africa needs a comprehensive estuary programme that sets out strategic interventions.

Above: Cape Town's Sandvlei Estuary. The City of Cape Town is managing the estuary mouth through an artificial solution, with good results.

Below: The CSIR's Dr Lara van Niekerk with a copy of the National Biodiversity Assessment 2018.

"Protection levels need to be increased, development in the estuary functional zone should be managed, nutrient reduction strategies need to be put in place and the pressure on fishing in the estuaries needs to be reduced. The international UN Decade of Restoration 2020-2030 provides many opportunities for such measures moving forward," says Van Niekerk.

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Using **climate modelling** to locate and prevent the *spread* of infectious diseases

It is widely known that many infectious diseases, such as seasonal diseases like malaria, pneumonia and diarrheal diseases, are driven by weather and climate or affected by extreme events, such as droughts and floods. However, what scientists have until recently not been able to do is predict whether the coming season or year will be worse or better from a disease outbreak point of view. A project completed in 2019 has changed this.

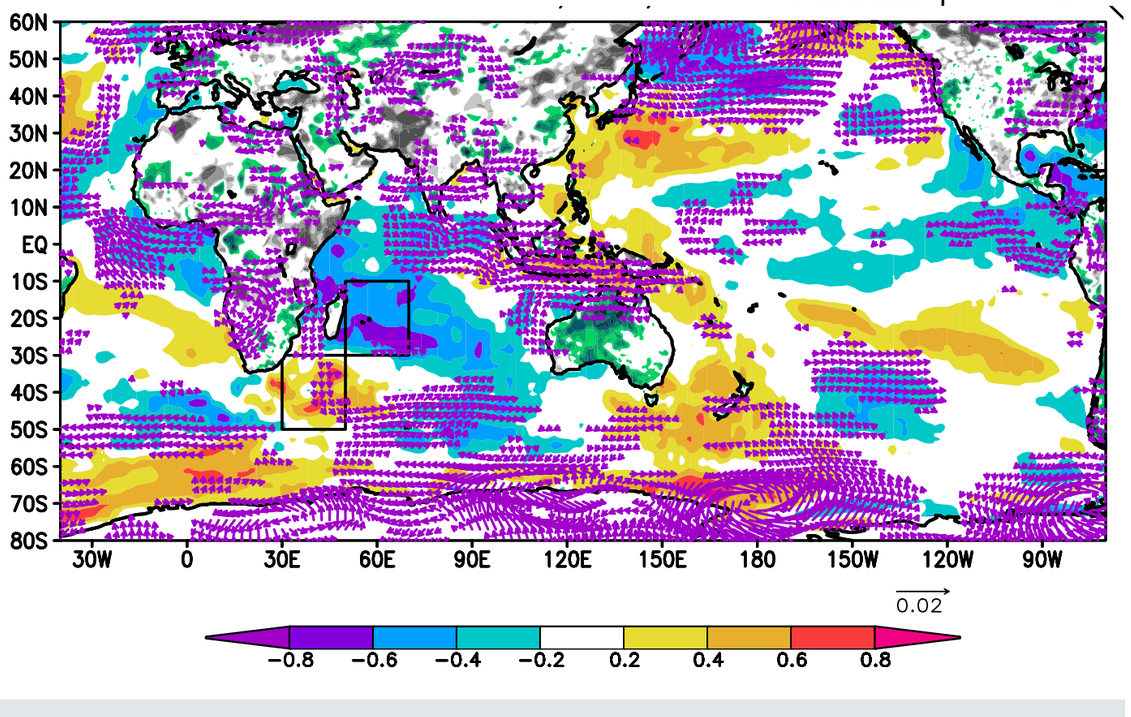
As part of the Infectious Diseases Early Warning System (iDEWS) project, a tool was deployed and tailored for predicting the climatic conditions with a 3 to 18-month time horizon, and linked with a variety of epidemiological data and parameters to predict the likely occurrence of disease outbreaks in Limpopo.

Using this approach, the partners from Japan and South Africa developed a set of climate-based malaria prediction models based on the elucidation of the relationship among climate variables and historical disease incidence records. For malaria, a notifiable disease with good quality data, the models are already operating experimentally in predictive mode and have shown that they can be successfully used by malaria control officials as an additional tool in combating this disease.

"The research has shown that there is significant correlation between regional climatic dynamics and malaria incidence in Limpopo. For example, with a three-month lag, above normal rainfall in Mozambique results in a spike in malaria incidence in Limpopo. At longer time scales, certain configurations of sea surface temperature (which control rainfall) in the proximal regions of the Indian Ocean and Madagascar can explain long-term variation in malaria incidence in the Vhembe district," says Dr Neville Sweijd, Director of the Alliance for Collaboration on Climate and Earth Systems Science, a research programme by the CSIR and the National Research Foundation.

For diarrheal diseases, which are not generally diagnosed but usually treated symptomatically by patients themselves or by clinicians, data is more difficult to come by. Using proxy data for incidence, the research has shown that, while temperature is still the biggest driver of incidence, water supply is also critical. Outbreaks of diarrheal disease tend to occur in periods of elevated temperatures and reduced rainfall (i.e. droughts). Using seasonal climate prediction, researchers can then issue a warning of the likelihood of diarrheal disease outbreaks when hot and dry conditions are predicted.

Above: Dr Neville Sweijd, Director of ACCESS. ACCESS has recently put together a group of experts to study the influence of climate and weather on COVID-19.



Above: The figure above shows how the climate parameters, in this case measured via sea surface temperature and rainfall, is related to infectious disease incidence. Conditions such as those shown east of Madagascar (relatively cooler sea surface temperatures on a decadal time scale) along with those south of Madagascar (relatively warmer sea surface temperatures) correlate with higher than average rainfall in Limpopo and increased malaria incidence in Limpopo.

"The results from the research demonstrate how climate science and climate modelling, in particular, is very useful in various sectors. Given that climate change is likely to manifest in changes in the typical seasonal patterns and that extreme climatic events are likely to intensify with time, it is clear that this kind of early-warning system is critical for climate change adaptation," he says.

While the project has been completed, the project partners have committed to continuing to work together and have agreed to set up an iDEWS Bureau to issue regular infectious disease outlook bulletins and serve as a platform to expand the work to other regions and other climate-dependent diseases of humans and animals.

The project partners are from the CSIR, the South African Weather Service, the South African Medical Research Council, the University of the Witwatersrand, the University of the Western Cape, the National Institute for Communicable Diseases, the Department of Health in Limpopo, the Japan Agency for Marine-Earth Science and Technology and the University of Nagasaki.

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Ten years of carbon-climate **science** in the ***Southern Ocean***

The Southern Ocean Carbon and Climate Observatory is a South African-born science programme that supports the Global Change Grand Challenge and the Marine and Antarctic Research Strategy. In addition, it uses the challenges in understanding the role of the Southern Ocean in regional and global climate to attract young South Africans to acquire advanced numerical, technological and analytical skills in support of a transformed knowledge-based economy.

Global climate science has led to the largest re-organisation of the global economy by establishing the link between carbon-intensive energy systems and climate change. A key part of that linkage is the role of the ocean, particularly the Southern Ocean, which takes up 50% of the ocean uptake of anthropogenic carbon dioxide (CO_2) and more than 70% of the excess heat generated by the accumulation of anthropogenic CO_2 in the atmosphere.

To address these challenges of ocean-climate science, the Southern Ocean Carbon and Climate Observatory (SOCCO) established a now globally recognised interdisciplinary team in ocean physics, chemistry and biogeochemistry, integrated with world-class ocean robotics technology and the power of high performance computing at the Department of Science and Innovation (DSI)-funded Centre for High-Performance Computing.

The Southern Ocean's uptake of anthropogenic CO_2 plays a critical role in slowing down the pace of global warming and climate change, giving society a window to transform towards low-carbon economic development and avoid catastrophic climate change. The Southern Ocean is the final frontier in the Earth system, says CSIR chief researcher Dr Pedro Monteiro. Despite its importance, the Southern Ocean is also the area that we are most unsure of in respect of contemporary and future estimates of global and regional climate.

