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ScienceScope

IDEAS THAT WORK FOR INDUSTRIAL DEVELOPMENT

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The South African economy is an efficiency-driven economy, with the intention to transition into a knowledge economy. For this to happen, we need to address the weaknesses in the current structure and performance of the South African economy, which hamper our global competitiveness. These include, amongst others, a declining manufacturing sector, heavy reliance on imports, an uncompetitive resource-based sector that is in need of transformative breakthrough innovations; and low labour productivity. National institutions, such as the CSIR, have a pivotal role to play in supporting the country to achieve this objective.

It is against this backdrop that the CSIR has taken a strategic decision to reposition its innovation portfolio to make a direct contribution to industrial development. This repositioning of the CSIR will require close alignment with all relevant stakeholders in the public and private sectors.

This conference edition of *ScienceScope* features research and innovation in which the CSIR draws on its multidisciplinary competences to develop products and systems that contribute to industrial development in multiple sectors.

Some of the themes highlighted in this issue feature successful partnerships between the CSIR, government and industry on research and development that contributes to an efficient rail, roads and transport system, which underpins the success of industries; the development of cutting-edge medical devices and diagnostics; and our multidisciplinary interventions to offer support in the areas of water security and sustainability.

I encourage you to send us your feedback and work with us to improve the quality of life of all South Africans.

DR THULANI DLAMINI
CSIR CHIEF EXECUTIVE OFFICER

IDEAS THAT WORK FOR

INDUSTRIAL DEVELOPMENT

IN THIS ISSUE

ON THE COVER

The CSIR is repositioning its innovation portfolio to make a direct contribution to South Africa's economic competitiveness through industrial development.

Positioning for **impact**

BY DR RACHEL CHIKWAMBA

In his foreword to this edition of *ScienceScope*, the CEO refers to the CSIR's decision to reposition its innovation portfolio to make a direct contribution to South Africa's economic competitiveness through industrial development. This initiative is one of the biggest that our organisation has ever undertaken – we are intentionally challenging the status quo and expect far-reaching results.

Synapse

Why Project Synapse?

Synapse refers to a region where nerve impulses are transmitted and received. The idea of a synapse is profound. It allows communication and is essential in enabling any kind of activity. It permits two elements to connect. In the CSIR world, this could translate to bridging the existing chasm between innovation and industrial competitiveness, commonly known as the 'valley of death'. The CSIR's Project Synapse is about the nerve connection between innovation and industry, between innovation and competitiveness, between the CSIR and its partners. We are creating or re-establishing the connections between our country's socioeconomic needs and the role innovation and industrial development can and must play to address these needs.

Project Synapse, in essence, is about connecting minds to ignite change, competitiveness, inclusivity, poverty alleviation and job creation.

The initiative, which has been dubbed Project Synapse, aims to amplify the 'I' in 'CSIR', repositioning the organisation to create the right balance between scientific development and industrial development to achieve the impact enshrined in the CSIR mandate.

The ensuing strategy will take a centennial view, a 30-year vision that prepares for industrial development interventions over three time horizons – immediate, transitionary and future – preparing the organisation as well as the science, engineering and technology (SET) and industrial landscape for the CSIR of the future.

It is intent on supporting industry more meaningfully, contributing to the competitiveness of the South African economy through a variety of approaches that support small, medium and micro enterprises (SMMEs) as well as large industry stakeholders. Support to new entrants, notably black industrialists, into various sectors of the economy, is a particular focus aimed at removing entrenched barriers to inclusive participation in the economy.

CLARIFY AND DIRECT

Specifically, this process and strategy will clarify the nature of our interventions in reaching our industrial development goals. It will, for example, give informed views on how the CSIR can meaningfully support existing industries, boosting industry productivity, profitability and sustainability through incremental innovations. Further consideration will be given to how declining industries could be revitalised, creating new value chains leading to competitiveness and growth, new products and job creation; as well as how to create new industries and transform existing industries through radical innovation. The strategy will provide clarity on how the CSIR can inspire new products, processes and services of tomorrow with the potential to unlock billions in value to industry and disrupt existing markets, create new sources of wealth, and encourage export opportunities. It will suggest ways, based on global best practice, on how we can systematically scale up research and development to bring ideas, processes and products closer to availability at scale and commercial release. We are keenly aware of the need for collaboration in the innovation space and the strategy will thus also guide our efforts to create deeper and more meaningful engagement with South African and global industries, tertiary education institutions, as well as public sector stakeholders, bringing industrialists, scientists and engineers together to bring new ideas to market.

HISTORICAL CONTRIBUTIONS TO INDUSTRIAL DEVELOPMENT

Through Project Synapse, we want to leverage our strong SET capability base and build on current industrial development opportunities. Our aim is a balanced scenario that will see a virtuous cycle where scientific and technological development drives industrial development, and the latter, as it evolves, informs the research agenda.

Historically, the CSIR has contributed significantly to South Africa's research, development and innovation by supporting university, medical and industrial research. It contributed to industrial development through setting up other specialised councils as well as successful start-up companies. To date, the CSIR is proud to have created 105 companies, 54 of which are still thriving. The CSIR has also enhanced and supported major participants in and key role players of the South African aerospace industry, among others.

WELL-CONSIDERED AND TIMELY

Not only are we doing this in collaboration with industry and government stakeholders, but we have drawn on a broad base of CSIR colleagues and partners to critically engage with the internal and external environment in which we work. Different work groups are considering several contexts, from geopolitical, economic, and social, to technological, legal and environmental. They will identify potential growth sectors, barriers to entry and competitiveness, and assess these against existing CSIR capabilities.

We are heartened by the positive feedback and support offered to this process by several of our key stakeholders, including the Department of Science and Technology, the Department of Trade and Industry, the Industrial Development Corporation, the Water Research Council, the United Nations Environment Programme, the United Nations Development Organization, and the Manufacturing Circle.

Our consultations continue with partners in the academic and public sectors, locally and globally.

The 6th CSIR Conference is an integral part of this engagement process, where we aim to share our current work in support of industrial development with key stakeholders, but also to create a platform of continuous engagement as we go on this journey towards our centennial vision.

OPPORTUNITIES ABOUND

We are looking into 29 industry sectors as identified by national frameworks such as the Industrial Policy Action Plan, the National Development Plan Vision 2030, and other growth strategies. The CSIR will focus on those sectors where it can make the biggest contribution in the short, medium and long term; as well as where South Africa could gain the most. Already a number of opportunities have been highlighted and we look forward to share these with our stakeholders in the months to come. Together with our stakeholders, we will use our SET and industrial development capabilities to respond to South Africa's triple challenges of poverty, inequality and unemployment.

DR RACHEL CHIKWAMBA
Group Executive: Industrial Development

Enabling **local production** of **biopharmaceuticals** in South Africa

Biopharmaceuticals is one of the fastest growing sectors of the pharmaceutical industry, mainly driven by a rapid expansion in the manufacture of recombinant protein-based drugs that are known for their efficacy and safety. However, as is often the case with novel drugs, those who need them most, do not have access to them. The CSIR and its partners are actively pursuing opportunities to develop, and locally manufacture several novel biopharmaceutical drugs in an effort to improve the cost and access to medicine in South Africa.

Access to affordable and good quality medicine is the cornerstone of any healthcare system. In South Africa, there is limited local production of generic active ingredients, therefore, multinational drug companies focus on the fill-and-finish processing of mostly imported active ingredients.

In addition, there is a huge disparity in the procurement and use of medicine between the public and private healthcare sectors. The latter supports only 16% of the total population, but accounts for 84% of total pharmaceutical expenditure. This disparity can also be seen in the access to biopharmaceuticals.

BIOPHARMACEUTICALS

Biopharmaceuticals are highly effective large macromolecular-based drugs, including antibodies, hormones, replacement enzymes and nucleic acids. In 2010, South Africa spent R2 billion on imported vaccines and biologics.

However, most recombinant insulin analogues are used by diabetics in the private sector, while state patients still receive first-generation human insulin. There is practically no use of biopharmaceutical antibodies against cancer in the state sector. The influenza vaccine uptake is 1% in the state sector, yet more than 30% of that population is at risk of severe influenza outcomes. The prohibitive cost of procuring these biologics is a major contributor to the limited use in the public system.

ADDRESSING PROHIBITIVELY EXPENSIVE CARRIER PROTEINS IN VACCINES

Cross Reacting Material 197 (CRM 197) is a protein reagent used in the preparation of conjugate vaccines for children, such as the pneumococcal vaccine. The reagent, which is an essential component of these vaccines, is prohibitively expensive, affecting the affordability of the vaccine.

To address this, the CSIR collaborated with the Biovac Institute, a public private partnership to revive strategically significant vaccine development and manufacturing capability in South Africa.

"CSIR researchers completed a proof of concept for a fermentation-based production of CRM197, a multiplex vaccine carrier protein in *E.coli* bacteria. The process involved the recombinant co-expression of CRM 197 with proteins that promoted its proper folding into its native, efficacious structure," says Dr Tsepo Tsekoa, principal researcher and research group leader for biomanufacturing technology demonstration at the CSIR.

"This work has significantly improved the CSIR's understanding and implementation of current good manufacturing practice approaches in bioprocess development for biologics. It will add to the armoury available to Biovac and the broader vaccines sector."

DR TSEPO TSEKOA
CSIR principal researcher and research group leader for biomanufacturing technology demonstration

"THIS WORK HAS SIGNIFICANTLY IMPROVED THE CSIR'S UNDERSTANDING AND IMPLEMENTATION OF CURRENT GOOD MANUFACTURING PRACTICE APPROACHES IN BIOPROCESS DEVELOPMENT FOR BIOLOGICS. IT WILL ADD TO THE ARMOURY AVAILABLE TO BIOVAC AND THE BROADER VACCINES SECTOR."

– DR TSEPO TSEKOA

POST-EXPOSURE PROPHYLAXIS AGAINST RABIES

In South Africa, rabies is endemic in dogs and wildlife species, such as jackals and mongooses. Mere scratches on the skin may lead to the virus infecting the central nervous system and brain. Once symptoms start, rabies is almost always fatal in unvaccinated people.

Current treatment involves vaccination, as well as the administration of human anti-rabies immunoglobulin (RIG) antibodies that are normally injected directly into the wound. RIG provides immediate protection, but is expensive as it is produced from the serum of immunised people, while the vaccine takes more than a week to become effective.

CSIR researchers have genetically engineered the micromachinery of a leafy tobacco plant to produce a significantly cheaper rabies antidote, called Rabivir™. This product could, in the future, significantly increase access to this type of preventative medicine.

"This technology is ready to enter pre-clinical studies to enable regulatory approval through clinical trials and the CSIR is sourcing funding for further development," says Tsekoa.

A scientist infiltrates genetic material into the leaf of a tobacco plant.

IN SOUTH AFRICA, RABIES IS ENDEMIC IN DOGS AND WILDLIFE SPECIES, SUCH AS JACKALS AND MONGOOSES. MERE SCRATCHES ON THE SKIN MAY LEAD TO THE VIRUS INFECTING THE CENTRAL NERVOUS SYSTEM AND BRAIN.

Dr Tsepo Tsekoa, CSIR principal researcher, preparing the *Nicotiana benthmiana* plant for antibody production.

PLANT-BASED PRODUCTION OF HIV ANTIBODIES

Using a species of tobacco plant, CSIR researchers have successfully produced HIV antibodies at levels that bring the health industry a small step closer to an economically viable preventative treatment against this infection. This work was done in collaboration with South Africa's National Institute of Communicable Diseases and Mapp Biopharmaceutical.

Antibodies are part of the human immune system and are crucial to fight diseases. They are also used to manufacture drugs. These drugs are normally produced using expensive biological systems, for example, mammalian cell culture.

CSIR researchers have now also succeeded in making equivalent antibodies using *Nicotiana benthmiana*, which is related to the commercial tobacco plant. Nicotiana-based antibody production is potentially significantly cheaper and the risk for accidental contamination of products by agents such as animal viruses and endotoxins from bacteria during production is also eliminated.

With this method, the genetic codes of the HIV antibodies were introduced into the leaves of the *Nicotiana benthmiana* to produce the antibodies in the plant.

"Tests showed that the plant-based antibodies were able to neutralise HIV isolates in the laboratory. The next phase of the project will produce a good manufacturing practice batch and validate the efficacy and safety of the plant-produced monoclonal antibodies in animal studies," says Tsekoa.

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FUTURE FOCUS: SMALL MOLECULES AND THE BIOSIMILARS OPPORTUNITY

In future work, the CSIR intends to expand this biopharmaceuticals competence and work in close partnership with industry. The organisation intends to become a significant player in the local biosimilars value chain. Biosimilars are follow-on biologics with a similar structure to the originator, manufactured using alternative, typically cost-competitive processes. In the next few years, several originator molecules will become available for manufacturing and marketing as biosimilars. The opportunity to expedite their broader availability at a reasonable cost is therefore a major opportunity for emerging markets.

In addition to its research and development capacity in biologics, the CSIR has a strong chemistry capability to support the local pharmaceutical industry. The goal of future proposed research is to provide advanced manufacturing toolkits to perform specific high-cost, high-risk and non-green chemical transformations faster, cheaper and greener. New biocatalytic, flow and immobilised catalyst technologies that encompass green principles, such as the use of less toxic materials, waste reduction and increased efficiency will be employed to develop the reaction toolkits.

Access to large-scale prototyping and pre-commercial manufacturing infrastructure, equipment and expertise are some of the challenges faced by newcomers in the biomanufacturing industry. The Biomanufacturing Industry Development Centre (BIDC) was established at the CSIR and has already supported several companies' efforts to convert new technology into market-ready biological products, such as food, cosmetic, water and sanitation products.

Developing South Africa's **biomanufacturing** industry

Biomanufacturing is a type of manufacturing or biotechnology that utilises biological systems to produce commercially important biomaterials and biomolecules for use in medicines, food and beverage processing, and industrial applications. In recent years, there has been a global shift towards bioprocessing, as these processes require less energy and lower capital input; produce less waste; and have a lower carbon footprint. The use of and preference for natural products as food additives and cosmetic and medicinal ingredients have also grown significantly.

Despite excellent local research and development in bio-based and natural products and processes, the conversion of outputs to commercialised products and technologies has been limited. Large and small businesses struggle to test or validate new and innovative products or technologies at market scale. Factors that contribute to the challenge include the limited availability of infrastructure and skills for product development, scale-up and prototyping and the fact that investment finance is often only available after market entry.

In response, the CSIR established the Biomanufacturing Industry Development Centre (BIDC), which was officially launched in 2016. The BIDC programme is funded by the Development Bank of Southern Africa through the Jobs Fund Programme and by the Department of Science and Technology's Industry Innovation Support Fund.

PROVIDING SKILLS, INFRASTRUCTURE AND EXPERTISE

The BIDC is a biomanufacturing and agroprocessing innovation hub where the CSIR provides access to experts in bioprocess development, product prototyping, scale-up and manufacturing. The organisation also houses laboratories for molecular biology, applied biochemistry, biocatalysis and fermentation, as well as laboratory and pilot-scale process development that can be mobilised to support industry. The latter includes expertise in the production and formulation of natural compounds into personal care, cosmetic, nutraceutical and medicinal products.

"The BIDC helps companies to optimise and validate their manufacturing processes and to make sure that their products meet regulatory, client and industry specifications. Through in-house expertise or partnerships, the BIDC also assists emerging businesses with access to markets and enterprise development. To date, the organisation has supported 23 companies, transferring 75 products and creating 179 permanent jobs," says Dr Daniel Visser, CSIR research and development strategy manager.

A final objective of the BIDC is to further enable the emerging biomanufacturing sector through developing a skilled workforce. In the past three years, the BIDC has formally trained 72 interns who have been placed with industry. The BIDC also provides practical agroprocessing and biomanufacturing training for government, academic and industry professionals.

DR DANIEL VISSER
CSIR research and development strategy manager

FORTIFIED FOOD PRODUCT

Instant porridge developed by Elvema Nutritions.

Elvema Nutritions tried to break into the retail market with their range of moringa-based food products.

The BIDC helped Elvema to develop validated formulations, to improve its packaging and to set up a manufacturing facility to supply a rising demand and reduce its reliance on contract manufacturing. The result is that its products are being sold in local retailers; 14 new permanent jobs were created; and the company is exporting 700 tonnes of product into the rest of Southern Africa.

Labelling for Elvema's moringa-based porridge.

PROCESSING MORINGA

Moringa leaves are processed to quality standards and supplied to manufacturers of various consumer products.

Biomoringa cultivates and processes moringa on a farm near Brits in the North West. Although the company had the required skills and experience to cultivate the moringa, it needed to be able to process the moringa to quality standards and add value to the processed moringa through further processing and packaging.

The BIDC assisted Biomoringa to standardise its leaf drying, milling and irradiation processes, as well as to design a seed pressing process to optimise the extraction of moringa seed oil. Biomoringa has signed a contract with Elvema to supply moringa leaves for incorporations into teabags and other products.

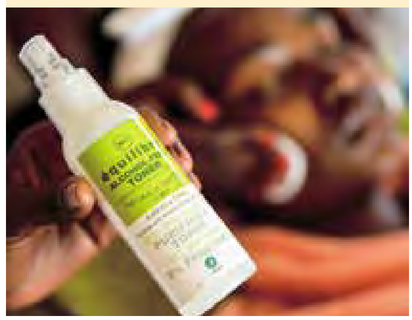
The CSIR was able to advise Biomoringa on the correct processing of the moringa to retain its nutritional and antioxidant properties, to scale up the production of dried moringa leaves and other products, specifying equipment needed at larger scale and to do nutritional and other testing.

GROWING A FORTIFIED SKIN CARE ENTERPRISE

Cosmetic products made by Marple Skin Care.

Marple Skin Care is one of the enterprises supported by the BIDC in the cosmetic sector. The enterprise manufactures skin care products that are fortified with indigenous African oils and butters.

The CSIR played a significant role in improving the competitiveness of these products and ensured that they stand out in the market by scientifically validating the product claims, thereby enhancing its selling proposition. Marple Skin Care's growth target for the first year after the CSIR's intervention is to double the size of the business.



GREEN CLEANING WITH ENVIRONMENTALLY-FRIENDLY PRODUCTS

Technologically advanced eco-friendly biological products.

The CSIR has built a library of naturally-occurring, South African *Bacillus* strains, bacteria that show promise for a number of industrial applications because they secrete enzymes that break down pollutants such as ammonia, nitrates and phosphates. The BIDC helped to establish the spin-out company, **OptimusBio**, which develops eco-friendly biological products for sanitation, water treatment, aquaculture and agriculture, using these indigenous bacteria.

To date, 22 products have been developed and transferred, leading to job creation in the company and its associated value chain. In 2016, the CSIR successfully implemented the use of these eco-friendly biological cleaning products across most of its campuses. The CSIR has also supported the South African National Defence Force to test the OptimusBio products for personal care, cleaning, as well as water and waste treatment during remote deployments in the Kruger National Park.

GROWING RECOMBINANT PROTEINS FOR BIOPHARMACEUTICALS

Products produced by JVS Biotech at the BIDC in Pretoria.

JVS Biotech acquired the rights to develop and manufacture technology for the production of insulin-like growth factor (IgF), a reagent used in cell culture media. To meet the market demand for the product, the technology has to be proven to work at laboratory scale and larger volumes need to be produced for market testing.

The BIDC has been instrumental in providing the necessary resources in terms of infrastructure, equipment and technical expertise required to develop these products and get them commercially viable. JVS Biotech was able to validate its technology and to ensure that it was feasible to manufacture locally.

LOCAL PRODUCTION OF A BIOPOLYMER FROM CRUSTACEAN SHELLS

Crustacean shells are used to produce chitosan, a high-value biopolymer.

ConnectMe wanted to use prawn, crab and langoustine shells to produce a high-value biopolymer for use in cosmetics, foods and fertilisers. The biopolymer (chitosan) was imported into South Africa at high cost and no manufacturing capability existed to produce it locally.

The CSIR helped ConnectMe to develop and scale up a manufacturing process for low and high molecular weight chitosan. More than 12 kg of market samples have been produced and there is already interest from an agrochemical solution provider to replace its current imports with locally manufactured chitosan.

