ScienceScope

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SOUTH AFRICA'S COUNCIL FOR SCIENTIFIC AND INDUSTRIAL RESEARCH

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Cover page: The cone calorimeter is a fire test instrument used to measure important fire parameters of materials, including the rate of heat release, time to ignition, mass-loss rate, smoke production and the concentrations of asphyxiants (carbon monoxide and carbon dioxide). The instrument is used extensively in the research and development of fire retardant systems for biopolymers and natural fibre composites, most notably for the aerospace industry.

Above: Senior researcher Steve Chapple and doctoral student Mfiso Mngomezulu at work using the instrument.

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FOREWORD

Equipped for world-class innovation

The link between a country's investment in research and development (R&D) and its economic growth and prosperity is widely acknowledged. The ability to innovate will continue to be a key determinant of the global competitiveness of nations in decades to come.

ONE OF THE UNDERLYING cornerstones of this ability to innovate is state-of-the-art infrastructure and equipment. For research to translate into solid scientific output – world-class publications; technology demonstrators; intellectual property – sound research infrastructure is required: laboratories, testing facilities, scientific instruments, equipment, machinery, clean rooms, pilot plants and other brick-and-mortar facilities.

This edition of *ScienceScope* demonstrates the central role that our infrastructure plays in our R&D activities.

Thanks to the continued support of particularly the Department of Science and Technology, but also other sectors of government, the CSIR has the capacity to undertake world-class R&D using world-class facilities – placing our scientists on par with their international peers. The CSIR has invested more than R800 million in property, plant and equipment during the past five years, a significant increase compared to previous periods.

We value our existing infrastructure, some of which dates back decades, but has been continuously enhanced in line with the technological requirements of the digital age. One such example is the CSIR's suite of wind tunnels, which has supported the aerodynamic design efforts of the South African aeronautical industry since the late 1960s and continues to do so today, thanks to continued upgrades and additions. Today, an upgraded computational fluid dynamics laboratory adds even further sophistication to the ability of engineers to design safe, light, modern aircraft at a lower cost. Read about this on page 77.

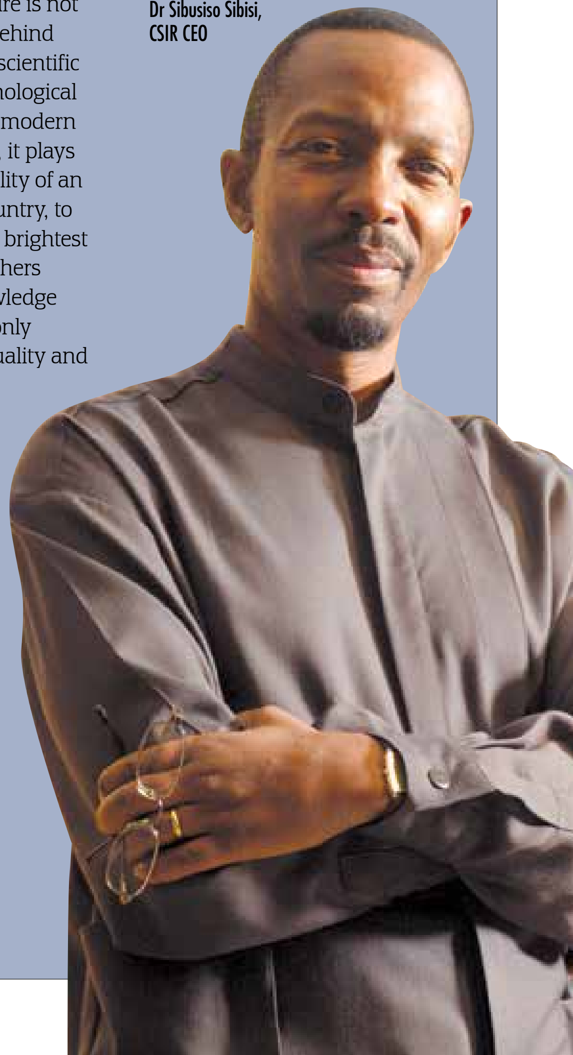
Some facilities have emerged as a result of rapid advances in technologies and others have come about as traditionally 'different' sciences met and overlapped to form new specialist areas. The advances in biology and information and communications technology have, for example, opened up a host of new possibilities in terms of health research. Read how the CSIR's synthetic biology laboratory has pioneered several machines and techniques in South Africa, which have already led to new discoveries (page 60).

The need for collaboration is an important consideration in the acquisition of highly specialised and expensive equipment and infrastructure. Collaboration between the research sector, industry and government on the shared use of facilities helps build bridges that will ultimately see the country benefit. Read how the CSIR's user facility for laser technology allows scientific communities access to specialised laser facilities (page 17), and how researchers from universities and industry use the facilities at the National Centre for Nano-Structured Materials (page 34).

Research infrastructure is not only a driving force behind some of the greatest scientific discoveries and technological developments of our modern world, but ultimately, it plays a huge role in the ability of an organisation, or a country, to attract and retain the brightest minds. These researchers know that new knowledge and innovation can only emerge from high-quality and accessible research infrastructure, and that their ability to make a difference depends on it.

World-class infrastructure is a necessary ingredient for the CSIR to fulfil its mandate of fostering industrial and scientific development through multidisciplinary research and technological innovation. In its absence, the mandate's call for the organisation to contribute to the quality of life of the people of South Africa will not be realised.

Dr Sibusiso Sibisi,
CSIR CEO



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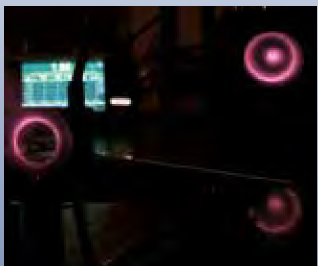
Additive manufacturing is finally finding a place in the mainstream manufacturing conversation in South Africa and looks set to define the manufacturing future in this country. The CSIR houses an additive manufacturing research and development facility and is championing this technology in collaboration with industry partner, Aerosud.

BREAKING THE MANUFACTURING MOULD ONE LAYER AT A TIME

State-of-the-art laser equipment ushers in a new era of manufacturing



THE ADVANCEMENT of additive manufacturing in South Africa, through the CSIR, will provide great benefits for the entire production value chain for both small and big manufacturing industries. CSIR engineers say that the geometrical freedom, brought about by additive manufacturing, allows them to engineer parts as they envision them, without many of the manufacturing constraints enforced by conventional manufacturing technologies.

A major benefit of this type of manufacturing is the ability to produce highly complex shapes and geometric features, while optimising material usage in the manufacturing process. Almost without exception, if a part can be modelled on a computer in three-dimensional (3D) form; it can be sliced and printed, layer by layer. This advantage, combined with the fact that there is very little raw material wastage in additive manufacturing, makes this technology attractive for the aerospace industry. The aerospace industry is particularly interested in using this manufacturing technology to produce lightweight, complex parts from high-performance materials, such as titanium.

It is against this backdrop that the CSIR is collaborating with Aerosud to establish the technology. Once established, the CSIR is set to collaborate with original equipment manufacturers in the aerospace industry such as Airbus, the European Aeronautics Defence and Space company (EADS) and Boeing, as well as local aerospace companies, such as Aerosud to develop manufacturing and qualification processes. Additive manufacturing is also particularly attractive for the medical industry, where the technology lends itself to the manufacture of customised implants and prosthesis from high-performance materials.

CSIR focus

The CSIR's focus is on high-speed large-area selective laser melting processes for titanium components, as well as laser metals deposition for new near-net shape and refurbishment applications. This innovative technology will be used for the production of uniquely finished goods for the aerospace, defence, automotive and medical industries. With regard to refurbishment application, the CSIR cooperates locally with, among others, ESKOM, ArcelorMittal, and many smaller industrial and manufacturing companies to develop new technologies for refurbishment applications in industry.

For the aviation industry, parts manufactured using the additive manufacturing facilities not only result in lighter aircraft and less fuel, but the design freedom allows new design approaches

A collaboration between government, aircraft parts manufacturer Aerosud and the CSIR, the Aeroswift project involves an additive manufacturing platform which allows for the manufacture of niche, high-value, low-volume parts from powdered titanium. Key to this project, is a 5 kW IPG single-fibre diode laser to use in the laser sintering machine.

(From the top) Rocky Ramokolo, senior laser technologist, focusing an infrared viewer on the laser beam; a partial view of the optical set-up for component testing; the project team at work; and the collimator of the fibre laser.

Ramokolo aligns the camera for beam shape measurement and Marius Vermeulen from Aerosud observes the power meter display.

A view of the power meter screen.

Meet facility technologist Rocky Ramakolo

Ramokolo is a CSIR senior technologist who has worked on numerous high-profile projects since joining the CSIR in 2004. He currently is part of project Aeroswift, in which experts from aircraft parts manufacturer, Aerosud, and the CSIR are working towards the development of an additive manufacturing pilot plant for the manufacture of niche, high-value, low-volume parts from powdered titanium.

that can improve production processes as well as reduce environmental impact. It allows the manufacture of parts with built-in movement without the need for post-production assembly.

Each layer is melted to the exact geometry defined by a computer-aided design model. Additive manufacturing allows for building parts with very complex geometries without tooling, fixtures and without producing any waste material.

The how of additive manufacturing

Additive manufacturing is done in various ways. In the Aeroswift project, additive manufacturing is undertaken through selective laser melting. In selective laser melting, parts are built by melting thin layers of powder. Successive layers allow one to 'print' a component layer by layer. Other additive manufacturing processes involve depositing thin layers of liquid via a heated nozzle. This is called fused deposition modelling and it uses mainly plastic materials through a heated nozzle, or powdered metals during a laser metals deposition process.

Just what the additive manufacturing future will look like and how South Africa, through the CSIR, might get there, is the subject of a technology showcase at the CSIR, where the organisation and its industry partners have invested in state-of-the-art laser machines and in human capital that matches the excellence of the infrastructure to drive this initiative.

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What is additive manufacturing?

Additive manufacturing is the process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies, such as traditional machining. Additive manufacturing is also known as rapid prototyping, additive fabrication, layer manufacturing, freeform manufacturing and 3D printing.

Advantages of using additive manufacturing:

Short lead times	Products can be manufactured with very short lead times. Typically, lead times are in the order of days, or even hours, rather than weeks as is the case with conventional technologies.
No tooling	Products can be manufactured without any tooling, which has a big impact on the cost of the parts.
High complexity	Highly complex parts can be manufactured; even parts that cannot be manufactured using conventional methods.
Freedom of design; Moving parts	Typical design rules do not apply. Almost any shape can be manufactured. Fully functional parts can be manufactured that include moving parts, such as integrated joints and couplings.
Customisation	Different configurations and versions of parts can be manufactured without additional costs as no tooling is required.
Materials	A wide range of materials can be used including polymers, plastics, flexible materials, metals, etc. A wide range of colours are available and it is even possible to print full colour models.

Fact box courtesy of RAPDASA

Africa's first laser-engineered net-shaping system to strengthen local manufacturing layer by layer

The acquisition of a laser-engineered net-shaping system by the CSIR has tipped the additive manufacturing scales in South Africa. It is lauded by laser engineers at the CSIR as a possible 'game changer' and revered by industry partners as key to improved competitiveness.

SINCE THE ADDITION of the laser-engineered net-shaping system (LENS) to the CSIR's arsenal of leading-edge laser processing equipment, local players in power generation, manufacturing, aerospace and the medical sector have been engaged in discussions with the organisation as the need to use this technology in a variety of applications becomes more imminent. The realised time and material savings due to the utilisation of this technology is impressive by all standards.

"The pressures of the changing world are leading manufacturers to develop novel approaches to stay competitive in the marketplace," explains CSIR welding engineer, Charl Smal. "Reductions in both time and cost to bring products from design to production, while allowing for maximum flexibility, are what set manufacturers apart from their competitors."

No other additive process combines excellent material properties with near-net-shape, directly from computer-aided design (CAD), part building and repair quite like this process. Applications include the repair of worn components; performing near-net-shape freeform builds directly from CAD files and the cladding of materials.

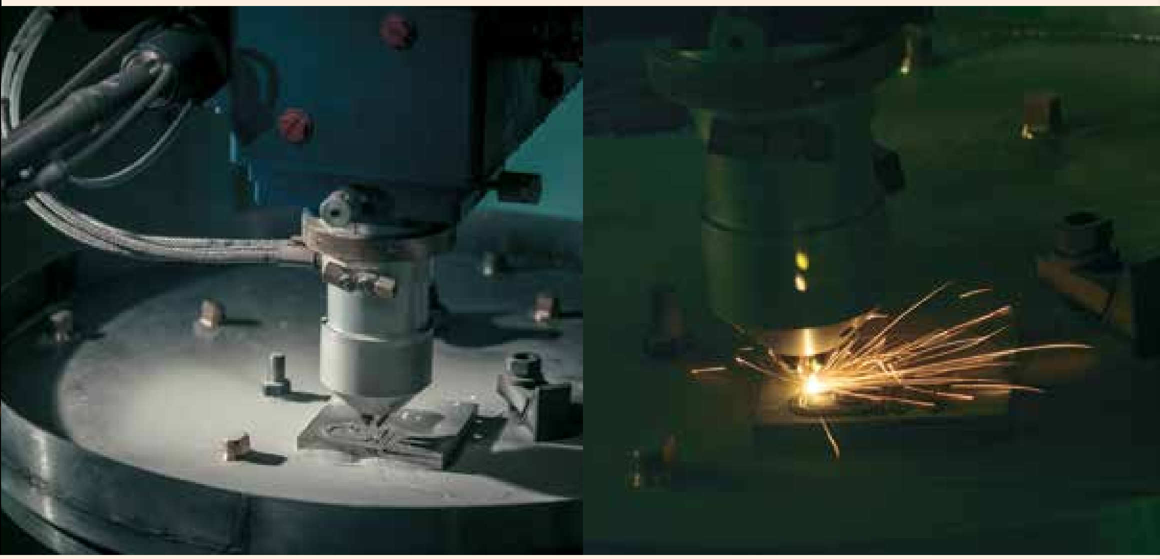
Looking through South Africa's first LENS

"The LENS is the first such unit in the country," Smal explains. "It uses a blown-powder principle, which makes repair on worn parts possible." The alternative technology for additive manufacturing (powder-bed systems) does not allow for repair work to be done.

He further notes that the unit is big enough to perform small batch industrial work – actual manufacturing. "Apart from a controlled atmosphere, the unit has additional diagnostic equipment (temperature measurement) that aids research investigations. Two powder feeders are also available on the system, enabling us to make alloys or vary alloy compositions 'on the fly' to accommodate researchers," he says.

The LENS brings with it versatility and flexibility. The benefits are evident in applications where a variety of materials are deposited on several different geometries at a wide range of process parameters. Another plus is the possibility to perform build-up and repair on titanium components in an oxidation-free environment that opens up many potential aerospace applications, as well as various commercial projects.

The real value of the LENS is to make small to medium-sized high-value parts and moulds. High-temperature alloys in particular are difficult to machine. The near-net-shape option available with additive manufacturing can eliminate this



The technology used in the laser-engineered net-shaping system (LENS) involves a high-power laser (500 W to 4 kW) to fuse powdered metals into fully dense, three-dimensional (3D) structures. The LENS 3D system uses the geometric information contained in a computer-aided design solid model to automatically drive the LENS process as it builds up a component, layer by layer (as shown in the pictures).

costly operation. The complexity of specific geometries is no longer a big obstacle to manufacturers. The process also proves its value when design changes are necessary during product development. A CAD file is changed with minimal effort, compared to the need for cumbersome remachining when conventional technology is used. This is not only cost-effective, but will save months of development time on some projects.

This freeform ability may revolutionise existing manufacturing processes by employing the concept of simplifying castings and forgings and then merely adding the small, complex features in a final additive manufacturing step.

Four nozzles direct streams of metal powder into a high-power laser beam which also heats the substrate material below the nozzles to create a tiny weld pool for material build-up. Both the nozzles and the substrate can be moved in a synchronised way to define the next layer of the part for metal deposition. The process is repeated layer by layer until the total component is built. Engineers slice a three-dimensional CAD model in horizontal sections to create the instruction for this process.

The process produces materials with outstanding mechanical properties – solid parts with high strength and ductility. Another advantage is the ability of the process to mix powder streams of different alloys.

Rapid prototyping has revolutionised the approach to fabricating geometrically complex hardware from a CAD solid model. The various rapid prototyping techniques allow component designers to directly fabricate conceptual models in plastics and polymer-coated metals. However, each of the techniques requires additional processes, such as investment casting, to allow the fabrication of functional metallic hardware. This limitation has provided the impetus for further development of solid freeform fabrication technologies which enable fabrication of functional metallic hardware directly from the CAD solid model. The LENS process holds promise in satisfying this need. This emerging technology has the capability to fabricate fully dense components with good dimensional accuracy and with unique material properties.

The acquisition of the LENS was made possible by the CSIR, the National Research Foundation, the Department of Science and Technology and the Aerospace Industry Support Initiative, with the dedicated effort of Prof Sisa Pityana, who is the principal investigator of the project.

CSIR engineers have already conducted the first upgrades – to make the LENS more stable and increase its robustness in a research environment.

– Mzimasi Gcukumana

Meet LENS manager **Charl Smal**

Smal is an international welding engineer at the CSIR and has worked on laser processing technologies since 2006. He obtained his MSc degree in welding technology from Cranfield University in the United Kingdom (UK) in 1988 where he specialised in welding arc diagnostics. Project leader on additive manufacturing, Smal is interested in the laser processing and finite element analysis simulation of metallic components. He is a member of the South African Institute of Mining and Metallurgy, the Engineering Council of South Africa and The Welding Institute in the UK.

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The titanium pilot plant, an outcome of the Titanium Centre of Competence.

SA'S TITANIUM PILOT PLANT, A FIRST IN AFRICA

The Titanium Centre of Competence (TiCoC), hosted by the CSIR and funded by the Department of Science and Technology (DST), has developed a suite of complementary technologies to help South Africa add value to its vast resources of titanium. Key to this programme is the development and commercialisation of a novel process for producing primary titanium metal, hence the establishment of a small-scale titanium pilot plant on the CSIR campus in Pretoria, focused on up-scaling the production of titanium metal powder.

The CSIR's Ghislain Tshilombo explains aspects of the pilot plant to guests at the launch.

CSIR Chief Executive Officer, Dr Sibusiso Sibisi and Chair of the CSIR Board, Prof Francis Petersen with the Minister of Science and Technology, Mr Derek Hanekom, after having unveiled a plaque at the launch of the pilot plant.

THE TITANIUM pilot plant is a step towards a commercial scale plant that will be able to produce titanium powder at a much lower cost than present imports, making this light metal an economically viable option from which many industries can be created and sustained. South Africa has large reserves of titanium-bearing mineral and is currently the second largest producer of mineral concentrate. Apart from concentrating the mineral to produce titanium slag and pig iron, little further value is added to the mineral before exporting it. It is believed that there is significant potential to add value and create much-needed employment if titanium metal is extracted from the mineral concentrate and a new downstream industry is created to manufacture titanium metal components and products.

Apart from the imperative to prove that the new titanium powder production technology can be scaled up, the pilot plant will also be used to produce relatively large quantities of titanium powder. This powder will be made available for testing to research institutions involved in research and development of titanium metal powder technologies, such as additive manufacturing, metal injection moulding technology, press and sinter technology, direct powder rolling technology and powder spheroidisation technology.

The pilot plant uses a novel and patented process that is competing internationally. The unique features of the process – resulting in cost and product quality advantages – include:

- The process is continuous – to date there is no titanium metal production plant that has operated successfully on a commercial scale in a continuous manner. Continuous processes are inherently cheaper than batch processes for large volume process plants.
- The process has the lowest operating temperature of all the variants of potential commercial titanium production technologies that are being developed elsewhere in the world.
- It is a zero effluent process – all the by-products are recycled.
- Minimal contamination of the product by-products, specifically chlorides.
- The product morphology (the form of the particles) can be varied and this gives it an added advantage in some downstream applications.

Science and Technology Minister, Mr Derek Hanekom, officially opened the titanium pilot plant in June this year. The DST has been a key stakeholder in this initiative and has allocated more than R100 million for this technology implementation via the TiCoC. The plant is designed to produce 2 kg of titanium metal powder per hour.

Boeing, the world's largest aerospace company, has subsequently formalised collaboration with the CSIR to cooperate on developing ways to incorporate titanium powder into novel industrial manufacturing processes and products by signing a memorandum of understanding with the CSIR, the host of the TiCoC. This mutually beneficial agreement supports the nation's long-term economic development goals that include the supply of titanium to many industries, including aerospace.

Boeing Research & Technology will oversee this technology implementation activity in collaboration with the TiCoC. The company is focused on developing future aerospace solutions and improving the cycle time, cost, quality and performance of current aerospace systems.

Meet facility manager Dr Dawie van Vuuren

Van Vuuren is a chemical engineer with 35 years of experience in the research, development and design of chemical and metallurgical processes. He worked in a broad range of fields including Fischer-Tropsch synthesis, briquetting of materials, coal combustion, waste water treatment, phosphoric acid purification, titanium dioxide extraction, solid state reduction of minerals, hydrogen generation and storage and titanium metal production.

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CATAPULTING LASER SYSTEMS

FROM LAB PROTOTYPES TO ADVANCED PRODUCTS

A new advanced photonics manufacturing facility will set the scene for the development of laser systems from laboratory prototypes to innovations. These innovations will have a technology readiness level that allows for an easy transfer to either a spin-out company or an existing company for commercialisation.

State-of-the-art equipment in the advanced photonics laboratory includes an inverted microscope for inspection of optical surfaces, here used by Ann Singh and Dr Aletta Karsten (and seen up close on page 10). CSIR technician Bafana Moya is seen with a fibre-based spectrometer covering a wavelength range from 1 100 nm to 2 400 nm.

IN RESPONSE to the need to develop and transfer technologies that will contribute towards a vibrant photonics industry that will address South Africa's socio-economic challenges, the CSIR is building an advanced photonics manufacturing facility.

This follows the pronouncement of the photonics strategy, known as the Photonics Initiative of South Africa (PISA), which was approved by the Department of Science and Technology (DST). The strategy calls for a strong industry focus to exploit new and existing opportunities in photonics. In particular, it calls for a national photonics centre to bridge the gaps between local higher education institutions, science councils and industry. Chief among its objectives is to support the CSIR's strategy around advanced manufacturing and smart product development.

Project leader Dr Aletta Karsten says that the advanced photonics manufacturing focus is to develop lasers to a stage at which it can be adopted by industry. Researchers in this area have already identified niche application areas suitable to the unique properties and wavelengths of CSIR-developed laser technology.

"Through the new photonics manufacturing facility, we will be able to take these technology demonstrators to advanced products," she says. "The establishment of this facility directly supports the photonics strategy by creating an environment where the outputs of technological innovation can be transferred to industrial partners in a structured way."

An optical characterisation laboratory, where lasers will be characterised and certified, will also form part of the facility. "This is a service that is not currently available in South Africa," Karsten explains. "This facility will facilitate transformation of not only the products that are being developed as part of these contracts, but also other proof-of-concept prototypes that are in the pipeline."

This, she says, will allow the CSIR to bridge the so-called technology chasm that is currently hampering the commercialisation of high technology products in South Africa.

Companies that stand to benefit from this facility are those that use lasers in their applications, from defence, to medical and manufacturing.

Another industry that looks set to benefit is aviation, through the Civil Aviation Authority, by improving the safety of aircraft, for example by protecting pilots from laser flashing. Laser importers and users in general will also benefit.

Technical specifications

According to Karsten, the facility will consist of three subdivisions: laser production; component preparation (mechanical and electronic); and a facility where lasers will be characterised in terms of laser wavelength, power, stability and beam parameters such as beam diameter and divergence.

In the production area, the laser systems will be assembled under very clean conditions. In the characterisation area, the systems will be measured and fully characterised on beam quality, wavelength and power (depending on the specific product); while in the preparation area, the mechanical and electronic components will be prepared and assembled.

Karsten concludes: "While the laboratory is in its infancy, our aim is to, once operational, accredit it locally through the South African National Accreditation Systems and internationally by gaining an ISO standard."

– Mzimasi Gcukumana

"The establishment of this facility directly supports the photonics strategy by creating an environment where the outputs of technological innovation can be transferred to industrial partners in a structured way."

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Close-up view of a custom-developed laser.

TAILORED LASER SOLUTIONS:

DEVELOPING CUSTOM LASERS FOR INDUSTRY

CSIR researchers and engineers work closely with clients to develop tailored laser sources suited for their applications.

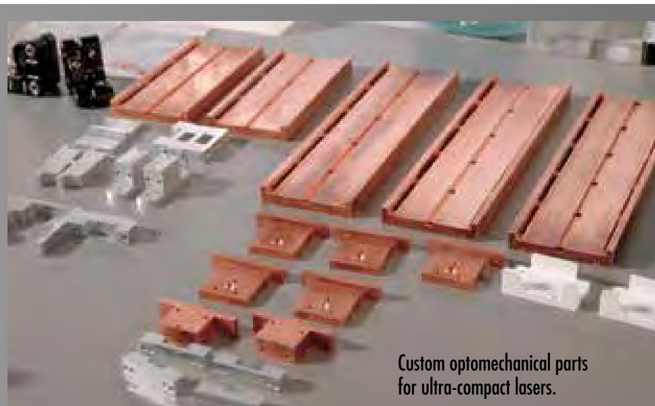
THE CSIR BOASTS a state-of-the-art solid-state laser research and development (R&D) laboratory, housed in a class 1 000 clean room facility with isolated class 100 and class 10 areas for highly sensitive dust-free work.

The laboratory, says Cobus Jacobs, project leader and senior scientist in the CSIR's laser sources group, is well equipped with a range of optical diagnostic equipment that supports the development, analysis and optimisation of novel laser systems across the optical spectrum.

"The research we conduct in novel solid-state lasers is mainly aimed at power and energy scaling while maintaining good beam quality of the laser output," notes Jacobs. "This includes research into novel laser concepts and geometries, thermal handling, laser resonator design and numerical modelling of the laser." Other areas of interest, according to him, are special operating regimes such as high spectral purity/single frequency lasers and active control of laser parameters.

"Our researchers and engineers work closely with our clients to develop tailored laser sources suited for their application," he says. "We develop the right light for the job, delivering custom laser prototypes directly to our clients," he says. Working with colleagues at the newly established advanced photonics manufacturing facility, rugged product-level laser systems can be manufactured and standard laser systems, based on existing designs, are set to be produced in the near future. Should the required laser already be available commercially, CSIR laser technology experts also offer specialised consulting services to help perfect the solution to the problem.

Laser technology has a very wide application space. "Whether you need to cut, drill, engrave, weld,



Custom optomechanical parts for ultra-compact lasers.

CSIR laser scientists use laser diagnostic equipment to characterise and optimise new laser systems.

join, build-up, scan, transmit, diagnose or detect, the CSIR laser sources group can assist in the research and feasibility study, the acquisition and development of the appropriate laser sources and components, as well as the testing and integration of the complete optical system required to solve your problem," says Jacobs.

He says that there are only a few such similar laser development laboratories worldwide. "Most of these are either closed/proprietary government or corporate labs, or academic university labs," he notes. "Our facility is well positioned to provide state-of-the-art technologies directly to industry."

This, in turn, provides the South African industry access to world-class expertise which can help find optical solutions that fit the South African market.

Through this facility, CSIR researchers have designed and developed a number of cutting-edge laser systems over the past years and have considerable expertise in efficient solid-state lasers in the visible and infrared region. Specifically, novel infrared laser sources have been developed operating at 1 μm, 1.3 μm, 1.9 - 2.1 μm and 3 - 5 μm.

Some of the CSIR's most recent successes in this domain are the use of thulium and holmium gain material to achieve power and energy scaling in bulk crystal rod and slab lasers. The results have been published in high-impact factor scientific journals.

Jacobs concludes: "In terms of engineering capabilities, this facility has developed rugged and portable laser systems that can withstand different environmental conditions, as well as ultra-compact lasers with strict requirements on size and efficiency."

– Mzimasi Gcukumana

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Prototype optomechanical parts ready for use.

LASER ENGINEERING:

Enabling SA industry to improve its global competitiveness

Over the past two decades, laser-based manufacturing has earned widespread recognition as a key technology for industrial competitiveness. Its advantages outweigh conventional processes used in manufacturing. Arguably the most powerful laser platform established at the CSIR to assist industry, is the high-power Nd:YAG laser cell, as it supports fundamental industrial processes, including welding (for joining), weld overlay (for cladding) and surface hardening.

Laser technology has the ability to combine high production rates with high levels of quality assurance, which in turn leads to high productivity, and ultimately improved profitability. In addition, laser technology drives industrial innovation by providing manufacturing solutions that would be impossible with conventional technology.

The CSIR is committed to ensuring that the South African manufacturing industry shares in the benefits of laser-enabled manufacturing technology. To do this, the CSIR has established a number of laser-based manufacturing platforms. These platforms are designed to support the entire value chain from research and development to industrialisation, implementation and pilot scale production.

The high-power Nd:YAG laser cell supports the fundamental industrial processeses of welding, weld overlay and surface hardening. The versatility of this system stems from the fact that it combines an Nd:YAG laser with an articulated arm-robot through optical fibre beam delivery. The short wavelength of the Nd:YAG laser enables improved laser beam absorption, especially in surface modification processes such as cladding and hardening, but also in the welding of highly reflective materials such as aluminium. The robotic manipulation of the fibre-delivered laser beam provides the required flexibility to access and process the complex geometries that are encountered in industrial applications.

Laser cell technical specifications

The laser cell is powered by a 4.4 kW Rofin Sinar DY 044 Nd:YAG laser. The laser beam is delivered to a six-axis articulated arm robot via a 400 or 600 micron step index optical fibre. The robot is also integrated with a DPK 400 two-axis positioner which provides an additional two axes of rotation. The beam delivery options include a Precitec YW50 general purpose welding module, a HighYAG ASK welding module with beam shaping capabilities required for aluminium welding, as well as a scanner which is used for surface hardening. To facilitate laser cladding, the YW50 is fitted with a range of powder injection nozzles which include off-axis, co-axial and three-beam nozzles.

When it works well

Laser welding combines deep penetration with very low heat input when compared to arc welding processes, while providing the speed and quality which are typical of a laser based process. Laser welding is ideal where a combination of high weld integrity and very low distortion is required. The CSIR was successful in exploiting these benefits of laser welding to develop successful welding processes for a broad range of industrial clients. These include welding of maraging steel rocket motor casings for Rheinmetal Munitions Western Cape, cyclotron radiation targets for iThemba LABS, aluminium electronic enclosures and heat exchangers for Cassidian and BAE systems, gear/shaft assemblies for Adept Airmotif and Denel Land Systems and gimbal brackets for an airborne surveillance camera.

Laser hardening

Laser hardening allows selective hardening of certain areas on a component. The laser beam is used as a heat source and it is self-quenching, since the rapid cooling required for the martensitic reaction is provided by bulk material. The process combines excellent control and hence repeatability, with very low distortion.

These attributes enabled the CSIR to develop laser-hardening processes for Volkswagen South Africa and Daimler Chrysler through which the wear on the critical functional surfaces of press and trim tools could be improved. The CSIR also developed a laser-hardening process which was implemented on the CV joints of the Toyota Hilux which competed in the 2013 Paris Dakar Rally. The laser process replaced an induction hardening process which caused repeated malfunctions during testing. Other applications which have been developed include the hardening of surfaces on artillery components which are subjected to sliding wear, and stub axle bearing journals and splines for Bell Equipment.

Laser cladding

Arguably the most important industrial process supported by the laser cell is known as laser cladding. Laser cladding is essentially a weld-overlay process where the laser is used as a heat source and the welding consumable is most often in metal powder form. The laser fuses the metal powder onto the surface of a substrate to form a layer. This layer can have the same chemical composition as the substrate or the chemical composition may differ, as long as 'weldability' considerations are not violated. Compared to conventional weld overlay processes, laser cladding offers much lower heat input and consequently significantly less distortion. When a dissimilar layer is applied, dilution of the layer by the substrate is minimal compared to arc welding, which enables the application of very thin layers.

The most important application of laser cladding is in the refurbishment of industrial components. Surface degradation is the single most important cause for the failure and consequential scrapping of industrial components. Laser cladding offers a cost effective method to refurbish worn surfaces and by choosing a suitable consumable it is often possible to enhance the properties of the surface to the extent that its performance will be superior to that of the manufactured surface. In this context, laser cladding is often used to improve abrasive wear, corrosion, erosion and oxidation resistance.

Maintenance is an important cost driver in manufacturing. In South Africa, where spare parts are subject to long lead times from overseas suppliers as well as high and unpredictable exchange rates, a cost effective refurbishment option is of great interest. The availability of this option through the CSIR has already prompted Tupperware Southern Africa to localise the refurbishment of their injection moulding equipment in South Africa – previously these components were shipped to Belgium.

Similarly, MANTurbo and Diesel qualified a CSIR-developed refurbishment of the mechanical seal on a compressor screw which previously also had to be returned to Germany for refurbishment. Other applications that have been developed to date, include a laser-cladding process which resulted in a significant increase in the service life of continuous casting rollers used by ArcelorMittal at their Vanderbijlpark works as well as power generation equipment such as turbine rotor shafts, blade carriers and generator couplings. Potentially the most significant development emerging from this facility to date, is the patented leak-sealing process which was used to seal stress corrosion cracks on large water storage tanks at Koeberg, thus extending the service life of a R1bn asset and keeping the lights on in Cape Town.


Laser cladding of a crankshaft.

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Helping SA manufacturing stay at the cutting edge with laser technology

For the CSIR's laser-enabled manufacturing arm, there is no component too complex to cut. This can be attributed in part to the organisation housing the only three-dimensional (3D) Trumpf laser facility in the country, but also to expert knowledge acquired over years.

THE SOUTH AFRICAN manufacturing industry, specifically the automotive sector, has in the past been dogged by the cost of toolmaking (making the tools to produce their products). However, South Africa's abilities to capitalise on the latest laser technologies, is helping to make the tooling challenge a relic of an earlier era.

"Thanks to the 3D Trumpf laser, we can say that we have never had a component that we could not cut. If it is a laser machinable component, we can cut it," says Hansie Pretorius, who heads up the CSIR's laser-enabled manufacturing.

The 3D facility has helped save the South African automotive industry millions of rands by increasing productivity and eliminating the need for downtime.

Typically, automotive industry engineers design a tool and outsource the toolmaking to an original equipment manufacturer, which then approaches the CSIR to do the specialised laser cutting. If a particular component cannot be cut by the Trumpf laser, the manufacturer has to ship that particular component abroad, with resultant down-time in the plant. Other components that the group cuts for this industry include catalytic convertor shells; heat shields; door members; and steering wheel assemblies. To date, the group has done laser cutting work for companies such as BMW, Denel Land Systems, Bell Equipment, Mitsubishi, Carl Zeiss, Mercedes Benz, VW/Audi, Ford, Nissan, Toyota and Maserati. "Our main objective is to fully introduce laser technology by making systems available at the CSIR that industry can embrace into its production processes," says Pretorius.

For the automotive industry, for example, the group cuts samples for testing, which is followed by the cutting of approximately 200 samples, so that the automotive manufacturers can start assembling vehicles. "We are able to run two processes simultaneously," he says. "While our industry partners build the trim tooling, we can produce components for production – with no associated downtime."

– *Mzimasi Gcukumana*

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This facility is made up of a 5kW carbon dioxide laser with a powerful 5 Axis laser-cutting system and 2.4 m cutting bed. It has a rotary axis for cutting round components or tubes.

A FACILITY DEDICATED TO BUILDING SCARCE LASER EXPERTISE

In keeping with its commitment to build much-needed scarce laser-based skills in South Africa and on the continent, the CSIR houses a suite of laboratories each boasting high-value laser equipment and diagnostics dedicated to training and research.

THE CSIR user facility for laser technology allows scientific communities access to specialised laser facilities. This means that higher education institutions (HEIs), for example, are able to save the costs of buying expensive laser and optics equipment. Instead, they can send their researchers and research students to the CSIR to conduct their research within approved protocols.

