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INFRASTRUCTURE
in support of industry

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our future through science

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Cover: The transparent wing of a new turbine that is being tested in the CSIR's seven-metre wind tunnel for its South African inventor, Robert Bray.

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Infrastructure in support of industry

The CSIR is acutely aware of the important role of infrastructure in innovation and new knowledge generation and, importantly, supporting South African industry in the quest to become more competitive. Quite simply, for the CSIR to undertake research and development, it needs modern and appropriate facilities and scientific infrastructure. Therefore, infrastructure renewal and development is one of the organisation's strategic objectives. We project and plan for our future built and scientific infrastructure needs and meticulously measure our investment and progress against these aims.

As part of our focused efforts to support industry development needs, in the past five years, the CSIR has – with support from government – embarked on the development of research and development facilities that provide capability for industrial innovation initiatives such as prototyping, upscaling, pilot manufacturing and testing that allow science to be translated into market-ready products. Government support manifested through the Industry Innovation Partnership (IIP) of the Department of Science and Technology, which is specifically aimed at improving industry competitiveness.

The most recent facility that we have launched as a result of support from the IIP, is a R37.5 million biorefinery industry development facility in Durban. This facility will help the forestry and other biomass industries to turn their waste into value-added products. These and other facilities are featured in this edition of *ScienceScope*.

The CSIR is currently developing a strategy that is very deliberate in its intention to make an even more direct and meaningful contribution to the country's industrial development. The organisation plans to focus on those sectors where it can make the biggest contribution and where South Africa could gain a significant competitive advantage. With the support of our stakeholders, we are confident about our ability to make a significant contribution to help address the country's challenges of poverty, inequality and unemployment. However, our ability to upscale the investment in infrastructure will be a key determinant of the extent of our success.

Our research and development infrastructure is housed on campuses in Cape Town, Durban, Johannesburg, Pretoria and Stellenbosch. The Durban site has experienced renewal in the form of the biorefinery industry development facility, while the Johannesburg campus now houses the Mandela Mining Precinct. Detailed plans to transform the Scientia campus in Pretoria into the desired research campus of the future are contained in the Campus Master Plan. This plan provides a guiding framework for the development of built form, open spaces and movement networks on the campus. We are excited about it and committed to its resourcing and implementation.

By featuring CSIR infrastructure in this edition, we hope to increase awareness among our collaborators in the public sector and South African industries about the research and development facilities and large-scale equipment that could play a role in improving their competitiveness. I urge and invite you to get in touch with the facility managers listed in this publication to find out how we can collaborate.

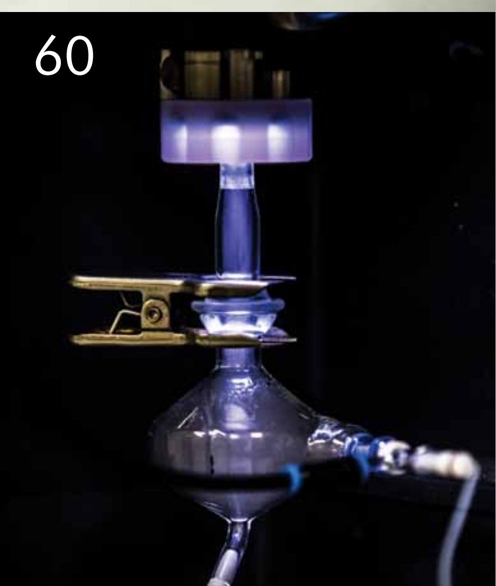
Dr Thulani Dlamini
CSIR Chief Executive Officer

IN THIS ISSUE

Infrastructure in support of industry


56


44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62

Extracting greater value from biomass

Aged processing and manufacturing technologies are resulting in significant biomass resources going to waste in South Africa. A biorefinery industry development facility, funded by the Department of Science and Technology at the CSIR in Durban, works with the forestry, agro-processing and other biomass industries to improve manufacturing technologies and to develop and implement biorefinery technologies to create additional high-value products from their waste.

Sawdust is considered wood waste. The facility is able to extract high-value chemicals from the sawdust, whereafter the remaining fibres are used in the production of high-value materials such as nanocrystaline cellulose, biocomposites and xylitol.

Reviving the old and creating a new industry: Forestry

Globally, the increasing use of digital communication technologies has led to a decrease in the demand for paper, resulting in a decline in the paper industry, with subsequent losses in jobs.

The initial focus of the biorefinery industry development facility (BIDF) is the forestry sector, which is under financial strain globally. Technology innovations have been earmarked to help prevent job losses and enable growth in this sector.

Biorefinery in South Africa's pulp and paper industry is practiced on a very limited scale. Wood, pulp and paper waste ends up in landfill sites or is burnt, stockpiled, or even pumped out to sea, and the potential to extract value from it, is not realised.

Additionally, the country is running out of landfill space. High-value speciality chemicals can be extracted from sawmill and dust shavings, while mill sludge can be converted into nanocrystalline cellulose, biopolymers and biogas.

An increase in the utilisation of the tree from the current low yields and the creation of new product value chains has the potential to deliver industrial development opportunities and create jobs.

Beneficiation of chicken feathers

The South African poultry industry produces more than 239 million kg of chicken feathers annually, most of which goes to waste. By employing biorefinery techniques, the BIDF is developing light-weight composites, super-absorbent materials and cosmetic additives such as keratin, from chicken feather waste. These advances can open up new business opportunities for existing players and new small, medium and micro enterprises.

Offering to industry

The BIDC has been established to help local industry improve its competitiveness by providing access to specialised analytical and pilot-scale facilities and skills that enable the more efficient use of the country's biomass resources, overcome significant organic waste challenges, and develop new products for market. Through technology innovation, the facility aims to revive ailing industries, create new value chains and thus jobs, assist industry from the laboratory scale to industrial scale and make industry more competitive.

The facility

The BIDF is home to some of the country's finest chemists and engineers, conducting research and performing tests in modern laboratories. The facility offers specialised chemical fractionation equipment, and advanced analytical facilities that can develop new and enhance existing technologies to suit South African biomass sources.

Meet the facility manager

Dr Bruce Sithole (below) 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. His key competencies are in biorefinery technologies as well as the valorisation of waste biomass.

@ Prof Bruce Sithole
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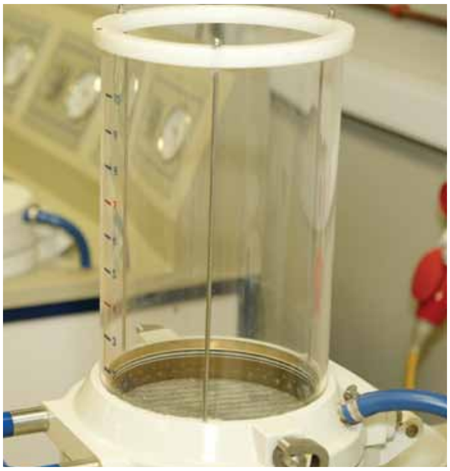

◀ Left (from top): Wood chips are placed in a rotating digestor for conversion into dissolving wood pulp, the result can be seen in the next image. The facility houses analytical equipment such as the size exclusion chromatography and high-performance ion chromatography instruments that are used for the analyses and characterisation of biomass and other high-value materials produced. ▲ Above: The electro spinner is used to process chicken feathers for the extraction of keratin, commonly used in cosmetics. The biorefinery industry development centre at the CSIR, headed by Prof Bruce Sithole (right), is the first facility of its kind in South Africa to process chicken feather waste into high-value material.

Access to infrastructure adds value to the agro-processing sector

The CSIR adds value to the agro-processing sector by providing infrastructure that offers expertise throughout the value chain; from laboratory-scale concept validation to technology prototyping and pilot manufacture. The agro-processing pilot facility is housed at the Biomanufacturing Industry Development Centre.

The agro-processing industry is part of the manufacturing sector. It transforms raw materials derived from the agricultural sector, including forestry and fisheries, into final products. The South African government – in its National Development Plan – has identified this sector as one with high growth potential due to its strong up- and downstream opportunities. According to the Department of Trade and Industry, food-processing is the largest manufacturing sector in employment terms as it contributes significantly to the country's gross domestic product. Upstream, the sector links to primary agriculture across a variety of farming models and products. Downstream, agro-processing outputs are both intermediate products, to which further value is added, and final goods that are marketed through wholesale and retail chains.

The CSIR's agro-processing pilot facility caters for many different types of post-harvesting equipment that is used to process selected plant and food raw materials, followed by drying and particle-size reduction.

Products made at the facility can either be packaged as final products or further extracted in the agro-processing extractions facility, which has the capacity to cater for up to 400 L. After extraction, the natural ingredients can be used in commercial applications in various wellness products that use nutraceutical or cosmeceutical formulations, food and some herbal medicines.

The maximum pilot-scale material batch size for this area is 500 kg per day. It is also used to train small, medium and micro enterprises (SMMEs) and indigenous knowledge holders in agro-processing production methods.

The facility offers advice to SMMEs and clients on product development; process validation; technology packaging and transfer; techno-economic assessment and evaluation; as well as agile product development and support for emerging enterprises and existing industry.

Fast facts

- The agro-processing pilot facility houses many different types of post-harvesting equipment, such as washers, centrifuges, cutters, slicers, pulpers, pressers, driers, blenders, mills, sieves and extruding processing equipment.
- A variety of product formulation options, ranging from tablets and capsules to tea bags and other liquid formulations, are available.
- Packaging options include blister packs, sachets and other standard packaging sourced from suppliers.
- Cosmetics formulation is also undertaken and concept products can be evaluated for stability and dermal safety in collaboration with partners.

About the Biomanufacturing Industry Development Centre

The CSIR is helping local industry to improve its competitiveness by providing access to specialised facilities and skills as part of the Industry Innovation Partnership Fund, supported by the Department of Science and Technology. Participants have access to large-scale prototyping and pre-commercial manufacturing infrastructure, equipment, expertise and access to business and technical networks.

Translating concept technologies into competitive products and new enterprises

The South African manufacturing industry creates jobs and drives economic growth in the country, but faces development challenges in the competitive and knowledge-intensive global market. These challenges include a skills deficit and limited access to sophisticated infrastructure, especially for smaller enterprises.

In response to this challenge, the CSIR established the Biomanufacturing Industry Development Centre, which was officially launched in 2016.

The centre provides laboratory and pilot-scale infrastructure and skills to catalyse the growth of natural products and the biomanufacturing industry.

Meet the facility manager

Dr Dusty Gardiner leads the Bio-manufacturing Industry Development Programme at the CSIR. He completed a PhD in biochemistry at Rhodes University before spending numerous years in industry.

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◀ Left: CSIR technologist Pumeza Melane demonstrates the operation of a rotary evaporator, which is used to remove solvents from reaction mixtures. (Inset) CSIR research technologist Nolan Govender inspects wet root material at the 2 000 L oven drier.

Finding diagnostic and drug targets for HIV and cancer

The structure of a protein determines its function. This simple but crucial fact lies at the heart of the HIV and cancer therapeutic research supported by the CSIR's core proteomics facility.

The CSIR's proteomics facility houses high-end analytical machines and the precision robots that operate them.

"We come in at the discovery stage," says CSIR senior researcher and manager of the facility, Dr Stoyan Stoychev.

Stoychev says the drug discovery pipeline is long and expensive, often beginning with the question, "What makes certain people susceptible to a disease but others not?"

To find the answer, researchers might first compare the genetic profiles of healthy and sick individuals. Because genes code for proteins, the next step is to see how such genetic differences might affect the composition and structure of a protein, which ultimately affects how well the protein functions to, for example, protect against disease.

"For instance, it is well understood that there are differences in cancer biology based on race, like susceptibility or how toxic certain drugs are. As a result, some treatments may be less effective or unsafe for people of African descent," says Stoychev. "Clinicians provide us with samples from cancer patients so that we can identify anomalies in their proteins – or markers – that could either be used to better diagnose the cancers, or could be tested as highly-specific drug targets."

In an air-conditioned room, a PhD student may spend much of their three-year study identifying such markers using a high-resolution machine called a liquid chromatography mass spectrometer, or LC-MS. This machine is able to separate incredibly complex samples into its individual components, and to measure various aspects of those individual components. In other words, the LC-MS is a powerful tool that allows researchers to study the structure of individual proteins.

"We also use robots to automate workflows so that we can perform high-throughput analysis in a reproducible manner. This is done in collaboration with a local biotechnology company, ReSyn Biosciences, a CSIR spin-off. The robots interact with the company's pioneering magnetic microspheres within samples to enable automated workflows," says Stoychev.

This set-up, coupled with the powerful LC-MS, allows researchers to study not only protein content and abundance, but also protein structural dynamics: "A genetic mutation or some other environmental factor might change how a protein folds – its structural dynamics – which ultimately would change how the protein functions."

◀ Left: Dr Sindisiwe Buthelezi explores the conformational dynamics of proteins using hydrogen/deuterium exchange mass spectrometry.

> "The expertise and equipment at the facility are useful at various stages of the health pipeline."

Stoychev says this enables the core facility to support the clinical and pharmaceutical sectors. For instance, one study looks at patient protein profiles to find out why some people infected with HIV do not develop Aids. In this case, the lab receives minute amounts of cells extracted from HIV patients, and researchers are currently working on efficiently processing the small amounts of proteins within the samples.

"While our cancer protein research is still in the early discovery phase, our HIV work is already on the verge of the verification stage," says Stoychev.

He describes another HIV study that aims to find out why certain anti-retroviral therapies result in acute kidney failure in 10% of patients. "We've generated protein profiles from HIV patients with kidney failure and compared those to patients who have HIV, but without kidney disease, with the aim of identifying markers of this condition," he says. Although such markers are first identified using an LC-MS-based approach, the scientific principle may eventually be carried through to develop diagnostic tests and other clinical assays.

"By the time clinicians see the side effects of the drug on these patients it is too late; that is a huge health and economic issue," he explains. "Diagnostic tests would help clinicians identify patients at risk of acute kidney failure before administering tenofovir."

Stoychev says the expertise and equipment at the facility are useful at various stages of this health pipeline, so it also supports bio-entrepreneurs working on taking diagnostics and drugs to market.

In addition, since PhD students are often trained on the equipment during their research, individuals skilled in sample preparation, operation and data analysis continuously enter the academic, clinical, pharmaceutical and food sectors.

Stoychev hopes the facility will eventually also support South Africa's broader biotechnology industry as protein science becomes more commonplace.

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Stimulating and growing South Africa's photonics innovation landscape

Photonics is an essential component of everyday technologies; it is found in lighting sources, such as lasers and light-emitting diodes, telecommunications, information processing and medical devices. Just like the invention of the transistor and integrated circuits revolutionised the 20th century through electronics, the invention of the laser and optical fibre is at the centre of the current technology revolution. To bolster the CSIR's ability to help create a vibrant photonics industry in South Africa, an advanced photonics prototyping facility has been taken into use.

Photonics-based technologies not only have the potential to address societal challenges such as energy generation, healthcare provision and security, but are also a driving force in accelerating economic growth. Identified market applications for photonics include defence and security; sensing and imaging; quantum optics and metrology; illumination and displays; energy, photovoltaic systems and materials; as well as information processing and communications.

South Africa currently has a miniscule market share of the lucrative photonics industry. This is evident from statistics on global revenues in photonics product production, as well as photonics-based companies per country. South Africa is a net importer of advanced photonics manufacturing technologies, with an estimated trade deficit of R6.3 billion in 2015. The major contributing factors to this local innovation challenge are: the fragmented research, development and innovation value chain, low levels of local technology transfer and minimal collaboration between stakeholders in industry, higher education and research. Some of the key barriers in capturing the value associated with the global photonics industry include a dependency on imported products, lacking export competitiveness and insufficient local manufacturing of photonics value-chain components.

To address these shortcomings in the South African photonics innovation landscape, activities at the photonics prototyping facility focus on advancing the technology readiness levels of local intellectual property towards completion. The principal function of the facility is to facilitate the development of prototypes, ultimately resulting in products that satisfy a market need associated with photonics-based technologies and devices. Through partnerships with industry and the formation of small, medium and micro enterprises (SMMEs), the uptake of prototypes developed in the photonics prototyping facility is set to lead to novel photonics products, thus improving industry competiveness.

“The aim of the prototyping facility is to translate photonics-based ideas into bankable business plans through the process of prototype development and market evaluation. One can view it as a photonics technology accelerator with emphasis on early pre-seed phase commercialisation,” says Technical Lead of the facility, Dr Angela Dudley.

Early wins

CSIR scientists, engineers, technicians and interns with expertise in photonics are sharing their expertise through two current seed projects that make use of the facility. Eighteen applications have been received to date.
The first project relies on optical coherence tomography for the 3D extraction of fingerprints. The novelty of this fingerprint acquisition device is that it is capable of extracting both the internal (sub-dermal) and external (surface) fingerprint, thus removing the possibility of spoofing the detection system. It also offers a non-contact approach. The technology has applications in banks, mortuaries and forensic service facilities. The prototype under development is expected to perform well in its selected application environment.

