ScienceScope

PUBLICATION OF THE CSIR

VOLUME 21 | NUMBER 1 OF 2024

SCIENCE, TECHNOLOGY
AND INNOVATION FOR A

CIRCULAR ECONOMY

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

CSIR
Touching lives through innovation

ENQUIRIES

enquiries@csir.co.za
+27 (0) 12 841 2911
www.csir.co.za

Guest editor: Prof. Linda Godfrey

Research, development and innovation communication manager: Alida Britz
aabritz@csir.co.za

Communication manager: CSIR Advanced Production and Security

Christa van der Merwe
cvanderm@csir.co.za

Communication manager: CSIR Advanced Chemistry and Life Sciences

Beeza Mtamzeli
bmtamzeli@csir.co.za

Communication manager: CSIR Smart Society

Lionel Jéan Michél
ljeanmichel@csir.co.za

CONTRIBUTORS

Beeza Mtamzeli, Phiwokuhle Ngcayiya, Christa van der Merwe, Lebo Rapulana, Lesley Nyawo, Lionel Jean Michel, Shahieda Davids, Sokhu Sibiya and Tsholo Mophosho.

EDITORS:

Valerie Kgasoe, Lehlohonolo Tau

COMPILED BY

CSIR Communication
CSIRComms@csir.co.za

DESIGN AND PRODUCTION

EPICreative
www.epicreative.co.za

THE CIRCULAR ECONOMY: AN OPPORTUNITY FOR SUSTAINABLE DEVELOPMENT

South Africa is a resource-rich country, however, its economy is predominantly linear and extractive, characterised by significant resource throughputs. A large portion of domestically extracted resources is exported for further beneficiation overseas, resulting in limited returns of resources back into the economy and minimal use for local infrastructure development. This exposes the country to risks of resource depletion or overexploitation, posing a direct threat to South Africa's future economic development.

The country's entry point into the circular economy, as with most countries, began with the waste sector. However, as shown in the following pages, the circular economy encompasses how resources are used within our economy to support sustainable socioeconomic development. With global resource demand on the rise, the circular economy is ultimately an economic and development issue.

The CSIR is well positioned to explore the complexities and opportunities of transitioning to a circular economy by leveraging science, technology and innovation.

In this edition of *ScienceScope*, Prof. Linda Godfrey, CSIR principal researcher and Manager of Circular Innovation South Africa, an initiative of the Department of Science and Innovation hosted by the CSIR, outlines why science, technology and innovation are critical to our transition to a more circular economy.

Additionally, read how the principles of a circular economy – such as designing out waste and pollution, keeping products and materials in use, and regenerating natural systems – are being applied across various sectors of our economy, including agriculture, energy, manufacturing, mining, mobility, settlements and water management.

Dr Thulani Dlamini
CSIR Chief Executive Officer

CONTENTS

Prof. Linda Godfrey shares a stage with Prof. Scott Valentine of the University of Brunei Darussalam at Circularity 2023 in Australia. *Image courtesy Circularity '23, Melbourne, Australian Circular Economy Hub*

WHY SCIENCE, TECHNOLOGY AND INNOVATION ARE CRITICAL TO OUR **TRANSITION TO A MORE CIRCULAR ECONOMY**

By Prof. Linda Godfrey, Manager of Circular Innovation South Africa, an initiative of the Department of Science and Innovation hosted by the CSIR

The circular economy is not about waste nor is it a synonym for recycling. The circular economy is about sustainable resource management. It's about national resource-security in support of socioeconomic development, through sustainable resource utilisation. The circular economy is centred on three principles – designing out waste and pollution, keeping products and materials in use and regenerating natural systems. Put simply, and when combined with the issue of sufficiency, it's about using longer, using again, making clean and using less.

Resources are at the heart of every economy. As such, sustainable resource management and the transitioning to a more circular economy is no longer a 'nice-to-have', but an economic, social and environmental imperative for every country.

Science, technology and innovation are critical to supporting a country's transition to a more sustainable, efficient and sufficient circular economy. The circular economy calls for disruption, innovation and system change, with a strong role for national systems of innovation. Our universities and science councils are crucial in unlocking technology opportunities; evidencing decision-making; evidencing policy development and implementation; and supporting business, especially small, medium and micro enterprises, to de-risk and scale circular interventions. The CSIR is active in all four of these strategic areas as shown throughout this edition of *ScienceScope*.

In **unlocking technology opportunities**, the CSIR has developed many innovative technologies to recover high-value products from organic waste streams, such as pulp and paper waste, agricultural waste and chicken feather waste, or innovative technology solutions for plastic waste. Some of these technologies can be accessed through the CSIR's Biorefinery Industry Development Facility, Biomanufacturing Industry Development Centre and the CSIR's Advanced Polymer Composites Group.

Over the past decade, we've seen four big drivers of a circular economy transition emerge globally, namely resource scarcity, climate mitigation and more recently – particularly in response to the global Covid-19 pandemic – economic recovery and socioeconomic development.

We are often asked why South Africa, or any developing country for that matter, should transition to a circular economy. It is therefore important for us to understand our drivers, but also to understand the opportunities a circular economy transition provides. This is possible through the **provision of sound evidence** that informs our development path.

As a multidisciplinary science council, the CSIR is one of a few institutions in South Africa that is positioned to better understand our drivers as a country and to explore what the circular economy means across different resource-intensive sectors of the economy. Our research shows that resource scarcity and climate mitigation are in fact drivers for South Africa to transition to a more circular economy. The studies undertaken in mining, agriculture, manufacturing, human settlements, mobility, energy and water also show that the circular economy is not new to South Africa, with many examples of circularity already in place, but perhaps not yet at the scale to achieve meaningful impact.

Science, technology and innovation are also important in **evidencing policy development and implementation**, as well as pre-empting policy needs. This is evident in the work of the CSIR, where we modelled the leakage of waste plastic into the aquatic and terrestrial environments to inform appropriate responses, including policy responses. The study, conducted in partnership with The Pew Charitable Trusts and the University of Oxford, provided insights into the potential effectiveness of various upstream and downstream interventions, including Extended Producer Responsibility Regulations, to mitigate plastic pollution. The CSIR is also currently working on a project, funded by the Department of Science and Innovation, to assess the potential for building circularity into South Africa's Nationally Determined Contributions in support of our climate commitments.

When it comes to **supporting businesses to de-risk and scale circular interventions**, the CSIR is actively engaged. The CSIR's Biorefinery Technologies Demonstration Programme and Circular Innovation South Africa's Demonstration Fund are examples of how our research institutions can be brought closer to the private sector to provide growth opportunities for business.

The CSIR's research on the opportunities and constraints to circular interventions across various sectors of the South African economy is publicly available at www.circulareconomy.co.za/csir.

The South African agriculture sector has implemented some circular economy interventions – such as intercropping, in this case, ginger intercropping with corn crop – although at varying scales.

CIRCULAR AGRICULTURE IN THE SOUTH AFRICAN ECONOMY

By Dr Blessed Okole, Programme Manager, CSIR Advanced Agriculture and Food

Agriculture plays an important role in the South African economy, being deeply interconnected and central to many other industries and their operations. South Africa is a major producer and exporter of agricultural products, with the country consistently remaining a net exporter over the last decade. Agricultural exports amounted to USD10.2 billion in 2020 and a record USD12.4 billion in 2021, creating 829 000 jobs. However, the agricultural sector is resource-intensive with a heavy reliance on water, energy, soil, nutrients, and natural cycles, as primary inputs that are finite.

Growing food demand and high population growth in South Africa have contributed to environmental challenges such as climate change, deforestation, biodiversity loss linked to the rapid expansion of human settlements, and land degradation impacting negatively on food security.

Feeding a growing South African population will require embracing new farming methods that can help increase productivity while reducing associated environmental impacts. Previous evolutions in farming have largely been driven by mechanical improvements (bigger and better machinery), genetic advances (improved seeds) or green revolution (more effective fertilisers, and so forth). The next big transformation is being driven by digital tools and lifestyle changes. Several new, disruptive technology trends are emerging in the agricultural sector and are regarded as key market opportunities, including circular agriculture.

Circular agriculture is not a new concept and was widely practised by pre-industrial societies. However, it has been pushed aside by modern farming based on large-scale, monoculture and highly intensive practices, which are often primarily focused on maximising profit over the protection of the environment.

(continued on page 10) »

CIRCULAR AGRICULTURE IN THE SA ECONOMY (CONTINUED)

As the sector faces growing constraints such as changing climates, deteriorating soil health, diseases, and access to potable water, large-scale monoculture may not provide the most appropriate approach to achieving food security. With time, big farms and businesses in the sector will need to transform to be sustainable, resilient and economically viable.

Circular agriculture as depicted in the graphic (right) centres on a regenerative system, with the production of agricultural commodities using a minimal number of external inputs; decoupling production and processing from resource utilisation; closing nutrient loops; restoring soil fertility; and reducing discharges to the environment.

In 2021/22, the Department of Science and Innovation commissioned the CSIR to carry out an in-depth assessment of the circular economy in the food and agricultural sector in South Africa from a resource perspective. The project was designed to inform public and private sector responses on where immediate circular economy opportunities are achievable.

Circular agriculture and the valorisation of unavoidable waste from the agri-food sector (adapted from Scholten, 2021 and AgroCycle, 2021).

The main findings showed that stakeholders are aware of most of the circular economy interventions applicable to the agricultural sector, such as inter-cropping, composting, mixed farming and agro-processing technologies. However, a few stakeholders were uncertain about the less familiar interventions, such as chemical leasing, zero tillage, equipment sharing, urban/peri-urban farming, vertical farming and precision agriculture. The South African agriculture sector is ready and has already implemented some circular economy interventions at various scales.

There are a few interventions that will take longer to implement because of certain challenges facing the sector. Financing appeared to be the most persistent barrier, including the high upfront investment costs for some interventions. However, for the sector to become sustainable, entrepreneurs and companies should be able to access conventional financing with preferential rates. The second-highest-rated challenge was the need for pilot and demonstration facilities to showcase circular interventions to farmers, policymakers and others. There is a need for policies that will favour the growth of the sector through sustainable and circular interventions. Awareness creation and the availability of the right technologies were also some of the barriers to scaling.

Business opportunities identified ranged from regenerative agriculture, precision agriculture, food waste interventions, agro-processing, sustainable packaging to extend product life, to urban farming.

Finally, stakeholders identified climate change as a severe challenge facing the South African agricultural sector. Agriculture has a major impact on the environment, being a leading contributor to greenhouse gas emissions, water consumption, and nitrate and ammonia pollution. Mitigations proposed were generally focused on regenerative agriculture interventions, such as crop rotation, minimum tillage, green manure and integrated pest management.

If done properly and scaled, circular agriculture has the potential to make businesses more economically viable, competitive and sustainable in the long-term. A transition to a circular agriculture requires a strong evidence base to understand the opportunities that this transition will yield for increased industrialisation.

ENQUIRIES:

>> **Dr Blessed Okole**
bokole@csir.co.za

From citrus waste to insect repellent.

GREEN TECHNOLOGIES TO RECOVER HIGH-VALUE PRODUCTS FROM CITRUS WASTE

A GREEN PECTIN PLAN FOR CITRUS PEELS

Production of citrus fruit crops worldwide exceeds 130 million tonnes per year, according to the World Citrus Organisation. More than a third of the world's output of citrus is processed, mostly into concentrated juice, and the fruit peels are mostly discarded. In line with a more circular agricultural approach to reduce waste, pectin – which has great value in food products – can be extracted from the citrus peel waste. A nagging issue, however, has been that most producers still use chemical methods to produce pectin. CSIR researchers believe they have found a solution.

Pectin. A scientific-sounding word that many people will say they have not encountered before. But it is as everyday as eating jam. The juices released when cooking fruit to make jam, and that eventually thickens the jam, is pectin. It is a polysaccharide found abundantly in the primary walls and the intercellular layers of plant cells. Citrus peel (lemon, grapefruit and orange) contains 30-35% pectin by mass of dried peel.