"Researchers and research students, both from South Africa and elsewhere in Africa, are able to visit the CSIR and use these facilities to carry out their research," says Dr Paul Motalane, who manages the CSIR's relationship with HEIs in terms of laser technology. "We are building scarce technological expertise in line with South Africa's national priorities."

Motalane notes that the user facility does not only allow access to the equipment, but importantly, it gives concomitant scientific and technical support to research done by those at HEIs and ultimately, laser-based research capacity.

"These facilities have also been used for the benefit of the photonics community throughout the African continent, where scientists and research students have been hosted under the auspices of the African Laser Centre.

"As a result, we have hosted more than 70 visiting scientists and research students between 2010 and 2012," he says.

Track record

The user facility measures its success by the number of Master's and doctoral students who use the facility in research that ultimately leads to the completion of their qualifications. "Once these students obtain their qualifications, they get snapped up by different institutes because of their experience in this environment," says Motalane.

The rental pool programme, the overarching programme that houses the user facility, has hosted about 807 students between 2005 and 2011, all of whom were working on research projects that were supported at participating HEI laboratories. In that same period, these researchers and research students have penned some 1 296 conference and journal papers. Some 95 patents and products have resulted from their endeavours and 230 students obtained their Master's and doctoral degrees.

– Mzimasi Gcukumana

The CSIR user facility for laser technology assists local and international university researchers and research students in conducting their experiments through a rental pool programme. Pictured are the CSIR's Steven Nkosi with University of Free State visiting student, Ali Wako (centre) and CSIR chief laser technician, Henk van Wyk. Next to Nkosi is a pulsed laser deposition system, used to grow nanometer-sized material in a film form. Wako grows these on materials that emit visible light in the visible range.

Meet research laboratory assistant Steven Nkosi

Nkosi joined the CSIR in 2009. He is currently finalising his PhD thesis in physics at the University of the Witwatersrand, where he specialises in magnetic and photonic materials. As part of his PhD work, he is also involved in international collaboration to develop gas sensing materials based on metal oxides with the FORTH institutes in Crete, Greece.

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CHISELLING PRECISE PARTS THE HIGH-TECH WAY

Logo engraving on a tool insert for a plastic injection mould.

Laser ablation, the process of selectively removing material from a surface with a laser, is an integral part of the specialised technical processes undertaken at the CSIR laser ablation facility. The technology finds its application in prototype mould or model-making; engraving or embossing; and toolmaking such as mould inserts, electrodes, tool tips, master models and for punches. Materials that are difficult to process, such as those used in the aerospace industry, can be processed more efficiently.

The sophisticated machines from which parameters can be set for customised machining.

LASER ABLATION is a more accurate, innovative solution for the removal of conductive and metallised layers from flexible substrates when compared to conventional methods such as chemical etching and printed metallisation. With etching, it is impossible to eliminate pattern variations caused by slight differences between work pieces. Laser ablation machines, on the other hand, produce precise repeatable patterns and textures directly from digital files, with no variations from component to component.

It is faster, quieter, and more repeatable, flexible and environmentally friendly than conventional manual and chemical processes.

Two-dimensional and three-dimensional details are machined from a high-quality digital image, allowing completely reproducible results for specific textures, engravings, marks or labels imparted on a wide variety of materials, including graphite, aluminium, copper, steel, carbide, brass and ceramics.

A bipolar plate for a hydrogen fuel cell machined on the laser ablator.

The equipment

The CSIR laser ablation facility operates a DML 40 (Sauer) laser ablator system dedicated to the creation of small features in mostly metals, by evaporation of materials in three-dimension. The machine was first acquired in 2004. Many components, dies and moulds have been produced and numerous research experiments on laser material interaction were conducted since then. Similar machines are in use at the South African Mint, Element 6 and Tshwane University of Technology (TUT).

Meet laser ablator specialist Oscar Sono

Sono is a mechanical engineering technologist at the CSIR; he joined the organisation in December 2008. He obtained his BTech degree in mechanical engineering from TUT where he specialised in design and manufacturing. Sono is currently assisting Lerato Tshabalala (from TUT) on her DTech project, focusing on surface enhancement of ceramic substrates by laser surface pre-treatment. They are experimenting using the DML 40 S laser ablation machine to process the surface of ceramic substrate to achieve a surface roughness that will enhance adhesion with a different material, to increase its lifespan.

With the small spot size of the laser beam and accurate positioning of the work piece, very small features can be machined with high precision. In addition, materials such as ceramics and hardened steels can be easily machined. This is not always the case with other technologies.

The technology is applied in experimental prototype development and specialist machining services for the South African industry. The CSIR also has experience in process development and feasibility studies and is able to assist industry in micro and meso machining areas.

Advantages of this micro-machining tool include direct machining of a work piece from a computer-aided design model; shorter production times for intricate parts; reproducible production; absence of tooling costs; and the ability to machine near vertical walls, and difficult materials such as ceramics.

Industries benefiting from this facility are those in plastic moulding, coining, quality assurance, calibration, air and space craft, materials and laser research.

Ablatable materials include steels (also hardened); tungsten carbide; ceramics; graphite; aluminium and brass/copper.

According to mechanical engineer Oscar Sono, the facility "has served the CSIR in many respects, from being able to offer support to private industries and the defence sector, to facilitating research for pebble bed modular reactor energy".

– Mzimasi Gcukumana

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INDUSTRY

SETTING TRAPS FOR SINGLE ATOMS

The CSIR is home to South Africa's first laboratory for quantum control of atoms and molecules (MAQClab). The facility is also one of only two laboratories in the country that investigate ultrafast dynamics.

IN QUANTUM PHYSICS, quantum control aims to go beyond mere observations of atomic and molecular properties to actually manipulating the dynamics of quantum systems using strong external fields. Atomic, molecular, and optical science demonstrate the ties of fundamental physics to society. Its very name reflects three of the greatest advances of 20th century physics: the establishment of the atom as a building block of matter; the development of quantum mechanics, which made it possible to understand the inner workings of atoms and molecules; and the invention of the laser, which changed everything from the way society thinks about light to the way we store and communicate information. The field encompasses the study of atoms, molecules and light, including the discovery of related applications and techniques.

Leading scientist in the field of quantum physics at the CSIR, Dr Hermann Uys, says that the establishment of the MAQClab at the CSIR will, among other projects, enable research and experiments in quantum simulation. "We hope to build the first quantum simulator in Africa," he says.

Uys says that, to the best of his knowledge, the CSIR ion-trapping lab is the first of its kind in Africa, and one of only a few in the Southern Hemisphere – ion-trapping research is also conducted in Australia.

Uys notes that scientists and engineers have squeezed so much out of classical physics (the physics of macroscopic objects: planets, rockets, cars, telephones), while on the other hand, "We quantum physicists always ask whether we can squeeze as many applications out of quantum physics. We know that we can control the classical world, and now we are trying to perfect control of the quantum world (the physics of atoms and molecules)," he notes. "We are still learning."

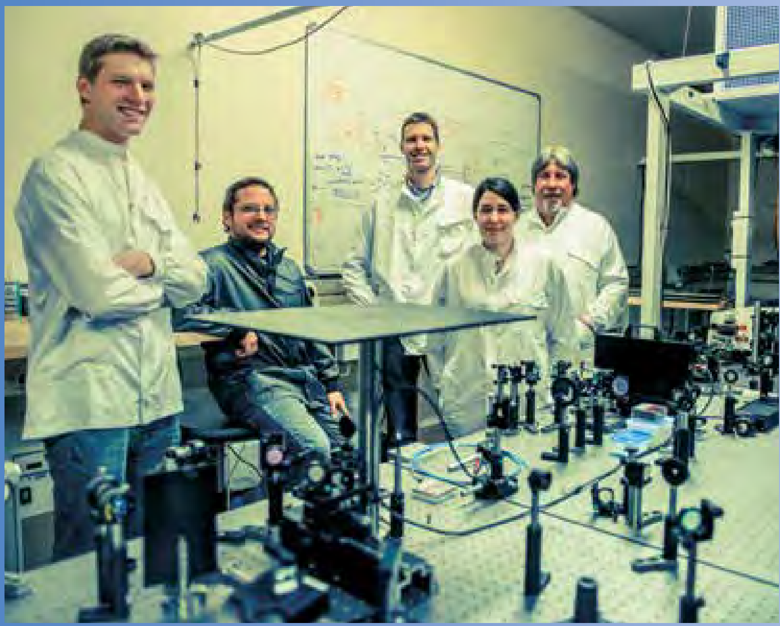
Uys is confident that with the team that he has put together, this lab will be world-class.

Facility details and use

MAQClab is primarily a research laboratory that studies physics in two rather extreme situations. The first is the study of ultra-fast processes in molecules; the technologies that enable these studies are two femtosecond lasers. Each laser can emit laser pulses that are only 100 femtoseconds in duration (that is, a tenth-of-a-millionth-of-a-millionth of a second). These short pulses enable researchers to take snap shots of molecular processes that take place on the same timescale, and allow them to control those processes.

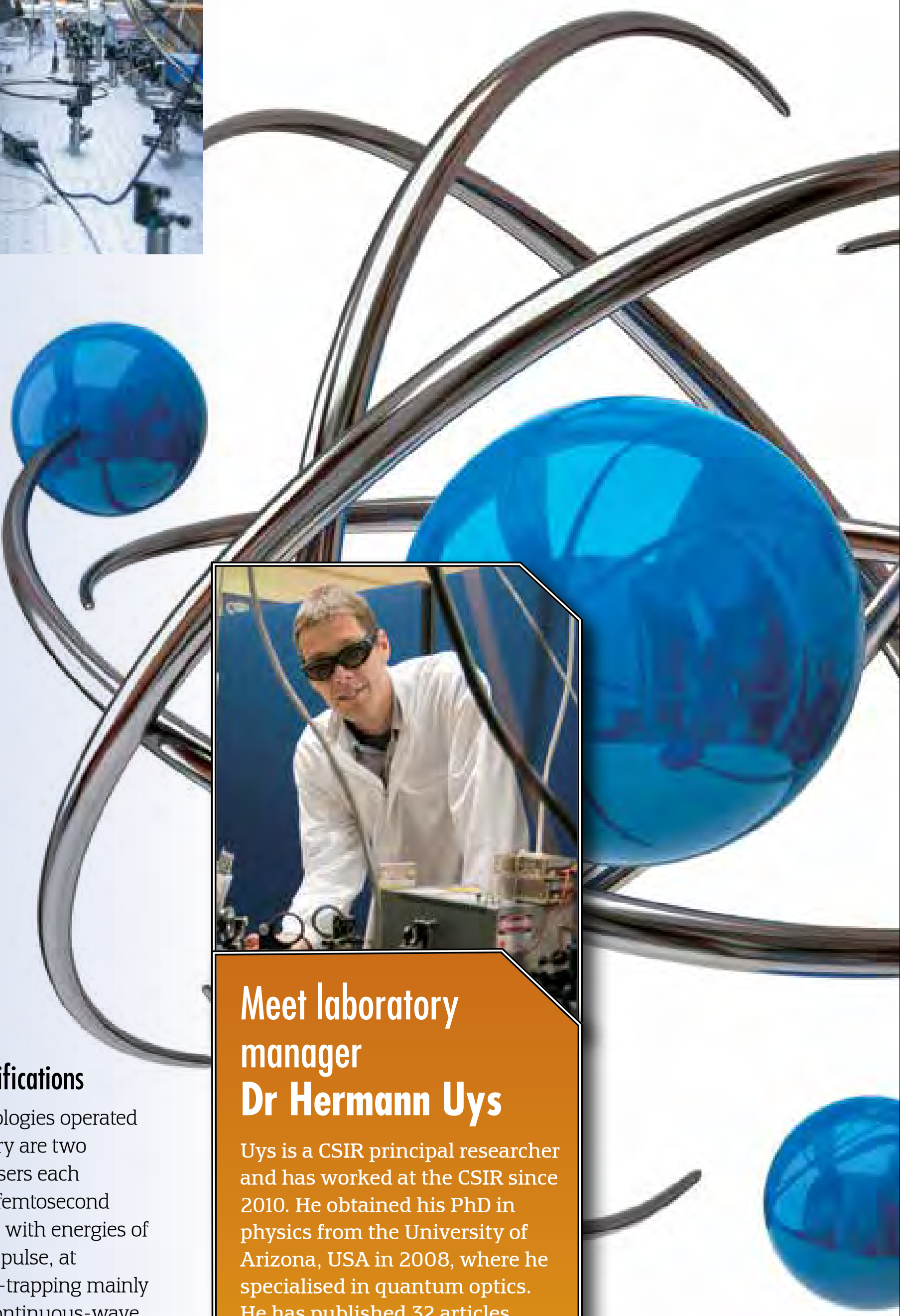
The second extreme situation is single, ionised atoms that are trapped in ultra-high vacuum conditions at microKelvin temperatures. This situation is rather extreme if you take into consideration that at atmospheric pressure one litre of air contains about 10^{22} molecules (ten thousand million million million) and each of those molecules collides with another about every nanosecond. In the ultrahigh vacuum at the 10^{-11} Torr pressure, there are only about 20 000 molecules left in one litre of the vacuum chamber, each molecule colliding with another molecule only about once a day. One therefore truly has the capability to interact with only one single atom at a time.

"In both of these extreme situations, one can only properly describe the dynamics of the system by using the principles of quantum mechanics. Our aim is to understand and control this quantum dynamics in search of new applications," he says.



Modern ion trapping experiments utilise a wide range of technologies, including narrow-band continuous wave lasers, phase-stable microwave sources, ultra-high vacuum technology and spectroscopic frequency references, among others. Seen in the picture are from left, Pieter du Toit, Attie Hendriks, Dr Hermann Uys, Nicolene Botha, and Andre Smit.

Dr Hermann Uys fine-tuning the ion-cooling laser in the MAQClab.



Collaboration

Our main partners are university research groups. "Currently, we have a very active collaboration with the University of KwaZulu-Natal, and we are entering into collaboration with both the University of Pretoria and with Unisa," explains Uys. "We also partner with international laboratories, namely the National Institute of Standards and Technology in Colorado in the USA, and the School of Physics at the University of Sydney in Australia."

Industries to benefit

Historically, many developments in quantum physics have led to commonplace modern day technologies. To name a few, atomic clocks rely at their core on quantum phenomena to provide very accurate time stamps used as widely as the telecoms industry and the Global Positioning System. Magnetic resonance imaging used in the medical field exploits coherent manipulation of the quantum dynamics of nuclear spins of atoms in the human body to diagnose diseases, and many modern computer hard drives exploit a quantum effect called tunnel magneto resistance to store and retrieve data. "In our lab, we aim to push the limits of control quantum phenomena in pursuit of new technologies," says Uys.

The ion-trap lab is under construction and funded through the CSIR and grants from the National Research Foundation.

Technical specifications

The core technologies operated by the laboratory are two femtosecond lasers each generating 115 femtosecond duration pulses with energies of 1 milliJoule per pulse, at 1 kilohertz. Ion-trapping mainly relies on four continuous-wave, external-cavity diode lasers, stabilised to have long-term line widths in the order of 1 MHz.

– *Mzimasi Gcukumana*

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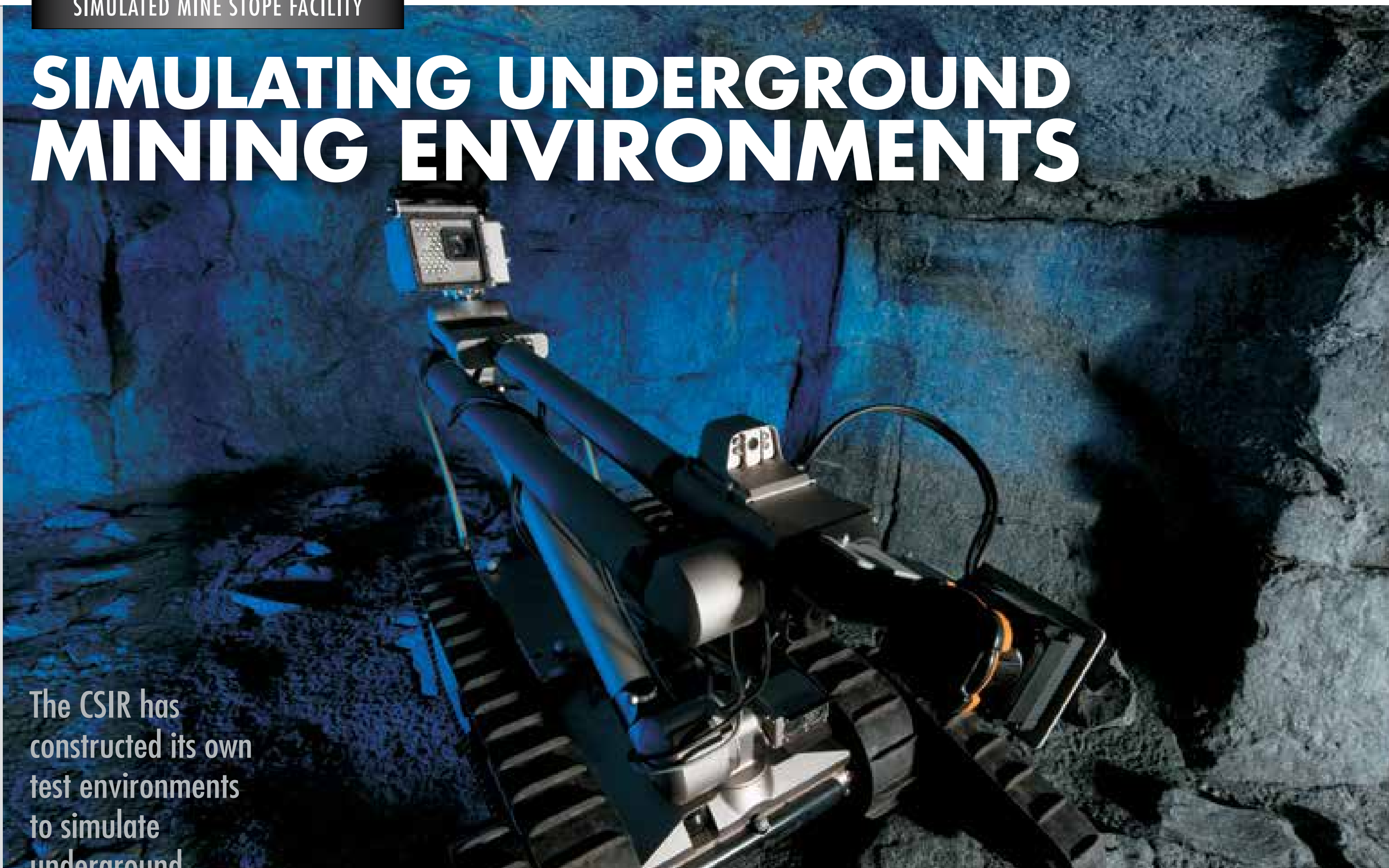
Meet laboratory manager Dr Hermann Uys

Uys is a CSIR principal researcher and has worked at the CSIR since 2010. He obtained his PhD in physics from the University of Arizona, USA in 2008, where he specialised in quantum optics. He has published 32 articles in respected peer-reviewed journals on diverse topics including ultra-cold atom physics, superradiance, Heisenberg limited interferometry, atom interferometry, quantum information and cold trapped ion physics. He is an associate of the National Institute of Theoretical Physics.

SIMULATING UNDERGROUND MINING ENVIRONMENTS



The CSIR has constructed its own test environments to simulate underground mining conditions for its mining field robotics research.

Simulated platinum stope

SOME ENVIRONMENTS are not readily accessible for the scientific testing of equipment and technology. Underground mines are such environments. The situation is made even more difficult in South Africa, where the mines are two to three kilometres deep.

To solve this challenge, the CSIR has built two simulated mine stopes to test various technologies, such as robotic platforms, sensors and related software. The two stopes represent different environments in underground mining operations in South Africa. The first represents a gold stope with variable dip up to 30 degrees. The second stope represents a platinum stope.

The stopes were built as part of the mine safety platform project. The aim of this project is to construct an autonomous vehicle capable of assessing the safety of a mine after blasting and during the period when toxic fumes make it difficult for workers to access the work area. As part of the mine safety platform project, research was conducted on sensors and algorithms for machine intelligence. Sensors included robotic vision, reef tracking, 3D laser scanners, thermal imagers, an underground geospatial positioning system, a communications protocol, and proximity sensors.

To test out these systems underground, mining environments were required. However, there were no facilities in South Africa to test new equipment and systems for underground operations. Though mines have their own test stopes, these are used for training purposes and as such are not geared to test machinery.

Testing, testing, one, two …

The first test stope is used for testing the performance of robotic platforms on terrains with variable dipping angles and the performance of roof integrity sensors. The width and the height of the stope are reconfigurable.

The second stope is used to test underground navigation and geo-location software. It has moveable packs and poles. Packs and poles are used to support the roof structure after blasting. This simulated stope has a removable roof which is split into two sections. The roof can thus be configured to suit the required experimental conditions. – *Bandile Sikwane*

Above and top of page 23: Simulated gold stope with variable dip up to 30 degrees.

The first stope, resembling a gold stope, was designed by Ruth Teleka. She completed her graduate diploma in mechanical engineering; she is now working on her MSc in mechanical engineering.

The second stope, resembling a platinum stope, was designed by Chioniso Kuchwa-Dube. She holds a BSc in electro-mechanical engineering and an MSc in electrical engineering.

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A multi-degree-of-freedom robot arm, an outdoor navigation robot (inset); and a robot used for mapping (left).

Pursuing intelligent behaviour through state-of-the-art robotics platforms

Robotics research at the CSIR is underpinned by investment in infrastructure. The mobile intelligent autonomous systems (MIAS) laboratory has a range of state-of-the-art robotics platforms, as well as supporting equipment, such as sensors.

THE MIAS LABORATORY conducts research on the intelligent autonomy components of robot systems: enabling platforms to operate with 'intelligence' – where a robot can use data about its environment, and algorithms for processing that information, to make decisions and take actions with little or no input from a person.

Among a number of platforms acquired for robotics work, the group has an iRobot packbot™ which is being employed to test algorithms for mapping and localisation. The laboratory also has a Seekur™ robot for autonomous work outdoors. It can transport goods on predefined paths or navigate through an unstructured environment such as veld. The laboratory undertakes work on intelligent manipulation and the platform on which applications are being developed, is a Barrett whole arm manipulator™, a multi-degree-of-freedom robot arm. To enable work in mobile manipulation, the arm will be mounted on a powerbot™ platform.

In the area of sensor systems, the CSIR has a Vicon™ motion capture system. The system is currently in use to provide ground-truth data for work with mobile platforms in the laboratory. It can also be used for human motion capture, for example, for analysis of human gait. Potential applications of the system include motion capture for animation and biomechanical analysis for sports performance improvement and health monitoring.

Acquisition of data is fundamental to robotics. Robot systems gather data about an environment, for example, to map an environment or to move through a space without colliding with objects. Robots, therefore, rely on sensors, and the CSIR has invested in multiple sensors for use with robot platforms. Sensors in the robotics laboratory include: time-of-flight cameras; laser scanners; a Velodyne lidar system; a high resolution Riegl scanner; and multiple cameras.

Examples of work undertaken using laboratory sensors include: collision avoidance methods based on laser data; an outdoor localisation system which fuses GPS and odometry data; and a camera-based tracking system. In more recent work, the robotics laboratory is investigating the use of Kinects™ for applications including gesture recognition.

The group also works on computer vision methods, particularly active vision methods, for verification and recognition of objects.

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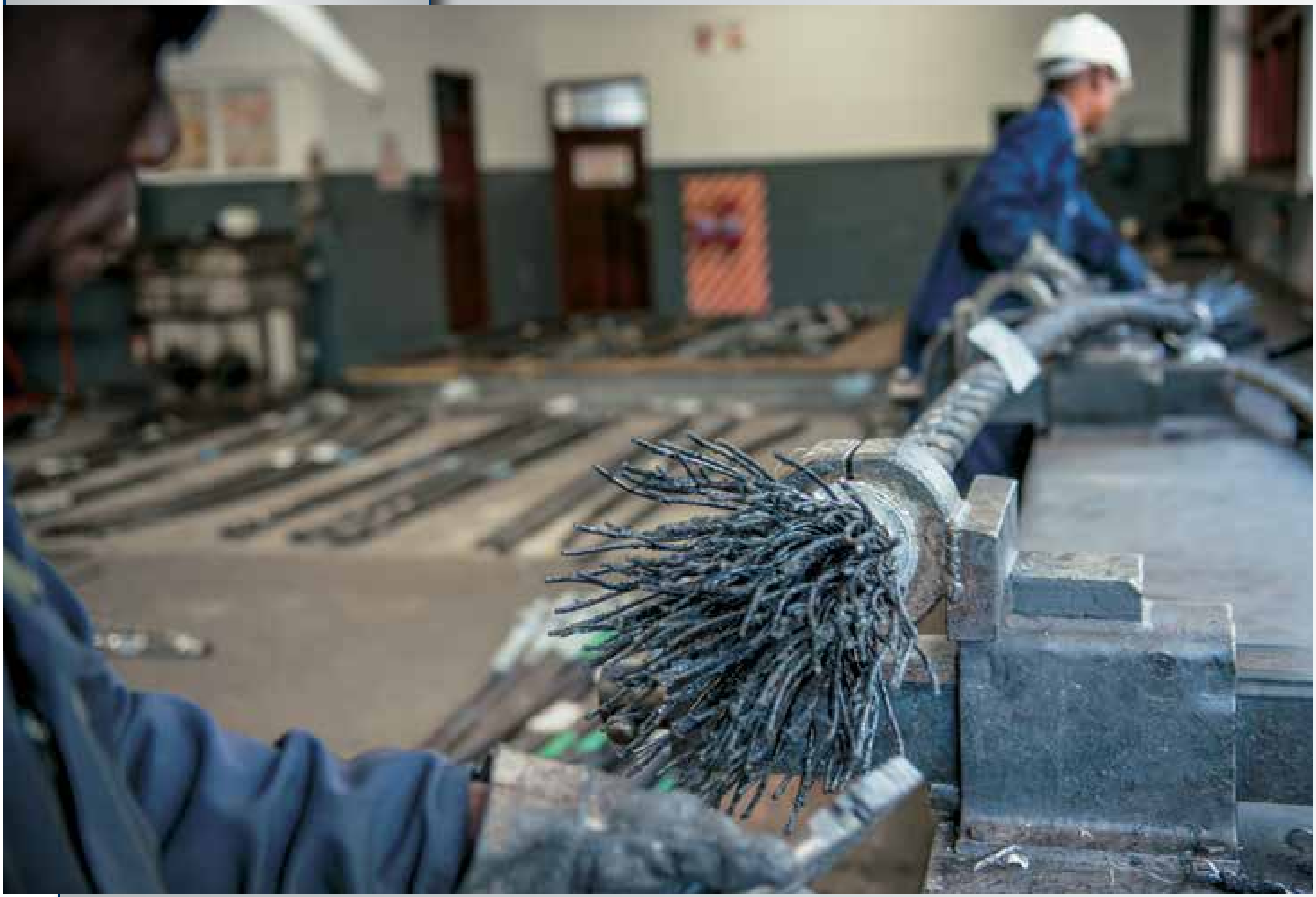
A STEELY RESOLVE TO KEEP OUR MINERS SAFE

The CSIR's steel wire rope testing facility is internationally recognised. On average, it tests about 2 200 rope specimens per year and serves the South African mining industry, as well as local and international manufacturers, in determining the breaking strength of steel wire ropes.



(Main photo) Laboratory assistants unlay the strands and wires of a rope in preparation for testing. (Above, from left) A rope diameter is measured prior to destructive testing. Once the rope is tested, the white metal alloy is reclaimed from the ends of the rope and re-used. A test officer inspects the fracture of the rope. He assesses wear and corrosion and notes the nature of fracture as well as the condition of the lubrication. Moulding to form a rope end cap.

The CSIR rope testing laboratory is one of only two facilities in South Africa authorised by the Department of Mineral Resources to conduct statutory testing of steel wire rope samples from mine winder installations.

STEEL WIRE ROPES are employed to hoist conveyances that transport people and material up and down hundreds of mine shafts in South Africa. The steel wire rope is the lifeline of these conveyances. Therefore, the structural integrity of the steel wire rope is of paramount importance. If it breaks, the consequences could be disastrous. All steel wire ropes deteriorate over time. Three of the causes of the deterioration are abrasion, corrosion and broken wires due to metal fatigue.

To maximise capacity, a conveyance may often have three decks and a carrying capacity of 150 persons (50 per deck) and travel at speeds of 15 m per second. The hoisting of broken ore to the surface is normally conducted in one or more dedicated compartments. These compartments are equipped with skips (a special type of conveyance designed to hoist rock) with capacities of up to 20 tons. Steel wire ropes are currently the only practical method of suspending and moving a conveyance between operating levels in the shaft and surface. A conveyance is suspended from one end of the steel wire rope, with the other end attached to the winding engine drum. As mines have gone deeper – today the deepest mine in South Africa, and the world, is operating 4 km below the surface – steel wire rope technology must continue to perform with absolute safety.

Failure of a mine winder rope in 1904 resulted in more than 40 lives being lost and prompted a government regulation requiring periodic destructive tensile testing of a specimen of a winding rope to assess its condition. The testing of winder rope specimens from mines all over South Africa has been done at Cottesloe, Johannesburg, since 1935 by what was then the Government Mechanical Laboratory of the Department of Mines. In 1964, the CSIR took over this laboratory and subsequently upgraded the rope testing facility by adding a new building and a 10 MN tensile testing machine in 1970. The facility was again improved in 1989 by extending the existing laboratory building and by the acquisition and installation of a 15 MN tensile testing machine. In 2009, the test machine was upgraded to a fully digital control system.

Apart from offering the testing service, the laboratory maintains a database of winder rope testing in South Africa (this includes tests by the CSIR laboratory, as well as those carried out by the Scaw Metals laboratory in Jupiter, Johannesburg). A web-based application developed by the CSIR allows customers to access their rope test results online.

The majority of work done by the rope testing laboratory is for the mining industry. However, the fact that the laboratory has the only tensile testing machine capable of testing in the 5 to 15 MN range, makes it a valuable asset to any company or organisation in need of testing in this force range. Apart from steel wire ropes, the laboratory regularly tests full-width conveyor belt specimens and large capacity lifting gear (lifting lugs, spreader beams and slings). The laboratory can test rope specimens up to 160 mm in diameter with a breaking strength up to 15 MN (1 500 tons). It can also test conveyor belts up to 1 200 mm wide with breaking strength up to 2 000 kN. The test machine can accommodate spreader beams of up to 8 m in length.

The CSIR rope testing laboratory is one of only two facilities in South Africa authorised by the Department of Mineral Resources to conduct statutory testing of steel wire rope samples from mine winder installations. It is the only such facility that can accommodate the large rope diameters in use in South Africa's ultra-deep mines.

The CSIR rope testing laboratory is regarded throughout the mining industry as the benchmark in wire rope testing.– *Mzimasi Gcukumana*

Meet steel wire rope testing facility manager Riaan Bergh

Bergh is the business manager of the CSIR mining and engineering laboratories in Cottesloe, Johannesburg, and has worked at the CSIR since 2010. He obtained Bachelor's and Honours degrees in mechanical engineering in 1999 and 2003, respectively and a Master's degree in engineering management in 2013, all from the University of Pretoria. Riaan has a keen interest in structural mechanics and has worked in the structural testing and measurement field since 2001.

Some technical specifications

The laboratory can test rope specimens up to 160 mm in diameter with a breaking strength up to 15 MN (1 500 tons). It can also test conveyor belts of up to 1 200 mm wide and with a breaking strength of up to 2 000 kN. The test machine can accommodate spreader beams (crosspieces for spacing chains or cables) of up to 8 m in length.

SANAS awarded the rope testing laboratory ISO 170125 accreditation in October 2012. The CSIR is currently the only laboratory accredited for tensile testing of steel wire rope in South Africa.

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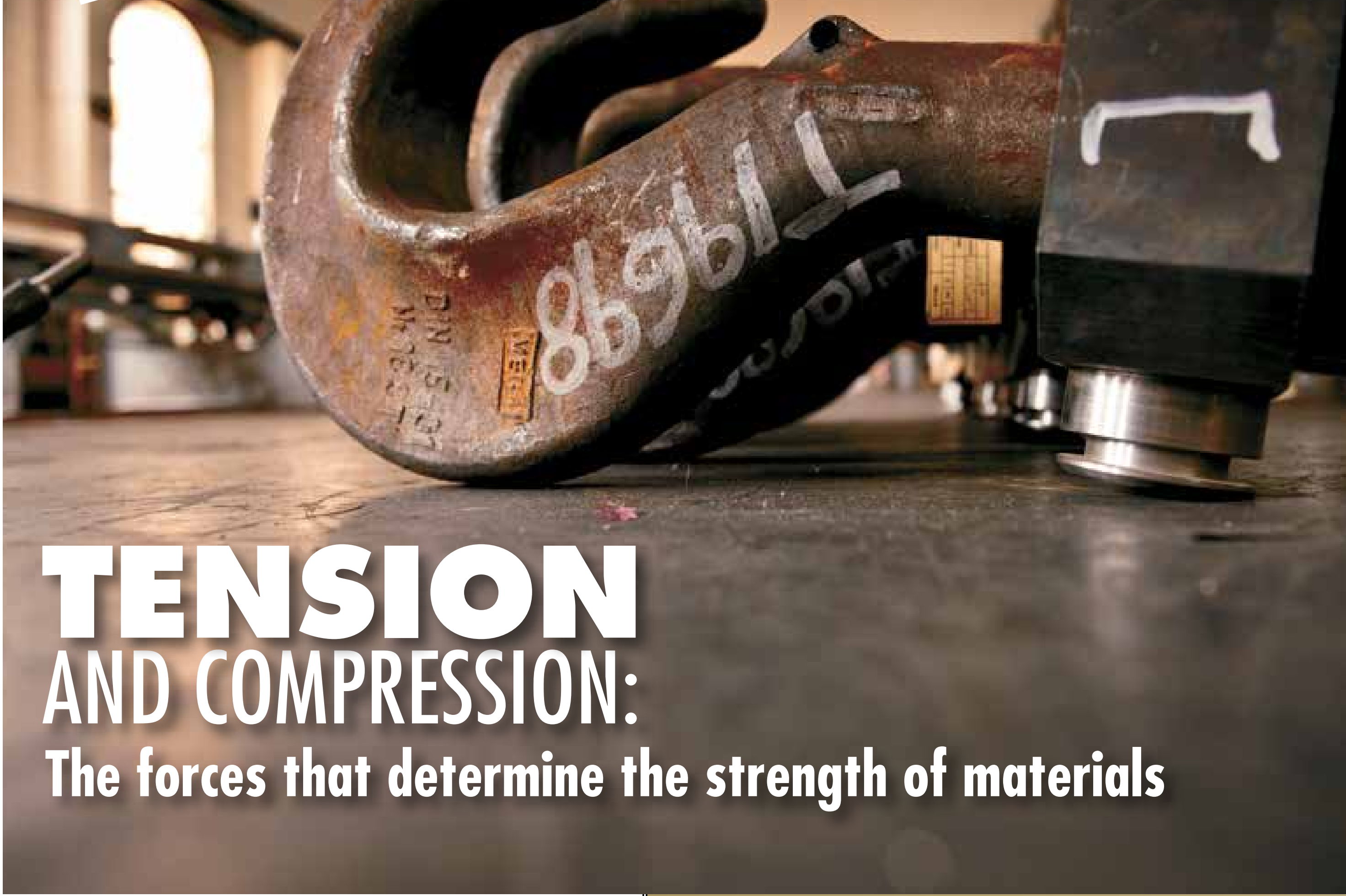
Laboratory assistants install a conductor test specimen – as used in Eskom's overhead power transmission lines – in the 500 ton Mohr & Federhaff tensile testing machine.

Below: A laboratory assistant adjusts the hydraulic control valves of the 1 000 ton Mohr & Federhaff compression testing machine.