The second project involves the development of a laser range-finder for inclusion in a fully automated bow-sight unit for the archery industry. The automation function of the bow-sight unit offers a time-reduction and ease of adjustment for the archer.

The facility is available to all photonics role players who have proven the concept of their innovative idea, but do not have the resources to take their inventions to the next phase. Such innovators may be from an established industry, existing SMMEs and start-ups or universities and research councils.

To expand the photonics innovation pipeline, the facility is promoting the benefits of access to its expertise and specialised equipment at conferences, exhibits and other events.

@ Dr Angela Dudley
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Objectives of the photonics prototype facility

- Providing the necessary infrastructure and skills to fast-track the prototyping process of photonics-based technologies
- Assessing the market need with intermediate- and end-users for related potential products aligned to these prototypes
- Facilitating meaningful engagement between stakeholders, in order to conduct financial valuations and to identify the necessary input for the development of bankable business plans
- Developing a clear understanding of the required value chain components for potential products, and to respond efficiently in order for stakeholders to access the requisite resources
- Fast-tracking the quality and quantity in through-put associated with the photonics value-chain.

◀ Left: One of three 1 000 clean rooms of the photonics prototyping facility with state-of- the-art electronic and optical equipment.

Growing our knowledge about the properties and behaviour of materials at nano-scale

The National Centre for Nanostructured Materials was launched in 2007 as part of the implementation of government's National Nanotechnology Strategy. In the past decade, the centre has undertaken innovative research on nanostructured materials and established an extensive research network with key local and international research organisations. The centre is well equipped with cutting-edge scaling up, polymer processing, characterisation and testing facilities, funded by the Department of Science and Technology.

One of the key facilities that has enabled the CSIR over the past 10 years to conduct world-class research and development in the field of nanotechnology, is the characterisation facility. It is a multi-user, public instrumentation facility for materials research ranging from nanotechnology to biology and medicine. It houses advanced equipment and capabilities for comprehensive analysis of a wide range of functional materials as well as polymer testing.

The main purpose of the characterisation facility is to provide support to the CSIR's multidisciplinary researchers while also offering characterisation services using the facility and its sophisticated equipment, to academia, industries and national laboratories. Researchers at the facility provide one-on-one equipment training to frequent users, staff and students that seek characterisation skills and knowledge in support of their research and educational goals.

Characterising the structure of materials at atomic and molecular levels

The characterisation facility comprises a suite of rooms specifically designed to facilitate world-class measurement techniques. Its characterisation and testing capabilities include microscopy via electron and ion beams made possible by scanning electron, transmission electron as well as focused ion beam scanning electron microscopes. These imaging techniques are used to characterise the structure of materials at atomic and molecular levels, so that scientists can understand how changes in structure translates into improved properties. The focussed ion beam scanning electron microscope in particular enables accurate milling (etching) of nanometre-thin layers of material at a time.

The facility team assists with sample preparation using in-house sample coating systems that include sputter and carbon coaters.

Equipped to investigate the truly tiny

The facility boasts world-class equipment to obtain ultra-thin sections, essential for the transmission of electron microscopy from hard materials (focused ion beam milling) or soft polymers (cryo-ultramicrotomy).

Within the broad category of optical techniques, the facility offers a wide range of spectroscopic capabilities including ultra-violet visible near infra-red radiation, Raman, Fourier transform infrared, photoluminescence as well as dynamic light scattering and ellipsometry.

◀ Left: A transmission electron microscope, such as the one operated by microscopist Rhandzu Rikhotso, is used to view thin specimens through which electrons can pass, thus generating a projection image.

Various thermal characterisation tools with different capabilities, tailored to clients' specific needs, are also available in the facility, including tools for thermogravimetric analysis, differential scanning calorimetry, dynamic mechanical analyses, and measurement of rheological properties of a material.

X-ray techniques such as X-ray diffraction and small angle X-ray scattering are used for atomic structure analysis. In addition to X-ray techniques, surface analysis services are also offered via atomic force microscope and chemi- and physisorption.

Other characterisation and testing capabilities in the facility include elemental and chemical imaging, including depth profiling; ion chromatography coupled with inductively coupled plasma mass spectrometry; electron spin resonance; as well as numerous polymer testing tools.

Fast facts

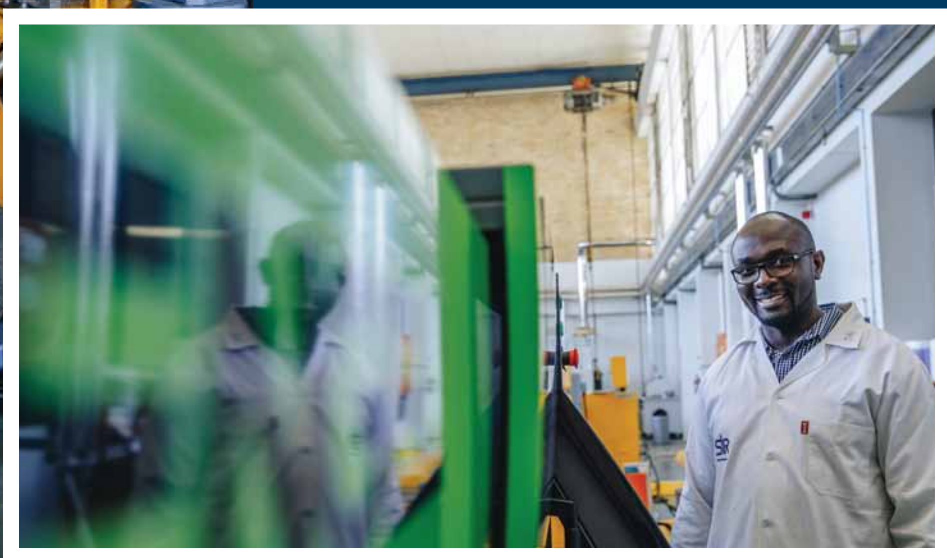
- The facility undertakes collaborative research projects with industrial players such as SAPPI, the global provider of sustainable woodfibre products and solutions. It also works closely with the University of South Africa and Nelson Mandela University.
- The facility engages with potential partners, such as the Sefako Makgatho Health Sciences University, to improve service delivery.
- As one of the best equipped scientific facilities in South Africa, the facility is frequently visited by visiting scientists, community groups, learners, students and teachers.

Meet the facility manager

Prof. Gugu Mhlongo (below) is a CSIR senior researcher and manager of the facility. She is an affiliated associate professor at the University of the Free State.

Bridging the lab-to-industry gap for nanomaterial-based products

The Nanomaterials Industrial Development Facility provides South African industry, research institutions and universities with access to flexible facilities that can scale up nano-based innovations to industrial and commercial levels, ultimately enhancing industry competitiveness and creating jobs.



The Nanomaterials Industrial Development Facility (NIDF) offers integrated access to three key research and development components, namely scale-up facilities, well-equipped characterisation labs and multidisciplinary researchers. It was specifically designed to enable the transition from laboratory to industrial scale. The facility offers support to small and large companies alike by assisting with scaling up of operations – including further process/technology optimisation – to produce sufficient quantities of material to enable companies to test and develop the market. In addition, CSIR researchers and engineers assist with the development of material applications as well as their characterisation and testing. The facility does not provide certification like that of the South African Bureau of Standards.

CSIR researchers rely on nanotechnology to manufacture, manipulate and use materials at the nanoscale (less than 100 nm) to achieve higher performance. Experimental results have proved that nanocomposites lead to new and improved properties such as improved stiffness, strength, heat resistance, decreased moisture absorption, flammability and permeability when compared to their micro and macro composite counterparts.

The (NIDF) consists of two specialised facilities. The **chemical processing plant** is equipped with high-temperature pressure chemical reactors, process tanks, a filter press, dryers and a bag house. In the **polymer formulation and processing facility**, the specialised equipment include a 40 L/D co-rotating twin screw extruder, 500 kN injection moulding machine, a five-layer cast sheet and blown film co-extrusion line, as well as other smaller processing equipment.

Current projects

Some of the ongoing research and development projects include the production of nano zinc oxide and nanoclays such as organophilic bentonite and hydrotalcite, and their application in polymers and cosmetics. Current partners include both established companies, such as Sappi, and small, medium and micro enterprises (SMMEs), such as Greenfields Innovation (Pty) Ltd. The NIDF is assisting Sappi with the development of nanocellulose-based products in cosmetics, polymers and food applications. Greenfields is being assisted with the scale up of layered double hydroxides nanoclays for market development. The CSIR team is working with Protechnik on the pilot-scale production of polymer nanocomposites for military applications.

Recently, CSIR polymer nanocomposite experts used the facility to produce one tonne of polymer material that was developed in-house. The material is a highly nucleated and dimensionally stable polypropylene material developed with the aim of reducing imports. It is being tested in the market for applications in roto-moulding, raffia bags and injection moulding.

◀ Left: CSIR polymer technologist Sifiso Skosana feeds a five-layer co-extrusion film blower with polymer pellets to make a high-barrier packaging film in the polymer formulation and processing facility.
(Inset) Dr Vincent Ojijo, manager of the polymer formulation and processing facility. ▶ Right: The chemical processing facility.

Accessing NIDF skills and equipment

The NIDF is overseen by an advisory panel and managed by a steering committee. The committee evaluates proposals on merit and availability of resources. While it is generally expected that users of the facility will contribute towards the costs, the NIDF assists SMMEs to access available funding sources. The NIDF considers proposals during its quarterly meetings.

Meet the facility managers

Dr Vincent Ojijo
Ojijo has a DTech degree in polymer technology and a Master's degree in chemical engineering. He manages the polymer formulation and processing facility.
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Dr Mike Masukume
Masukume has a DTech degree in chemical engineering and a Master's degree in project management. He manages the chemical and processing facility.
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Dr Manfred Scriba
Scriba has a PhD in experimental physics from the University of Cape Town. He is the programme manager of the Nanomaterials Industrial Development Programme.
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Upscaling the production of titanium metal powder

The titanium pilot plant was constructed to produce commercially pure grade titanium powder for downstream titanium alloy powder production and for the manufacture of titanium components for industry. The establishment of the Department of Science and Technology-funded plant was an important goal of the strategy of the SA Titanium Centre of Competence (TiCoC), which aims to beneficiate South African minerals.

South Africa has some of the largest reserves of titanium-bearing minerals, such as ilmenite, primarily comprising iron oxide and titanium dioxide. Iron is typically separated from the ilmenite ore through a pig-iron smelting process to make a slag containing a high percentage of titanium dioxide. South Africa is one of the largest producers of titanium-bearing slag globally. Whilst this slag can be used in the manufacture of pigment used in paint, paper, plastics as well as titanium metal, local beneficiation of the titanium-rich slag is virtually non-existent, hence the economic need to beneficiate and add value to the country's base-minerals.

The titanium pilot plant design targets the continuous production of titanium metal powder. The process is based on a CSIR-developed and patented high-temperature, alkali-metal reduction process, capable of producing titanium powder. The facility is specialised in that process equipment has been customised for the first-of-a-kind engineering process.

Some of the customised equipment that was designed and built in-house are the titanium tetrachloride feed system, molten alkali-metal feed system and reactor vessels employed by the process. There are also facilities for the recrystallisation, leaching and electrolysis needed for downstream recovery of the alkali-metal salts, these being important for ensuring the cost-effectiveness of the process. The current plant intends to fulfil key technology development requirements needed for a fully commercialised plant.

The plant is currently being optimised to improve process efficiency and plant reliability. The optimised plant layout is scheduled to be operational by the third-quarter of 2018. Collaboration with industrial partners is viewed as a key factor towards ultimate commercialisation of the CSIR titanium process. It is expected that collaboration with potential commercial partners will manifest as the technology readiness level of the process is enhanced.

Fast fact

Two CSIR process-related patents were granted in numerous territories. A third patent is pending for a new design, aimed at improving titanium powder quality.

Technical capabilities

Operating temperature:	650 – 700 °C
Operating pressure:	Atmospheric
Atmosphere:	Inert (Argon gas)
Production rate:	2 kg/hour

Meet the facility manager

Dr Shahed Fazluddin (below) is the CSIR research group leader for primary processes. He has a PhD in materials science and more than 20 years of experience.

@ Dr Shahed Fazluddin
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◀ Left: Some of the customised equipment that was designed and built in-house includes the titanium tetrachloride feed system, the molten alkali-metal feed system and reactor vessels in which the complex metal powder formation process occurs via a series of reaction stages. (Inset) Titanium power produced at the CSIR. ▲ Above: The CSIR titanium pilot plant.

Outperforming conventional manufacturing with laser-based manufacturing

The CSIR has built a sound track record in developing and customising laser-based technologies to improve the efficiency and competitiveness of numerous industry players, large state-owned companies such as Eskom and Denel, as well as supporting government initiatives such as the Aerospace Industry Support Initiative. The ability to provide this specialised support is rooted in a first-rate laser-based manufacturing facility with highly specialised equipment.

A diverse range of manufacturers is benefitting from using laser-based technology solutions to improve the competitiveness of their product lines. With a two-pronged approach in laser-based technology solutions for industry, the CSIR has steadily extended its reach across sectors such as defence, power generation, mining, tooling, marine and transport.

The CSIR offers a number of laser technology solutions and services such as laser welding, laser hardening, laser cladding, 3D laser cutting and a mobile laser system for on-site processing applications.

"These diverse laser technology solutions have the ability to reduce costs, enhance performance, provide opportunities for innovative design and extend the lifespan of equipment in the industrial market," says Hardus Greyling, CSIR National Laser Centre commercialisation manager.

A mobile laser system for laser-based refurbishment

Over the years, the CSIR has amplified its laser-based manufacturing competences, specifically in laser-based refurbishment, a laser weld overlay or cladding technology. Specialised equipment in the laser-based manufacturing facility is the mobile laser system used in the repairs of turbine blades, bearing journals, gears and drive shafts.

"This capability is invaluable for the refurbishment of large and high-value components as it translates to faster response times and significant cost saving for industry," adds Greyling. He says laser-based refurbishment also offers the opportunity to repair components that were previously scrapped due to industry not having access to this new, low-heat inputs repair process.

Eskom experienced the benefits of using the CSIR's mobile-refurbishment system first-hand. In 2011, some of the water tanks at the Eskom power station had developed stress-corrosion cracking.

"Replacing the tanks was not an option as it would have been costly, time-consuming and would have interrupted daily operations. A conventional welding technique was not a viable solution either due to the thickness of the walls. We developed a laser-based cladding procedure for the in-situ sealing of water vessels," says Hansie Pretorius, production manager for the CSIR's laser engineering group.

The CSIR team managed to extend the service life of the Eskom power station tanks with more than five years.

Additionally, using the same technology, the CSIR plays an instrumental role in Eskom's turbine blade refurbishment programme. The programme focuses on the development of new repair techniques based on laser-based refurbishment and the development of repair procedures for turbines blades and turbine journals.

A laser engineering net-shaping 3d platform to build parts

The CSIR's laser engineering net-shaping 3D platform makes it possible to create fully-functional parts made from titanium, nickel, metal matrix composites and zirconium. The platform also has the capability to improve existing parts through the deposition of new surface layers and build up of damaged areas. It enables hybrid manufacturing processes for complex geometries. The additive manufacturing platform has proven to be particularly beneficial to the automotive and aerospace industries.

To help ensure that South African manufacturers remain competitive through advanced, innovative laser-based manufacturing, the CSIR also has valuable expertise in and access to equipment for 3D laser and pipe cutting, laser hardening and welding.