In addition to its uses in food products as the gelling agent in jams and jellies, it is also used in some liquid pharmaceutical preparations to add viscosity and stabilise emulsions and suspensions and it has potential health benefits, including a prebiotic effect and potential cardiovascular benefits by lowering low-density lipoprotein cholesterol. It even has potential to be used in edible packaging that can be tailored to deliver bioactives such as phytonutrients, vitamins or even pharmaceuticals directly to the gut.

CSIR principal researcher Dr Lucia Steenkamp says that while the demand for pectin continues to rise, most producers still use chemical methods to produce it. This is despite consumers increasingly demanding 'greener' products. In response, the CSIR has developed a green technology that can be easily adopted using the existing infrastructure in chemical plants.

"We applied an enzyme that is used commercially in the clarification of fruit juices. The CSIR developed a technology to produce low methoxy pectin using this enzyme. Low methoxy pectin has the added advantage that it does not require sugar for gelling. The normal high methoxy pectin obtained straight from the peels requires sugar for gelling. With low methoxy pectin, gelling is accomplished by adding calcium. This results in a product which can be safely used by people with diabetes and for weight loss products. The enzyme used for producing low methoxy pectin from high methoxy pectin can control the outcome of the final product more accurately, while chemical breakdown to low methoxy pectin usually can result in significantly different product qualities if not very well controlled.

"Significant improvements were made in the experimental development of methods, especially because no current commercial production facility makes use of an enzyme-catalysed conversion to the product. The technology resulted in a significant reduction of harsh chemicals such as sulphuric or hydrochloric acid," Steenkamp says.

CHOOSING ENZYMES OVER CHEMICALS TO PRODUCE INSECT REPELLENTS FROM CITRUS ESSENTIAL OILS

Citrus essential oils are derived from the peels of citrus fruits and are typically used in aromatherapy, household cleaning and skincare products. While lemon oils are often used in products to repel insects, the CSIR drew on its skills in biocatalysis to help a biotech enterprise to optimise a technology using orange oil to produce a new insect-repelling product, called Noot-a-bug.

Biocatalysis offers several advantages over traditional chemical catalysis, such as higher specificity, lower energy consumption, milder reaction conditions, less waste generation and better compatibility with renewable feedstocks – all aspects that are important in a circular economy.

"Biocatalysis is the ultimate green technology," says CSIR principal researcher Dr Lucia Steenkamp.

Optimisation of the bioconversion of citrus oil to nootkatone.

(continued on page 14) »

"Through biocatalysis, we identify and optimise microorganisms and/or enzymes to accomplish specific reactions and produce certain desired molecules, instead of using classical chemical technologies. The technologies we develop do not require harsh chemicals or high temperatures; they consume little energy and normally generate little to no waste," she says.

The CSIR's experts in biocatalysis used an enzyme system to bioconvert compounds in the citrus oil into other more useful compounds with insect-repellent activities for small, medium and micro enterprise Applied Protein Biotechnologies (APBIO). The research team also developed a second product, nootkatone, for APBIO. This product is normally obtained commercially through the extraction of approximately 400 000 grapefruit to obtain 1 kg of nootkatone. Nootkatone is a sought-after natural organic compound in the flavours and fragrance sector and is also an insecticidal compound that repels and kills insects.

The CSIR technology uses a much cheaper compound found in orange oil, which is then bioconverted with an enzyme system to nootkatone at significant yields. The collaboration between the CSIR and APBIO resulted from the Industrial Biocatalysis Hub's mission to develop and localise technologies using biocatalysis. The hub is funded by the Technology Innovation Agency and the Department of Science and Innovation.

The scale-up of the technology resulted in the production of a market sample that exceeded agreed specifications, which led to APBIO signing a licence agreement with the CSIR. A complete dossier of the technology has been transferred to APBIO to enable the company to commercialise the technology and produce the two products of interest. APBIO has made good progress with the marketing of the products. The company is selling the Noot-a-bug oil to third parties who then include the oil as part of their own products. Some examples include the use of the product in an insect repellent product by Optimus Bio, marketed as Bug-away. The product was distributed as samples to delegates at the 2023 BioAfrica convention in Durban. Another example is Fever Tree, which now offers its lotion at most Clicks stores and will soon launch a normal cream (without sunblock). APBIO partnered with companies in Uganda and Tanzania that have tested Noot-a-bug in various formulations and found it superior to many others. They are now in the process of registering these in their respective countries. APBIO is exploring markets in China and Australia through a similar pathway.

The biggest success for APBIO to date was the work it did with African Applied Chemicals on nootkatone, which resulted in long-lasting insecticidal mosquito nets using a slow-release formula – and for which they are also pursuing World Health Organization (WHO) approval.

CSIR postdoctoral researcher Dr Moloko Mathipa Mdakane is one of a team that creates products from citrus waste using biocatalysis.

The price of pure nootkatone had proved prohibitely expensive for use in mosquito nets. APBIO participated in trials in Tanzania in which nets were used that contained APBIO's nootkatone formulations. If WHO approval is secured, APBIO may have to supply up to 60 tonnes per annum, slowly building up over the next 10 years.

WORKING WITH NATURE TO CREATE DISINFECTANTS FROM A CITRUS FRUIT EXTRACT

The CSIR has helped formulate a series of biocides for Biodx (Pty) Ltd, a company that has set out to reduce society's dependence on synthetic chemicals. The biocides are products formulated for surface disinfection for food contact and general surface disinfection.

Biodx (Pty) Ltd has spent 16 years researching and developing cutting-edge antimicrobial and antiviral technologies. The company drew on the technical skills of the CSIR and the Netherlands Organisation for Applied Scientific Research (TNO), and funding support from the South African Technology Innovation Agency and the South African Industrial Development Corporation to develop a new generation of disinfectants that no longer relied on synthetic chemical solutions.

CSIR principal researcher Dr Lucia Steenkamp says her team has assisted Biodx (Pty) Ltd with a product that is non-corrosive, Earth-friendly and rapidly kills many bacteria species and viruses. The company ran trials with large clients during Covid-19 and it was found to kill 99.9% of the virus in seconds on surfaces.

Biodx has sold tonne quantities of the products – first registered on 23 June 2021 as the only type 2 and 4 biocides from Africa in the European Union – to different local and international markets.

ENQUIRIES:

>> **Dr Lucia Steenkamp**
lsteenkamp@csir.co.za

CSIR principal researcher Dr Sudhakar Muniyasamy (right) and CSIR senior researcher Dr OJ Botlhoko, inspecting mulch film their team has produced.

GOOD NEWS FOR SUSTAINABLE **AGRICULTURE AS BIODEGRADABLE MULCH FILM FIELD TRIALS START**

The CSIR has developed biodegradable mulch films for the agricultural sector. CSIR researchers in advanced polymer composites collaborated with their peers at the Elizade University in Nigeria, as part of a project of the United Kingdom-based Sustainable Manufacturing and Environmental Pollution Programme, and the Department of Science and Innovation (DSI).

Mulch films are an essential part of many forms of crop farming. These plastic films enable farmers to enhance their crop yield through weed control, water retention, decreased use of pesticides and prevention of soil erosion.

The problem, says Dr Vincent Ojijo, CSIR research group leader for advanced polymer composites, is that plastic mulch films often end up being disposed of in the environment and break down into microplastics, causing ecological impacts such as impeding nutrient cycling in the soil, reducing soil aeration, water infiltration and root penetration – ultimately affecting plant growth and reducing agricultural yields.

Crops under mulch films.

> "BIODEGRADABLE MULCH FILMS ARE AN ENVIRONMENTALLY SUSTAINABLE ALTERNATIVE TO CONVENTIONAL MULCH FILMS."
> *– Dr Vincent Ojijo, CSIR*

He says that biodegradable mulch films are an environmentally sustainable alternative to conventional mulch films, with notable benefits such as biodegradability to carbon dioxide, water and biomass – ultimately enriching the soil post crop life.

“The AgriBioMulch project has made tremendous strides since its inception in January 2022. Now in its third phase, the project has demonstrated the industrial manufacturability of two minimum viable biodegradable mulch film products for short-term crops. These mulch films are currently under field trials in Nigeria. Recently, we sent samples to our local partner, the Agricultural Research Council, for field trials,” he says.

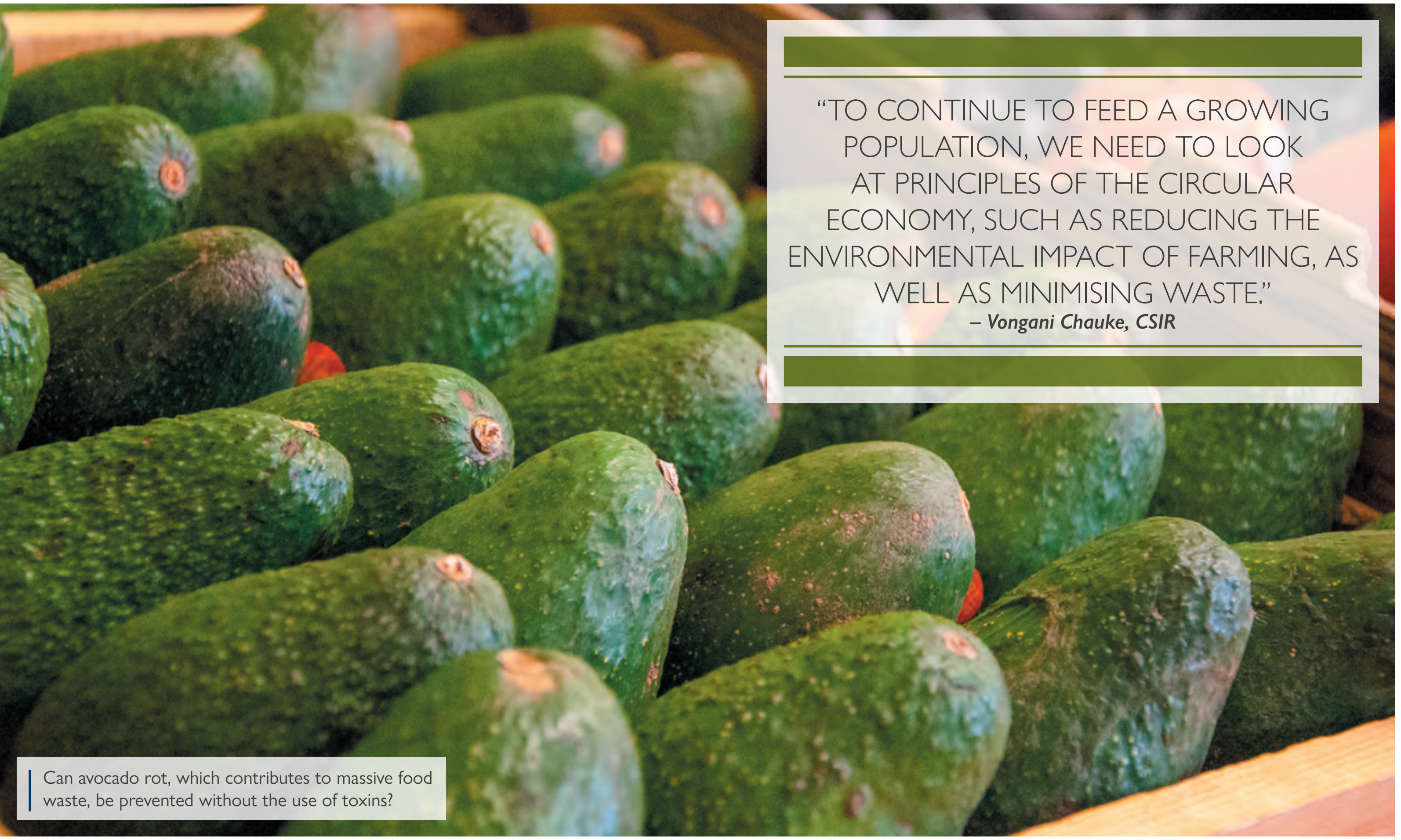
The research team will also do field trials for the long-term product, for which the project secured funding from the DSI's Circular Economy Demonstration Fund, managed by Circular Innovation South Africa. The long-term field trials will run for two and a half years from the start of 2024.