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CSIR contributions to **maximise the value of industry waste**

BY PROF. BRUCE SITHOLE

Waste is a valuable resource with an estimated value of at least R25.2 billion per annum (0.86% of GDP). The value of waste from 13 potentially recyclable waste streams generated in South Africa, which is currently lost to South Africa's economy through landfilling, is estimated to be in excess of R17 billion per annum. Combined with the high unemployment rate in South Africa, the waste sector has been identified in national and provincial strategy and policy documents as a sector that can contribute towards the country's economic growth and job creation.

As a young economic sector, with an estimated turnover of at least R15.3 billion per annum, the waste sector has the potential to grow to at least twice this size through strong government and private sector investment. Waste recycling, recovery and beneficiation should become the focus of integrated waste management. This article highlights the CSIR's contributions in this domain.

The CSIR's research on industrial waste currently focuses on integrated waste management, waste and resource economics, waste innovation (technological and non-technological), waste data and information, and new value chains from organic waste.

The current recycling of 10% of waste unlocks R8.2 billion per year worth of resources into the South African economy. Therefore, there is potential to recover a further R17 billion per annum worth of resources back into the economy.

However, there are challenges in attempting to do this, especially for industrial waste. Waste is often not separated at the source, resulting in the contamination and loss of value and recycling potential. Furthermore, it is expensive to transport the waste and even more so if it has a high hazard rating. These costs are often limiting factors in the reuse and recycling of waste and in addition,

The forestry, timber, pulp and paper industries are inefficient in that they extract only about 35 - 47% of value from a tree, with the majority of the tree being lost as waste.

large volumes of relatively low-hazard waste are often situated far from markets. To beneficiate waste, high-tech solutions and skills are required. Lastly, legislative barriers hamper the reuse and recycling of waste.

South Africa can achieve waste beneficiation by focusing on two sides of the waste problem:

Supply side: Investment in infrastructure for the collection of waste, creating entrepreneurial opportunities and implementing policies and incentives that encourage the beneficiation of waste.

Demand side: Developing innovative uses of recycled materials in South Africa; the development of innovative new high-quality products from waste; and the development and implementation of biorefinery technologies.

Some examples of the CSIR's involvement in the valorisation and beneficiation of industrial waste are outlined below.

BENEFICIATION OF FORESTRY WASTE

The forestry, timber, pulp and paper industries are inefficient in that they extract only about 35 – 47% of value from a tree, with the majority of the tree being lost as waste. The waste is in the form of bark, branches, sawdust, process waste such as black liquor, red liquor, effluents and sludge, which is currently disposed of by landfilling or released into receiving waters (depending on the waste). These disposal methods are not environmentally sustainable. A closer look at the nature and chemistry of the wastes indicates that there is value that can be extracted from the materials. One promising technology is the application of the biorefinery concept. Biorefinery is analogous to today's petroleum refineries, which produce multiple fuels and products from petroleum. A biorefinery is a facility that integrates biomass conversion processes and equipment to produce fuels, power and chemicals from biomass. It is considered the most promising route to the creation of a new domestic bio-based industry.

By applying biorefinery technologies, high-value materials and products can be generated from the waste – the materials and products can be sold to help improve the financial balance of mills. In this manner, tree utilisation increases to well over 95% with no or little waste generated. Experience from industries that apply biorefinery technologies shows profits from biorefinery products that often exceed those obtained from the traditional products.

PROF. BRUCE SITHOLE
CSIR chief researcher and research group leader for biorefinery and forest products

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In the South African context, the CSIR is developing technologies for extracting high-value chemicals and materials from sawdust waste as follows:

HEMICELLULOSE SUGARS

Hemicellulose sugars are lost in chemical pulping of wood as they are not needed for pulp and papermaking. The CSIR is extracting these sugars from sawdust to collect xylose, which can be converted to xylitol, a low-calorific sweetening agent. Xylitol is a high-value product that is currently being imported into South Africa. It is a safe, low calorie sugar replacement for diabetics. Succeeding with the technology development would mean that the production of this material, which is currently selling for R150 per kg vs R40 for sugar, could be localised.

PINE OILS

The CSIR is developing methods to optimise the extraction of pine oils from pine sawdust. The pine oils are precursors for turpentine and phytosterols. Currently, a company in South Africa imports 20 tons of pine oil every three weeks and sells the product on the local market for approximately R40 – R60 per kg. Pine oil has many commercial uses such as in industrial and household cleaning products, disinfectants, solvents, fragrances, medicinal and aromatherapy products.

NANOCRYSTALLINE CELLULOSE

After the extraction of sugars and oils, the fibres that remain must be disposed of. The CSIR has developed a technology to convert the fibres into nanocrystalline cellulose – a high-value material that currently sells for US $1 000 per kg. The technology currently used to produce this type of cellulose uses dissolving wood pulp as a starting material. Dissolving wood pulp sells for about $1 200 per ton and the nanocrystalline cellulose yield from the pulp is about 15%. Our technology uses sawdust waste, which is currently available for free, and the nanocrystalline yield is about 40%.

MAXIMISING THE VALUE OF INDUSTRY WASTE

The CSIR works and helps industry to maximise the value of waste through research and development in the following areas:

- Waste policy and governance, and evaluation of best-practices
- Waste innovation: Opportunities for technological and social innovation
- Resource economics: Economic instruments, determining the true costs and benefits of waste management
- Waste behaviour: Human behaviour regarding waste recycling and waste picking
- Waste information management: Quantification and modelling of waste streams
- Hosting the implementation of South Africa's 10-year Waste Research, Development and Implementation (RD&I) Roadmap that is aimed at guiding RD&I and public and private sector investment in solid waste RD&I.

THE BIOREFINERY INDUSTRY DEVELOPMENT FACILITY

Development of biorefinery technologies and new high-value chains from waste is facilitated by the recently established Biorefinery Industry Development Facility (BIDF) in Durban. The BIDF was funded by the Department of Science and Technology and the CSIR and is a world-class facility, situated centrally to the major biomass process production region in South Africa.

WASTE CHICKEN FEATHERS

Poultry consumption generates more than five million tons of feathers a year. Demand for this by-product is unfortunately low, with most of it ending up being burned, buried or ground up as feed for livestock. The CSIR and the University of KwaZulu-Natal are researching cost-effective ways to extract keratin protein from chicken feathers for the manufacture of high-value products.

Feather meal, the current primary use of feathers, contains about 70 – 80% crude protein, but the digestibility of the protein is poor. The availability of nitrogen from feathers as fertiliser is also low, unless it is mixed with manure. Hence the majority of feathers are disposed of by landfilling or incineration. The problem with the disposal of feathers through incineration and burial is that these methods are energy intensive and not environmentally friendly, presenting biohazards.

Since feathers are made up of mainly keratin (91%), extraction of keratin protein or fibres from feathers would be a source of high-value materials. Keratin is in high demand in a variety of high-value industries, resulting in it selling for more than R2 400 per kilogram. By extracting keratin from feathers we may, in effect, be able to make this by-product more valuable than poultry meat. The harvested proteins could also be made useful in the form of keratin bio-fibres or keratin protein-based products. Electrospinning could, for example, be used to regenerate keratin bio-fibres that could in turn be used to replace synthetic petroleum-based fibres in the textile industry.

The CSIR is investigating options for the use of proteins extracted from chicken feather waste.

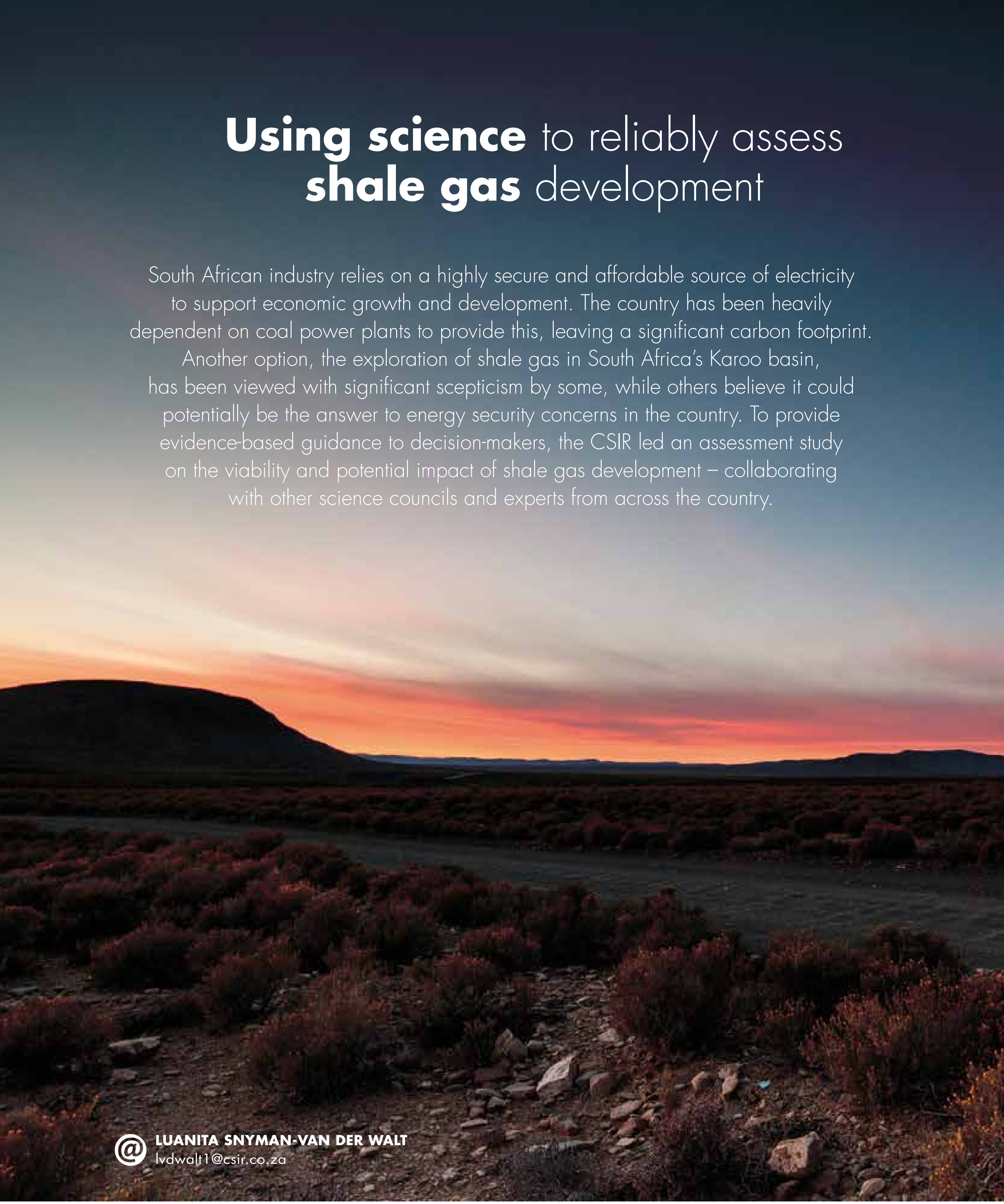
BENEFICIATION OF PULP AND PAPER MILL SLUDGE

In South Africa, approximately 500 000 tons per annum of sludge is produced from pulp, tissue and paper mills.

This sludge waste is mostly landfilled, discharged into the ocean via a sea outfall pipeline or incinerated. Implementation of environmental legislation, such as the National Environmental Management: Waste Act, 2008 (Act 59 of 2008) places the sector under considerable pressure to find better management practices for mill sludge disposal. However, apart from legislative pressure, pulp and paper mills can benefit from finding alternative methods of sludge management by producing value-added products to supplement the mills' income and reduce their carbon footprint.

The difficulty with pulp and paper mill sludge is the variants in process conditions (from mill to mill) and the type of fibre feedstock (virgin fibre or recycled fibre), which result in the properties of mill sludge being different. Therefore, a single solution for mill sludge diversion from landfill is not realistic and some beneficiation options might be better suited to certain mill types than others.

A typical sludge contains about 60% organic matter and 40% inorganic matter. The inorganic matter can be beneficiated through the manufacture of bricks whereas the organic matter can be beneficiated by the separation of fibres and converting them to nanocrystalline cellulose, as well as by the microbial processing of the sludge to produce biopolymer plastics.



Using science to reliably assess **shale gas** development

South African industry relies on a highly secure and affordable source of electricity to support economic growth and development. The country has been heavily dependent on coal power plants to provide this, leaving a significant carbon footprint. Another option, the exploration of shale gas in South Africa's Karoo basin, has been viewed with significant scepticism by some, while others believe it could potentially be the answer to energy security concerns in the country. To provide evidence-based guidance to decision-makers, the CSIR led an assessment study on the viability and potential impact of shale gas development – collaborating with other science councils and experts from across the country.

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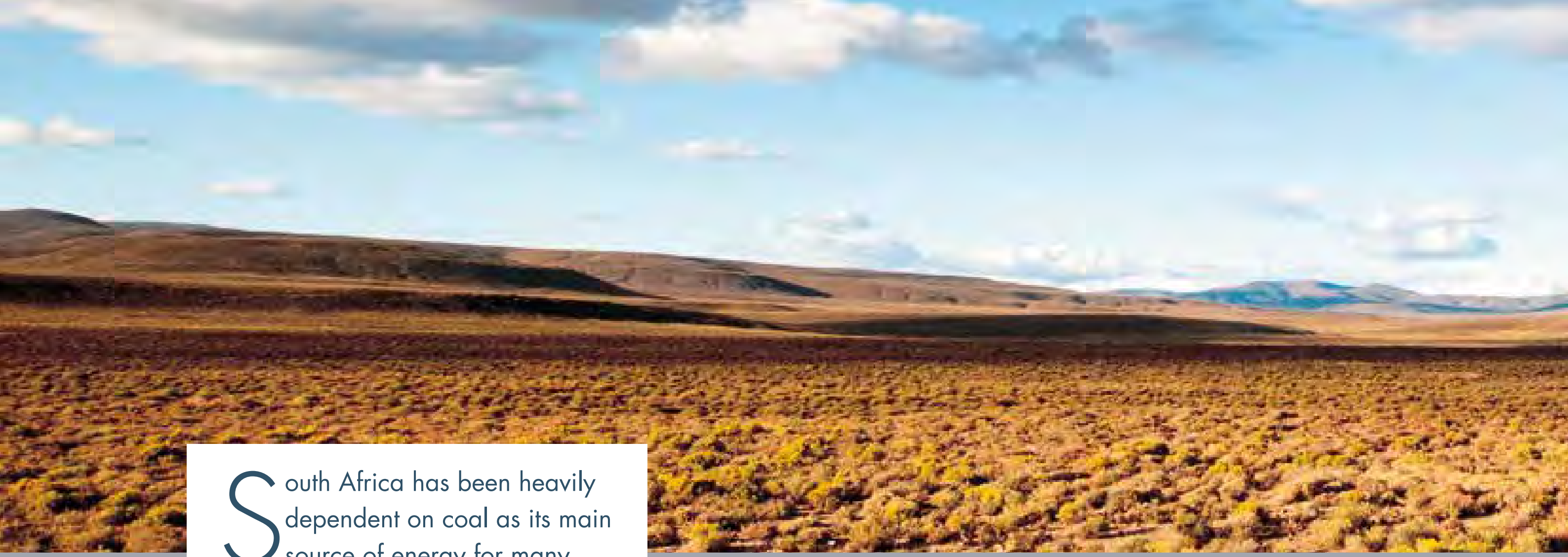
LUANITA SNYMAN-VAN DER WALT
CSIR environmental scientist and assessment practitioner



South Africa has been heavily dependent on coal as its main source of energy for many decades, with coal accounting for approximately 77% of South Africa's primary energy needs and 91% of our electricity generation. In line with global efforts to mitigate global warming, South Africa has been investigating alternative sources of energy, one being the introduction of more natural gas into the energy mix.

A potential option is to exploit naturally occurring methane from deep shale layers in the Central Karoo, through horizontal drilling and hydraulic fracturing, also known as 'fracking'.

"This has been a contentious issue with members of the public, scientists and decision-makers holding highly polarised views," says CSIR environmental scientist, Luanita Snyman-Van der Walt, who has been involved in the national strategic environmental assessment (SEA) for shale gas development in the Karoo.

"The questions relating to shale gas development have been presented as a trade-off between economic opportunity on the one hand and environmental protection on the other. Until recently, the issues were poorly informed by publically available and trusted evidence."

RISKS AND OPPORTUNITIES

Very little is known about the distribution and magnitude of the gas resource or whether or not it can be extracted at economically viable rates. If shale gas was found at economically viable flow rates, the economic and energy security opportunities could be substantial; however, there may be socio-economic and environmental risks associated with the life-cycle of a domestic gas industry.

Successful shale gas exploration could lead to significant economic benefits, energy security and reduced greenhouse gas emissions if it replaces coal burning. Potential risks include water use and contamination, pressures on existing municipal infrastructure and services, and changes to the social fabric and character of the iconic Karoo landscape.

COMMISSIONING SCIENTISTS

In 2015, the South African government appointed three science councils – the CSIR, the South African National Biodiversity Institute and the Council for Geoscience – to conduct this SEA to support responsible decision-making about shale gas development.

"The scientific assessment component of the SEA was completed in November 2016 following 12 months of intense investigation. It is the largest and most comprehensive scientific assessment ever undertaken in South Africa," says Snyman-Van der Walt.

"The process included detailed inputs from 146 expert authors covering 18 topic chapters, 75 independent peer reviewers, multiple governance groups representing a diversity of sectors and hundreds of stakeholders who participated in the process through various communication and outreach forums."

The outcomes of the scientific assessment presented the risks and opportunities associated with a range of plausible development scenarios. The results have been published as a peer-reviewed e-book and are freely available at **http://seasgd.csir.co.za/scientific-assessment-chapters/.**

CSIR CAPABILITIES

CSIR researchers contributed their expertise in the measurement and projection of air quality and greenhouse gas emissions, water resources, human health, geophysics, waste management, national energy planning and spatial planning and infrastructure. The assessment called for the collaboration of the CSIR experts in the field of natural resources and the environment, energy, the built environment, and implementation teams with private sector, research institutions, industry and government.

A semi arid Karoo landscape as sunset approaches.

KEY FINDINGS

The first outcome of the study was a set of plausible development scenarios for shale gas in the Karoo, based on a synthesis of the best available information. The study assessed the potential risk and opportunities for various issues, including biophysical aspects such as seismicity, water and biodiversity, as well as socio-economic aspects. The CSIR prepared a set of best-practice guidelines and ongoing monitoring requirements that should be satisfied by industry across the lifecycle of shale gas development.

"Key findings relating to water are that current potable water resources in the Karoo are already fully allocated. Any additional water requirements for shale gas development would need to make use of water from non-potable sources such as the treatment and transport of seawater from the coast or sourcing deep saline groundwater when undertaking drilling and fracking activities," says Snyman-Van der Walt.

"The risk assessment also identified the need for the treatment of groundwater from deep drilling, the need for a centralised waste facility, as well as requirements for wastewater treatment and recycling. The study found that one of the highest risks is that the fracking fluid leaks into the surface water and shallow aquifers used by people and ecosystems due to the inadequate sealing of the upper parts of the borehole or the surface-stored fracking fluid spills, for instance, during a storm. These risks can be mitigated, but not eliminated, by good engineering."

In terms of biodiversity risks, the actual spatial impact of the wellpads and connecting roads and pipelines is small. The biggest and least tractable impacts are likely to be social – the introduction of noise, traffic, lights, workers, work-seekers and their dependents into a formerly tranquil environment.

The results of the scientific assessment were finally packaged as a decision-support framework to guide decision-making and provide clear guidance for industry and government to proceed with shale gas exploration in an environmentally responsible manner.

Right: Volunteer scientists and naturalists collect and identify plants and animals in the Karoo as part of the South African National Biodiversity Institute's BioBlitz Programme to contribute to the biodiversity knowledge in the areas where shale gas development is proposed.

Infrastructure innovation as an enabler for **industrial development**

BY LLEWELLYN VAN WYK AND CHRIS RUST

CSIR experts have identified new sectors and trends for industrial development in infrastructure design and delivery, as well as specific opportunities for the CSIR to add value in construction, capital projects and infrastructure. This is in response to a CSIR drive to leverage its strong science, engineering and technology capability base to build and strengthen the organisation's contribution to industrial development.