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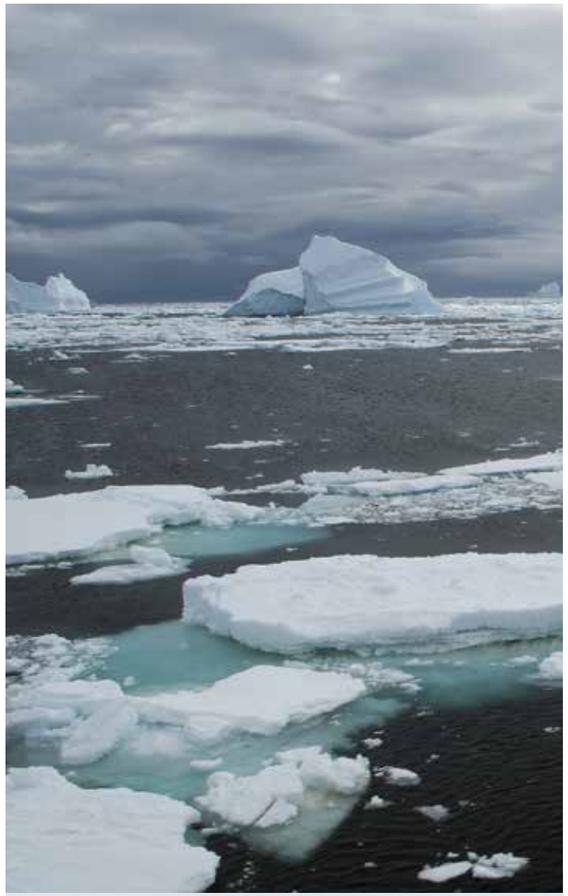
Location, location, location

Monteiro says, "South Africa has a strong comparative geographical advantage in respect of the Southern Ocean, which offers our science community the opportunity to make a strong contribution in advancing this critical science and simultaneously address the urgent advanced skills development needed for a 21st century developing nation. On this basis, SOCCO grew as a DSI-CSIR co-funded national research programme hosted at the CSIR."

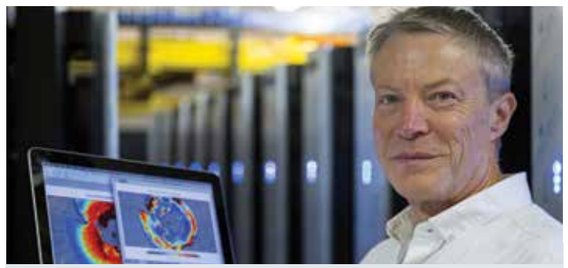
SOCCO is presently the largest South African ocean-climate research programme and it targets the comparative geographical advantage, as well as a niche in the global ocean carbon-climate research space, using the seasonal cycle to diagnose the mechanisms that drive climate sensitivities. This niche is based on the idea that fine-scale processes not resolved in global models, are critical to being able to explain variability and predict the future evolution of the ocean carbon sink and climate change.

However, there is a significant challenge in representing sub-grid-scale (mesoscale and sub-mesoscale) ocean circulation dynamics in Earth system models. These sub-grid scale dynamics influence the magnitudes and rates of change of the physical and biogeochemical processes that drive air-sea exchange and the storage of CO_2 and heat in the ocean. These processes are also critical to primary production, which governs biological carbon sequestration. SOCCO research has shown how the misrepresentation of sub-grid scale processes results in biases that may persist in longer-term variability and future projections.



Above: A Southern Ocean seasonal sea-ice field showing the open water leads through which carbon dioxide and heat exchange with the atmosphere.

Above: The SA Agulhas navigating through a sea-ice field towards Antarctica.



Above: Dr Pedro Monteiro, Head of the Southern Ocean Carbon and Climate Observatory at the Centre for High Performance Computing in Cape Town.

Above: One of the carbon wave gliders being loaded onto the SA Agulhas II for a long mission in the Southern Ocean.

The **seasonal cycle** of carbon dioxide ***exchange between*** the Southern Ocean and the atmosphere

Carbon dioxide (CO_2) is the main driver of global warming and climate change. A better understanding of the processes that regulate its uptake by the ocean is therefore critical for long-term prediction of climate and effective mitigation strategies. SOCCO's carbon dioxide science and observations are framed by a global challenge to resolve the seasonal cycle of the air-sea fluxes of CO_2 in the global ocean by using high-precision long-term observations, machine learning and model projections.

Helping make the unknown, known

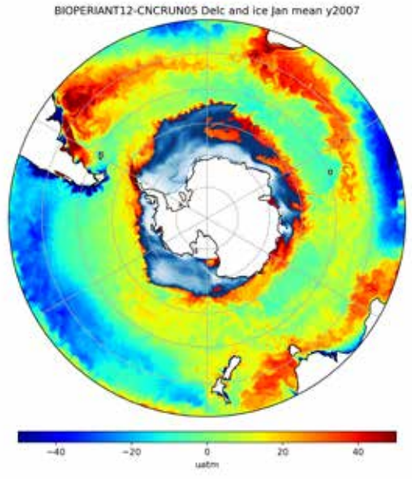
Research undertaken by SOCCO addresses the seasonal bias in observations, a major source of uncertainty in the global ocean sink for CO_2 particularly in the Southern Ocean. Given the critical role of the Southern Ocean in the global ocean sink for anthropogenic CO_2, this became an opportunity for SOCCO to make a significant contribution to both regional and global science.

Over the past 10 years, research at SOCCO has made a contribution to address three main challenges in understanding and predicting the variability and trends of CO_2 in the Southern Ocean. Firstly, reducing the uncertainty of the calculated mean annual fluxes of CO_2 between the Southern Ocean and the atmosphere. SOCCO has made a significant contribution to closing the data gap in the global Surface Ocean CO_2Atlas (SOCAT) dataset across the Southeast Atlantic - Southern Ocean, as well as reduced the seasonal bias by providing regular winter data. South Africa is the only country other than the USA, to do so systematically. Moreover, SOCCO has combined observations with advanced machine learning techniques to develop a globally recognised ocean partial pressure of CO_2 data product that spans the entire ocean with a very low (<10%) mean error.

Secondly, SOCCO has pioneered the use of ocean robotics to observe and understand the processes that link ocean physics to CO_2 variability and trends and possible sensitivity to climate change. This work has shown that the seasonal cycle of CO_2 is strongly influenced by the physical impact of storms and that the inter-annual variability of the CO_2 sink in the Southern Ocean may be linked to variable storm characteristics. The work has also advanced the insight of the sampling frequency that is required to minimise the error in the estimated CO_2 fluxes.

Lastly, SOCCO research has revealed important biases in the 10 - 100 year projections from earth system models and helped provide insight into the modelled processes that explain these biases. This is important because biases distort the end of the century projected magnitudes of the CO_2 sink and in that way can also reduce the robustness of climate projections on that scale. SOCCO will be using these findings to improve the results from the South African Earth system model for the Sixth Assessment Report (AR6). This report, due in 2022, is being prepared by the Intergovernmental Panel on Climate Change, the United Nations body for assessing the science relating to climate change.

Above: A wave glider during sea trials in Table Bay prior to being sent on a mission to the Southern Ocean.

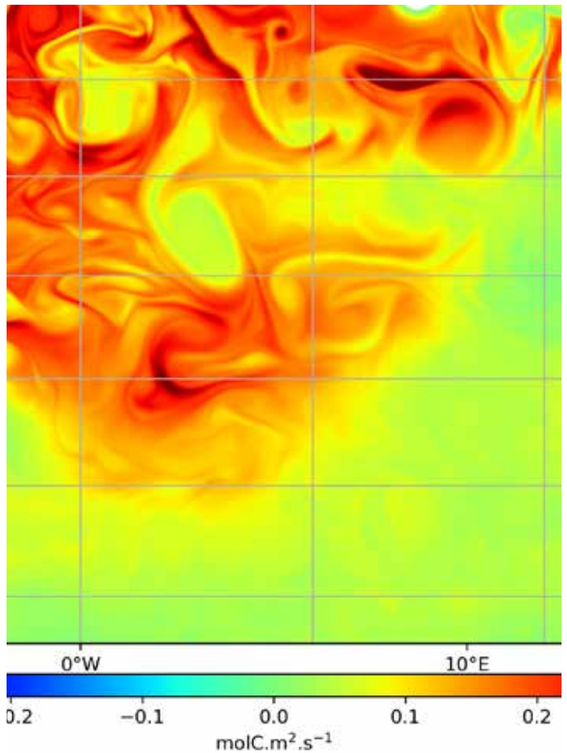


Above: A high-resolution model output of Southern Ocean carbon dioxide, showing areas where the ocean is taking up carbon dioxide (red) and where it is releasing carbon dioxide to the atmosphere (blue).