“In addition to demonstrating industrial manufacturability of the long-term biodegradable mulch film, we will test the feasibility of a novel re-use model for the product as part of field trials and carry out a life-cycle assessment. These activities will help to de-risk commercialisation of the technology, which is the next step, to advance circular economy ideals,” Ojijo says.

CSIR-formulated pellets ready for biodegradable mulch film production.

ENQUIRIES:

>> Dr Vincent Ojijo
vojijo@csir.co.za



"TO CONTINUE TO FEED A GROWING POPULATION, WE NEED TO LOOK AT PRINCIPLES OF THE CIRCULAR ECONOMY, SUCH AS REDUCING THE ENVIRONMENTAL IMPACT OF FARMING, AS WELL AS MINIMISING WASTE."
– Vongani Chauke, CSIR

Can avocado rot, which contributes to massive food waste, be prevented without the use of toxins?

USING ESSENTIAL OILS TO PRESERVE **AVOCADOS ON THEIR WAY TO MARKET**

The CSIR has developed a natural alternative that aims to revolutionise the way that the agricultural industry preserves what is often dubbed 'green gold' or avocados, thereby reducing wastage.

South Africa is one of the leading avocado-producing countries in Africa, with most of the avocado produce exported to European countries. But it faces a challenge. The European Union is set to ban the use of prochloraz, a common pesticide used to prolong the lifespan of avocados post-harvest, due to its unfavourable toxicological characteristics. Research indicates that prolonged or high levels of exposure to the pesticide may increase workers' chances of adverse health risks.

CSIR senior researcher Vongani Chauke says, "We use natural oils as pesticides and herbicides for the treatment of avocados. Avocados are known for their high nutritional value and wide array of health benefits, however, they tend to spoil quickly due to fungal infections, particularly post-harvest. Our approach makes use of an essential oil made from thyme to protect crops post-harvest," she explains.

The thyme herb is known to offer numerous benefits – its leaves are used as a flavour enhancer in the culinary world and the stalks are pressed for oil used in medicinal remedies. The multifaceted herb contains a compound that has potent antimicrobial properties.

"We extract this active ingredient in the thyme called thymol. This ingredient is what is responsible for killing the bacteria, microbial and other funguses. We create an emulsion to mask the strong smell of the oil and to stabilise the oil/water mixture without losing its efficacy, and this mixture can be sprayed on the avocados post-harvest or dipped into this emulsion," says Chauke.

CSIR researchers have developed a herbicide as an alternative to pesticides to treat avocados. Thyme oil, with its potent antimicrobial properties (above) is added to an emulsion (below) to mask its strong smell without losing its efficacy.

Thyme oil not only addresses the challenge of preserving avocados but also promotes sustainable agriculture, with the safety of consumers and workers put at the forefront. "Adopting natural pesticides and herbicides in the value chain of food produce is a matter of life or death for many workers in the agricultural industry as prolonged exposure to the current harmful pesticides can cause cancer. The CSIR-developed herbicide ensures that there is an alternative to chemical pesticides to treat avocados," she says.

"To continue to feed a growing South African population, we need to look at principles of the circular economy, such as reducing the environmental impact of farming, as well as minimising waste. We believe this CSIR-developed alternative to chemical pesticide to prevent stem rot, is a step in the right direction," Chauke says.

ENQUIRIES:

>> Vongani Chauke
vchauke@csir.co.za

CSIR researchers use various technical instruments and devices to measure the water use of fruit trees.

BEING SMART ABOUT WATER **IN FRUIT FARMING**

South Africa is one of the world's largest producers of fresh fruit. Approximately 90% of the country's fruit is exported to the international market. However, the sector is resource-intensive, with a heavy reliance on water. In this context, the CSIR contributes to circular economy principles by undertaking research to improve water use efficiency in orchards to eliminate water waste and to regenerate natural systems.

The consumptive use of water in South Africa's fruit industry – where water is lost via soil evaporation and tree transpiration to the atmosphere and not discharged to any location – furthers the statistic of the agricultural sector using 61% of the country's water allocation. The National Water Resource Strategy states that half of the water used in the agriculture sector is lost to irrigation inefficiencies and leakages. The high water use in agriculture is not unique to South Africa with the United Nations Food and Agriculture Organization encouraging the development of water use efficiency studies in the sector.

Considering that South Africa is one of the driest countries in the world, better management of available water resources through more efficient methods of water application is crucial to future food security. Climate change forecasts predict an increased frequency and intensity in the occurrence of drought in the country. This is of great concern when viewed in the context of the envisaged impact on agriculture and the vulnerability of rural households and the urban poor. The incidence of crop failure will likely increase, severely impacting food and nutrition security. This concern has led the CSIR to revisit the way water is being used in irrigated agriculture.

To understand the physiological responses of fruit tree species to water scarcity, researchers measured the total evaporation rates in plants. This was useful for validating and improving tools or models that can be potentially used to determine crop water requirements. Moreover, the method was also used to improve irrigation scheduling and minimise non-beneficial water use.

"This will increase water use efficiency in orchards – we talk about more crop per drop – which will allow farmers to expand their fields and irrigate more crops with the same or a reduced volume of water. For long-term sustainability, it is therefore important for the fruit industry to adopt practices that increase the water productivity of the orchards. This can be achieved by using different irrigation systems. For example, surface or flood irrigation is the least efficient method of irrigation in fruit orchards in South Africa. In some cases, some of the applied water is used by the grass that grows on the orchard floor; this is water that is non-beneficial for the growth of fruit trees or promoting any fruit yield," says CSIR senior researcher Mpumi Mobe.

> "FOR LONG-TERM SUSTAINABILITY, IT IS IMPORTANT FOR THE FRUIT INDUSTRY TO ADOPT PRACTICES THAT INCREASE THE WATER PRODUCTIVITY OF FRUIT ORCHARDS."
> *– Mpumi Mobe, CSIR*

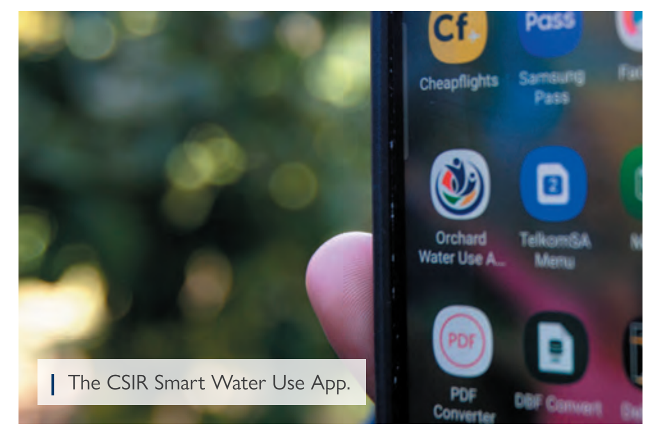
There has been significant growth in the scientific knowledge around fruit tree water use in South Africa in the last decade, as more research is being done on improving water use efficiency.

"Innovative technologies, management approaches and modelling tools to improve irrigation scheduling, save water, increase farmers' income and reduce the environmental burden are gaining traction in the agricultural sector. An innovative tool such as the CSIR Smart Water Use App has been developed to estimate actual evapotranspiration derived from reference evapotranspiration and crop coefficients. This approach has been accepted by researchers and is considered inexpensive and practical for irrigation scheduling. The uptake and use of this tool can be useful in irrigated agriculture. Providing detailed forecasts of the actual orchard evapotranspiration and its components will improve irrigation scheduling and water allocation planning," she says.

Precision farming and the efficient use of water resources are a key element of the circular economy in the agriculture sector.

ENQUIRIES:

>> Mpumi Mobe
tmobe@csir.co.za



The CSIR Smart Water Use App.

Vitamin A-rich, orange-fleshed sweetpotato has become the lead biofortified crop in Africa.

WHERE NOTHING IS LOST: DEVELOPING NEW **PROCESSED PRODUCTS FROM ORANGE-FLESHED SWEET POTATO**

In a circular economy, nutritious food products from diverse sources are derived from healthy production systems to provide healthy nutrition while limiting food waste and leaving nature in a better state than previously. But it calls for food design: the series of decisions that are taken from deciding what crops to grow until these end up on a consumer's plate. In a considered move, researchers at the CSIR and the Agricultural Research Council (ARC) are collaborating to develop new orange-fleshed sweet potato processed products and enterprises to market these products.

Millions of households in Africa are growing and eating vitamin-A-rich, orange-fleshed sweet potatoes. Farmers with limited access to financial resources, including materials and equipment, can produce this drought- and heat-tolerant crop. These sweet potatoes are a natural source of provitamin A carotenoids, and thus their uptake helps reduce malnutrition associated with Vitamin A deficiency, which is prevalent in sub-Saharan Africa. By developing new processed products, nutritious foodstuffs with a longer shelf life can be produced, thereby minimising food spoilage and waste when production surpasses the demand for fresh produce.

"We set out to develop market-ready products from orange-fleshed sweet potato cultivars that have been developed by the ARC," says CSIR principal researcher and food scientist Dr Nomusa Dlamini.

"We are also working towards localising technologies from abroad for shelf-stable puree through collaboration with two local companies.

"We believe that our work will catalyse the creation of a vibrant orange-fleshed sweet potato industry that creates jobs and economic opportunities across the value chain.

"We are looking into purees, flour and crisps. Once these products have passed food safety checks and comply with relevant regulatory frameworks, we will incubate three small, medium and micro enterprises for eventual wide-scale marketing and sales," she says.

The project takes a full value chain approach – supporting objectives such as determining the techno-economics of the orange-fleshed sweet potato businesses, developing tools to mitigate pre- and post-harvest losses, establishing a framework for effective partnerships, as well as evaluating the uptake and impact of the value chain.

The CSIR has develped new processed products from orange-fleshed sweet potatoes to help minimise food waste when production surpasses demand. These include baked products (below) and chips (right).

Baked products containing orange flesh sweet potatoes.

Cut orange-fleshed sweet potatoes.

Orange-fleshed sweet potato chips.

Dlamini is passionate about developing innovative methods for improving the quality and texture of foods. She says the team also intends to localise the microwave technology for processing shelf-stable orange-fleshed sweet potato puree. This will ensure the availability of nutritious food products throughout the year – contributing to reduced food losses when excess fresh food spoils," she says.

The Department of Science and Innovation has made funds available for high-end microwave processing equipment.

ENQUIRIES:

>> Dr Nomusa Dlamini
nrdlamini@csir.co.za

Kenokatha Farms in Midrand, Gauteng has harvested the first baby marrows that had been cultivated using the farm's own biocompost. Owner Quinty Rabophala showing the first harvest.

JOINING FORCES TO COMBAT FOOD WASTE **AND ADDRESS FOOD SECURITY**

South Africa faces a paradox: climate change and a shortage of fertilisers affect the country's ability to provide enough food for the domestic and export market, but food imported to meet the demand often spoils due to incorrect storage facilities, resulting in food wastage. CSIR experts in agricultural processes have developed a programme to train small agri-businesses in food waste management to support sustainable farming.

One of the focus areas of the circular economy is keeping products and materials in use. In South Africa, just like in the rest of the world, food waste is a growing reality. CSIR senior researcher and acting research group leader Phatheka Ndzotoyi says, "According to research by the CSIR, annual food losses and waste in South Africa is 10.3 million tonnes, Africa's largest contributor to food waste. This food waste often ends up in landfills, which results in the generation of greenhouse gases and leachate, which negatively impact air and water quality. Sadly, 20% of South African households experience food inadequacy and hunger.