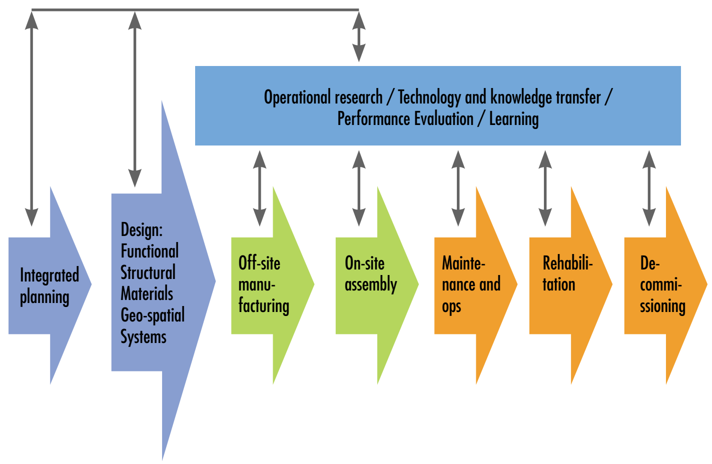
A globally emerging trend is to align the design and delivery of infrastructure – the fundamental facilities and systems serving a country, city or area, including the services and facilities necessary for its economy to function – with manufacturing sector processes. The trend has emerged for two reasons. Firstly, a well-functioning infrastructure and an efficient built environment are crucial to socio-economic development and poverty alleviation. This is emphasised in a number of government policies including the Medium Term Economic Framework, the National Planning Commission Diagnostic Report, the National Development Plan and the National Infrastructure Plan. Secondly, manufacturing remains a key driver for sustained economic development. It has high economic multipliers because of its value-addition, linkages to the upstream production sectors of the economy (mining and agriculture) and the downstream sectors, including services, and its all-round contribution to strengthening integrated value chains. In addition, certain manufacturing sectors have high employment multipliers across the value chains, drive technology and innovation through technology absorption and diffusion as well as research and development. These sectors support and enable the growth of the national skills capacity and capabilities and the movement towards a knowledge economy. Alignment of the two present a significant win-win scenario for the country.

A key research question is how new industrial processes can be developed and applied to the design and delivery of construction, capital projects and infrastructure such as:

- Building design, materials, products and construction processes
- Road design, materials, products and construction processes
- Airport and runway design, materials and construction
- Railway design, materials and construction
- Water infrastructure design, materials and construction, specifically rainwater, stormwater, greywater and blackwater harvesting, treatment, recycling and reuse infrastructure
- Port design, materials and construction.

The industrialisation of construction activity has been a global research and development topic for some time and some examples of the application of this philosophy has been seen. In essence, this implies increased off-site manufacturing of most of the components for infrastructure and on-site assembly. This will modify the value chain (see below).

A modified supply chain for the infrastructure and construction sector to allow for the industrialisation of the process



LLEWELLYN VAN WYK
CSIR principal researcher

The CSIR is involved in more than 100 projects for the public and private sectors in infrastructure planning, design, materials, delivery, maintenance, operation, rehabilitation and upgrading and decommissioning. Some of the projects with an industrial development impact are outlined below.

Precast insulated concrete house

The CSIR experimented with the design and construction of a precast insulated low-income house on the CSIR Innovation Site on the Pretoria Campus. The house was designed to be constructed from a set of six parts. The set comprised four external walls, one internal wall and one roof panel, multiplied four times. The panels consisted of high-performance concrete skins with an insulated core. The wall panels were complete with windows and doors as required.

The foundations and floor slab of the house were constructed using conventional construction technologies and methods. After curing the floor slab, the precast panels were hoisted into position using a 40-ton crane. From hoisting the first panel into position, to the house being closed up, took 8.5 hours, with the only outstanding tasks being connecting the services and installing the fittings.

The work followed an agreement between the CSIR and the Royal Danish Embassy in Pretoria to apply research in construction materials and methods to improve housing in South Africa. The project included an assessment of various manufactured housing technologies with a view to selecting one deemed appropriate and relevant to South Africa and the construction of a demonstration house using this technology.

A demonstration house constructed at the CSIR using manufactured housing technologies suitable for South African conditions.

Hoisting a precast walling element of the demonstration house into place.

A modular clinic

The CSIR has designed a modular clinic that is self-sufficient, sustainable and robust.

It comprises a centrally manufactured set of parts, which can be deployed by truck to any site in South Africa and easily assembled with minimal site preparation – ready for service. The truck will contain all the necessary items for operation, even to support water, energy and security needs. All fittings, furnishings and essential equipment will be included. Units will comply with South African national norms and standards for healthcare infrastructure and, more importantly, National Building Regulations. Although the units will be made with lightweight materials, indoor comfort and performance will be engineered for the South African climate. Each unit is self-sufficient and units can be incrementally added over time to form a complex building. They will require relatively low maintenance and can be demounted and removed from site at the end of service life.

Metakaolin cement blend

The CSIR has developed a replacement for Ordinary Portland Cement (OPC) called metakaolin, based on the clay mineral, kaolinite. Metakaolin can be used to make concrete, blocks, bricks and pavers. The potential benefits of metakaolin over OPC include: A lower carbon footprint, enhanced strength, higher durability and lower production cost. The next developmental milestone is the setting up of an industrial-scale pilot plant to produce metakaolin and cement blends.

Geo-polymer bricks

The CSIR has developed cementitious binders that are free of OPC. The inventions are a family of fly ash-based geopolymer binders that have been used to make bricks, blocks and pavers on a laboratory scale. Fly ash-based geopolymer binders are attractive alternatives to OPC for making building and construction materials and for the encapsulation of hazardous waste due to their high strength, low oxygen permeability, low shrinkage, as well as sulphate and acid-resisting properties. The advantages of using a fly ash-based binder over OPC include a much lower carbon footprint, higher durability and a lower production cost. The fly ash-based binders are three-dimensional alumina-silicate materials formed by poly-condensation of alkali-activated alumina-silicate precursors at room temperature or at slightly elevated temperature and controlled humidity.

The CSIR's Lorato Motsatsi inspecting a scale model of the modular clinic.

The impact of heightened industrial development in the construction sector can be potentially profound. However, it will require high-level discussion and cooperation with many stakeholders and partners. It will require an industrial development strategy that is aimed firstly at providing infrastructure to government (all publicly owned infrastructure), based on a completely new business model involving a number of new industrialists that can serve this market effectively. This will, in turn, require engineers and technologists who have been educated and trained in new construction processes, methods and materials. Lastly, it will require extensive research and development by the CSIR in determining the most optimal modalities for the South African context.

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Innovation in the **transport sector** to **support industrial development**

The CSIR is drawing on its multidisciplinary competences to develop products and systems with the potential to contribute to industrial development in the transport sector. The organisation also undertakes research and development that contributes to an efficient rail, roads and ports transport system, which enables the movement of goods and people between manufacturers, producers, service providers and their clients and markets.

Right: Field trials of a rail inspection device that travels the rail autonomously, performing inspection of various parameters of interest on both the rails and surrounding infrastructure.

Innovative transport products and systems with industrial development impact

A LOCOMOTIVE TO SUPPORT RAIL TRANSPORT IN AFRICA

A market analysis commissioned by Transnet Engineering identified significant opportunities in Africa for locomotives designed for African conditions. Transnet wants to establish itself as the preferred original equipment manufacturer for rolling stock in Africa, reducing the need to import skills and components from abroad.

The CSIR has partnered with Transnet to support an initiative that focuses on the development of the Trans Africa Locomotive.

A train condition monitoring subsystem provides for essential information on many locomotive functions. Therefore, its efficiency is critical to safety. Transnet and the CSIR formed a joint team consisting of system engineers, electronic engineers and software developers for the development of this system. The first phase of this collaboration focused on establishing the system requirement and interface specifications. The team developed the electronic hardware, as well as the software for the first prototype unit as part of an effort to establish this development capability. This unit will be integrated in the first prototype of the Trans Africa Locomotive.

Innovative transport products and systems with industrial development impact

The Busmark production facility (top left). The CSIR has developed a condition monitoring system (top and below left) for the company's fleet of buses.

INTELLIGENT VEHICLE MONITORING

Vehicles such as trains and buses need to operate reliably and cost-effectively. They also need preventative maintenance to prevent costly breakdowns.

CSIR researchers have developed vehicle condition monitoring systems for the rail and bus transport industry that collect and analyse vehicle, driver and passenger data to optimise the operation of buses and locomotives. They are working on prototypes for Busmark's fleet of buses and Transnet's locomotives. These systems collect data from on-board sensors, cameras, engine control units, third-party systems, as well as provide information such as global positioning data. This is communicated to drivers, supervisors and fleet operators. The data is transmitted to a central server and analysed with computer algorithms to detect journey and vehicle anomalies, as well as analyse trends. The system can determine vehicle location, detect driver and commuter behaviour, capture incidents and monitor fuel consumption amongst other parameters. All of this data are generated and analysed in real-time and the system can generate early warnings.

The project has the potential to create local expertise through the manufacturing of these devices, jobs and faster turnaround times in maintenance and repairs.

THE AFRICA TRUCK

The CSIR, Denel Vehicle Systems, Armscor and the South African National Defence Force (SANDF) have joined forces to develop a versatile protected vehicle that can withstand the challenges of rough terrain and various threats encountered in the SANDF operational environment, while fulfilling national commitments and the demands of our armed forces in Africa.

The intent is to create a family of vehicles with modular, interchangeable attributes to offer a range of transportation options, limit the environmental footprint of a military logistics support capability, and open opportunities for the development of new enterprises, jobs and skills.

The Africa Truck is similar to the RG31, a South African-developed mine protected vehicle that is sold internationally and has a proven track record of saving lives in conflict environments.

The capability demonstrator configuration of the truck has a roll-on-roll-off load carriage that enables it to transport different cargoes such as personnel, fuel, water, medical supplies or a full field hospital. Other enhancements include integrated armaments and protection against landmines and improvised explosive devices, which are increasingly being encountered.

The Department of Defence (DoD) has initiated a formal acquisition process to further develop, industrialise and manufacture the truck against the SANDF user requirement specification.

The broader intentions of the development are well aligned to the national priorities of small, medium and micro enterprise development, technology localisation and economic stimulation, locally and elsewhere on the continent. The CSIR, through its national mandate, its technology directive from the DoD and its diversified capability base, is well positioned to assist the programme to deliver on these intentions.

The Africa Truck rapid development capability demonstrator. The Africa Truck is a versatile protected vehicle able to withstand threats encountered by the South African National Defence Force in the operational environment.

SMART TRUCKS FOR TRANSPORT EFFICIENCY

Designers of heavy vehicles can now use innovative solutions and the latest technology to meet the required performance, safety and productivity standards. This follows a new performance-based standards approach adapted from a similar Australian system by the CSIR as part of the Smart Truck pilot project in South Africa.

The CSIR's Smart Truck standards framework was specifically tailored for South African conditions and comprises 12 safety and two infrastructure standards that govern actual on-road vehicle performance.

Initially, all performance-based assessments, which involve sophisticated modelling and simulation, were outsourced to experts in Australia and New Zealand. CSIR engineers have helped to build local capacity for conducting these vehicle safety assessments in collaboration with other technical experts. These standards ensure that trucks are stable on the road, can turn and stop safely and are road and structure-friendly.

The CSIR records operational data of each Smart Truck on a monthly basis, tracking key performance indicators. To date, after some 100 million vehicle kilometres, the 230 Smart Trucks in use have shown a 65% reduction in crash rates, 14% reduction in fuel consumption, saving over 362 000 trips, 10.9 million litres of fuel and more than 28 000 tons of carbon dioxide.

Smart Truck designs are assessed using simulation tools developed by the University of Michigan, as well as pavement analysis software developed by the CSIR.

An efficient transport system to underpin industrial development

An efficient rail, roads and ports transport system is vital for the South African economy and for increased industrial activity as it enables the movement of goods and people between manufacturers, producers, service providers and their clients and markets. The CSIR's contribution in this regard is pivotal.

The railway survey and inspection device is fitted with sensors that detect hazards and alert the train driver.

The ultrasonic broken rail detector system.

CONTRIBUTING TO EFFICIENT RAIL TRANSPORT

Defects and obstacles on and around train tracks cause delays and deadly accidents and cost the railway industry millions every year. CSIR engineers have developed a **survey and inspection device** that travels ahead of the locomotive, alerting the driver of obstacles and potential hazards at level crossings. The device is also designed to inspect and report the condition of the rail infrastructure. The device is fitted with sensors such as cameras and laser scanners and will travel 1-2 km ahead of the locomotive, surveying the track for obstacles such as animals, vehicles or missing tracks. Once an obstacle is detected, the unit notifies the train driver with live video feedback.

The CSIR has also developed ultrasonic transducers used in a system that effectively monitors railway infrastructure. Broken rails are a major cause of derailments that cost Transnet Freight Rail millions per incident.

Transnet contracted the Institute of Maritime Technology (IMT) to develop an **ultrasonic broken rail detector system** that could detect broken rails along the length of the rail line in near real time. The CSIR was subcontracted by the IMT to develop ultrasonic transducers that form an integral part of this system. The solar-powered system has the ability to continuously monitor railway lines for breaks without human intervention.

The piezoelectric transducers are permanently attached to the rail and transmit ultrasonic waves along the rail between transmit and receive stations, which are placed alternately along the length of the rail. If the required ultrasonic signals are not received, an alarm is activated to indicate that there is a broken rail.

The broken rail detector system is currently installed on Transnet's heavy-duty iron ore line (860 km of track between Sishen and Saldanha Bay), on sections of their coal line (460 km of double track from Ermelo to Richard's Bay) and on two test sections in India. In the past, the system detected seven rail breaks and prevented potential derailments, which could have cost as much as R80 m per event.

Research performed at the CSIR on the excitation and propagation of guided wave ultrasound in rails has led to the development of a second-generation transducer that is smaller, but more powerful than the original transducers. This transducer will be used in the next version of the system, which is in the final stages of testing. This system will have doubled the distance between transmit and receive stations, thereby significantly reducing the per-kilometre cost of the system. Currently, research is being performed on the detection of cracks prior to the occurrence of a rail break. The intention is to add functionality to the system to detect defects before breaks occur and to therefore prevent rail breaks. Efforts are underway to commercialise the system in South Africa and abroad.

The CSIR has developed advanced asphalt products that have been used on these heavily trafficked roads in KwaZulu-Natal.

CONTRIBUTING TO AN EFFICIENT ROAD NETWORK

South Africa's economy relies on a vast road network. The CSIR has a long track record in research and development that contributes to an efficient road network.

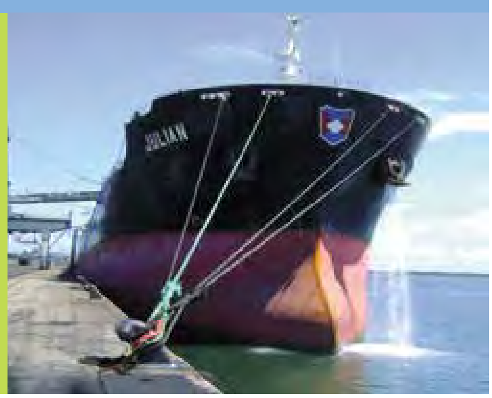
The organisation has developed a number of advanced asphalt products for roads. One example is High Modulus Asphalt (HiMA), which is a product that can be used on very heavily trafficked roads. The CSIR has completed a five-year monitoring programme following the construction of a long-life road using HiMA. The test was conducted along a part of the South Coast Road in Durban and demonstrated that the test road was able to withstand heavy traffic. HiMA is a mixture of very hard paving-grade bitumen and good quality fully-crushed aggregates, customised to South African conditions. The outcomes of the monitoring programme will feed into the future revision of the HiMA performance specifications in South Africa. The test, conducted on behalf of the Southern African Bitumen Association, commenced in 2011 with the construction of the base layers.

Other examples of CSIR contributions to an efficient road infrastructure include the revision and updating of the South African Road Design Method for the South African National Roads Agency Limited and supporting the Gauteng Department of Roads and Transport with its road asset management system.

THE CSIR HAS COMPLETED A FIVE-YEAR MONITORING PROGRAMME FOLLOWING THE CONSTRUCTION OF A LONG-LIFE ROAD USING HiMA.

CONTRIBUTING TO EFFICIENT PORTS OPERATION

South Africa's economy depends on international trade and its eight main ports are gateways to over 90% of South African trade. CSIR research helps make these ports safer and more efficient. Coastal engineers model and study the impact of proposed port development such as widening port entrance channels, simulating how moored vessels will respond to changes in port structure and doing numerical model simulations of the loading and unloading efficiency of moored vessels. The organisation also monitors ports and harbours by integrating data on waves, currents, tides and wind and water quality.



Committed to **mining research** for the **benefit of South Africa**

BY NAVIN SINGH

The CSIR is committed to undertaking research, development and innovation to benefit the South African mining sector. The organisation affirmed this commitment through the development and implementation of the South African Mining, Extraction, Research, Development and Innovation (SAMERDI) strategy – a key outcome of the Operation Phakisa: Mining programme.
The strategy seeks to extend the life of platinum and gold mines in South Africa beyond 2025 and establish global leadership in narrow-reef, hard-rock mining systems.

The mining industry has the potential to become an engine of industrial development, both in terms of the upstream capital goods sector and the downstream beneficiation sectors, such as the steel and high-technology industries, for example, fuel cell manufacturing.

But like all industries, the competitiveness of the mining industry will be determined by the continuity, extent and quality of innovation across the entire value chain. The challenge for South African mining is that the country's most profitable orebodies have been exploited and the remaining resources have become harder to access and extract. The technical challenges to mine have become even more severe, compounded by economic constraints and the increasing cost of labour.

The lack of development and implementation of new technologies necessitate a shift in mining philosophies to ensure the longevity of the industry in South Africa. Hence, the rapid developments of new systems with a strong focus on localisation of design and manufacturing is required, coupled with significant investments in research and development.

The South African mining sector requires innovative and multidisciplinary solutions to become an engine of industrial development.

NAVIN SINGH
CSIR competence area manager for mining and mineral resources

CHURNING THE WHEELS OF THE ECONOMY

Mining is a major driver of South Africa's economic engine, accounting for **8% of the country's gross domestic product**.

The sector provides **jobs** for nearly **half a million people** directly and another **six million** indirectly.

Unpacking the SAMERDI strategy

Guided by the outcomes of the Mining Phakisa, the Mining Precinct at Carlow Road was established at the historical home of mining research at the CSIR's Carlow Road facility in Johannesburg, from where the CSIR will drive mining industry research and innovation.

The key objectives of the strategy are to rebuild and reposition South Africa as the world leader in mining research and development in tabular reef mining, to establish a viable and enduring mining research and development hub involving industry, academia and relevant science councils and ultimately, to improve the competitiveness of the sector while creating new opportunities for South African-based companies.

The strategy outlines three key focus areas that will ensure the longevity of mining operations in South Africa. The focus areas are current mining operations, mechanised drilling and blasting and 24/7 non-explosive rock breaking. The first focus area seeks to understand the efficiency of current operations in terms of extraction while reducing costs and improving occupational health and safety. The second focus is on the development of fully mechanised mining systems that will enable drilling in narrow, hard-rock mines. Finally, to ensure the longevity of mining operations in South Africa, the third focus is on the development of complete mining systems for extraction that is wholly independent of explosives.

The Mining Precinct

The Johannesburg-based Mining Precinct is geared to develop new people-centred technologies and techniques that will empower mines and prepare them for modern mining methods. The establishment of the precinct means that the public and private sectors are now sitting under one roof to ease collaboration. The precinct hosts different hubs that focus on mining technology, manufacturing and sustainable development.

The precinct works with other entities including the CSIR, the Department of Trade and Industry, the Department of Science and Technology and the Chamber of Mines to provide a collaborative and communicative environment that encourages open innovation.

A key focus is to motivate not only South African mines, but also local equipment manufacturers, to increase the production of mining products, conduct research and development into new equipment, as well as to manufacture specialised products to supply the South African mining industry.

Exporting locally manufactured mining equipment is also a cornerstone of the push for localisation. Specifically, the aim is to increase the visibility of the South African mining equipment manufacturing sector as a reliable source of modern, specialised underground mining equipment for narrow-reef, hard-rock mines – specifically to the international mining sector.

Top right: The CSIR is assessing the use of electrical resistance tomography as an alternative to on-going borehole monitoring of acid mine drainage.

Right: The CSIR's RockPulse platform, a microseismic data acquisition and processing platform, is an early-warning system for large rockfalls, goafing during stooping operations and the optimisation of safe re-entry time after blasting operations.