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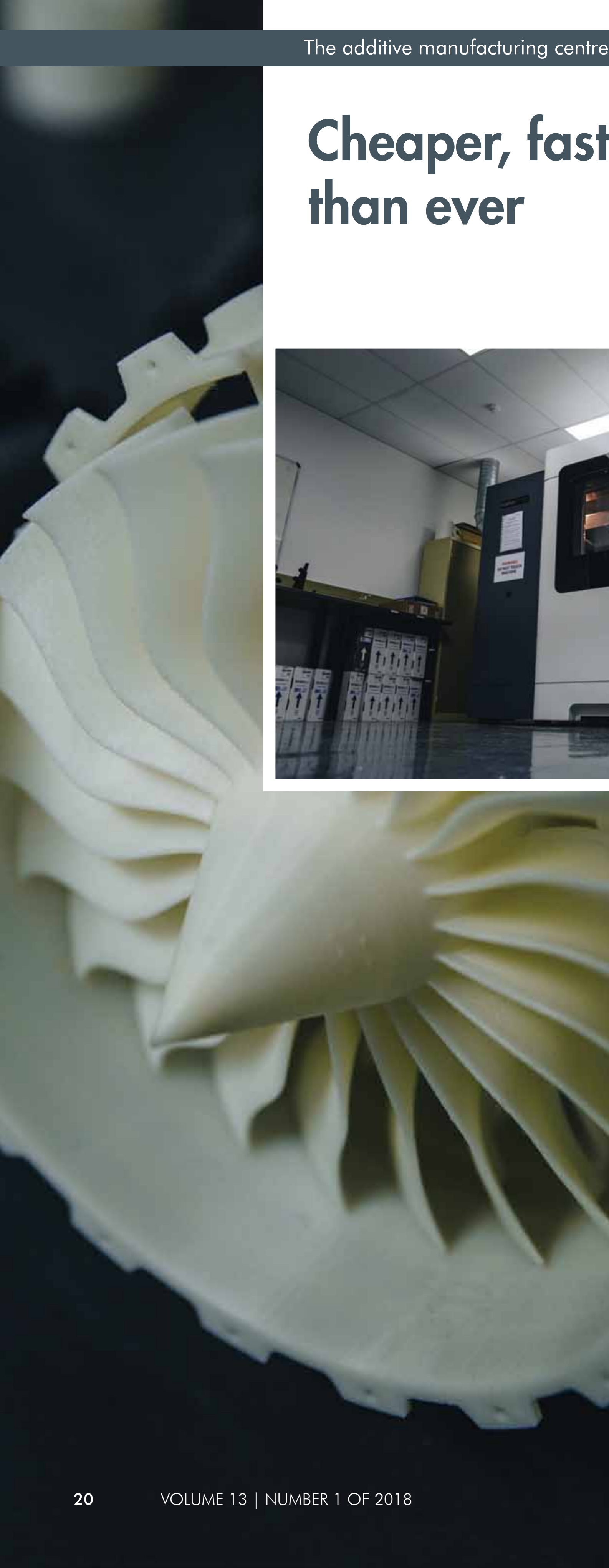
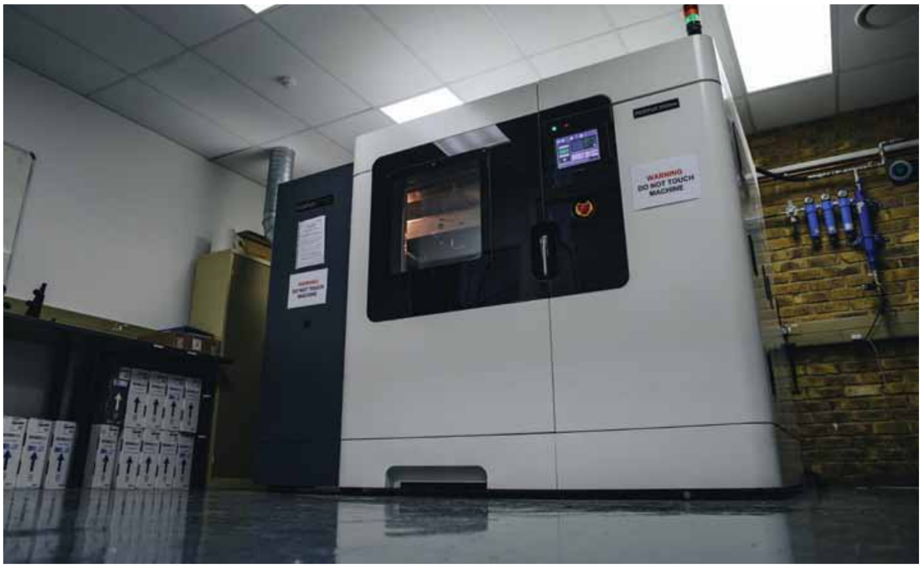
◀ Left: The CSIR's 3D laser-cutting capability offers a cost-effective solution for manufacturing of formed components. ▲ Above: The CSIR has built a strong competence in laser-based refurbishment based on laser cladding technology. This technology is best suited for the repair of large and high-value components, such as generator rotors.

Cheaper, faster and more effective than ever





Additive manufacturing allows for the designing and printing of parts that cannot be manufactured using traditional methods. The CSIR's advanced manufacturing centre offers industry an avenue to explore and maximise the benefits of additive manufacturing. It offers clients custom-designed solutions to unique problems.

The additive manufacturing centre offers specialised services that support and develop South African small, medium and micro enterprises and young engineers, technicians and designers starting their careers. These specialised services in additive manufacturing include advanced research, training, design and manufacturing.

Industry sectors supported by additive manufacturing include aerospace, automotive, dental, medical as well as consumer products.

“Many breakthroughs have been achieved in the medical industry with this technology, for example, unique prosthetic limbs and jaw replacements have been manufactured. Businesses are also increasingly opting to install small printers to assist engineers in the design and prototyping process to speed up delivery times and print from functional printers for functional use,” says CSIR technologist Sudesh Budram.

Additive manufacturing enhances the advanced mechanical engineering capability, especially when complex mechanical engineering solutions are required. The designer can use direct manufacturing to produce scaled models of actual structures, terrains or areas, as well as prototypes of parts. Actual items can also be produced in cases where a small volume is required and the material is acceptable. 3D printing can be used as an alternative to high-production investment casting, injection moulds, sand moulds, as well as soft tooling.

Equipment and infrastructure

The facility features a Fortus 900mc printer from Stratasys that can print structures and parts using durable thermoplastics that are used in traditional injection moulded plastic parts. In addition, the centre offers 3D scanning that can be used for scan-to-print, verification and validation and reverse engineering. “Our scanning capabilities complements the additive manufacturing side of business and supports product lifecycle management,” says Budram.

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 improves turn-around time. It reduces material waste associated with conventional forms of manufacture, lowers energy use, and allows for the design of unusual and more organic shapes and forms. Printed parts are durable enough to be used as advanced conceptual models, functional prototypes, manufacturing tools and productions parts.

“The capability can be used by anyone who needs a design turned into an actual object as a prototype, scale model or test version. The CSIR team can, for example, create novel shapes for artistic use, ceramic design and models for architects or sculptors,” says Budram.

“Additive manufacturing is a rapidly growing technology world-wide. It has helped designers to design parts which previously could not be built due to limitations. Additive manufacturing is creating new possibilities in education, training, research and development as well as new business development.

Fast facts

- The Fortus 900mc is the most precise and powerful fused deposition modelling system available.
- It uses engineering-grade thermoplastics to build robust production parts, jigs, fixtures, factory tooling and functional prototypes.
- The Fortus 900mc has a range of 13 different materials.

Meet the facility manager

Sudesh Budram (below) is a senior mechanical design draughtsman and additive manufacturing expert at the CSIR. He studied electrical and mechanical engineering and is a qualified electro-weapons mechanic and qualified design draughtsman. Budram has experience in designing, draughting, designing for additive manufacturing and 3D scanning (scanning, post-processing and data for computer-aided design).

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◀ Left: A scaled turbine printed as a demonstration model to showcase the possibilities of additive manufacturing. (Inset): The CSIR’s additive manufacturing centre features a Fortus 900mc printer from Stratasys that can print structures and parts using durable thermoplastics that are used in traditional injection-moulded plastic parts.

Turbines, fan blades and frames

The CSIR investment casting facility is the only foundry in South Africa with a production-level vacuum casting capability. The foundry was founded on the ability to produce single crystal nickel-based super alloy turbine blades for gas turbine engines and has more recently established the niche capability to manufacture titanium alloys using investment casting.

The CSIR investment casting facility was established in 1984 to develop a nickel-based alloy vacuum casting capability for turbine blades in support of the South African Airforce. It grew with the addition of an industrial multi-chamber vacuum casting furnace, state-of-the-art vacuum heat treatment and other specialised processes. During the late 1980s and early 1990s, the CSIR investment casting foundry established the capability to produce nickel-based super alloy turbine blades from standard equiaxed grained blades to complex single crystal hollow blades that were bench tested on commercial military jet engines. This technology was transferred to the Denel foundry, where it was implemented on an industrial scale.

During the 1990s and early 2000s, the CSIR worked closely with several industrial partners to localise the manufacturing of products. The most significant intervention was the casting and qualification of the 9mm pistol for the South African Police in collaboration with Hausler Scientific. The first batch of 500 pistols was produced and subsequently the foundry assisted with limited production for Hausler scientific.

The vacuum casting capability was used from 2006 to establish the process chain for titanium investment casting in support of the downstream beneficiation of titanium metal.

Although the investment casting foundry has been established based on the advanced vacuum casting capability, it has the capability to provide support to the wider metals forming industry. It continues to provide support to a variety of industries, from product development to small production runs, to fill a gap that local investment casting foundries cannot service.

Facility manager

Pierre Rossouw (below) is a principal metallurgical technologist with over 30 years' experience in investment casting. He is one of the founding technicians involved in establishing the advanced investment casting capability at the CSIR.

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Technology enablers

- Vacuum melting and casting
- Ceramic mould system (the reactivity of titanium is severe on most refractories)
- Chemical milling
- Hot isostatic pressing (for closing micro porosity prevalent in all titanium castings because of the high solidification rate of titanium)
- Low superheat which restricts feeding of the casting.

Key infrastructure and capabilities

- Modified and upgraded vacuum casting furnace
- Development of a vacuum heat treatment cycle: Significant cast and heat-treated mechanical properties were reliably achieved against the ASTM 8E standard for titanium castings
- Chemical milling on semi-industrial scale.

Examples of products produced for local industry

- Air gun
- Speaker frame
- Micro-gas turbine rotor and stator for Model Mechanics
- Steel fan blades for commercial air movement systems for Mechal.

◀ Left: A three-chamber vacuum casting furnace. (Inset) A commercial micro turbine stator and rotor casting produced at the CSIR. ▲ Above: The CSIR's Pierre Rossouw with a newly installed de-waxing boiler for wax removal from moulds. (right) A titanium-casted aileron produced in the facility. An aileron is a hinged flight control surface used on fixed-wing aircraft.

Fabricating complex metal parts using metal injection moulding

The CSIR has developed a customised metal injection moulding technology platform that allows for the cost-effective mass production of complex near-net shaped components from fine titanium powder. This technology platform makes it possible to overcome the geometrical and productivity limitations of traditional production techniques.

The metal injection moulding facility offers a combination of tooling design and manufacturing capabilities in addition to the mass production of a wide range of small metal parts. Outputs have high dimensional accuracy and replication fidelity on a nearly unlimited choice of material, through powder metallurgy. While the existing metals industry are already benefiting from the facility, a future downstream titanium industry is also set to benefit significantly.

The metal injection moulding facility was set up in preparation for the creation of a new downstream titanium industry in South Africa in line with the national mineral beneficial strategy. Funding for the facility was primarily through the Department of Science and Technology's Advanced Metals Initiative and the Titanium Centre of Competence flagship programmes.

The facility is the only one in South Africa to successfully develop in-house methods of fabricating products and custom feedstocks using metal injection moulding. It houses expertise and equipment as part of a one-stop resource for conceptualising, designing and manufacturing complex precision components. The facility is in the process of acquiring a new industrial-scale metal injection moulding furnace to scale-up from small batch to a mass production scale.

Fast facts

- The size of the global market for metal injection moulding is valued at over R20 billion globally. The rapid rise in demand from end-use industries such as automotive and aerospace, consumer goods, medical devices and firearm components are expected to grow this industry at 12% per annum from 2018 to 2025.
- Metal injection moulding is a metalworking technology in which finely-powdered metal is mixed with binder material to create a feedstock that is shaped via injection moulding and solidified by way of high-temperature high-vacuum sintering. The metal injection moulding process allows for the high-volume production of complex shaped components for a variety of alloys.

Meet the facility manager

Dr Ronald Machaka (below) is a senior researcher who leads metal injection moulding research at the CSIR. He is experienced in powder metallurgy, metal injection moulding and processing of biomedical materials, and supporting SMMEs in these fields.

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◀ Left: Candidate researcher Mandy Seerane operating the 40 ton ARBURG Allrounder 270U 400-70 injection moulding machine. (Inset) Anodised titanium bicycle brake calipers produced at the CSIR through metal injection moulding. ▲ Above: Fish hooks for deep-sea fishing manufactured using the metal injection moulding technology developed at the CSIR (top). The CSIR metal injection moulding facility.

Fractures, fatigue and physical strength: Testing the mechanical properties of materials

The mechanical properties of structural components are vitally important as they indicate how materials perform when subjected to stress. The mechanical testing laboratory was established to support mechanical properties testing for the research and development of light metals. The range of materials tested has since been expanded.

The mechanical testing laboratory mainly determines the mechanical properties of metallic materials, ceramic materials and powder compacts. Depending on the scope of the work required, other materials, like polymers, glass and composites, are also tested.

The mechanical testing laboratory has over the years extended its services in assisting South African industries and universities to perform material and component evaluation. In addition, international clients have also used the laboratory for material qualification.

The mechanical testing facility is capable of performing the following tests:

- Tensile testing at room temperature
- Tensile testing up to 650 °C
- Fatigue testing (low-cycle and high-cycle fatigue)
- Fatigue crack growth rates
- Fracture toughness
- Compression testing
- Bend testing (Three-point bend test)
- Diametral compression test
- Limited component testing (such as fish hooks and hand cuffs)
- Strain gauging of specimens and components during testing.

The facility started as a support unit for research and development in light metals, but has over the years extended it services to support local and international clients. South African universities now also regularly use the facilities for specialised tests. The facility takes part in international proficiency tests to qualify materials and approve test methods.

The laboratory was used for the qualification of materials used in the construction of the Square Kilometre Array (SKA) and advanced materials testing for Eskom power stations. In addition, the laboratory tested materials for the construction of the Nelson Mandela Bridge and the 2010 soccer world cup stadia. Some of the tests are ISO/IEC 17025:2005 accredited, making the facility even more attractive to many industrial clients, especially for material qualification.

The mechanical testing laboratory collaborates with other test facilities such as inspection, testing, verification and certification company, SGS, Scaw metals, Security Metal Products (SecMet), the South African Bureau of Standards, Cermalab and Transnet.

Meet the facility manager

Stephen Masete (below) has a Master's degree in physical metallurgy (applied science) from the University of Pretoria. He has extensive experience in material properties testing and materials behaviour testing.

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◀ Left: Fatigue testing of a master link in progress. (Inset) Facility manager Stephen Masete sets up a crack tip opening displacement gauge prior to fracture toughness testing. ▲ Above: The CSIR mechanical testing laboratory.

Rapidly producing prototypes for the landward defence environment

At the CSIR landward mechanical workshop, researchers develop and package technology demonstrators and artefacts that are derived from core CSIR research, such that commercialisation is more easily achieved. The prototypes are mostly developed as a result of research conducted in the landward defence environment and evolve from proof of concept, to experimentation, to actual development of the product.

The CSIR's landward mechanical workshop facility was established in 2000, when Denel's Mechem research and development division was integrated into the CSIR.

The workshop has a sound track record in the development of prototypes; an example is the Buffalo mine-resistant ambush protected vehicle, which resulted in a licencing venture between the CSIR and General Dynamics Land Systems, an American manufacturer of military vehicles.

More recently, the workshop produced a test-bed tactical vehicle called the Landward Technology Demonstrator, which is currently being used to demonstrate research outputs, ranging from increased situational awareness to unmanned, autonomous vehicle applications. "The vehicle was not designed to replace any vehicle in the South African National Defence Force fleet; nor is it a product for sale, but rather it is a mobile laboratory to evaluate and demonstrate relevant technologies," says Leon Broodryk, manager of the facility.

The mechanical workshop played a key role in determining which vehicles would be best suited for a range of new military vehicles that will be used to patrol South Africa's borders. Factory standard vehicles were modified – for specific purposes and without compromising the factory warranty from the original equipment manufacturer – to include different mobility packages. "Alterations included features such as the installation of roll-over safety frames, water tanks, diesel tanks with dispensing systems, and extra storage. Standard, commercially available vehicles were turned into field ambulances, mobile command and control stations, logistical modules and troop carriers," says Broodryk.

◀ Left: The landwards mechanical workshop is used to develop technology demonstrators and prototypes resulting from research in the landward environment. ▲ Above: The South African National Defence Force launched a range of new military vehicles that will be used to patrol South Africa's borders. The CSIR played a key role in determining which vehicles would be best suited for the job as well as how these can be modified to achieve maximum impact, while also reducing the environmental impact caused by larger military type vehicles.

"We specialise in rapid prototyping systems to be evaluated in the field by the customer. We do not focus on production, but rather on rapid prototype manufacturing," says Broodryk.

Capabilities

The workshop is equiped for advanced prototype manufacturing and basic metal cutting. It has fabrication machinery, a welding bay with various commercially available welding processes, an abrasive water-jet cutter, as well as sophisticated vertical and horizontal computer numerical controlled (CNC) machining centres.

Manufacturing equipment

- Saws, guillotines and waterjet cutters for material rough cutting
- Welding equipment for arc welding, metal inert gas welding and tungsten inert gas welding
- CNC operations/machining equipment
- 100 ton vertical hydraulic press
- 20 ton overhead crane
- Ring and plate rollers

Material used in prototype manufacturing

- Armour steels
- Structural steels
- Aluminium alloys
- Non-metallic materials such as polymers and wood

Meet the facility manager

Leon Broodryk (below) is the landwards mechanical workshop facility manager. He is a mechanical engineering technician with 30 years manufacturing and prototyping experience.