Above: A diving seaglider is being prepared for deployment off the SA Agulhas II.

Understanding how the Southern Ocean is ***influenced*** and will influence future climate

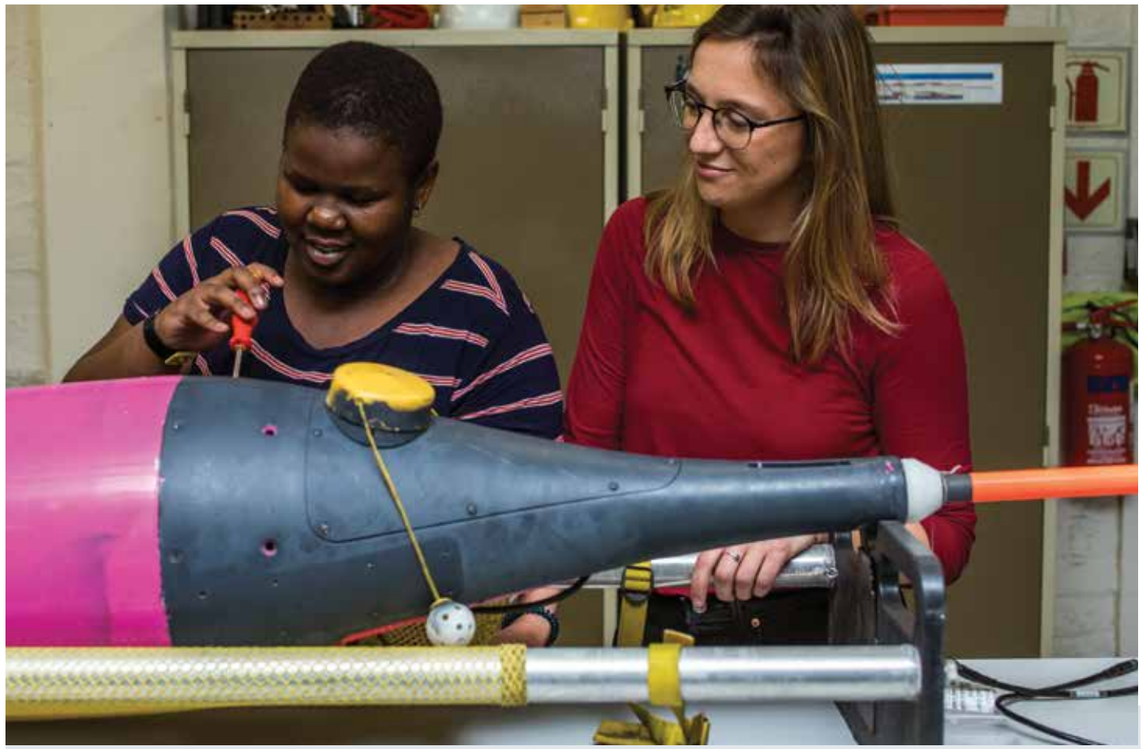
Interdisciplinary research at the Southern Ocean Carbon and Climate Observatory (SOCCO) links fine-scale dynamics in the physics of the Southern Ocean to changes in the carbon cycle through observations and numerical models to enhance the confidence of future climate projections.



Above: An ultra-high resolution model output of the flux of carbon dioxide showing how the fine-scale vortex and instability physics influence the uptake (red) and release (green) of carbon dioxide.

With the rapid onset of satellite observations, the global view that the ocean is dominated by large-scale ocean currents has shifted to a far more complex picture over the last 25 years. It is now widely recognised that the ocean is influenced by numerous fine-scale (few hundred meters to a few kilometers in size) eddies, fronts and filaments. These fine-scale dynamics are highly rotational in nature and swirl the ocean's less dense waters over heavier waters, resulting in horizontal and vertical exchanges that locally increase ocean stratification and vertical transport. The Southern Ocean, in particular, is a region of prevalent fine-scale dynamics due to turbulent eddies which shed off the larger scale Antarctic Circumpolar current that flows around Antarctica. Here, strong winds (hurricane strength) from the regular passage of large atmospheric storms add an additional layer of complexity – the rotating wind interacts with fine-scale dynamics to further amplify the mixing effects.

CSIR oceanographer Dr Sarah Nicholson says, "What is currently missing in this field of research is the ability to effectively and systematically measure these multiscale and multicomponent interactions. There is a severe lack of observations of the various scale-interactions, which has led researchers at SOCCO to develop novel and innovative approaches using multiple state-of-the-art autonomous ocean robots, which can remotely perform these critical measurements of the ocean continuously (multiple months at a time) at high spatial and temporal resolution."



Above: Dr Sarah Nicholson (right), a researcher at the Southern Ocean Carbon and Climate Observatory oversees the dismantling of a profiling seaglider by Pholani Magam (left), an electronic engineering student technician from the Cape Peninsula University of Technology, who is doing her in-service training at Sea Technology Services, a Cape Town-based oceanographic engineering and services company.

The presence of fine-scale-induced rapid re-stratification is estimated to warm the sea surface up to 0.3 °C globally due to less downward mixing and the bringing up of cold water. Increased stratification also increases light availability in the top few hundred meters of the ocean, while enhanced vertical movement of water supplies nutrients to the surface; both actions favour phytoplankton growth and influence air-sea CO_2 exchange. These unique transport properties of fine-scale flows are not captured in Earth system models due to their relatively low resolution and their influence is thus not included in future climate projections. This is a challenge being addressed by the Southern Ocean Carbon and Climate Observatory.

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Understanding the seasonal evolution of ***phytoplankton*** production in the Southern Ocean

Phytoplankton, which are microscopic plants of the ocean, are responsible for roughly 50% of the global primary production of oxygen. Their associated seasonal blooms play an important role in the cycling of elements as they result in the substantial transport of organic material from the sunlit surface waters to the ocean's interior. This flux of organic material, known as the biological carbon pump, contributes to the uptake of atmospheric carbon dioxide, and the Southern Ocean plays a disproportionate role in this flux.

Changes in climate are likely to affect the composition, abundance and productivity of phytoplankton, with feedbacks that threaten the ecosystem services they provide, namely sustaining biodiversity, fuelling the food web and fisheries, and mediating global climate through an altered efficiency of the biological carbon pump.

The conditions necessary for phytoplankton blooms in the Southern Ocean are linked to the availability of sunlight and micronutrients such as iron, as well as low pressure by grazers. As such, a better understanding of the seasonal evolution of phytoplankton production and export can provide a sensitive index of climate change through their dependence on physical processes that transport nutrients and control the exposure of phytoplankton to sunlight.

The only way to predict future trajectories of the global carbon cycle is through model simulations. However, these climate projection models are unable to reflect the seasonal timing and magnitude accurately. CSIR senior researcher Dr Thato Mtshali says, "This highlights our lack of understanding of how the biogeochemical system responds to changes in the physical forcing and the scales at which climate and biogeochemistry are linked. For example, the remineralisation length scales of exported carbon are typically based upon observations in the Pacific, yet it has been demonstrated that there are different length scales north and south of the Antarctic Polar Front during summer. Another example is the parameterisation of phytoplankton chlorophyll to carbon ratios, which, when compared with optically derived measurements, showed inverse relationships."

In order to address these challenges, SOCCO has engaged a multiplatform approach involving multiple field-based programmes. The most recent was a specific seasonal cycle experiment, with research cruises in winter, spring and summer, called the Southern oCean seAsonaL Experiment (SCALE).

SOCCO is a novel interdisciplinary programme that spans seasonal to decadal timescales in the southeast Atlantic sector of the Southern Ocean. In conjunction with multiple national and international partners, it contributes both long-term and experimental observations towards a greater understanding of fine-scale dynamics in shaping the phasing and magnitude of the Southern Ocean seasonal cycle.

Above: Through photosynthesis, phytoplankton in the oceans use carbon dioxide on a scale equivalent to forests and other land plants.

Above: CSIR senior researcher Dr Thato Mtshali.

Above: CSIR principal researcher Dr Sandy Thomalla.

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SOCCO ***pioneers*** the use of **ocean robotics** technology

SOCCO's use of research to determine the solutions needed to understand how the Southern Ocean works, and the role it can play in climate change, have given birth to unique technologies. Researchers have collaborated with Sea Technology Services, a small-to-medium enterprise in ocean engineering services, to create a high-tech observations-driven platform called SA-RobOTIC.