TENSION
AND COMPRESSION:
The forces that determine the strength of materials

These overhead crane hooks have passed the test and are certified safe to return to use.
(Opposite page) The test officer positions a heavy duty trestle for compressive proof load testing.

The CSIR mechanical laboratory in Cottesloe, Johannesburg, houses two of the largest mechanical testing machines in South Africa. Established in 1935 as the government mechanical laboratory by the then Department of Mines, the facility was intended to serve the mining and other industries. Today, it continues to play an important role in testing industrial products and materials to ensure that safety standards are adhered to.

Test items include high voltage aluminium conductors that Eskom uses in its overhead power transmission lines. The CSIR tests samples of these conductors prior to installation, to ensure that the conductor and dead-end fixtures are strong enough to withstand the tensile loads generated due to their own weight.

THE 1 000 TON compression testing and the 500 ton tensile machines were acquired in 1935. These machines, manufactured in Germany by Mohr & Federhaff, originally used an intricate hydraulic-mass balance system to record test data on graph paper. Today, the machines are equipped with digital data capture systems, but the original structural and mechanical components have stood the test of time and remain in daily use.

"The unique combination of the machines' force capacity and the size of the test specimen that can be accommodated is what make these machines special," says CSIR business manager for this domain, Riaan Bergh. The 1 000 ton compression testing machine can accommodate test specimens up to 4.5 m in length and is regularly used to evaluate the compressive resistance of a variety of roof support systems employed in modern underground mining. Large-capacity load cells and hydraulic jacks are calibrated against the testing machine, which is traceable to an international standard of force measurement.

The 500 ton tensile testing machine, with its 25 m test bed and 2 m stroke length, is used to carry out proof load testing and destructive tensile testing to evaluate the mechanical properties of a wide variety of products.

The proof-load testing of lifting equipment ensures that items receiving the laboratory's stamp of approval meet the safety requirements of the Occupational Health and Safety Act (No. 85 of 1993), as well as a host of product specific national and international standards.

"Big is not always best," says Bergh. The laboratory also uses smaller testing machines in the 100 kN and 1 000 kN ranges to test smaller items such as lifting chain, webbing, roof bolts and smaller load cells with great precision. Custom test rigs allow automated cyclic testing of the chain blocks and lever hoists that riggers use on a daily basis to lift and position heavy objects, especially during maintenance on machines and equipment.

The laboratory is also equipped with machines for hardness testing and Charpy impact toughness – one of two types of tests that a laboratory can perform to assess the impact toughness of a material specimen.

The test facility management is working towards obtaining ISO 17025 accreditation for a selection of test methods. – *Mzimasi Gcukumana*

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SAFEGUARDING THE BREATH OF LIFE FOR UNDERGROUND MINERS:

A world-class facility to test all self-contained self-rescuers in SA mines

Richard Rapoo undertakes functional tests on the breathing simulator of the self-contained self-rescuer.

A self-contained self-rescuer being leak tested on the electronic leak detector.

AFTER THE KINROSS TRAGEDY of September 1986, during which 177 employees lost their lives in the aftermath of an underground fire, belt-worn self-contained self-rescuers were deployed in the South African mining industry.

These rescuers supply mine workers with oxygen during emergencies such as fires or explosions underground. They make it possible for mineworkers to escape from an irrespirable atmosphere. In 2012, a total number of more than 200 000 self-contained self-rescuers were deployed in the South African mining industry.

To ensure that the self-rescuers deployed underground are in good working order, the need for a programme to monitor these devices, and to detect any unacceptable deterioration in their functional performance, was recognised.

Today, the CSIR is the only accredited testing authority in South Africa to perform this monitoring programme.

The monitoring programme in its present format was established in 1996 at the direction of the Chief Inspector of Mines and is controlled by a tripartite technical committee consisting of representatives of government, labour unions and the mining industry.

"Individual mines also get the results and we make them aware of possible risks if there are any," says CSIR senior research engineer, Wilfried Schreiber.

"At present, more than 200 mines/shafts are taking part in this monitoring programme and more than 2 200 self-contained self-rescuers are being tested annually."

The main objectives of the monitoring programme are:

- To detect adverse performance trends in self-contained self-rescuers in daily underground deployment which could ultimately jeopardise a successful escape in the event of an emergency;
- To assist mine management in achieving legal compliance with Regulation 16.4 of the Mine Health and Safety Act, 1996, that is, "employer to ensure that no defective self-contained self-rescuer is issued";

Underground mines are dangerous working environments and the health and safety of the underground workforce is of paramount importance to the South African mining industry.

Senior laboratory technicians Richard Rapoo, Jonathan Manganye and Johan Sachse with different self-contained self-rescuers in front of a breathing simulator.

Two CSIR innovations used in self-contained-self-rescuers such as the one featured here, are a rubber mouthpiece and a noseclip (inset), to prevent the inhalation of harmful gases.

- To detect any trend indicative of premature deterioration in terms of negotiated agreements including periods of guarantee;
- To identify units which remain functional within established norms subsequent to the expiry of negotiated periods of guarantee; mines will therefore benefit in that premature replacement or refurbishment of fully functional units would have been averted;
- To provide sound technical advice on-site to the mines; and
- To give feedback, through formal reports, on all makes of self-contained self-rescuers, thereby enabling comparative evaluations on an on-going basis.

The monitoring programme has shown that different units – even when deployed under similar conditions – react and show different degrees of functional performance deterioration.
In some types of units, this deterioration is more serious than in others. In the last few years, signs of normal wear and tear, as well as deterioration of functional performance, were not identified as the only faults. Material failures, structural faults and design weaknesses, which are not related to normal wear and tear, were also identified. Subsequently, pro-active remedial actions could be initiated to rectify these problems timeously. If the on-going performance monitoring programme had not been in place, any of these problems might only have emerged when the units were used during an emergency, with possible fatal consequences.

During 2012, as in the past, a substantial number of self-contained self-rescuers were activated and in all of these incidents, not a single device malfunctioned. Training, as well as maintenance and care, is essential in this respect but, fundamentally, the monitoring programme provides the level of support required to achieve such outcomes.

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Meet self-contained self-rescuer testing facility manager **Wilfried Schreiber**

Schreiber is a senior research engineer at the CSIR and has worked for the organisation since 1996. As project manager, he is in charge of the self-contained self-rescuer testing facility in Cottesloe, Johannesburg. He obtained his higher diploma in mechanical engineering in 1970 from Polytechnicon Grossenhain in the then East Germany. He has specialised in breathing protection technology since 1976. He is an inventor/co-inventor of five products/systems that are all related to breathing protection technology and which are patented by the CSIR. He is an associate of the Mine Ventilation Society of South Africa.

ZERO HARM

Squaring up to industrial risks of fires and explosions

Helping to achieve safe working conditions for South Africans in industries where fires and explosions may occur, is paramount to the Kloppersbos testing and training facility.

Timeline for Kloppersbos

1983
Coal characteristics: First full-scale explosion tests in 40 L vessel

1985
Sod turning at Kloppersbos: 200 m explosion gallery

1990
Facility management complies with legal requirements for licensing to conduct explosions

1994
Certified safety/explosives manager appointed. Ongoing involvement with local and international clients

2013
Training of over 2 500 miners per year in explosion awareness

The 200 m explosion gallery is used for research on novel methods to prevent fires and explosions.

SOME 40 KILOMETRES from Tshwane lies the Kloppersbos facility, comprising a range of test and research and development (R&D) facilities, some of which are unique in the world. At the heart of its operations is a commitment to conducting full-scale surface tests for fires and explosions in a controlled environment, overseen by experienced staff. The facility is managed by the CSIR on behalf of the departments of Mineral Resources, and Public Works.

Local and international clients

Kloppersbos has seen more than 30 years of service to local and international clients, the latter from Europe, China, Australia and New Zealand.

The CSIR's Isaac Mthombeni explains, "The Kloppersbos 200 m explosion gallery is one of our most established facilities. It is unique in the world and continues to draw the attention of international companies whose R&D, and testing regimen, demand the use of this facility."

Training of miners

Kloppersbos offers awareness training seminars to underground workers in the mining industry. Mthombeni highlights, "As a unique facility, we are in demand for training in explosion suppression for both hard and soft rock mining." The proactive safety training is designed to reinforce levels of awareness among underground workers of the dangers associated with methane and methane/coal dust mixtures in an underground environment, as well as those associated with hard rock mining, such as gold and platinum mining. Miners are taught best practices for prevention of potential dangers and how to deal with dangerous conditions underground.

Demonstrations are conducted in the 10 m and 20 m tunnels, as well as the ventilation tunnel.

Dust is defined as powders with particles less than 500 micrometres in diameter. A micro-metre is one millionth of a metre.

The South African mining industry employs over half a million workers.

A small-scale methane roof-layer ignition model is used to inform a group of trainees how methane disseminates.

Industrial dust explosion test in the 20 litre explosion vessel.

Dust explosions as industrial hazards

A dust explosion is the fast combustion of dust particles suspended in the air in an enclosed location. While coal dust explosions are a frequent hazard in underground coal mines, many otherwise mundane materials, such as grain, flour, sugar, powdered milk and pollen, can lead to a dangerous dust cloud. An explosion may result when concentration of dust in the air is high, combined with oxygen and an ignition source.

The Kloppersbos team is responsible for the testing of explosion parameters for various industrial dust samples at the facility. Mthombeni reveals, “Dust has a very large surface area compared to its mass. Burning occurs at the surface of these solids, where it can react with oxygen – dust is much more flammable than bulk materials.”

Kloppersbos conducts tests in its 20 L and 40 L explosion vessels to determine the explosibility index of various dust particles with a view to assisting industry to put in place safe practices to counter this danger to lives and infrastructure.

Other services

Conveyor belts are essential to industrial operations and are treated with fire retardants. The Kloppersbos conveyor belt fire test gallery is used to conduct fire tests for this equipment.

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Two trainees emerge from the 200 m test tunnel after getting it ready for an explosion to take place.


INVESTMENT INTO FACILITIES AND EQUIPMENT TO UNLOCK THE POTENTIAL OF A BIOCOMPOSITES INDUSTRY






Over the past few years, the CSIR has made significant investments into fibres and biocomposite research and infrastructure at its Port Elizabeth site. The Department of Science and Technology (DST) has invested approximately R10.8 million in new equipment to complement this research. This investment in infrastructure and the creation of the Biocomposites Centre of Competence will help unlock the significant potential of a fully developed biocomposites industry in South Africa.

THE MAJORITY OF RESEARCH at the CSIR's facilities in Port Elizabeth focuses on nonwoven and composite products and the more traditional fibre processing route. Fibre modification, where chemicals and techniques are applied to fibres to change their properties, also remains a strong focus with continued support given to industry on fibres and textiles.

The 4 300 square metre facility includes extensive infrastructure for processing and analysing natural fibres and natural fibre-based composites along the whole value chain, from fibre extraction and processing, to intermediate products such as nonwovens, to final natural-fibre composite products and components. It is, essentially, a complete pilot production line.

The processes involved in the nonwoven pilot production line include fibre blending and opening; carding and cross-lapping for web formation; needle punching; hydro entanglement; foam impregnation; hot air bonding; curing and drying, as well as hot calendaring and winding.

The pilot plant facility is supplemented by a comprehensive range of testing instruments to characterise nonwoven materials for a variety of properties. These instruments can test for air and water permeability; acoustic and thermal conductivity; filtration efficiency; dynamic contact angle; surface tension; pore size and distribution; water vapour permeability; universal tensile testing with attachments for pull-out force and puncture resistance measurement; hydraulic transmissivity, abrasion and peeling. In addition, digital image processing and microscopy analysis are also done.

Composites are prepared using natural fibres such as flax, hemp, kenaf and agave; including thermoplastic and thermoset resins; as well as biopolymers such as soy protein, polylactic acid and polyfurfuryl alcohol. The mechanical, thermal, thermo-mechanical and fire retardancy properties of fibre-reinforced composites are optimised for application in the automotive and aerospace industries.

Developing new biopolymers and resins is an important activity in the development of biocomposites, therefore the CSIR's fully integrated composite processing facility includes a 2 700 kN compression moulding hydraulic press, vacuum-assisted resin transfer moulding, twin screw extruder and an injection moulding machine.

The composites laboratory houses state-of-the-art equipment for measuring the mechanical and thermal properties of composites. A weathering chamber has recently been installed to study the influence of temperature, humidity and sunlight on composite materials, which is crucial for components that are used in outdoor environments.

The procurement and commissioning of the equipment under the DST infrastructure grant has been completed. Additional equipment that includes the pulveriser, ultra centrifugal mill and super-mass colloider are being procured to start new projects on utilising post-harvest agriculture waste and plant residues. This will further advance the scope of the research in developing diversified bio-based and allied products.

Apart from research and development, this centre is also frequented by industry, seeking assistance with problem-solving, quality control and guidance on maintaining ecological standards. In addition, the centre conducts hands-on training sessions for university students and industry.

Meet chief researcher Dr Rajesh Anandjiwala

Anandjiwala has earned a PhD from the University of Leeds, England in textile engineering. He has seven years of research and development experience in the textile industry in India and eight years in academic research in the USA. Anandjiwala is a CSIR chief researcher and research group leader for nonwovens and composites. He has published extensively.

Anandjiwala is a Fellow of the Textile Institute of Manchester and a member of the International Fibre Society, USA. He is also rated as an established researcher by the National Research Foundation of South Africa and serves as an Adjunct Professor at the Post-graduate Department of Textile Science at the Nelson Mandela Metropolitan University, Port Elizabeth.

Some highlights emerging from this facility

- Development of biodegradable packaging from biopolymers, resulting in compostable wrappings for fresh produce in addition to affording improved functionalities such as a longer shelf life
- Development of natural fibre-thermoset and thermoplastics composites for automotive (rear parcel trays) and aerospace (overhead baggage compartments) applications
- Development of novel solutions to improve the fire retardancy of biocomposites and fibre-reinforced composites for application in automotive and aerospace industries
- Value-addition to agricultural wastes and residues such as making nanocomposite material
- Development of cellulose and chitin-based bio-nanocomposite fibres for textile and biomedical applications.

A wide range of fibre and composite processing equipment for compounding and extrusion, injection moulding, compression moulding, resin infusion and a nonwoven pilot plant make up the infrastructure that enables biocomposite research. In addition, there is extensive characterisation equipment for polymers, composites and nonwovens in the thermal, mechanical and fire retardancy application areas. The facility also has novel fibre processing equipment for the production of specialised fibres. Shown (top to bottom, from left): a dynamic mechanical analyser; capillary flow porometer; air filtration sample; weathering and light stability tester; fibre processing line; compression moulding; air filtration tester; thermo gravimetric analyser and cone calorimetry.

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A focused ion beam scanning electron microscope to obtain cross-sections from hard materials.

Promising material improvements thanks to WORLD-CLASS FACILITY for nano-structured materials

The realisation that an in-depth understanding of the properties and behaviour of materials at the nano (10^{-9} m) level could lead to new applications and revolutionise aspects of life, saw South Africa take up nanotechnology for materials in its research and development strategies and roadmaps in the early 2000s.

INVESTMENT IN NANO-TECHNOLOGY materialised through the establishment of the National Centre for Nano-Structured Materials (NCNSM) by the Department of Science and Technology (DST). The Centre was created in 2007 and is hosted by the CSIR.

While research peers at other institutions lead the quest to investigate the use of nanotechnology for mining and minerals, water and health, the CSIR-hosted centre focuses on the modelling, synthesis, characterisation and fabrication of new and novel nano-structured materials with specific properties.

Research and development at the NCNSM makes possible the manufacture of bulk materials with improved properties, such as plastics with greater tolerance to freezing or being able to withstand high temperatures; or plastics that possess fire retardant properties or have higher resistance to tearing.

On the other hand, detection devices that use carbon nanotubes or nanowires (nanosensors) become capable of detecting with greater sensitivity and accuracy, either flammable or toxic gases at even parts-per-million levels. This can save lives in mining or industrial environments.

Characterising materials

The necessary platform to characterise these materials at the nanoscale is provided by sophisticated instrumentation and the expertise of world-class researchers who are skilled to operate equipment optimally, while conducting world-class nanotechnology research.

The facility has a wide range of imaging instruments (high resolution transmission and scanning electron, scanning probe, visible light, Raman and Fourier Transform Infra-Red microscopes). Imaging is an important part of what needs to be done in order to characterise the

Analysts studying nano-structures using a scanning electron microscope.

The National Centre for Nano-Structured Materials is housed at the CSIR in Pretoria.

Small-angle x-ray scattering is a non-destructive method for investigating nano-structures from less than a 1 nm up to 200 nm in size.

structure of materials at atomic and molecular levels, so that scientists can understand how changes in structure translate into improved properties.

The facility houses state-of-the-art equipment to obtain ultra-thin sections required for transmission electron microscopy from hard materials (focused ion beam milling) or soft polymers (cryo-ultramicrotomy). A great deal of this equipment has been purchased with the generous support of the DST.

Wide empowerment of materials researchers

The use of the nanofacility is not restricted to CSIR researchers. Researchers from universities and industry are encouraged to further their research via access to these world-class facilities. Researchers at the NCNSM oversee post-graduate and post-doctoral fellows from South African universities. Access to all equipment is done via an electronic booking system, charged on a running cost-recovery basis. The ethos of the facility is to teach students and staff to operate instruments at the highest level and in doing so, empower them to progress in their research careers.

Polymer nanocomposites

One research area that is attracting great attention and investment from the DST and the CSIR is the up-scaling of the manufacture of polymer nanocomposites. This entails progressing from a modest laboratory bench-scale project that produces a few grams of the improved material to an industrial one with the potential of producing 100 kg or more and that can be tested in industrial applications. This amounts to a 'proof of concept' or 'acid test' regarding the usefulness of the new product. Improvements to the bulk properties of materials will impact various industries that include automotive, paint, cosmetics and pharmaceuticals.

The centre is a hub of worldclass analytical and imaging instrumentation that is unique, in that it has unrivalled expertise and a rare spread of analytical and imaging instrumentation, all under one roof. The characterisation facility is rapidly becoming a leading centre in the imaging of polymers, which are notoriously difficult materials to study at the nanoscale level because they demand delicate sample preparation routines. At this level, they also rapidly degrade under the beam inside electron microscopes.

Adding expertise and capabilities

The NCSM has appointed additional staff to cope with the growing demands for analysis. The addition of a scanning attachment system to the high resolution transmission electron microscope increases the centre's ability to visualise the interaction between nanoclays and the surrounding polymer matrix, as well as establish the 3D dispersion of the nanoadditives that underlies the success or failure of these new materials.

The use of clays in nanocomposites increases desirable properties, such as tensile strength, modulus and fire-retardancy. Optimum results are achieved when the clay particles become exfoliated and highly dispersed in the polymer matrix during processing. Establishing the degree of dispersion without distorting the structure of the nanocomposite is challenging, but three approaches used at the centre make this possible.

The focused ion beam scanning electron microscope enables accurate milling (etching) of nanometre-thin layers of material at a time. Successive capture and stacking of images acquired after each milling step allows 3D visualisation of the distribution of clays in the material. Alternatively, the relatively soft nanocomposites can be hardened by cooling to -120 °C and 70-100 nm thin sections cut at that temperature using a cryo-microtome for subsequent observation using the transmission electron microscope. Soon, the centre will further be able to perform tomography of these thin sections in the HRTEM, which will provide even higher 3D information on the interface between clays and polymers than previously achieved.

Meet facility manager Dr James Wesley-Smith

Wesley-Smith joined the NCNSM during 2012, bringing more than 23 years' experience in light and electron microscopy accumulated while managing a multi-user microscopy and microanalysis facility at a higher education institution. A keen researcher himself, he has a strong bias towards ensuring that work of only the highest quality leaves the characterisation facility, by advising – wherever possible – on appropriate sample preparation and maximising the performance of the instrument to make the information sought, visible. He is an ardent advocate of capacity development in the scarce skill of microscopy, regularly providing theoretical and hands-on training to users of the facility himself, or by inviting leading experts in various fields of materials characterisation to the centre.

He has been President of the Microscopy Society of Southern Africa since 2009, and is also Chair of the User Group of the double spherical aberration Cs corrected high resolution transmission electron microscope at the Nelson Mandela Metro-politan University.

Wesley-Smith has a PhD in cell biology and is a Fellow of the Royal Microscopical Society (UK) .

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BIOREFINERY:

A NEW TRICK FOR AN OLD INDUSTRY

The CSIR and the University of KwaZulu-Natal are pioneering a technique aimed at breathing life into the aging pulp and paper industry.

THE CSIR and the University of KwaZulu-Natal (UKZN) have partnered to aid the pulp and paper industry to be more profitable through diversification, using a novel technique in South Africa.

> Internationally, biorefining was started approximately five years ago. Dr Bruce Sithole was recruited from the Pulp and Paper Research Institute of Canada to head up biorefining activities at the CSIR.

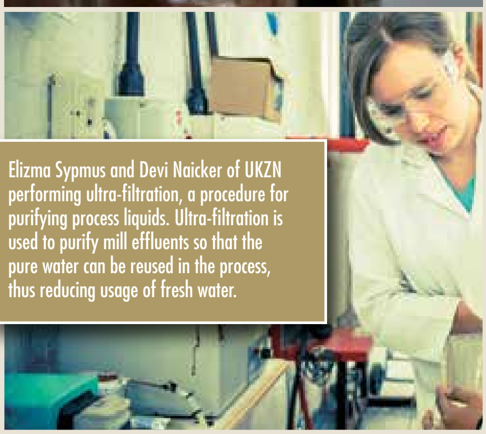
The pulp and paper industry is a mature industry, which means that it is an industry in decline, says Dr Bruce Sithole, CSIR lead researcher for this initiative.

"New technologies have led to less demand for paper. In fact, a number of mills have closed down," he explains. "Our approach is governed by what is needed to help the industry to survive," he states.

Collaboration between the CSIR and UKZN – with CSIR and industry financial support – has seen the introduction of new technologies, designed to reduce wastage of raw materials and extract value from biomass in addition to making traditional pulp and paper products. The technique is called biorefinery and currently is not practised in South Africa's pulp and paper industry. Biorefinery technologies are being studied using pilot plant equipment and testing platforms.

Inside the pulping process

There are three types of pulping, namely, mechanical; chemical; and recycling. Mechanical pulping is used in manufacturing low-quality paper such as newsprint. Chemical pulping is used for stronger paper, typically for packaging and office paper. Another type of chemical pulp makes dissolving pulp that is used for premium products. With this method, pulp is converted into viscose and rayon, which is then used in the manufacturing of garments. Recycled pulp is made from used paper that is repulped and the ink removed by a flotation process, before conversion into paper. The Forestry and Forest Products Research Centre, a joint venture



Elizma Sypmus and Devi Naicker of UKZN performing ultra-filtration, a procedure for purifying process liquids. Ultra-filtration is used to purify mill effluents so that the pure water can be reused in the process, thus reducing usage of fresh water.

In the temperature and humidity-controlled paper-testing laboratory, measurements of pulp properties, such as burst, tear, tensile strengths and brightness are taken.

The CSIR, in collaboration with UKZN, operates the Forestry and Forest Products Research Centre that has a variety of pilot plants and equipment for simulation of pulping, papermaking and biorefinery technologies. It is based in Durban at the Howard College campus of UKZN.

See http://ffp.csir.co.za

between the CSIR and UKZN, aids the industry in all forms of pulp and papermaking with the objective of making the industry competitive and profitable.

"The typical yield in chemical pulping is 50%. By this I mean we only use 50% of the material of a tree, the rest is lost in the process. We strip the bark, leaves and branches, and remove lignin from the wood, which constitutes half of the tree. This is a huge waste," says Sithole. "Through biorefining, we can derive value from the wasted material. We create other products such as fuel pellets and bio-composites," he explains. "We can also recover chemicals and convert them to high-value products," he says. Sithole adds that the pulp industry has no way of land-filling the large amounts of sludge it produces, but with biorefining, it is now possible to convert the sludge into high-value products. – ***Bandile Sikwane***

Prabashni Lekha of the CSIR is seen using an ultra-microtome for microscopy sample preparation. The ultra-microtome is used to cut ultra-thin sections of resin-embedded samples using a glass or diamond knife. To view biological samples on the transmission electron microscope, the sections need to be 100 nm thick so that the electron beam can pass through the sample to create an image.

Mughandan Rajah and Blessing Makununika using the electrically heated rotating digesters needed to simulate chemical pulping processes. A rotating digester can also be used for biorefinery applications, such as pre-hydrolysis of hemicelluloses from wood chips prior to pulping.

Meet lead researcher Dr Bruce Sithole

Sithole completed his undergraduate degree in chemistry. He obtained his Master's in chemistry at the University of Aberdeen in Scotland after which he completed his PhD in chemistry in Canada. He states: "Before I joined the Pulp and Paper Research Institute of Canada in the 1990s, I knew nothing about the pulp and paper industry. I was surprised at how much science goes into making paper."

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EQUIPPING PROFESSIONALS TO HELP INDUSTRY SAVE ENERGY

A range of cool 'toys' at the NCPC-SA makes energy assessments and systems testing look like child's play – but with world-class accuracy and cost-saving results.

The National Cleaner Production Centre of South Africa (NCPC-SA), hosted by the CSIR on behalf of the Department of Trade and Industry, has a strong focus on capacitating industry in the area of energy efficiency. The centre is supported in this by the United Nations Industrial Development Organization (UNIDO).

Through the Industrial Energy Efficiency Project (IEE Project), the NCPC-SA has trained over 1 200 professionals in energy management systems and energy systems optimisation since its inception in 2010. In addition to the skills learned from UNIDO's international experts, this cadre of energy professionals has the use of highly advanced technical equipment, specifically for energy systems optimisation.

Equipment use and value

Numerous processes and systems operated in a typical industrial plant are high energy users and improving – or optimising – these systems can save thousands of kWh of energy, and of course rands. The systems that the IEE Project currently focuses on include steam, fans, pumps, electric motors and compressed air.

(From left) An infra-red thermometer; thermal imaging camera for steam systems; and steam system expert level training.

ALFRED HARTZENBURG, senior project manager at the NCPC-SA and a UNIDO certified expert in a number of energy systems, says: "Our approach is to first determine the energy needs of the process and then to measure the generation capacity of the energy system. This informs the generation of energy savings opportunities and is the basis of our optimisation philosophy.

"The industrial energy systems optimisation test and measuring equipment is used primarily to confirm initial quick scan evaluations in identifying focus areas and to enhance the energy assessor's understanding of operating processes and energy usage in the plant."

How it works

"Let's consider the assessment of a steam system with its generation, distribution, end-use and recovery components," says Hartzenburg.

"Generation is typically a good starting point and boiler combustion efficiency is a key measure of generation performance, so we use the flue gas analyser to measure flue gas temperature, excess oxygen levels in the stack, as well as carbon monoxide and carbon dioxide levels.

"This allows us to establish the boiler efficiency for different loads and possibly prompt the assessor to consider the benefit of a condensing or feedwater economiser that will capture exhaust heat to preheat feed water going into the boiler, thereby improving boiler efficiency.

"We will then use the thermal imaging camera to check for refractory losses on the boiler shell and associated piping. Improving insulation of the boiler shell, associated piping, as well as valves, reduces heat losses and further contributes to steam generation and boiler efficiency," he adds.

Benefits to industry

As part of its capacity-building efforts, the NCPC-SA makes the equipment available, free of charge, to all its qualified energy systems experts, as well as the two-day advanced end-user course delegates who have attended its equipment workshops.

According to Hartzenburg, many of the items on the equipment list are highly specific and specialised and purchasing them would not be a viable option for assessment professionals, many of whom are consultants or work in small and medium enterprises. With a full set in Durban, Cape Town and Pretoria, consultants can use the IEE Project equipment to enhance their service offering and the results of their work in industry.

In addition, the use of the equipment ensures more accurate assessment results and often quicker implementation times for energy efficiency interventions. "I have witnessed a significant improvement in the quality of NCPC-SA energy assessments since the introduction and use of our equipment. The quantification of losses and determination of potential savings is now effected more scientifically."

"The result is increased integrity of assessments that often allows companies to move much quicker onto implementation. It also supports the measurement and verification of energy savings," concludes Hartzenburg.

With a full set in Durban, Cape Town and Pretoria, consultants can use the IEE Project equipment seen above and on the opposite page to enhance their service offering and the results of their work in industry.

A set consists of various instruments specific to certain energy systems, as well a range of software developed by the Department of Energy in the United States.

The total estimated value is R2.5 million.

Industrial energy systems optimisation test and measuring equipment of the NCPC-SA IEE Project

This equipment is used in an industrial setting:

- manufacturing plants, mines, foundries, etc.
- to accurately test and measure the energy use and patterns of a system so as to identify areas for improvement that will result in energy savings.

(From left) A flow kinetics FKT electronic manometer for fan systems (back); a power meter for measuring KW, Amps and Volts; an infra-red thermometer; a humidity/temperature meter for fan systems; another infra-red thermometer and a current clamp (also seen on page 38).

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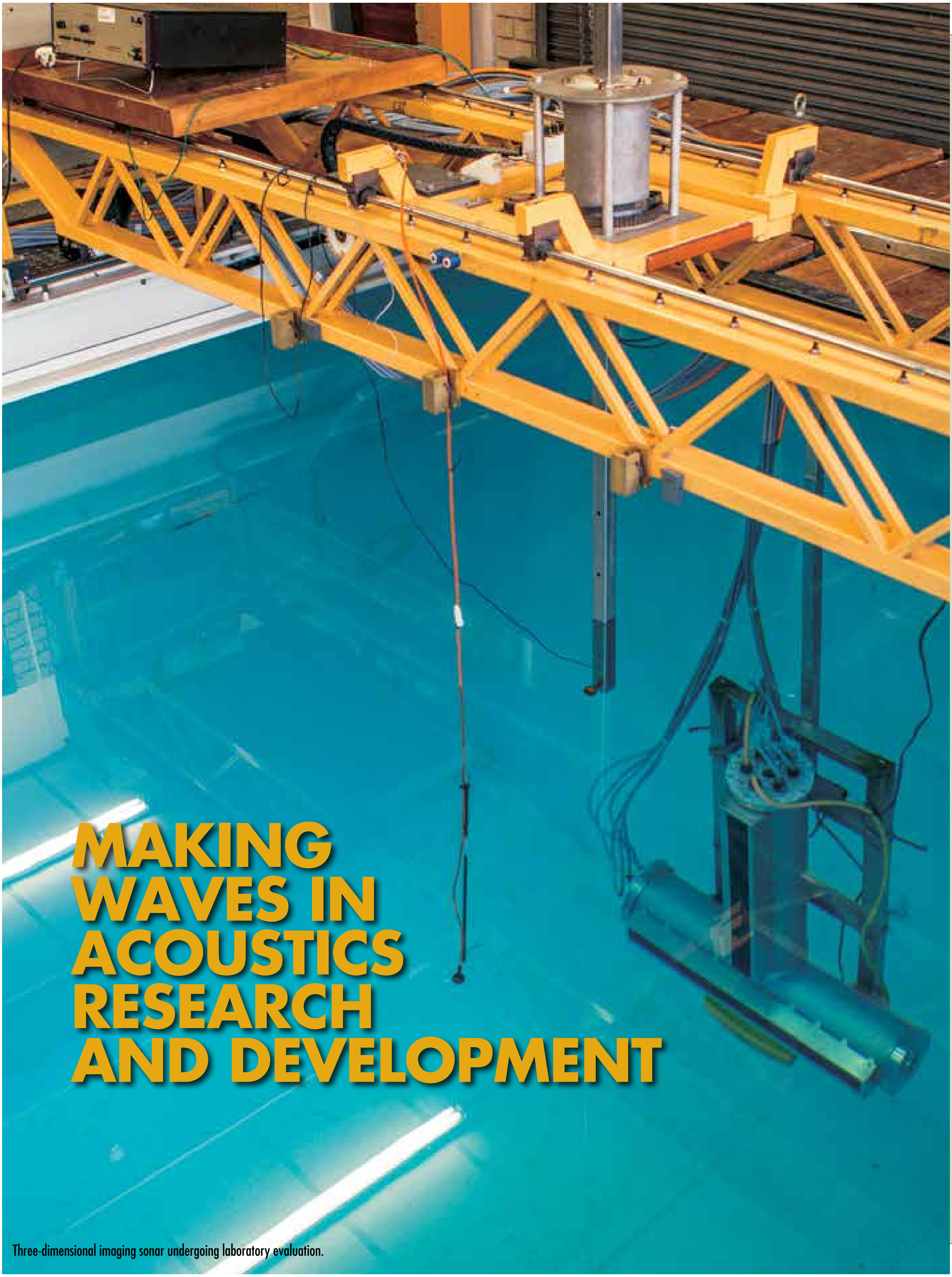

MAKING WAVES IN ACOUSTICS RESEARCH AND DEVELOPMENT

Three-dimensional imaging sonar undergoing laboratory evaluation.

Naval and commercial shipping can benefit tremendously from three-dimensional images with detailed information on features encountered underwater. The most obvious benefit lies in ensuring the safe operations of vessels, but also in terms of, for example, curtailing smuggling by hiding cargo underneath the hull of a ship. For a new invention such as this to be brought to market, rigorous testing in a suitable facility is required.

THE ELECTRO-ACOUSTIC underwater test facility at the CSIR is such a facility. It is key in the testing of underwater sonar transmitters, receivers and arrays in respect of their acoustic sensitivity, acoustic beam-patterns and electrical properties.

The electro-acoustic underwater test facility was originally established by the South African Navy and is mostly funded through the CSIR, with support from Armscor. The facility permits local characterisation of newly manufactured or refurbished transducers, providing significant cost and time savings. It allows for acoustic testing, electrical testing, as well as high pressure (depth) tests to be performed.

The facility is one of two in South Africa, the other facility being in Cape Town under the control of the South African Navy at the Institute for Maritime Technology.

The facility was recently upgraded with new instrumentation, automation technologies and testing software. It has been used in all sonar development projects undertaken by the CSIR for the Navy and has also been used to characterise all of the wet-end sonar transducers deployed on the Navy's current submarines and Corvettes (surface vessels).

The facility can test underwater transducers from 3 kHz to 500 kHz and simulate depths of up to 650 m.