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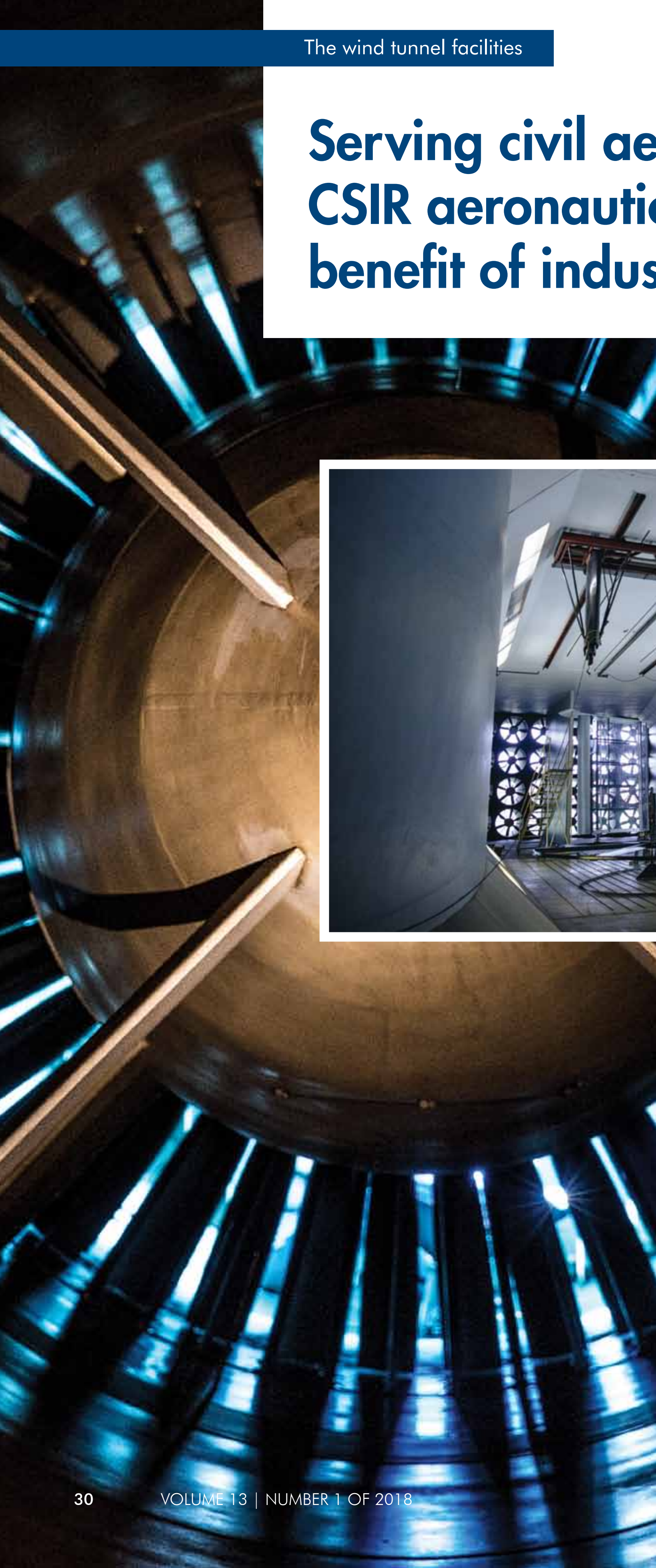
Serving civil aerospace: Extending CSIR aeronautics capabilities for the benefit of industry



The CSIR's suite of wind tunnels provides a specialised research and experimental environment that supports the aerodynamic design efforts of the South African aeronautics industry. Testing in a wind tunnel simulates the flow environment encountered by an aircraft during flight.

The design of flight vehicles requires significant investment and a huge burden on the developer to get things right the first time. Wind tunnels provide an essential tool to study and determine performance characteristics early in the design phase. The CSIR wind tunnel facilities have made a significant contribution over many years to evaluate the aerodynamic behaviour of airframes at significantly reduced cost and timescales in comparison to flight tests.

The CSIR is extending it aeronautics capabilities to increasingly benefit industry.

"In the past, the wind tunnel facilities were primarily used for research, design, development, as well as test and evaluation of defence systems for strategic defence requirements of the country. With increasing global activity and opportunities in civil aerospace, the CSIR has to adapt and direct its aeronautical capability to serve this sector," says Dr Kavendra Naidoo, manager of the CSIR aeronautic systems research group.

Numerous systems have been tested in these facilities. These range from gyrocopters, helicopters, unmanned aerial systems and military trainer aircraft to supersonic missiles. Data collected by these facilities are used to understand complex aerodynamic behaviour. The data can also be used to develop modelling and simulation environments for doctrine development and training.

"Ultimately, we are empowering a world-class, competitive aerospace industry through the advancement of aerodynamics research, design, development, test and evaluation through our facilities and our people."

How it works

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 aerodynamic performance of the airframe, at various flow speeds and attitudes, is measured.

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 according 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 (a mix of flow regimes both higher and lower than the speed of sound).

Analysing the performance of a novel wind turbine that is set to change the renewable energy scenario in cities

The CSIR seven-metre wind tunnel - the ideal test ground for the BRAYFOIL

Generating energy from wind in cities has been limited to micro turbines, mostly with horizontal axis units of less than 3 m in diameter, due to the high noise, vibration and visual pollution aspects of the current technology.

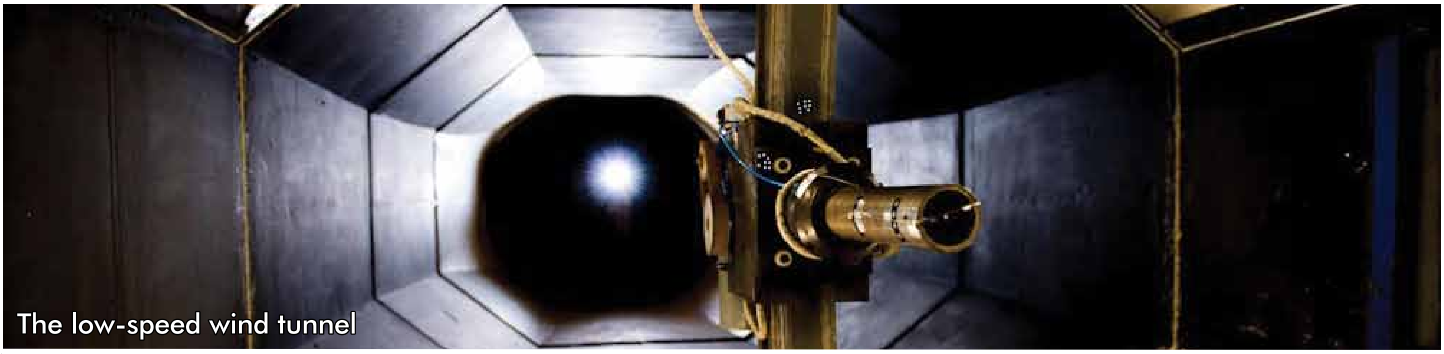
A patented South African invention of an auto-setting morphing wing is about to change this. The new wing – known as a BRAYFOIL, after its inventor, South African architect, Robert Bray – has the ability to reverse lift from one surface to another, instantaneously, and sets an appropriate angle of attack with the shape change automatically relying on a reflex section form in the morphing transition.

The first full-size wing was tested in the seven-metre wind tunnel at the CSIR in Pretoria in February 2018. The tests provide valuable information on which profile shape is best-suited for this embedded power wind application. The wing also has application in hydro power, aircraft, wingsails and active automotive force wings. Once the desired profile shape has been determined on the test wing, the first prototype turbine will be assembled in the free air at the rear of the wind tunnel, where the vertical axis BRAYFOIL turbine will be assessed for its power output potential.

First simulations by the CSIR team and engineers Worley Parsons SA, are showing positive results. The six wings on the first trial are 3 m high and 2.35 m wide. This is likely to produce some 40 kW of mechanical power in a 10 m/s wind, according to simulations. The wings have transparent surfaces for low visual impact -being made of polycarbonate- and the speed of rotation is about half the wind speed. Therefore the action will be slow, virtually silent and non-invasive.

This form of renewable power may change the landscape of renewable energy forever, as predictions exceed the performance and cost of solar photovoltaic by many times. This may reduce the reliance on grid power in cities world-wide, particularly in coastal zones where wind resource is greatest.

◀ Left: (inset) The CSIR's seven-metre wind tunnel is being used to test a patented South African invention of an auto-setting morphing wing.


The low-speed wind tunnel


The calibration wind tunnel


The seven-metre wind tunnel


The medium-speed wind tunnel


The high-speed wind tunnel

The low-speed wind tunnel is a continuous, single-return wind tunnel with a closed test section. Strut-mounted models are suspended from an overhead six-component virtual centre balance. An auxiliary pitch sector allows sting-supported models to be mounted on a variety of internal strain gauge balances.

Tests undertaken

- Scaled aircraft loads and static stability
- Pressure distribution
- Air data probe calibration
- Flutter
- Flow visualisation (oil flow, tufts, liquid crystals)
- Helicopter intake characterisation

Specifications

- Speed range: 5 m/s to 120 m/s
- Test section: 2.1 m x 1.5 m rectangular with corner fillets
- Atmospheric tunnel
- Reynolds number: 6 x 10^6/m

The calibration wind tunnel is a continuous, open-circuit wind tunnel with a closed test section. Appropriate gauzes and plates downstream from the test section are configured for the tunnel to operate in four speed ranges.

Instrument types tested in the wind tunnel

- Mechanical vane anemometers
- Pitot tubes
- Hotwire anemometers
- Velocity transmitters

Specifications

- Speed range: 0.04 m/s to 35 m/s
- Test section: 0.61 m x 0.61 m octagonal close test section

The calibration wind tunnel is SANAS 17025:2005 accredited, which means all calibrated instruments are traceable to the national standards.

The seven-metre wind tunnel is a continuous, open-circuit tunnel powered by 28 axial flow fans of 30 kW each. Uniform flow distribution across the speed range of the tunnel is achieved by running the fans in one of 13 different symmetrical patterns.

Test capabilities

- Force measurement (internal balance, platform balance)
- Pressure measurement (Scanivalve system)
- Flow visualisation (tufts, oil flow, smoke)
- Flow-field measurement (multi-hole probes)
- Unmanned aerial vehicle test rigs
- Propeller test rigs

Specifications

- Speed: 2 m/s to 32 m/s in discreet steps
- Test section: 7.5 m x 6.5 m x 13 m
- Continuous, open circuit

The medium-speed wind tunnel is one of the best-equipped and most sophisticated tunnels of its kind in the southern hemisphere. A 20 MW electric motor drives a three-stage axial compressor with variable guide vanes and stator blade angles for accurate Mach number control. This variable density transonic tunnel operates continuously for optimum productivity and accuracy. The square test section is slotted, with a porosity of 5% for the best possible flow at transonic Mach numbers.

Tests undertaken

- Captive trajectory (store separation) tests
- Force and pressure measurement
- Flow visualisation

Specifications:

- Mach no. range: M 0.2 to M 1.4
- Test section: 1.5 m x 1.5 m x 4.5 m
- Reynolds number: 31 x 10^6/m (M 0.8 – 1.4)
- Closed circuit, variable pressure, continuous
- Stagnation pressure: 20 to 250 kPa

The high-speed wind tunnel is a trisonic, blow-down wind tunnel equipped with a colour Schlieren system for flow visualisation. Subsonic and supersonic Mach numbers are tested using the standard wind tunnel setup, while tests in the transonic regime employ an extra cart, which is fitted with a plenum evacuation system and porous walls.

Tests undertaken

- Force measurement
- Pressure measurement
- Inlet flow measurement
- Flow visualisation

Specifications

- Mach no. range: M 0.6 to M 4.0
- Test section: 0.45 m x 0.45 m
- Run time: 10 to 40 seconds
- Reynolds number: 6 to 50 x 10^6/m
- Stagnation pressure range: 70 to 950 kPa
- Trisonic intermittent blow down wind tunnel

Equipped for innovative hydrogen storage technologies

The CSIR is developing porous materials-based hydrogen storage technologies and high-pressure composite cylinders for lightweight applications. The research and development is being undertaken in the hydrogen storage facility at the CSIR. The facility is part of the Department of Science and Technology's National Hydrogen and Fuel Cells Technologies Flagship project, branded Hydrogen South Africa (HySA). HySA Infrastructure, one of three centres of competence, consists of two facilities, one at North-West University and the other at the CSIR.

HySA Infrastructure intends to contribute significantly to the renewable production, storage and distribution of hydrogen both locally and internationally.

At the CSIR, researchers are aiming to develop cost-effective hydrogen storage systems for use in selected portable power and fuel cell vehicle applications. The porous materials being developed may also find application in other areas such as methane storage, carbon dioxide capture and storage, water treatment and catalysis, amongst others. The composite cylinders being developed can also be used for lightweight storage of other gases such as compressed natural gas for vehicle applications.

HySA Infrastructure at the CSIR comprises a team of researchers with chemistry, materials science and chemical engineering skills who are developing innovative solutions to the hydrogen storage problem.

CSIR principal researcher and research leader, Dr Henrietta Langmi says, "The facility is critical in supporting the team's research towards a common goal of developing viable hydrogen storage solutions through a multifaceted approach."

Hydrogen storage is a key enabling technology for fuel cells and thus the facility supports beneficiation of platinum, a critical component of hydrogen fuel cells. The hydrogen storage technologies that are being developed will find application where weight is an issue, such as in the transport industry.

What is the challenge?

The demand for energy around the world has increased as a result of a growing human population and an increasing standard of living. The rapid depletion of fossil fuel reserves and the environmental impact of burning fossil fuels have led to the search for alternative sources of energy. Hydrogen is an attractive alternative energy source, but its storage is a challenge.

Fast facts

- The hydrogen storage facility is spread over 400 m^2 and comprises state-of-the-art equipment for materials synthesis, characterisation, powder shaping, testing and small-scale composite cylinder production.
- The facility is equipped with an autoclave, split tube furnace, microwave/ultraviolet/ultrasonic synthesis reactor, glovebox, pycnometer, sorption analyser, granulator, 3D printer and desktop filament winder, amongst others.
- A team of 10 researchers and students are working on the development of cost-effective metal-organic framework materials and their composites, as well as high pressure composite cylinders with improved mechanical properties and weight considerations.

Meet the facility manager

Dr Henrietta Langmi (below) is a CSIR principal researcher. She holds a PhD in metallurgy and materials from the University of Birmingham in the United Kingdom.

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◀ Left: Doctorate student Lerato Molefe handling air-sensitive chemicals in an inert atmosphere glovebox. ▲ Above (left): Xoliswa Dyosiba, who is working towards a DEng in chemical engineering, setting up a synthesis reaction in an autoclave.

Developing materials-based technologies for energy storage systems

CSIR researchers are developing new materials-based technologies which make up the components of battery cells. They hope to improve the electrochemical properties that are used in energy storage systems. A battery materials development and research centre at the CSIR in Pretoria is at the centre of this work.

Most people understand that batteries store electricity and therefore are an important aspect of energy storage. They understand this because they use batteries in portable electronic devices such as cameras and cellphones. However, the scale at which energy has to be stored has taken on a whole new meaning with the introduction of large amounts of renewable energies in the form of solar photovoltaic and wind energy, into a power system. Renewable energy produced in excess of the grid's immediate needs, can be stored for later use. Efficient energy storage is also necessary for energy supply when demand outstrips renewable energy supply. In short, while renewable energy generation has become a competitive technology, for it to be truly impactful, innovation is needed to revolutionise batteries.

South Africa is particularly well-positioned for research into energy storage, as energy and advanced materials derived from the country's abundant manganese and other mineral resources can be tailored for energy use in mobile and motor industries. The CSIR is experimenting and producing various materials that will be used, amongst other applications, to best store renewable energy. Researchers are identifying and testing materials that can be made into products which will be supplied to firms to be used in cell assembly, battery modules, pack integration as well as end-user vehicle manufacturing.

A materials development and research facility tests the technologies with a specific focus on battery cathode materials, titanium-based anode materials and scaling up cathode material production. Researchers tailor the country's varied battery mineral resources used in battery cell applications for mobile and stationary energy storage. The minerals are used to develop the materials composition, structure and product design, which needs to be integrated and dynamic. The market requirements for energy storage inform the product performance and lifetime testing standards.

Patents submitted since 2012

- Doped spinel material that improves the cycling performance of lithium batteries
- A hybrid microwave synthesis procedure used for spinel cathode materials
- Production of a layered lithium-manganese-nickel-cobalt cathode material for lithium-ion batteries
- Creation of dual-active cathode material for lithium-ion batteries
- One-pot synthesis of lithium-metal-oxide cathode materials for lithium ion batteries
- Production of hierarchical one-dimensional ammonium metal phosphate nanorods for pseudocapacitors.