The drivers of SOCCO's technological innovations

In response to the need for world-leading precision in ocean carbon dioxide (CO_2) observations, the engineers at SA-RobOTIC designed and built a new instrument for pCO_2 observations that can cope with the extreme conditions found in the Southern Ocean. The instrument can function autonomously for one year and gives precise results of CO_2 in the atmosphere and ocean.

"From this challenge emerged the VeGAS-pCO^2 series of instruments that has now been expanded beyond robotics to ship-base and terrestrial applications. Manufacturing of the first two units built for export to Germany has started," says CSIR chief researcher, Dr Pedro Monteiro.

In response to the challenge of the present limitations of robotics operations during the low and no-sunlight seasons in the Southern Ocean, SA-RobOTIC, in collaboration with aeronautical engineers at the Centre for High Performance Computing, is developing a bespoke underwater generator called HydroGen, which is capable of delivering sufficient power at the low speed of the wavegliders. This is still in the early development stages (technology readiness level 3), but is ready for the first sea trials.

In response to the need to develop a pervasive observation capability in support of strengthening ocean governance and long-term observations in the exclusive economic zones of South Africa and internationally, SOCCO partnered with defence experts and SA-RobOTIC to build robotics that provide real-time information about the ocean, in order to change the way fisheries and the governance of the ocean are managed.

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Above: Ocean robotics pioneers are from left (front), Waajidah Arends (STS), Dr Sandy Thomalla (CSIR), Craig Lavis (STS) and Zimkhitha Mbekeni (Cape Peninsula University of Technology). Back from left are Andre Hoek (STS), Pholani Magam (Cape Peninsula University of Technology), Marcel du Plessis (CSIR), Sean Lavis (STS), Dr Sarah Nicholson (CSIR), Ryno Els (STS), Derek Needham (STS) and Hendrik Janse van Rensburg (STS).

Above: The VeGAS-pCO_2 wave glider sensor that is being prepared for deployment in the Southern Ocean.

Above:The antenna of a Seaglider, an autonomous underwater vehicle, is inspected before deployment.

Developing South Africa's *Earth System Model*

Researchers at the Southern Ocean Carbon Climate Observatory are collaborating with local and international partners to establish South Africa's first Earth System Model, which will be instrumental in making medium to long-term climate projections in Africa and the Southern Hemisphere. These projections are key in supporting societal needs in health, water resource planning, agriculture, biodiversity management and, more broadly, in economic development in the region.

Earth system models seek to simulate all relevant aspects of the Earth system. Conventional climate models include atmosphere, ocean, sea-ice and land-surface models; an earth system model is a global climate model that encompasses the carbon cycle, which adds carbon in the atmosphere, ocean and land. The ambitious collaborative model will be used in the Coupled Model Inter-comparison Project of the World Climate Research Programme and the *6th Assessment Report* of the Intergovernmental Panel on Climate Change.

Researchers at the Southern Ocean Carbon and Climate Observatory (SOCCO) work with the Global Change Institute at Wits University and with other national partner institutions to build the Earth System Model. It is a scientifically and computationally challenging task – each of the coupled numerical model codes pass information to the other and the computational resources and time required to run such a model is significant. The project is dependent on the resources of the Centre for High Performance Computing of the National Integrated Cyber Infrastructure System to run its massive parallel code.

SOCCO works on the ocean-biogeochemistry components of the model by using numerical ocean models as tools to simulate and explore process and scale questions that help understand the links between carbon and climate in the Southern Ocean, which are then implemented in the Earth System Model for climate projections.

Researchers have developed a hierarchy of ocean-ice-biogeochemistry models at different horizontal resolutions and domain sizes that allow them to explore sub-grid scale processes and develop parameters to relate the fine-scale dynamic to coarse resolution of the model. SOCCO's novel high-resolution measurements of the Southern Ocean have enabled the team to improve how the biogeochemistry in the model is represented and determine where the model needs to be improved. Through the long-running models, researchers can investigate how the climate sensitivities of the Southern Ocean may evolve.

CSIR senior researcher Nicolette Chang says, "In addition to using our scientific knowledge to address gaps in the Earth System Model, we are contributing to the technical aspect of building it by coupling the ocean model with the biogeochemical model PISCES. This involves coding the models to exchange information, so that simulated ocean conditions can mirror biogeochemical processes in the ocean, for example the distribution and variability of CO_2 and the subsequent growth/decline of the biological carbon pump."

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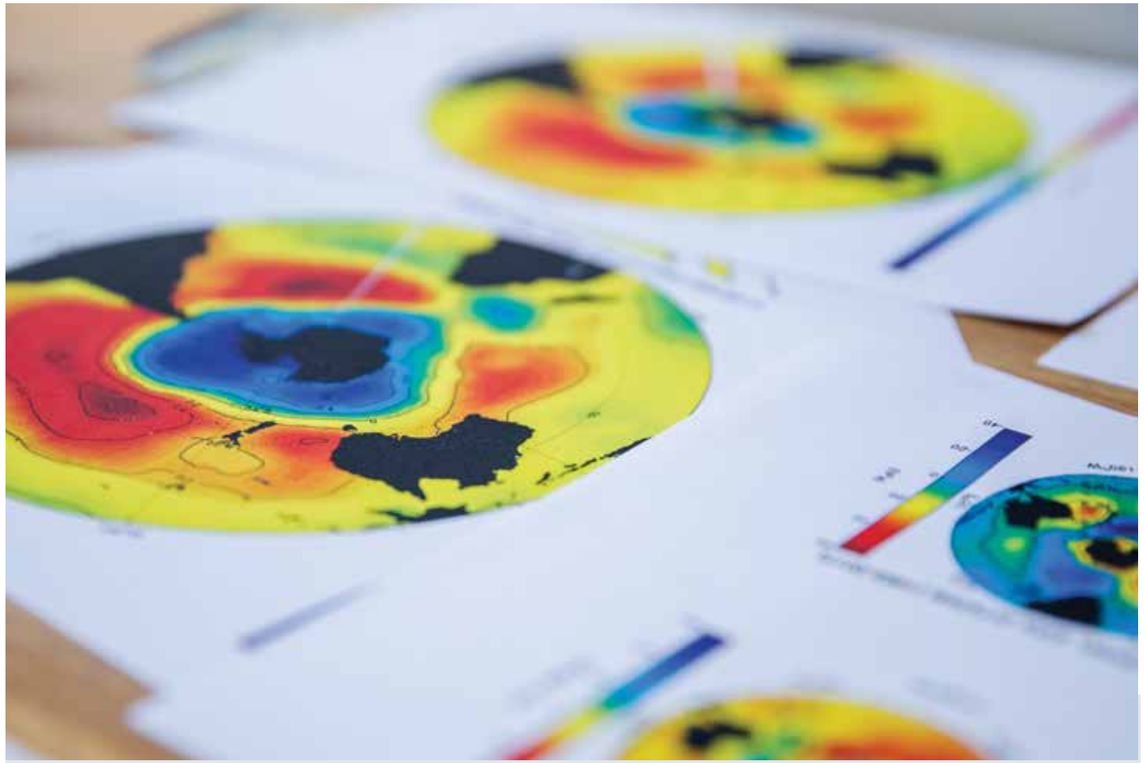

Above: Circumpolar coupled climate model outputs for the polar regions.

Above: CSIR senior researcher Nicolette Chang.

Above: Improved Southern African regional climate projections are the main objective of the South African Earth System Model.

Building a *diverse and dynamic* South African workforce in **marine sciences** through ocean climate sciences

Human capital development is a key national priority in the country's National Development Plan, which calls for an increase in the number of South African PhD and MSc science and engineering graduates. To help ensure that the country meets its goal of a diverse, representative and dynamic South African workforce, suitable for the knowledge economy, the Southern Ocean Carbon and Climate Observatory actively recruits individuals from historically disadvantaged groups, and mainly from historically disadvantaged institutions, as part of its redress agenda. It undertakes an annual nationwide recruitment programme to actively attract students by exposing them to the application of the science in addressing global problems such as climate change.

The SOCCO approach to learning

The Southern Ocean Carbon and Climate Observatory (SOCCO) prioritises developing human capital through extensive student training in interdisciplinary multidisciplinary skills. Its research addresses issues relating to the role of the Southern Ocean in driving 21st century regional and global climate through advanced interdisciplinary research at the intersection of oceanography, physics, biogeochemistry, marine technology, ocean colour remote sensing and numerical modelling. The technological and science platforms that the students are exposed to are helping address transformation needs in scientific and technological research and innovation.