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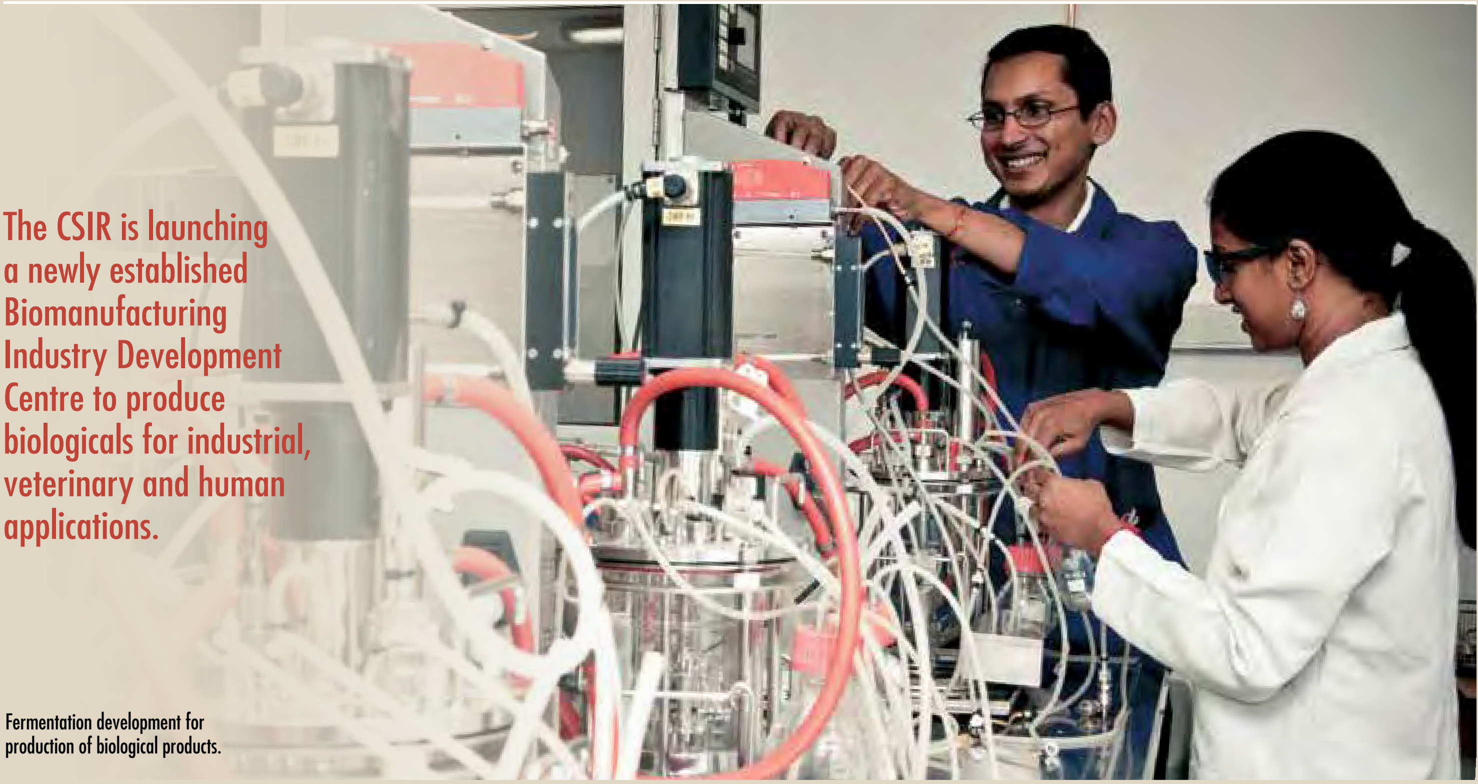
Meet facility manager **Kiri Nicolaides**

Nicolaides leads ultrasonics research at the CSIR. He has 25 years of research and development experience in the field of piezoelectric devices, military sonar, as well as medical and industrial ultrasonic systems. The ultrasonic group undertakes research and development, as well as the development of specialised military, industrial and medical products in the field of sonar and ultrasonic systems.

The electro-acoustic test facility.

An open-innovation platform dedicated to biomanufacturing



The CSIR is launching a newly established Biomanufacturing Industry Development Centre to produce biologicals for industrial, veterinary and human applications.

Fermentation development for production of biological products.

FUNDED THROUGH the Jobs Fund of the Development Bank of Southern Africa (DBSA) and the Department of Science and Technology (DST), the centre is the first-of-its kind built in the country. The Biomanufacturing Industry Development Centre (BIDC) is meant to become a hub for open-innovation in bio-manufacturing and is specifically dedicated to start-ups and Small, Medium and Micro-sized Enterprises (SMMEs) in the development of new technologies and products. It will provide incubated companies with access to ready-to-use biomanufacturing facilities and supporting research and development (R&D) laboratories, as well as access to a great number of experts in the fields related to bioprocess development and scale-up.

Supported companies will be managing their own projects; the centre will support them through the prototyping and scale-up phase and assist them to do market acceptance testing and to launch products on the market. The companies will remain the sole owners of their innovations and retain absolute control over their future in terms of added value and partnerships. The facility will also help lower the cost and barriers that inhibit innovative enterprises from translating their inventions into market-ready products and will play an enabling role in developing necessary partnerships that will directly contribute to sustainable job creation.

Acting Centre Manager, Fanie Marais, says: "After numerous months of meticulous planning, and with the vital support of our partners, we are pleased to be moving this new centre to its completion and readiness to start operating. The facility exemplifies the CSIR's commitment to the development of entrepreneurship and the advancement of SMMEs in the biomanufacturing industry."

The establishment of a well-resourced and operational biomanufacturing centre producing prototypes for the industrial, agricultural and health sectors requires a significant long-term investment in both infrastructure and specialised skills. Strong business development support will be provided through partnerships with business incubators (e.g. eGoLiBio and The Innovation Hub), business administration support and facilitators of manufacturing nodes (e.g. the Technology Innovation Agency (TIA) Bioprocessing Platform, Algal Platform, Fort Hare Natural Product Processing Facility and the envisaged TIA Agroprocessing Facility in Limpopo) and industry partners such as BioVAC, Afriplex and Onderstepoort Biological Products (OBP).

"What makes the BIDC a unique resource is the blending of R&D, industrial and commercial expertise, within the context of a working pilot-scale biomanufacturing plant that resembles the environment where the entrepreneurs will eventually work," says Marais.

The BIDC is part of an expansion to the CSIR's already significant presence in the biosciences. Over the past years the CSIR has, through its main funders, invested millions in R&D and infrastructure. These investments have come in the form of outstanding new facilities, supported by up-to-date technology and laboratory space. Most notably, the CSIR has recently invested R50 million in a new R&D facility that will support the proposed centre. The project of R90 million spans three years and R72 million will be funded by the DBSA, while the CSIR through funding by the DST will co-fund the project with an R18 million investment. The project includes R40 million that will be an investment in new infrastructure to procure specialised large-scale infrastructure to complement the existing pilot plants at the CSIR.

"Furthermore, the BIDC is designed in such a way that it is highly flexible and adaptable, because we believe this synthesis of academic and industrial activity will accelerate innovation and process development. With entrepreneurs, students and industrial experts all in the mix, we expect the BIDC to help evolve the best practices of biomanufacturing by providing applied experience for the incubatees to go out there and became well-established businesspeople," Marais says.

Key infrastructure and equipment

Infrastructure investments over the last few years have seen the rise of a basic biomanufacturing platform at the CSIR, capable of demonstrating technologies at a gram to kilogram scale. The BIDC has mostly 20 litre fermenters, as well as one 200 litre fermenter with associated downstream equipment, and this is currently used in process development.

In order to achieve the goal of making product prototypes, several pieces of equipment have been installed in the existing pilot plants, using the funding provided.

Biomanufacturing encompasses four major categories of production technology: natural product extraction; microbial fermentation; biocatalysis; and cell culture. Irrespective of how the biomass is generated, all technologies require downstream processing (usually extraction and purification), followed by formulation, filling and packaging. Biomanufacturing serves a variety of industries, including biopharmaceuticals, industrial biologics (sold to the chemical and fuel sectors, including enzymes, vitamins, bioremediation products and biofuels), food and feed bioproducts (including probiotics, additives, bio-control agents, supplements and natural products), diagnostic reagents and cosmetics (extraction and formulation of natural products obtained through fermentation or conventional aqueous/solvent extraction.)

Capabilities and competences

The CSIR invested in the development of platform competences and infrastructure for plant, yeast and other microbial expression systems over the past five years and has a strong collaborative position in human and veterinary biologicals in South Africa, as well as internationally.

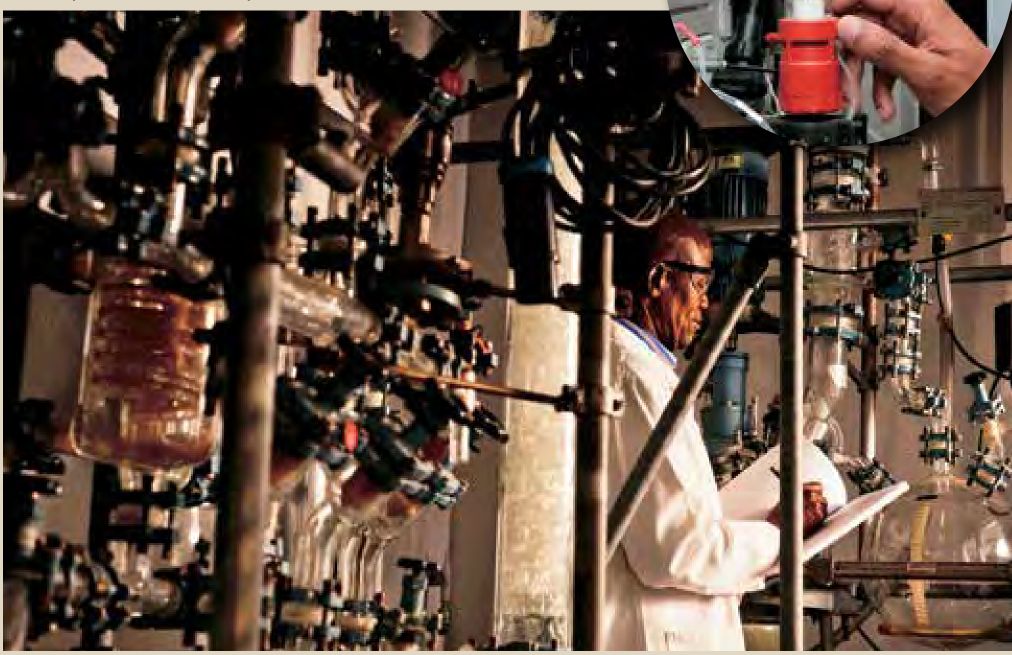
What role does the BIDC aim to play?

It aims to develop at least 12 businesses over the next three years, leading to a potential Gross Domestic Product contribution of up to R180 million per annum. The true benefit of this investment however, will be seen in the years thereafter as the biomanufacturing sector grows.

"An existing building has been renovated by the CSIR (at a cost of about R50 million) and a portion of this building was reserved to house the proposed pilot plant," says Marais.

The BIDC is located in this newly refurbished building at the CSIR campus in Pretoria. The launch of this building is scheduled for December this year, with the initiative already having started its operations.

Pilot scale purification of natural compounds.



Meet BIDC manager Fanie Marais

Marais manages the newly established BIDC. He was entrusted with the development of a business plan to the DBSA to fund this job creation initiative and establish the BIDC.

This intervention will consolidate a critical mass of specialised skills, including bioprocess engineers, bioproduct development and formulation specialists and process biochemists.

Marais is a seasoned professional with extensive experience in constructing business value propositions, business plans and managing the incubation, commercial development and launch of small, sustainable biotechnology enterprises.

He is an astute businessman with more than 20 years of experience in the biosciences field. He holds a Master of Business Administration and a Master of Science in Organic Chemistry.

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Access to digital fabrication through Fablabs

As part of its endeavours to inspire and present science and technology as an attractive field with great career potential to the youth of South Africa, the Department of Science and Technology introduced the South African FabLab network in 2005. This network of small-scale versions of mass production factories provides a platform for youngsters to develop their ideas for application in the real world.

THE FABLAB PROJECT has resulted in seven laboratories in Gauteng, the Western Cape, North West, the Northern Cape, Limpopo and the Free State. The project is funded by the Department of Science and Technology (DST), managed by the CSIR and hosted by private companies and higher education institutions.

The FabLabs are used by individuals to create prototypes ranging from arts and crafts, to engineering and architecture models – taking digital files and turning them into products.

FabKids

Through the FabKids project, Grades 1-12 learners are exposed to the high-tech, rapid-prototyping environment of FabLabs, by giving them tasks aligned to their school curriculum. The project was spearheaded by the realisation that being able to spend time in a high-tech, rapid-prototyping environment could potentially be a career-changing opportunity for many learners. The FabKids pedagogy aims to achieve just that.

Tsoseletso High School learners during a FabKids session held at Bloemfontein FabLab, working on a task to fabricate a cartoon character with two light-emitting diode lamps.

The FabLabs were nominated and twice became finalists (2008 & 2009) in the National Science and Technology Forum Awards.

Dietrich Primary School FabKids sessions during the Mobile FabLab Deployment in the Eastern Cape.

Learners at Kimkgolo Primary School are given a design task at the Kimberley FabLab.

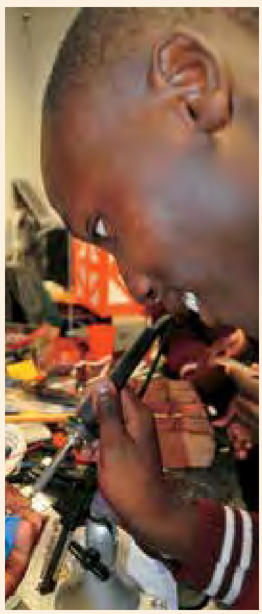
Local community access

The FabLab project furthermore facilitates inventions at grassroots level by providing a platform that allows local communities access to tools that help people solve local problems themselves. These problems can vary from bridging the digital divide to design verification. The laboratories are open to people of all ages, even those with little or no education.

Easy access to the FabLabs gives communities a head start in basic engineering and design technologies, and an opportunity to experiment and learn from others. This introduces them to the world of science and technology – which typically would have required adults to have a technical professional qualification before earning the right to access and experiment.

Fully equipped

A typical FabLab comprises seven computer workstations, a laser cutter (for 2D structures), a vinyl cutter that plots and cuts copper, a high-resolution milling machine that makes circuit boards and precision parts, together with a suit of electronic components and programming tools for a low-cost high-speed microcontroller. Fablabs also house computer numerical controller routers for larger 2D structures and a 3D printer for additive manufacturing.



Meet facility manager **Lindi Mophuti**

Mophuti is the first woman globally to manage a fabrication laboratory. Mophuti is a computer systems engineer and has recently completed her MSc in technology and innovation management. She serves on the board of the International Fab Lab Association and is one of the founders of the FabLab African Network Alliance.

Mophuti is passionate about youth empowerment and getting the community involved. She believes that the Fablabs are an important component in helping people understand how to be relevant and participate in the economy and development of the future.

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SA completes site to CALIBRATE SATELLITES

South Africa has completed what is believed to be the only specifically built and designed satellite sensor radiometric calibration site in the Southern Hemisphere. The site will be used for the vicarious calibration of satellites and airborne sensors.

VICARIOUS CALIBRATION refers to techniques that make use of natural or artificial sites on the surface of the Earth for the post-launch calibration of sensors. It is said that sensors on-board Earth observation satellites need to be calibrated at least twice a year to correct for drift or change in the satellite orbit, changes to the sensor structure itself and the electronic characteristics of the detector arrays.

The Department of Science and Technology funded investigations into the most suitable solutions and the eventual construction of the artificial target reference site.

In setting up the site, various reference targets located in South Africa, as well as Botswana were considered and characterised. Options for such reference sites include large surfaces of known surface spectral reflectance, either natural (deserts or salt pans) or man-made (tarps or concrete). Due to their spectral characteristics, dry salt pans are in most cases the first choice for use as vicarious calibration targets. However, the eventual decision was to establish a man-made calibration site at Paardefontein, 50 km north of Pretoria.

The site comprises an area of 10 000 m^2. The process of finding the right pavers included a rigorous testing of pavers made from different processes, material and sand-cement-water ratios. These different pavers where tested for durability and spectral characteristics.

The pavers were manufactured and cured in a controlled environment to promote uniformity with reference to colour and texture.

The facility contributes to the aims of South Africa's space programme.

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Facilities to do things rapidly

In military deployments, time is often of the essence. The South African Special Forces cadres rely on the CSIR as their technology support base to perform 'quick reaction tasks' to support their missions. One component of this is the ability to rapidly create custom parts, tools or other technology adaptations. Herein lies the need for a rapid prototyping or 3D printing facility.

3D PRINTING or direct manufacturing allows one to take a design, capture and simulate it digitally, and produce an actual, tangible object. Much faster than manual or numerically controlled manufacturing, the process is also more cost effective, reduces labour cost and increases turn-around time. It also reduces material waste associated with conventional forms of manufacture, plus lowers energy use, and allows for the design of unusual and more organic shapes and forms.

It also enhances the advanced mechanical engineering capability, especially when complex mechanical engineering solutions are required. The designer can use direct manufacturing to produce the following: scaled models of actual structures, terrains, areas, prototypes of parts, actual items (if a small volume is required and the material is acceptable); and as a high production volume input to investment casting (for patterns), injection moulds (for hard tooling), sand moulds, and soft tooling (for cores).

Direct manufacture comprises the stereolithography apparatus, where a laser sets a layer of wax or photosensitive material in a bath; three-dimensional printing, which uses injection technology to create a thermo plastic structure; and selective laser sintering that uses a laser to fuse powder (nylon, polycarbonate, polymer and metal). Because colour terrain models are a particular requirement of a stakeholder such as the SA Special Forces, the CSIR uses a 3D printer that uses colour ink jet technology. Similar to a normal printer that would print a photograph, this equipment prints layer upon layer, using material that builds up on the previous layer of material. The input into the printer has to be created either in computer-aided design software or by using a 3D scanner to capture all dimensions of a particular object or shape.

The CSIR works closely with the Central University of Technology, Stellenbosch University and SoSolid in Cape Town to build a national rapid prototyping and direct manufacturing capability.

The capability is not restricted to research and development efforts; it can be used by anyone who needs a design turned into an actual object as a prototype, scale model or test version. The team can, for example, create novel shapes for artistic use, ceramic design and models for architects or sculptors.

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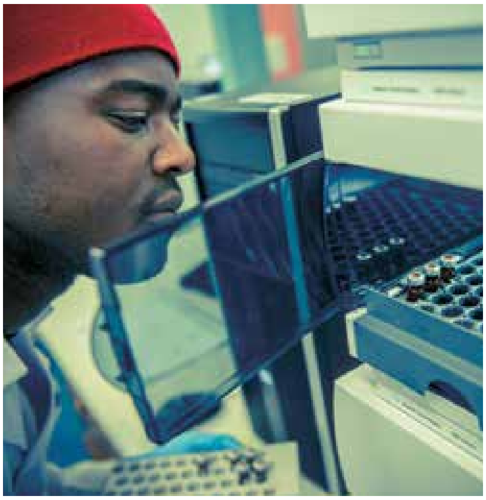
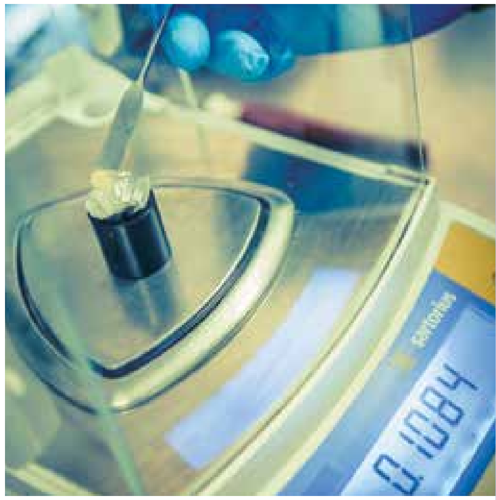
In the case of 3D terrain products, input data from Geographical Information Systems are used to recreate all aspects of an area, as well as any specific information required by a client, in colour. Sudesh Budram inspects a 3D model on completion of the post-processing phase.





A critical contribution in the quest for food quality and correct labelling

(Top, from left) An instrument used for metal analyses, for example, arsenic and selenium; a high performance liquid chromatography (HPLC) instrument used in, for example, the detection of biotoxins; a weighing balance, used to weigh out the amount of sample needed to perform the analysis.

(Second row, from left) A mercury analyser; loading of a tray on the HPLC tandem mass spectrometer used for the analysis of vitamins and diarrhetic shellfish poisonings.

(Third row, from left) A wider view of the HPLC spectrometer; jars with samples after having been homogenised.

The CSIR has equipped its facilities in Durban, Cape Town and Pretoria with sophisticated instruments and highly competent technicians in food and beverage analytical chemistry. The aim is to provide testing services to the food industry for it to meet industry standards. Tests conducted at these laboratories include the analysis of protein; glycaemic carbohydrates; fatty acid composition (e.g. saturated fats); cholesterol; and energy.

THE CSIR food and beverage Laboratory in Cape Town was the first laboratory in the country to obtain accreditation for all the methods required for the labelling legislation (R146) for food products and has since expanded these capabilities to KwaZulu-Natal and Gauteng.

In addition, the Cape Town-based laboratory remains the only accredited testing facility for marine biotoxins for the aquaculture industry in southern Africa. It also tests for food contaminants in fish, such as heavy metals and histamine, a regulatory requirement for the fishing industry in support of the export market, required by the National Regulator for Compulsory Specification.

Yoliswa Kula, CSIR business development manager for CSIR Consulting and Analytical Services, explains: "The correct labelling of food products is crucial, as some individuals may be allergic to some of the ingredients used during the manufacturing process of food products or those allergens that occur due to contamination during packaging or transportation of the manufactured foods."

Among many other reasons, regulation R146 was introduced as a result of inconsistencies that existed in the labelling of food products. The regulation provides information on what sort of information must appear on food labels. The R146 regulation relates to the labelling and advertising of foodstuffs in the Foodstuffs, Cosmetics and Disinfectants Act (No. 54 of 1972) which requires that food manufacturers comply with relevant labelling regulations. Testing is also done in compliance with European Union regulations to support the local fish export market and thereby promote international trade.

The CSIR laboratories are able to analyse food products and provide this type of information to the food manufacturers so that they can comply with this regulation.

"The nutritional information on a food label also gives information to the consumers on the health benefits of a certain product," notes Kula.

"For example, the product might have high dietary fibre content and thus have a corresponding health benefit associated with it, for example to maintain a healthy digestive system."

Kula adds that all the laboratories participate in national and international proficiency testing schemes to ensure optimal quality control accuracy and analytical performance. All methods and measurements are traceable to international standards.

"To assure the quality of analytical processes, procedures and results, the laboratory adheres to the ISO 17025 standard which details the quality policies and procedures required of an accredited laboratory. All the laboratories are accredited by the South African National Accreditation System (SANAS) which is aligned to the ISO 17025 standard."

– Mzimasi Gcukumana

To assure the quality of analytical processes, procedures and results, the laboratory adheres to the ISO 17025 standard which details the quality policies and procedures required of an accredited laboratory.

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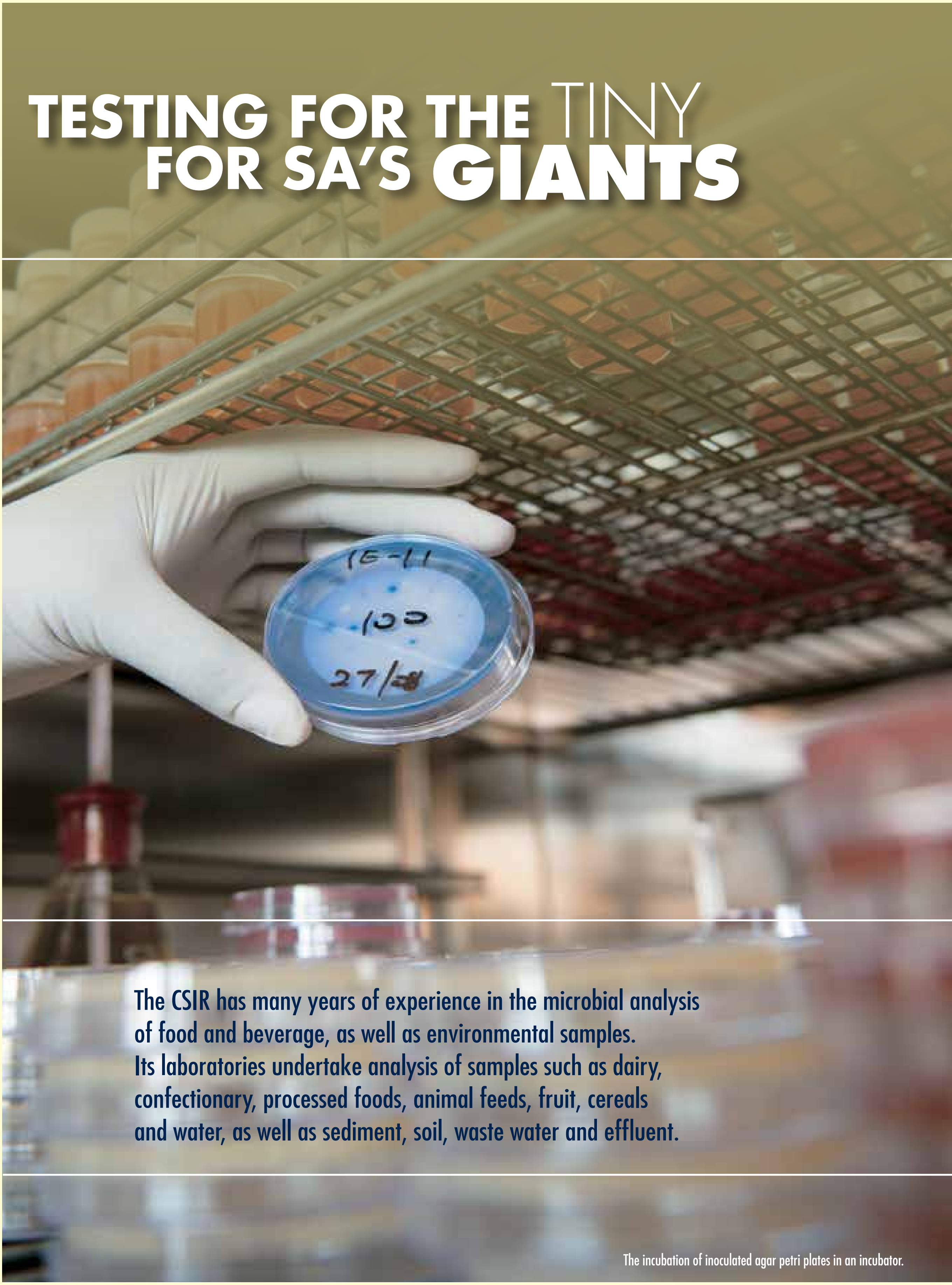
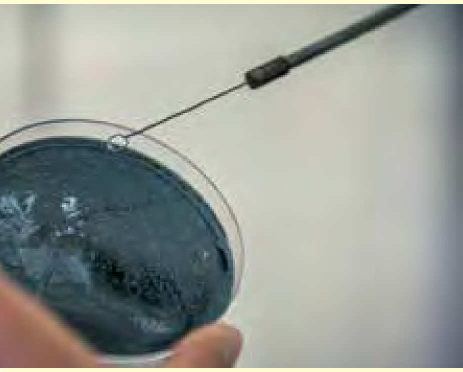
TESTING FOR THE TINY FOR SA'S GIANTS



The CSIR has many years of experience in the microbial analysis of food and beverage, as well as environmental samples. Its laboratories undertake analysis of samples such as dairy, confectionary, processed foods, animal feeds, fruit, cereals and water, as well as sediment, soil, waste water and effluent.

The incubation of inoculated agar petri plates in an incubator.



Scraping colonies off a *Legionella* bacteria plate for microscopic identification.

Microscope slide preparation in a bioflow cabinet.

Fluorescence microscopy.

A PROUD TRACK RECORD and securing the accreditation necessitated by legislation governing the food industry have contributed to the CSIR remaining the preferred laboratory for many of South Africa's giant food manufacturers.

In part, the CSIR's track record is rooted in the investment made in state-of-the-art testing technologies. Competent, technically proficient microbiologists and technicians make up the other part, says CSIR business development manager for CSIR Consulting and Analytical Services national laboratories, Yoliswa Kula.

The CSIR has microbiological laboratories in Durban and Pretoria. The environmental microbiological laboratory in Pretoria was one of the first laboratories in the country to obtain SANAS accreditation for testing for *Legionella* bacteria.

"At this facility, we test all kinds of foods, ranging from raw ingredients, to ready-to-eat food and to processed and manufactured foods," she says.

In the food industry, explains Kula, there will always be testing requirements based on various legislation, which demand different testing requirements for different components, such as the analytical aspect and microbiological component.

"This facility, which tests for microbial aspects, basically supports our food and beverage laboratory as well as our environmental laboratories," she says.

"Legislation sometimes dictates that we test the food product or the water for specific parameters. We test drinking water, river water, borehole water, sewage water and sludge."

Regulations concerning the maximum tolerances for specific pathogenic and non-pathogenic microorganisms in specific samples and food groups, are used as guideline for test requirements.

"We make sure that we are familiar with existing legislation, legislation under development and regulation on food products that are being exported," Kula says.

"Many countries for which South African products are destined are very strict, with detailed and stringent export requirements. We help South African exporters ensure that they comply."

Companies who regularly use CSIR testing services are suppliers of food and beverage retailers. "For some retailers, quality is what their brand is all about. For them, testing is about living up to their brands and they do not view it as a nuisance," she says.

"We provide these highly specialised services to giants in the food industry. Kula concludes: "Our clients have faith in the accuracy of our results. With that comes a huge responsibility on our part."

Meet microbiology laboratory manager **Everton Barnes**

Barnes has worked at the CSIR since 2008. He obtained his BSc Honours degree from the University of Pretoria in 2003 where he specialised in water utilisation.

Membrane filter on agar.

Incubation of agar media in bottles and petri dishes.

Incubation of inoculated total plate count agar.

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An x-ray diffraction instrument is used for the analysis of silica on dust filters by bombarding the sample with x-rays. This is an instrument used for the analysis of diesel particulate matter sampled on quartz filters. The technique uses a combination of temperature, gas and laser light.

A particle size analyser is shown. This technique is used for the analysis of the size of particles in a given sample.

Gravimmetry or weighing, a technique used for weighing filter papers either with dust or without dust.

THE SCIENCE OF MEASURING DUST AS A HEALTH HAZARD

The CSIR air and dust laboratory provides testing services to the mining industry to monitor the human health hazards contained in airborne dust.

TESTS RELATING TO AIR and dust allow mining companies and the authorities to monitor the exposure levels of mineworkers to respirable crystalline silica (RCS) on an on-going basis. This is in line with government's national occupational exposure limits for RCS, which is defined as crystalline silica particles smaller than 10 micron, in workplace air. In South Africa, the exposure limit in the workplaces is 0.1 mg per m^3. Industries are required to monitor and report RCS concentrations to the regulators.

The CSIR laboratory is based in Pretoria and is equipped with sophisticated instruments and highly competent technicians in the field. The laboratory is widely acknowledged for its expertise relating to the measurement of respirable dust and it plays a significant role in the goals of the mining sector, locally and internationally, to eliminate silicosis, a lung disease caused by RCS. The laboratory participates in the International Standards Organisation working group that develops new international test methods on the measurement of RCS in workplace air and actively contributes to the information that is compiled in these international methods.

In addition to testing silica concentrations, the laboratory also conducts tests for diesel particulate matter – the particulate fraction from diesel exhaust.

A national occupational exposure limit for diesel particular matter is imminent as the International Agency for Research on Cancer has classified diesel engine emissions as a human carcinogen. Diesel particulate matter is typically also measured in industries using distribution centres that are reliant on diesel machinery.

Service offerings are not limited to respirable silica and diesel particulate matter testing. The techniques and methods employed can test a range of health hazards in the airborne dust of workplaces, as well as environmental air quality samples. "Our test methods are not limited to the mining industry only, says CSIR laboratory supervisor, Vusi Mahlangu. "Testing can be carried out for health hazards found in the workplace air of non-mining industries. We also test for airborne pollutants that are released by industries that have a negative effect on environmental air quality."

"There are health effects that are associated with both short- and

Atomic absorption spectroscopy is shown. This is an instrument used for the analysis of elements in a given liquid sample using either a flame or graphite furnace.

long-term exposure, depending on the duration of exposure and the amount of chemicals that an individual is exposed to," says CSIR business development manager for consulting and analytical services, Yoliswa Kula. "The departments of Mineral Resources, Environmental Affairs, and Labour rely on the services of these types of laboratories to monitor compliance by the mines and industries to the specified limits."

Laboratory accreditation

In order to assure the quality of analytical processes, procedures and results, the laboratory adheres to the ISO 17025 standard which details the quality policies and procedures required of an accredited laboratory. This laboratory is accredited by the South African National Accreditation System (SANAS) which is aligned to the ISO 17025 standard.

SANAS accredited methods of testing

Alpha-quartz analysis using MDHS 101: In this test, laboratory staff use an instrument called an x-ray powder diffractometer to determine the amount of crystalline silica (i.e. alpha-quartz) in the dust samples. Fourier transform infrared can be used as an alternative method.

Diesel particulate matter according to NIOSH 5040: The elemental and organic carbon content is determined using a thermal-optical method.

Gravimetric weighing: The amount of respirable dust is measured using a micro-balance accurate to 1 microgram.

Particle size analysis: The particle size distribution of dust samples are measured using laser light scattering.

Two as yet unaccredited test methods are also conducted, namely rate of fall-out dust according to ASTM 1739 and elemental analysis using atomic absorption spectrometry.

Meet laboratory supervisor **Vusi Mahlangu**

Mahlangu is the laboratory supervisor of the CSIR air and dust laboratory and has worked at the CSIR since August 2012. He obtained his BTech degree in chemistry from the Tshwane University of Technology in 2007.

Silicosis

Silicosis, a deadly lung disease, is one of the oldest occupational diseases in the world. It is caused by inhalation of respirable dust (particles less than ten micron) containing free crystalline silica, which is a basic component of many minerals and rocks. South African miners, particularly gold miners, face this lurking danger during underground operations. Gold ore typically contains a lot of quartz, which is the most common form of crystalline silica.

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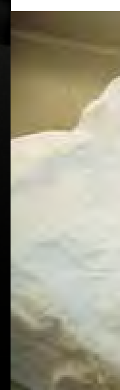
MODERN FACILITY

for research and development in HIV/Aids and TB

CSIR research and development on novel tools for the diagnosis of tuberculosis (TB) and methods of combating HIV/Aids has gained momentum since the establishment of state-of-the-art facilities for experiments conducted with live strains of the pathogens.

THE FACILITY was funded by the Department of Science and Technology through a multi-million rand research grant. Known as the high- containment facility or biosafety level 3 (BSL-3) facility, it is a controlled access laboratory required for all experiments involving hazard group 3 pathogens – pathogens of high potential risk to laboratory personnel and the environment, such as HIV/Aids and TB pathogens. It allows further development and testing of potential aptamer-based TB diagnostics tools and HIV drugs in cell-based functional assays with real clinically isolated Aids viruses and TB pathogens.

Aptamers are man-made molecules engineered in a test tube and which provide specific binding to various targets, such as small molecules, cancer cells, viral and bacterial proteins and whole micro-organisms. Scientists at the CSIR are investigating the value of aptamers as an alternative to antibodies. Aptamers are considered more efficient due to their small size and ability for high affinity and specificity – meaning a specific aptamer can be engineered to recognise and neutralise a specific target in the HI-virus system.



DR JABULANI NHLAPO, laboratory manager and senior researcher at the CSIR, says: "This is a state-of-the-art facility which enables scientists to conduct research and proof-of-concept studies in developing new diagnostics or therapeutics in HIV/Aids and TB research areas."

He says: "Access to the laboratories is facilitated by a set of two processes; all personnel seeking access must have read and understood a code of conduct document, and satisfactorily completed hands-on training according to a standardised training manual. These two documents detail all aspects of the laboratories and what is expected of the users."

Key infrastructure and equipment

The laboratories are equipped with ESCO airstream class II biosafety cabinets for manipulation of live pathogens; high capacity ThermoScientific Forma 700 freezers and New Brunswick Galaxy 170R incubators. In addition, the HIV laboratory has S- and C-1000 thermal cyclers, a culture microscope, a Beckmann Coulter DTX 880 multimode detector, as well as an Optima L-80XP ultracentrifuge, while the TB lab has a fluorescent microscope. A STARLIM laboratory information management programme is used to track and monitor resources and reagents.

Safety equipment

Access to the laboratory is controlled by a biometric system. It is accessed via two self-closing and self-locking doors to restrict and control entry while provision is made for independent laboratory suites to enable research on the different organisms in separate lab space. Protective laboratory clothing are worn by workers when in the laboratory. Eye and face protection items such as goggles and masks are used for potential splashes or sprays of infectious or other hazardous materials while gloves are worn to protect hands from exposure to hazardous materials.

According to Nhlapo, the BSL-3 facility is essential for providing a conducive and safe environment for researchers conducting experiments using organisms that are potentially harmful. "It allows scientists to elucidate the mechanisms of disease of HIV/Aids with a view to developing novel tools such as aptamers for prophylactics and therapeutics."

"Before personnel are given access to laboratories they receive specific training in handling HIV and TB pathogens as per the code of conduct and training manual.

"All procedures involving the manipulation of infectious material are conducted within biosafety compliance regulation. Laboratory personnel have specific training in handling pathogenic and potentially lethal agents, and are supervised by competent scientists who are experienced in working with these agents," says Nhlapo.