To resolve this problem, the CSIR has piloted a nationwide project that identified and trained eight small-scale farmers and staff on technologies to process food waste into highly nutritious biocompost that can replace expensive chemical fertilisers used in farming. The farmers completed the comprehensive Food Waste Entrepreneurship Course which comprised seven theoretical modules and one practical module. The course explored a variety of biocomposting approaches for household, commercial kitchen and vegetable market food waste; vegetable cultivation using biocompost; as well as the financial sustainability of the business.

"The course takes the trainees through the process of making biocompost using the Bokashi process. This process has proven to be a sustainable and green solution for small-scale farmers and was demonstrated in a joint project of the CSIR, Black Umbrella and Nedbank. The process uses vegetable scraps, mixed with enzymes, to speed up the decomposition journey," says CSIR senior technologist and project principal investigator Ndumiso Ndlovu.

Farmers were provided with Bokashi Bran microorganisms, various gardening tools, an assortment of seeds for cultivation and the basic equipment required for the fermentation of the food waste and processing of the biocompost.

More than 10 tonnes of foodwaste has been converted into biocompost at the various sites and is being used as an alternative to chemical fertilisers.

Ndzotoyi says the next stage of the programme is to expand the project and include more small-scale farmers. "We are targeting to convert at least 50 tonnes of food waste to biocompost, create employment and improve the income generation capabilities of the small-scale farmers."

ENQUIRIES:

>> Phatheka Ndzotoyi
pndzotoyi@csir.co.za

Food waste is converted into high-quality compost using the Bokashi process. From the top: Microorganisms are added to food waste, fermented for six weeks and applied as compost two weeks before planting.

CSIR chemical engineering technologist Londani Mbambo oversees potato bag pulping. As part of this work, the CSIR has designed a fibre recovery pilot plant for paper-based waste streams.

RECOVERING USEFUL FIBRES FROM **USED POTATO BAGS**

The CSIR has developed a technology to recover fibres from used potato bags. The Paper Manufacturers Association of South Africa (PAMSA) and the Department of Science and Innovation (DSI) co-funded the work.

Fibres recovered from used potato bags are repurposed and used to manufacture paper-based packaging materials such as fluting, a corrugated medium used in paper packaging materials. The use of wastepaper offers economic and environmental benefits in line with circular economy ideals.

Fibres procured from waste paper are less expensive compared to virgin fibres, and the use of waste fibres downsizes the requirements of the upstream processes in the pulp production process value chain, resulting in a significant reduction in chemicals, energy and water usage.

CSIR principal researcher Jonas Johakimu says, “The goal was to generate reliable research and development data, also on capital and operational cost, to assist PAMSA and the DSI to design and implement a series of commercial-scale modular plants in South Africa that would be beneficial to small, medium and micro enterprises.”

The CSIR Biorefinery Industry Development Facility, which undertook this work, assists local industry to improve its competitiveness by providing access to specialised analytical and pilot-scale facilities, skills that enable the more efficient use of the country’s biomass resources, and how to overcome significant organic waste challenges and develop new products for markets.

“Improving the recyclability of these paper materials in South Africa will lead to a meaningful contribution towards the realisation of the circular economy. It will improve the sustainability and competitiveness of local companies and create opportunities for new emerging small-scale enterprises and entrepreneurs. It will also create and preserve jobs while increasing waste paper recovery rates in line with global trends and standards,” Johakimu says.

ENQUIRIES:

>> **Jonas Johakimu**
jjohakimu@csir.co.za

Packaging material generated from used potato bags.

Useful fibres recovered from used potato bags.

Biomass fractionation is the cornerstone for any circular economy technology that seeks to unlock the valorisation of waste wood biomass streams through thermal and chemical fractionation pathways. The CSIR uses a thermal biomass fractionation facility for the development of new biobased materials, biofuel and chemicals. A biochar bench scale unit (2 kg/hr) is used for testing various biomass feedstocks, and technology development, whereas a biochar bench scale unit (50 kg/hr) is used for technology scale up, validation and optimisation. The equipment is available for contract manufacturing for emerging SMMEs.

UNLOCKING HIGH-VALUE PRODUCTS FROM **SAWDUST BIOMASS WASTE**

The CSIR is in the process of developing a protocol aimed at optimising the extraction of xylitol, a high-value product from xylose, a sugar isolated from wood or sawdust biomass. Maximising the value of underutilised byproducts or waste aligns closely with the principles of a circular economy.

A new extraction protocol, developed at the CSIR Biorefinery Industry Development Facility, provides comprehensive guidelines for evaluating and processing parameters to convert xylose into an important platform for sustainable bioproducts, particularly targeting the xylitol market. Xylitol is widely used as a food and beverage sweetener and its market is expanding.

According to CSIR principal researcher Jonas Johakimu, "The transformation of lignocellulose biomass (organic waste from the forestry and agriculture sector) into value-added products like biofuel or chemicals hinges greatly on their purity. Attaining a high degree of selectivity during biomass fractionation is imperative to ensure acceptable yields and purities in each fractionated stream, meeting the requirements of end users."

Ongoing research and development endeavours entail investigating the impact of process parameters on yield while identifying optimal process conditions, laying the groundwork for subsequent investigations.

Sawdust, an underutilised byproduct.

"There is consensus at national and industry level that the future of the bioeconomy will be derived from biobased products. In contrast to existing biomass processing industries, future biobased industries must adopt an integrated biorefinery approach capable of yielding multiple products from a singular feedstock source," says Johakimu.

Having completed an upstream process for sawdust biomass fractionation, the focus now shifts to downstream processing, encompassing the conversion into value-added products such as xylitol.

Upon successful demonstration, the technology will be licensable to small, medium and micro enterprises seeking to locally manufacture xylitol, serving as a direct substitute for imported xylitol currently being sold in South Africa.

Xylitol is a sugar alcohol made from xylose, which is extracted from sawdust wood biomass. Xylitol can be used as an alternative low-calorie sweetener in chewing gum, sweetener coating in pharmaceutical products and as toothpaste.

ENQUIRIES:
>> **Jonas Johakimu**
jjohakimu@csir.co.za

IMPROVING ENERGY SECURITY IN SOUTH AFRICA THROUGH A MORE CIRCULAR ENERGY SECTOR

The CSIR's photovoltaic (PV) module quality and reliability testing laboratory includes world-class equipment for localising accelerated reliability stress testing on PV modules.

The integration of circular economy initiatives into South Africa's current energy landscape is not only essential but presents a transformative avenue for the nation's energy sector. This transition offers a spectrum of potential benefits, ranging from enhancing energy security to decarbonisation and enhancing competitiveness. Realising these advantages requires the establishment of supportive policy frameworks, robust financing mechanisms and effective stakeholder engagement.

In a research paper titled "Improving energy security in South Africa through a more circular energy sector", CSIR researchers premise that the successful implementation of circular energy initiatives not only ensures an energy-secure future, but also positions the nation as a pioneer in sustainable energy innovation.

The South African energy sector, the backbone of the nation's economy, currently operates within the confines of an antiquated linear model characterised by the 'extract-make-use-dispose' paradigm. This model, underscored by a heavy reliance on coal as the predominant indigenous energy resource, yields numerous detrimental externalities, including high resource intensity, inefficiency, carbon emissions leading to greenhouse gases, and hazardous waste generation. These negative outcomes highlight the sector's inherent unsustainability, necessitating a profound transformation to diminish resource and carbon intensity while concurrently enhancing overall efficiency.

CSIR researchers advocate for the incorporation of circularity into the design, utilisation and selection of energy pathways and technologies, facilitating a much-needed evolution within the sector. A circular approach presents a unique opportunity to decarbonise the energy sector, reduce dependence on non-renewable resources, minimise hazardous waste streams, stimulate energy generation, fortify national energy security, and disentangle economic development from resource intensity in interconnected sectors.

As South Africa grapples with the environmental challenges posed by its current energy practices, the integration of circular economy principles holds the potential to forge a sustainable and resilient energy future. An examination of South Africa's dynamic energy sector reveals both challenges and opportunities that demand innovative solutions. The energy sector continues to predominantly rely on resource-intensive coal and thermal generation, which contributes to 46% of the country's greenhouse gas emissions. Escalating blackouts underscore the urgency for a transformative shift toward renewables.

The researchers emphasise the importance of transitioning towards a more circular energy sector in the interest of resilience and sustainability. They argue that the energy sector must embrace circularity across the entire spectrum, from production and distribution to the manufacturing and end-of-life management of energy technologies.

Stakeholder interventions focusing on circular energy utility and circular energy materials underscore the potential benefits of the circular economy, including enhanced competitiveness, job creation and environmental sustainability within the energy sector.

Well-established interventions like solar photovoltaic, energy storage, energy efficiency, onshore wind, and waste-to-energy enjoy widespread support, while newer concepts such as carbon capture and concentrating solar power face a more cautious reception.

Readiness levels for implementing circular energy solutions vary, with solar photovoltaic, onshore wind, energy storage, hydroelectric, and waste-to-energy leading the pack. Energy efficiency emerges as a unanimous favourite, while certain innovations like carbon capture, utilisation and storage and green hydrogen lag. In the realm of circular energy materials, extending technology lifespans and promoting repair and recycling exhibit the highest levels of readiness.

While South Africa sees a growing share of renewable energy technologies, the manufacturing and recycling processes remain limited, hindering local control. Despite the potential to offset imports through local recycling, challenges such as a lack of awareness and insufficient scale inhibit impactful change.

The report draws insights from industry experts through online questionnaires and one-on-one interviews, providing a nuanced perspective on the appropriateness, readiness and current implementation levels of circular interventions. Recycling and energy efficiency interventions emerge as lucrative prospects, solidifying the study's overarching message; the adoption of circular economy principles in the energy sector promises manifold benefits, contingent on supportive policies, robust financing and effective stakeholder engagement to drive successful implementation and decouple economic development from energy demand.

CSIR engineer Muhammad Sheik, left, with Clifford Hartley at CERadvance Engineering Ceramics. The CSIR designed and installed thermal storage tanks for waste heat recovery and thermal storage at CERadvance.

ENERGY STORAGE CONSIDERATIONS FOR A **CIRCULAR ECONOMY**

THE IMPORTANCE OF ENERGY STORAGE SYSTEMS THAT STORE ELECTRICITY AS THERMAL ENERGY

By Muhammad Sheik, CSIR engineer

For wind and solar power to satisfy the global energy demand and come close to replacing fossil fuel, solutions must be found to store energy at a sufficiently big scale. One of the ways to do this is through energy storage systems that store electricity as thermal energy, such as Carnot batteries.

Energy is the main resource required to produce circular products and materials – products and materials that can be reused, recycled, refurbished and maintained. Fossil fuels currently supply more than 80% of the world's energy, but they will eventually become depleted. Additionally, these fuels are widely recognised to be the origin of industrial pollution that causes climate change and are therefore planned to be phased out. Renewable energy sources such as wind and solar are set to replace fossil fuels. However, these sources are variable – across a single day and in a seasonal context – and therefore require some form of storage to ensure a consistent supply of energy to meet the demand.

The most widely used grid-scale storage technology is pumped-storage hydropower, where water is pumped into a reservoir and then released to generate electricity when required. However, this can only be achieved in certain areas. Battery installations are on the increase as they can be installed in any geographic location and a wide range of capacities. For large-scale applications, for the last decade, the focus has been on lithium-ion batteries. In 2018, pumped hydro storage accounted for 98% of existing power storage capacity according to the Geological Survey of Finland, GTK. If the equivalent power buffer was to be delivered using lithium-ion battery banks, the required mass of lithium-ion batteries would be 2.5 billion tonnes. The total amount of copper and nickel required to produce one generation of battery units to phase out fossil fuels is 4.7 billion and 971 million tonnes, respectively. The reported global reserves for copper and nickel are only 18.6% and 9.79% of the required amount, which implies that chemical batteries alone are not practical to phase out fossil fuels.