The ability to problem-solve and objectively analyse data sets and understand ecosystem functioning are skills that can be transferred to all sectors of the economy. In addition, postgraduate students gain a high level of competency in written publications and oral presentation essential to producing globally competitive science PhD/MSc theses and peer-reviewed papers, and present their findings to international scientific communities.

SOCCO uses a variety of models of training postgraduate students. These include the traditional apprenticeship model (a one-on-one mentoring relationship between student and supervisor with co-supervisory arrangements and scholarly exchanges), the course-based model (using a structured curriculum) and degree by publication (examined on the basis of a series of peer-reviewed academic papers). In addition, they employ the more recent cohort-based model, which represents a shift from a solitary experience defined by an individual student-supervisor relationship, to a shared (group) experience defined by a specified time cycle. Finally, international summer schools, exchanges and co-supervision arrangements are also a critical part of exposing the students to world-class research spaces and network building.

CSIR researchers Drs Sandy Thomalla and Alice Lebehot agree that, one of the advantages of a cohort model in the South African context is that it provides a critical mass of students and supervisors. From here, SOCCO seeks to consolidate emerging South African expertise in the domain by transitioning graduating PhD students into postdoctoral fellowship positions.

Above: Zimkhitha Mbekeni (left) from the Cape Peninsula University of Technology and Ryno Els from STS checking the underwater connector on a wave glider's electronic enclosures.

Collaboration

To achieve its human capital development goals, SOCCO collaborates with national and international tertiary education facilities.

Nationally: The MaRe Marine Research Institute at the University of Cape Town, Nelson Mandela University, University of the Witwatersrand, University of Pretoria, Stellenbosch University and North-West University.

Internationally: University of Paris VI-Sorbonne, France; University of Princeton, USA and Gothenburg University, Sweden, as well as multi-institutional links with the European Union through research and Marie Curie exchange projects.

Above: Pholani Magam from the Cape Peninsula University of Technology (left) and Andre Hoek from STS inspecting newly assembled printed circuit boards.

PARTNERING & INFRASTRUCTURE

Introducing The *Impact* Catalyst

A mechanism for collective impact

The Impact Catalyst is an initiative founded by Anglo American, Exxaro, the CSIR and World Vision South Africa, to create mechanisms that drive large-scale socio-economic development programmes through public-private partnerships.

How does it work?

A collective impact model is used to drive long-term, high-impact initiatives, enabled though a co-developed systemic strategy. The strategy is developed between the public and private sector and civil society to foster strategic alignment, a shared vision and co-investment of resources.

The Impact Catalyst, together with the provincial government, produces a Collaborative Regional Development platform – a virtual structure through which shared programmes are implemented – to achieve socio-economic change for the specific province of South Africa.

Limpopo Collaborative Regional Development Platform

The first platform was launched in Limpopo in October 2019, in partnership with the Office of the Premier in the province. The focus of this programme is on improving the health, wellbeing and living conditions of communities across Limpopo.

The following are examples of projects being planned as pilots for possible implementation at scale across the province:

The Mooihoek-Groenfontein Integrated Game Farm: This initiative will see a number of game farms supply meat to a central processing facility for the local market and for export to international markets, alongside hunting and eco-tourism.

Community-oriented Primary Health Care: This initiative will focus on community-based services, complemented by the use of mobile technology, delivered to and from homes by clinically led healthcare teams, which also include community healthcare workers from the target community.

Agro-Processing and Biodiesel Production Facility: The focus of this programme is on a multi-purpose facility designed to process selected crops into value-added products, such as oil, canned food, biodiesel and other industrial-related products. It is envisaged that such a facility could contribute towards the creation of much-needed jobs for communities in Limpopo.

Personal Protective Equipment (PPE): The aim is to localise the manufacturing of PPE in partnership with other mining houses, government and relevant industries and, in turn, contribute to local economic growth and job creation in Limpopo.

Fresh Produce Market: The goal is to establish a vibrant and sustainable agri-business where emerging farmers can retail their products to the local market. This will improve general food security in the local community, generate employment and stimulate the economic development of rural communities.

Laser-based Refurbishment and Additive Manufacturing: This project will explore relevant applications for laser-based refurbishment and 3D printing technologies for the repair, surface hardening and enhancement of metal components as an alternative to conventional repair techniques in mining.

Establishing inclusive, collaborative, cross-sectoral platforms, initiatives and partnerships to achieve systemic socio-economic impact is the **main vision** of *The Impact Catalyst.*

Corporate South Africa and the public sector are invited to take part in these initiatives which promise to move the needle on key local, sustainable development challenges in South Africa.

For more information visit
www.impactcatalyst.co.za

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Above: The Impact Catalyst drives large-scale socio-economic development programmes through public-private partnerships.

New **partnership** to enable *spectrum sharing*

The CSIR and the OpenCellular (OC) Project Group of the Telecom Infra Project are working on an initiative that will enable underserved communities in South Africa and other developing countries to gain access to affordable broadband connectivity using spectrum-sharing techniques.

The objective of a new initiative on affordable bandwidth is to formulate and develop a new open standard for a communication protocol and technique that will allow spectrum sharing among generations of cellular network technologies, such as 2G, 3G, 4G, 5G and Television White Space (TVWS) network technologies, using geo-location spectrum databases. Through this open standard, the CSIR's geo-location spectrum database and low-cost spectrum-sensing technologies will enable low-income communities to run their own broadband networks using a combination of affordable hardware developed by the OC and TVWS networking solutions.

CSIR principal researcher Dr Luzango Mfupe says, "We are involved in this initiative because its objectives are in line with our mandate to improve the lives of South Africans. We believe that we have a contribution to make through technologies that allow South Africans to have access to affordable broadband communication and digital inclusion. Communities in peri-urban, rural and hard-to-reach areas are often overlooked by large network operators due to the high costs of rolling out traditional broadband networks in those areas compared to the return on investment. This initiative will allow such communities, as well as small-scale entrepreneurs, to effectively run their own low-cost wireless broadband networks and therefore contribute to closing the digital inclusion gap. Our technologies utilise automatic spectrum-sharing frameworks. Therefore, improving the spectrum utilisation efficiency provides users with greater certainty and ultimately lowers the costs of communicating."

The CSIR geo-location spectrum database: A tool that improves the utilisation of national spectrum

The CSIR has developed geo-location spectrum database technology to improve the effective utilisation of national spectrum resources in the Very High Frequency/Ultra High Frequency bands, and is working on extending the technology to other spectrum bands. Spectrum is the medium over which all wireless communications devices, such as televisions, mobile phones and radios, communicate.

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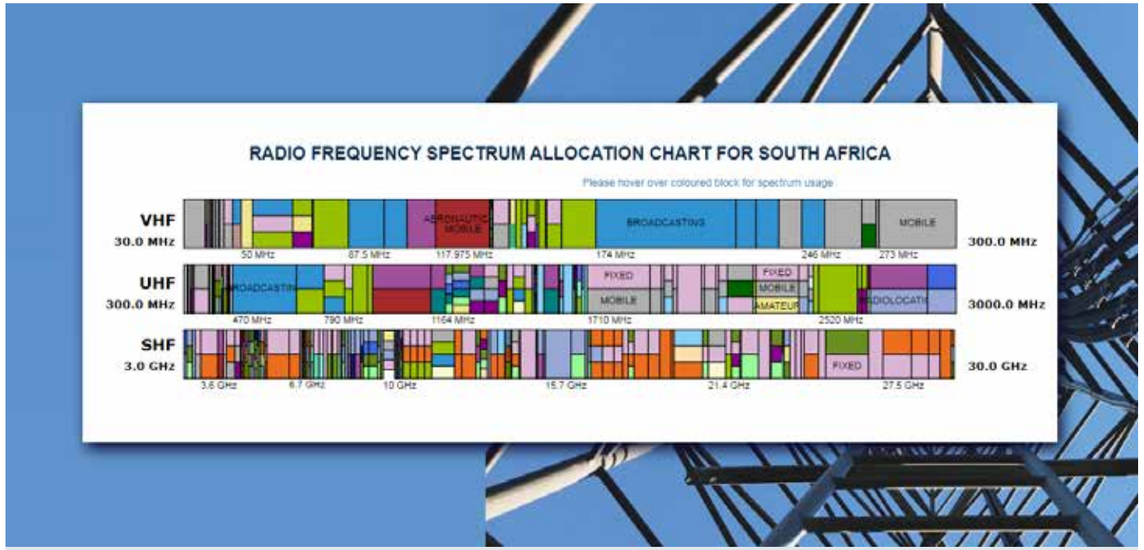
Above: A prototype of the CSIR-developed low-cost spectrum monitoring device.