Skills and competences

Training includes an oral interview about the code of conduct and training manual, followed by hands-on-training. Topics that are covered in both the interview and hands-on training sessions are on entry, work, storage, emergency, housekeeping and exit procedures, as well as transport of infectious material and dealing with incidences.

Meet biosafety level 3 facility manager **Dr Jabulani Nhlapo**

Nhlapo spent the last 10 years of his professional life conducting research on HIV-1 and recently, TB, working with cell culture in containment level-3 laboratories. This entailed minimising bio-hazards and containing risks and ensuring adherence to prescribed laboratory etiquette and code of practice. He is responsible for managing the research process in the facility to ensure that the team fulfills the objectives of the project, as well as meet stakeholders' expectations. His involvement in risk assessment and safety, health, environment and quality activities of the laboratories in the last two years has given him exposure to the International Organisation for Standardisation quality systems and the need for compliance.



The biosafety level 3 laboratories have been equipped with state-of-the-art equipment for tuberculosis and HIV/Aids research.

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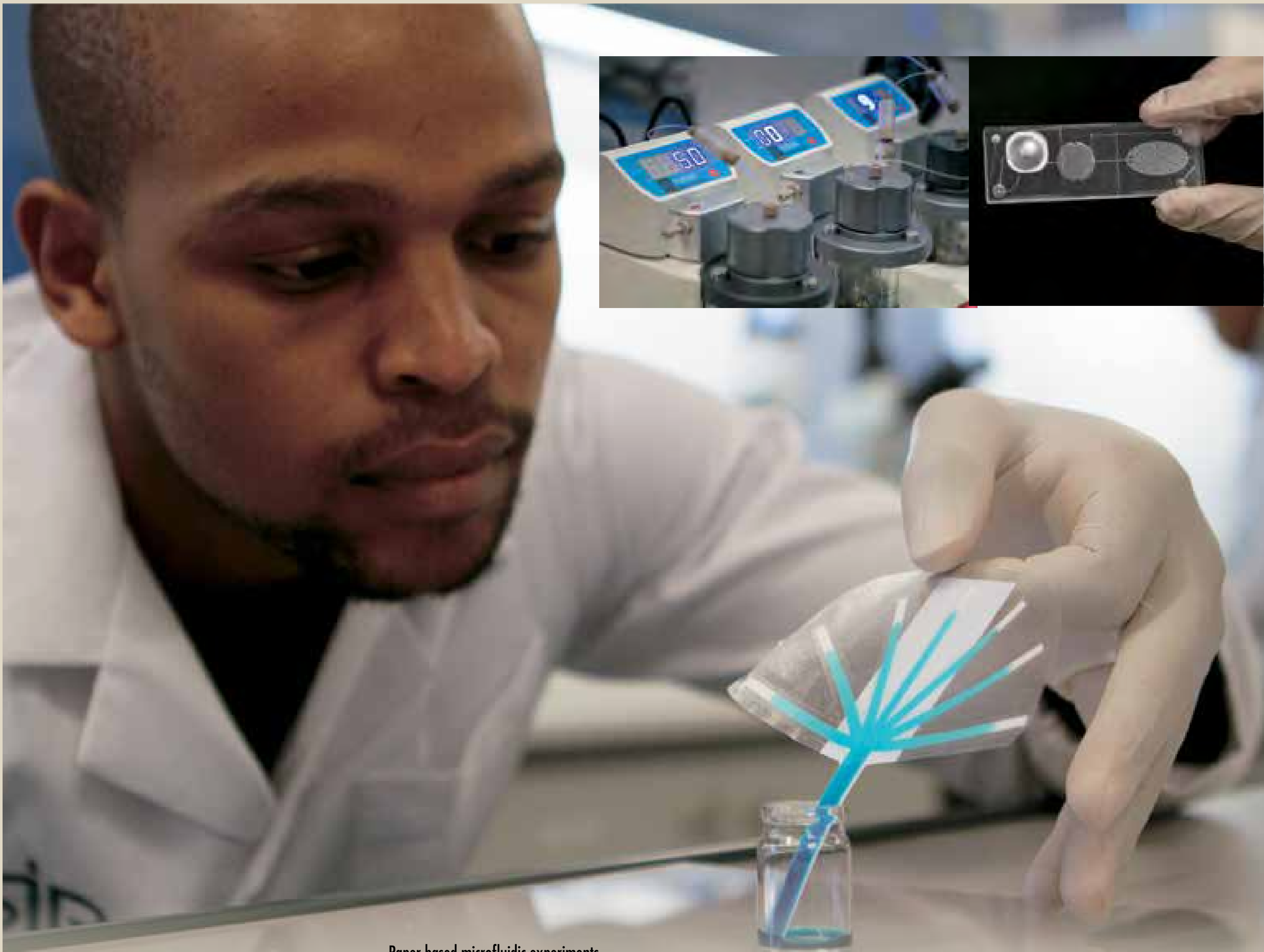

Paper-based microfluidic experiments demonstrating the ability of fluids to flow in a controlled manner into paper test substrates.

Smaller, faster, **smarter**
AT THE CSIR MICROFLUIDIC LABORATORY

In an environment where many different designs require testing, scientists require facilities that give a competitive edge with a quick turnaround time. This also holds true for the ability to quickly design, prototype and quantify microfluidic devices that cater for the flow of liquids in channels of micrometre size.

(From left) Pressure pumps for controlling fluid flow in microfluidic devices; development of cartridge-based microfluidic devices; microscopes available in the laboratory; the microfluidic testing facility; and an example of a microfluidic device manufactured in the facility.

FREED FROM THE RELIANCE on international facilities with a turnaround time of four to six weeks, staff members at the CSIR mechatronics and micro manufacturing laboratories are able to do a typical design in less than a week at the microfluidic foundry facility.

The microfluidic foundry facility is a clean room for the manufacturing of silicon wafer moulds. The laboratory houses compact and low-cost systems for chemical and diagnostic applications, including multiple microfluidic technology platforms. This facility is complemented by a newly established biological safety level 2 laboratory that allows for samples, such as bacteria and blood, to be handled.

The facility provides an advantage to South African users from various fields and with varied skill sets. Miniaturisation of chemical and biological processes can be tested rapidly at the facility, enabling the development of point-of-care diagnostic devices, which have great potential for South Africa's rural community in providing health monitoring products.

The universities of the Witwatersrand and Pretoria, with expertise ranging from chemistry to electronic-related fields, often take advantage of these facilities. In addition, commercial entities utilise the facility to test new product ideas.

Collaborations with international experts in the field of microfluidics have allowed the infrastructure to grow, extending the facilities to centrifugal and paper-based microfluidic platforms. These are now also available for use by industry and provide a larger scope of use.

The microfluidic foundry facility is the only one of its kind in South Africa, with a unique hands-on approach to finding microfluidic solutions where the need and impact is greatest. The laboratory is constantly maintained and upgraded. In addition to the biological safety level 2 capability, soft lithography (the process used for the manufacture of microstructures through printing and moulding) and centrifugal microfluidic platforms, were established. Only a few research groups worldwide focus on research and development in this field. The centrifugal microfluidic platform enables microfluidic disc devices to be manufactured and assembled using low-cost plastic and adhesive layers.

A test set-up to rotate the discs to manipulate fluid through centrifugal forces and to record and analyse the discs, has also been implemented.

Upgraded microscopes and camera systems allow for high-resolution images and high-speed videos of the microfluidic devices in action to be captured and analysed in the microfluidic manufacturing laboratory. Testing platforms for various projects have been and continue to be set up, including mechanical and electronic designs to implement fluid propulsion in the microfluidic devices in a controlled manner. Examples include actuation set-ups to allow ports on microfluidic devices to be closed, as well as blister packs serving as reagent storage mechanisms on-board microfluidic devices to be released, in a controlled and repeatable manner.

The clean room equipment includes spin coaters, programmable hot plates, a mask aligner, laminar flow hoods and wafer development facilities. The manufacturing laboratory has an oven, oxygen plasma unit, jigs for polymer casting, and polymer mixing and curing capabilities.

The centrifugal microfluidic platform includes materials and equipment for manufacturing the microfluidic disc components. Polycarbonate sheeting, machined using a milling machine, as well as pressure-sensitive adhesive layers machined using a vinyl cutter plotter create the layers of the discs, which are assembled using a cold roll laminator. The discs are tested using a set-up containing a motor to spin the disc at different speeds, and a visualisation unit consisting of a camera and synchronisation hardware to capture images and analyse the disc operation as it spins.

Meet platform leader **Kevin Land**

Land holds a BSc in physics from the Nelson Mandela Metropolitan University (then University of Port Elizabeth) in 1988. He completed a BSc (Hons) in physics cum laude from the same university in 1989. He joined the CSIR to focus on the design and manufacture of various different laser systems. He completed an MSc in physics at the University of Pretoria in 1998, focusing on the development of nonlinear eye-safe laser systems for range finding.

In 2007, Land was tasked with establishing a micro manufacturing group at the CSIR. The group is currently engaged with projects including: polymer-based micro cantilevers, rapid bacterial detection utilising paper-based microfluidics, mobile diagnostic point-of-care applications, and the manufacture of novel self-immobilised enzyme biocatalysts utilising droplet microfluidics.

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ADDING VALUE TO INDIGENOUS KNOWLEDGE THROUGH SCIENTIFIC NOVELTY

The output of new drugs to the market has risen only modestly in the past 20 years or so, despite the huge increase in research and development. The CSIR intends to provide much-needed, fresh and – compared to standard product development – instantaneous research and development opportunities with its newly renovated clinical and botanical supply units.

THE CLINICAL and botanical supplies unit is a state-of-the-art medicinal plant processing facility designed to produce pharmaceutical grade herbal products, bridging the gap between laboratory research and clinical trials.

The facility is HACCP-accredited (a food safety management system that enables food processing and catering industries to introduce and maintain a cost effective, on-going and safety programme). It is equipped to develop and demonstrate technologies that are beyond laboratory scale, up to a 100 litre scale. The facility has a 150 litre reactor (extraction vessel), herb dryer, drum drier, automated vibratory washing machine, automated slicer (1 – 45 mm thickness), industrial mincer, high performance liquid chromatography instrumentation, bench-top capsule-making machine, spray drier (8 -15 litre per hour), and hydraulic press (50 litre capacity, 400 Bar maximum pressure). Such a facility will now allow the CSIR to take biotechnology, agroprocessing and chemistry-based project leads from proof of concept to a tangible commercial product through stringent process development and piloting.

Automated plant washing in the botanical supplies unit.

Dried plant roots.

Laboratory-scale algal raceway pond.

Capsuling of dried plant extract.

"This facility is specifically aimed at the development and supply of small quantities of pharmaceutical raw material based on indigenous plants. The main purpose of this facility is to allow the early clinical validation of patented botanicals, prior to licensing to multinational pharmaceutical companies," says Dheepak Maharajh, a science innovation leader at the CSIR.

"With this facility, we also aim to transform current traditional medicines into products that can be validated scientifically, and are of acceptable quality, proved safety and efficacy."

Key infrastructure and equipment

Infrastructure is available to support bioprospecting, agroprocessing and algae technology development, which are aimed to support agreed national priorities.

Chemistry pilot plant

The chemistry pilot plant houses various organic and inorganic reactors, centrifuges, condensers/ evaporators (scrubber/vacuum system), a wiped film evaporator, short-path distillation equipment, six-inch fractionating column, continuous-counter current extraction equipment and many more. The facilities can accommodate research and production from as little as a 10 litre scale, up to a pilot scale of about 400 litre.

Food and feed processing plant

The facility is also equipped with food and feed pilot production equipment that can be used to undertake research for the food, beverage, fishing and agro-processing industries. In addition to this, technology-based services and support to these industries are offered. This is a fully-equipped food and feed processing plant, with both a twin screw extruder and a single screw extruder suitable for production of specialised foods and feeds. Availability of such equipment allows for the manufacturing of aqua feeds in a multitude of shapes, sizes, densities and textures, which can be both floating and sinking feeds. It also has a small fish tank system for dedicated studies on live fish that is used to assist in developing novel aqua feeds for specific species.

"The facility has access to supporting laboratories for specific analytical and microbiological studies. It is also used to train food science and engineering students, as well as local communities in agro-processing and food processing methods," says Maharajh.

Core competencies include product development and formulation, as well as value addition to by-products from oil, fish and fruit industries. Support to the food and aqua feed industry is also offered in terms of expertise and knowledge in routine and complex product and process development.

Algal research laboratory

The facility boasts a fully equipped algal research laboratory with flow cytometer; fluorescent spectrophotometers; ultraviolet-visible spectrophotometer; gas chromatography-mass spectroscopy; liquid chromatography and liquid chromatography mass spectrometry (a method that combines the features of gas-liquid chromatography and mass spectrometry to identify different substances within a test sample); liquid extraction equipment and many more.

Skills and competences

The team that works in this facility is made up of bioprocess engineers, process chemists, natural product chemists, as well as food and chemical engineers. The group has extensive expertise in the areas of process chemistry, protein and plant extractions, food and feed engineering; and algal biotechnology with their respective skills ranging from process and product development and optimisation, process trouble-shooting, process flow sheeting, process design, techno-economic (feasibility) assessments, technology packaging, technology transfer and implementation.

The team's competitive advantage lies in its strong product and development skills, as well as its experience of industry needs and challenges.

Meet clinical and botanical supply unit manager **Dheepak Maharajh**

Maharajh boasts extensive experience in fermentation process development and production of high value fermentation metabolites, algal biotechnology, algal biofuels, enzyme production and biological control agents. His specialties include fermentation, bioprocess engineering, algal biotechnology, technology transfer and commercialisation.

He is responsible for research and development into biological products, ranging from vitamin production in algae to whole-cell probiotics. Maharajh holds an MSc degree in process engineering from Stellenbosch University and is studying towards his PhD.

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A high-throughput microscope to screen for host factors used by the HI virus during infection.

OPEN ACCESS HARDWARE AND THE SEARCH FOR ANTI-HIV DRUGS

Microscopes, advanced software and other genetic and cellular engineering research tools are key to understanding and treating diseases like HIV/Aids. The CSIR's synthetic biology laboratory, headed up by Dr Musa M Mhlanga, has pioneered several machines and techniques in South Africa and the team is now carrying a torch for the open access movement in the country.

The facility in short

The laboratory's advanced imaging technologies allow scientists to screen for drug targets against diseases like HIV, and to determine the function of immune-related genes. Researchers also use other infrastructure to make discrete changes to genomes and cellular machinery that could protect organisms against disease.

IN MARCH 2013, Dr Mhlanga began working with the Department of Science and Technology (DST) and the Max-Planck Institute (MPI) in Germany to make high-tech Selective Plane Illumination Microscopy (SPIM) microscopes more accessible to the South African research community. This was done through an MPI initiative known as OpenSPIM, led by Pavel Tomancak and Peter Pitrone. These so-called 'light-sheet' microscopes have become the choice tool for analysing whole organisms, embryos and organs in 3D high resolution. A laboratory could permanently acquire a commercial SPIM for the equivalent of about R5 million, but OpenSPIM aims to make mobile versions available for just R70 000 – R90 000, using a rental pool system. In this way researchers can gain some familiarity with the machine, and even some experimental data, which would help in applying for funding to purchase a commercial system. The mobile device is also incredibly easy to assemble out of a small suitcase – high school students visiting the CSIR have done so in under two hours.

Skills development

The idea for a South African OpenSPIM chapter emerged at an internationally renowned microscopy course hosted at the CSIR. The practical course trains local and international PhD students and post-doctoral researchers in the use of state-of-the-art microscopes and imaging techniques, including super-resolution, spinning disk and point scanning confocal microscopy, as well as light-sheet microscopy. It is principally funded by EMBO, an organisation dedicated to the promotion of excellence in the life sciences, as well as the National Research Foundation and the DST.

Expensive toys

The on-site PALM/STORM super-resolution light microscope was self-built by Mhlanga and his former PhD student, Ricardo Henriques. It is a large, complicated contraption but it can achieve resolutions of just 20 nm – small enough to observe single biological molecules like proteins, DNA and RNA. It uses pulsed laser light to illuminate the target sample, causing it to 'blink'.

Powerful open source software known as QuickPALM then translates the 'blinking' data set (about 100 gigabytes in size) into a live image on a computer screen.

The lab's microscopes and other biological tools, such as pluripotent stem cells and siRNA libraries, allow the researchers to create *in vitro* models of disease. These assist them to better understand the causes of disease and to find targets for potential therapies. "We call it the disease-in-a-dish approach," says Mhlanga.

"We have a lot of 'toys' here at the CSIR, but for me the people are the real infrastructure. And although the research can be expensive, it is worth it since we have the potential to find novel cures for major illnesses like HIV," he says. In fact, thanks to these high-tech toys, his team of researchers are in the process of patenting a number of potential anti-HIV drug targets.

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Open-source hardware: OpenSPIM

The OpenSPIM project was established as a platform for teaching a special type of microscopy known as light-sheet microscopy. Pavel Tomancak, from the Max Planck Institute of Molecular Cell Biology and Genetics in Germany, brought the mobile SPIM microscope to South Africa as part of an EMBO-funded course organised by Mhlanga and others. 'SPIM' is short for 'selective/single plane illumination microscopy' and it represents a revolution in life science as it enables the rotation of samples for high-resolution 3D imaging. The July 2013 issue of *Nature Methods* features the OpenSPIM project as an example of how open-source hardware serves to enhance basic research.

QuickPALM: The global gold standard

QuickPALM open source software reconstructs 3D data from the CSIR's PALM/STORM (photoactivated localisation microscopy/ stochastic optical resolution microscopy) microscope into an image in real-time. It was developed by Mhlanga's team, featured in *Nature Methods* in 2010 and has now become the predominant algorithm in the world for super-resolution. "It is the gold standard," says Mhlanga.

South African firsts

Mhlanga and his team built South Africa's first super resolution microscopes, and installed the country's first high-throughput automated confocal microscope. The latter can analyse a batch of up to 384 samples in just 15 minutes.

Their lab is also home to South Africa's only siRNA libraries and it was the first facility in the country to routinely use induced pluripotent stem cell (iPSC) technology. siRNA libraries enable CSIR scientists to study gene function by observing the effects of switching genes on and off, while iPSC allows them to convert adult cells into stem cells and 'disease-in-a-dish' models. Together, these and other tools facilitate in-depth studies of diseases like HIV. For example, using cells from adults who are resistant to HIV, researchers can combine iPSC, RNA libraries and microscopy to find the human host genes responsible for limiting HIV replication. This information is useful for designing targeted drugs against the disease.

Meet synthetic biology research group leader Dr Musa M Mhlanga

Mhlanga holds a PhD in cell biology and molecular genetics from the New York University School of Medicine (2003).

He began his PhD at the Rockefeller University in the laboratory of David Ho where he worked on spectral genotyping of human alleles. He then went on to work on the development of *in vitro* and *in vivo* applications of molecular beacons and their use in visualising RNA in living cells with Fred Russell Kramer and Sanjay Tyagi at the New York University School of Medicine. Upon completion of his doctoral work, he was awarded a prestigious US National Science Foundation post-doctoral fellowship at the Institut Pasteur in Paris to work in the laboratory of nuclear cell biology. There he worked on RNA transport and single molecule imaging and tracking of RNA in living cells. In June 2008, he joined the CSIR in South Africa. He also holds a joint appointment to the Institute of Molecular Medicine in Lisbon, Portugal.

Keeping tabs on carbon dioxide

Towering over southern savannas and gliding through southern seas

Global warming is driven by the build-up of carbon dioxide (CO_2) in the atmosphere. For the past century, it has been mitigated thanks to the ability of our oceans and ecosystems on land to take up the excess CO_2; but man, and man's track record of unsustainable development, cannot be 'saved' by Mother Nature indefinitely.

CSIR SCIENTISTS are collaborating on land and sea using state-of-the-art equipment and models to measure CO_2 exchange and related factors with the aim to more accurately predict and help mitigate the CO_2 build-up that could lead to high risk and costly climate change.

The South African Integrated Carbon Observatory Network (SA-ICON) was established to consolidate carbon data and knowledge from institutions across the country. Other members include the South African Weather Service, the Department of Environmental Affairs, the South African National Biodiversity Institute and the City of Cape Town. This network is expected to grow when its products become operational.

Ocean robots

In March 2013, CSIR researchers completed a six-month mission during which ocean robotics platforms were deployed from the newly commissioned polar ship, SA Agulhas II.

Five sea gliders were launched at sites in the Southern Ocean thousands of kilometres south of Africa to measure factors which influence the global carbon cycle in the Southern Ocean, such as salinity, temperature, depth, dissolved oxygen, light and chlorophyll levels at unprecedented resolution in space and time.

The gliders were remotely navigated from the Southern Ocean Engineering Research and Development Centre in Cape Town. They collected high-resolution data to 1 km below the surface and sent it back in real-time where it is now being analysed.

Wave-powered gliders – a second type of newer technology – were test-launched off Cape Town for a three-week mission in preparation for a five-month mission which started on 13 October 2013 to measure CO_2 and oxygen gas exchange through the entire seasonal cycle in the Southern Ocean.

According to Dr Pedro Monteiro, head of the Southern Ocean Carbon-Climate Observatory (SOCCO) in Cape Town, scientists estimate that human (anthropogenic) activity accounts for 37 billion tonnes of global CO_2 emissions per year, of which half remain and build up in the atmosphere, while the ocean and ecosystems on land take up a quarter each.

The natural combined terrestrial and ocean carbon cycle is much larger at approximately 500 billion tonnes CO_2 in and out, but until recently, natural emissions have been balanced by the natural uptake. Thus, even relatively small climate-change linked disruption in the much larger natural carbon cycle could have negative impacts in the effectiveness of global CO_2 mitigation. Half of the anthropogenic CO_2 absorbed by the oceans is taken up by the Southern Ocean.

"Yet, we know very little of this cycle and its sensitivity to climate change, partly due to challenges around measurements," says Monteiro.

"Until now, oceanography has largely relied on ships, which are too expensive to have at sea in large numbers, needed for system scale studies, while satellites only measure the surface of the ocean. Our capacity to make accurate predictions of atmospheric CO_2 for the next 100 years is not very strong. Ocean robots complement ships by making observations in places and at times far beyond the ability of ships alone. Better quality data will improve the accuracy of models used to predict the impact on the climate."

Flux towers

Researchers have also been keeping tabs on CO_2 exchange on land.

According to Dr Bob Scholes, CSIR Fellow and systems ecologist, it is difficult to achieve representative measurements over land, as the surfaces vary so much (as opposed to the ocean). Measurements in particular areas could be greatly influenced by a nearby sink or source of CO_2. By measuring CO_2 flux and concentrations at different places, and combining it with modelling and satellite observations, researchers hope to get a more accurate idea of carbon exchange from land ecosystems.

The Skukuza flux tower in the Kruger National Park is one of the longest-running flux towers in Africa. There are only a few in savannas, those areas typified by grassland and scattered trees, covering 20% of land areas worldwide. An additional flux tower has been operated at Malopeni near the Phalaborwa gate in Mopane veld. This differs from the vegetation at Skukuza which is dominated by *Acacia* and *Combretum* trees. Thus, CO_2 exchange in two of the major types of southern African savannas is covered. These towers have been taking detailed measurements of the exchanges of energy, water, CO_2 and other substances between the land and the atmosphere since 2000.


Flux towers in South African savanna and (opposite page) engineering intern Sinekhaya Bilana inspecting a wave glider in Cape Town.

TECHNOLOGY IN SHORT

Wave gliders

Wave gliders consist of a fibre glass surface unit that carries the sensors and solar panels to power them. This unit is connected by an umbilical structure to a power unit at a depth of 7 m.

These gliders can be steered via satellite from anywhere in the world. They can move at a speed of 2 km/h, converting wave energy into forward propulsion, and be at sea for several months at a time.

The gliders are fitted with sensors that measure atmospheric and ocean carbon levels, ocean acidity, temperature, salinity and depth.

Sea gliders

They are remotely navigated and collect oceanographic data up to 1 km below the surface, sending it back in real-time via satellite. They are fitted with sensors that collect data about conductivity, temperature and depth; dissolved oxygen, light and chlorophyll. These gliders can be deployed for several months.

Flux towers

These are tall steel structures fitted with eddy-covariance sensors that measure the upward and downward movement of gases above the vegetation canopy due to air turbulence, 20 times per second.

Also part of the SA-ICON collaboration is researchers' attempts to measure the carbon footprint of the City of Cape Town, a project which could be expanded countrywide in future. A ring of high-precision CO_2 monitors has been placed around the city, combining data from the long-running Cape Point Global Atmospheric Watch station with new stations at Cape Hangklip and Robben Island. CSIR researcher Alecia Nickless uses a detailed model of air movement over the Cape Peninsula, also run by the CSIR, to work out where the measured CO_2 comes from. – *Antoinette Oosthuizen*

Southern Ocean Engineering Research and Development Centre

The engineering company, Sea Technology Services, has been contracted by the CSIR to establish the Southern Ocean Engineering Research and Development Centre SOERDC at East Pier at the V&A Waterfront in Cape Town, where it opened its doors late in 2012. The centre provides servicing, refurbishment and repair of gliders. The engineers have established a glider port and the vessels are navigated remotely from the premises. The purpose is also to develop new technology and to grow marine and oceanographic engineering expertise in South Africa.

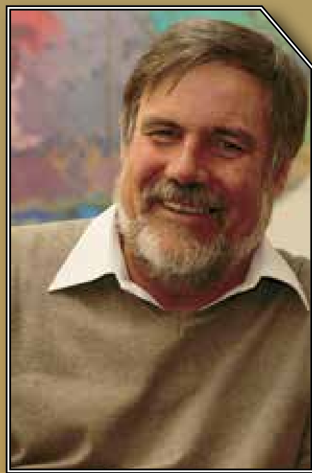
Why invest in infrastructure to measure CO_2?

The uptake and release of CO_2 between the atmosphere, oceans, plants, animals, soil and micro-organisms is part of Earth's natural carbon exchange cycle which is approximately balanced in the long term, but has been disturbed by human activities since the Industrial Revolution. CO_2 is the primary greenhouse gas emitted through human activity, such as the burning of fossil fuels for electricity, transport and industry and the clearing of land for agriculture.

Too much CO_2 in the atmosphere increases the absorption of heat from the sun, almost like a blanket, causing the lower atmosphere, land surface and ocean temperature of the Earth to rise. This is the main cause of modern climate change, prompting international attempts to limit the rise in CO_2 and other greenhouse gases.

To improve climate models, researchers need to understand and predict both how the ocean and terrestrial uptake of anthropogenic and natural CO_2 might be affected by climate change, and how they drive long-term risk to economic development.

GUARDIANS OF THE CSIR'S CARBON DIOXIDE INFRASTRUCTURE



Dr Bob Scholes

Scholes leads the CSIR's research in respect of global change and ecosystem dynamics and is a CSIR Fellow. He has been with the CSIR since 1992. Before that, he led the South African Savanna Biome Research Programme. He is a systems ecologist who studies how global change processes, such as climate change, affect ecosystems, especially the terrestrial ecosystems of Africa.

"Africa is regarded as approximately balanced between being a source and sink of CO_2, but we need to understand the processes of photosynthesis and respiration from the continent's ecosystems to be able to predict the carbon cycle.

The data generated by the flux towers will be compared to atmospheric measurements and collated with oceanographic findings, information which can help us to fine-tune the models we use to make these predictions," he says.

This data is part of a global repository, known as FluxNet.

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Dr Pedro Monteiro

Monteiro is chief oceanographer at the CSIR with a special interest in the carbon-climate system in the Southern Ocean and the way that natural and human carbon exchange in the Southern Ocean influences the long-term CO_2 build-up in the atmosphere. He heads the Southern Ocean Carbon-Climate Observatory (SOCCO).

He says that "the ocean robotics capability allows us to address questions of importance to climate models in a way that was not possible in the 20th century. Due to their ability to be navigated, gliders enable us to close a key sampling gap for CO_2 and other oceanographic measurements which will improve the reliability of our climate models."

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Africa's first 'clean laboratory' to accurately measure trace elements in seawater

In a carefully balanced natural process which is influenced by light and iron, phytoplankton in the oceans absorbs atmospheric CO_2 like a sponge through photosynthesis. Mankind needs to learn more about this process and its possible sensitivity to climate change and impact on global warming, which is why the recent establishment of a world-class 'clean lab' at the Stellenbosch University is welcomed by local environmental researchers.

Dr Thato Mtshali with a fast repetition rate fluorometer used to measure phytoplankton physiology. The equipment helps researchers to understand how the phytoplankton responds to environmental changes in the ocean.

UNTIL RECENTLY, South African researchers did not have the facilities to measure bioactive trace elements, like iron, in seawater in very controlled sterile conditions. This is important as the trace levels of iron in seawater are so low, that the slightest contamination due to human error or contaminated equipment – for example by rust on a ship – could lead to false positive test results or experimental biases.

Before the establishment of the trace and experimental biogeochemistry clean laboratory, scientists had to send their samples to laboratories in the US and Europe for analysis, which was costly and time consuming.

Scientists are now able to collect and test their own samples locally, putting them on par with their international peers in being able to design and run experiments that advance our understanding of the trajectory of climate change in the 21st Century and will help assess the feasibility of iron-linked geo-engineering options to reduce atmospheric CO_2.

They are also able to participate in long-term international observational programmes, such as GEOTRACES, which aim to improve the understanding of biogeochemical cycles and large-scale distribution of trace elements and their isotopes in all major ocean basins over the next decade.

The R2.2 million laboratory was co-funded by the Department of Science and Technology through the CSIR's Southern Ocean Carbon-Climate Observatory (SOCCO) programme, as well as the Stellenbosch University Rector's strategic fund.

Based at the university, a SOCCO participant, it is part of a broader strategy to integrate research infrastructure development. This includes the provision of new analytical equipment, for example, the titanium frame GEOTRACES CTD rosette, which is used to sample sea water to measure trace metal, and mobile clean laboratories that can be fitted in the polar research ship, SA Agulhas II.

The infrastructure

Trace and experimental biochemistry clean laboratory

This is a sterile environment and the air is virtually free from any form of contamination – only 10 000 (> = 0.1 μm)) particles per 1 m^3 (cubic metre) of air – which enables scientists to measure minute quantities of trace elements in seawater.

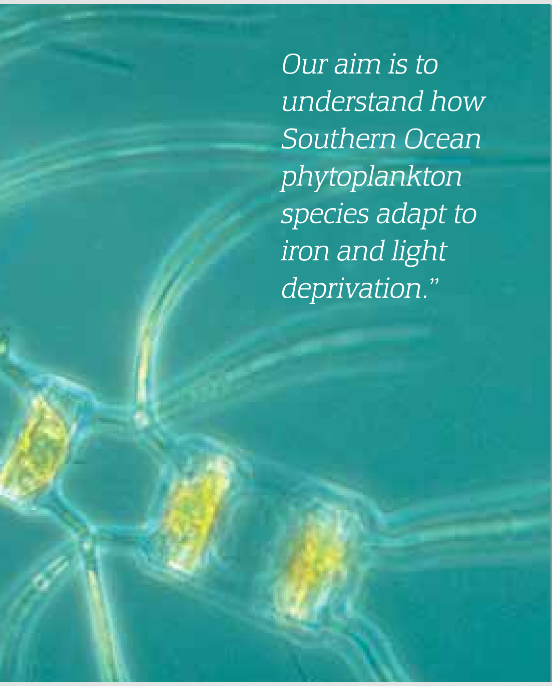
The 20 m^2 laboratory consists of three separate rooms with air pressure from high to low, to ensure that contaminated air does not flow into, but rather out of the third 'clean' room when the door is opened.

Sampling equipment

The titanium frame GEOTRACES CTD rosette is a piece of equipment used for sampling. It is fitted with twenty-four 12 L GO-FLO bottles and weighs more than 300 kg. This rosette is used to collect seawater samples for trace metal analysis at different depths. It is deployed using a Kevlar/Dynema nylon rope instead of a steel cable to prevent metal contamination.

Trace metal clean containers

The CSIR houses two clean containers (sampling and flow injection analyser (FIA) containers). The sampling container is used to store GO-FLO bottles and collect and filter clean seawater subsamples, while the FIA container is used for measuring low levels of iron concentrations in seawater using an FIA with chemiluminescence detection. These containers weigh 60 tons each and can be used during fieldwork at sea on board the SA Agulhas I or II, or on land at the CSIR. The units are fitted with laminar flow hoods which ensure that the air circulation inside remains clean.



Our aim is to understand how Southern Ocean phytoplankton species adapt to iron and light deprivation."

An example of an Antarctic diatom, *Chaetoceros sp.* (phytoplankton species) Source: Richard Crawford/Alfred Wegener Institute, Germany

The importance of iron

Phytoplankton grows in the upper layers of the oceans, because it needs light for photosynthesis to create food and energy for itself. It absorbs CO_2 and plays an important role in the carbon cycle. Iron is a micronutrient which assists with photosynthesis and researchers have found that phytoplankton does not grow that well in open ocean regions such as the Southern Ocean, that are low in iron.

"These tiny microscopic plant-like organisms form the base of the marine food chain and they need iron for growth, as it plays an important role in their different metabolic processes. Elevated iron concentrations can result in phytoplankton blooms which influence the carbon cycle through the biological carbon pump which transports carbon into the deep ocean," says Mtshali.

These trace metal containers are the first of their kind in South Africa and can also be used on land.

This means that samples are kept under prescribed conditions from when they are collected at sea, until they can be analysed on board or stored for analysis on land. The CSIR's Dr Thato Mtshali was instrumental in securing ISO certifications for these containers.

The particle count from these clean containers fall under category #2 of the ISO standard 14644, according to Mtshali.

Dr Pedro Monteiro, head of SOCCO, says recent estimates indicate that approximately 50% of all CO_2, which is emitted by human activity and absorbed by oceans, is stored in the Southern Ocean.

It is also estimated that 85% of non-polar ocean productivity is supported by nutrients derived from the Southern Ocean, yet researchers know little about the sensitivity of its carbon and nutrient fluxes to climate change. – *Antoinette Oosthuizen*

Customised incubators

These specialised incubators are modified fridge cabinets used to grow phytoplankton species under different conditions on board a ship or on land at the CSIR laboratories in Stellenbosch. They are equipped with four stainless-steel shelves to accommodate more than forty 2.4 L polycarbonate bottles, and a LED strip light at the top of each shelf to supply light for growth. The temperature can be controlled from -5 to 55 °C and the door is designed to block external light from the surroundings.

Meet 'iron man' Dr Thato Mtshali

Mtshali obtained a PhD in organic chemistry at the University of the Free State and lectured there for two years before joining the CSIR in July 2009. He is a senior researcher who studies the biogeochemistry of iron in seawater.

Mtshali and his colleagues collected samples during a recent cruise as part of the Southern Ocean Seasonal Cycle Experiment to investigate the influence of light and iron supply on phytoplankton processes. Seawater samples containing phytoplankton were spiked with iron and incubated in specialised incubators at different light and temperature conditions. This enabled researchers to investigate the impact of changing iron concentrations on phytoplankton growth and photophysiology (how they react to light).

"Our aim is to understand how Southern Ocean phytoplankton species adapt to iron and light deprivation. Access to the clean laboratory in Stellenbosch also means that we are now able to set-up and grow specific plankton species using our own prepared trace metal clean seawater solution (AQUIL) and allow it to adapt to different iron and light conditions, similar to those of the Southern Ocean. We can now measure specific parameters in a way which was not locally possible before," Mtshali remarks.

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Measuring the WATER USE of trees and forests

CSIR researchers are using micrometeorological instruments to measure the water use of fruit tree orchards, indigenous trees and invasive alien plants in South Africa.

THE HISTORY OF MEASURING the quantity of water consumed by trees and forests dates back nearly 80 years in South Africa. The first experiments were established in mountain catchments at Jonkershoek in the Western Cape in 1935. Since then, much valuable data, information and knowledge have been gathered about tree water use and their impacts on water resources. Along the way, the techniques for quantifying the volumes of water taken up by trees and forests have changed from catchment studies on the impacts of planted stands of trees on stream flow, to micrometeorological measurements in tree stems and above forest canopies. Technological advances in sap flow and energy balance monitoring instrumentation have made it possible to accurately conduct measurements of transpiration (individual tree water use) and evapo-transpiration (orchard or forest water use).