Mining Phakisa objectives to benefit from CSIR's multidisciplinary offering

The CSIR's multidisciplinary skills base is key in helping to solve the increasingly complex challenges of our time. It enables us, for example, to assemble a project team drawing on experts in information and communications technology, microbiology, geology, mechanical engineering and mathematical modelling to find suitable solutions.

While the SAMERDI strategy – a fairly new strategy – details bold plans for the future of mining in South Africa, it largely integrates the pre-existing strategies of the Departments of Science and Technology, and Mineral Resources, as well as that of the CSIR. Hence, as in the past, the CSIR continues to develop fatigue, dust and noise management programmes for a variety of industries, including mining. Dedicated occupational hygienists are working in one of the most advanced facilities for monitoring dust exposure in the workplace, in South Africa.

Additionally, the CSIR continues to address technologies that will enable mechanisation and automation for both underground and surface mining, including underground positioning, location and navigation, and the development of autonomous mining systems and related sensor networks.

Mine safety remains a core focus for the CSIR. One of the most recent monitoring systems is GoafWarn – a sensor system that provides warning prior to the onset of a collapse in coal mines and warns miners who may be affected. Furthermore, geophysical techniques and seismological applications continue to allow various on-mine risk mitigation strategies and support for analysing natural hazards.

The CSIR also manages a fire and explosion testing, training and research and development facility at Kloppersbos, north of Pretoria. The facility conducts research into the explosive characteristics of South African coal mines. It is one of five CSIR testing laboratories and provides a full-scale surface-testing facility for the evaluation of underground explosion suppression systems; the flammability of conveyor belts; dust suppression systems for continuous mining; and similar investigations.

At the CSIR, we are very conscious of the fact that mining R&D does not take place in isolation. Mining activities are part of much larger social, economic, and natural systems. We therefore also undertake research that supports post-mining landscapes, decision-making processes and enterprise-creation development, particularly in areas such as water, air quality, and land use.

Mining has a powerful contribution to make in the context of the goals of the National Development Plan and Industrial Policy Action Plan. But, it also carries with it a legacy of environmental and human health impacts, as well as socio-economic concerns. What the sector needs are innovative, multidisciplinary solutions that will ensure the continuation of the economic and developmental contributions of the sector to the country, but also enhanced safety, reduced environmental impact and options for alternative land-use post mining. The CSIR is well positioned to deliver on this important mandate.

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"From manufacturers looking to gain greater insights into streamlining production, reducing time-to-market and increasing product quality to financial services firms seeking to upsell clients, analytics is now essential for any business looking to stay competitive. Marketing is going through its own transformation, away from traditional tactics to analytics – and data-driven strategies that deliver measurable results."

From: "Roundup of Analytics, Big Data; Business Intelligence Forecasts And Market Estimates", 2014, Forbes Technology

Growing South Africa's **wealth** through **digital innovation**

BY DR QUENTIN WILLIAMS

Since the 18th century, there has been continuous additions to the spectrum of jobs involved in human labour – from manual jobs, which have diminished but not disappeared, to machine operations, factory management and computer controllers, to creators of artificial intelligence (AI) and digital or robotic manifestations.

This revolution has taken us from being reliant on nature for creation and production (agriculture), to creating our own products and services crediting human ingenuity (industry), to utilising our creations (AI and robots) for product and service development (digital). This change in the nature of jobs has accelerated in recent years through the advancement of AI and brings to question the impact this will have on the structure of and numbers available in the South African job market.

UNDERSTANDING THE IMPORTANCE OF JOBS

According to the World Bank's South Africa Economic Update 2017, "Innovation, when successful (leading to increased sales), generates additional employment, even if entailing more capital-intensive production processes." This is in stark contrast to South Africa's rising unemployment rate and the loss in professionals with advanced skills, fuelled by emigration. This interplay of factors is severely hampering South Africa's ability to create additional wealth, or in other words, its ability to more efficiently produce goods and services that can be expanded to other markets.

Throughout history, efficiency in the production of goods and services has always been increased through the combination of machines' production consistency and speed; human insights and creativity, and importantly, innovative business processes that combined what machines produced with human labour for new business models and delivery mechanisms. Aside from Henry Ford's assembly lines more than 100 years ago, recent examples like Zara's fast fashions, Google's Deepmind applied to healthcare and energy distribution, X.ai's digital personal assistant, and Uptake technologies' insight platform, show how rapidly machine + human + process is changing our ability to create goods and services.

DR QUENTIN WILLIAMS
Strategic research manager: CSIR Meraka Institute

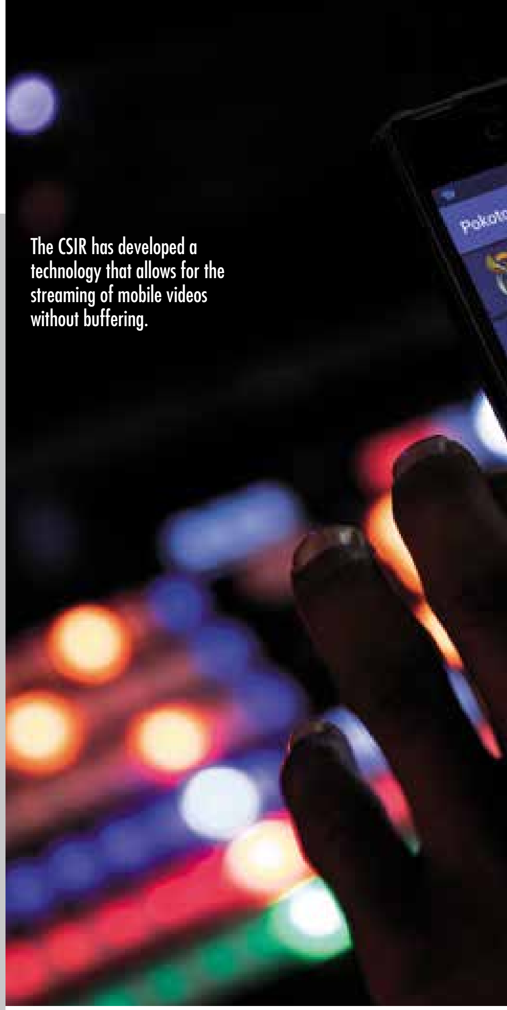
South Africa has increasingly become a net importer of information and communications technology goods and services.

A REVOLUTION IS A TERRIBLE THING TO WASTE

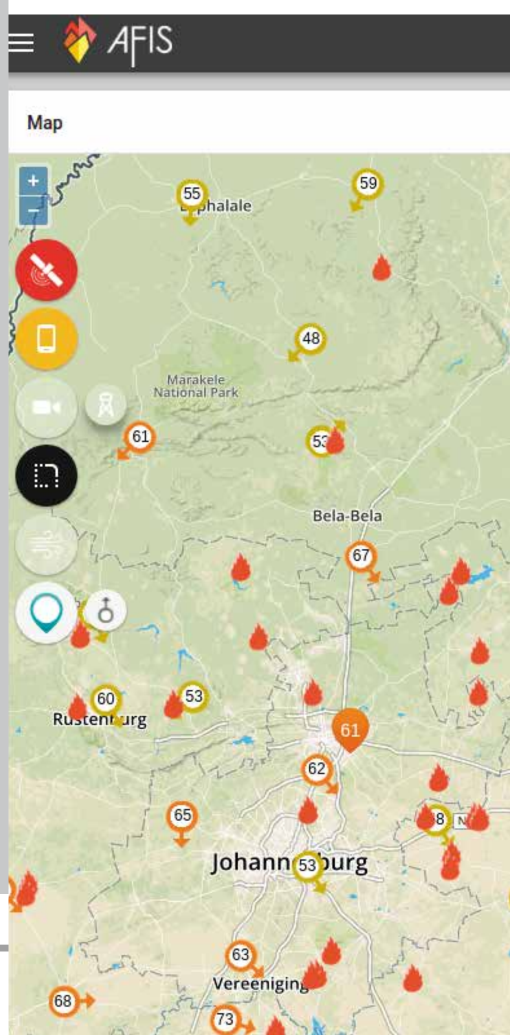
During this time, and in particular in the last 40 years of the digital era (personal computers, the Internet, mobile phones), South Africa has increasingly become a net importer of information and communications technology (ICT) goods and services (see graph above). The trade deficit for ICT has grown since 2011, from R42 billion in 2011, to R97 billion in 2014. Almost half of ICT imports (47,5%) consisted of radio, television and communication equipment, and 30,7% consisted of office and computing machinery. This highlights South Africa's reliance on other countries to provide it with ICT equipment, such as smartphones, tablets, computers and servers. South Africa's largest ICT export, 60,5% of all ICT exports, was broadcasting, telecommunications and information supply services related to South Africa's expansion into Africa with cellphone services and pay television.

In contrast, countries like the United States of America (Silicon Valley), China (17 national-level innovation demonstration zones), India (Bangalore's technology park) and the United Kingdom (Silicon Fen) have created ecosystems where new start-ups can rise and fail, as well as succeed phenomenally (Google, Tencent, Mindtree and Markit) creating new wealth for their countries.

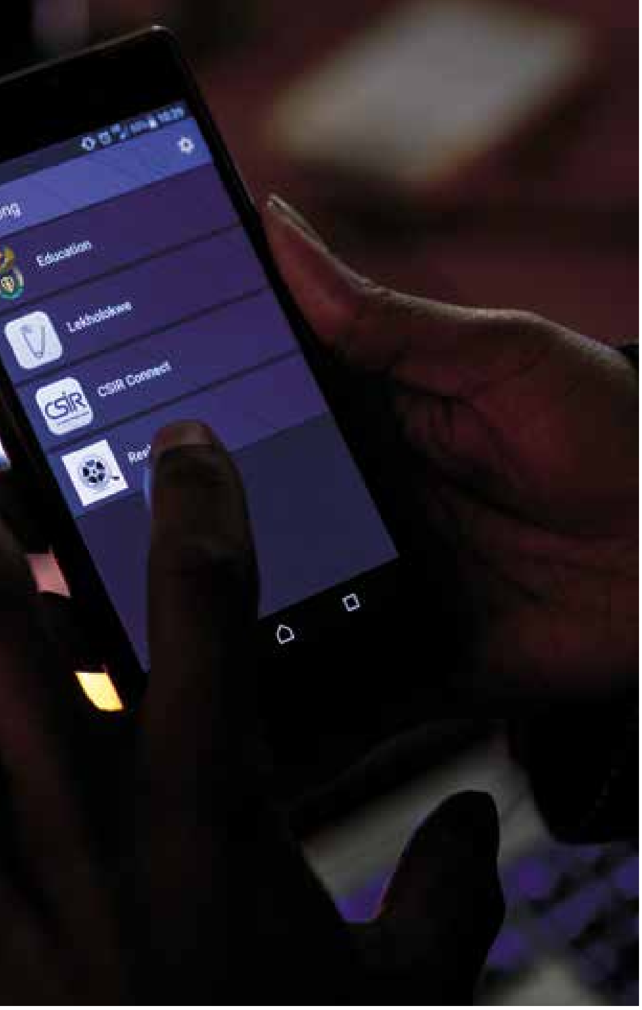
Digital technologies are unleashing new economic and social dynamics that result in the digital transformation of industries and societies such as Uber, Airbnb and Zara. Businesses and government institutions are increasingly moving towards data-driven business and delivery models. Therefore, it is important for any country to hold the data it creates (and thus own) and to localise the analysis of it (creating economic value), as opposed to importing these technologies or services. The mastery of these technologies is essential to South Africa's industrial competitiveness and our ability to integrate into competitive global value chains.

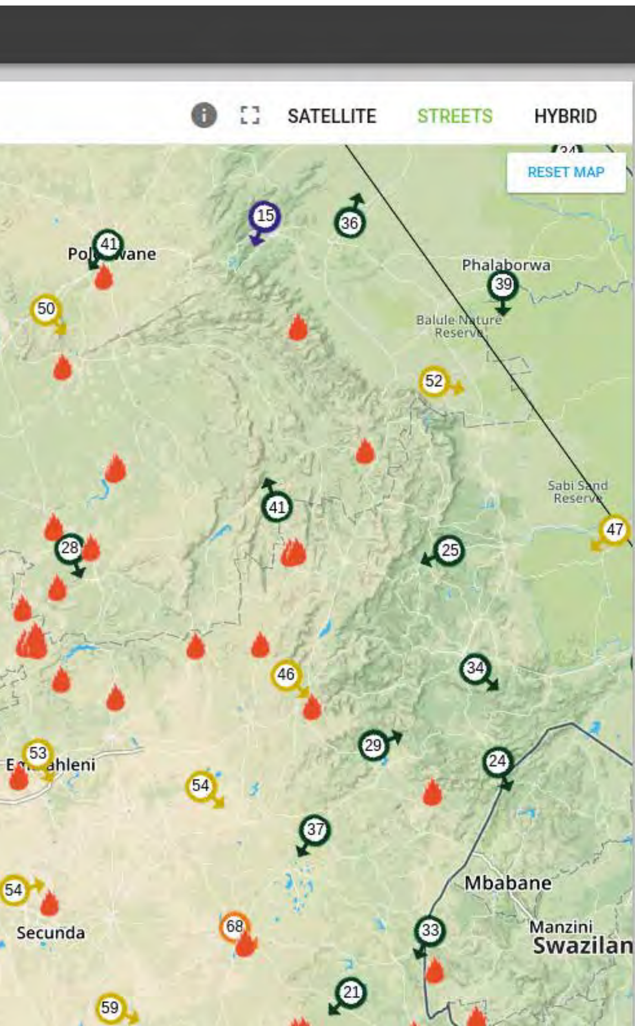


The CSIR has developed a technology that allows for the streaming of mobile videos without buffering.



Right: A screen view of the CSIR's Advanced Fire Information System. The system has grown into a globally used, easily accessible system that provides immediate fire and fire risk information and automatically sends it to users.





TOOLS FOR AN INCREASED DIVISION OF LABOUR

South Africa is facing significant challenges in utilising these emerging technologies for the effective production of goods and services, creating new jobs and wealth. Apart from advanced skills, there is also a lack of locally produced tools and platforms that can lower the barrier for the creation of innovative new products, services and business models.

The CSIR is ideally placed to significantly change around the net import status of South Africa and create new wealth – a digital advantage – based on local research and developed technologies (base tools and platforms), in combination with human ingenuity and process innovation. CSIR technologies, such as the Advanced Fire Information System (AFIS), are already being exported to Asia, Europe and North America, as a data-driven fire management service. Artificial intelligence-based fire-spread models built into software systems are creating new ways of combating fire disasters. The CSIR's Micro-Enterprise Media Engine platform is creating youth employment through mobile TV innovations, unlocking global audiences for mobile television production, permitting local stories, songs, life experiences and filming talent to be shared with global audiences, creating a new emerging economy to emerging economy industry. The organisation's data science solutions factory is providing low-code data science platforms, solutions and capabilities for small, medium and micro enterprises to build analytics services for South African companies. These are just a few examples, in which the CSIR is developing digital innovations that create new wealth through:

- Technologies that enable the South African industry to develop applications and content that are relevant to South Africa and can be exported to other emerging economies
- Technologies that can be transferred to local industry to improve efficiencies in the delivery of services, in the ICT sector, as well as in other sectors
- Technologies that disrupt entire industries and as a result create new markets and industries.

The CSIR is continuously researching and developing these new innovations and will play a significant role in shaping an ecosystem that will allow new businesses to be created. This can only be done in partnership with others in the National System of Innovation that provide support in the form of infrastructure, policies, product development, implementation, business model innovations and venture capital. Therefore, in the age of the 4th Industrial Revolution, new jobs, an increase in wealth, economic prosperity and growth, lie ahead for South Africa.

DR QUENTIN WILLIAMS
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What **smart technology** implies for the **industry of the future**

BY LEE ANNAMALAI

It is inevitable that all products in the future will be smart and connected. However, what does this mean for the manufacturers of these products? Essentially – leveraging the power of digital to create more connected and customised customer experiences will become the core business model of the future.

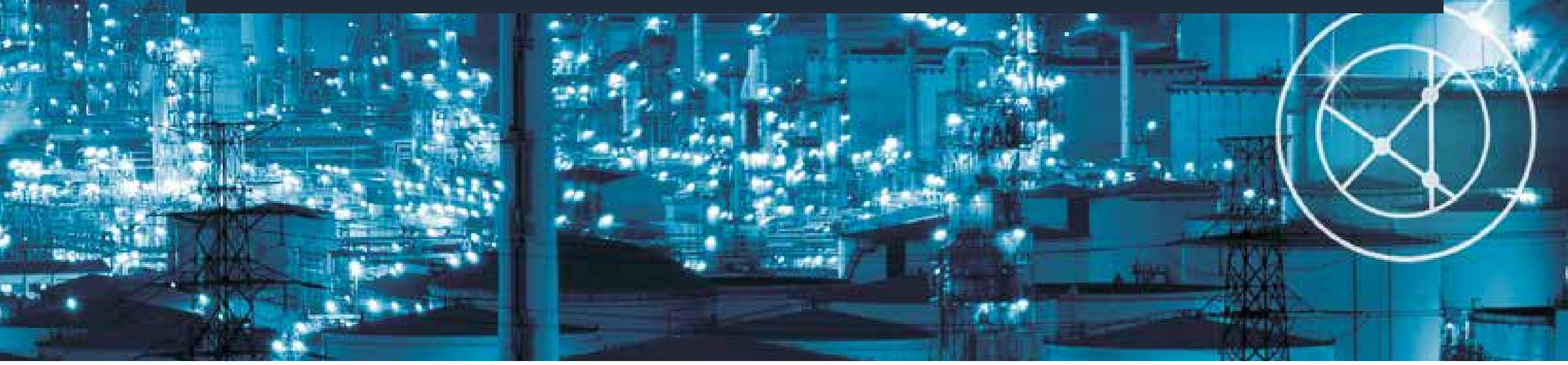
On the journey to this digital future, which is not that far ahead, a host of new design approaches, manufacturing technologies and partner ecosystems will have to be adopted and integrated into the business at a dizzying speed or customers and markets will move on and leave the business behind.

The concept of ubiquitous computing was introduced in a paper by Mark Weiser in 1991, a mere 26 years ago. It envisaged a ubiquitous sensate environment in which cognitive engines (software-enabled analytical machines) are able to respond relevantly to real-world events, essentially creating an augmented cyber-physical world. The growth and roll out of wireless sensing has accelerated in the past decade and this has been the bridge between the digital and physical worlds. These connected sensors measure any aspect of machine or product state and relay data back to manufacturers, owners or operators. This essentially opens up new work processes and business models and increasingly the collected data is first analysed by a machine before it reaches human eyes, generating forecasts, correlations and options for decision-making. For example Standard Bank uses IBM's Watson artificial intelligence (AI) engine to speed up the handling of customer queries, allowing the bank to respond faster.

The instrumenting of manufacturing plants is in itself not a new concept. Intraweb style connected controllers and data collection has been in extensive use across industries as diverse as paper production and heavy machinery production for many years. However, the scale at which connectivity can now be achieved in what is referred to as the Industrial Internet of Things (IIoT), and its fusion with the broader consumer-based Internet of Things, promise to join the factories, their machinery and their products into a connected web of information flows.

From this new paradigm comes improved efficiency. Production line machines can be monitored to enable the analysis of their conditions, algorithms predict future failure conditions and enable the smart scheduling of preventative maintenance.

Once created, products with embedded sensors will be able to immediately relay their state, which will enable the factory to analyse and optimise the production line if quality deviations are detected. Machines in the field will relay their status back to manufacturers so that engineers can work on software updates and next-generation upgrades. Products such as advanced jet engines are instrumented down to individual turbine blades, enabling data to be analysed retrospectively and in real time such that the appropriate maintenance can be determined and scheduled.



LEE ANNAMALAI
CSIR competence area manager for smart systems

Research from a number of industrial companies and consultants has indicated growth trends in industrial uptake of the connected technology revolution. 2016 Information from Forrester Research has highlighted that the hottest interest areas are in primary manufacturing, high-tech and industrial production, transportation and logistics, retail and wholesale.

Case studies from industry-led innovation and research and development (R&D) projects support these forecasts and business investment trends. Of particular interest are two projects from General Electric highlighting the integration of 10 000 sensors into the full production facilities of its new battery production plant and R&D into the instrumentation of aircraft engines to enhance preventative maintenance and aircraft safety through AI-led data analytics.