Above: The national spectrum allocation chart as depicted on the homepage of the CSIR-developed Secondary Geo-location Spectrum Database.

Technology development leads to ***local manufacture*** of chemical oxygen demand kits in South Africa

The CSIR has demonstrated its ability to facilitate technology localisation by assisting a small, medium and micro enterprise in the development of South Africa's first locally produced chemical oxygen demand kit.

The development of chemical oxygen demand kits is a prime example of the CSIR's role, through its Biomanufacturing Industry Development Centre (BIDC), in developing products and supporting small, medium and micro enterprises (SMMEs) as part of efforts to create a vibrant bioeconomy for South Africa.

"The chemical oxygen demand (COD) kit developed by CSIR engineers Prisha Naicker and Frances O'Brien works in six of the top-selling photometer brands and offers customers and researchers an alternative locally produced and cheaper kit," says CSIR research group leader for bioprocessing, Dr Santosh Ramchuran.

COD is a critical waste treatment measurement in everything from municipal systems to food manufacturing waste streams. It is an indirect measurement of the amount of organic matter in a sample. International original equipment manufacturers have been customising these kits for use specifically in their equipment since the 1970s, making South Africa reliant on the importation of both the equipment and these measuring kits at a fluctuating and high cost. Recently, CSIR researchers developed a unique and cost-efficient formulation that will allow local manufacture and supply of these kits.

Under the guidance of the BIDC, led by Lara Kotze-Jacobs, the technology was licensed and transferred to PLS (Pty) Ltd for local manufacture and supply to the African and global market.

"As part of the SMME support programme, the CSIR was able to develop these products for the measurement of both high and medium-range contaminants, which were validated for use in municipal and industrial waste effluents. Furthermore, the techno-economic assessment for the local manufacture of these kits showed that these products were not only cost competitive, compared to imports, but allowed the flexibility of use that was independent of the photometer," says Kotze-Jacobs.

The BIDC assists both SMMEs and established industry to translate early-stage research and development into market-ready products. PLS was selected by the BIDC Steering Committee, following its application for support in June 2018. Their project kicked off in September 2018 and the technology was transferred to PLS in July 2019.

"I had worked with the CSIR before this project and when I heard about this type of support, I enquired about it and decided to apply for development assistance. I had seen the dedication and professionalism of the CSIR in a previous project and I have seen some great successes in various other projects. I felt that the CSIR is an organisation that I would want to be associated with and a suitable partner for the future," says Jaco Swanepoel, Director at PLS.

PLS was established in 1999 as a primary supplier of water-testing reagents and equipment for water treatment companies. The company has access to clients who purchase imported COD kits from them on a regular basis. The market for the kits was thus well established and the route to market already in place.

PLS will now start setting up its facility to locally produce the kits and have already submitted tenders to local municipalities with the intent of supplying the locally developed and manufactured COD kits. There is potential to export the kits to the rest of the continent.

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Above: The team behind the development of the chemical oxygen demand (COD) kit, from left, CSIR engineer Frances O'Brien, CSIR senior engineer Prisha Naicker, CSIR bioprocessing research group leader Dr Santosh Ramchuran, Jaco Swanepoel PLS Director and Lara Kotzé-Jacobs, BIDC Programme manager from the CSIR.

Above: High and medium range COD kits developed.

Anechoic chamber: Developing **sensors and effectors** in the radar and *electronic warfare* domain

The CSIR's anechoic chamber is used to measure antenna performance, including antenna patterns. The organisation's radar and electronic warfare impact area uses these antenna measurements and patterns to develop advanced radar sensors and effective countermeasures against modern radar systems.

The CSIR's anechoic chamber was established in 2018, and while there are other chambers of a similar design available in South Africa, the CSIR and its clients utilise this specific facility for commercially or military sensitive projects.

How does the chamber work?

The tapered anechoic chamber optimises the distance between the device under test and the test equipment over a wide frequency band. The tapered shape is tailored to the frequency and, as it moves up in frequency, the length of the chamber is extended by adding sections with smaller diameter apertures. In other words, the lower the frequency, the larger the aperture and the shorter the test distance.

Inside the electromagnetic anechoic chamber, anechoic cones are placed on the roof, walls and floor to absorb reflections, ensuring that only the intended path effects are measured.

Antennas can be placed on positioners on the tapered point and inside the chamber, which allows them to be rotated around multiple axes. There is also an X-Y positioner, which can position an antenna along two axes.

An operator can control the positioners, as well as the test equipment, using a computer. The heart of the testing and measurement setup is a network analyser that was repurposed from the previous anechoic chamber.

The benefit of having the chamber on-site at the CSIR lies in the ability to expand its use to measure system-level parameters and in its other uses, such as antenna array measurements. The chamber is shielded, forming a Faraday cage, keeping unwanted emissions from the outside, such as those from mobile phones, from entering it.

> "The anechoic chamber is made up of multiple anechoic foam cones, which suppress reflections in order to obtain accurate measurements."
>
> -Johann de Jager

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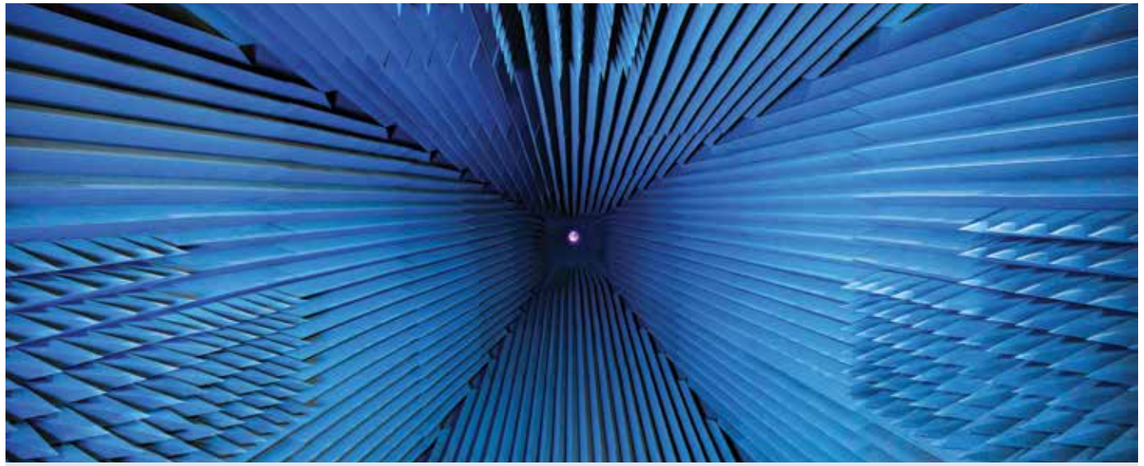
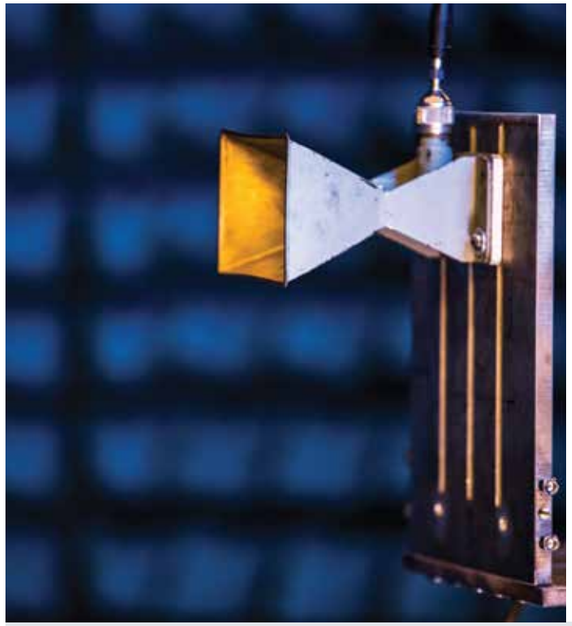
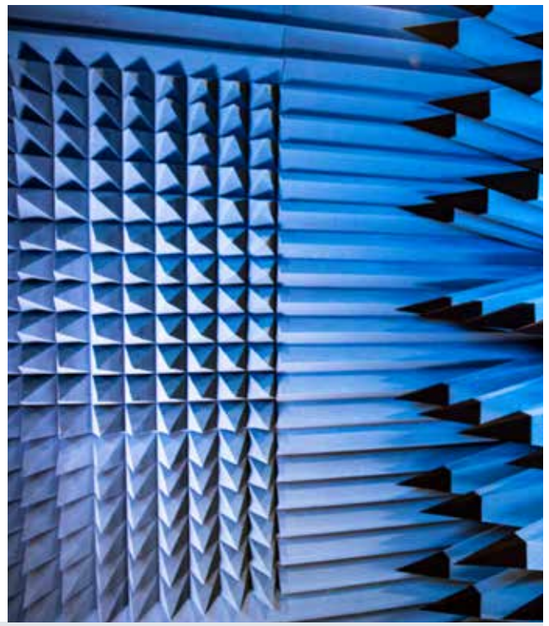


Above: The inside view of the anechoic chamber, looking towards the source.