Besides global supply chain issues for lithium-ion battery development, the life expectancy of the batteries is between five and ten years, after which the batteries need to be replaced. The old batteries should be recycled, but, it is estimated that only 5% of the world's lithium-ion batteries are recycled due to perceived complexities. The rest of the batteries are disposed of as waste. The projected amount of waste generated from this source, by 2040, could be approximately 8 million tonnes, which will lead to toxic elements leaching into the environment. Furthermore, these batteries contain a flammable electrolyte that can result in fire or explosions when damaged or heated, which could have serious consequences for the environment and recycling centres. Lastly, lithium-ion batteries may affect grid stability as there is no grid inertia to deal with fluctuations in electricity demand. Therefore, an alternative system must be developed. If not, wind and solar power generation may not be able to be scaled up to satisfy the global energy demand.

A viable alternative to lithium-ion batteries is Carnot batteries. This type of battery comprises a group of technologies that converts electricity to thermal energy and stores it in thermal energy storage systems. During the charging process, electricity is converted into heat and stored in a suitable storage medium. During a time of need, the stored heat is converted back into electricity using some kind of heat engine. According to the American National Renewable Energy Laboratory, the efficiency of a Carnot battery is between 40% and 70%. The energy density of a Carnot battery is approximately 50 kWh/m^3 and the energy cost is between 25-250 $/kWh.

The advantages of a Carnot battery include that it has no geographical constraints; typically has a life expectancy of more than 30 years; is modular; inexpensive; sustainable; and offers a non-toxic storage medium. In addition, it can be easily integrated with existing technologies and other systems and is far more suitable for bulk power services.

Carnot batteries can be used to store excess energy from variable renewable energy sources in the grid and to produce electricity when needed. These battery systems can also supply direct stored thermal energy for other applications, such as district heating and cooling for data centres at higher efficiencies. They can also be used to convert existing coal-fired power plants into fossil-fuel-free generation systems by replacing the coal-fuelled boiler. The existing facilities in power plants, such as the turbine and transmission systems, can be used.

A CSIR thermal/Carnot battery capable of storing waste heat in industry and converting it to electricity when required.

Chemical batteries are not fully circular by design – they have a limited lifespan which leads to waste generation and a negative environmental impact. In contrast, Carnot batteries are produced from abundant and non-toxic materials such as silica sand, rocks, alumina and magnetite. They have long life expectancies and a minimal environmental impact. They can also be integrated easily into existing fossil fuel power stations and are more stable. Carnot batteries are therefore critical in transitioning to a circular economy and phasing out fossil fuels.

Thermal systems are an emerging research focus for the CSIR. The organisation's Energy Research Centre is establishing capabilities in thermal process design and optimisation, as well as targeted technology development in large-scale and high-temperature waste heat recovery and thermal energy storage solutions. High-temperature testing of alumina and magnetite has been successfully performed at the CSIR thermal laboratory. The lab-scale tests validated numerical models that can be used to design and develop performance characteristics of grid-scale Carnot batteries for integration into electricity generation planning.

ENQUIRIES:
>> **Muhammad Sheik**
msheik@csir.co.za

From left, Carlo Mol, Project Manager: Unit Energy Technology, VITO; Bruno Reyntjens, VITO Commercial Director; and the CSIR's Renesh Thakordeen in the CSIR Indoor Energy Storage Testbed. The facility resulted from an ongoing collaboration agreement between the CSIR and VITO, the Flemish Institute for Technological Research.

The CSIR Indoor Energy Storage Testbed, where the performance and reliability of batteries are tested. The facility is equipped with a high-precision system for battery module and pack tests (above). It has many channels to test numerous batteries in parallel under dissimilar test cycles. It also has a new-generation temperature chamber (right) to provide data on the operating behaviour of batteries used in harsh climates – which will impact optimal performance.

BATTERY TESTING: PAVING THE WAY FOR A **CIRCULAR ECONOMY IN SOUTH AFRICA**

By Renesh Thakoordeen, CSIR engineer

South Africa finds itself at a critical turning point. The ongoing energy, climate and employment crises are demanding unprecedented scales of innovation. The transition to green technologies is crucial in mitigating environmental deterioration. However, a resilient balance must be achieved to ensure a robust future. Energy storage, particularly batteries, will play a decisive role in South Africa's future. To ensure a circular economy, the impact of battery technology must be maximised while minimising resource use and wastage.

The United Nations defines a circular economy as one in which products are designed for durability, reuse and recyclability.

The vast majority of the world has operated within a linear economy since the industrial revolution. This approach involves the extraction of resources, processing and utilisation - which ultimately ends in waste.

South Africa has an abundance of mineral resources and hence adopting a circular economy, while developing a just energy transition, is vital. This involves a great responsibility concerning the management of raw materials, which are essential for producing technologies such as batteries.

THE ROLE OF BATTERIES IN SUSTAINABLE DEVELOPMENT

Batteries play a pivotal role in the shift towards renewable energy. This technology effectively stores and releases energy, addressing the intermittency inherent in renewable energy systems. Additionally, batteries are indispensable in electric mobility and grid stabilisation efforts.

However, the production of batteries heavily relies on critical raw materials like lithium, cobalt, manganese and nickel. These resources are not only finite but their extraction often presents environmental and social challenges. It's imperative to source and manage these materials ethically, ensuring environmental and social responsibility and accountability throughout the supply chain.

BATTERY TESTING: ENSURING LONGEVITY AND RELIABILITY

Battery testing stands as the cornerstone of South Africa's transition towards a just energy future, centered on renewable energy and a circular economy. Thorough testing protocols are essential in guaranteeing the longevity and reliability of batteries, thereby helping to design out waste. Accelerated aging tests, thermal cycling and performance testing are some of the tests that assist developers and manufacturers in the early detection of potential issues during the development process. This translates to extended battery life and the reduced need for battery replacement, thereby reducing the demand for critical raw materials.

Battery testing serves as the initial step in the reuse of batteries. By testing batteries that have been deemed unusable for certain applications, they may find a second life in alternative applications. This process significantly contributes to resource conservation by reducing the need for new materials.

In South Africa, testing plays a crucial role in bridging gaps and facilitating the establishment of manufacturing plants that require skilled and unskilled labour. This is applicable to other industries involving importers, developers and assemblers. It also bolsters the country's technological capabilities and stimulates economic growth. Moreover, it promotes knowledge transfer and skills development, positioning South Africa as a regional leader in sustainable energy technologies.

In this context, the CSIR Indoor Energy Storage Testbed was established. In partnership with VITO, the Flemish Institute for Technological Research and the Flemish government, the CSIR, through the World Bank's Energy Storge Partnership framework, commissioned a battery testing facility to test lithium-ion and next-generation batteries.

A circular economy offers many benefits for South Africa, particularly in addressing the challenges of the just energy transition, climate crises and energy demands. The state and future innovations in battery technology significantly impact these environmental, technological and social issues. Therefore, battery testing assumes a pivotal role in guiding the nation's trajectory toward addressing these challenges effectively.

ENQUIRIES:

>> Renesh Thakoordeen
rthakoordeen@csir.co.za

CSIR intern Thapelo Pechu in the CSIR Learning Factory. The CSIR has created vocational training modules in 4IR-related domains such as human/computer interfacing, artificial intelligence, augmented reality, virtual reality and robotics. The modules have been customised to address specific skills applications in the different industry sectors such as mining, aerospace and automotive.

MANUFACTURING: A SECTOR WITH GAMECHANGER POTENTIAL FOR A SOUTH AFRICAN CIRCULAR ECONOMY

The circular economy presents a promising opportunity for the manufacturing sector to achieve sustainable growth, reduce environmental impact and create economic value. By embracing circular economy principles and adopting innovative approaches, manufacturers can contribute to a more sustainable, resource-efficient and low-carbon economy, with the added potential to unlock new jobs and businesses. This implies a fundamental shift in thinking by regenerating natural capital, designing for zero waste and using renewable energy and resources.

In 2021, a multidisciplinary CSIR team conducted a study that revealed important industry perspectives regarding the manufacturing sector's circular economy development path, measures already implemented or planned, as well as opportunities to grow circular economy interventions within the sector.

CSIR research group leader for design and testing at CSIR Future Production: Manufacturing, Dr Shahed Fazluddin, who led the manufacturing sector study along with CSIR principal researcher Dr Vincent Ojijo, explains: "The manufacturing sector has a pivotal role to play in driving re-industrialisation and the transition to a more circular economy. Manufactured products, chemicals, plastics and industrial machinery play a key role in the productivity and growth of both upstream and downstream economic sectors, such as mining, agriculture, mobility, energy and water."

(continued on page 38) »

"By applying circular principles from the product design stage, manufacturing companies can influence the production process, and indeed the entire product life cycle, including usage and end-of-life scenarios," he adds.

The CSIR circular economy study on manufacturing outlines the need for systemic shifts in production and consumption patterns to enable effective resource utilisation to achieve sustainable economic growth, preserving natural capital and improving socio-economic wellbeing. However, it was found that the local manufacturing sector continues to operate predominantly on the linear 'take-make-dispose' economic model, which is plagued by excessive resource demand, unsustainable production and consumption patterns, and high levels of wastage.

A heavy reliance on the export of unbeneficiated mineral resources and base metals, coupled with a weak demand for South African manufactured finished products as well as policy lags, instability of energy supply, and lack of skilled labour are areas of concern. Addressing the challenges will require technological advancements, changes in consumer behaviour and attitudes, establishing effective recycling systems, and building circular supply chains.

The study revealed a relatively mature level of development and implementation in certain industries, but much room for expansion overall. Advanced interventions include material looping, resource efficiency and cleaner production, and renewable energy technologies, while certain interventions are considered to be at a lower level of readiness – such as green steel manufacturing, chemical leasing, circular design and manufacturing, circular business models, and bio-based fuels or materials, and will require greater action to fast-track.

An evaluation of circular economy principles and practices, including an assessment of global case studies, highlighted the potential for the circular economy approach to transform the sector in terms of resilience, competitiveness and sustainability, with the added potential for economic growth and job creation in line with global trends.

Challenges the sector faces in attempting to roll out circular economy interventions include a lack of awareness, the cost of implementing and the lack of sustainable financing mechanisms, a lack of appropriate skills and local case studies or demonstration projects, and the lack of available markets.

"The evaluation provides clear evidence that the circular economy offers the sector opportunities to enhance its sustainability in terms of resource utilisation, water and energy consumption, greenhouse gas emissions reduction and waste valorisation, all of which would contribute to the sector and economy as a whole in achieving climate and sustainability goals," Fazluddin says.

Global trends indicate a rapid uptake of fourth industrial revolution (4IR)-related technologies to enhance manufacturing capability, productivity and efficiency, enabling massive gains in resource optimisation, reduced energy and material consumption, upskilling of the workforce, and tracking of materials and waste throughout the circular economy value chain. Unique opportunities for innovative circular economy interventions lie in technologies such as digital twinning, big data and blockchain, cobots in the workforce, the exploitation of augmented reality for training and operations, and the application of bio-based materials in the manufacture of advanced, lightweight components.

In this regard, the CSIR has already developed notable capabilities in advanced manufacturing focused on additive manufacturing, laser-enabled repair and refurbishment of high-end industrial equipment and machinery, and metal injection moulding. The CSIR Centre for Robotics and Future Production is focused on digitalisation of manufacturing, virtual simulation of manufacturing processes and plant layouts, including process monitoring and optimisation. One of the centre's focus areas is the establishment of smart (learning) factories aimed at simulating various CSIR in-house manufacturing technologies and associated facilities with a long-term view of enabling virtual learning, training and skills development in support of the local manufacturing industry and a 4IR-enabled workforce.

In the related area of advanced materials engineering, researchers continue to develop processes to enable more effective re-use and recycling of aluminium alloys, which poses specific industry challenges given the diversity of alloys in use commercially and the need to ensure these re-enter process streams as required. In addition, the CSIR invests in research groups involved in the recycling of plastics, bio-degradable plastics development and commercialisation, as well as the re-use and/or recycling of coal fly ash for the construction and mobility sectors.