In the consumer goods space, innovation at shoemaker Adidas, supported by the German Government and several partners within the German National Innovation System, is focusing on a new era of manufacturing, where production processes are converging with information and communication technologies. The approach foresees reduced energy consumption and cleaner production. Importantly, there is also an emphasis on flexible production infrastructure to cater to the imminent demand for highly individualised products.

Our R&D work at the CSIR cuts across several industry sectors and is already investigating the convergence of digital technologies with traditional industries. A few highlights are outlined below.

- Additive manufacturing in the aerospace industry where digital computer-aided design, local titanium powder production and laser technology are utilised to create a new machine for the 3D printing of aircraft parts.
- In a related project, but following a more 'maker-style' approach, optical design innovation and 3D printing is being used to rapidly prototype and produce a nanosatellite which will test a novel space-based fire detection sensor. The data from the satellite will feed into a spatial data analytics system that is used to monitor wildfires, predict their spread and generate alerts and notifications.
- Early work with local mining companies aims to utilise IIoT architectures to monitor miner health and safety, especially from rock falls. AI algorithms are able to determine from micro-seismic measurements, the minute tell-tale patterns that precede an underground rockfall and notify workers in the near vicinity to evacuate. This sensor system is further integrated with a wide-area automated satellite, capable of determining small-scale surface deformations which are early warnings of possible surface collapse that will impact infrastructure and societies on the surface.

The CSIR's Josias Nonyana with a sensor system designed to detect the tell-tale signs that precede an underground rockfall.

Ongoing R&D needs to focus on the technical challenges that still hamper wide-scale adoption. These include:

- **Interoperability:** the software and communication systems needed for machines, devices, sensors and people to connect and communicate with one another
- **Information transparency:** the creation of a digital twin in which sensors and software create a copy in cyberspace of the real world to contextualise information
- **Decision-support tools:** effective design of systems to support humans in making decisions and solving problems and the ability to assist humans with tasks that are too difficult or unsafe for them
- **Decentralised decision-making:** design of computing and analytical engines that sit closer to the sensors and machines to speed up autonomous decision-making, or what is known as decision-making at the edge

With this level of connectedness the new business models that are emerging are driving a far more efficient utilisation of resources and giving momentum to a much broader service and circular economy. These present further interesting techno-economic research topics which aim to drive the investment cases around the industries of the future.

It's inevitable then that all production and products in the future will be smart and connected. Keeping pace with the rate of change is critical if industries are to remain competitive and relevant.

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Preparing industry for the next industrial revolution

BY DR NEIL TROLLIP

The rapid rise and convergence of emerging technologies is bringing disruptive change to the global manufacturing industry, driving the next industrial revolution, which is also referred to as Industry 4.0. However, at a time when manufacturing should be driving development in South Africa, industry is in an extended phase of decline. To help address this, the CSIR has developed capabilities in new and emerging technologies that drive the next industrial revolution, for example, advanced automation and robotics, additive manufacturing and micro-manufacturing.

Industry 4.0 builds on the digital revolution and draws together cyber-physical systems, the Internet of Things (IoT) and the Internet of Services. It is enabled by technologies like the mobile Internet, big data analytics and embedded and ubiquitous sensors. Under this new manufacturing paradigm, value chains will be completely integrated at a global level. This provides significant opportunities to companies of all sizes, if they are able to master the new and emerging technologies driving this revolution.

TECHNOLOGICAL INNOVATION TO HALT THE DECLINE OF INDUSTRY

The decline of the South African manufacturing industry has been caused, among other things, by rising input costs, low productivity, industrial policy uncertainty, ageing infrastructure and, in recent years, a stagnant global economy. Therefore, the sector's contribution to the gross domestic product has dropped from 24% in the early 1980s to less than 13% currently. Employment in the sector has dropped by more than 25% over the same period.

The link between technological innovation and competitiveness is well known and is particularly relevant in the current transition to the next industrial revolution. This disruption provides an opportunity for South African firms to make huge gains in productivity and to access new global markets, through embracing new technologies and business models.

CSIR CAPABILITIES AND CONTRIBUTIONS TO HELP DRIVE THE NEXT INDUSTRIAL REVOLUTION

The CSIR has capabilities in new and emerging technologies that drive the next industrial revolution, and develops and transfers solutions that equip manufacturing firms to compete successfully in the rapidly emerging future. Technology platforms under development include advanced automation and robotics, additive manufacturing and micro manufacturing. Technologies associated with industrial analytics, the IoT and product life-cycle management are also areas of focus aimed at equipping the manufacturing industry for the next industrial revolution.

DR NEIL TROLLIP
Strategic research manager: CSIR Materials Science and Manufacturing

Advanced automation and robotics

The CSIR has developed several ground-based robotic platforms that have been fitted with a wide range of sensors, including laser scanners, cameras, inertia measurement units and positioning devices. These sensors and platforms support the research and development of algorithms for perception, navigation, planning, machine learning and intelligent manipulation in mobile robotic applications.

There is a specific focus on developing cooperative robotics, also known as cobots, designed to physically interact with humans in a shared workspace. This human-centred automation is in contrast with the more traditional robots, which are designed to operate autonomously or with limited guidance. Human-centred automation is designed to assist human beings with specific tasks and this collaborative approach between humans and robots is attractive for South Africa with its skills challenges and high unemployment rate.

Specific applications under development for industry clients include automation and robotics to support the mining mechanisation and modernisation efforts as part of the Mining Phakisa; an integrated vehicle condition monitoring sensor hub; and an integrated information system and data analytics for the mobility industry. Infrastructure inspection platforms that can operate on land, in the air and under water, as well as a suite of non-destructive inspection and mapping sensors are also being developed.

All of these robotic platforms and their sensor readings are integrated into a common data storage and visualisation platform. This enables the different perspectives obtained from the different environments of data collection to be fused into a single detailed view.

Micromanufacturing

Micromanufacturing is concerned with the manufacture of products and devices with micron-scale features. This includes a variety of technologies and applications such as injection moulding, embossing, laser machining, printed functionality, microfluidics, micro-electro mechanical systems, micro-optics and actuation. Micromanufacturing is a key technology of the future due to its ability to add high value and functionality not possible with other technologies. It is also typically seen as a bridge between conventional manufacturing, nano-scale manufacturing and biomanufacturing, making it an excellent enabling technology.

The CSIR is actively involved in a number of key micromanufacturing technologies. These include microfluidics, printed electronics, printed functionality and laser micromachining. Examples of specific capabilities and products under development include a microfluidic-based blood cell counting cartridge together with the National Health Laboratory Service, a paper-based sensor for the detection of bacteria in wastewater, printed electronic devices for passive temperature control, and novel manufacturing methods and markers for health and environmental sensors.

Additive manufacturing

Additive manufacturing is a disruptive, new manufacturing technology that is considered one of the building blocks of the next industrial revolution. It is the process of joining materials to make objects from 3D model data, usually layer-upon-layer, as opposed to subtractive manufacturing methodologies.

The CSIR manages and participates in the Collaborative Programme in Additive Manufacturing (CPAM), which is the implementation programme for the South African Additive Manufacturing Strategy. The CPAM network consists of the CSIR, five universities and a number of industry partners, and the research and development focus is on the qualification of metal additive manufacturing for medical and aerospace applications, the design for additive manufacturing and polymer additive manufacturing. Excellent progress has been made to date in supporting post-graduate research in this domain.

The Aeroswift team produced parts for the South African developed AHRLAC aircraft.

Industrial analytics and the IoT

The IoT is seen as a primary disruptor in industry. It is an ecosystem of different technologies including devices, services and sense-making algorithms. It is driven by the abundance of small, low-power devices fitted with sensors and actuators, the pervasive nature of the Internet and the advent of highly scalable and elastic computing facilities (public and private cloud offerings). Sense-making is facilitated by advances in big-data, analytics and visualisation algorithms.

Using data acquired from, for example, an assembly line or factory floor, analytic algorithms can be implemented to create a host of solutions that can improve efficiencies, enhance safety or optimise logistics. Examples include preventative maintenance on factory equipment or improved efficiencies in the logistics chain.

CSIR research in this domain has created solutions over a broad range of application areas. These include optimising energy use as part of smart cities work and using advanced IoT concepts to demonstrate smart decision-making in a port terminal environment as part of smart industry work. The organisation has collaborated in a European Union initiative to develop internationally federated research infrastructure and has created fit-for-purpose IoT middleware platforms that facilitate the rapid development and deployment of IoT solutions in multiple domains. Current research and development is focused on the Industrial IoT and its application within a future mining context. Furthermore, it is developing demonstrators for smart warehouses to illustrate the value and impact of IoT.

Product lifecycle management

Product lifecycle management enables the simulation and management of the entire lifecycle of a product from its conception, through design, development and manufacture, to service and recycling. It integrates people, data, processes and business systems and provides a product information backbone for companies and their extended value chains, an essential enabling platform for the next industrial revolution. The CSIR has reached an agreement with the Department of Trade and Industry to host a full suite of product lifecycle management software and to roll it out to small and medium enterprises in support of their product development processes. This is a multi-year programme that will provide initial support to 12 companies already identified and will expand to about 2 000 companies over a seven-year period.

Smart factory

The CSIR is planning to establish, as a public-private partnership, a smart factory that demonstrates, on a pilot scale, the technologies and principles that underpin the next industrial revolution. The facility will also provide a collaborative research and development space for the transfer of solutions to the manufacturing sector. This approach is in line with global best practice, with numerous countries having already established smart factory demonstrators to prove the feasibility of the next industrial revolution, and to prepare industry for the opportunities it brings.

The CSIR, in partnership with Aerosud Innovation Centre, has developed the Aeroswift additive manufacturing technology platform. Aeroswift is a large-area, high-speed powder-bed fusion metal additive manufacturing system that can manufacture bigger parts and at faster processing speeds than present commercial systems. The first titanium demonstrator parts have been produced, including a test part for a large international original equipment manufacturer. A throttle grip was also produced for the South African-developed Advanced High Performance Reconnaissance Light Aircraft (AHRLAC), which will be the first locally produced Ti6Al4V additive manufacturing part that will be flown on an aircraft. Going forward, the CSIR is proposing to establish a pre-industrial platform to demonstrate the full additive manufacturing value chain, thereby reducing the entry barriers for industry to adopt this as a new manufacturing technology.

The Aeroswift additive manufacturing system.

High-performance computing and modelling for industrial competitiveness

Developed countries are increasingly recognising the value of incorporating modelling and digital science, as well as high-performance computing, into their competitiveness strategies. The CSIR's renewed focus on industrial development opens new opportunities for the adoption of computational solutions that these fields offer industry.

Assisting industry through advanced modelling

The CSIR has strong capabilities in information security, mathematical modelling and mobile intelligent autonomous systems. The organisation develops novel solutions to address societal and industrial challenges through modelling and simulation in engineering and natural systems. Researchers use multi-scale, multi-physics modelling, analysis and advanced computation across multiple systems to develop integrated models to address challenges.

"Our research focuses on the water-energy nexus and includes modelling of climate, materials, energy, carbon emissions, ecosystems, water quality and quantity, hydrology, as well as coastal and wave modelling," says Director for the Centre for High Performance Computing, Dr Happy Sithole.

"Sectors that are benefiting from the CSIR's competences in advanced modelling include agriculture, energy (forecasting, efficiency and storage), engineering (rail, aeronautics and mining), marine and maritime, as well as water and sanitation."

MODELLING AND SIMULATION CASE STUDY

Computational fluid dynamic modelling of low-temperature oxidation on a coal dump

THE PROBLEM: Qualifying and quantifying the mechanisms leading to emissions from coal heaps

The emissions market is one of the fastest growing segments in the financial industry and was worth about €30 billion on the London Stock Exchange in 2007.

Carbon is tipped to become the world's biggest commodity market in the near future. The CSIR conducted a study that was part of a bigger project aimed at claiming carbon credits via the relevant instrument of the Kyoto Protocol.

A local mining company enlisted the help of the CSIR to develop a simulation model, which is able to qualify and quantify the mechanisms leading to the release of the greenhouse gases, carbon dioxide and methane, from the spontaneous, low-temperature oxidation of coal heaps.

Ultimately, the model will be able to establish a baseline for carbon dioxide and methane emissions resulting from low-temperature oxidation of coal heaps.

The modelling and simulation intervention

The coal dump is an example of a reacting system, which involves flow, driven by natural convection, coupled with a chemical reaction in a porous medium. A model set-up for computational fluid dynamics (CFD) simulations, which makes use of applied mathematics, physics and computational software to visualise how a gas or liquid flows around or within, and affects objects, can predict phenomena such as flow regimes, temperature increase, as well as emissions of gases such as carbon dioxide and methane.

Researchers needed to determine the chemical processes involved in low-temperature oxidation and the thermodynamic effects on temperature, as well as the rates of reaction. They also needed to integrate these two mechanisms into a simulation model to quantify the release of the gases from the low-temperature oxidation mechanism.

The phenomena occurring during the low-temperature oxidation of coal are complex and not yet fully understood, A coal dump in South Africa showing gas emissions due to thermodynamic reactions between the coal as it reacts exothermally with atmospheric oxygen while being transported or stored at utility plants or when low-grade coal has been dumped as a heap on site.

DR HAPPY SITHOLE

Director of the Centre for High Performance Computing

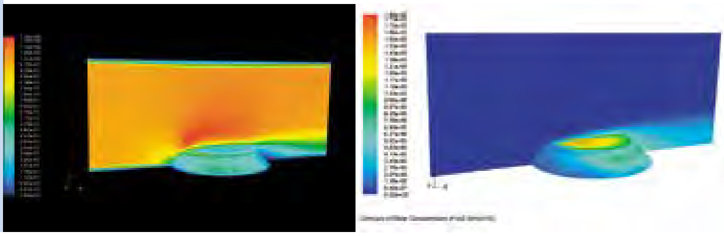
especially due to the complex nature of the coal matrix. However, through modelling, certain phenomena can be explained and quantified to a reasonable extent.

A CFD model was developed to estimate the release of carbon dioxide and methane from a discard dump using known equations for low-temperature oxidation, gasification, volatiles release and heat transfer. Values used in the modelling effort have been obtained predominantly from literature and the success of quantifying the phenomena specific to the dump was reliant on obtaining specifications that relate to the coal composition and geometrical parameters in that particular discard dump.

The study demonstrated the ability of CFD to capture the dynamics of low-temperature oxidation in a coal discard dump and helped to quantify the amounts of emission released into the atmosphere.

Going forward, researchers will focus on a 3D model of the coal dump, with emphasis on the actual geometry of the discard dump. To do this, they will rely on high-performance computing, which will provide more computational resources. This will enable the modelling of transient simulations whereby emissions can be tracked on a day-to-day basis. It will also give the modellers flexibility to cater for changing conditions such as rain (moisture), wind speed and direction and ambient temperature, all of which can have an influence on the underlying phenomena.

The flow profile and the carbon dioxide profile (kmol/m^3) around the coal dump.



Assisting industry through high-performance computing

High-performance computing is an expensive resource for any business to procure and manage, even more so for small, medium and micro enterprises. The CSIR offers the resource and support services on a cost-recovery basis to South African industry. Over the years, the CSIR has developed experience related to specific industries and as a result, researchers are able to provide specialised support. Companies that have benefited are from an array of sectors, including oil and gas, electricity supply, pharmaceutical, agriculture, rail, port and logistics, mining, engineering, animation, manufacturing, as well as climate and weather forecasting.

With the advent of artificial intelligence and machine learning, tailored solutions are also possible to newer industries that are not already engaged. The CSIR offers a complete solution for novice clients that start using high-performance computing and generally offers access to central processing unit cycles, feasibility and scaling testing, code porting and commissioning, hardware testing, configuration and advice, and a full consultancy where necessary. New users are trained to help bridge the gap.

With the continuously escalating cost of engaging in innovation, many companies are opting for virtual prototyping. Virtual prototyping is becoming a useful tool to companies that wish to lower their development costs while accelerating their time to market of new products. High-performance computing engineers can create a product that will meet the design specifications of a client faster and more effectively than traditional prototyping methods.

Collaborating on architectural design

The Eastern Cape Infrastructure Joint Venture (ECIJV) provides engineering, procurement and construction management services in the Eastern Cape. The company won a Transnet tender for design and build services for several projects at the ports of East London, Port Elizabeth and Ngqura.

THE PROBLEM: Optimising architectural designs in a windy, exposed Port Elizabeth site

ECIJV enlisted the services of the CSIR in the design of two buildings at the Port of Ngqura in Port Elizabeth. Because of its windy location and specific environmental conditions, the building owner wanted to ensure optimal design for building aesthetics and functionality. Themba Nkabinde, ECIJV Project Director, says, "ECIJV knew that a high-quality computational engineering study of wind dynamics was necessary to deliver optimal design and cost savings for the proposed buildings considering the environment and exposed location of the sites."

The study focused on optimising architectural designs of two buildings in the Port of Ngqura, namely a five-storey, 10 000 m^2 building for the Transnet National Ports Authority and the ACB Services Building, a two-storey building near the water's edge.

The high-performance computing intervention

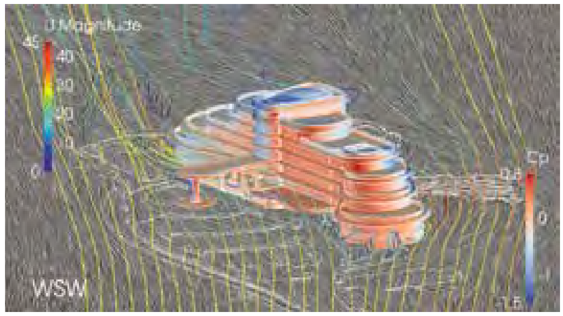
ECIJV commissioned a CFD study to better understand the impact of wind on proposed architectural designs, sand encroachment as well as minimising the effect of the sand and other wind-related problems such as wind dynamics on pedestrians.

A CFD model of a large building on a complex landscape necessitates dealing with length scales that vary between hundreds of metres and one or two centimetres. The resulting model was fairly large, consisting of about 60 million grid cells, which necessitated high-performance computing. Run times were approximately three hours per wind direction on a small cluster consisting of 120 cores.

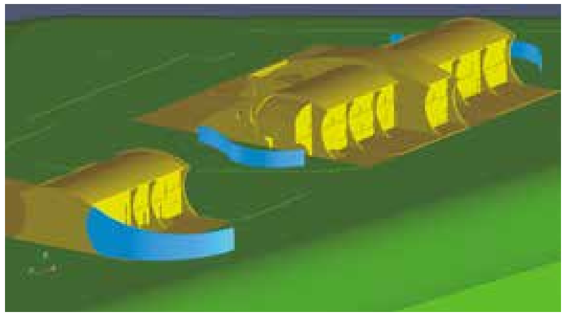
The ACB Services building is located near the water's edge next to the eastern breakwater in the Port of Ngqura. The building is rectangular with curved roofs, has two levels and an open space parking. The building is exposed to particularly strong winds from the southwest and east, and a wind analysis was regarded as essential. Due to insights derived from the CFD studies, the design of the building was substantially changed in several iterations from the initial concept. It was necessary to give special consideration to wind loads on the fire station garage doors, sand and water ingress on stepped areas, as well as local regions of swirling airflow. Due to the extensive dune field to the east, wind-blown sand will remain problematic, but valuable insight into sand migration patterns has been developed.

The project presented an unexpected opportunity to apply modern high-performance computing-aided engineering to a real-world development project.

The CSIR's competences in high-performance computing and advanced modelling offer industry an invaluable opportunity to develop world-class, competitive solutions and products.



Transnet National Ports Authority building: Investigating wind loads and pedestrian comfort and safety.



ACB Services building: Investigating options to manage wind and wind-blown sand.

THE PROJECT PRESENTED AN UNEXPECTED OPPORTUNITY TO APPLY MODERN HIGH-PERFORMANCE COMPUTING-AIDED ENGINEERING TO A REAL-WORLD DEVELOPMENT PROJECT.

Improving cybersecurity for industry

The global digital revolution has resulted in a dramatic shift of human business and social activity to the cyber domain. This has led to cybercriminals exploiting weaknesses in computer networks to commit financial crimes and identity theft, for religious and political reasons and even for pure hacking entertainment or rivalry. The CSIR works with government and industry to develop technologies and strategies to improve cybersecurity in the country.

In their most disruptive form, cybercriminals take aim at the economic, political, military and infrastructural assets of a country, its businesses or its people. This requires a professional and sometimes highly technical response to ensure continuity of business in the face of cyberattacks.