Researchers are developing the most appropriate crop water use models for selected fruit trees from data collected at seven different sites, ranging from Ceres (apples) and Wolseley (nectarines) in the Western Cape, to Rustenburg (peaches), Cullinan (pecans), Groblersdal (Valencia & Navel oranges), Malelane (Navel oranges) and White River (macadamias).

Through the use of the latest micrometeorological instruments, CSIR researchers have taken on ambitious projects to measure the water use of fruit tree orchards, indigenous trees and invasive alien plants in South Africa. These projects have largely been solicited and funded by the Water Research Commission, with co-funding from government departments such as Agriculture, Forestry and Fisheries; and Environmental Affairs.

The research has advanced scientists' ability to quantify the water use of trees – not only how much they use, but when they use it, what factors affect their water use and how best to model and predict likely water use scenarios under different conditions. Improved understanding and predictive ability promote better management, allocation and efficiency of water use in the agricultural and forest sectors – a critical requirement in a water-competitive country such as South Africa.

A closer look at the techniques

Two particular techniques that are used to measure tree water use are the Heat Pulse Velocity (HPV) sap flow monitoring technique, and the Eddy Covariance (EC) technique.

The HPV technique uses heat as a tracer of sap flow in the stems of woody plants – sap flow being synonymous with transpiration or water use. Temperature-sensitive thermocouples placed above and below a heater probe are inserted into the stems of individual trees at strategic points in the xylem (sapwood). Temperatures in the upper and lower thermocouples are measured just before a pulse of heat is fired into the stem. The resultant pulse of heat is taken up by the sap moving through the stem, and subsequent temperature changes registered by the thermocouples indicate the sap flow velocity. When multiplied by the cross-sectional area of sapwood, these measurements allow the calculation of sap flow volumes on an hourly basis.

The EC technique measures turbulent eddies of air above a vegetation canopy, which are important drivers of water vapour exchange (evapo-transpiration) from the underlying vegetation. The EC technique requires estimates of all the components of the shortened energy balance equation, namely net radiation, soil heat flux, sensible heat flux and latent heat flux to be individually measured, or derived by subtraction.

The equipment

These components are measured using the following scientific equipment:

- NR-Lite net radiometers for net radiation
- HFP-01 Hukseflux soil heat flux plates and TCAV-L soil temperature averaging probes for soil heat flux
- A CSAT3 three-dimensional sonic anemometer for sensible heat flux
- A LI-7500 open path infrared gas analyser for latent heat flux.

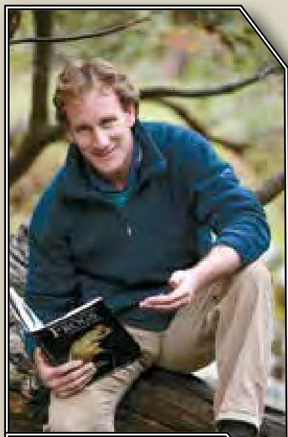
Additional measurements of air temperature and humidity are sampled using an HMP45C Vaisala temperature and humidity probe, while a CS616 time-domain reflectometer probes measure soil water content. Measurements are taken at a frequency of 10 Hz, processed using data packers, and logged on a CR5000 data-logger.

Most of these sensitive, expensive instruments are positioned above the vegetation, usually by means of mounting on a lattice mast (for shorter trees, e.g. orchards under 9 m) or on a Clark WT8 pneumatic telescopic mast (for taller trees, e.g. indigenous forests up to 25 m high), so that they project above the top of the canopy.

– *Mark Gush and Bandile Sikwane*

Some local, some imported equipment

The Heat Pulse Velocity (HPV) and Eddy covariance (EC) equipment is a combination of locally manufactured and imported items. Specialised sensors for the EC system and data-loggers are imported to South Africa by a company called Campbell Scientific, from whom the items are sourced. Other equipment, such as the thermocouples, heater probes and strong-boxes and batteries for the HPV systems are manufactured locally.



Meet agricultural and forest meteorologist Dr Mark Gush

Gush started at the CSIR in 1997, with a BSc in forestry and nature conservation from Stellenbosch University. He then completed his MSc in hydrology at the University of KwaZulu-Natal and a PhD in botany at the University of Cape Town, on studies of the water use of introduced (exotic) and indigenous trees, respectively.

He states: "I enjoy this field of research as it combines and integrates micro-scale aspects of plant physiology (e.g. sap flow) with macro-scale impacts of land cover on water resources. Discovering more about how, when and where plants use water, and how this knowledge can be used for social, economic and environmental benefit in South Africa, is what fuels my passion for this work."

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Henk van Wyk aligns the scanner for measurements.
Lerato Shikwambana optimises and aligns the laser beam, with Henk van Wyk and Bafana Moya looking on.

MOBILE LIDAR LAB

A PLUS FOR SA'S ENVIRONMENTAL STUDIES

Light detection and ranging (Lidar) systems have become synonymous with atmospheric measurements in countries with advanced research and development capabilities. Only two lidar systems are in operation on the African continent: one at the CSIR and the other at the University of KwaZulu-Natal (UKZN).

LIDAR HAS NUMEROUS applications, from insect monitoring; detection in autonomous flight; and the calculation of ore volumes in mining; to the creation of digital elevation models and the probing of aerosols in relation to climate change. Lidar is one of the most powerful techniques for active remote sensing of the Earth's atmosphere. It is an optical remote sensing technology that combines laser light and positioning measurements to provide highly accurate digital elevation measurements. Advancements in both laser and detector technology, as well as improvements in data collection and analysis techniques, have made lidar a reliable tool for atmospheric remote sensing.

The CSIR system

The difference between the CSIR system and the UKZN system is that the former is mobile, with the benefit of deployment anywhere in the country, allowing researchers to map the distribution of aerosol measurements over a wide area.

As part of an undertaking to measure the distribution of aerosol, temperature and water vapour throughout South Africa, using this mobile system, the team conducted on-site measurements in Stellenbosch, Durban and on the CSIR campus in Pretoria.

The CSIR system is capable of providing aerosol/cloud backscatter measurements for the height region from ground to 30 km, with a 10 m vertical height resolution. The measurements elucidate the aerosol concentration, optical depth, cloud position, thickness and other general properties of the cloud that are important for a better understanding of the Earth-radiation budget, global climate change and turbulence.

In support of another South African science milestone, the mobile lidar system can be used for three-dimensional mapping at various Square Kilometre Array sites. Radio propagation is affected by the daily changes of water vapour in the troposphere and ionisation in the upper atmosphere due to the sun, and lidar can help researchers make measurements of the water vapour during the acquisition of data by the telescopes.

Recent upgrades

"Our next step is to upgrade the lidar system by adding an X-Y scanner and a radar system," says Lerato Shikwambana, a PhD student whose research is on atmospheric remote sensing using lidar. "Currently, this system can only do vertical measurements and we believe that once upgraded, we will be able to do two-dimensional mapping." Once the above is in place, he adds, his team will also start with its measurement campaigns in various parts of the country. "We are targeting 16 sites throughout South Africa, including the Square Kilometre Array site," he says.

– Mzimasi Gcukumana

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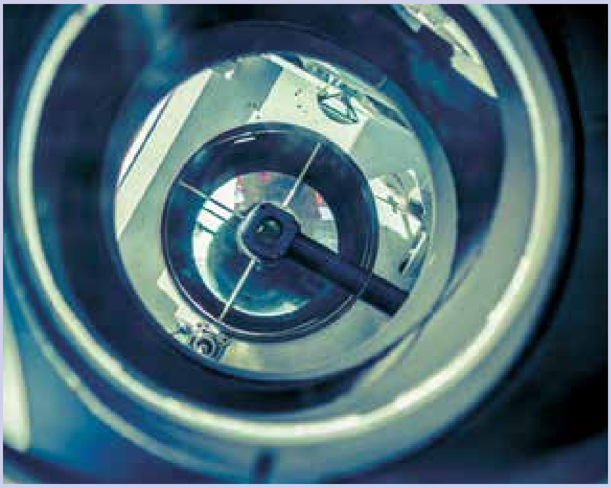

A Newtonian telescope with a 404 mm primary mirror used for collection of the backscattered light from the atmosphere.

Technical specifications

PARAMETERS	SPECIFICATIONS
TRANSMITTER	
Laser source	Nd:YAG-Continuum®
Operating wavelength	532 nm
Average pulse energy	150 mJ (@532 nm)
Beam expander	3 x
Pulse width	7 ns
Pulse repetition	10 Hz
Beam divergence	0.2 mrad after beam expander
RECEIVER	
Telescope type	Newtonian
Diameter	404 mm
Field of view	0.5 mrad
PMT	Hamamatsu® R7400-U20
Optical fibre	Multimode, 600 µm core
Field FWHM	0.7 nm
SIGNAL AND DATA PROCESSING	
Model	Licel® TR15-40
Memory depth	4096
Maximum range	40.96 km
Spatial resolution	10 m
PERSONAL COMPUTER	
TR-40 interface	Ethernet
Processor	Intel® CoreDuo 2.6 GHz
Operating system	Windows® XP Pro
Software interface	NI LabView®

Meet lidar projects manager **Lerato Shikwambana**

Shikwambana is a CSIR researcher who joined the organisation in 2009. He obtained his MSc in physics from the University of the Witwatersrand in 2011 where he specialised in nanoscience and laser-material interactions.

Shikwambana is interested in atmospheric physics, especially aerosols, clouds and water vapour studies. He is a member of local and international societies such as the South African Institute of Physics, the South African Society of Atmospheric Science, the Optical Society of America and the Golden Key International Honour Society.

Meet chief laser technician **Henk van Wyk**

Van Wyk is a CSIR chief laser technician and has worked at the CSIR since 1998. He obtained his national technical diploma in mechanical engineering and also qualified as a fitter and turner of trade from Pretoria Technical College and Iscor Training Centre. He specialised in laser technology.

THE DEVIL IS IN THE DETAIL

A nanomaterial risk assessment laboratory takes shape

With the advent of nanotechnology at the turn of the 21st century, there has been a proliferation of industrial applications and consumer products containing nanomaterials. However, not much is known about the inherent risks associated with these products.

Environmental scientist Dr Ndeke Musee in the space that is being transformed into a new nanomaterial risk assessment laboratory.

The acidity levels, electrical conductivity and total number of dissolved solids are measured inside the aeration chambers of the simulated wastewater treatment plant after samples had been taken.

Senior researcher Dr John Zvimba showing a simulated wastewater treatment plant, the only of its kind in the Southern Hemisphere, where wastewater from Daspoort treatment plant is used for contamination with different nanomaterials in a continuous process.

A sample of water and sludge from the aeration chambers of the simulated wastewater treatment plant. Samples are taken three times a week and then twice on those days at exactly the same time, to analyse and compare the microorganisms therein.

THE CSIR IS IN THE PROCESS of building a nanomaterials risk assessment laboratory to study the behaviour of nanomaterials, their movement, and what eventually becomes of them after they are released into the environment.

Understanding the risk

Materials at a nanoscale behave very differently from their counterpart parent materials, says CSIR environmental scientist Dr Ndeke Musee. "Typically, materials at the nanoscale acquire new properties," he explains. "Because there are various kinds of nanomaterials, and so many of them, we have no idea which ones are toxic and which are not, what happens to them once they reach the environment, and risks they potentially pose to the environment," he states.

"It's important we know this," he argues. "For instance, should nanomaterials end up in wastewater treatment works, how do they interact with the useful bacteria? Could this interaction cause negative effects on wastewater treatment efficiency? Would more investment in wastewater treatment works be needed to mitigate possible harmful effects?"

The right tools and the right people

As any technology advances, so do emerging contaminants. This is no different in the nanotechnology domain. To mitigate the risk of these emerging contaminants, we need to analyse, assess, understand, and characterise them, says Musee. A thorough assessment needs a well-equipped laboratory with highly skilled researchers. As it stands, neither South Africa, nor the CSIR has such facilities for the researchers to undertake an assessment of this nature, he adds. Furthermore, the science is yet to be developed on assessing the risk posed by waste streams containing nanomaterials, he states.

The laboratory, which the CSIR is in the process of building, will help grow skills capacity along with the requisite science to perform the necessary assessments.

According to Musee, the laboratory will be divided into three sections. "The first section will be for analysing how these materials behave in the environment. We want to determine what exactly happens and the types of changes these materials undergo when they are in the environment," he says.

"The second section of the lab will house toxicity studies of nanomaterials. This is where we will study the interactions of nanomaterials with biological life forms in the environment," he adds.

"The third section of the lab will house a group of scientists tasked to model and predict the impacts of nanomaterials in the environment, based on the outcomes of the tests. The aim will be to develop decision-support systems to enhance responsible and sustainable governance of nanotechnology," he explains.

"It is envisaged that the laboratory will be operational towards the end of the year. The laboratory is being funded by the CSIR, including some of the needed equipment, and we also envisage acquiring additional equipment through funding from the National Research Foundation and the private sector. The lab will support and strengthen the implementation of a national research platform on risk assessment of nanotechnology recently developed by the Department of Science and Technology, and also the Water Research Commission research framework of evaluating nanomaterials risks in the environment," he concludes.

– Bandile Sikwane

The lab will support and strengthen the implementation of a national research platform on risk assessment of nanotechnology recently developed by the Department of Science and Technology.

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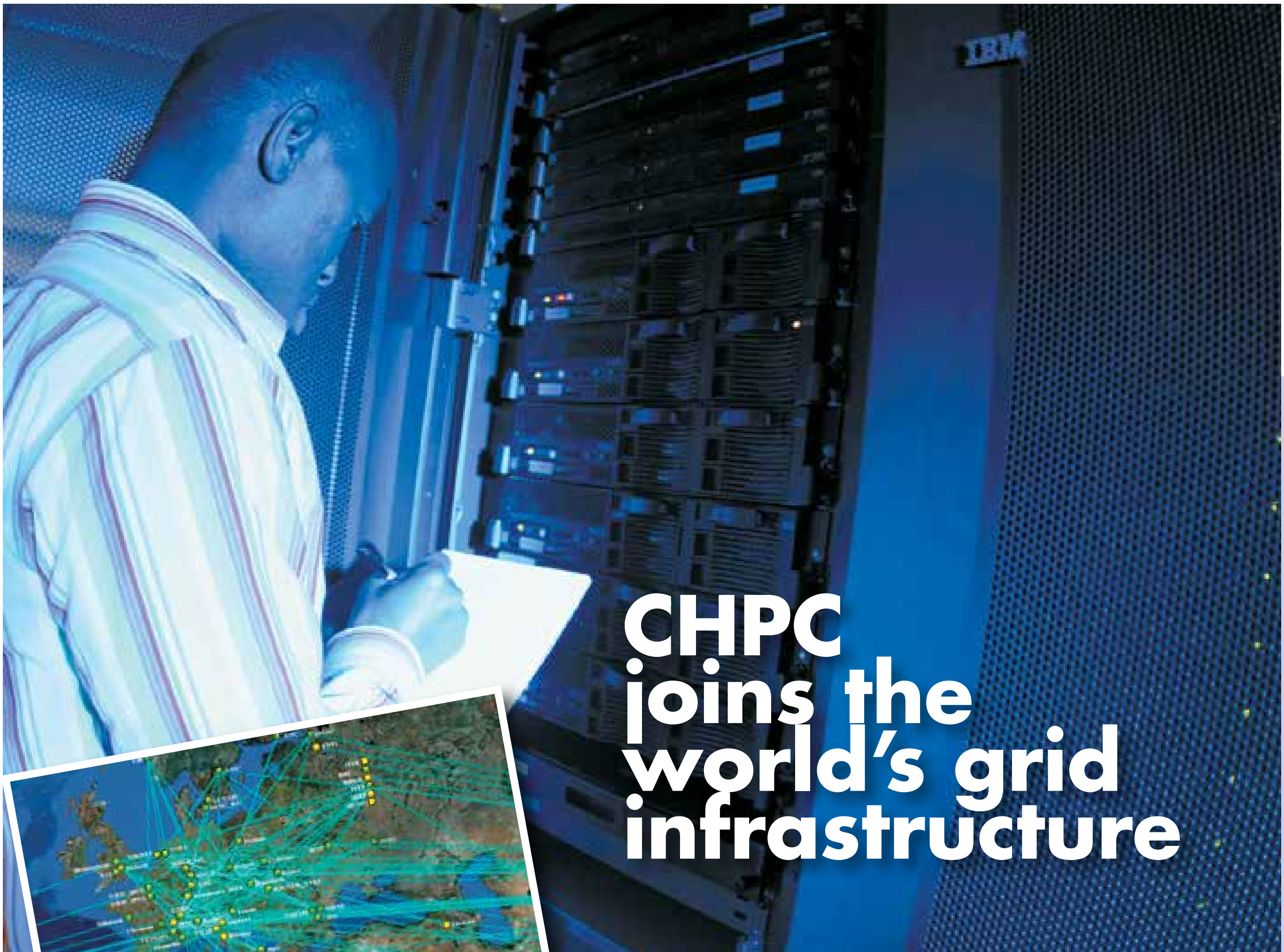

CHPC joins the world's grid infrastructure

Local participation in global science programmes has been given a boost through recent agreements in terms of distributed computing infrastructure.

A geographical representation of the ALICE compute grid. South Africa contributes to the several hundred thousand hours of central processing unit time per year needed.

THE CSIR has been integrated into the South African National Grid through the Centre for High Performance Computing (CHPC). The national grid provides the coordination of national resources to international infrastructure, allowing South Africa to efficiently participate in cutting-edge international experiments. This is made possible through a memorandum of understanding with the European Grid Initiative. The iQudu cluster at the CHPC, with its 50TB storage, is currently being utilised by the international research community, primarily by an experiment at CERN's Large Hadron Collider called, 'A Large Ion Collider Experiment' (ALICE).

The national grid forms part of the country's e-infrastructure and provides support to users of scientific computing in their collaboration efforts. The distributed computing facilities are owned, managed and operated by a federation of universities, national laboratories and research groups, integrated with a middleware layer to provide seamless access to a diverse set of research communities. This project is coordinated from the CSIR, as part of the cyberinfrastructure programme. This has been a major achievement for South Africa, as the commitment to support participation of researchers in global facilities and experiments, was long overdue.

The development of similar activities in other countries in Sub-Saharan Africa is also being stimulated by the CSIR, in the context of the Africa-Arabia Regional Operations Centre (ROC) (http://roc.africa-grid.org). The CSIR has provided support and training to technical experts from all over Africa during the HP-UNESCO Brain Gain Initiative and is consolidating this role in the development of the ROC services, where the South African National Research Network also plays a strong part. These services include monitoring and alarms, service level negotiation, operating level agreements, accounting and support.

"We have integrated sites in Ghana, Nigeria, Kenya and Tanzania, with others in Uganda, Cameroon, Zimbabwe and elsewhere under way," says Dr Bruce Becker, Coordinator of the South African National Grid. This activity is supported by many activities, including the FP7 projects CHAIN-REDS (http://www.chain-project.eu) and ei4Africa (http://www.i4africa.eu), in partnership with the Ubuntunet Alliance.

The CSIR plays a critical role in enabling South Africa to participate in global science programmes, such as the ALICE collaboration, by contributing a Tier 2 facility. Currently, the site at the CHPC is a productive contributor to the ALICE compute grid, with over 500 Monte Carlo simulations processed for the ALICE project on a daily basis. "These simulations attempt to accurately describe the collisions created by the beams of the Large Hadron Collider machine by tracking hundreds of thousands of particles produced at extreme energies, through the huge volume and millions of channels of the ALICE detector," explains Becker.

The centre improved support for ALICE following an upgrade of international bandwidth to 100 Mb/s in October 2012. ALICE is one of the four large detectors built around the Large Hadron Collider at CERN. Further resources are being considered for the ATLAS experiment (A Toroidal LHC Apparatus), which is one of the two large, general-purpose detectors which are undertaking primarily the search for new physics.

South Africa participates in the ALICE experiment, as well as the ATLAS experiment, via the Department of Science and Technology funded SA-CERN Consortium, an umbrella for the collaboration between South Africa and the world's largest physics laboratory. South African physicists participate in the analysis of data acquired at the detector, as well as the development and testing of various theoretical models. ALICE produces several petabytes of data annually, and requires several hundred thousand hours of central processing unit (CPU) time per year. This CPU time is provided by the members of the collaboration via the Worldwide Large Hadron Collider Compute Grid, which includes the CHPC's IBM iQudu supercomputer and several other sites in South Africa, via the national grid.

Meet national coordinator Dr Bruce Becker

Becker is a senior researcher and has worked at the CSIR since 2009. He obtained his PhD in ultrarelativistic nuclear physics from the University of Cape Town in 2007, working on the performance analysis of the ALICE dimuon spectrometer high-level trigger, as well as high performance computing applications for high-energy physics.

After two postdocs in France and Italy, Becker returned to South Africa to coordinate the development of a national grid for e-Science along with collaborating universities, national laboratories and research groups. Since then, he has overseen the development of grid infrastructure in South Africa and further afield in Africa through the United Nations Educational, Scientific and Cultural Organization-Hewlett-Packard Brain Gain Initiative and a series of European Union-FP7 projects. He currently works closely with the South African National Research Network to develop advanced services for the network, and is responsible for collaboration with the European Grid Initiative through the Africa-Arabia Regional Operations Centre.

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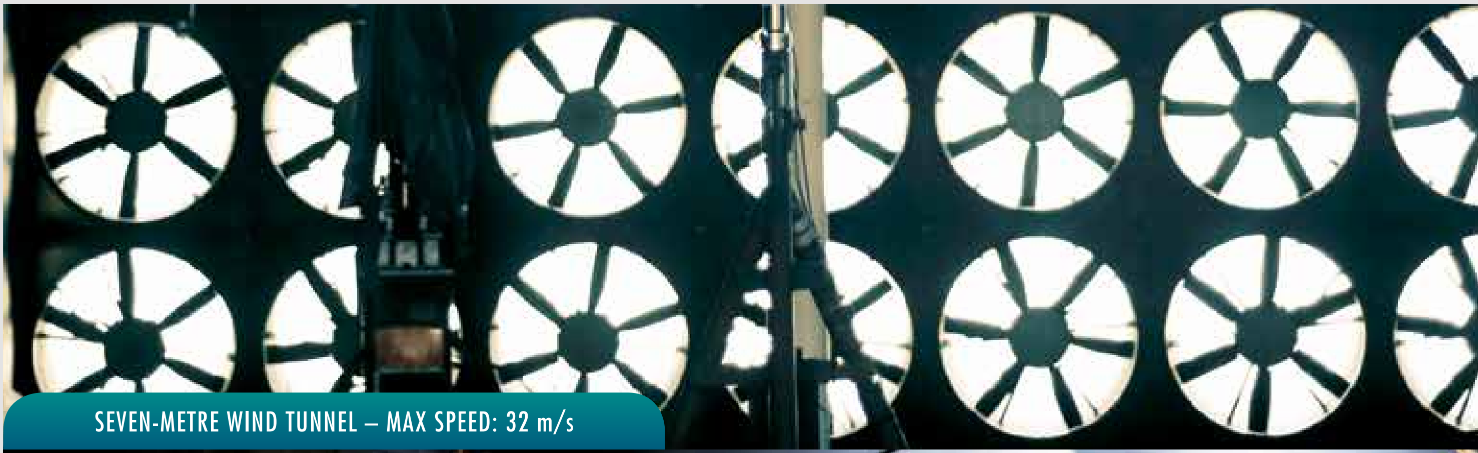

SEVEN-METRE WIND TUNNEL – MAX SPEED: 32 m/s

LOW-SPEED WIND TUNNEL – MAX SPEED: 120 m/s

MEDIUM-SPEED WIND TUNNEL – MAX SPEED: MACH 4.4

SUPERSONIC WIND TUNNEL – MAX SPEED: MACH 4.3

FLYING THE FLAG FOR LOCAL **AERODYNAMICS RESEARCH**

The CSIR's suite of wind tunnels has provided a scientific research and experimental foundation to the aerodynamic design efforts of the South African aeronautical industry over many years. Installed over a period of 30 to 35 years from the late 1960s onwards, the suite received its flagship, the transonic medium-speed wind tunnel, in 1989.

NUMEROUS AIRFRAMES have been tested in the CSIR wind tunnel facilities. These range from subsonic types such as gyrocopters, helicopters, unmanned aerial systems and military trainers – to transonic type airframes, such as bombs and combat aircraft, and to 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 and to populate complex modelling and simulation environments for broader mission simulation predictions, doctrine development and training.

Approximately 5 tons of air are held in these tanks and emptied through the high-speed wind tunnel at a rate of approximately 3 tons in 20 seconds.

An aeronautical engineer doing a final inspection on a wind tunnel model.

A rare view down the low-speed wind tunnel.

THE ROLE OF WIND TUNNELS AND AERONAUTICS RESEACH

The design of flight vehicles requires significant industrial investments and poses a huge burden on the developer to 'get things right' the first time. Sufficient accuracy in airframe performance prediction affects the economic viability of the product – but has to be balanced by equally important aspects, such as safe operation and purposeful performance to specification, to ensure its ultimate success.

Relying only on a flight test of a prototype and discovering inefficiencies against specifications, can lead to the failure of a development programme. A wind tunnel provides an optimal tool to study and determine performance predictions early on in the design phase. Airframe aerodynamic behaviour can be predicted rapidly and at relatively low cost and later in the development cycle, such testing can provide extensive performance characterisation.

The value of these predictions can be enhanced when used to complement computational fluid dynamics methods and proven empirical methods. This leads to another important use of wind tunnels, namely the validation of computational and empirical methods before application of these methods in productive development processes.

The application of experimental aerodynamics in the validation of modern computational tools provides a large pool of research test cases and resources that link into the training of young aeronautical engineers at universities. The complementary use of computational and experimental methods in aerodynamic research enhances the understanding of flow phenomena and spills over into the development of new simulation techniques, reducing the risks in the predictive phases of airframe design.

WHAT HAPPENS INSIDE THE WIND TUNNEL

Testing within a wind tunnel simulates the flow environment encountered by an aircraft during flight. The wind tunnel generates wind or air flow over a static airframe supported in a controlled test environment. Instrumentation in or on the supported test item provides the data with which the aerodynamic behaviour of the airframe at various flow speeds and attitudes are measured.

Most wind tunnel testing is performed on sub-scale replicas (models) of the full-size aircraft or components. A wind tunnel is characterised by the size of its test section, which determines the maximum size of the model that can be tested and its maximum speed. Generally, wind tunnel facilities are classified with respect to the speed of sound (sonic), hence they can be subsonic (flow speeds lower than the speed of sound), supersonic (higher than the speed of sound), and transonic (flow speeds both higher and lower than the speed of sound).

The CSIR operates six aerodynamic wind tunnels, a water tunnel and three specialised gas turbine test facilities. The four main commercial tunnels cover a speed range from very low subsonic speed up to 4.3 times the speed of sound in the supersonic facility. These are used commercially due to the maturity of their capability and calibrated flow conditions that are used to characterise airframes for clients.

In the subsonic tunnels, the test section sizes range from 7.5 m x 6.5 m in the 7 m wind tunnel, with maximum speed of 32 m/s, to 2.1 m x 1.5 m in the closed-circuit low speed wind tunnel (max speed 120 m/s). On the high speed end, the transonic wind tunnel has a square cross-section test section of 1.5 m x 1.5 m and reaches speeds of Mach 1.4, while the high speed (supersonic) wind tunnel has a test section of 0.45 m x 0.45 m and can reach Mach 4.3.

Sean Tuling, transonic testing and medium-speed wind tunnel facility expert.

STAFFING THE FACILITIES: INTERNATIONALLY RECOGNISED SPECIALISTS

The operation of this complex infrastructure requires a complement of multidisciplinary specialists. The CSIR's experimental aerodynamics research group comprises principal and senior aeronautics engineers, as well as technologists and technicians. Domain specialists have garnered international recognition by regularly participating in specialised work groups, such as the Supersonic Testing Association International (STAI), the Subsonic Aerodynamics Testing Association and the International Symposium of Strain Gauge Balances.

In 2012, the CSIR was awarded the Presidency of STAI in the person of Sean Tuling, transonic testing and medium-speed wind tunnel facility expert. The group's engineers are frequent presenters at the International Council of the Aeronautical Sciences and the International Ballistic Symposium.

The experimental aerodynamics research group is supported by peers with broader aeronautical sciences skills including aero-structures, computational aerodynamics and propulsion and power.

The CSIR wind tunnels boast a 30-year history of participation in the broader aeronautical and industrial developments in South Africa through involvement in projects such as the aerodynamic characterisation done on the Rooivalk, Mirage, Cheetah and frigates, as well as local missile development, development of unmanned aerial systems, evaluation of aircraft and helicopter prototypes, combat aircraft upgrades, weapons integrations, and weapons release research.

DID YOU KNOW?

- Wind tunnel testing is not limited to utilisation in aircraft design and evaluation. The CSIR has participated in maritime studies; flow studies for oil platforms; flow interference with helicopter deck landings on frigates; ship superstructure interference flows on supply ships, such as the Naval supply and replenishment ships SAS Outeniqua and SAS Drakensberg.
- Within the automotive industry, the CSIR supports motorsport aerodynamic optimisations and performance characterisations, external and internal cooling flow characterisations, wind interference, noise abatement and public transport design optimisation. In the mining sector, work is performed on mine ventilation, mine dump erosion, deep mine cable oscillation and in mine safety valve studies. Wind generation work is done to support turbine design and testing.
- A specialised boundary layer tunnel investigating wind loading on structures is mostly used for the built environment and was used for the testing of South Africa's Antarctic base to ensure that it is not buried in snow during winter blizzards. The base stands on stilts of roughly 4 m high, positioning it above the snow and allowing the snow to blow through and not collect on the structure itself. Over time, the base get completely buried and increasing hard to access, plus unsafe as the walls can buckle under the pressure of the ice.

Meet aeronautics facility manager Mauro Morelli

Morelli is the CSIR research group leader for experimental aero-dynamics. He graduated at the University of Pisa, Italy in aeronautical engineering. He has more than 20 years experience at the CSIR wind tunnels.

His cites career highlights as testing a local upgrade development for a South African fighter aircraft and a sabbatical during which he was a transonic wind tunnel test consultant on a combat aircraft.

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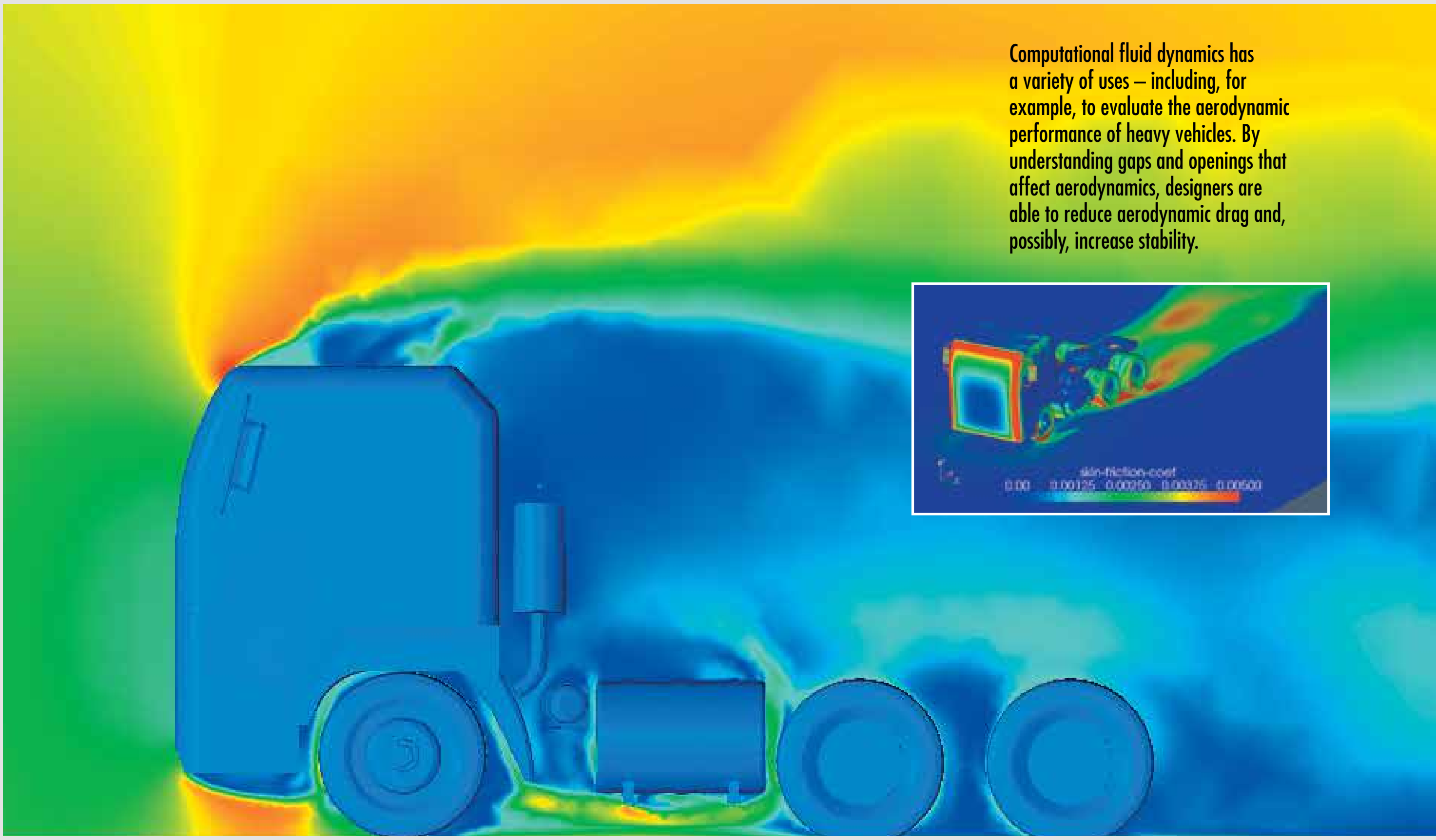
MATHEMATICS AND MODELLING TO PREDICT FLOW PHENOMENA



Computational fluid dynamics has a variety of uses – including, for example, to evaluate the aerodynamic performance of heavy vehicles. By understanding gaps and openings that affect aerodynamics, designers are able to reduce aerodynamic drag and, possibly, increase stability.

The CSIR's computational fluid dynamics laboratory consists of 325 powerful computers working in parallel. This facility underpins integrative engineering solutions – for example, in the case of integrated wind tunnel and experimental fluid dynamics studies in aerospace, or industrial (e.g. building design, automotive) applications.

IN THE CASE OF store integration – that is, adding a weapon to an aircraft – tests have to be conducted to determine whether the craft can carry the addition, as well as how it will change the flow of air and affect the release envelope of the weapon.

Another example is to determine what happens when fluids slosh in large fuel tanks, such as those in the wings of aeroplanes, in terms of both the loading on structures and the potential threats to the vehicle's dynamic stability or balance.

Other examples include ventilation analysis, casting, smelting and molten metal flows and wave modelling.

Computational clusters run a variety of commercial and in-house developed analysis codes, and custom code development is also undertaken through research in numerical algorithm design and high-performance computing.

Results can be presented in multiphase and multiphysics simulations.

Sharing access

The aeronautics facilities are regularly used by academic institutions for their under-graduate research studies, as well as postgraduate studies. The aim is to make the infrastructure available to higher education institutions with aeronautical interest, in a structured manner to allow the benefit of these capital-intensive facilities to feature earlier in the fundamental research cycle, to pique interest and foster skills in this specialist domain.