The next step is to drive on-the-ground action and facilitate the implementation of these technologies given the fact that significant infrastructure, skills development and technology adoption are still required for South Africa's reindustrialisation and to reap the significant benefits of 4IR technologies.

OVERVIEW: MANUFACTURING SECTOR AND THE CIRCULAR ECONOMY

Circular economy strategies: The circular economy is based on three key strategies: reduce, reuse and recycle. These strategies aim to minimise waste generation, optimise resource use, and promote the longevity of products and materials through their lifecycle.

Economic benefits: Implementing circular economy practices in manufacturing can lead to economic benefits. By reducing waste and optimising resource use, companies can lower production costs and increase profitability. Additionally, the circular economy can create new jobs and stimulate economic growth through the development of innovative technologies and business models.

Environmental benefits: The circular economy has significant environmental benefits. By promoting recycling and reuse, it reduces the extraction of raw materials and reduces the pressure on natural resources. It also helps to reduce greenhouse gas emissions and minimise pollution associated with the manufacturing process.

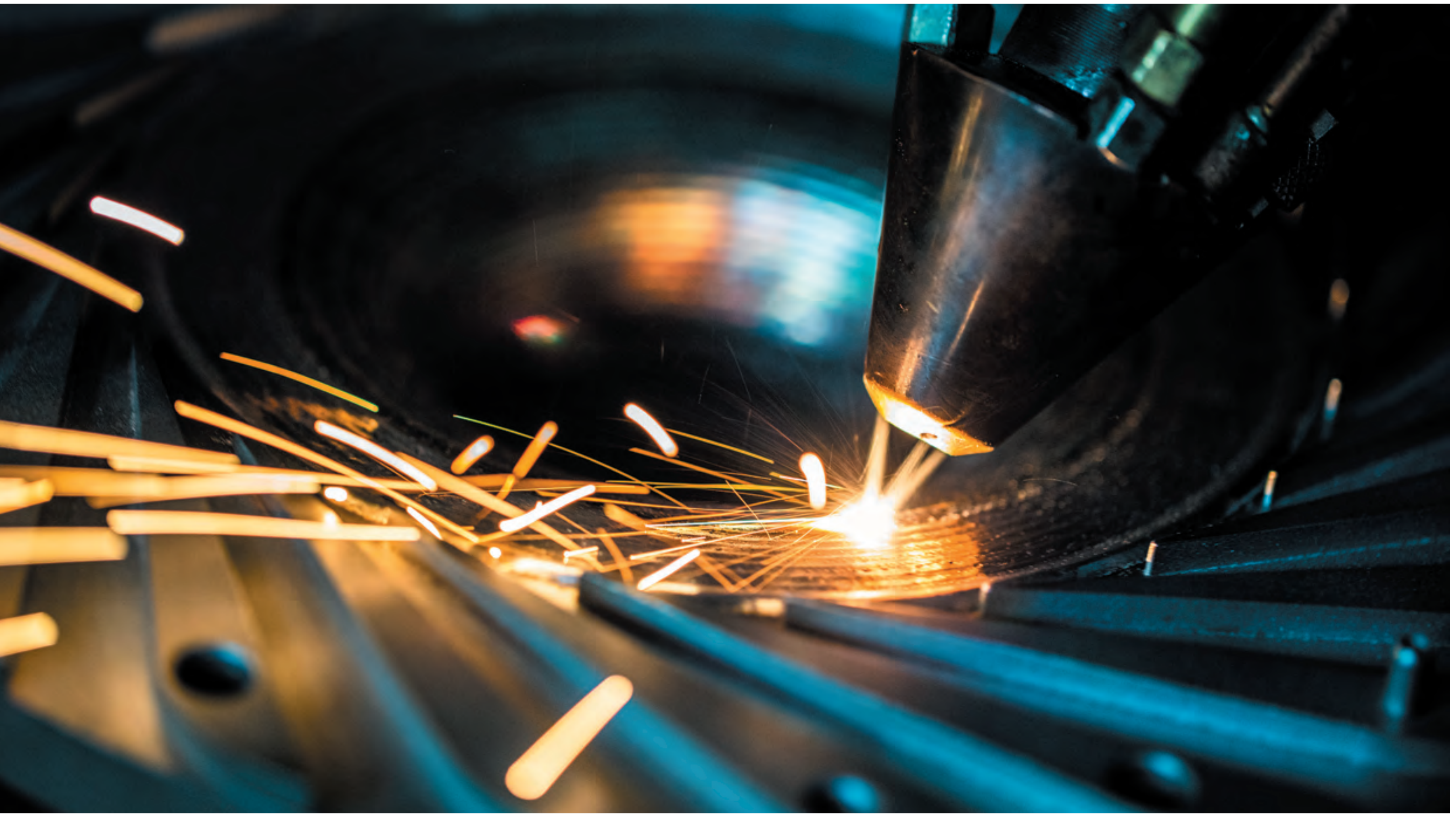
Policy and regulatory support: Governments around the world are recognising the importance of the circular economy and are implementing policies to support its adoption. These policies include waste management regulations, incentives for recycling and reuse, and support for research and development in circular economy technologies and practices.

Collaboration and stakeholder engagement: The transition to a circular economy requires collaboration and engagement from various stakeholders. This includes manufacturers, consumers, government agencies, non-governmental organisations and research institutions. Collaborative efforts can help drive innovation, contribute to the sharing of best practices, and address common challenges.

Circular design and innovation: Circular design is an essential component of the circular economy. It involves designing products with durability, repairability and recyclability in mind. Innovations such as eco-design, modular products, and product-as-a-service models are emerging as ways to promote circularity in manufacturing.

Transition challenges: While the circular economy offers significant benefits, there are challenges in transitioning to circular practices. These challenges include the need for technological advancements, changes in consumer behaviour and attitudes, establishing effective recycling systems, and building circular supply chains.

Overall, the circular economy presents a promising opportunity for the manufacturing sector to achieve sustainable growth, reduce environmental impact, and create economic value. By embracing circular economy principles and adopting innovative approaches, manufacturers can contribute to a more sustainable and resource-efficient future.



LASERS MAKE LIGHT OF **COMPONENT PRODUCTION AND MAINTENANCE**

The CSIR Photonics Centre assists industry clients to gain optimal use from components – be that through improving part resilience, refurbishing and retouching to increase useful life, or reducing downtimes during component fails through onsite, on-demand component production using novel metal printing and additive manufacturing capabilities. In a manufacturing context, the contribution of such laser-based technologies to the circular economy principles of reuse, remanufacturing, refurbishment and repair, and the resultant reduction in waste generation, is undeniably impactful.

In the manufacturing sector, laser-based technologies play an increasingly important role. A familiar example is flatbed laser cutting systems that demonstrate high accuracy, very high production rates and reduced wastage. Laser-based selective hardening of components, laser welding applications for components that are sensitive to heat input, and laser weld overlay or laser cladding for the repair and/or refurbishment of high-value components are all applications that are increasingly being utilised by the South African manufacturing industry.

The metals, metal products, machinery and equipment sector is a significant contributor to the economy, both in terms of revenue and employment, making up over 60% of the total sectoral contributions. Remanufacturing and refurbishment thus support the recovery of value.

The CSIR has a diverse and specialised portfolio of laser-based technologies to support local industry. Designing novel technologies and enhanced processing approaches, the aim is to reduce costs, save time by limiting downtime, reduce wastage and enhance performance.

The surface engineering technology of choice at the CSIR Photonics Centre is laser cladding or weld overlay – one of the latest, fastest and most accurate technologies – but also one of the most expensive compared to more traditional (or conventional) methods. Laser cladding is a laser weld overlay technique also known as direct energy deposition, direct laser deposition, direct metal deposition or laser hardfacing. It has found particularly significant uptake in the power-generation, manufacturing, defence and transport industries to restore and/or improve the surface conditions, performance and material properties of structural or functional equipment.

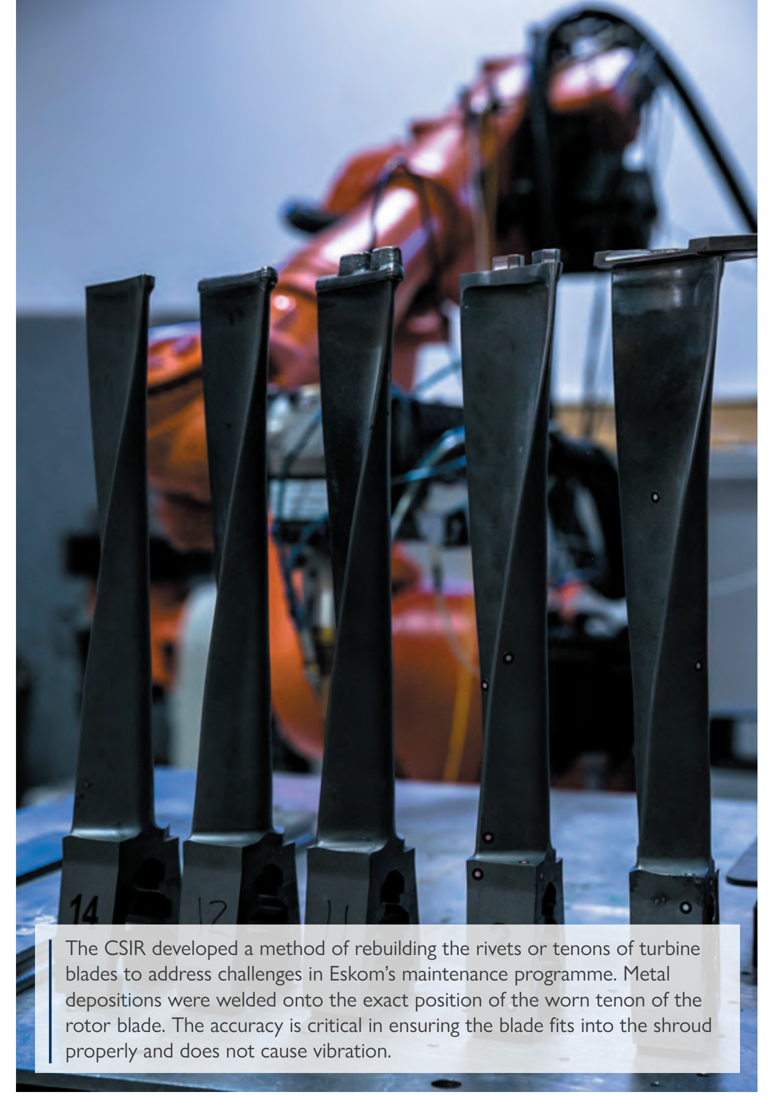
The choice of technology for resurfacing is influenced by factors such as warranty stipulations, materials, the nature of the damage, the type of component, the cost of replacement and the urgency of refurbishment.

Technology review and development are ongoing. Hencharl Strauss, Manager of the CSIR Photonics Centre, explains: "The CSIR is taking a platform approach to develop multiple solutions more efficiently. Ultimately, we want industry to work smarter – and cleaner – and become more competitive," he says. "For instance, both laser cladding and welding processing use robotics to deliver light and deposition material to working surfaces."

A robotics laser processing platform is being developed that will service both cladding and welding applications as well as laser shock processing. Similarly, a common laser scanning platform is being developed that will be able to provide laser-assisted powder fusion (metal and polymer 3D printing), laser marking, precision welding and laser cutting solutions to industry.

THE MELTDOWN AND THE BUILD-UP

The heat input of a laser-based welding process is approximately ten times lower compared to conventional welding processes such as tungsten inert gas welding or metal inert gas welding. Since a laser can be focused on an accurate, precise spot size, it ensures a very efficient delivery of energy for the welding process. In addition, the laser beam can be delivered very accurately, and the delivery is almost always automated by using an articulated arm robotic system. The result is that the technology allows accurate and also complex profile weld build-up on existing components, with limited distortion of the component. So, in cases where accuracy is critical and where a thin profile build-up is required, laser welding becomes both a requirement and an obvious choice.