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◀ Left: CSIR senior researcher Dr Mark Rohwer cuts cathodes for pouch cell assembly and testing. (Inset) The battery research team. (Back, from left) Dr Mesfin Kebede, Dr Hongze Luo, Dr Lukas le Roux, Dr Bonani Seteni and Dr Mark Rohwer. (Front, from left) Dr Kumar Raju, Nomasonto Rapulenyane, Dr Haitao Zheng, Dr Nithyadharseni Palaniyandy, Lusanda Fikeni, Funeka Nkosi, Sinethemba Manquthu and Dr Mmalewane Modibedi. ▲ Above: Funeka Nkosi, who is working towards her PhD, demonstrates the assembly of pouch cells. Above (right): Post-doctoral researcher Dr Bonani Seteni and intern Lusando Fikeni assemble cells in a glove box.

Studying and piloting cleaner energy alternatives for industry

The CSIR uses its combustion and gasification pilot plant for various research and development projects, but also to supply a specialised service to clients who wish to assess their fuels, often for the self-generation of energy in the form of hot gas, steam or electricity. In addition to fuel assessment, samples of ash and gaseous emissions can be generated to assist in environmental impact assessments.

Originally established as a clean coal pilot plant, the facility catered for the calcination of minerals and fluidised bed combustion of coal. Its current function and capabilities include fluidised bed combustion, gasification and pyrolysis of coal and opportunity fuels.

Fluidised bed combustion and gasification are attractive technologies due to the following features:

- Low-grade and high-moisture fuels, such as discard and run-of-mine coal, can be utilised
- Swings in fuel quality can be accommodated
- Co-firing several fuels can be achieved
- There are no moving parts in the hot zone (reduced maintenance)
- Sulphur dioxide can be removed in situ (dry) by injection of sorbent.

Fast facts

- The pilot-scale fluidised bed facility can combust approximately 5 kg/h of coal, and gasify approximately 25 kg/h of coal. A smaller 50 mm-diameter externally heated fluidised bed can combust 200g/h and gasify 1 kg/h.
- Upgrades to the plant have enabled the CSIR to operate it continuously, and to operate it in gasification mode.

Cleaner coal

South Africa has an estimated coal reserve of 67 billion tonnes. However, there is pressure on reducing the use of coal, as it is known to produce carbon dioxide, a greenhouse gas. Additionally, the combustion of coal can produce oxides of sulphur and nitrogen. These are acid and greenhouse gases respectively. The plant therefore focuses on clean coal technology. Co-combustion of coal with biomass can reduce the carbon footprint, as biomass is carbon dioxide-neutral. A process known as chemical looping combustion can capture the carbon dioxide with a lower energy penalty than is the case for post-combustion removal using amine scrubbers. A cold circulating fluidised bed model was built to investigate the hydrodynamics in the fuel reactor of a chemical looping combustion system.

Sulphur oxides can be significantly reduced through in situ capture, using limestone or dolomite as a sorbent. This is a dry process, and avoids the use of water associated with flue gas desulphurisation systems. The relatively low combustion temperatures in fluidised beds also result in lower emissions of nitrogen oxides.

Industry and research use

The facility has been utilised by a number of South African industries to test their fuels, often as part of a feasibility study for independent power production.

Several industrial fluidised bed combustion plants have been designed on results obtained using the CSIR pilot plant. These include a hot gas generator, a coal and biomass co-fired boiler, a deodoriser and a waste-to-energy plant.

CSIR researchers have also collaborated with several universities.

In addition to fuel utilisation, the facility also has fuel preparation facilities.

Reducing the ash content of coal through a dry process

In general, run-of-mine coal needs to be beneficiated to produce a fuel suitable for the domestic and export markets. In order to reduce the ash content of a coal, and thereby also increase its calorific value, it is 'washed'. This entails using a water-based suspension of magnetite. The product quality can be tailored by varying the concentration of the magnetite, and thereby the density of the medium. However, this is a water-intensive process. The CSIR is investigating a dry process using a fluidised bed of materials such as sand, ilmenite and magnetite. The results of this research were well-received at the recent Industrial Fluidisation South Africa conference.

Briquetting

Fine materials are often discarded, or under-valued, because of the difficulty in handling them. Briquetting is a way to agglomerate the fine material into an easily-handled lump. A briquetting press is available in the pilot plant for clients to investigate the effect of different pressures and binders on briquette strength. Materials that have been successfully briquetted include coal, some ores, metals and biomass.

Facility managers

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Briquetting plant
Ashton Swartbooi, aswartbooi@csir.co.za

◀ Left: CSIR researcher Lerato Molefe taking readings at the master control cabinet. The pilot plant management team: (from left) Ashton Swartbooi, Dr Brian North and Dr André Engelbrecht. (Inset) CSIR researcher, Lerato Molefe, using the large-particle thermogravimetric analyser to measure mass loss as a function of temperature and time.

CSIR expands its solar research infrastructure to benefit South African energy research

The CSIR has completed the first phase of its new solar energy research and testing infrastructure. The photovoltaic testing facility, with its outdoor test facility and its indoor reliability lab will, on its completion, be the most advanced in the country.

The photovoltaic testing facility will support the domestic solar photovoltaic (PV) industry with aspects of industrial development, research, quality assurance, knowledge generation and human capital development.

The facility was conceived to support the burgeoning PV manufacturing sector in South Africa as a pre-qualification test facility so that the design, build and test of new products could happen in parallel, shortening the time to market for South African components.

The facility will also support the renewable energy industry, specifically on PV module quality, reliability, design, system modelling, operations, maintenance and monitoring. The facility will furthermore contribute to knowledge transfer and human capital development through research, publication of results and by training emerging researchers.

The outdoor testing facility

The construction of the outdoor testing facility was completed in December 2017.

"As the photovoltaic industry in South Africa grows, there is a need for high-quality research on solar system design and optimisation in realistic outdoor environmental conditions. This testing facility makes it possible to study the performance of PV modules that have been manufactured locally and internationally under real-world South African climatic conditions," says Dr Kittesa Roro, CSIR senior researcher and PV expert.

"It enables laboratory-quality diagnostic measurements on PV modules and small systems of 5 kilowatt of alternating current in a fielded environment. The facility is key in improving model accuracy, optimising on-site battery storage, and analysing the performance of different PV technologies. Contributing to the facility's uniqueness, is the ability to collect high-resolution measurements of the direct current measurements on module performance at desired time intervals and contribute AC energy (the power accumulated over time) to the building where the facility is situated in between measurements," he says.

A weather monitoring system forms an integral part of the outdoor testing facility. The outputs of the photovoltaic modules and systems will be measured continuously and their performance is correlated to the meteorological readings. Data derived from the weather system are

◀ Left and above: The CSIR outdoor testing system is used for research on solar system design and optimisation in realistic outdoor environmental conditions. (Inset) The performance of the system is correlated to meteorological readings derived from a weather monitoring system.

integrated into the Southern African Universities Radiometric Network for anyone to download.

The indoor reliability lab

The indoor reliability lab is designed for pre-qualification testing of PV modules and for conducting quality and reliability test protocols that are emerging throughout the global PV market.

"The indoor lab tests accelerate the learning that can otherwise take years to occur naturally in the field. The data from these accelerated stress tests will help ensure that the right products are developed and installed in South Africa," says Roro.

The environmental and mechanical stress testing in the lab forms the foundation for the pre-qualification of new concepts, certification of new products, and reliability testing of existing technology.

Accelerated stress tests shorten the learning cycle for development of new products. "We subject the modules to harsh conditions which mimic the actual life-time of the modules which otherwise would have taken up to 25 years. On the other end of the spectrum, we inform system owners about the lifetime of PV modules already installed. The test facility will also support a standards body such as the South African Bureau of Standards in the development of local standards," Roro says.

"By investing in this infrastructure, we are contributing to the knowledge base on energy in the South African context – students can undertake directed research using the infrastructure to collect data; knowledge is transferred in the form of published journal articles; and the South African PV industry benefits from the quality assurance testing.

"To add to this, we are now able to contribute to international teams of researchers and standards developers, and put the global manufacturers of PV modules on alert that we are checking to ensure that only quality products are installed in South Africa," says Lawrence Pratt, CSIR principal engineer.

Meet the facility manager

Lawrence Pratt is a CSIR principal engineer with a Master's in applied statistics and over 10 years of experience in the solar industry. His background includes research and development of emitter wrap through solar cells and modules, high-volume manufacturing of computer chips, performance and reliability testing of solar cells and modules, and international certification of solar modules.

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Technical capabilities

- Module-level, grid-tied outdoor performance monitoring, including current-voltage curves
- String-level outdoor performance monitoring of AC and DC power, current and voltage
- Electroluminescence and infrared imaging
- Field IV curves for modules and strings
- Real-time estimates of soiling losses
- Model validation for AC and DC energy generation
- Power quality analysis for small systems, including frequency, harmonics, reactive and apparent power
- Correlation studies to meteorological data: irradiance, ambient weather, and spectral measurements
- Statistical analysis of test data, including machine learning for fault detection models
- Soiling studies on various module types, mounting configurations and anti-soiling solutions.

▲ Above: Earlier the CSIR had installed a dual-axis photovoltaic plant as part of a project to use the campus as a real-world research platform for a cost-efficient future energy system based on renewable energy.

A new software-defined networking laboratory to strengthen the competitiveness of SA networking products

The CSIR has taken into use a new laboratory that will strengthen the competitiveness of South African networking products. The laboratory supports research and development in software defined networking and network function virtualisation as well as accreditation of emerging software defined networking standard equipment.

Software defined networking (SDN) separates the network's control and forwarding plane functions and provides a centralised view of the distributed network for more efficient arrangement and automation of network services. Network function virtualisation (NFV) focuses on enhancing the network services themselves. It decouples the network functions from proprietary hardware appliances, so they can run in software to accelerate service innovation and provisioning, particularly within service provider environments.

Together, these standards increase programmability of the telecommunication network and increase flexibility in sharing of networks. The new laboratory offers professional services and issues certification for conformance of network switches to OpenFlow, a protocol that allows for centralised management and control of network switches. It is the first OpenFlow conformance testing facility in the southern hemisphere and Africa and will strengthen the global competitiveness of South African networking products.

The lab recently hosted a hackathon with a group of students from local universities, where they learnt about SDN, NFV and life-cycle service orchestration. They also completed a practical project during which they were required to develop an adapter to be used on an SDN controller. The adapter would then be used to monitor and control bridges that are created over a SDN. The hackathon forms part of the CSIR's efforts to assist the country to transform its existing telecoms infrastructure and operations/business systems to take advantage of new technologies and standards.

CSIR engineers have been trained on the SANAS ISO 17025 Management Systems and completed internal auditing courses which are required for certification of the laboratory.

The laboratory is funded by the Department of Science and Technology.

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▶ Right: CSIR engineer Mpho Nkosi (left) and CSIR senior engineer Lawrence Mboweni (right) with a group of students from local universities who recently participated in a CSIR-hosted hackathon at the software defined networking laboratory.

Revolutionising manufacturing by accelerating robot learning

Research and development at the CSIR's mobile intelligent autonomous systems laboratory is underpinned by a range of robotics platforms, as well as supporting equipment, such as sensors.

The fourth industrial revolution has led to rapid increases in manufacturing and inventions. The automobile manufacturing sector is experiencing an associated increase in demand. To meet the needs of its customers, the sector has to increase its manufacturing line processes and improve its flexibility.

When new tasks are introduced in the assembly line, a robot expert will typically redesign the task and reprogram the robot – a costly and time-consuming process. The learning-based robot programming framework has been adopted as an alternative to manual robot programming. This approach has the potential to revolutionise the current manufacturing sector as it allows for non-robotic experts to quickly and flexibly program robots by demonstrating new tasks.

CSIR researcher Ndivhuwo Makondo is investigating the learning-based approach, which will enable a human operator to program the robot. The operator will demonstrate a task to the robot through visual sensors and by physically guiding the robot to fine-tune the demonstrated task. This will require the human operator to be trained, whereafter the operator will then train the robot using a graphical user interface, which does not require the human operator to be competent in complex mathematics and computer programming.

"In my work, this is accomplished by extracting human motion data while operators demonstrate the tasks through vision-based systems – such as the Viscon motion-capture system – adapting these to the body of the robot and encoding them into a representation that allows the robot to reproduce them," says Makondo.

The CSIR's mobile autonomous intelligent systems laboratory, with its modern robotics equipment, is ideal for a testbed for this research. The equipment includes a compliant robot manipulator, which is ideal for human-robot interaction because it has sensors for measuring forces acting on it; as well as a motion capture system, which is an ideal visual motion sensor for recording human movements. The equipment is used in unison with software developed at the laboratory for processing data, which allows for the extraction of human and robot movement.

The benefit of using the learning-based approach is that robots will be taught new tasks required in the new assembly configuration. This will lead to a flexible assembly line that can be adapted to new configurations rapidly. As a result, it will open up robot programming to a wider community of factory workers and save costs associated with the current approach of hiring expert robot engineers and reprogramming the robot to perform new tasks. Makondo says that the research aims to change the current assembly lines to shared environments in which humans and robots work together. "In essence, a human teaches a robot the desired skills and the robot transfers the acquired skills to the other robot," he says.

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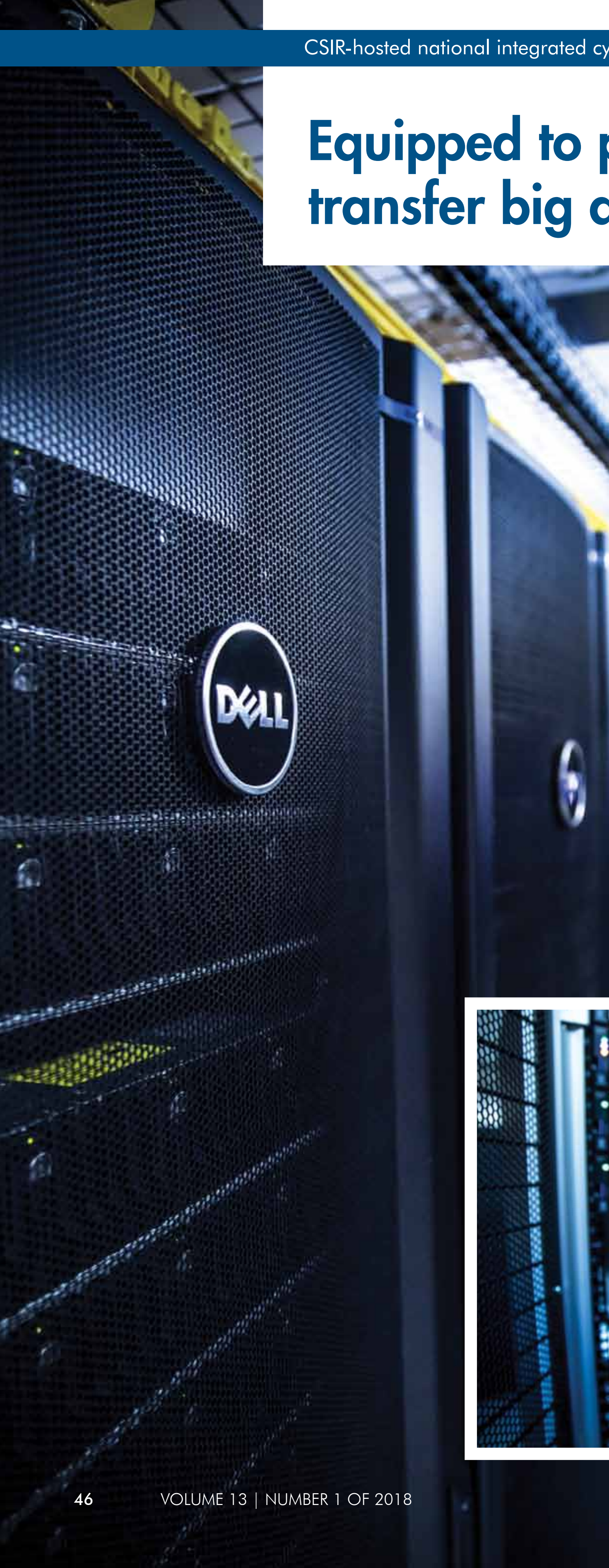
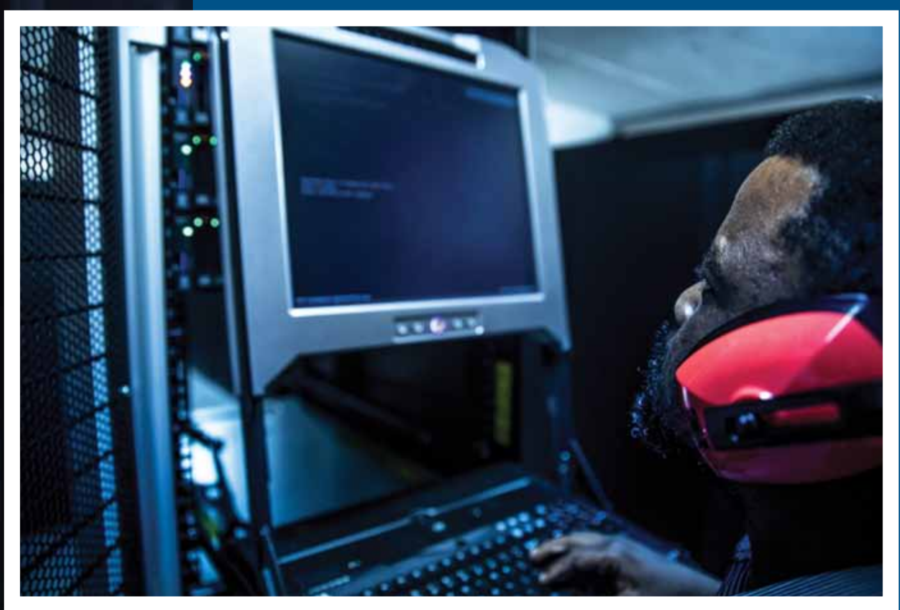
◀ Left: Numerous industry sectors have benefitted from the facilities and capabilities of the mobile intelligent autonomous systems laboratory. In agriculture, machine-learning methods have been applied to fertiliser modelling, and a prototype post-harvest fruit processor was developed using computer vision and laser cutting for the removal of stems from passion fruit. In mining, concepts for robot use have been produced and an artificial mining stope was designed and used to support the development of an experimental, entry-inspection robot. Computer vision has also been used in environmental monitoring for the study of coastal erosion and for wave tracking. The laboratory's Vicon® motion-capture system, used for high-accuracy position measurement, has been applied to human gait analysis. ▲ Above: CSIR researcher Dr Ndivhuwo Makondo (right) and student Sicelukwanda Zwane program the hybrid autonomous manipulation platform.