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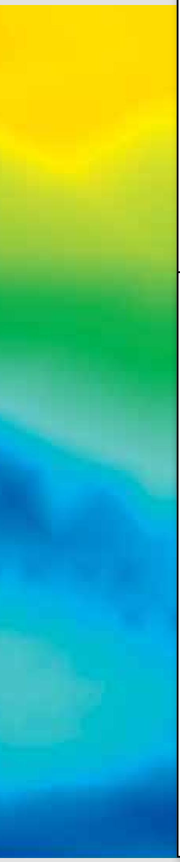
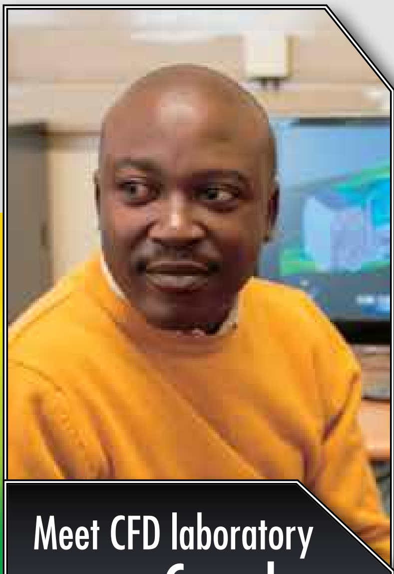
Some 325 powerful computers work in parallel at the CSIR computational fluid dynamics laboratory.





Meet CFD laboratory manager **Conrad Mahlase**

Mahlase – Antarctic explorer, laser physicist, fluid dynamicist and computational specialist at the CSIR's aeronautic systems group. Mahlase oversees the development and maintenance of a cost-effective and powerful computational cluster for the group's varied fluid dynamics applications.

He completed his MSc on shock lenses for high-power lasers earlier this year.

Researching and developing

UNMANNED AIRCRAFT SYSTEMS

The CSIR's aeronautic systems capability includes an unmanned aircraft system (UAS) laboratory. The facility consists of a high-fidelity flight simulator in which an UAS can be test-flown virtually, using real aircraft sub-systems, such as autopilot and control surface servo actuators. The modelling and simulation-based systems engineering approach to UAS development is a cost-effective and efficient way to develop the concepts.

A HIGH-FIDELITY FLIGHT model of the modular UAS developed through this laboratory was demonstrated to industry and universities to encourage more research.

The CSIR also has two characterised mini UAS airframes, Indiza and Sekwa, each capable in their own right. With a 2-m span, the land-launched mini research UAS, Indiza, has been aerodynamically characterised in the CSIR wind tunnels and is used for border safeguarding exercises, while Sekwa, as a 1.7-m span variable-stability UAS, is used for relaxed stability and systems identification research.

The success of such remotely controlled aircraft in conflict situations is changing the acquisition priorities of defence forces worldwide. Not dissimilar to model aeroplanes, but far more sophisticated, UAS are complex aeroplanes that fly through the use of a mission controller. They range in size from large to micro. Some UAS fly at altitiudes higher than commercial airliners, nonstop for more than 24 hours; some can be hidden in a hand, yet can carry intricate cameras and surveillance systems.

The CSIR's development of UAS over the past 30 years concentrated on airframe development for military applications. The first UAS civilian application in South Africa was the use of Denel's Seeker during the 1994 election and subsequently for anti-crime operations. The CSIR's first UAS for commercial application is a concept demonstrator for power-line monitoring which comprises a unique multi-spectral camera mounted on a rotary wing airframe that acts as the primary sensor for picking up electrical faults on power lines.

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CSIR HOME TO COMPLEX RADAR, ELECTRO-OPTICAL AND ELECTRONIC WARFARE INFRASTRUCTURE

The South African radar, optronic and electronic warfare communities have built an internationally recognised reputation for cutting-edge research and development (R&D), as well as test and evaluation capabilities and infrastructure developed in this field. This track record dates back to technical breakthroughs achieved in World War II.

Operators and scientists monitor the radar data on the console inside a shelter specially designed to withstand extreme temperatures.

VIEWED BY SOME as a culmination of the CSIR's leadership role in this domain, the first baseline of a novel, integrated mobile research, development, test and evaluation capability for radar, electro-optical and electronic warfare systems was established in 2013. The importance of this development lies in the fact that all the complex components and systems integrated into this facility were developed by the CSIR and are either one of a kind or compare very favourably with the best systems of their kind internationally.

The core of the capability comprises the Fynmeet II radar cross section measurement facility and the Zingela tracking radar research facility, which form part of a long-standing collaborative programme with an international technology peer organisation. These components are critical to the bigger integrated system, yet are also used independently as electronic warfare infrastructure.

The development of the next generation of specialised R&D, and test and evaluation facilities is a major milestone that was achieved through a close partnership between the CSIR, Armscor, the South African National Defence Force and South African industry and with the support of a number of international collaborative R&D programmes.

About Fynmeet and Fynmeet II

Fynmeet II is a second-generation, mobile microwave measurement facility, capable of performing high-resolution radar cross section and that measures the effectiveness of chaff and jamming.

The first Fynmeet system was commissioned in 1997 and was developed with funding by the Department of Defence (DoD) to address the South African Air Force (SAAF) requirement for dynamic radar measurement of fighter aircraft and chaff. The evolution of the system included the added functionality to evaluate installed electronic self-protection system performance and to support research programmes funded by the DoD and the Department of Science and Technology. The first system was used on a number of operational, test and evaluation exercises with the SAAF, on acquisition decision support for the South African Navy and to support several research programmes, including research on non-cooperative target recognition and detection of small targets in sea clutter – that is, unwanted signals or 'returns' from the reflective surface of the ocean.

Positioned at an elevated level, the optical target designator has a broader field of view to detect a target – on the sea or in the air.

The Fynmeet II and Taba radars in this mobile facility form a radio frequency signal measurement system that tracks and measures targets. Measurements enable the operator to identify the specific target type.

Did you know?

- The South African radar capability originated from technology transferred from the United Kingdom. Under the leadership of Dr Basil Schonland, who later became a founding member of the CSIR, the first radar echo from a South African-designed radar was received on 16 December 1939. This radar community again surprised the world in 1958 with the tellurometer – an invention that revolutionised geographical surveying. More than 20 000 tellurometers were produced in Cape Town under a CSIR patent and distributed worldwide. Capitalising on the strong history in tracking radar and platform self-protection against electromagnetic threats, the CSIR has built a significant knowledge base and specialised facilities in the broader field of radar and electronic warfare over several decades.
- The CSIR's state-of-the-art, internationally competitive digital radio frequency memory technology, developed since the late 1980s, can be found in specialised R&D, test and training facilities the world over.
- The Gripen fighter aircraft has highly advanced sensors. The CSIR's radar and electronic warfare experts support the SAAF in its use and optimisation of this technology.
- The scarcity of technical skills in radar and electronic warfare is a concern in this industry. The CSIR, through partnerships with local and international research and academic organisations, has contributed to the establishment of Master's degree programmes at the Universities of Cape Town and Pretoria, supported by involvement of international experts as lecturers.

JAMMING: A technique to disrupt either a communication link or a radar system. Simplistically, a jammer will saturate the target receiver with a higher level of energy than the intended transmitter can deliver at the receiver.

The role of radar and electronic warfare in a safer South Africa

South Africa faces the challenge of protecting its territories and people against activities such as illegal border crossings, weapons trafficking, smuggling, piracy, poaching, organised crime, and terrorism on land, at sea and in the air. The country also contributes regionally and nationally to ensure freedom of travel of oceangoing vessels in support of economic activity, the fulfilment of monitoring, control and surveillance responsibilities for the Exclusive Economic Zone and the protection and safeguarding of natural resources.

Modern radar and electronic warfare technology can provide a force multiplication effect by providing wide-area, real-time, recognised situation pictures that enhance the situational awareness of commanders, and thereby the quality of their command decisions and the efficiency and effectiveness of the security operation.

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VIDEO WALL gives a clear vision of cybertraffic

The installation of a video wall is enhancing the effectiveness of the CSIR's cyberdefence and security research capability.

Cyber defence experts Schalk Peach, Sipho Ngobeni, Joey Jansen van Vuuren and Sune von Solms in front of the video wall.

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INSTALLED EARLIER THIS YEAR – and funded by the CSIR and the Department of Defence – the video wall is designed as part of the equipment needed for an Internet simulator. The simulator is currently in the first phase of development; it will be used to test the configuration of different networking equipment, as well as the effect of malware on corporate local area networks.

The video wall makes it possible to monitor a vast amount of information at once in order to make an informed decision, similar to the video walls used in security operation centres; it is 4.2 m wide and 1.8 m high. It replaces projectors, because it provides better contrast, brightness, uniformity and colour reproduction than that of a projector. It has a clear resolution of 24.8 megapixels. Multiple presentations, including multimedia, can be displayed simultaneously on 12 monitors, that can be split into a total of 24 screens. CSIR cyber defence researcher Schalk Peach says that the video wall's presentation setup increases the awareness of the audience as it could typically include an overview slide, active demonstrations, as well as auxiliary feeds.

Ship motion simulator for accurate maritime surveillance footage

The CSIR undertakes research and development to support the South African Navy and Special Forces with maritime surveillance to monitor or defend the sovereignty of the country's oceanic terrain. One specific area of interest is the use of optronics for improved surveillance at sea. This work led to the development of a motion simulator that emulates a ship's movement.

Meet opto-mechatronics research group leader **Hendrik Theron**

Theron (front) leads the CSIR's optomechatronics research group. He started at the CSIR as a bursar in 1989 and has been in the mechatronics industry for eight years. He is responsible for the modelling of the ship motion simulator, validation of the model as well as the non-linear control system used. "We need the system to refine tracking performance of surveillance systems and we need to emulate platform motion," says Theron.

THE CSIR DEVELOPED a novel camera-based surveillance system that provides a real-time, 360 degree video view of a ship's surrounds, and that is able to detect and zoom in on small targets. However, the system has to provide a stable view – despite being used on board a constantly rocking vessel. The CSIR optronics team devised a motion simulator that emulates a ship's movement at sea based on pneumatics and custom mechanical design, which was done by Hendrik Theron and Mark Halloway.

Achieving this meant that continued development of the camera system could be done on land, and not even near the ocean, ensuring that the completed system would deliver effective visual outputs, despite the rise and fall of the ship it is used on.

The ship motion simulator is a modified version of the three degrees of freedom Stewart platform. It operates on a roll and pitch axis at different frequencies and amplitudes using a combination of pneumatic actuators and position feedback into a custom control system. In this way, optronics experts could be sure that the camera system would be effective despite the challenges of shifting horizons, changing clouds and water swells obscuring objects.

The CSIR has made the simulator available to the University of Pretoria's Department of Mechanical Engineering to support postgraduate research on mathematical modelling and control systems studies. The University of Pretoria devised the control system for the ship motion simulator.

Using this same methodology, the team will also be looking at motion platforms to support systems on mobile land-based patrol or response vehicles.

Optronics in maritime security

The navy's duty to protect the sovereignty of the state includes involvement in search and rescue missions, harbour-based criminal activity and the scourge of poaching and smuggling of South Africa's wildlife, such as abalone.

Real-time, 360 degree surveillance is the 'golden chalice' in security; having that 'all seeing eye' to detect clearly what is happening in the full spectrum of your surrounds in order to respond rapidly and appropriately.

Optronic sensors offer an important complementary choice of surveillance to the generally used radar systems on ships. It is better able to detect even small objects (e.g. smaller wooden boats often used by poachers) against the highly cluttered background of waves and white caps. The CSIR's camera-based surveillance system consists of five high-resolution cameras, each capturing a section of the surrounds. Footage is then 'stitched together' to create a real-time, 360 degree video-based view of the entire area surrounding a vessel.

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Knowing the shape of ROCK

CSIR researchers have developed a laser scanning approach to accurately measure the shape and surface area properties of natural crushed rock, as well as recycled and marginal aggregates to improve the durability of road and railway infrastructure and ultimately safety. In future, this can replace less accurate manual measuring techniques, which have been used for decades.

THE SHAPES OF AGGREGATE PARTICLES used in the layers of road, airfield and railway structures are critical determinants of the durability of this infrastructure. Without proper drainage and a strong capability to carry heavy loads, roads and railway infrastructure can deteriorate to such an extent that it incurs increased or unforeseen spending on infrastructure and even fatal road accidents or train derailment.

Dr Joseph Anochie-Boateng, principal research engineer at the CSIR, is leading the development of a method using three-dimensional (3D) laser technology, as well as numerical modelling and analysis to determine the exact shapes of these aggregate particles.

In the construction of asphalt roads, the shape and surface characteristics of aggregates are factored in the mix design when calculating the optimal thickness of bitumen, which is used to bind the material.

The optimal shape of stone, as well as the larger ballasts used in railway construction, must preferably be angular rather than rounded. This enables it to interlock for a strong aggregate skeleton and increased ability to carry vehicular loads as opposed to particles with rounded edges which tend to slide or roll past each other, leading to instability.

Since 1942, the standard method used worldwide for measuring the surface area of coarse particles (larger than 4.75 mm in size) for asphalt mix design, was based on the assumption that all aggregate particles are spherical in shape, says Anochie-Boateng.

In fact, aggregate particles are not spherical. Their shapes are so irregular that the methods – which include manual

A laser scanner is used to measure the shape and surface area properties of natural crushed rock.

The importance of aggregate shape

Aggregates, crushed rock and stone are used as surfacing and base materials in road infrastructure and as ballast and sub-ballast in railways infrastructure. It provides stability which determines the durability of infra-structure that carries heavy load. Poor quality road infrastructure can lead to potholes, cracking and rutting, causing dangerous transport conditions.

Specification of the equipment

The CSIR uses the Roland LPX-1200 3D laser scanner which can scan objects up to 130 mm in diameter. The device scans objects on a rotating table using a laser beam which travels vertically up the rotating object to generate a digital file. The device uses advanced data processing software, which allows automatic calculation of the surface, volume, width, height and depth of the aggregates.

measurements by technicians using callipers, sieves, gauge slots, etc. in laboratories – produce average values which could influence the durability and performance of road and railway infrastructure.

According to Anochie-Boateng, 3D laser technology has been used in health care for many years to visualise dental and orthopaedic structures. He was introduced to the possibility to use this technology in construction while at the University of Illinois in the United States between 2002 and 2007.

His team discovered that a portable and relatively affordable 3D laser scanner could measure the shape and surface properties of aggregates accurately. They developed mathematical relationships to compute the surface areas for coarse aggregates in five typical South African asphalt mixes. The team found that the standard method under-estimated the surface area of the particles by 10% to 30%, which could have implications for the calculation of the bitumen thickness of these asphalt mixes.

Before their work, many of the attempts by researchers to improve on traditional measuring techniques relied on two-dimensional information, which still made it difficult to determine the mass or volume of the rocks. The researchers have already compiled a library of 3D polyhedrons (the typically multi-faced geometric shapes of aggregates) and are still adding to it. This includes 3D data of at least 3 029 aggregate types and 251 railway ballasts.

The measurements to compute surface area and volume can never be 100% accurate, due to the fact that each particle is essentially unique. It is, however, a substantial improvement on standard methods.

According to Anochie-Boateng, the technology can compare the shape quality of rocks from different stone quarries, which might be crushed by different types of technology. Those producing inferior quality aggregate shapes, could improve their output by using better technology based on advice obtained after the laser measurement.

The researchers have registered a patent in South Africa which covers the numerical aspect of the laser research. They also use laboratory equipment to validate their numerical and laser findings, which physically test the rocks to determine the strength, stiffness and the extent to which they deform.

The first phase of the research, which is aimed at establishing a proof of the laser concept and applications in transport infrastructure, will be completed in 2014.

The CSIR is already in talks with Transnet about the possible future application of the technology and Anochie-Boateng says that the concept has been well received by the local industry and during presentations at the US Transportation Research Board annual meetings. The researchers also intend to strengthen existing cooperation with local and international industries, universities and research centres.

– Antoinette Oosthuizen

Meet facility manager Dr Joseph Anochie-Boateng

Anochie-Boateng is a principal researcher and has worked at the CSIR since 2008. He obtained his PhD in civil engineering from the University of Illinois at Urbana-Champaign in the United States in 2007, where he specialised in transport infrastructure engineering (roads and airfields).

Anochie-Boateng supervises three PhD and three Master's students from UP and TUT who will be obtaining their respective degrees on the project.

He is a member of local and international transport infrastructure committees including the South African National Road Agency Ltd materials cluster, and the United States Transportation Research Board mineral aggregate committees.

The facility in brief

CSIR researchers are developing applications in the use of three-dimensional scanning and numerical methods to determine the exact shape of rock aggregate used in the construction of roads, railway and airfield infrastructure. This more accurate measurement could replace traditional manual and time-consuming methods which have been in use over several decades.

The concept has been well received in the transport industry locally and internationally. The researchers are also collaborating with the Tshwane University of Technology (TUT) and the University of Pretoria (UP) through the co-supervising of postgraduate students.

The researchers envisage that the outcome of this research will enable the construction industry to use all aggregate and ballast sourced from quarries, as well as recycled aggregate and marginal material. The latter does not meet specifications and normally cannot be used.

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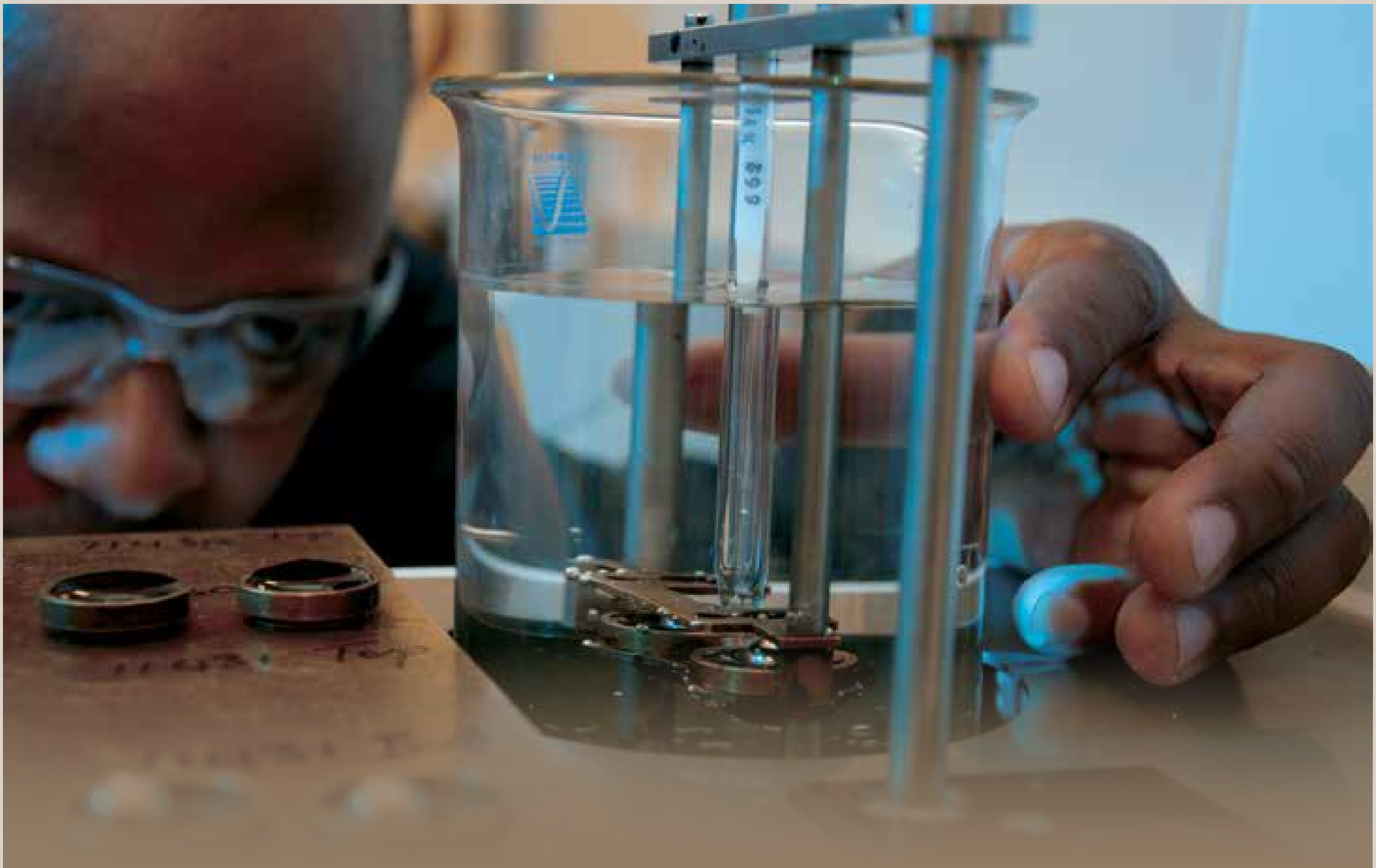


ADVANCED ROAD MATERIALS TESTS
save money before, during and after construction

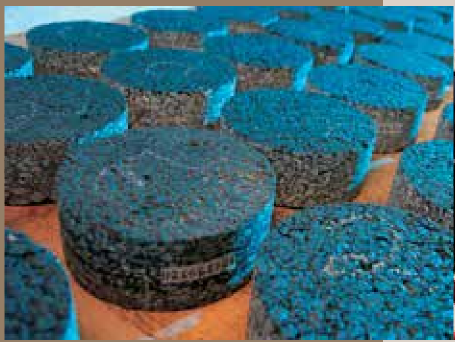
The CSIR advanced materials testing laboratories conduct tests on road building materials for road engineers and researchers, road owners, construction groups and consultants.

THE COSTS OF BUILDING and maintaining a road are much higher than people expect. In a developing country, the roads budgets also compete with other essential services. According to the 9th State of Logistics™ survey released in June 2013, South Africa's per lane-km road construction costs are R30 million, with our road maintenance costs being R0.3 million per lane-km. The survey puts our construction to maintenance cost ratio at 100.

To ensure the most cost-effective construction of roads, and its increased lifespan, road owners must pay attention to the specific road materials to be used in the structural and other layers of the road, taking into account the specific situation where, and the purpose for which, the road will be constructed.

The CSIR's advanced materials testing laboratories conduct most tests on road building materials needed by researchers and road engineers, both from the CSIR and externally, including numerous clients such as consultants, road owners and construction groups. The specifications set out in these laboratories have been incorporated into the recently updated system, the South African Pavement Design Method (SAPDM). The SAPDM has been a multiyear project undertaken by the CSIR and others for the South African National Roads Agency Limited (SANRAL).

"I believe in socio-economic impact – if our advanced testing did not have an economic, and long-term positive impact on society, I would not be doing this job," notes Dave Ventura, manager of all the materials testing laboratories.



Structural behaviour of roads

"The way a paved road behaves structurally during its expected lifespan depends on the interaction between the strength of the various layers, the environment and the loads that pass over the paved road," explains Ventura. Materials to be used in the structural layers of roads should be selected according to fitness-for-purpose, availability, economic factors, material characteristics and previous experiences. This must be done during the design stage so that the materials selected are the most economical and best suited to the prevailing conditions.

The surface layer (trafficked layer) of paved roads normally consists of a mixture of bitumen (the black binder seen on most paved roads) and graded stones placed on top of a base layer as an asphalt mix or as a surfacing seal.

"All material properties have certain inherent variability, which should obviously be taken into account when specifying properties for specific road construction projects. Material types currently used in South Africa include natural soils and gravels, processed gravels and rock, bituminous and cementitious-treated material, and Portland cement concrete," says Ventura.

Advanced laboratories

The materials testing laboratories comprise facilities for granular materials; asphalt; bituminous binders and a dynamic testing section. All these laboratories are ISO 17025 accredited, as are the procedures used in the labs and specific individual test methods. Laboratory technicians and technologists have also been declared competent to conduct these tests.

"In our materials laboratories, we have a large base of external clients, with some of the most well-known being SANRAL and the South African Bitumen Association (Sabita), as well as the association's members who are typically producers and applicators of bituminous products, consulting engineers and educational institutions," notes Ventura. "We conduct tests on graded stones – soils, gravels, binders and mixtures of these – to be used in road layers during construction for compliance or for research purposes. The laboratory produces various asphalt specimens – materials bound with bitumen – in a variety of ways for testing, with different tests being done on specimens."

For a number of years already, South Africa no longer uses tar on roads due to its carcinogenic effect on road workers. "The bituminous binders laboratory investigates various bituminous mixes, as bitumen has become very scarce and expensive. We add rubber and polymers to see how these enhance the properties of the binder and the performance of the composite material. We have started with standardised, as well as specialised testing for looking at alternative binder additives, such as agribinders," Ventura says.

The dynamic testing section involves more advanced testing using specialised equipment. Researchers investigate materials' durability, stiffness, permanent deformation characteristics and resistance to cracking, among others. The properties of the manufactured samples are tested as if they would be used on the road. This results in researchers being able to provide guidelines for how roads should be constituted.

"When people need routine testing, they would go to commercial laboratories that specialise in routine tests. Most of the specialised tests would be done in our laboratories. We run one of only very few laboratories of their kind in South Africa, where contractors and consultants can get materials to undergo specialised testing as part of the design and testing to assess their fitness-for-purposes," he concludes.

Ideal future

What would be Ventura's ideal? "South Africa needs a standardised laboratory – a reference laboratory known for its unbiased testing and specialised information and specifications. Such a laboratory should also get more involved in the training of technicians to do the actual tests. The country needs far more trained materials testing individuals; external people should be able to get their training at such a standardised, reference laboratory for South Africa," Ventura concludes.

– Hilda van Rooyen

Meet advanced materials testing laboratories manager **Dave Ventura**

After obtaining a higher diploma in civil engineering, Ventura joined the CSIR materials testing laboratories, at the time as a technologist. He worked in a variety of the laboratories, heading up the chemistry laboratory at one stage, which involved a huge amount of field work and research on road materials and treatments of innovative stabilisers for gravel roads. Ventura also holds a BCom from the University of South Africa.

Ventura has more than 24 years of experience in aspects of materials testing, assessment of road pavement performance, training and technology transfer. He has been involved in several road failure investigations in South Africa, Namibia, Lesotho, Botswana and Malawi. He has long-standing contact with public and private sector bodies in the road construction industry and has written or co-written more than 40 reports pertaining to the testing or evaluation of road construction materials.

(From left): Some asphalt cores; Georges Mturi testing bitumen; and Allan Crawford testing the shear resistance of asphalt.

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Researching and modelling novel solutions for coastal engineering

The CSIR's coastal and hydraulics laboratory is one of four facilities of its size in the world, where accurately built scale models are constructed to test harbour and coastal engineering design.

A VISIT TO THE COASTAL and hydraulics laboratory at the CSIR's Stellenbosch site is an experience similar to stepping onto a movie set for a science fiction film.

Located in a hangar-sized hall, the laboratory allows researchers to construct to precision, physical models of harbours, breakwaters, rivers and dams – down to the last details and with precision-built model ships to match.

The laboratory is used mainly for breakwater stability, wave attenuation and moored ship response model studies. Each project is scoped according to the brief by the client.

Action on set: Model basins

The actors on the set are a group of 20 engineers and technicians with backgrounds varying from civil, mechanical and naval engineering to numerical modelling and artisan skills united by a common research interest in coastal engineering.

Kishan Tulsi manages the laboratory and explains, "We have a range of three-dimensional (3D) model basins and two-dimensional wave channels, which we use to construct physical models; two wave basins for vessel response and wave penetration tests; two basins for breakwater stability tests, a wind flume; two concrete wave flumes; a glass flume and a deep water tank." A flume is a channel for water, and is used to recreate a defined subsection of a model basin, which requires particular investigation.

The model basins have multi-directional irregular shallow water wave generators. Wave paddles in the wave basin and the wave channels are equipped with dynamic wave absorption.

Action is carefully captured in a number of ways: Movements of the model ships and the wave agitation are measured by the CSIR-designed Keoship and Keofloats, respectively. The Keoship system allows for the monitoring of model ships, which includes mooring lines and fender force calculations. Specific methodology is used to monitor and capture the effect of waves on the motions of these ships.

Keofloat data captured by video image processing specialists are analysed using a computer algorithm. It is possible to determine the vertical position of the Keofloat at sub-pixel accuracy. The estimated accuracy is 0.2 mm or better for waves smaller than 10 mm, whereas conventional probes guarantee 0.5 mm to 1 mm accuracy.

Survey technology

The latest tool in the box of the CSIR's coastal engineers is RiSCAN, a commercial product for 3D laser mapping using imaging and laser scanning. Introduced by Tulsi for physical modelling, the survey technology is roof-mounted and able to detect the exact position of each object in

The CSIR coastal and hydraulics laboratory has ISO 9001 accreditation.

(From left) A researcher undertaking a measurement before the construction of a new wave basin; a 3D harbour breakwater construction; and a set of wave generators.

(Inset) A dolos is a concrete block in a complex geometric shape weighing up to 30 tons, used in great numbers to protect harbour walls from the erosive force of ocean waves. Developed in East London in 1963 by harbour engineer Eric Merrifield and his team, dolosse are found in use at ports around the world.

the hall and produce a 3D colour image. He says, "By introducing colour on scanned data, for example, the armour which is often dolosse, we can visualise how each element of the data has changed in the physical model and where breakwater design needs to be improved."

Competitive edge

Tulsi ascribes the success of his group and particularly that of the coastal and hydraulics laboratory to the ability of researchers to integrate resident expertise with equipment. "We can take on big projects because we take an overview of the whole problem, and use our skills in building physical models with our ability to combine this with numerical modelling and analysis. We endeavour to stay at the top of our game by constantly researching and implementing new solutions."

Collaboration with local and international experts and laboratories has, at times, proved to be useful ways of achieving project deliverables.

The group has a strong record of working with local and international clients. A recent project for international consultants Baird & Associates required both physical and numerical model studies for the Port Hedland expansion project in Australia. Other international projects of note include the proposed new Port of Doha, Qatar, and the new Khalifa Port in Abu Dhabi, United Arab Emirates; Mackay and Barrow Island, Australia; Dawie Port, Myanmar; Port of Poti, Georgia; St Annes Zilwa, Seychelles, and Costa Azul, Mexico.

The CSIR has demonstrated its ability to put to great effect at its coastal and hydraulics laboratory, a unique combination of expertise, equipment and a strong interest in exploring novel solutions.

– Biffy van Rooyen

The eight commercial harbours on South Africa's 2 954 km coastline – Richards Bay, Durban, East London, Ngqura, Port Elizabeth, Mossel Bay, Cape Town and Saldanha – are managed by the Transnet National Ports Authority, with expert support as and when needed from the CSIR's group on coastal engineering and ports.

Long waves represent one of the two major threats to moored ships. Visible only as surges of up to 35 cm on a harbour wall, long waves build up at sea and have a peak period of between 100 and 200 seconds. This frequency resonates with a moored carrier and can result in disruption of harbour operations and even broken mooring lines. The second threat is high winds. Both threats can be managed by adjusting the mooring systems, but also by installing early warning systems based on real-time and stand-alone measurements of environmental parameters, such as waves, currents, tide and wind.

Meet facility manager **Kishan Tulsi**

Tulsi is a man with a passion for coastal engineering structures and technical equipment and who is not afraid to get his gumboots wet in his work environment.

Initially as a technology and engineering apprentice, and later as manager of the hydraulics laboratory, he has been involved in a number of large projects locally and abroad over the past 10 years. Most of these studies have required the building of physical models, testing of breakwater and monitoring of ship motions.

He holds a BTech in civil engineering (cum laude) from the Durban University of Technology and is enrolled for an MEng degree at Stellenbosch University. He is a registered member of the South African Institution of Civil Engineering.

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Specifications

The CSIR wind tunnel is 18 m long with a cross-section of 2 x 1 m. It is powered by a 75 kW motor, with air speeds of up to 22 m per second. It is the only boundary-layer wind tunnel in Africa. The tunnel is well suited to simulate the earth's boundary layer on a scale of 1:500 to 1:2 000.

Dr Adam Goliger (left) and Ters van Wyk with a topographical model of part of Cape Town.

Equipped for research on some ill wind that blows no good

Wind-tunnel research is undertaken to evaluate and predict the impact of wind before structures are designed and built. The CSIR boundary-layer wind-tunnel laboratory is an asset to South Africa's built environment.

WIND IS A POWERFUL and sometimes dangerous force of nature, affecting the built and natural environments, as well as human lives. Wind has various parameters that must be taken into account, including its energy content, its turbulence characteristics in terms of wind flow in spatial and time correlations, and gusts that can envelop the whole structure or parts of it.

"In this context, wind-tunnel research can evaluate and predict the impact of wind before structures are designed and built," says Dr Adam Goliger, structural engineer and project leader of the CSIR's boundary-layer wind-tunnel laboratory. "Structural loading and environmental issues are researched, which will impact positively on the environment where buildings are constructed and there is a built-up environment where people interact," he notes.

Built-up environment

Engineers and architects are concerned mainly with the effect wind has on structures, and have not traditionally paid much attention to the effect of structures on the local wind environment that pedestrians experience when walking where the wind makes it unpleasant, and sometimes even dangerous.

The physical effects of wind on people can be classified into two categories, namely mechanical and thermal, varying from eye irritation, chilly skin and difficulty in walking, to being blown over. These adverse environmental effects could lead to people avoiding certain areas in a city centre deliberately, resulting in a significant drop in trade.

The size of the CSIR wind tunnel allows for modelling of a preliminary topographical investigation and not only the essential portions of the city infrastructure, such as a few street blocks. Typically, the building and other structures on these blocks are modelled and the conditions at

Soccer stadia

Before the 2010 Soccer World Cup, Goliger and his colleague, Ters van Wyk, were involved in testing the Mbombela, Athlone and Mangaung stadia and their topographical research studies formed the initial basis for further tests in Germany of Cape Town's Green Point Stadium. Models of the stadia were built at the CSIR to test them structurally for spectator safety regarding wind surges, as well as the fairness of the game, given the distribution of the airflow over the soccer fields.

the specific site are measured both quantitatively and qualitatively. The qualitative measurement results are combined with the climatic data, expressed in statistical terms and evaluated against acceptable comfort criteria.

"As we know, the Cape Peninsula is a windy place and the Metro of Cape Town has been developed with major winds around it. The CSIR was involved in research and advice regarding wind nuisance problems across the city, specifically around the northern foreshore, the V&A Waterfront and the port," Goliger mentions.

Unlike in Europe and the USA, wind-tunnel investigations in South Africa are often perceived as an 'expensive' scientific addition, not an essential ingredient. "Wind-tunnel tests can lead to recommendations saving lives before or after a building has been constructed, as well as the avoidance or reduction of potential pedestrian problems through small architectural changes," highlights Goliger. Some of the principles to reduce the wind impact due to the design of buildings include:

- Setting the appropriate relationship between the height of buildings surrounding a public space – the skyline should be designed in a series of 'steps' ascending towards the city centre to allow airflow to slip over it;
- Setting the appropriate size and spacing between buildings. The area influenced by the wind nuisance usually increases with the size of the building. This can be mitigated by the shape of the building and the landscape surrounding it. If a large building stands alone, winds are less severe than if it is surrounded by low buildings.
- Setting the appropriate shape and orientation of the built form – rectangular-shaped, exposed buildings normal to the prevailing wind direction should be avoided. Rounded-off corners and surfaces minimise adverse effects. 'Slab'-type buildings facing a prevailing wind direction should be avoided particularly. The downdraft from an exposed slab can increase the street-level wind speed by 20% for a five storey-building and 120% for 35 storeys. These percentages would increase even more if a bar-shaped, low building was placed up-wind of tall buildings.

Goliger continues: "Other simple architectural adjustments include alternative distribution of the bulk of buildings, landscaping such as terraces and trees, free-standing wind screens, wind brakes and wind deflectors, alternative positioning and orientation of entrances, terraces, resting places, street crossings or passages. Due to the complexity of wind eddies, the optimal choice of an optional variant, its layout and position can be predicted, but the final result can be proved only on the basis of a wind-tunnel investigation."