Above (Left): A 1-18 GHz horn antenna mounted on a bracket on the positioner.

Above (Right): A view of the radar-absorbing material inside the chamber. On the right is the rear of the anechoic chamber. These radar-absorbing material blocks are longer because they have to absorb the radio frequency waves directly from the front.

OPINION

The worldwide **herbal** market: *Trends and opportunities*

By Dr Sechaba Bareetseng, Programme Manager: NEPAD SANBio, CSIR

The worldwide herbal medicine market has continued to grow over the years, with the demand also increasing in developing countries. This is partly because of population growth, the preferred health benefits of herbal products, as well as such products being considered safer and more cost-effective than pharmaceutical drugs. The United States of America is the largest market for herbal medicines, followed by Europe, Australia and Canada.

Reports indicate that between 75 and 80% of the world's population rely on herbal medicines to meet their primary healthcare needs. For instance, today, pharmacies in developed countries sell plant-derived drugs over the counter.

According to the World Health Organization (WHO), about 11% of the about 250 drugs that are considered essential for basic healthcare are of plant origin. Examples of drugs that are used in their natural state include quinine and artemisin (antimalarials), reserpine (antihypertensive), paclitaxel, docetaxel, irinotican and etoposide (anticancer drugs), digitalis (cardiotonic), morphine (narcotic analgesic) and turbocurarine (muscle relaxant).

The WHO refers to herbal medicines as preparations and/or finished products made of whole plants, parts of plants, or other plant materials, including leaves, bark, berries, flowers and roots, and/or their extracts as active ingredients intended for human therapeutic use or for other benefits in humans and sometimes animals. Herbal medicines are also known as botanical medicines and make use of medicinal plants linked to the traditional knowledge of local and indigenous communities, which guide a product development process to treat a specific disease. Developed countries, such as France, Germany, Italy, the United Kingdom and the United States of America (USA) make up the largest market for herbal medicines.

It is projected that emerging economies such as Brazil, China and India will have faster growth than developed countries in the coming years in both the consumption and production of herbal medicines. China is set to become the largest global producer and consumer of herbal medicines during this year. The global herbal medicine market is estimated to be worth $26 to 30 billion according to various market sources.

The increased interest of pharmaceutical companies in medicinal plant use in the last two decades can be attributed to the public and scientific community's increased awareness and interest in medicinal plants. More than 250 pharmaceutical companies are starting scientific research and development programmes targeting plant species to develop into herbal medicines with active ingredients of therapeutic value in line with the market requirements. In the USA alone, more than 25% of prescription drugs contain active ingredients that are derived from plants.

Like Brazil, China and Indonesia, South Africa is rich in plant species and the demand for medicinal plant species by pharmaceutical companies, locally and internationally, is rising. The economic value of trade in raw medicinal plant species in South Africa is estimated at R520 million, contributing towards the

worth of the herbal medicine market at R2.6 billion per year. With an estimated 27 million consumers of herbal medicines, the trade is vibrant and widespread. There are at least 133 000 people employed in the trade, a large percentage of them being rural women. The plant trade is a key rural industry and business incubator. As in many countries, herbal medicines are widely available in supermarkets, pharmacies and health shops. The bulk of traditional medicines are herbal. Each year, around 20 000 tons of plant materials are collected from the 771 plant species used by local traditional health practitioners to develop new herbal medicines.

There are various key drivers of the interest in the development of the herbal medicines market, including a desire to bring diversity to a product portfolio, particularly when these medicines can be protected through the relevant intellectual property rights laws with regards to their formulation and processing technologies. Other drivers include an increasing belief among the public that naturally derived compounds are better than those that are synthetic and have proven lower toxicity profiles compared to pharmaceutical drugs. Furthermore, many substances for many ailments have a long history of successful and safe use; increasing healthcare costs could potentially be offset by the use of naturally derived as opposed to synthetically created compounds; markets in countries like China and India are increasingly becoming open for the exchange of medicinal plants materials; and the development of many botanicals is potentially less costly, given that extracts are not subject to isolation, but can be moved directly to testing for clinical efficacy.

The new regulatory process for herbal medicines in South Africa is much the same as for synthetic drugs. However, it has certain freedoms, such as reduced time-to-market for drugs with established safety, efficacy and quality profiles in humans and no requirement to further purify extracts. Like the regulatory process for synthetic drugs, the new process also includes Good Manufacturing Practices, Good Laboratory Practices and Good Agricultural Practices in terms of the allowances and constraints made on the manufacture of plant-derived drugs. More specifically, according to the new Food and Drug Administration guidelines, to prepare for a Phase 1 or 2 clinical trial with a botanical product, *(continued on page 70)*

companies need to submit information on the active constituent or marker compound, all documentation on the historic and current use of those elements and some chemical, manufacture and control information. For Phase 3 trials, regardless of whether the product has been used as a dietary supplement, more chemical, manufacturing and control information is needed on preclinical safety and additional toxicology studies.

The WHO reported that member states with regulations or laws for herbal medicines increased from 65 in 1995 to 124 in 2018. Regulations of herbal medicines, according to the WHO, mean principle, rule or law designed to control or govern manufacturers and producers of herbal medicines. In other words, regulations require herbal medicines to be safe, effective and of good quality for human consumption, and this principle is common across all the signatories to the WHO. South Africa is such a country, regulating herbal medicines under the Medicines and Related Substances Act, 1965 (Act 101 of 1965), of which the South African Health Product Regulatory Authority operationalises this law by regulating all medicines, and medical devices in South Africa by ensuring that they meet standards of safety, efficacy and quality. While countries may have the regulatory systems for herbal medicines, the harmonisation of regulations across countries globally is promoted as a way of streamlining and providing clarity on what are currently extremely inconsistent regulatory frameworks. Regulations within the European Union, for example, are considered some of the most stringent in the world, while the relatively lax US regulatory environment is sometimes referred to as the "wild west".

Regulators across the world require a range of data from companies to ensure the identity, purity, quality, strength, potency and consistency of botanical drugs. Proving efficacy requires additional clinical trials that are time-consuming and might run into many millions of dollars, and so are undertaken by only the largest companies. In addition to that found in large companies, advanced research is undertaken by government and academic research programmes; companies will also make use of pharmaceutical company's research and development on products that have been abandoned.

Traditional knowledge is the primary guide to new product development; it is integral to acquiring approval from regulatory agencies and is used when marketing products to consumers by validating claims for safety and efficacy. Therefore, it is the foundation of the herbal medicine industry. Unlike most sectors that demand access to genetic resources, herbal medicines continue to depend on traditional knowledge. As such, the regulators are required to address the implementation of the Nagoya Protocol on Access and Benefit Sharing to promote the equitable and sustainable use of genetic resources. The Nagoya Protocol also offers opportunities for the herbal medicine industry to better clarify their obligations and responsibilities to the traditional health practitioners who are the holders of traditional knowledge.

Herbal medicinal products are gaining global importance because of their health benefits. The demand for access to new medicinal plant species and traditional knowledge persists, but awareness of the Nagoya Protocol on Access and Benefit Sharing and the legal and ethical obligations associated with using traditional knowledge, and bringing new species to market, remains limited.

Above: Herbal products produced at the CSIR following earlier research.