Equipped to process, store and transfer big data



The cost of innovating continues to escalate, resulting in many companies opting for virtual prototyping, which is one of the offerings made possible by the high-performance computing capability of the National Integrated Cyberinfrastructure System.



The National Integrated Cyberinfrastructure System (NICIS) is a national initiative of the Department of Science and Technology and is implemented by the CSIR. It promotes scientific and industrial development through the provision of high-performance computing capability, high-speed network capacity and a national research data storage infrastructure. These three capabilities integrate hierarchically into globally-connected systems and local systems, providing seamless access for the research and teaching community.

The Centre for High Performance Computing (CHPC) is one of the three pillars of the NICIS. It provides massive parallel processing capabilities and services to researchers in industry and academia, in South Africa and abroad.

Sectors that have benefited from access to the specialised high-performance computing skills and infrastructure provided by the CHPC include oil and gas, electricity supply, pharmaceutical, agriculture, rail, maritime and logistics, mining, engineering, animation, manufacturing, as well as climate and weather forecasting.

Meet Lengau (Setswana for cheetah)

The CHPC's petascale machine, Lengau, is the fastest computer on the African continent. It has a speed of roughly one petaflop (1 000 teraflops), which is 15 times faster than the previous system, named Tsessebe (Setswana for antelope).

Lengau puts the country in the league of leading supercomputing nations. After the Tsessebe cluster, it is the only other system in Africa that made it onto the Top500 List. The list, which is published twice a year at the world's major supercomputing conferences, ranks the most powerful supercomputers in the world. At 1.029 petaflops, Lengau is number 165 and it is the second-fastest supercomputer in the southern hemisphere, following the Australian computer, Magnus, housed at the Pawsey Computing Centre, in Perth, which is number 141 on the Top500 List, with 1.097 petaflops.

Dr Happy Sithole, Director: CHPC, says South Africa is committed to ensuring world-class services to its research community and industry.

Fast facts

- The CHPC provides 1 167 registered users with access to high-performance computing. In 2017/18, 555 active users used at least 1 000 central processing unit hours over a period of three months.
- About 64% of active users were from South African academic institutions; 19% from African academic institutions; 12% from the local public sector and 3% from local industry.
- The system is mostly used for physics (27%), followed by chemistry (17%), bioinformatics (16%), earth sciences (13%), material science (10%), computational mechanics (4%), astrophysics (2%), applied and computational mathematics (2%), computer science (1%), electrical engineering (1%) and the rest for environmental sciences, data science, chemical engineering, imaging and others.

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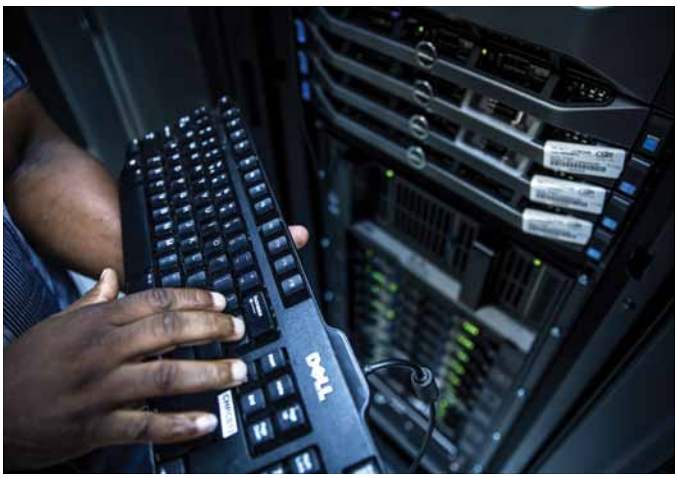

◀ Left: Lengau, Africa's fastest supercomputer and number 165 on the Top500 list of supercomputers. ▲ Above: World-class high performance computing infrastructure for more innovative and competitive industrial and academic sectors.

Improving the security posture of society

The CSIR's network emulation and simulation laboratory provides a platform for the design, development and deployment of cybersecurity processes and tools in a simulated environment.

Completed in 2017, the network emulation and simulation laboratory allows for the replication of existing or planned networks through a combination of physical and virtual devices. "The laboratory was developed as a platform to contribute to the development of cybersecurity specialists and knowledge creation and innovation in information security. A key aspect in the development of cybersecurity specialists and capabilities is access to high-quality infrastructure, which is costly. The network emulation and simulation laboratory provides a cost-effective solution as it allows remote access to infrastructure configured for information security-related activities," says Aubrey Labuschagne, a senior researcher at the CSIR.

The impact of information technology – especially information security – has been highlighted with cyber security incidents that occurred in recent times, and which have had severe financial implications. The laboratory uses processes and tools to test concepts with the emulation and simulation of real-world, legitimate traffic. This includes malware and therefore helps to identify security vulnerabilities and inefficiencies in computer networks.

The laboratory provides cybersecurity researchers with the ability to perform network configuration validation, cybersecurity training, security product research and advanced analytics to study cyber risks in an environment that mirrors reality. It also enables the delivery of tested, proven, effective and practical security solutions.

The platform is ideal for use by researchers, including postgraduate students in cybersecurity, as well as companies developing cybersecurity products.

"The lab provides security-focused researchers with access to an environment where they can design and develop security-focused solutions. The effectiveness of these solutions could be validated within the simulated environment before deployment in an operational environment, resulting in reducing the risk profile of security solutions and ultimately improving the security posture of society," says Labuschagne.

"A key driver of industrial development is the ability to apply knowledge resulting in solutions that improve the economy. The network emulation and simulation laboratory provides an environment where skills are improved and experience is gained through the application and validation of knowledge within simulated operational environments," he says.

Laboratory objectives

- Enhances cybersecurity skills development in South Africa
- Develops and transfers new technologies, tools and techniques to secure and improve the foundational elements of the national critical infrastructure
- Improves cybersecurity research by providing coordination and research and development leadership to national and municipal government, international partners, the private sector and academia.

Meet the facility manager

Aubrey Labuschagne (below) started his career in tertiary education in the fields of programming, networking and security. He is part of the CSIR cyber operations group which focuses on the operational readiness of technologies. He is a CSIR senior researcher in the fields of social media, social engineering and cyber security awareness with the main focus of reducing the risk profile of society against cyber threats.

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◀ Left: (Inset) Manager of the network emulation and simulation laboratory, Aubrey Labuschagne (centre), with the team, from left, Gianni Twigg, Mfundo Masango, Pedro de Souza and Alex Ramatswana. ▲ Above: CSIR senior researcher Aubrey Labuschagne and (bottom) Gianni Twigg, CSIR senior technology researcher, conducting cybersecurity training in the laboratory.

In singular pursuit of safer and more efficient mining in South Africa

The CSIR develops technologies and innovations to optimise mine operations, specifically improving occupational health and safety, increasing productivity and reducing costs. To do this, and to serve the mining sector, the organisation houses a number of highly specialised laboratories and scientific equipment.

The CSIR has developed high tech mine-safety equipment targeted at reducing fatalities in underground mining. These include a mining robotic platform and a rock-mass monitoring system.

Monster: a mining robotic platform

Inaccessibility of some underground areas makes it difficult and dangerous for inspections after blasting and prior to re-entry to the working areas. The CSIR has developed a robotic platform equipped with safety inspection sensors to enter mines during safety periods. Named 'Monster', the robot was developed to assess and identify risks in underground mines. Objects emit infra-red radiations which are detected by the robot. The robot is capable of autonomously inspecting the hanging wall and generating a risk map for miners.

Rockpulse: capturing the telltale signs of looming rockfalls

RockPulse is an early-warning and monitoring system that constantly monitors rockmass for micro-seismicity. The device is compact and battery-operated. With RockPulse, it is possible to listen to raw micro-seismicity; extract micro-fracture features and analyse the resulting series of features to detect potential instabilities taking place in the rockmass, early on. Continuous real-time monitoring of instabilities also allows for optimised safe re-entry times after hazardous events.

Specialised laboratories

The CSIR runs a number of specialised laboratories that undertake specialised testing for the mining sector, and in some cases for other industrial sectors. It includes a laboratory where self-contained self-rescuers, the devices that supply mine workers with oxygen during emergencies, are tested; a wire-rope testing facility where the general condition of ropes used to hoist conveyances up and down mine shafts are tested, and a fire and explosion testing, training and research and development facility to test underground explosion suppression systems and help prevent underground explosions and fires.

Meet the manager

Navin Singh (right) holds a Master's degree in mining engineering from the University of the Witwatersrand. He has 20 years of working experience in the mining and minerals sector and his interests lie in mechanised mining. Singh is responsible for driving the South African Mining, Extraction Research, Development and Innovation strategy developed by the CSIR in partnership with government and the private sector.

Revitalising mining

Earlier, the CSIR, in consultation with public and private sector stakeholders in the mining sector, developed a mining research and development strategy (SAMERDI). The strategy – a direct result of the Mining Phakisa programme – consists of six research streams aimed at the successful development of technologies and innovations to optimise mine operations, focusing on improved occupational health and safety, increased productivity and reduced costs.

In the first year of the implementation of the strategy, SAMERDI focused on establishing collaborative networks with the mining industry, government departments, academia and science councils. The work concentrated on establishing baseline studies on current challenges in mining operations, determining solutions for mechanised mining systems towards ultimately developing a continuous mining method using non-explosive rock breaking techniques. Cross-cutting initiatives also investigated geophysical systems to delineate geological disturbances and reef position ahead of the rock face and the ability to introduce real-time information management systems that will provide a holistic approach to managing risks in the underground environment.

The second year of the strategy focuses on further developing systems and technologies that – once commercialised – will help achieve the mandate of improving occupational health and safety, increasing productivity and reducing costs.

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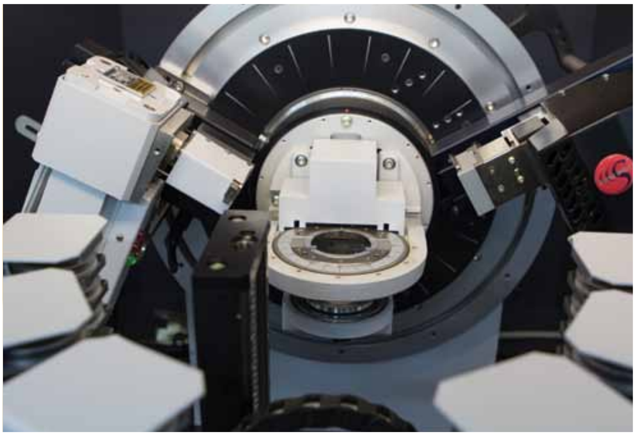
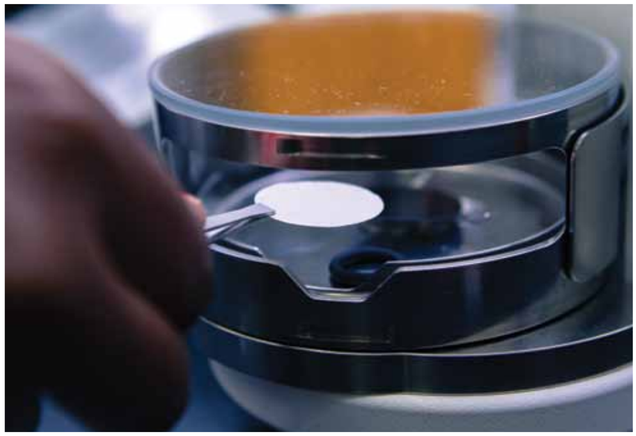
◀ Left: South African mineworkers are at the centre of efforts to improve mine health and safety as well as to halt job losses. (Inset) The CSIR robotic platform, Monster, contributes to the objective of zero harm by assessing risks after a blasting operation. ▲ Above: Dr Navin Singh of the CSIR.

Air and dust laboratory key to help eliminate silicosis in mining industry





The CSIR air and dust laboratory in Pretoria is equipped with sophisticated instruments, operated by highly competent technicians in the field. The laboratory excels in the measurement of respirable dust, and in conjunction with the Mine Health and Safety Council, it supports the efforts of government to eliminate silicosis in the mining industry. Silicosis is caused by the inhalation of dust containing silica.

The air and dust laboratory is a member of the International Standards Organisation working group that develops new international methods on the measurement of silica in workplace air, and actively contributes to the information that is compiled in these international methods.

In addition to supporting the departments of Mineral Resources, Environmental Affairs and Labour to monitor compliance to specified limits, the laboratory provides mining companies with analyses and related services on pollutants that are harmful to employees, surrounding communities and the natural environment.

Airborne pollutants in the workplace and the natural environment of mining operations must be managed in line with the regulations of the Department of Mineral Resources. Such pollutants include respirable crystalline silica, diesel particulate matter and total respirable dust.

Environmental tests done in accordance with environmental regulations

Analyses conducted on environmental pollutants are in accordance with the standards of the Department of Environmental Affairs.

Areas covered

- Diesel particulate matter analysis
- Particle size distribution analysis
- Direct-on-filter analysis of respirable dust samples for alpha-quartz (crystalline silica)
- Qualitative determination of the mineral composition of dust samples such as tailings dust or material used for tamping
- Gravimetric weighing of filters
- Fall-out dust analysis.

Through collaboration with other laboratories, the lab has access to specialised analytical techniques such as scanning electron microscopy and Fourier-transform infrared imaging. CSIR researchers based at the laboratory participate in occupational health research projects linked to the South African mining industry.

Fast facts

- **Experience:** The laboratory has many years of experience in airborne dust analysis in mines. This includes environmental air as well as the occupational hygiene filters of mine employees.
- **International standards:** The laboratory can measure diesel particulate matter according to the international method NIOSH 5040 and was the first laboratory to obtain SANAS accreditation for direct-on-filter analysis using X-ray powder diffraction according to international method MDHS 101.
- **Accuracy:** The laboratory participates in national and international proficiency testing schemes to optimise quality control accuracy and analytical performance. All methods and measurements are traceable to international standards.
- **Accreditation:** In order to assure the quality of analytical processes, procedures and results, the laboratory adheres to the standards set by the International Standards Organisation which details the quality policies and procedures required of accredited laboratories. The laboratory is accredited by the South African National Accreditation System (SANAS), which is aligned to the ISO 17025 standard.
- **Independent:** As an independent laboratory, clients are provided with unbiased, high-precision analytical data. All information and test results are secure and confidential.

Meet the facility manager

Vusi Mahlangu has more than 16 years of experience in chemical analytical work – developing, validating and optimising analytical methods. He holds BTech degrees in chemistry and laboratory management from the Tshwane University of Technology as well as a postgraduate diploma in project management.

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◀ The CSIR's Vusi Mahlangu conducting particle size analysis to determine the size of particles deposited on filters and in powders. Top (from left): X-ray diffraction is used to analyse silica on filters from the mines and other dust-generating industries. A balance used for gravimetric weighing of filters used to sample for silica, which is analysed using X-ray diffraction.

Prioritising the safety of South Africa's underground workforce

Self-contained self-rescuers are a source of oxygen for mine workers during underground fires and explosions or toxic gas leakages. In case of emergency, mine workers don the devices to escape from an irrespirable atmosphere to the nearest place of safety or refuge chamber. The CSIR is the only accredited testing authority mandated by the Department of Mineral Resources in South Africa to monitor the functional performance of these devices. The tests are conducted in the CSIR self-contained self-rescuer testing laboratory in Johannesburg.