Structural engineering tests

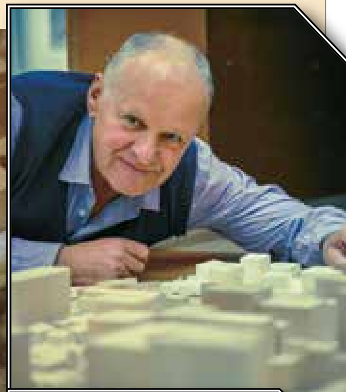
Design codes of practice for wind action on structures are not able to predict and address all design and environmental situations, and, in principle, refer to idealised cases of buildings with standard geometry being in isolation. Research conducted at the CSIR's boundary-layer wind tunnel supplies wind engineering data for design of buildings and structures, and provides specialised testing services for industry, engineers, architects and consultants, in relation to specific design situations.

Wind forces on buildings and structures are studied by constructing, at a reduced scale, models of buildings under investigation with its surrounding terrain. The structural model could be of various degrees of complexity.

The most common type of structural wind-tunnel investigations undertaken are:

- The study of structures of unusual geometry to determine the forces which can be generated;
- Design of cladding systems, thus detailed assessments of surface pressure and cladding loads for buildings; and
- Evaluation of the wind loading and response of dynamically sensitive structures, such as chimneys, towers and masts.

The CSIR boundary-layer wind tunnel has been used in various international projects involving countries such as Germany, Poland and Japan. – ***Hilda van Rooyen***



Meet boundary-level wind-tunnel project leader Dr Adam Goliger

Goliger joined the CSIR in 1985 and obtained his PhD in structural engineering from Stellenbosch University in 2002. He is seen as one of the pioneers of topographical wind environmental studies.

He has served on numerous international committees concentrating on wind phenomena and has been involved in several wind-tunnel studies. Locally, he serves on South African Bureau of Standards committees and is involved with the South African Weather Service. Goliger presents short courses on building design for wind at various universities and postgraduate courses.

Currently, three PhD and two MSc students are involved in projects using the wind tunnel as a research facility for their degree studies under Goliger's co-supervision.

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Accelerated road-testing facility improves road construction and maintenance processes

It is a known fact that high volumes of traffic, especially heavy vehicles, have detrimental effects on roads. This is specifically the case where roads may have been constructed inappropriately for the local situation or where overloading has become just too much for the roads to bear. Accelerated road testing is undertaken at the CSIR heavy vehicle simulator laboratory.

Road deformation and cracks under repetitive loading pressure applied by the HVS wheels (different cracks and deformations spray-painted for clarity).

A ROAD'S LIFESPAN is about 30 years when constructed and maintained correctly. The CSIR has had a trusted stalwart for accelerated road testing for many years – the heavy vehicle simulator (HVS). With the first machine built at the CSIR in the late 1960s, the current one is a Mark VI version, developed with the assistance of the CSIR's commercialisation partner, Dynatest. The Mark VI costs less than its predecessors, is lighter and thus easier to tow on public roads and is less complex with increased wheel speed and test beam length.

It enables road owners to have improved road design and construction practices. Damage caused by traffic over a period of 20 years can be simulated within as short a period as three months. With the relatively high cost of road construction and maintenance, it is important to 'get it right' the first time to ensure cost-effectiveness and efficiency.

"The HVS laboratory has instruments that measure and analyse the performance of road structures and material layers to use when researchers test whether a specific road will have an acceptable lifespan," says Joseph Marima, HVS operator for more than 10 years. The laboratory collects data on typical pavement performance measures, such as deflections, crack growth and permanent deformation.

"It also gathers weather information, such as wind speed and direction, humidity, rain and temperature, as all of these have an impact on the behaviour on paved roads," Marima comments. An HVS is capable of operating in snow or in a desert, with temperatures ranging from −15 °C to +40 °C, as long as an appropriate hydraulic oil type and viscosity is used.

The mobile laboratory furthermore acts as the control room for the HVS, where speed, number of repetitions required, load pressure and test patterns are set. The road's behaviour is also monitored with embedded instrumentation to measure road movements, stresses, strains, moisture and deflections. When researchers analyse the data, they first verify and calibrate it by means of mathematical equations to verify the road monitoring, notes Louw du Plessis, an international expert in accelerated road pavement.

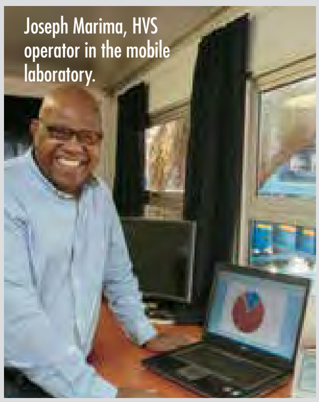
Eleven HVS machines have been exported, with the latest ones ordered by Indonesia, Costa Rica and the US Federal Aviation Administration (FAA). "South Africa's own HVS units – one owned by the CSIR and the other by the Gauteng Provincial Department of Roads and Transport (GPDRT) – have contributed tremendously to our understanding of paved road material behaviour and advanced pavement engineering in South Africa. It has also enabled us to participate with the HVS owners from abroad in the HVS research programme," says Du Plessis.

"CSIR research using the HVS will be aligned with the GPDRT's strategy over the next few years to rehabilitate and upgrade Gauteng's road network cost-effectively – more than 70% of this road network has reached the end of its design lifespan. Specific attention will be given to public transport routes, freight corridors and the upgrading of unpaved roads with a strong focus on labour-intensive construction techniques," explains Du Plessis.

The sale of HVS units has earned South African foreign revenue of more than R220 million since the successful partnering with Dynatest from 1994. HVS machines have been exported to a number of countries, with units active worldwide and technology transfer programmes provided by the CSIR to the owners.

During the past two years alone, machines have also been sold to South Korea and Mexico. Once a year, members of the HVS International Alliance meet to promote and share knowledge relating to HVS technology and to optimise the use of resources through the coordination of HVS-related research. This group includes HVS owners, funders and operators of accelerated pavement testing facilities worldwide.

– Hilda van Rooyen



Joseph Marima, HVS operator in the mobile laboratory.

Meet HVS project leader Louw du Plessis

Du Plessis holds a BSc in mathematics, a BEng (Hons) in civil engineering and a Master's in transportation engineering, the last from the University of California, Berkeley. He is a professional registered engineer and serves on the HVS International Alliance executive committee. He is also co-chair of the Accelerated Pavement Testing International Alliance committee of the international Transport Research Board.

Du Plessis has been closely involved with the HVS in South Africa and the USA for more than 20 years. "What excites me is the opportunity to meet different cultures and communities whenever a new country joins the HVS family. I see myself as being very fortunate to share technical information and research with other nations that appreciate a truly South African invention," he comments.

Biggest HVS for the Federal Aviation Administration, USA

Louw du Plessis with the huge HVS manufactured for the US Federal Aviation Administration.

The biggest and longest HVS ever designed is under construction currently for the US Federal Aviation Administration (FAA). Some of the interesting specifications are compared to the Mark VI version in brackets.

- The overall length of this HVS is 37 m (23 m)
- The metric mass is 115 tons (40 tons)
- The maximum load that can be applied to the testing wheels is 450 kN (210 kN)
- The total length of the controlled test section is 18 m (6 m)

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FITNESS-FOR-PURPOSE TESTS
and certification of construction products

Non-standardised, new construction processes and products cannot simply be 'dumped' on the public or construction industry without having a valid certificate from Agrément South Africa.

AGRÉMENT SOUTH AFRICA is managed by the CSIR, and is an objective and internationally recognised technical evaluation and certification body for products, processes, systems, materials and components that are not fully covered by a South African Bureau of Standards (SABS) code of practice or standard.

The SABS has a representative on the Board of Agrément South Africa. There have been numerous instances where non-standardised and innovative products initially covered by an Agrément South Africa certificate have subsequently moved into the ambit of the SABS.

Examples of such products include acrylic baths; a solar water heating system; hard-drawn copper tubing; and certain plastic pipes.

Some of the roof structures being tested at the Agrément South Africa test site on the CSIR campus in Pretoria.

The French word 'agrément' means 'sanction' or 'permission'.

Rust resistance is tested inside a Q-Fog salt spray chamber.

A Q-Sun Xenon test chamber used for ultraviolet testing of, for example, paint.

"In assessing fitness-for-purpose of innovative, non-standard construction products, processes and the like, a holistic view must be taken," says Joe Odhiambo, CEO of Agrément South Africa. "This includes technical, commercial and social factors, for example, economic viability, cost benefit and consumer acceptability." The agency facilitates the introduction, application and use of satisfactory innovation and technology development in a manner that will add value to the process.

"We have a test site on the CSIR campus where our technical assessors conduct required tests for some products and processes. We have also tested the demonstration low-income house developed by the CSIR, and some of the ultra-thin concrete roads developed by the CSIR."

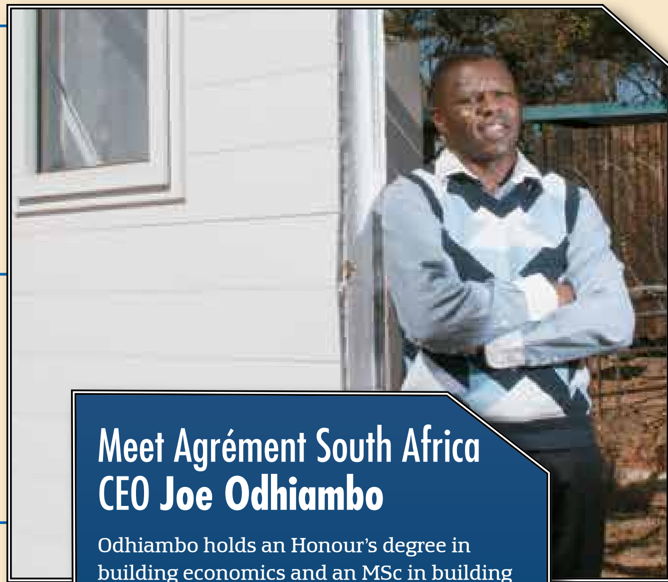
Odhiambo adds, "Agrément South Africa, which has a track record of more than 40 years, is a founder member of the World Federation of Technical Assessment Organisations."

Certificates issued by the agency can be used to demonstrate compliance with regulations, as specified, while the identification symbol of Agrément South Africa must appear on all products covered by a certificate.

Certificate holders can use these for acceptance or approval by designers; regulatory authorities; mortgage lenders and financial institutions; and community-support organisations. "The certificate supports the technical merits of, for example, a product; it lists the uses for which the product has been assessed to be fit; it summarises the levels of performance that may be expected; and lists the precautions that must be taken to assure the right performance levels," Odhiambo explains.

The agency has a directory of all valid certificates on its website, and also distributes it widely to building professionals and local authorities. The certification is recognised in the National Building Regulations.

– Hilda van Rooyen



Meet Agrément South Africa CEO **Joe Odhiambo**

Odhiambo holds an Honour's degree in building economics and an MSc in building science and project manage-ment. He has also obtained an MBA degree from the University of Pretoria.

Before joining Agrément South Africa in 2003, Odhiambo was a senior engineer in project management at Sasol Techno-logies, within the synfuels plants. Before that, Odhiambo was a lecturer at the University of the Witwatersrand in the school of construction economics and management.

He has vast experience in innovative, non-standardised construction products, systems, materials, components and processes which are not yet fully covered by a national standard or code of practice. His expertise supports the construction industry by facilitating the safe introduction, application and utilisation of satisfactory innovation and technology development by providing assurance of fitness-for-purpose of such technologies, which optimise resource utilisation and realise cost savings.

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TECHNOLOGY TO GAUGE CONTACT STRESSES

BETWEEN TYRES AND ROADS FROM HEAVY VEHICLES

The stress-in-motion facility at the CSIR enables measurement and quantification of the effects of the multi-dimensional stress on both tyres and roads.

THE FORCES resulting from the contact between a moving tyre of a heavy vehicle and its suspension system, and the road it travels on, have a direct impact on the performance and lifespan of the tyre and of the design life of the road, especially the surface. Manufacturers of tyres and road-surfacing materials can improve the performance of their products when using design recommendations by the CSIR.

The recommendations follow from research and development (R&D) on the actual contact stresses between tyres and the road surface. The CSIR, in collaboration with industry and academia, has developed unique stress-in-motion (SIM) technology to measure and quantify the effects of the multi-dimensional stress on both tyres and roads.

Dr Morris de Beer, project manager of SIM, explains: "The system simultaneously measures the vertical (Z), transverse (Y) and longitudinal (X) vehicle tyre/road interface contact stresses under a moving wheel load. This SIM technology provides some of the most important inputs into modern mechanistically based road pavement design for optimising the cost of roads over their design life." It can thus measure tyre and road stresses in one, two or three-dimensions.

The SIM instrumentation was developed mainly for the measurement of slow-moving, full-scale pneumatic truck tires. The SIM measurements provide rational descriptions of multi-dimensional tyre and road contact stresses that can be used for tyre and road design, testing and evaluation. Partly industrialised versions are available as SIM Mark V.

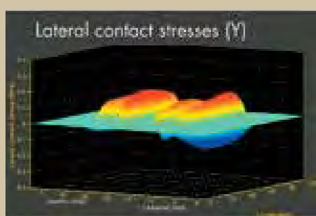
Tyre load sharing

"Our research using SIM technology has proved that significant unequal load sharing exists between the individual tyres and also the axles of heavy vehicles. This leads to uneven deformation of the tyres, as well as the road surface. These results disprove previous assumptions in tyre and road design that equal weight is shared between the various tyres and axle groups for a given heavy vehicle," De Beer notes.

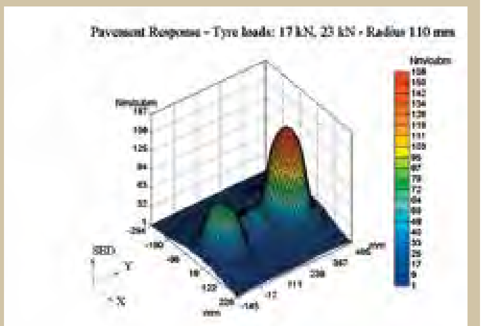
"The vehicle, suspension, tyre and road surface should be viewed as one holistic system. That is why tyre, vehicle and road engineers should have a close working relationship, something that is currently not the norm in our industry, nor internationally," adds De Beer.

In a CSIR real-time study for the South African National Roads Agency Ltd, in total, close to 3 000 heavy vehicles were tested, which represent a unique data set of about 57 000 tyres.

The SIM Mark V system consists of a large number of key components; along with its technical specifications with mechanical, electrical/electronic and software system; data



Pavement response due to unequal tyre loading from a dual tyre-pair.



acquisition and its measuring principle of a rolling tyre that triggers an integral device.

Applications

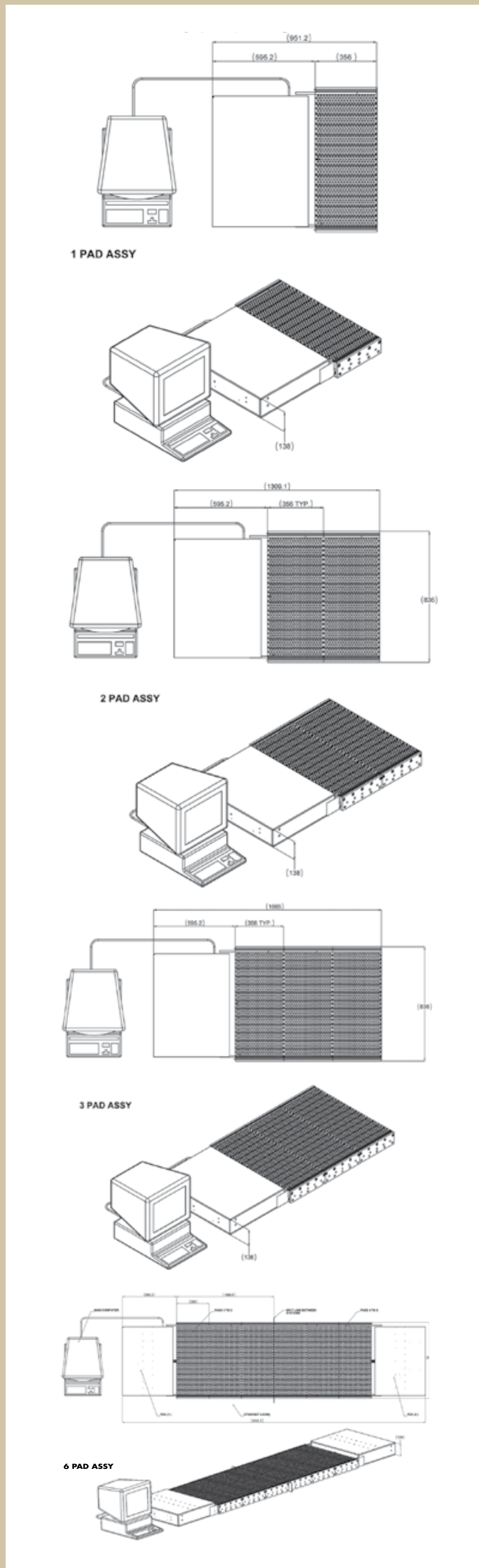
"The CSIR research results can be used to improve the design and performance of tyres, truck and trailer suspension design and the performance of construction materials, and the methodology of road construction. The CSIR has built up expertise on tyres, roads and heavy vehicles and their interactions over many years.

"Our advanced R&D using SIM will in future allow for high-resolution road contact stress measurements, such as from passenger car tyres, requiring a holistic approach with due cognisance of global trends.

"My vision for the SIM technology is that it will someday be fully integrated with all or most of our highways as part of the intelligent road network to inform travellers, especially about heavy vehicle traffic loading demand on our roads – our local and national assets," concludes De Beer.

– Hilda van Rooyen

SIM systems used for tyre mass data.



Meet stress-in-motion technology project manager Dr Morris de Beer

De Beer started at the CSIR in the 1970s in the soil laboratory as a technician. Later, he obtained MEng and PhD degrees in civil engineering, both on lightly cementitious pavement (paved roads) layers.

De Beer has been active in flexible and rigid road pavement materials, new design and analysis methods, accelerated pavement testing and rehabilitation of pavements. During the past 10 years, he focused primarily on tyre-pavement interaction with the locally developed tyre-road pavement SIM system.

De Beer has published more than 95 research reports and contributed to more than 60 international papers, presentations and seven journal articles.

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Life-size Sanitation Technology Demonstration Centre disseminates information

The CSIR and the Water Research Commission jointly established an open-air, full-size sanitation technology demonstration centre at the CSIR.

SANITATION IS ONE OF the basic human needs for health and hygiene and an issue put in the spotlight along with other pressing South African service delivery challenges. Sanitation is becoming a major factor in the contamination of scarce drinking water and a severe backlog exists in supplying people with safe sanitation. Many community leaders and decision-makers from all three tiers of government – national, provincial and local municipalities – may not know which sanitation technologies are available, and which ones are best suited to specific circumstances.

To create awareness about sanitation and sanitation technologies, the CSIR and the Water Research Commission (WRC) jointly established the Sanitation Technology Demonstration Centre at the CSIR, through which many feet have passed since its opening two years ago. It is the only open air, full-size demonstration centre of its kind in Africa and one of a few worldwide. It contains existing sanitation technologies, from the ventilated improved pit (VIP) toilet to high-tech commercial options.

The CSIR does not endorse any of the commercial options, but wants to contribute to showing the wide range available. The technologies on demonstration are all intended for on-site sanitation purposes, not as part of municipal sewage systems.

The visit to the centre starts at the very basic technology, easily built and maintained if built correctly, for example, the VIP toilet, the Blair toilet that had its origins in Zimbabwe, and the Fossa Alterna that is widely used in central Africa. The pedestals (toilet seats) with the buildings around them are shown, as well as, separately, the parts that have to be built below the ground, such as a lined pit, twin pits or a composting pit.

"The most basic technologies are aimed at water-scarce areas where no water exists for flushing away human waste," notes Louiza Duncker, a CSIR principal researcher and the centre manager.

"We then move on to show the above and below-the-ground parts of separation/dehydration technologies where the solids and liquids are separated and could find further use as soil conditioners. The last part of the centre shows on-site waterborne sanitation options, with a variety of innovative commercial designs," Duncker says.

Tours of the centre have been undertaken by local and national government departments,

Louiza Duncker, project leader of the Sanitation Technology Demonstration Centre, with the ventilated improved pit toilet (left) and the Blair toilet.

Quotes from the centre visitors' book

The Global Dry Toilet Association of Finland: "Excellent work, this type of demonstration centre really makes the comparison and further development easier."

Johannesburg Water: "Addition of emerging technologies will be appreciated."

Private consultant: "Great technologies for the communities to choose from."

The CSIR's Louiza Duncker (far left) is showing some of the members of the group a below-the-ground part of a dry sanitation option while on a tour of the various facilities at the Sanitation Technology Demonstration Centre.

municipalities, Parliamentary portfolio committees, the board of the WRC, private consultants, university students, and numerous other interested parties, including from Malawi, Uganda and Zambia and as far afield as Finland.

"If I could have my wish for the future of the centre, I would like to see expansion to include even more existing and innovative technologies, as well as a sanitation knowledge centre where visitors could learn not only about the sanitation technologies, but also about the aspects of user perceptions and acceptance. Furthermore, I would really enjoy doing research on the impact of the centre on decision-making by municipalities and beneficiaries regarding their sanitation choices and for them to participate in an online system so that we could monitor existing sanitation technologies in use and evaluate the new technologies," Duncker concludes. – *Hilda van Rooyen*

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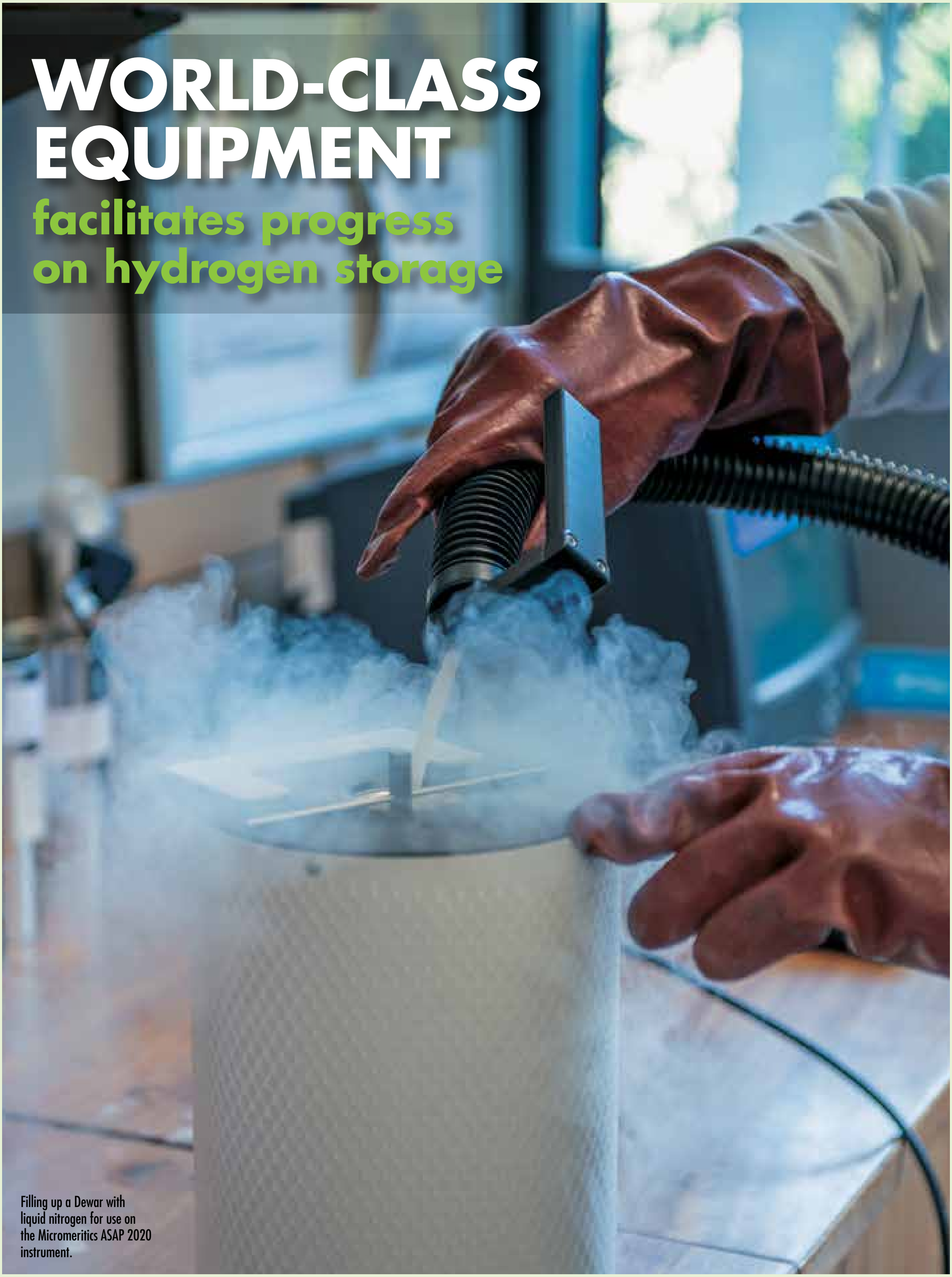
Meet Sanitation Technology Demonstration Centre project leader **Louiza Duncker**

Duncker holds a Master's in anthropology from the University of Pretoria. She has been involved in research in rural and urban areas on many social and community dynamics and behavioural patterns. These include projects on gender issues, housing, alternative sanitation and infrastructure technologies, empowerment of women in development projects, women and cost recovery for municipal services, water conservation, and health and hygiene in developing communities. The results of some of these projects were used in the development of policies and strategies in a number of South African national governmental departments, as well as manuals and guidelines for gender, sanitation and appropriate technologies.

Duncker has managed large research projects in developing and implementing a monitoring and evaluation strategic framework, research methodology and tools for the assessment of rural water supply and sanitation projects in the water, housing, health and education sectors and accelerating sustainable water service delivery to deep rural communities. Currently, she conducts research on effective and efficient methods of managing and allocating sanitation subsidies and finalising a strategy for government on mainstreaming appropriate technologies in the water sector.

WORLD-CLASS EQUIPMENT
facilitates progress on hydrogen storage



Filling up a Dewar with liquid nitrogen for use on the Micromeritics ASAP 2020 instrument.

Noteworthy progress has been made with the synthesis, characterisation and performance testing of candidate hydrogen storage materials. Establishing leading-edge facilities have been key in facilitating this progress.

THE FACILITY BECAME operational in 2012. Over the last 18 months, state-of-the-art equipment was purchased and commissioned to research aspects of hydrogen storage, and newly refurbished laboratories will now be occupied.

The use of hydrogen to deliver energy for cars, portable devices and buildings is seen as one of the key steps to reduce emissions of greenhouse gases. South Africa's national hydrogen strategy, HySA, aims to develop and guide innovation along the value chain of hydrogen and fuel cell technologies nationally.

Fuel cell vehicles, powered by hydrogen, have no emissions at the point of use other than water vapour. However, despite hydrogen being an attractive energy carrier for many reasons, a major stumbling block exists, due to the low volumetric energy density of hydrogen. This makes it very difficult to distribute and store a sufficient quantity of it on board a vehicle, or at a remote site such as a telecommunications tower.

The Department of Science and Technology's HySA Infrastructure Centre of Competence – co-hosted by the CSIR and North-West University – is developing innovative solutions to this challenge. Various hydrogen storage/delivery options are being investigated, including metal-organic frameworks, carbon nanostructures, high pressure composite cylinders and chemical carriers.

Successful synthesis of metal-organic frameworks has been accomplished and benchmarking results of structure, morphology and low pressure hydrogen storage capacity have been obtained.

Scaling up of the synthesis procedure has been demonstrated and optimisation is being carried out to reproducibly generate kilogram quantities of the metal-organic framework. The material will undergo further processing, and its engineering properties will be evaluated in order to build prototype hydrogen storage units. The ultimate aim is to develop practical, affordable and safe hydrogen storage systems for use in selected portable, stationary and fuel cell vehicles applications.

The facilities currently comprise set-ups for materials syntheses – such as metal-organic framework synthesis apparatus and chemical vapour deposition set-up – an MBraun glovebox with an inbuilt oven, Micromeritics AccuPyc II 1340 pycnometer, a BZL-300 centrifugal granulator, a Micromeritics ASAP 2020 HD analyser with a cryostat, a Setaram PCTPro E&E instrument and homebuit Sieverts-type instrument.

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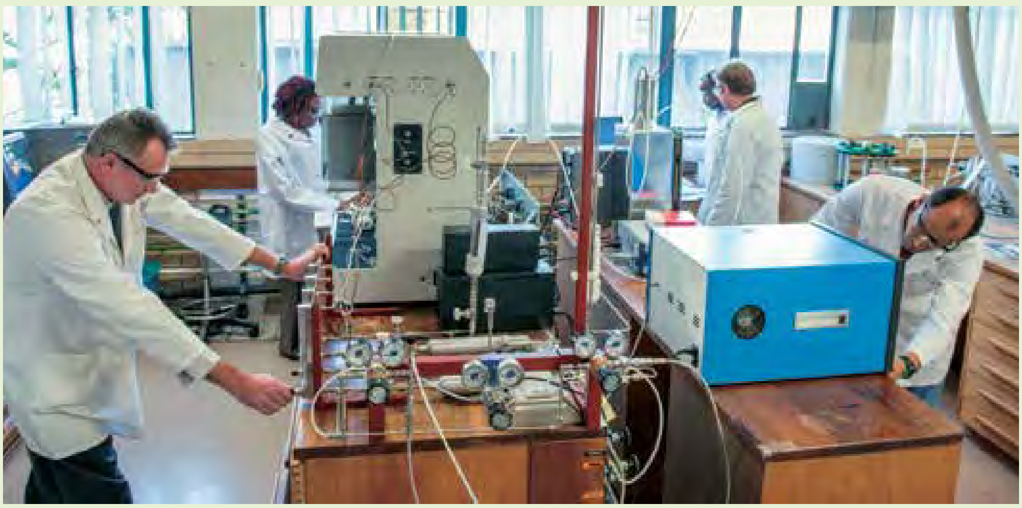
Dr Dave Rogers fills up a Dewar with liquid nitrogen.

Gas supply network to analytical equipment.

Researchers at work in the hydrogen storage laboratory.



Adjusting the gas supply to the Micromeritics ASAP 2020 instrument.

CSIR's anaerobic digester in full swing; PRODUCING BIOGAS

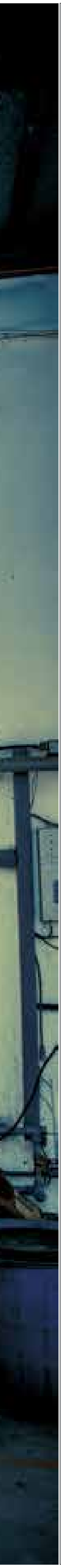
The CSIR-patented pilot-scale anaerobic digester on the CSIR site remains the 'real deal' and the origin of the other digesters.

While not the first anaerobic digester on the market, the CSIR has designed and constructed a unique digester that holds a South African patent. With energy savings top of mind, the digester, built on the CSIR site, produces a good quality and quantity of biogas, using municipal sludge. Human and animal waste, household waste and some industrial waste can be used as 'fuel' to fill the digester's 360 litre capacity.

RENEWABLE ENERGY – solar energy – is used for converting the digester's energy into a renewable fuel like biogas. The digester allows for the safe harvesting of biogas and the process will render stabilised sludge as an organic fertiliser and treated grey water.

The digester is currently being used as the basis for an experiment for a major metro to test the quality and quantity of biogas provided by waste products. Several interventions are being applied to improve the quantity of methane produced from the waste.

Using normal wastewater sludge, the original pilot-scale reactor already produces biogas with a 72% methane content. For the tests for the major metro, six laboratory-scale reactors are set up in triplicate, with one experiment thus repeated three times to ensure the scientific rigour of the experiment.



One reactor in all three set-ups of the six see-through reactor pots is used as a control, with the other reactors using different forms of methane enhancing interventions.

The metro's municipal waste by itself will be used as the control, with different experiments in the other lab-scale reactors. An example of an intervention is the addition of a product with a high carbon content (such as molasses). Some of the other reactors will undergo physical interventions, such as an electrical intervention and adding thermal energy.

The reactors will all have the same heat source and the same stirring mechanisms. Once it is established which intervention produces the highest quantity methane gas on a laboratory scale, it will be up-scaled to be checked in the original pilot-scale reactor before the results are given to the client.

Mobile platform

The digester team – Mauritz Lindeque and Debbie Jooste – has furthermore constructed a reactor platform that is mobile. It is the exact size of the original reactor and could be taken to a specific site for testing energy potential and doing other experiments for a client. Built onto a sturdy trailer, the reactor can be moved easily with a strong towing vehicle.

The research carried out on the original and mobile digesters, along with the small-scale equipment, will allow clients to establish the energy potential from their specific wastes. These data sets will assist in the development of sound business plans with accurate estimates of pay-back times on large waste-to-energy projects.

Anaerobic digestion

The digester project follows on earlier research funded by the CSIR and the South African National Energy Research Institute to investigate the conversion of organic waste, such as human waste, into biogas via the anaerobic digestion process. The first phase of this project consisted of investigations by CSIR researchers to establish whether paper waste could be digested. The success of that research led to the digestion of kitchen waste and other waste products, which resulted in the production of biogas.

As the digester can use solar energy, it allows hardware such as the original pilot digester to be operated off grid. The equipment runs on an automated system and reduces the retention time of the sludge by maintaining the parameters that assist in the biological breakdown of organic waste. The reduced retention time results in smaller infrastructure needed, thus reducing the space for accommodating the digester.

The CSIR digester has been designed and constructed with off-the-shelf hardware that will be readily available in most general dealers and hardware stores. Due to the simplistic design, people with limited skills will be able to maintain the hardware. Operators will not have to manage the required parameters – these are computer-controlled, which will also reduce failures and shut downs due to human error.

– Hilda van Rooyen

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Making Earth observations discoverable and accessible

The web-based South African Earth Observation System of Systems (SAEOSS) portal offers the South African Earth observations community the opportunity to discover, access and eventually analyse Earth observations datasets.

South Africa faces the challenge of making Earth observations discoverable, accessible and usable at local, provincial and national levels of government, as well as to the private sector, academia, science councils, and more recently, to educators and learners.

Nine societal benefit areas are recognised internationally as critical to people and society in addressing environmental challenges and putting in place measures to mitigate natural and human-induced disasters. These are disasters, health, energy, climate, water, weather, ecosystems, agriculture and biodiversity.

SAEOSS facilitates Earth observation data discovery, access and use to address these societal benefit areas. Data include measurements and monitoring of the Earth; its land surface and what lies beneath; its water surfaces and what lies below them; its air and air quality; and its atmospheric conditions. These data are used to measure the health of human, plants and animals within South Africa.

NEOSS
NATIONAL EARTH OBSERVATIONS AND SPACE SECRETARIAT

The National Earth Observations and Space Secretariat (NEOSS) is responsible for SAEOSS. This secretariat is an initiative of the Department of Science and Technology and is hosted by the CSIR.

Locally relevant, globally connected

As an infrastructure, SAEOSS strives to provide free and open access to timely, relevant and appropriate Earth observations data primarily for South Africans. Derived products such as the Advanced Fire Information System and the Risk and Vulnerability Atlas are linked from this portal. Various decision support systems and models will in time become available and will cover a range of online resources for planners responsible for resource allocation.

Within a global context, SAEOSS contributes to the Global Earth Observation System of Systems (GEOSS). GEOSS is a global, flexible network of content providers allowing decision-makers to access an extensive range of information.

SUMMARY OF DATASET STATUS WITHIN SAEOSS/GEOSS CHANNEL	
No impediments: data are publicly available and standardised	912
Data are available but consent must be obtained for public dissemination	15 727
Data are available but are being standardised/processed prior to publication	2 498
Data are publicly available but not standardised	1 340
Data can be released once scientific publication is completed	27
Data volume is too large for existing infrastructure, or systems development is required	1 220
Meta-data references are available, but the preferred dissemination channel is elsewhere	1 450
	23 174

SAEOSS represents an ongoing process to document and provide (increasingly open) access to more and more datasets.

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