"Many industries lack the internal resources to effectively defend themselves and need to outsource this type of support. This includes highly innovative companies that have started to leverage intelligent, connected devices in their factories, embracing what is called the industrial Internet or Industry 4.0. Inter-connected devices collect large volumes of data for the manufacturing industry to achieve greater speed and efficiency. The reliance on off-site, cloud-based solutions where information is aggregated, analysed and shared with multiple end-users, adds to the security challenge," says Dr Barend Taute, Manager: Information and Communications Technology Contract Research and Development at the CSIR Meraka Institute.

THE CSIR RESPONSE

A company's resilience against cyberattacks – minimising events and quick recovery – depends on its ability to understand attacks, conceptualise attack scenarios and prepare adequately, to timeously identify breaches and to continuously adapt its cybersecurity strategy.

"The CSIR has a sound track record of working with South African government departments and industries to develop cybersecurity policies, strategies, technology and tools that have been used to share threat intelligence and to respond to cyberattacks," says Taute.

SUPPORTING THE NATIONAL CYBERSECURITY POLICY

The CSIR contributed to the formulation of the National Cybersecurity Policy Framework and has supported government departments with the conceptualisation, planning and implementation of cybersecurity infrastructure. As an example, the Cybersecurity Hub of the Department of Telecommunications and Postal Services (DTPS), which serves as a central point for collaboration between industry, government and civil society in cybersecurity related incidents in South Africa, is hosted at the CSIR and technically supported by the CSIR. The CSIR has also worked with the Department of Science and Technology (DST) in developing a national cybersecurity research, development and innovation programme.

A COMPUTER SECURITY INCIDENT RESPONSE TEAM

The South African National Research Network (SANReN) is a high-speed IT network dedicated to science, research, education and innovation traffic. It is part of the DST's National Integrated Cyber Infrastructure System, implemented by the CSIR.

In March 2016, the SANReN computer security incident response team that comprises CSIR experts, and is based at the CSIR, was launched to provide proactive IT security services to the beneficiaries of the SANReN network.

To date, activities include conducting vulnerability assessments for 11 beneficiary institutions. The team has also been working on the early detection of malicious activity within the research and education community, as well as on a cybersecurity challenge for students to be hosted at the annual conference of the Centre for High Performance Computing.

SECURITY OPERATION CENTRES

The CSIR designs, implements, validates and verifies security operation centres. These are centralised units that house an information security team responsible for the monitoring and analysis of an organisation's cybersecurity. Specifications cover all security functions for users, services, network resources, infrastructure and suppliers. Current CSIR support extends to defence, policing, municipal operations and empowering small and medium enterprises to sustain the delivery of services in this environment.

COLLABORATING TO BE AT THE INNOVATION FOREFRONT

The CSIR is establishing a collaborative cybersecurity centre for innovation in South Africa that follows an integrated and multidisciplinary approach to improve cybersecurity in the country. The emphasis is not only on technology but also on the role of humans, processes, organisations and governance, therefore bringing together government, research organisations, industry, business and the higher education sector. The centre is currently creating regional forums at universities to support interaction between industry and academia regarding cybersecurity innovations and it is engaging with universities on curriculum development for cybersecurity qualifications that are relevant to industry.

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DR BAREND TAUTE
Manager: Information and Communications Technology Contract Research and Development, CSIR Meraka Institute.

Above: The CSIR's Dr Graham Barbour and Kgotsofatso Kgang are part of a team that specialises in security audits, digital forensics and security research. Right: Computers are essential to many business environments, providing design tools, easy communication, collaboration networks and the means for sharing data. These same devices can become tools for spying, theft of private or proprietary information, financial fraud or malicious attacks that may threaten an organisation's existence.

EARLY-WARNING DETECTION TECHNOLOGY

Cybersecurity experts at the CSIR have developed a prototype software package for personal computers and servers that rapidly and accurately detects network hacking activity.

As an initial step in compromising a network, cybercriminals often perform network reconnaissance to discover computers that are connected to the network, as well as services offered by these systems. This activity is referred to as ping sweeps or network port scanning. The early detection of such activity can alert a host to an impending cyberattack.

CSIR researchers developed a network port scan detection algorithm that uses a novel detection metric that incorporates statistical modelling of connection attempts. The algorithm is unique because of its ability to detect port scans and ping sweeps that are spread out over very long periods of time, a stealth technique used by attackers.

The CSIR's technology has been benchmarked against a free and open-source network intrusion prevention system that is widely used in industry and it has a better detection-rate for both slow and fast scans.

NETWORK EMULATION AND SIMULATION LABORATORY

Supported by the Department of Science and Technology, the CSIR has implemented a network emulation and simulation laboratory that provides a platform for the design, development and deployment of cybersecurity processes and tools that resemble a real-world network. Existing or planned networks are simulated through a combination of physical and virtual devices.

The laboratory tests cybersecurity concepts through the emulation of real-world legitimate traffic, as well as malware and therefore helps to identify security vulnerabilities and ineffectiveness in computer networks. The laboratory provides cybersecurity researchers with the ability to perform network bandwidth modelling, cybersecurity training, device 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.

FINDING VULNERABLE DEVICES TO PREVENT THE LEAKING OF PERSONAL IDENTIFIABLE INFORMATION

The CSIR developed an innovative tool called Cyber Protect for enabling businesses to be compliant with the Protection of Personal Information Act and to prevent the leaking of personal identifiable information from devices connected to the Internet. The tool can proactively find vulnerable devices before criminals do, including devices that form part of the Internet of Things (computing devices embedded in everyday objects that are interconnected via the Internet, enabling them to send and receive data). The tool has been tested in different environments, including the Cybersecurity Hub of the DTPS.

Vulnerability searches can highlight the extent of risk for a potential attack scenario. Searching is flexible enough to handle context, as well as keyword searches. It also provides relevant numbers on how damaging a specific device targeted by a virus could be to the country's infrastructure.

Cyber Protect provides a graphical way for an operator to navigate the data instead of working with plain text files, therefore reducing the skill and experience level required to become an effective operator. The system visualises information from different data sets related to cybersecurity in an integrated one-stop application environment, for example, the average time span that a web server deployed in the South African domain has before it is updated to a newer version, allowing for proactive, corrective action.

INVESTIGATING THE WORKINGS OF THE DARK WEB

Known for hosting illegal activities, the dark web is a vast anonymous network hidden from most Internet users on the more commonly visible surface web. It exists in a part of the Internet that requires specific software or authorisation to access and is not indexed by search engines like Google.

To mitigate the threat that it poses, cybersecurity experts at the CSIR extended their crime prevention strategies beyond the surface web to understand the workings of the dark web and other evolving hidden systems.

The CSIR has created a cybercrime combating platform that proactively identifies cybercrime related activities through data collection on both the surface web and the dark web, building real-time analytics of cybercrime and reporting it to authorities.

MOBILE VERIFICATION CENTRE Mobile phone technology is popular and constantly evolving, creating many opportunities or loopholes for cybercriminals and making it difficult to maintain security. The CSIR has created a mobile verification centre that helps organisations to identify threats on their mobile phones. The tool is used to audit phone applications installed on a device.

Industry 4.0 meets Cyber 4.0

The CSIR's Kgwadi Matenche and Sophia Moganedi (front) develop new methods to defend against cyber threats.

The CSIR is playing an instrumental role in research, development and innovation to prepare for a future where cybersecurity becomes the critical enabler for a secure Industry 4.0.

Three major developments changed the face of industry over time: the introduction of steam engines that enabled the mechanisation of basic machinery, the first spark of electricity and the assembly line that enabled mass production, and the invention of computers, which gave birth to automation. We are now entering the next era known as Industry 4.0 or the 4th Industrial Revolution. It involves the automation of processes and data exchange between humans and physical systems in manufacturing technologies. It includes cyber-physical systems, the Internet of Things (IoT), cloud computing and cognitive computing. It is a world in which robotics are remotely connected to computer systems that are running on learning algorithms. This means that these machines can learn and control machinery robotics with very little input from human operators.

Industry 4.0 creates smart factories, in which local and widely distributed cyber-physical systems, also known as cyber twins, monitor the physical processes of a factory. CSIR defence research group leader, Dr Jabu Mtsweni, says, "In a smart factory, cyber-physical systems communicate wirelessly with each other, as well as human operators, and make intelligent, rapid and decentralised decisions."

A typical use case of Industry 4.0 would be where widely distributed, yet highly interconnected and integrated cloud services, sensor networks, IoT, embedded systems and other cyber-physical systems transcending different domains are converging and transacting (with minimal human involvement) to enable innovative operations. These operations can be automated and robotised, meaning machine-to-machine and machine-to-humans communications are central.

Four factors that must be present for a factory or system to be considered Industry 4.0 include interoperability, information transparency, technical assistance and decentralised decision-making.

BENEFICIAL OR TOO RISKY?

The benefits of Industry 4.0 and smart factories are numerous and positively affect almost every aspect of a fully functioning plant. The connectedness will promote innovation, as it links scientists, engineers and designers to machines in ways that optimise working relationships. Better working relationships will, in turn, benefit a plant's effectiveness.

"As with all new technological advancements that offer incredible benefits, Industry 4.0 also introduces a number of security and safety risks. The convergence creates complex safety and security challenges that public and private organisations are neither prepared for, nor ready to combat," says Mtsweni. "The critical puzzle in the realisation of a secured Industry 4.0, is cybersecurity. Without it, we will never be able to achieve the full potential of the Industry 4.0 vision."

DR JABU MTSWENI
CSIR research group leader for defence

"AS WITH ALL NEW TECHNOLOGICAL ADVANCEMENTS THAT OFFER INCREDIBLE BENEFITS, INDUSTRY 4.0 ALSO INTRODUCES A NUMBER OF SECURITY AND SAFETY RISKS. THE CONVERGENCE CREATES COMPLEX SAFETY AND SECURITY CHALLENGES THAT PUBLIC AND PRIVATE ORGANISATIONS ARE NEITHER PREPARED FOR NOR READY TO COMBAT."

– DR JABU MTSWENI

SO WHAT EXACTLY COULD GO WRONG?

"Because everything is connected, it is safe to say that where there is a connection, there is a possibility of an attack. A typical Industry 4.0 cyberattack could involve a number of serious incidences such as a ransomware attack, malware distribution, data transmission monitoring, denial of service, deception attacks, physical tampering or a man-in-the-middle attack. Any of these will have a severe impact on critical manufacturing processes," says Mtsweni.

Research studies suggest that most security compromises occur because of flaws in processes (90%) and technology (10%).

"Industry 4.0 is made possible by Internet Protocol-enabled devices, which are basically computers of different scales, all of which are hackable. We are yet to crack the solution for a 100% secured computer so it remains critical that all cybersecurity solutions consider people, processes and technology," he says.

CSIR CYBERSECURITY THINKING FOR INDUSTRY 4.0

The CSIR is playing an instrumental role in research, development and innovation to prepare for a future where cybersecurity becomes the critical enabler for a secure Industry 4.0.

The organisation embarked on a number of national capability building initiatives that contribute to the safety and security of South Africans. "The focus is on equipping industries and government with capabilities and abilities to respond to cybersecurity challenges. These capabilities include automated and optimised incident response management, artificial intelligence, enhanced intrusion detection and prevention, as well as advanced situational awareness throughout the supply chain of cloud manufacturing," Mtsweni says.

"The organisation addresses security issues in a number of projects that satisfy the requirements for a safe and secure Industry 4.0."

The CSIR's Cyber Protect system addresses the need to monitor the threat landscape of South Africa and plays an imperative role in the safeguarding of South Africa's digital borders. The system focuses on the cyberattack surface for hardware, software and people. It consists of a visualisation component, a hardware and software infrastructure information sensor and a personally identifiable information (PII) sensor. These components proactively visualise the potential attack surface related to hardware, software and PII data. In addition, Cyber Protect is capable of detecting vulnerabilities within devices connected to the Internet.

Another technology innovation from the CSIR is an early-warning detection system that combines hardware and software techniques for detecting cyberattacks from around the globe in internal networks using anomaly detection techniques. The value of the system is that it is efficient at detecting attacks, while still in the reconnaissance phase – before hackers strike.

Other CSIR projects that address requirements for a safe and secure Industry 4.0 include research in big data security, including predictive modelling, an integrated view on government departments and municipalities, monitoring and evaluation and real-time analytics, such as during elections.

CYBERATTACK FAST FACTS

Ransomware attacks: Control centre systems are encrypted by an external source demanding a payment for the reconnection of services.

Data transmission monitoring: Data coming to and from the control centre are monitored by an external source to determine peak network hours for further attacks or extract confidential customer data.

Denial of service: External actors can take control of the grid and cut off supply to the customer base.

Physical tampering: Smart meters can be tampered with to hide either true consumption readings or diversions within the known network structure.

Deception attacks: Malicious technologies masquerading as a true component can be inserted into the network to feed incorrect data or instructions.

Behaviour alteration: Network components can be compromised to act in a malicious manner to disguise true, but anomalous network conditions as expected network conditions.

Man-in-the-middle attacks: Data and instruction transmissions may be diverted to an unknown, malicious third party, allowing for undetected alterations.

Malware distribution: Infected network components can be used to spread malware through the network and into the wider cyber environment through other Internet-capable devices such as user smart phones and personal computers.

Within smart grid applications, there are many opportunities for the use of Internet Protocol-enabled technologies to independently automate and adjust network operations to always maintain the most efficient, cost-effective configurations. Unfortunately, as these IP-enabled technologies are without adequate security, there is also ample opportunity for malicious attacks with devastating effects.

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The CSIR in aerospace:
An engine for future industrial growth

The CSIR is home to leading aerospace research and development in South Africa with a track record of technological advances and achievements in support of South Africa's military industrial complex, built over many decades.

South Africa's need for strategic military independence resulted in the establishment of a wide range of capabilities and significant infrastructure for vertical product integration for a number of aerospace systems, including weapons systems, unmanned aerial systems (UAS), helicopters, satellites and fighter aircraft, for more than seven decades.

"The CSIR and industry have multiple capabilities in the aerospace sector, including design, development, advanced manufacturing, integration, testing, industrialisation and production, amongst others. This is remarkable considering the size of South Africa's economy," says Dr Kavendra Naidoo, CSIR aeronautic systems manager.

Large aerospace test facilities established in the country include the suite of wind tunnels at the CSIR in Pretoria, the Overberg missile test range, the test flight and development centre, the Alkantpan ballistics range, as well as a satellite integration facility in Grabouw.

"A recent industry study highlighted the growth provided by the industry in the past and its ability to be the engine of future economic growth. The study also indicated that industry has to export and innovate more for sustainability. This is an area in which the CSIR can play a significant role," says Naidoo.

"A critical ingredient in achieving research, development and innovation that is taken up by industry, is the joint development and evolution of strategy with users, original equipment manufacturers (OEMs) and others in the value chain."

The CSIR developed a synthetic aperture radar technology demonstrator. It was tested in November 2016 during a test flight on board an Atlas Angel aircraft.

DR KAVENDRA NAIDOO
CSIR aeronautic systems manager

The CSIR has overcome significant technical challenges to produce titanium metal powder – suitable for the aerospace industry and large aircraft manufacturers – at its semi-batch pilot processing plant.

"A CRITICAL INGREDIENT IN ACHIEVING USEFUL RESEARCH, DEVELOPMENT AND INNOVATION IS THE JOINT DEVELOPMENT AND EVOLUTION OF STRATEGY WITH USERS, OEMs AND OTHERS IN THE VALUE CHAIN."

– DR KAVENDRA NAIDOO

Denel and Aerosud are exporting to global aircraft OEMs. Both organisations have manufactured components and assemblies for Airbus as part of the A400M Military Aircraft Programme.

The Aeroswift programme, a joint programme between the CSIR, DST and the Aerosud Innovation Centre set out to develop, build and qualify the largest additive manufacturing platform in the world.

Advanced manufacturing

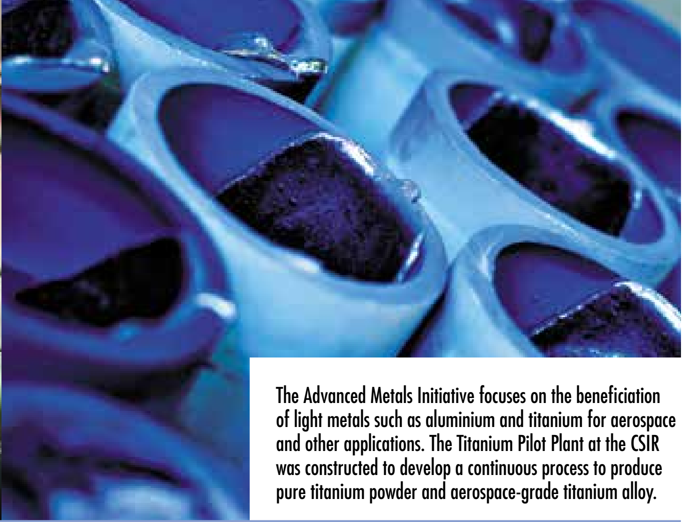
The CSIR recently facilitated the development of the Aerospace Aerostructures Advanced Manufacturing Roadmap on behalf of the Department of Science and Technology (DST). The local aerostructures sector is currently worth approximately R2 billion annually, but draws more than 80% of its revenue abroad. Long-term sustainability and growth of the sector are reliant on securing future business with large OEMs like Airbus, Boeing, Embraer, Bombardier and others.

The sector operates in a global market in which there are requirements to reduce greenhouse gas emissions and travel costs, which drive the demand for cheaper, lighter and stronger aerostructures.

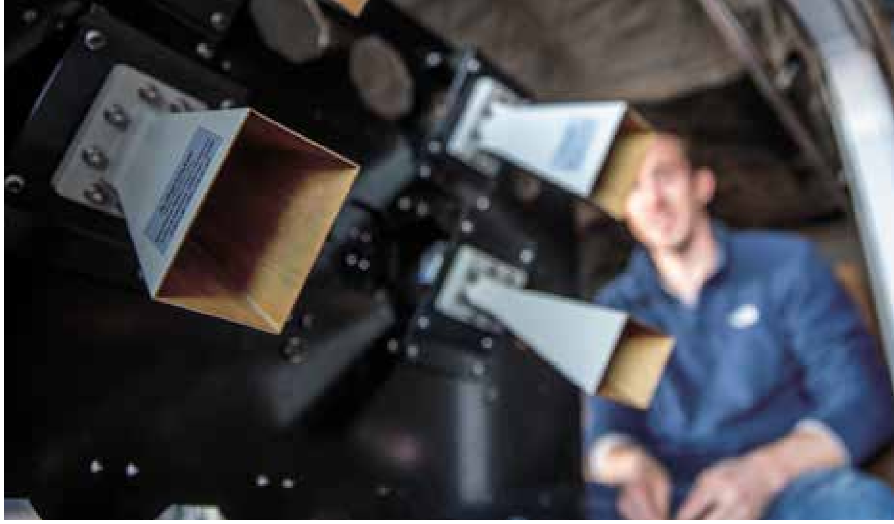
A competitive global market and the prevalence of advanced manufacturing technologies place pressure on the South African sector to innovate. "What is required to increase the sector's global footprint to grow the economy and employment? Currently, we have the benefit of market access and insight. Now is an opportune time to position and secure future opportunities in this sector," says Naidoo.

Industry requires capabilities to manufacture more complex parts, sub-assemblies and assemblies for global OEMs at reduced cost and time. This requires targeted investment in material sciences, thermoset processes, carbon-fibre reinforced thermoplastics, natural fibre composites, out of autoclave technologies, non-destructive testing technologies, additive manufacturing, automation and digital manufacturing, amongst others. Some of these are in development at the CSIR, for example the advanced metals initiative and Aeroswift programmes of the DST. These technologies could be useful to provide local UAS or locally developed airframes with a competitive edge in terms of reduced weight, increased payload carrying capacity, endurance and range. "Further engagement, consolidated planning and resource allocation between government, industry and the CSIR are required to implement the recommendations of the roadmap," says Naidoo.

The electronic warfare testing and evaluation pod with the recently installed ram air turbine being installed in the transonic wind tunnel at the CSIR. The pod was tested under simulated flight conditions in preparation for flight tests on a fast-jet aircraft.