The CSIR developed a method of rebuilding the rivets or tenons of turbine blades to address challenges in Eskom's maintenance programme. Metal depositions were welded onto the exact position of the worn tenon of the rotor blade. The accuracy is critical in ensuring the blade fits into the shroud properly and does not cause vibration.

(continued on page 42) »

Before welding, the technology has to be qualified – i.e., tested according to relevant international standards. This ensures that the weld does not affect the integrity of the component and that the weldment meets metallurgical and mechanical properties such as microstructure, strength and hardness of the material. After welding, the qualified welding process may stipulate a heat treatment cycle to reduce stress in the component, or to achieve the required mechanical characteristics or specifications stipulated by the manufacturer of the component.

The CSIR can design and optimise the laser welding parameters to meet these stringent requirements to accomplish the task. The data form part of a welding procedure qualification, to be signed off by a welding engineer.

CASE STUDY

The CSIR developed a laser-based metal deposition technology for MAN Energy Solutions, which was jointly implemented to improve the efficiency of in-service blower rotors at Sasol.

The refurbishment project improved the efficiency of the rotors by more than 10%. This resulted in significant energy cost savings for Sasol, because of the lower energy input required to achieve the same airflow output.

The technology enables accurate and complex weld build-up profiles on existing components, with limited distortion of the original component. This is made possible by the low heat input of the laser welding process. Laser welding proved ideal because of the accuracy required for the blades on such a compressor and the need for a thin profile build-up.

The CSIR, through its complementary relationship with MAN Energy Solutions, tested and demonstrated technology that has been under development at the CSIR since 2002. MAN Energy Solutions has an extensive manufacturing and workshop facility where massive components are produced, serviced and repaired. Together the two organisations support high-value component sectors with laser-based services to make use of cleaner, faster and cost-effective technology.

PHOTONICS: REPAIR, DON'T REPLACE

South Africa has endured energy shortages and periods of rolling blackouts for the past number of years – due in part to ailing unmaintained infrastructure causing extended unavailability and costly, protracted part importation and replacement efforts. For over a decade, the CSIR has supported the national electricity provider with the repair and refurbishment of critical infrastructure components while new energy generation facilities are being commissioned.

Steam turbines that include low-pressure turbines, such as those used locally, operate by converting energy from steam to rotational energy to drive large electricity generators – a key contributor to national energy generation. These turbines operate for thousands of hours at a time and are tested for any degradation after such a runtime.

Inside these huge turbines, stages of blades of up to 1.5 m drive the rotary movement of the central shaft.

The blade design and construction – the shape, strength, placement and accurate size or length – are critical to the effectiveness of the turbine as well as to prevent vibration during operation that could lead to catastrophic failure. Because of the technical precision, in the past, whole sets of blades were scrapped due to a faulty blade. Laser-assisted repair technology developed by the CSIR has made it possible to repair and refurbish blades at a considerably lower cost and far shorter downtime.

One example of where laser weld repair technology is implemented on turbine blades is when rebuilding blade rivets on blades where the rivets are removed for maintenance purposes. A rivet on the blade is used to locate it in a shroud band that ties packets of blades together on the rotor body. Due to certain modes of failure of some of the components on a rotor, it is sometimes necessary to remove the shroud. The shroud removal typically leads to the scrapping of a whole row of blades on a rotor, with large cost implications for the power generation utility.

Through a laser weld method, it is possible to match the blade properties and dimensions of damaged areas on a turbine blade. Once weld repairs are done, the refurbished blade undergoes non-destructive testing to ensure its safe and efficient operation.

The financial benefit of refurbishment versus replacement is significant, even when not taking into account the lost time associated with the decommissioning of a turbine to procure and install replacements.

Hardus Greyling, who manages laser engineering services at the CSIR Photonics Centre, explains: "Generally, a large number of turbine blades are scrapped during turbine maintenance and repair projects. The in-situ rebuilding of the damaged areas on turbine rotors by laser metal deposition is a time and cost-efficient option for repairing the blades for continued use."

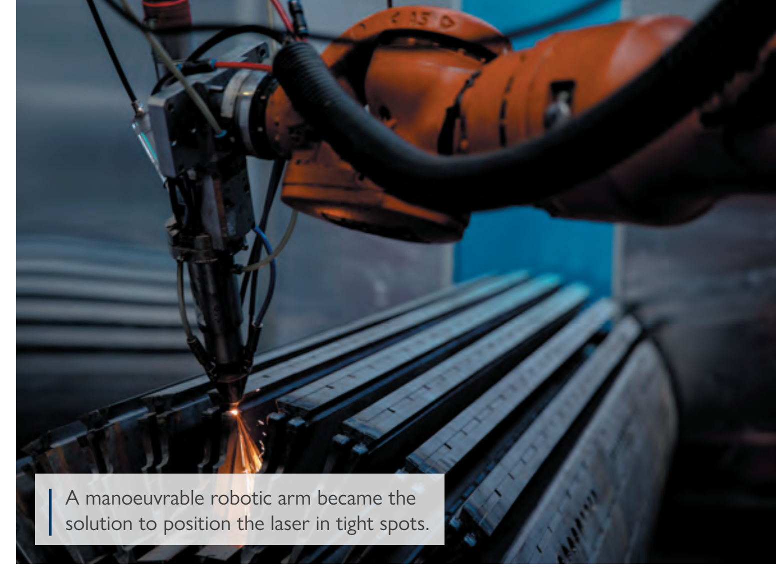
"This also means that only the blades that are affected by the maintenance activity need to be refurbished, without the need to scrap or remove any blades from a rotor," he adds.

Another way the refurbishment reduces costs is by ensuring that several rows of scrapped blades can return to service or be available as spare sets after a complete refurbishment. This is not only a saving on parts replacement, but also avoiding downtime.

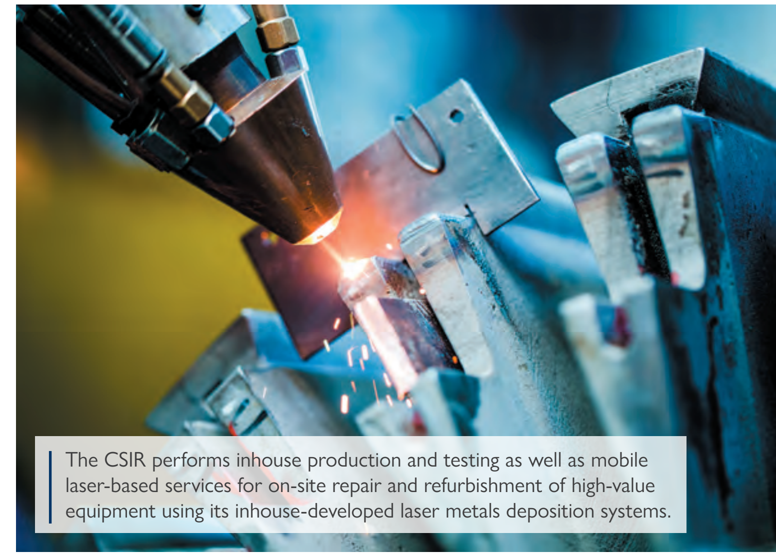
"Working with turbine engineers, the CSIR researched the properties of the turbine components and the stresses under which they operate," Greyling says.

"The exact design of these turbines, with the inclined blades placed in different stages onto the shaft was also a challenge as there is hardly any room in between the blades to operate equipment. Once the shroud is removed, the blades relax from their positions, and tenon positions may differ by almost 1mm when referenced to the blade-end profile. The blade position has to be captured precisely before removal," he says.

The blade tenon refurbishment technology was developed as part of a CSIR-Eskom bilateral-funded programme.



A manoeuvrable robotic arm became the solution to position the laser in tight spots.



The CSIR performs inhouse production and testing as well as mobile laser-based services for on-site repair and refurbishment of high-value equipment using its inhouse-developed laser metals deposition systems.

Optimex 3D printing using metal deposition
The CSIR Photonics Centre houses a critical core of photonics and laser-based manufacturing expertise and infrastructure to support the manufacturing sector in South Africa and further afield.

ADDITIVE MANUFACTURING: LESS WASTE, MORE INNOVATION AND SPEED

Globally, additive manufacturing has disrupted traditional manufacturing processes, enabling reductions in development costs, resource utilisation, waste and energy consumption. Its on-demand, digitally distributed manufacturing allows for reduced physical inventories and more resilient supply chains. It offers greater design freedom and customisation – no moulds and no tooling – plus adds to material recovery and reuse in that recycled materials from other processes, scrap metal, etc. can be transformed into 3D printing feedstock.

This makes additive manufacturing technologies and techniques powerful enablers of the circular economy by contributing to the reduction of waste, the boost in reparations and re-manufacturing activities, as well as its impact on companies' innovation and business models.

The CSIR has played a leading role in demonstrating the capabilities and providing access to additive manufacturing technology on the strength of expertise in metal, polymers, lasers, automation and mechatronics. This includes design, printing and post-processing capabilities, testing of new materials and techniques, developing printing machines or establishing partner networks for collaborative research and development, and availability of printing equipment.

Additive manufacturing's unparalleled design flexibility makes it easy to recreate flawed components, restoring items to their original performance standard. As 3D scanning technology continuously advances, the accuracy of computer-aided model recreations is improving, and the restoration capability thus continues to develop in scope.

Over the past decade, there has been a significant uptake of 3D printing technologies as part of mainstream manufacturing. Polymer-based 3D printing is playing an important role in prototyping applications, as well as industrial parts. More recently, the delivery and installation of 3D printers for metal parts have increased – specifically in manufacturing concerns that support the medical device manufacturing sector, the tooling sector and high-end manufacturing for the aerospace industry.

THE AEROSWIFT EXAMPLE

The CSIR has a track record in developing and implementing novel, high-speed 3D printing, through the Aeroswift programme. In 2017, the CSIR and Aerosud, an aeronautical engineering and manufacturing company, developed an advanced 3D printer for metal components as part of project Aeroswift. Funded by the Department of Science and Innovation (DSI), the project formed an important part of the national titanium beneficiation strategy, which aims to transform South Africa from an exporter of raw materials to an exporter of semi-finished or finished goods.

The metal additive manufacturing system uses a laser to melt titanium powder to produce metal parts for the commercial aerospace manufacturing sector. The system can produce geometrically complex parts according to specifications, minimising material wastage while processing difficult-to-machine materials. It is also used to manufacture parts for the power generation, automotive tooling, defence and manufacturing sectors. During proof-of-concept trials, the machine achieved production speeds up to 10 times faster than currently available commercial laser melting machines.

In contrast to conventional manufacturing technologies, which often rely on the removal of material through a machining process to produce a final component, additive manufacturing relies on various energy-depositing technologies to fuse powdered or wire-based materials into 3D functional near-net-shape parts.

New at the time of the Aeroswift launch, metal 3D printing has gone on to receive significant uptake in several sectors. In the past year, the CSIR has sourced industry partnerships for the commercialisation of the technology platform.

A 3D printed unmanned aerial vehicle frame sized 600x100 mm produced by the CSIR Photonics Centre.

The CSIR supported local company Aditiv Solutions in the development of the first South African metal printer. The technology was refined at the CSIR Photonics Prototyping Facility, a capability funded by the DSI.

Included in the suite of 4IR technologies advancing circular economy implementation is additive manufacturing, which creates opportunities to reduce energy consumption, development costs, resource utilisation and wastage. Its on-demand, digitally distributed manufacturing allows for reduced physical inventories and more resilient supply chains. This light aircraft throttle grip was produced at the CSIR.

The adoption of 3D printing is one of the large focus areas for research and development investment at present, globally as well as in South Africa. The CSIR manages and coordinates a national network to support research, development and innovation at local research institutions, and in cooperation with industry, to drive the manufacturing readiness of additive manufacturing and its adoption in industry. This is done through defining postgraduate research projects and supporting students to complete their studies in this method of manufacturing technology. This network, called CPAM (The Collaborative Programme in Additive Manufacturing), is funded by the Department of Science and Innovation, and works closely with RAPDASA, the South African Industry Association for 3D printing. The programme focuses on four main themes, namely the qualification of metal additive manufacturing for industrial applications, a design-for-additive manufacturing programme, an industrialisation of polymer additive manufacturing programme and an industry development programme.