The tragedies at the Kinross, Ermelo and Middelburg underground coal mines in 1986, 1987 and 1993 respectively, during which 264 employees lost their lives due to underground fires, necessitated the compulsory deployment of belt-worn self-contained self-rescuers in South African coal mines. The deployment of the devices was further extended to mines other than coal mines to mitigate against the recurrence of fatalities resulting from inhaling toxic gases. In 2017, approximately 240 000 of these devices were deployed in the South African mining industry.

To ensure that the self-contained self-rescuers deployed underground are in good working order, the need for a programme to monitor these devices, and detect any unacceptable deterioration in their functional performance, was recognised. The CSIR ensures that these respiratory protective devices are sampled and tested annually in accordance with *SANS 1737, Body-worn escape type breathing apparatus* and the requirements of Mine Health and Safety Act, Regulations 16.4 to ensure that safety is not compromised.

In addition to the monitoring programme, the CSIR assists local and international original equipment manufacturers of self-contained self-rescuers by testing their research and development units before the final products are submitted for the SANS 1737 approval process.

Key equipment used in the laboratory

The laboratory is equipped with two mechanical lung breathing simulators and a vacuum leak testing machine.

The breathing simulators are used to perform the functional performance tests of self-contained self-rescuers. Each breathing simulator comprises a mechanical lung, a control panel, oxygen and carbon dioxide analysers, temperature probes, an inhalation and exhalation pressure measuring device and a data acquisition system. The vacuum leak testing machine comprises an electronic control unit and a test chamber.

Fast fact

The testing laboratory has tested 22 873 self-contained self-rescuers in the last decade (2007-2017). In doing so, it contributed significantly to the reduction of the industry-wide failure rate of the devices – from nine units per 100 units to less than one unit per 100 units since its establishment in 1996.

Main objectives of the monitoring programme

- Detecting 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
- Assisting mine management in achieving legal compliance with regulation 16.4 of the Mine Health and Safety Act, 1996, which states that the employer must ensure that no defective self-contained self-rescuer is issued
- Detecting any trends indicative of premature deterioration in terms of negotiated agreements including periods of guarantee
- Identifying units which remain functional within established norms subsequent to the expiry of negotiated periods of guarantee, which means that mines do not prematurely replace or refurbish functional units
- Providing sound technical advice on-site at mines
- Providing feedback through formal reports, on all makes of self-contained self-rescuers, thereby enabling comparative evaluations on an ongoing basis.

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◀ Left: The laboratory where self-contained self-rescuers used in South African mines, are tested. ▲ Above: The breathing apparatus that produces oxygen for underground workers during an emergency escape.

Guarding over the integrity of a mining lifeline

The CSIR's internationally recognised steel wire rope testing laboratory tests, on average, 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 and general condition of steel wire ropes.

Steel wire ropes are used to hoist conveyances that transport people and material up and down hundreds of mines shafts in South Africa. The CSIR steel wire 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 facility that can accommodate the large rope diameters in use in South Africa's ultra-deep mines.

The CSIR also maintains a comprehensive database of steel wire rope test results which provide instantaneous access to past and present test certificates via an on-line platform. Wire ropes – up to 160 mm in diameter and with a 1 500 ton breaking-strength – have been tested for heavy lifting and marine industry application.

The CSIR steel wire rope testing laboratory is the only laboratory in South Africa that is accredited by the South African National Accreditation System (SANAS) for compliance with ISO 17025, which can be viewed as recognition of the quality of work and validity of results produced by the lab.

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◀ Left: Inspection of a fractured steel rope at the steel wire rope testing laboratory in Johannesburg. (Inset) A rope test piece is cut to the required length for testing. ▲ Above: Measuring the rope diameter using vernier calipers designed specifically for this task. Measuring the rope size ensures that the correct sample is tested, while it will also indicate the change in diameter of a rope under tension. This helps the laboratory establish that none of the strands have become loose, which may affect the rope performance negatively in terms of breaking strength.

Determining the strength of materials in the interest of safety

The CSIR mechanical testing laboratory houses two of the largest mechanical testing machines in South Africa, serving the mining and other industries since 1935. Today, it continues to play an important role in testing industrial products and materials to ensure that safety standards are adhered to.

The unique combination of machine force capacity and the size of the test specimen that can be accommodated is what makes the CSIR mechanical testing machines special. 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.

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 variety of products, including high-voltage conductors, lifting and hoisting equipment and heavy-vehicle towing attachments.

The machines continue to play an important role in assisting the industry to test against legislative standards, such as standards for lifting equipment, and to promote the general health and safety of workers in mining, manufacturing and construction.

The proof-load testing of lifting equipment ensures that items receiving the laboratory's stamp of approval meet customer safety requirements, as well as a host of product specific national and international standards.

Meet the facility manager

Ruth Teleka is the testing services manager for CSIR mining initiatives. She has an MEng in mechanical engineering, backed by 15 years in mining safety-related testing and research.

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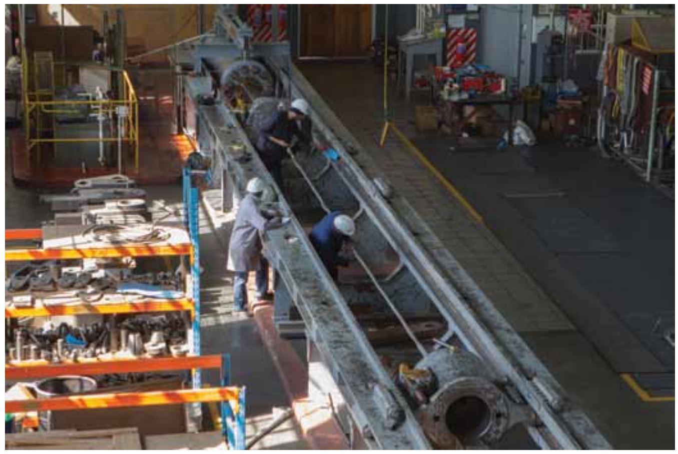
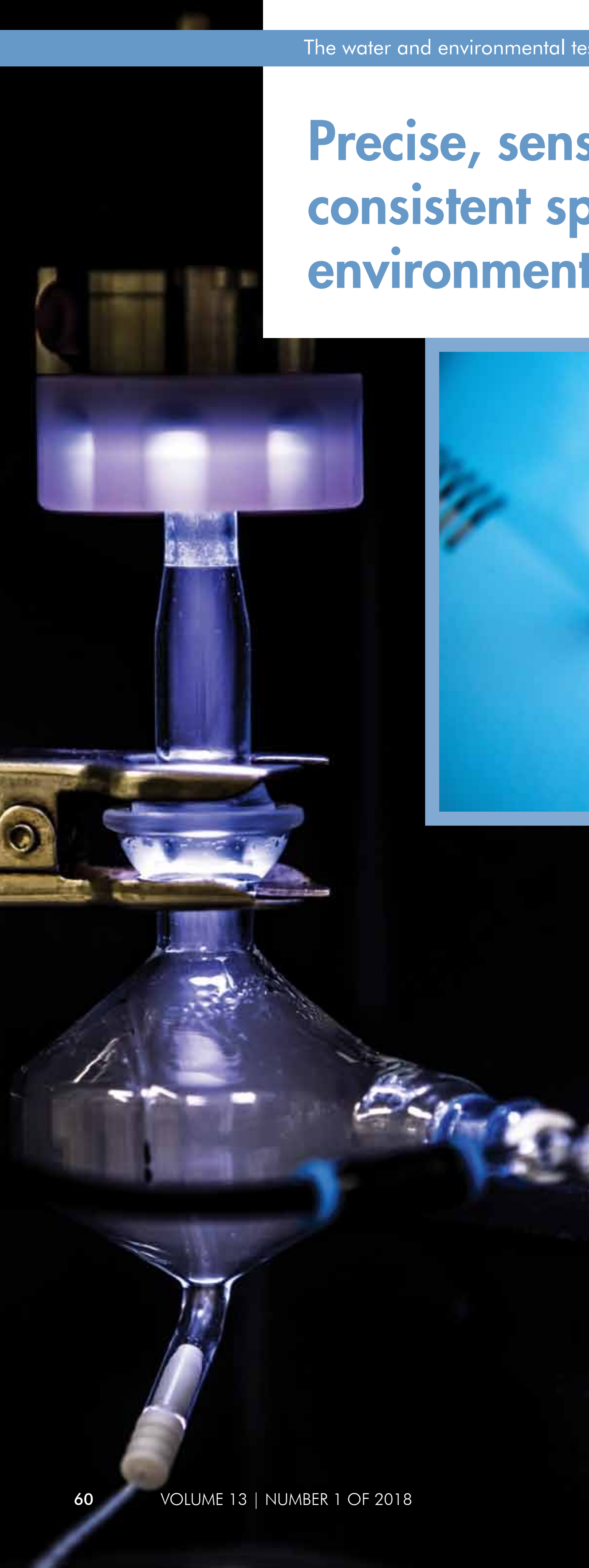


◀ Left: A laboratory assistant undertakes tests on specimens such as the overhead crane hooks (inset) that have passed the test and have been certified safe.
▲ Above: (top) The 500-ton tensile testing machine with its 25 m long test bed. The machine is used to test a variety of products to ensure compliance to set specifications. The results can also be used to verify designs for new products.

Precise, sensitive, efficient and consistent specialised water and environmental testing



The CSIR's environmental laboratories are equipped to test water samples for an extensive set of quality parameters and harmful impurities, including minerals, chemicals and organic substances. The laboratories also offer other related, specialised water services.

The CSIR has a sound track record in the analysis of various types of matrices. The specialised skills of the various laboratories take into consideration the geographic location of the sectors they predominantly serve. The Stellenbosch-based laboratory specialises in sample analysis from the estuarine and marine environments. Both the Stellenbosch and Durban laboratories have developed the capability to analyse seawater and the Stellenbosch laboratory also analyses biological tissue and sediments from these environments for general physiochemical properties, nutrients, metals and organic chemicals. The laboratories also analyse water and effluent samples for similar constituents. The laboratory in Pretoria undertakes specialised analysis of organic compounds in soil, sediment and water samples.

To assure the quality of analytical results, the laboratory adheres to the ISO 17025 standard which details the quality policies and procedures required of an accredited laboratory. All laboratories have been accredited by the South African National Accreditation System (SANAS) for over 20 years.

Analytical services: various domains

- Groundwater, such as boreholes;
- Surface water, such as pools, ponds, dams, lakes, rivers and streams;
- Wastewater, such as industry effluents, leachate and mine water;
- Drinking water;
- Bottled water; and
- Seawater (Durban and Stellenbosch).

Test results are used for the following regulations and compliance:

- Blue Drop certification for drinking water;
- Green Drop analytical requirements;
- Site, sample and waste characterisation;
- Land/site remediation projects;
- Ground water monitoring; and
- Quality control and regulatory requirements standards for drinking water (SANS 241) and for bottled water (SANS 1657).

Test parameters

Basic testing: Electrical conductivity, fluoride, nitrite, nitrate and nitrite, pH, turbidity, *E.coli*, heterotrophic plate count and total coliforms

Boreholes (Irrigation water): Alkalinity, calcium, chloride, electrical conductivity, fluoride, iron, magnesium, manganese, nitrite, nitrate and nitrite, pH, sodium, sulphate, total hardness, turbidity, *E. coli*, heterotrophic plate count and total coliforms

SANS 241 standard (Municipal water): Aluminium, ammonia, antimony, arsenic, barium, boron, cadmium, chloride, chlorine (free), chromium (total), colour, electrical conductivity, copper, cryptosporidium, cyanide (total), fluoride, giardia, iron, lead, manganese, mercury, nickel, nitrate, nitrite, combined nitrate and nitrite ratio, pH, phenols, selenium, sodium, sulphate, total dissolved solids, total organic carbon, trihalomethanes, combined trihalomethanes ratio, turbidity, uranium, zinc, *E. coli*, heterotrophic plate count, faecal coliforms, total coliforms and somatic coliphages (Microcystin tests are not undertaken)

SANS 1657 standard (Bottled water): both untreated and treated product
Storm water as per by-laws, Durban
Effluent water as per National Water Act no. 36 of 1998 limits and by-laws, Durban, Pretoria and Stellenbosch

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◀ Left: A sample introduction system for the inductively coupled plasma used at the Stellenbosch Environmental Laboratory to perform accredited testing of cations and trace metals in environmental samples. (Inset) A sample is introduced into a direct mercury analyser used in the Stellenbosch Environmental Laboratory. Mercury testing of environmental samples is one of the services offered.

Small-scale planning with a big impact: Physical models to test planned coastal infrastructure

The CSIR's coastal and hydraulics laboratory is used as a design tool where engineers and scientist can build small-scale versions of planned coastal infrastructure and its surrounding area. The coastal processes and wave conditions are then simulated to test the performance of the planned infrastructure as well as the unintended impact such structures may have on the surrounding coastline and coastal processes. The impact of future climate change can also be tested in these physical models.

The process of designing coastal infrastructure by building small-scale versions all starts by fitting the desired area and infrastructure into the wave basin. This requires rotating, positioning and scaling everything down to accomplish the best fit at the largest possible scale.

The bathymetry profile is constructed to resemble the latest survey data of the specific area. The seabed profile is constructed using a sand and mortar mix which is left to cure. Any accuracy error in the model will lead to an error in prototype, which magnitude will be equal to that of the model scale. In other words, an error of 1 cm in a model with a scale of 1 to 100 will equal an error of 1 m in prototype. For this reason, construction of the seabed profile is a tedious process with a model accuracy target of 0.5 mm.

Bathymetry is the underwater equivalent of topography. In the same way that topographic maps show the three-dimensional features of overland terrain, bathymetric maps illustrate the land that lies underwater.

Once complete, the wave basin is filled with water and the wave conditions to model are calibrated. Calibration of the wave conditions is a tedious process as it needs to ensure that the desired wave field and wave direction with wave spreading can be reproduced in the model. The wave machines, also called wave makers, can produce a wide variety of wave types. This includes the option to reproduce what was measured on site by an instrument deployed for a specific period of time in advance.

Once complete, the wave basin is emptied and the coastal infrastructure constructed to engineering drawings provided. The wave basin is then re-filled with water and the same wave conditions which were calibrated are then produced with the planned infrastructure in place. This allows for the complete testing of the structural integrity and verifies the design life of a harbour or breakwater. Measurements on the structural integrity as well as wave and current measurements during a physical model test can then be used to support infrastructure decisions and shipping operations within a port.

Track record

Significant projects in South Africa include physical modelling work for the Port of Ngqura and the entrance channel widening for the Port of Durban harbour. Recent work includes testing various rehabilitation options for a portion of the main breakwater at Cape Town harbour. The implementation of one of these options was completed in December 2017.

International work conducted during 2016 and 2017 includes model testing on newly planned harbours in Chile, Saudi Arabia, Ghana and Nigeria.

With more than 35 years of experience in the area of coastal and port engineering research, the CSIR has a vast network of local and international clients. One of the CSIR's main priorities in coastal and port engineering is assisting with rehabilitation and repair work as well as harbour expansions for Transnet National Port Authority. This includes research and development studies on coastal infrastructure and the impact it may have on the surroundings.

Meet the facility manager

Johan Kieviet (below, right) has an MSc degree in coastal engineering from Stellenbosch University. Kieviet has extensive knowledge of coastal processes and civil structures.

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◀ Left: The CSIR's coastal and hydraulics laboratory is one of four facilities of its size in the world, where scale models are built to test harbour and coastal engineering design. ▲ Above (centre): Rafick Jappie sets up a wave-height gauge to measure wave height and wave direction.

Testing and upscaling treatment technologies for mine wastewater and metal recovery

The CSIR is building on its early successes in the development of technologies for the treatment of mine wastewater by refining and testing processes at a newly constructed pilot plant. Acid mine drainage in the Witwatersrand area continues to present a threat, with acid mine water from abandoned and some operational mines flowing into streams, dams and sources of groundwater.

While numerous mine wastewater treatment technologies have been developed and implemented over time, their application is limited by inefficiencies, selective treatment capabilities, cost and generation of secondary sludge that is toxic and expensive to dispose of. The search for cheaper, effective and efficient mine water treatment technology has thus continued.

Potable water and valuable minerals from mine wastewater

The CSIR has developed and patented technology which – when integrated with commercially available reverse osmosis and eutectic freeze/cooling technologies – is able to clean mine wastewater to a standard that is suitable for domestic, agricultural and industrial purposes. At the heart of the innovation lies the MASRO (magnesite, softeners and reverse osmosis) process, during which drinking water and valuable minerals are recovered from acid mine drainage. The brine (a highly concentrated water solution of common salt) from this treatment process is used to recover additional salts that have commercial value, such as sodium-based salts. The first phase of the treatment chain recovers iron that is useful in paint-making industries; while the second phase recovers gypsum that can be used in fertiliser industries and metallurgical processes. In phase three, limestone is recovered that can be used in a number of industrial applications.