The Advanced Metals Initiative focuses on the beneficiation of light metals such as aluminium and titanium for aerospace and other applications. The Titanium Pilot Plant at the CSIR was constructed to develop a continuous process to produce pure titanium powder and aerospace-grade titanium alloy.



The SAR technology demonstrator, funded by the DST, is intended for UAS platforms, airborne reconnaissance pods and other airborne platforms.

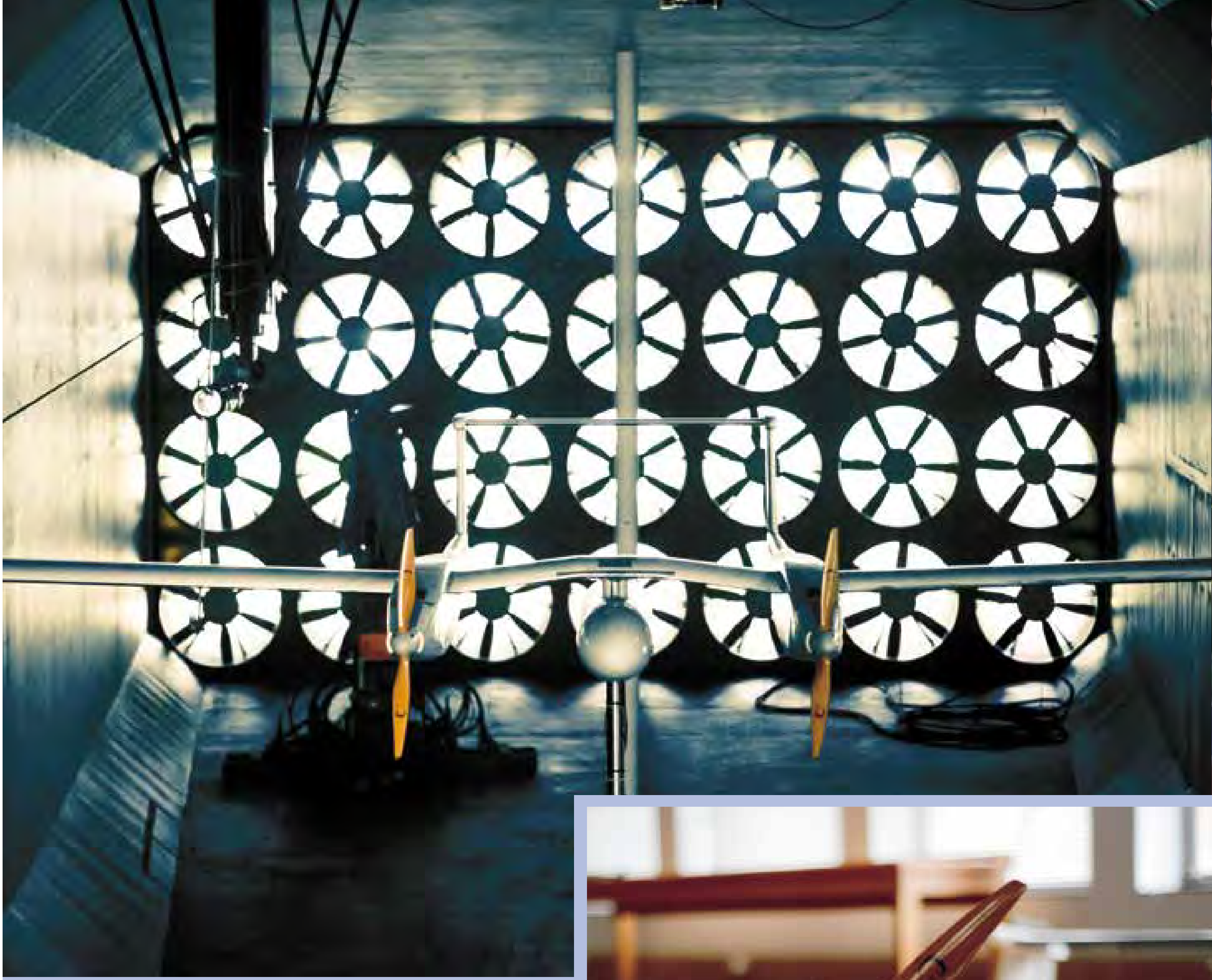
Sensor systems and electronic warfare

The CSIR's radar, optronic sensors and electronic warfare (EW) capabilities are of strategic importance to the South African National Defence Force. These capabilities are essential in the protection of our soldiers and military assets, as well as to maintain a strategic military advantage in terms of threat detection. The capabilities include sensor development, sensor networks and sensor data processing for decision-making and are characterised by world-class modelling, testing and evaluation, as well as hardware development.

"With the ability to model the system in its entirety, the essential performance drivers can be optimised and developed for world-class solutions. Systems developed by these groups have recently been deployed on South African border-safeguarding and crime prevention missions. This capability has been and can be further harnessed for industrial development, in particular defence and security product niches," says Naidoo.

The CSIR has made sound progress in the development of Synthetic Aperture Radar (SAR) technology intended for UAS platforms, airborne reconnaissance pods and other airborne platforms. Local SAR technology enables the development of a niche sensor, which supports export of local systems.

The CSIR developed the electro-optical imager for the SunSat Satellite in 1999, performed calibrations for the Sumbandilla Satellite in 2009, as well as established the South African National Radiometric Calibration Site at Paardefontein in 2014 for satellite sensor calibration. Recently, the organisation developed a novel satellite sensor concept for forest fire detection using commercial off-the-shelf components with high-fidelity at low-cost, demonstrating the CSIR's capability to develop high-performance, low-cost optronic sensors.



Above: A long-endurance UAS developed by the CSIR for border safeguarding experiments and sub-system test and evaluation.

Aeronautics for industry

The CSIR hosts the largest suite of wind tunnels in Africa, as well as the largest transonic facility in the southern hemisphere. The current infrastructure suite enables aerodynamic testing and evaluation from very low subsonic speeds, up to Mach 4.5. It also includes a suite of facilities to perform aircraft flutter clearances and non-destructive testing of structures, using X-ray, ultrasound and thermography.

These facilities, together with the Alkantpan ballistics range, the Overberg test range and the test flight and development centre represent critical testing and evaluation installations for many of South Africa's strategic national defence capabilities. The CSIR was the birth-place of the Rooivalk helicopter and has been critical in the development of the full suite of Denel's missile systems. The wind tunnels are also critical in maintaining South Africa's independent weapons integration capabilities. "While maintaining a science, engineering and technology base to support modelling and simulation, analysis, as well as testing and evaluation, the CSIR has focused its aeronautical capabilities to support technology for product development, for example UAS, propulsion systems and next-generation missiles, benefiting industry, small, medium and micro enterprises (SMMEs) and other users," says Naidoo.

The radar and electronic warfare pod being prepared for tests in the transonic wind tunnel at the CSIR.

Another recent programme in this area is the development of an airborne radar and electronic warfare testing, evaluation and training pod. The programme is targeted at transferring high-fidelity, laboratory-based testing and evaluation hardware into an airborne system to enable training of radar and EW operators on land and at sea, combat simulation exercises and EW test and evaluation. The programme draws on a broad range of experts, capabilities and capital-intensive infrastructure to develop a complex, niche system in short timescales. It included the efforts of experts in radar and EW, mechanical design, aerodynamic design, power electronics, aircraft stores integration, turbomachinery and aerodynamic testing.

The recent full-scale wind tunnel tests of the pod at Mach 0.95 in the CSIR's transonic wind tunnel, the largest facility of its kind in the southern hemisphere, enabled essential hardware-in-the-loop testing of the on-board ram air turbine and power electronics. The self-contained power generation system for the pod payload allows the pod to be independent from the aircraft, reducing the cost, time and risk associated with aircraft integration. "This is an example of how the broad base of multidisciplinary capabilities within the CSIR can be combined to develop innovative and complex systems," says Naidoo.

Enabling initiatives at the CSIR

The CSIR hosts a number of enabling government initiatives, including the Aerospace Industry Support Initiative of the Department of Trade and Industry (**the dti**), which develops relevant, industry-focused capabilities and facilitates transfer of technology. It aims to identify, develop, support and promote the interests and capabilities of the South African aerospace and defence industry.

The CSIR hosts an integrated Product Lifecycle Management (PLM) platform to enable aerospace product development. It facilitates concurrent engineering from a lifecycle point of view, as well as multidisciplinary engineering and technical management by managing product data generated during all lifecycle phases of a product from the initial idea, through product development, manufacturing, operations and maintenance, to retirement. PLM is increasingly becoming the platform used by aerospace OEMs to improve supply chain integration.

Aerospace-related research and development at the CSIR has the potential to contribute to the competitiveness and growth of South Africa's aerospace industry. The CSIR provides access to world-class testing and evaluation facilities and associated knowledge services in the fields of materials, manufacturing, sensors, aerodynamics, structures and propulsion, amongst others. The organisation has the ability to enhance its impact on industry and SMMEs through opportunities in advanced aerostructures, new sensor technologies, as well as world-class EW and aeronautical technologies.

"A future strategy will require constant, open dialogue, action and feedback, as well as a burning desire for success as we seek to grow South Africa's economy in leaps and bounds," concludes Naidoo.

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The CSIR, in partnership with the National Health Laboratory Service, has developed the Cellnostics device to perform quick and effective on-site blood tests to reduce the time between tests and diagnosis and subsequent treatment.

Developing **cutting-edge medical devices** and **diagnostics**

The South African medical device industry faces numerous challenges, including the cost and quality of materials (which are mostly imported) and complying with regulatory requirements. The CSIR has developed a number of medical devices and sensors to improve test turnaround time, quality of care and health information for primary healthcare facilities.

The organisation has also proposed a solution to optimise the process of the development of medical devices and sensors, which includes ensuring that they comply with regulatory requirements, using the medical device lifecycle management approach.

South Africa's medical device market is worth about R12 billion, accounting for 4,2% of all health expenditure. However, 94% of products are imported with only a few local manufacturers employing a small number of people.

Barriers to entry in the medical device industry include a lack of incentives, a shortage of skilled and semi-skilled workers as well as the prohibitive cost of raw materials. In addition, the regulatory environment is uncertain, with the cost of regulatory compliance including the setting up of quality management systems, certification and regular compliance testing.

"The CSIR has developed a number of medical devices and sensors that have the potential to not only improve health, but to also stimulate industrial development," says CSIR senior researcher, Dr Busisiwe Vilakazi.

POINT-OF-CARE DEVICES

The South African public health system provides healthcare services to the majority of people. Many of its facilities face serious resource constraints, including the lack of appropriate healthcare information at the point of care to facilitate diagnostic, treatment and referral decisions. To address some of these challenges, the CSIR has developed a number of medical devices and sensors to improve test turnaround time, quality of care and health information for primary healthcare facilities.

DR BUSISIWE VILAKAZI
CSIR senior researcher

"THE CSIR HAS DEVELOPED A NUMBER OF MEDICAL DEVICES AND SENSORS TO IMPROVE TEST TURNAROUND TIME, QUALITY OF CARE AND HEALTH INFORMATION FOR PRIMARY HEALTHCARE FACILITIES."
– DR BUSISIWE VILAKAZI

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ULTRASONIC DEVICE FOR PRIMARY CARE

Ultrasonic devices use sound waves to view and manipulate internal body structures such as organs and blood flow. The CSIR focuses on the development of this technology for the primary care setting.

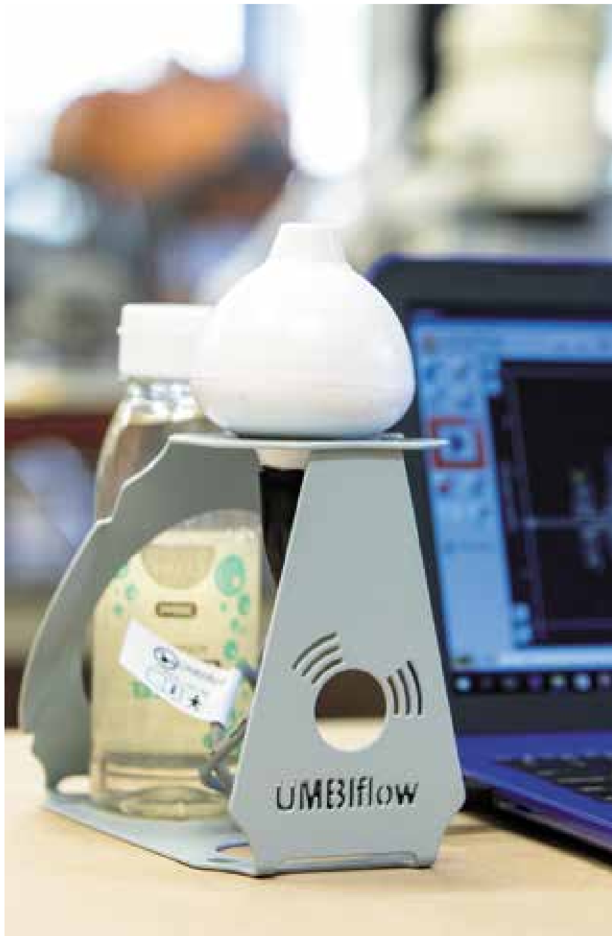
CSIR researchers have developed a Doppler ultrasound device called Umbiflow that can be used at a health clinic to reduce unnecessary referrals of pregnant women. By measuring the blood flow in the umbilical cord, the device detects when the placenta is no longer providing sufficient nutrients and oxygen for the baby to reach its growth potential.

In trials undertaken in the Tshwane district, it was shown that the Umbiflow device has the potential to significantly reduce the perinatal mortality rate.

The Tshwane clinical trial started on 4 May 2015 and is currently in its second year in multiple clinics. To date more than 2 640 women have participated in the trial of which 324 were classified as high risk and referred to the Mamelodi Hospital.

Of a group of 1 096 women who have given birth, 10% showed abnormal results with the Umbiflow screening. It is estimated that about 10% of the group showing abnormal results would reasonably have been expected to have a stillbirth if the abnormal reading had not been detected by Umbiflow.

The perinatal mortality rate for women who had access to Umbiflow testing was 11.3/1 000 deliveries, and among those who were not Umbiflow-screened, the mortality rate was 21/1 000. This indicates that Umbiflow has the potential to reduce the perinatal mortality rate by up to 50%. Umbiflow is also highly cost-effective – each screening costs less than R500.

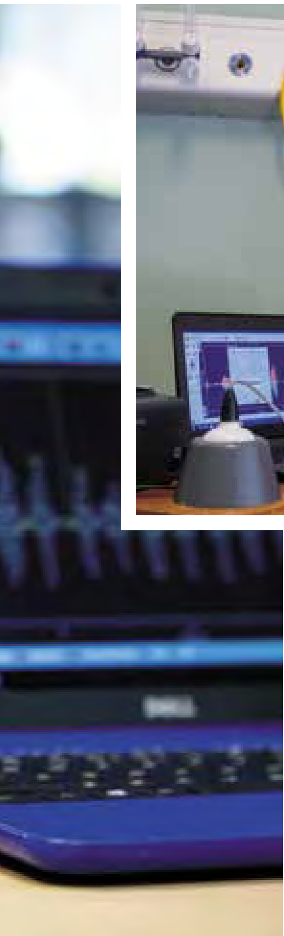


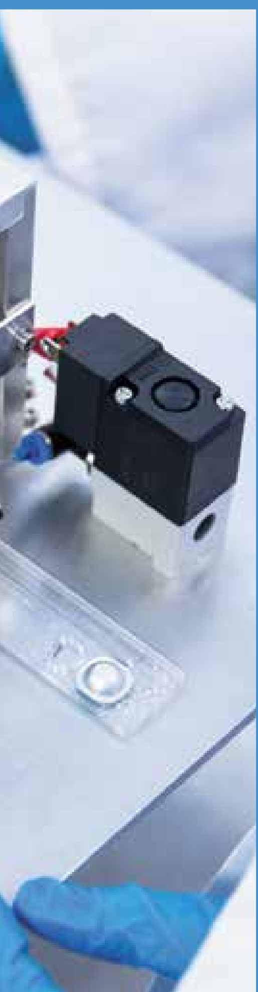
A MICROFLUIDICS TECHNOLOGY PLATFORM

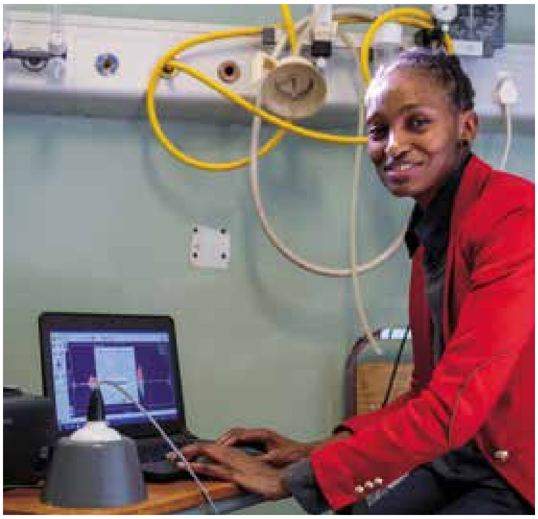
Microfluidics allows for the precise control of extremely small volumes of fluid in diagnostic devices. The CSIR has assisted industry to develop paper-based and cartridge-based diagnostic devices for drug discovery blood counting and disease diagnostics. An example is the Cellnostics device for full blood-count analysis. When healthcare centres are located far from centralised laboratories, the delays caused by the transport of blood samples and test results may detrimentally affect the quality of patient care. In partnership with the National Health Laboratory Service (NHLS), CSIR researchers have developed this device to perform quick and effective on-site blood tests to reduce the time between tests and diagnosis and subsequent treatment. The portable, wireless blood analyser allows for two-way communication between the clinic and a central laboratory. Medical professionals can also access the information using their mobile devices.

Two design versions of the microfluidic cartridge have been tested and evaluated in CSIR laboratories and their performance was found to be comparable to gold standard tests in a pathologist's laboratory. The next step is to conduct clinical assessments with the device in partnership with the NHLS. Two patents related to the device, a 4D light field microscope and an analysis system, have been registered.

Equipment used to develop Cellnostics, a device for full blood-count analysis.







Dr Busisiwe Vilakazi (top) working with the Umbiflow technology (left).

The CSIR has licensed its microsphere technology to ReSyn Biosciences (Pty) Ltd.

A MICROSPHERE TECHNOLOGY PLATFORM

The CSIR has developed and patented an innovative next-generation microsphere technology platform (ReSyn). The ReSyn technology comprises a hyper-porous polymer matrix that allows penetration of biological and synthetic molecules throughout the volume of the beads, as opposed to limited surface-based binding of conventional bead technologies. In addition, the technology offers exceptional surface area for binding of molecules and is particularly suitable for applications where volumetric productivity (low microsphere content or concentrated sample preparation) is important. The microspheres also have added exceptional value to the high-throughput screening platforms using phosphopeptide enrichment techniques in cancer biomarker discovery research.

The microsphere technology platform has been licensed to a CSIR spin-out company, ReSyn Biosciences (Pty) Ltd.

PHOTONICS-BASED POINT-OF-CARE DIAGNOSTICS

With the use of photonics, researchers aim to use light to influence and manipulate living systems at cellular, subcellular and molecular level. The CSIR has assisted industry to design, develop and manufacture photonics-based point-of-care devices, for example the Ukukhanya device that will save time and cost for HIV testing compared to existing methods. It provides rapid HIV viral load testing at the patient's bedside to assist the healthcare provider to make better treatment decisions, informed by the genetic diversity of the tested sample.

MEDICAL DEVICE LIFE-CYCLE MANAGEMENT

The lifecycle of a medical device comprises several phases including the design and development of the concept, the manufacturing phase, the packaging, labelling, advertising and sales phase, followed by its use and disposal.

The CSIR has looked at the challenges the industry faces, particularly on compliance and cost. CSIR experts have proposed a solution to integrate the various segments of this lifecycle in an optimal way. An aspect of this is the extraction of information and insight from device data and how to use that to improve its design and maintenance.

The four main pillars of this solution include product lifecycle software environments for managing the product throughout its lifetime; cloud-based and web applications for real monitoring of data and processes during the various stages of the lifecycles; integration of the quality management framework to capture all the needed regulatory requirements; and machine learning techniques to extract insights from the data collected throughout the product lifecycles.

From top: The Tugela River in KwaZulu-Natal, a waste dump in Johannesburg, Gauteng and the Knysna wetlands in the Western Cape.