R&D on African ginger

The CSIR collaborates with a traditional healers committee that has networks across South Africa. Through this collaboration, African ginger was identified as having been used traditionally for mild allergic asthma, colds, influenza and sinus problems. The method of preparation of the traditional remedy includes cold and hot infusions of the rhizomes and roots, steaming of the rhizomes and inhaling the vapour, and chewing on the fresh rhizomes. The CSIR has fully characterised African ginger through research and development. Scientists have undertaken animal studies for allergy and asthma and the remedy is now ready for development into herbal medicine through clinical studies and registration as a complementary medicine, as part of the implementation of the Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from their Utilisation (also known as the Nagoya Protocol on Access and Benefit Sharing) of 2010 by the South African National Department of Environment, Forestry and Fisheries. Capitalising on the scientific evidence produced by the CSIR, African ginger provides an ideal opportunity for the development of herbal medicine.

Above: Dr Sechaba Bareetseng

> "Traditional knowledge is the primary guide to new product development... Therefore it is the foundation of the herbal medicine industry."
>
> - Dr Sechaba Bareetseng

Industrialisation – Is there **hope** for *Africa*?

By Zvikomborero Tangawamira, CSIR programme manager

The World Bank estimates that Africa's working-age population will increase by nearly 70% by 2035. Without industrialisation to create jobs, it will be difficult to achieve sustainable development. East Asian countries experienced rapid industrialisation, led by the manufacturing sector, but in Africa, manufacturing to promote economic growth continues to be challenging for many countries.

Africa has 33 of the 47 least-developed countries in the world. These countries face significant structural impediments to growth and contribute less than 1% of world trade and global gross domestic product. Despite some African countries, like Ethiopia, showing impressive growth, many struggle with the challenges of poverty, unemployment, inequality, commodity dependence and environmental degradation. With a growing youth population, most governments in Africa are concerned about where the jobs will come from.

Central to creating jobs are industrialisation and economic growth, which, in turn, are crucial for improving health, education, nutrition, survival, standards of living and poverty eradication. Ultimately, this is where we all want to see the African nations get to – a state where people no longer live on a dollar a day or less and where people no longer die from diseases that can easily be treated. To get to this state, it is imperative to transform factors that determine productivity, such as infrastructure development, health and wellbeing, skills development, information communication technology adoption and increased industry competitiveness. This will ensure that our industries can compete equally in global value chains and create jobs for our people.

Most African countries do not have large industries and are not taking advantage of the fourth industrial revolution to leapfrog their current state to one of economic growth. In addition, the 2019 Global Competitiveness Report showed that sub-Saharan Africa is overall the least competitive region. It needs to improve its institutions, infrastructure, information and communication technology adoption, skills, innovation capacity and market size.

Although the region has these challenges, it is not all gloom, as these challenges present opportunities, particularly for start-up companies and small and medium enterprises, to provide solutions for the region and international markets. We see this with the Kenyan financial sector whose innovation capacity exceeds that of some developed countries, and other African markets, like Ethiopia, enhancing their services and light manufacturing industries by supporting industrial zones and attracting international companies to support local value chains.

Support at a regional level

There are also opportunities to integrate value chains and support enterprises at regional level as countries within the region are at different levels of growth and have varying priorities that limit their investments in research, development and innovation and the associated infrastructure. In the Southern African Development Community region, South Africa has invested significantly in platforms that can support start-up and small-scale enterprises. These include the four technology development platforms available at the CSIR that support technology development from lab to market. These platforms are the Biomanufacturing Industry Development Centre (BIDC), the Biorefinery Industry Development Facility (BIDF), the Nanomaterials Industrial Development Facility (NIDF) and the Photonic Prototyping Facility (PPF), which can be accessed by enterprises and industry to develop high-quality innovative products for global competitiveness. The PPF supports an industry of which Africa has a market share of below 1% and with a negative balance of trade due to imports. The BIDF is creating new products from biomass waste, such as high-value chemicals. The BIDC is supporting the development of food and cosmetic products from different ingredients, including indigenous plants. The NIDF is supporting the development of new technologies, rooted in nanotechnology that will change the norm for different industries, from plastics to construction.

Across the border, Botswana is also investing in its innovation ecosystem, with various players like the Botswana Innovation Hub (BIH) supporting enterprises to be competitive locally and internationally. The BIH, like the CSIR, does not work in isolation, but feeds into an ecosystem that includes universities, governments, funders and other stakeholders to support the development of enterprises for national economic development. Access to accredited quality testing and safe assessment facilities are key enablers to the success of enterprises in the national innovation ecosystem.

Above: Zvi Tangawamira

Collective Strength

Ultimately, for Africa to be more competitive globally, we have to build on our strengths, while leveraging on the investments and strengths of our neighbours to ensure that we create efficient and competitive industries. As it is, the African Continental Free Trade Area that went into force in May 2019 opens a more than $1 billion market for local enterprises. While we may not yet be able to invest in research, development and innovation at the same level as other developed countries, collectively we can leverage the investments made in each country to support our industries to grow our economies and create jobs for the current and future working populations.

So, is there hope for Africa to industrialise? I say, "Yes, there is!"

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Stimulating **translational** research and development in South Africa's ***polymer*** industry

By Dr Vincent Ojijo, CSIR Research Group Leader: Advanced Polymer Composites

The South African plastic industry is vibrant and has a significant impact on the economy of the country and the social wellbeing of its citizens. It contributes about R70 billion to the GDP and employs about 60 000 people. However, it is facing a number of challenges and constraints, such as a lack of downstream research and development (R&D) activities as well as translation of the R&D outputs into marketable goods and services. More is needed, in terms of downstream R&D, to make the industry more competitive.

Typically, early stage research ought to occur in institutions of higher learning, with the expectations that industry, together with science councils and other suitable players within the National System of Innovation, will utilise the knowledge generated to develop marketable products and services. However, a technology 'valley of death' is often reached during the experimental development stage due to lack of appropriate infrastructural capacity to demonstrate the technology at a pilot scale, among other things. Yet, this is the stage that the market, especially the would-be innovators and early adopters, is waiting eagerly for – to feel and experience the newly developed technology first hand. This is the stage at which product and process optimisation and eventual technical validation ought to be done. Without piloting, we would not be able to test the market cost-effectively; neither would we be able to get feedback on the reception of the technology in the market. To partly bridge this innovation chasm, the Department of Science and Innovation (DSI)-funded Nanomaterial Industrial Development Facility (NIDF) was established at the CSIR, with an initial strong focus on nanomaterials production and demonstration at pilot-scale, as well as the utilisation of these materials polymer nanocomposites in research development and innovation, among others.

Established in 2014, by the then Department of Science and Technology, the NIDF has two pilot-scale facilities, one for the production of chemicals and nanomaterials and a polymer processing facility. The polymer processing facility comprises co-rotating twin-screw extruders, injection moulding machines, three-layer and five-layer cast sheet and blown film co-extrusion lines, as well as melt-spinning equipment and roto-moulding equipment; and is supported by a well-equipped characterisation lab.

The primary objective of the NIDF is to make industry competitive. It does this through a multipronged approach, namely advancing the readiness levels of technologies developed by the industry, the CSIR or universities by scaling up lab outputs to pilot scales; assisting with the localisation of technologies; assisting with toll manufacturing of products for market test and validations; offering material testing and characterisation; and training interns to industry-ready status. Importantly, it also acts as a critical node in the industry/university/science councils interactions, which allows for the diffusion of polymer material and process technologies.

Above: Feeding of the coextrusion film blower with polymer pellets to make a high-barrier packaging film.

Above: CSIR chemical engineering technologist Mbongeni Mahlangu at the NIDF chemical scale-up plant.

Above: The control panel of a five-layer film blower inside the NIDF.

Above: Dr Vincent Ojijo.

The facility has had a number of success stories, including the conclusion of industry-sponsored product development projects, training of over 50 interns, generation of more than 10 technology demonstrators, licensing and transfer of products, and assisting small, medium and micro enterprises and universities with the scale-up of technologies. The facility is also currently assisting an industrial partner with localising polymer material technology. This is despite some challenges that it has experienced over the years, including a lower than desired industry utilisation rate.

I believe that pilot-scale facilities, such as the NIDF, will continue to fulfil a key role in enhancing technology readiness levels to bridge the technological 'valley of death' and help diffuse these technologies within the National System of Innovation. This fulfils the aspirations of the new CSIR Strategy, which are about growth, focused on industrial development.

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