A pilot plant to bridge the gap from laboratory to real-world implementation

The CSIR erected a mine wastewater treatment pilot plant at its campus in Pretoria. The pilot plant is able to treat 3 500 L of acid mine drainage per day and produces water that complies with SANS 241 drinking water specifications and standards. In addition to clean water, it can also produce valuable minerals such as gypsum, limestone and iron-based minerals. These minerals can be sold to metallurgical houses – offsetting the running costs from the return monetary value – making the process self-sustainable. Engineers running the facility successfully tested the performance of the plant using acid mine drainage from gold and coal mines. Attempts to improve the technology's robustness in an industrial set-up and harsh field conditions continue. The CSIR is in discussion with a number of mining houses, government departments and agencies about uptake of the technology.

South Africa and acid mine drainage

Gold mines in the Witwatersrand basin ceased operations over a number of years as gold resources became depleted. As mines closed and ceased pumping, water began to accumulate in the void and was then discharged into neighbouring mines and its connecting underground tunnels. "Active and abandoned mines in South Africa discharge millions of megalitres of metalliferous and acidic drainage laden with toxic and hazardous chemicals per year. This can pose serious health risks to humans and other living organisms," says CSIR senior researcher Dr Vhahangwele Masindi.

Meet the facility manager

Dr Vhahangwele Masindi (bottom, right) is the co-inventor of the technology, along with CSIR senior engineer, Muhammad Osman. He has vast experience in environmental chemistry, geochemistry, environmental engineering, and wastewater treatment and depollution science. The project is supported by a number of specialists within the organisation, including process engineers, chemists, civil engineers, hydrologists, geo-hydrologists, material scientists, environmental scientists and statisticians.

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◀ Left: The mine wastewater pilot plant currently takes about eight hours to treat 3 500 L. Recoveries can be increased by increasing the size of the plant. The plant can also be packaged in a modular form or can be semi-mobile, depending on end-user requirements. ▲ Above: CSIR chemical engineer Rhulani Shingwenyama (left) is responsible for the design, sizing and construction of the plant.

Accelerated road testing facility makes its mark internationally

A road is designed to last between 20 and 30 years if constructed and maintained correctly. This implies that when a new material or design is developed, a trial section needs to be built to evaluate how it responds to being subjected to traffic for many years – a costly and time-consuming approach. The CSIR's heavy vehicle simulator is a mobile laboratory used by decision-makers and road builders to apply and monitor the effect of 20 years of traffic to a road section in just three months.

South Africa is world-renowned for its accelerated pavement testing programme. The technology has been used to evaluate a variety of road structures and materials. The results of the programme have formed the basis for South Africa's well-respected road pavement structural design methodology.

The HVS: Technical capabilities behind the stalwart

The heavy vehicle simulator (HVS) consists of a loading frame that allows for the application of dual truck or aircraft wheel loads from 20 kN to 200 kN. The latest version, Mark VI, can also apply dynamic loading to simulate the action of a truck suspension. The traffic load, speed and pattern can be set through the control computer.

The system includes a variety of instruments either embedded in the road structure or used on the surface to monitor the performance of the road under the loading. This includes the measurement of deflection influence lines at various depths using the multi-depth deflectometer, the measurement of pressure and strain in the road layers, as well as the measurement of permanent deformation on the surface using a laser device. The testing environment is controlled through a system of water addition to the surface and into the layers below the surface, as well as a temperature-control chamber to heat or cool the road surface.

The HVS is computer controlled and the data acquisition system records and analyses the road structure response to the loading and the environmental conditions. The data are used by road engineers to develop an understanding of the complex behaviour of road materials and designs to optimise the design process. The HVS units deployed in South Africa – one owned by the CSIR and the other by the Gauteng Provincial Department of Roads and Transport – have contributed significantly to the understanding of road material performance and road design in South Africa.

World-wide uptake

The CSIR collaborated with Dynatest USA to commercialise the system. The partnership has led to the sale of 18 HVS machines world-wide and the technology is currently used in countries such as the United States of America (USA), Sweden, Mexico, Costa Rica, Saudi Arabia, China and India.

◀ Left: The HVS system can simulate dynamic loading effects of trucks on a road and evaluate the structural response. ▶ Right: The HVS has been exported to numerous countries around the world, this one to Finland.

The Federal Aviation Administration in the USA owns a double-sized machine that can load airfield pavements to 400 kN. The latest HVS order is for Argentina and will include a full technology transfer and training programme offered by the CSIR.

South Africa's work in heavy vehicle simulation has also enabled the organisation to undertake collaborative research with HVS owners from abroad. The oldest collaboration programme is with the University of California at Davis which has been funded by the California Department of Transportation since 1994. 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.

Continued innovation

The CSIR has developed a new conceptual design for an advanced HVS called the traffic stream simulator. This simulator will be able to test at much higher speeds than the HVS and will be able to simulate a stream of mixed traffic.

Meet the facility manager

Dr Chris Rust obtained a PhD in civil engineering specialising in roads engineering and materials, and has also done a course on technology management at the Massachusetts Institute of Technology in the USA. Rust has more than 50 peer-reviewed publications, several of which focused on the HVS and its impact.

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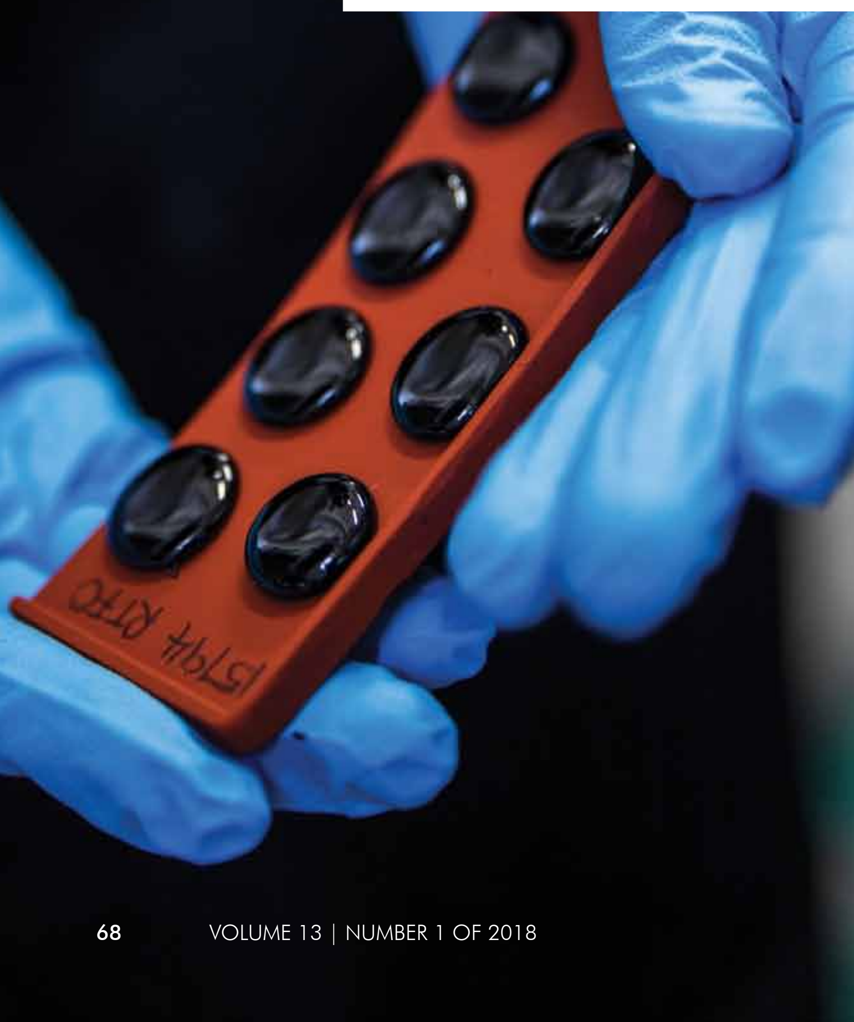
Testing road construction materials for improved road design and construction in Africa



At the heart of improved roads design and construction, leading to longer-lasting roads and lower maintenance, lies the CSIR's advanced material testing laboratories. The laboratories, where tests are conducted on road building materials, help road engineers, construction groups and decision-makers design and develop better roads.

Established almost 70 years ago, the advanced road material testing laboratories undertake most of the standard testing required for road construction materials. These include testing of soils, gravels, aggregates, bitumen, asphalt materials and concrete.

The laboratories support research studies, investigations into road failures, product development, and also act as a reference laboratory for industry.

Laboratory manager Georges Mturi says the laboratories are key to the Southern African Development Community region. "Given the increasing road failures in the region, we investigate why they happen within the current testing framework," he adds.

Mturi says the forensic investigations into road infrastructure failures over the years have all pointed to the limitations of current standards for testing and designing roads. "This led to many research studies on how we can introduce new and better ways of designing roads and selecting materials for road infrastructure."

"Over the past few years, the CSIR has been called upon to investigate road failures in numerous SADC countries. In some instances, failures involved tens of kilometres. Our task, through our laboratory analysis, is to find the source of these road failures," he says.

Mturi says these investigations have highlighted the need for more performance-related research into modern ways of testing and selecting materials.

He says the research has shown that there are a number of emerging factors to consider when selecting materials. Such factors include climate and traffic conditions, which vary from one country to the other. "New performance-based specifications encourage engineers to select materials based on the climate of the region and as per the predicted traffic levels," he says.

At the CSIR, laboratory research is undertaken to improve existing methods, formulate recommendations for future standards and specifications as well as for the development of new products.

Key to research and development activities is that standard and non-standard testing are carried out according to the customised requirements of clients but within the quality guidelines of ISO 17025 system requirements.

Recent forensic investigations on the continent

Tanzania – Supported the development of asphalt specifications and manuals as well as delivering gravel road testing kits for rural needs
Namibia – Supported investigations into road distresses
Democratic Republic of Congo – Supported the refining and incorporation of natural asphalt into asphalt mix designs
Ghana – Supported the use of new polymer modifiers for asphalt bituminous binders according to performance-related specifications
Zambia – Supported investigations into incidences of road distress
South Africa – Supported the development of modern manuals and asphalt bituminous binders specifications based on performance requirements.

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◀ Left: Samples to be tested using a dynamic shear rheometer, which is used to characterise the viscous and elastic behavior of asphalt binders at medium to high service temperatures. (Inset) CSIR lab technician Nomashaka Hawes uses a flash point tester to determine the temperature at which the sample will ignite.
▲ Above (left): CSIR laboratory technician Nomashaka Hawes pours a bitumen sample into a mould to test its properties at low temperatures, using the bending beam rheometer. Right: CSIR laboratory technician David Molebalo conducts an unconfined compressive strength test on a compacted soil material sample.

Towards a comprehensive understanding of South African road user behaviour

Driving is an ordinary task, undertaken by ordinary people every day. A driving license constitutes a symbol of freedom. But with this freedom comes a risk and a responsibility to manage that risk for the driver, passengers and other road users. Human error is the most significant contributor to road traffic crashes in South Africa. Yet little is known about the human factors that contribute to the carnage on our roads. The CSIR naturalistic driving studies laboratory aims to help change this.

The CSIR is employing naturalistic driving studies, a fairly new research methodology, to observe road user behaviour in a natural environment. Naturalistic observation refers to studies that are undertaken to study a subject in its natural environment without any manipulation from the researcher, as opposed to studies that are undertaken in a laboratory or simulation environment. For example, the driver is able to drive the way that he or she normally drives – without any instructions or special interference from experimenters.

From these observations, CSIR researchers are able to come to conclusions regarding the road user, vehicle and environment in which this behaviour occurs. Therefore, the research enables an in-depth understanding of road user behaviour in a number of situations, ranging from different weather conditions, roadways and near collisions or actual collisions. Understanding these relationships improves the decision-maker's insight into making the South African road and traffic system safer.

Naturalistic driving studies refer to the unobtrusive approach to studying road user behaviour in context of the vehicle, road and environment. The underlying assumption of this approach is that driver behaviour will not be significantly altered by being observed over the long-term. Therefore, these studies reflect natural driver behaviour over time and provide insight into actions and behaviours that precede crashes and near-crash events.

Equipment and infrastructure to collect and analyse data

The CSIR uses a data acquisition system, installed in test vehicles, to collect data from the driver, vehicle, road and environment. The system consists of three cameras, an on-board computer and a GPS device.

The data acquisition system collects large quantities of qualitative and quantitative information resulting in very large databases. Multiple videos (qualitative data) give information relating to driver behaviour (in relation to other road users, vehicles and environment), including the position of the head, eye movements, as well as distractions. The on-board computer, which is connected to the control area network of the vehicle, provides acceleration and deceleration data, speed and GPS information capturing location, time and velocity.

◀ Left from the top: CSIR researchers use a data acquisition system consisting of three cameras, one facing the driver, one facing the back and one facing the front of the vehicle. An on-board computer logs information relating to the vehicle, including global positioning coordinates, acceleration and deceleration information, as well as speed. Karien Venter (left) is a social scientist specialising in human factor and transport research. Khangwelo Muronga (right), is a senior technologist, specialising in ICT systems and security.

The large volumes of data need to be managed effectively as the datasets take up a large amount of storage space and are in different formats, which necessitates the use of different software programs to download, transcribe and analyse the data.

The CSIR team manages the different datasets in terms of compatibility, ease of downloading, transcribing and ultimately, analysing. Different qualitative and quantitative techniques and software are used to analyse the data. New techniques for data management include exploring machine learning and deep learning technologies for coding and analysing the large datasets.

The rich contextual data derived from the naturalistic driving studies approach facilitates a comprehensive understanding of driving behaviour in a number of situations, including different weather conditions, roadways and near collisions or actual collisions. An understanding of these relationships and the conclusions drawn from the different studies provide an evidence base for the design and implementation of interventions to move towards a safer transport system.

"Decision-makers in government must prioritise issues of road safety. Cognitive and behavioural aspects of road use are a neglected field in South Africa and without scientific, evidence-based research it is difficult to develop countermeasures, influence policy or formulate strategies to curb the road safety problem in South Africa," says the CSIR's Karien Venter.

Since the initiation of these types of studies, various research topics have been looked into. In a study exploring novice versus experienced driver behaviour, researchers compared the driver behaviour of young and inexperienced drivers to mature and experienced drivers. The study investigated the perceptions of and relationships between the two road user groups and how they behave whilst sharing the road. The researchers also studied the road user behaviour of motorised and non-motorised transport users. A third study explored the potential role that distracted driving can play in unsafe driving.

Currently, a longitudinal research project to be completed in March 2019, explores how hazard perception develops in learner drivers over time.

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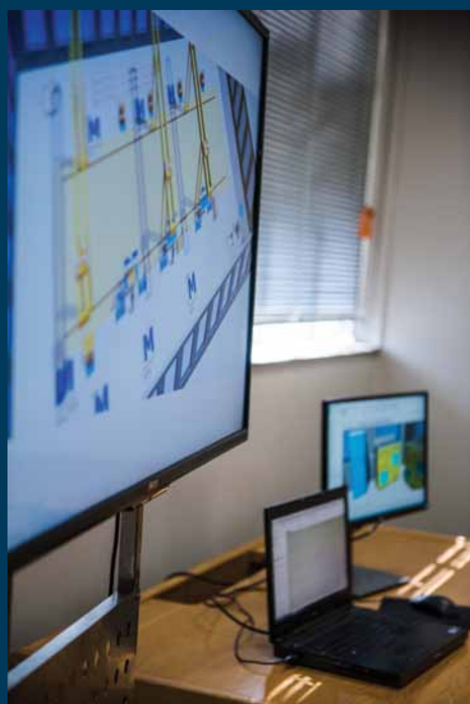
New collaborative product development space to help drive industrial digital transformation

Having recognised the enabling role of product lifecycle management (PLM) technology, the Department of Trade and Industry supported the establishment of a new PLM technology centre at the CSIR, by making Siemens PLM software licenses available to the CSIR. This software will be used to support small, medium and micro enterprises.

The Industry 4.0 PLM Centre of Technology provides a collaborative product development space for industry and researchers alike.

The rapid rise and convergence of emerging technologies is driving the fourth industrial revolution. This is a collective term for technologies and concepts of value chain organisation that draw together cyber-physical systems, the Internet of Things and the Internet of Services, as well as other emerging technologies, such as cloud technology, big data, predictive analytics, artificial intelligence, augmented reality, agile and collaborative robots, and additive manufacturing. By enabling smart factories, virtual and physical systems of manufacturing globally cooperate with each other in a flexible way. PLM is an important enabler of the fourth industrial revolution.

The new centre will help to drive the digital transformation of industry with cooperation at all levels among companies, industries and institutions. The centre will provide Industry 4.0 readiness assessments and benchmarking against similar companies; plant simulation and optimisation services; plant automation and human-centred automation solutions, including robotics; product development support; regulatory support and the building of digital replicas of physical assets for products and plants.



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