The path towards a more sustainable South Africa

– a story of water, waste and wetlands

Worldwide, the modern economic focus on growth at any cost has put unbearable strain on the ecosystems, natural resources, and communities. It has become clear that the planet is headed for disaster if we don't step back from the breakneck consumption of fossil fuels and pollution of water resources that characterised the 20th century. But how do we go about changing centuries of behaviour that favours consumption, exploitation and growth? How to do we turn our global economy from brown to green? And in a water-scarce, developing country like South Africa, how do we do it without sacrificing the socioeconomic development we so desperately need? CSIR researchers illuminate that path.

CONFLICTING PRIORITIES

The idea of 'greening the economy' has been around for many years, but what it actually means depends very much on who you talk to. There are many ways to interpret the phrase, but that doesn't stop it getting bandied about by politicians and researchers alike.

In South Africa, greening the economy entered the political lexicon with the National Development Plan, developed by the National Planning Commission and launched in 2012. Trevor Manuel, who headed the Commission, said in a 2011 speech, "We have to change [our] patterns of consumption and we have to learn to use our natural resources more efficiently. We must do this with appropriate consideration for jobs, energy and food prices."

What he identified in that speech is that socioeconomic growth in the 21st century must be sustainable, a challenge for both developed and developing countries. According to CSIR water resources researcher, Dr Marius Claassen, South Africa has it particularly bad in this regard.

"The reality is that there is an extreme need right now for socioeconomic development and we need to do the best we can to serve that need," he says. "But we can't do it in such a way as to bring about significant risk in the future."

Unfortunately, Claassen says, there is no agreed scientific answer to the question of how to balance those conflicting priorities, and in a highly politicised domain like socioeconomic development, politics can often drown out the scientific arguments for going green.

Into that fray steps a new book, written in part by CSIR researchers, called "Greening the South African Economy." With contributions from researchers around South Africa, it looks to define the state of the South African economy in a new way. The book argues for an overhaul of our economy and society through a process of becoming more economically, socially and environmentally sustainable. It also provides some guidance about how to go about making those changes.

Bringing about widespread change in a society is no easy task, and requires some new and unusual approaches. In particular, social scientists and natural scientists need to find ways to work together (as well as with economists and politicians) to know which changes to make, how to go about implementing those changes, and measure whether the changes are effective or not. It is becoming increasingly clear that the key to sustainability lies in changing people's behaviour.

MULTIDISCIPLINARY RESEARCH

The CSIR is building the kind of multidisciplinary team needed to tackle these thorny problems. Economists, environmental and resource economists, anthropologists and development specialists are working toward improving the sustainability of our water, waste and energy sectors.

"We have to start with behavioural change around the water-waste-energy nexus," says CSIR principal researcher Dr Willem de Lange. "How do we incentivise people to step lighter, to act more sustainably? There's a lot of environmental and behavioural psychology, even cognitive psychology behind that."

He recently applied his alternative way of thinking to a problem in the Berg River catchment area. Known as eutrophication, an excess of nutrient run-off from farms and agri-industry in the area has caused an explosion of blue-green algae in the Berg River and its tributaries. This ecological imbalance leads to poor water quality and kills fish and plant life in the rivers. In addition, blue-green algae release toxins into the water, which can poison humans and livestock.

Drawing on work on several contract research projects for different organisations, De Lange conceived and designed a system of what he calls 'pollution permits'. In his envisaged solution, instead of being fined or otherwise punished for polluting the water, farms and other organisations will pay a permit for the 'right' to pollute.

"There are two broad approaches to managing pollution, the stick or the carrot. If you always use a stick, people will look for loopholes," says De Lange. "I wanted to create a carrot – an opportunity for companies to make some money out of their efforts to pollute less. Some companies can and will adapt more quickly than others; the pollution permit system facilitates that process."

His work outlined everything needed to make the permit system a reality – the economic rationale, how the different authorities would be involved, and the costs of the permits themselves. "If the authorities wanted to go that route," says De Lange, "that report would be their starting point."

PROCESS AND PROGRESS

For De Lange and Claassen, this is greening the economy: focusing on the processes required to make our economy and society more sustainable. Both say that sustainable development focuses too much on lofty goals and not enough on the details of how to reach those goals.

De Lange describes it as climbing a mountain – sustainable development is the summit, but greening the economy is mapping out the path that you will take to get there. And along the way, you need a global positioning system to make sure you are still on track – indicators and monitoring systems that allow you to understand where you are in the process.

Both researchers also go to great lengths to emphasise that the social and economic context should determine the approach to greening. South Africa battles with the highest social inequality in the world, an energy-hungry, carbon-intensive and extraction-heavy economy, and low labour productivity. Add to this the socioeconomic legacy of apartheid, and you have a challenging context in which to reach the sustainable development summit.

The CSIR, in collaboration with the South African National Biodiversity Institute and the Working for Wetlands programme of the Department of Environmental Affairs, rehabilitated a wetland in the Zaalklapspruit wetland system. The wetland showed an almost immediate improvement following the intervention, with decreased acidity and decreased levels of dissolved metals in the water flowing through the wetland.

SECURE WATER ACCESS FOR ALL

Claassen works with a number of different groups within the CSIR, focusing on different parts of South Africa's water problem. Their major concern is making sure that all South Africans have access to water. There are two parts to that challenge – making sure the access is secure and isn't going to fail, and getting the water to the people who need it.

The first part means looking for new ways to expand the water supply, or make more efficient use of what little water we have. One group at the CSIR is looking into using rainwater harvesting to add new water to the strained national supply.

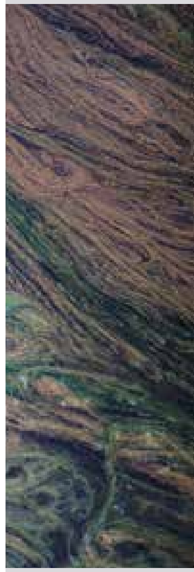
Another group works on improving water use efficiency through improving municipal governance. The project is looking at water-use licenses to find where water is going to waste, or where it can be allocated elsewhere to get more value.

The second part of the challenge – getting water where it's needed – is currently very energy- and infrastructure-intensive, which also translates to being carbon-intensive and therefore unsustainable.

"Instead of bringing new water from distant places, or 'destroying' water by discarding it, why don't we put it back into the system?" Claassen muses. "You can make huge savings on infrastructure and energy costs when you reuse and recycle water locally, so we spend a lot of time on technologies that can contribute to that."

One such technology is using algae to treat wastewater, allowing it to be reused for other purposes. Claassen and his colleagues are using this approach to treat water from wastewater treatment plants. A similar technique involves using wetlands to restore toxic mine runoff.

"These approaches require a low energy input, but hopefully have high value in terms of providing useful water," he says. "It should also reduce water demand across vast geographical spaces by using locally available water."



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PREPARING FOR AN UNCERTAIN FUTURE

Through all these efforts, there is an overarching drive to improve resilience, which can be thought of as the ability of a system to respond to an uncertain future. Resilience can be built at the level of natural systems, infrastructure and governance.

"Building wetlands to deal with mine runoff creates a resilient natural system by reducing the impacts of flooding and water treatment on the natural environment," Claassen says. Building dams is increasing infrastructure resilience by storing water. But perhaps most important for water security is building resilient governance.

"Resilience in governance is about adopting the correct management approach – a resilient system is adaptable. If you manage the system as if all things are constant, then your approach is not resilient."

Claassen says the authorities need to carefully monitor how things are going, adapt, and make rapid decisions when needed. It requires a change in mindset in how government works – authorities must plan for uncertainty rather than assuming certainty.

In South Africa, greening the economy means planning for an uncertain future while looking after the pressing socioeconomic needs of the present. It means encouraging growth, but not at the cost of our water and other natural resources. And it means listening to researchers, not just business people, in conversations about economics.

CSIR technologies and interventions to **maximise the availability of water** for scenarios of industrial growth

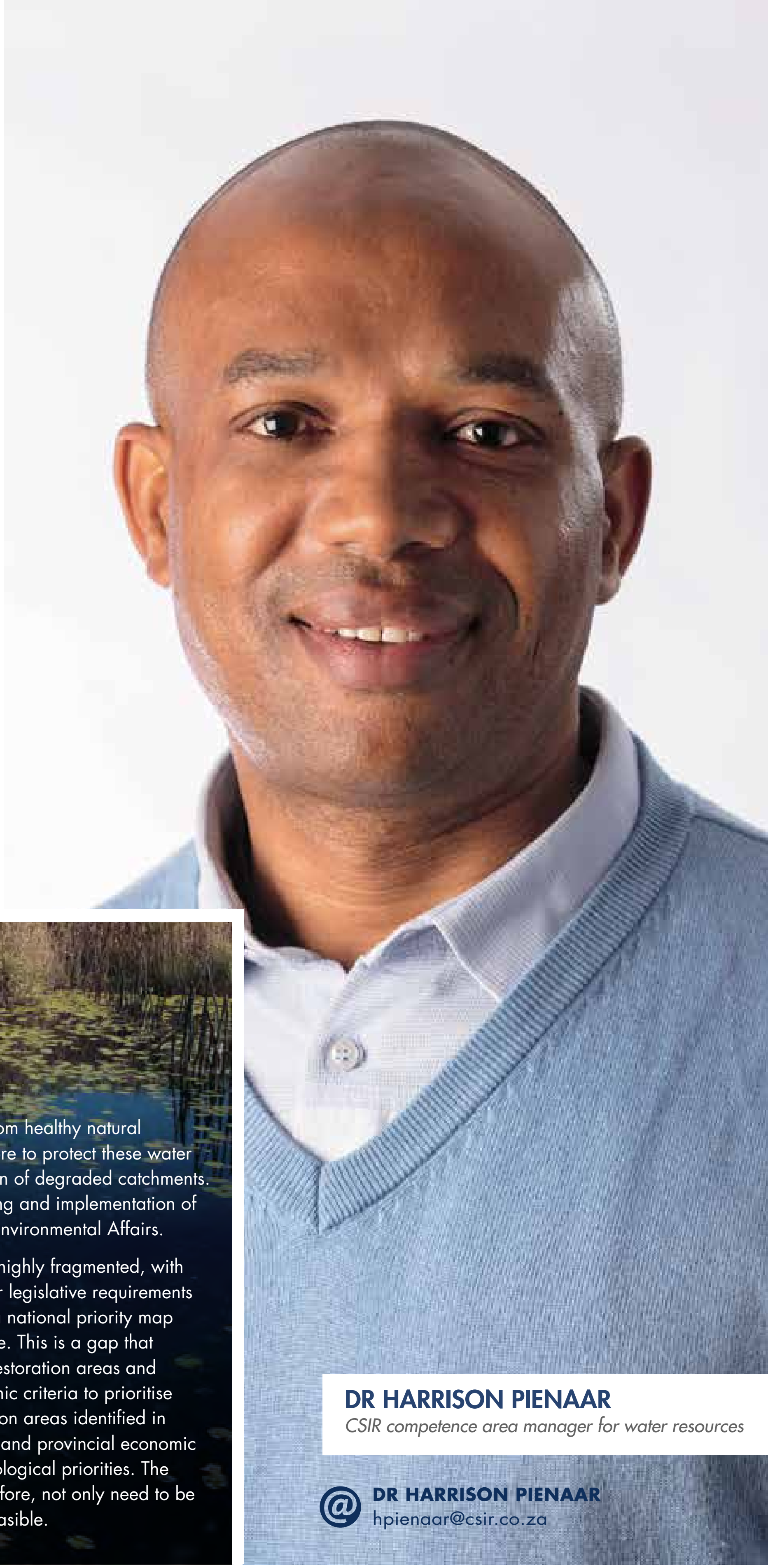
BY DR HARRISON PIENAAR

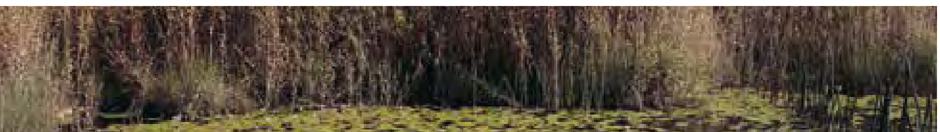
The CSIR's multidisciplinary nature perfectly positions the organisation to intervene and offer support in the areas of water security and sustainability. Our skills can be applied in the areas of water infrastructure; water resources and services management; adaption to and mitigation of climate change, industrialisation and urbanisation; water and human health; mine, industrial and wastewater treatment and water resource monitoring. The organisation's involvement in water-sector activities and initiatives include research, development and innovation, implementation support, operational efficiency optimisation, network management and skills development support.

Chromium (VI) is a toxic and hazardous element to living organisms and the environment. It can reach groundwater through the discharge of wastewater from industries. The CSIR is investigating the use of clay nanocomposites as a low-cost adsorbent to remove chromium (VI) from wastewater.

South Africa is a semi-arid country with a mean annual rainfall half of the world average at 490 mm. To compound the scarcity, evaporation rates exceed rainfall in a large area of the country. Coupled with rising population and economic growth projections, and based on the current usage trends, South Africa is expected to face a water deficit of 17% by 2030. This will have a significant impact on the rate at which key sectors in the economy can grow. In addition to major water users such as mines and major industrial users, a significant number of industrial water users that receive their water from municipalities and whose allocations are classified as urban, also have to be taken into consideration when considering the water demands of industry. A key requirement for industrial users is a secure and sustained supply of good quality water.

Global trends in water innovation and technology can be categorised into three areas: Reduce, remediate, and reuse (3-Rs). In response to the 3-Rs of water, this article outlines several innovations identified by the CSIR in its science, engineering and technology portfolio to reduce water dependence and achieve wastewater discharge compliance, to treat wastewater (remediation), reuse water and beneficiate nutrients.





PRODUCE:

PROTECTING OUR WATER 'FACTORIES'

Water does not come from dams and/or taps; it comes from healthy natural ecosystems. A logical first step in securing water is therefore to protect these water 'factories'. A key component of protection is the restoration of degraded catchments. The CSIR plays a role in supporting the restoration planning and implementation of the Working for Water programme of the Department of Environmental Affairs.

Catchment restoration efforts in the country are generally highly fragmented, with no coordinated national effort or strategy to deliver on our legislative requirements and commitments. Currently, South Africa does not have a national priority map for restoration, with recommendations of what to do where. This is a gap that the CSIR intends to help address by identifying strategic restoration areas and developing guidelines, using ecological and socio-economic criteria to prioritise restoration efforts. More specifically, the strategic restoration areas identified in this work will be informed, inter alia, by relevant national and provincial economic and social development policies and plans, as well as ecological priorities. The cost of restoration is inherently expensive; decisions, therefore, not only need to be ecologically and socially balanced, but also financially feasible.

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REDUCE: Improving the efficiency of water use and reducing water pollution

Industrial water use and re-use is the fastest growing sector of the global water market, with each industry facing increasing challenges to its business, including stricter water quality standards and wastewater discharge regulations, compounded by the issue of scarce water resources. This means that there are now major opportunities for science, engineering and technology to put forward cost-effective, innovative solutions designed to reduce water use through improved efficiency.

Some of the CSIR's current and future interventions in this regard are outlined below.

Water accounting assessments – Developing site-specific water accounting assessments for industry (water foot-printing for specific commodities and products) and providing fit-for-purpose solutions that mitigate water risks and enhance productivity.

In an ongoing project with Eskom, CSIR researchers are examining the quality and quantity of process and wastewater streams from electricity generation and investigating potential treatment options for its re-use as part of assessments to reduce water quality and quantity impacts in areas where power stations are located.

Water-use monitoring – Developing real and near real-time fixed and mobile water-use monitors and predictors for agriculture and manufacturing industries.

For example, the CSIR is refining estimates to reduce uncertainty in estimating the water requirements of apple orchards in the Western Cape.

Assessing water use for allocation purposes – Analysing water user behaviours through the development of a national water use behaviour assessment for more accurate monitoring and planning of water allocations to promote water use efficiency and enhance productive water uses – more jobs per drop, more rands per drop and more crop per drop of water used.

The CSIR is working with the Department of Water and Sanitation and the Breede Gouritz Catchment Management Agency to determine how much water is being used by different sectors in KwaZulu-Natal and a part of the Western Cape, including farming and commercial forestry. The Department will use the information for their Water User Authorisation Registration Management System.

Reduce also refers to the reduction of water pollution. Globally, the detection and treatment of emerging contaminants in urban water sources, including micro-pollutants such as drug residuals and endocrine disruptors, are recognised as major challenges. There is also a growing awareness about pollution from pharmaceutical products in the environment. In this regard, the CSIR aims to grow its capacity, particularly in the characterisation and assessment of waste streams, to minimise the impact on water resources and human and environmental health. Additionally, it prioritises the development and refinement of methods in the assessment of water-borne pathogens, like protozoan parasites and viruses, to protect human health.

Below: CSIR researchers use micrometeorological instruments to measure the water use of fruit tree orchards, in this case, high-yielding apple orchards in the Western Cape.

REMEDIATE: **Treating wastewater**

Water sources are increasingly limited and polluted, which necessitates going beyond the traditional (chemical and biological) water treatment process. Governments and others in the business of producing water and treating wastewater can thus expect increasing demands for innovative alternative solutions and technologies. The market for industrial water treatment technologies is set to expand over the next five years, from $7 billion in 2015 to $11 billion in 2020 (Global Water Index, 2015).

In direct response to this global trend and South Africa's needs, the CSIR focus on remediation will be on the development of low-technology, low-cost-alternative (partial) wastewater treatment options that are less energy and chemical-intensive compared to conventional wastewater treatment systems. CSIR studies on alternative wastewater remediation technologies will focus on the South African and African markets.

Bioremediation of waste at industry, domestic and business level is necessary to reduce the burden on existing municipal plants and promote reuse of the treated water. This improves the operational performance of the municipal plants (specifically plants that are barely meeting or exceeding discharge specifications) and promotes efficiency and reuse options within various industries.
A variety of biological treatment products are currently imported into South Africa. Negative consequences of this practice are the introduction of non-indigenous organisms into the country, with an associated negative effect on local ecosystems; higher costs to the end-user; and the hampering of local manufacturing growth.

To provide holistic solutions to industry for water remediation, reuse and safe discharge, the CSIR has a complement of skills that include, among others, biotechnology, microbiology, biochemistry and engineering.

The CSIR offers specialised technical support, services and products relating to water remediation, some of which are:

- An existing bacteria database of indigenous microorganisms with a host of bio-remediating properties, which can be assembled to target and treat specific wastes
- Pilot-testing facilities for the development of technologies, as well as the ability to contract-manufacture biological agents used in the formulation of biological products
- Pilot-scale systems for industry, to demonstrate the efficacy of products and processes
- An algal platform for investigating the use of algae for bioremediation
- CSIR adsorption-based technologies using functionalised hybrid polymer-based materials as an alternative approach to conventional wastewater treatment methods for removal and/or recovery of commonly occurring contaminants such as phosphates, nitrates, sulphates, fluorides and chromium (VI) from groundwater, municipal and industrial wastewater. The technology has been scaled up in pilot facility for producing 10 kg batches for field studies and can be applied for both municipal and industrial water treatment applications.

Above and below: CSIR researchers doing experiments on the use of nanocomposites as a low-cost adsorbent to remove chromium (VI) from wastewater.

REUSE: **Recovering nutrients**

Israel is a world leader in water reuse, boasting a reuse rate of more than 80%, which it aims to raise to 90% by creating a national treated wastewater distribution grid. By comparison, South Africa's water reuse rate is less than 20%. Water reuse is not a new area of research for the CSIR; it has a well-established portfolio of water treatment interventions that it can leverage. The CSIR will concentrate on further studies on the recovery of reusable minerals and nutrients from degraded water resources, industrial waste streams and post-mining landscapes. In water-scarce regions, water use and reuse will receive an increasing focus, particularly grey-water treatment and reuse – especially in urban environments – through wastewater desalination, stormwater use, rainwater harvesting as well as green infrastructure investments.

The CSIR is also focusing on the energy requirements of various water and wastewater treatment options; enabling water sector regulatory frameworks; the risks, social acceptance, environmental and economic feasibility as well as integration into existing conventional water supply and wastewater networks.
It is paramount that there is public sector involvement to sustainably manage water resources given our regulatory and institutional landscape.

Right: The CSIR has successfully implemented an algae-based wastewater treatment solution at the Motetema wastewater treatment works in the Sekhukhune District Municipality in Limpopo to facilitate the effective and efficient removal of nutrients and pathogens in wastewater treatment works.

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