Further localisation and adoption of 3D printing will benefit South Africa's re-industrialisation by driving component development, particularly in mining equipment, and the automotive, aerospace, healthcare, energy generation and rail sectors.

ENQUIRIES:

>> Hencharl Strauss
hstrauss@csir.co.za

(continued on page 46) »

RAPID PARTS PRODUCTION, REPAIR AND HARDENING: APPLICATIONS OF LASER TECHNOLOGY

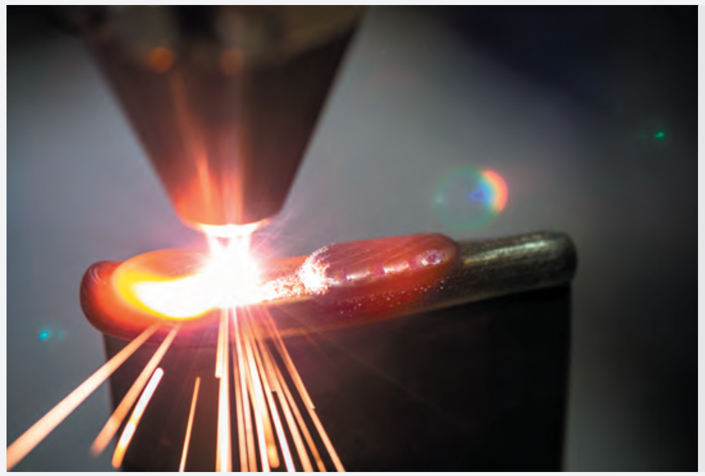
The CSIR Photonics Centre offers a range of laser and photonics tools, facilities and processes geared towards rapid prototyping and production, low-waste techniques such as 3D printing, extending the useful life of parts, and saving expensive parts replacement through various refurbishment technologies. Its portfolio caters for high-power lasers in all wavelengths across the infrared spectrum from 1μm to 10μm.

LASER WELDING

Laser welding and cutting (2D and 3D) are energy- and time-efficient production techniques. Highly manoeuvrable robotic arms apply the laser in hard-to-reach areas.

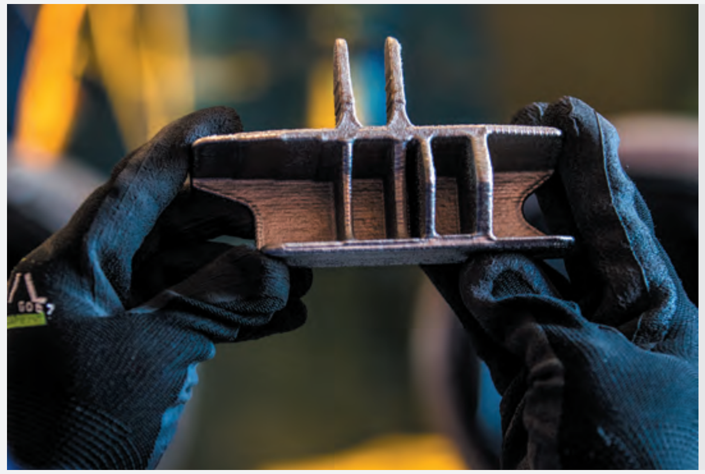
METAL 3D PRINTING

Supporting metal 3D printing across the full value chain: The CSIR conducts investigations into different metal alloys, process optimisation, post-processing strategies, as well as test and evaluation of final parts used in various industry segments.



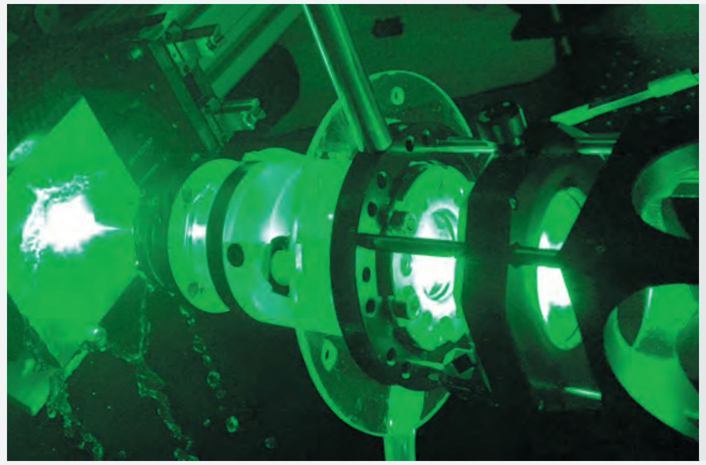
LASER CLADDING AND WELD OVERLAY

Surface engineering technologies include laser cladding or weld overlay for part strengthening or repair.



ADDITIVE MANUFACTURING

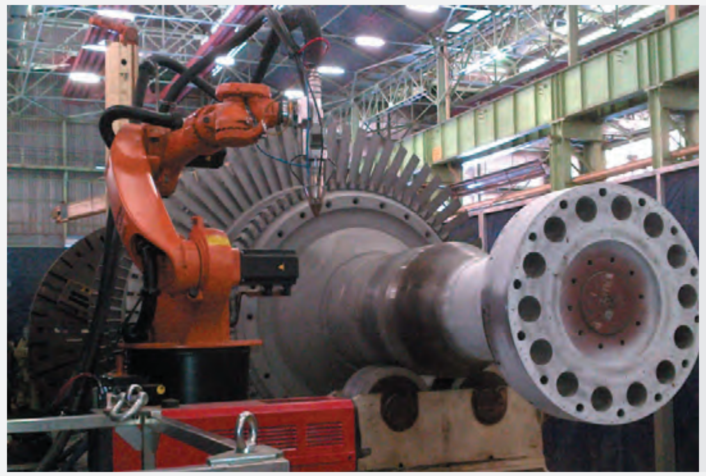
Additive manufacturing is a high-speed and low-waste technique with a low carbon footprint. The CSIR can produce parts sized up to 600 x 600 x 2000 mm using rapid printing equipment and multiple materials including titanium, aluminium and steel, plus new alloys and polymers not available elsewhere.



LASER SHOCK PEENING

Laser shock peening is performed to extend the service life of high-wear components. A high-power laser is applied at a short pulse, creating an induced compressive stress layer to improve the wear characteristics, corrosion resistance or the fatigue properties of components in use.

The CSIR's locally unique laser shock processing system has been proven to prevent crack formation in turbine blades.



MOBILE LASER TECHNOLOGIES

A mobile laser system is used for on-site repair, where components are too large to move or rapid repair is required. The system is truck-based and rapidly deployed, with a flexible robotic delivery system.

A mixed reality station at the CSIR Learning Factory. CSIR engineer Mihlali Tapi demonstrating the installation of brake pads in augmented reality using HoloLens glasses. This innovative technology transforms interactive learning, industrial training and assembly processes.

BUILDING SKILLS FOR A CIRCULAR ECONOMY

The CSIR Learning Factory plays a pivotal role in advancing toward a sustainable, resource-efficient circular economy. At the heart of this transformative endeavour lies the urgent need for expertise and skills capable of driving innovation, entrepreneurship and the integration of modern technologies. In the midst of the fourth industrial revolution, characterised by the dominance of technology, these competencies are indispensable.

South Africa's commitment to fostering employment and job creation is evident through national initiatives like the National Development Plan and the National Skills Development Plan. However, significant challenges persist, characterised by high unemployment rates and low literacy levels. Moreover, the rapid pace of technological advancement far surpasses the rate of skills development necessary to keep pace.

In this rapidly evolving landscape, inventors, entrepreneurs and business leaders must adopt a circular approach to design, production and consumption. Embracing modern tools and digital technologies is imperative, with fourth industrial revolution (4IR) technologies emerging as pivotal forces in shaping the circular economy.

In collaboration with the Manufacturing, Engineering and Related Services Sector Education and Training Authority, the CSIR has pioneered the establishment of a learning factory. This facility serves as a hub for skills development, awareness and entrepreneurial innovation in 4IR and associated digital technologies. The CSIR Learning Factory simulates industrial environments, providing hands-on vocational training. Its flexible curriculum seamlessly integrates virtual courses with practical experiences, catering to various skill levels ranging from operators and artisans to engineers, technologists and business managers. Augmented reality, digital twinning, robotics and artificial intelligence propel the digital transformation necessary to optimise resource use and rethink production processes.

Dr Belinda Matebese, Manager of the Learning Factory at the CSIR, elucidates the initiative's objective regarding skills development: "Some see the 4IR as a threat, fearing job displacement by machines. However, these technologies shape the future of work. We are committed to upskilling, reskilling and cross-skilling to ensure workforce growth, not replacement, as technology evolves. We want to avoid job losses or greater skills gaps."

Learning factories are being established at technical and vocational education and training colleges nationwide, tailored to specific technologies, curricula and best practices.

Sector-specific learning factories are in development, driven by heightened interest from the mining, automotive and agricultural sectors that recognise the urgency of modernisation, digitalisation and the circular economy.

Matebese continues: "Disruptive technologies associated with 4IR – such as the internet of things (IoT), additive manufacturing, digital twinning and robotics – play pivotal roles in implementing innovative manufacturing processes and business models."

"Access to skills presents a challenge, but we also observe a pressing need for technology access among producers, particularly small, medium and micro enterprises," Matebese explains. Several CSIR client projects have taken shape at the factory, utilising digital manufacturing and product lifecycle tools, integrating collaborative robots (co-bots) and robotic interactions, implementing smart operations through the IoT and incorporating augmented reality.

"The tools are here," says Matebase. "This serves as a means to de-risk technologies for industry and serves as a test bed to determine how modern tools and technologies can drive the development of a flourishing circular economy."

Notable modules and technology projects currently active at the CSIR encompass collaborative robots, interactive human-computer parts assembly, digital twinning of autonomous transport systems, virtual reality training for underground safety and digital welding. Additionally, a smart house setup utilises IoT to run the day-to-day housework grind.

"The circular economy presents a new growth opportunity for South Africa, demanding an innovative, transdisciplinary strategy grounded in science, technology and innovation. Through technology, we can enhance production efficiency, reduce costs and foster job creation and industries that benefit the economy, citizens and the environment," she adds. "The key is adequate, appropriate and high-quality skills."

ENQUIRIES:

>> **Belinda Matebese**
bmatebese@csir.co.za

THE CSIR LEARNING FACTORY FOSTERS SKILLS DEVELOPMENT FROM A THEORETICAL AND PRACTICAL REAL-WORLD PERSPECTIVE. IT DRIVES RESEARCH AND INNOVATION IN THE 4IR SPACE, INCLUDING DESIGN, INCUBATION AND PROTOTYPING.

SUPPORTING INDUSTRY TO BECOME MORE **COMPETITIVE THROUGH IMPROVED RESOURCE EFFICIENCY**

Resource-efficiency and cleaner production has been central to the work of the National Cleaner Production Centre South Africa (NCPC-SA) for the last 21 years. It is helping to transition industry to a greener and more sustainable way of doing business. The introduction of circular economy principles and practices is maturing the broad field of resource-efficient and cleaner production and industrial sustainability, and NCPC-SA's services to industry.

The NCPC-SA, a programme hosted by the CSIR on behalf of the Department of Trade, Industry and Competition (**the dtic**), is leading the implementation of several projects that apply the circular economy principles of repairing, re-manufacturing, reusing and recycling products, and the sharing of underused assets. The projects are currently aimed at the clothing, textiles, footwear, leather and leather goods industries, eco-industrial parks, and small-, medium- and mid-sized enterprises.

"One cannot practice efficient resource use without applying the principle of circularity," says Ndivhuho Raphulu, who heads up the NCPC-SA.

CIRCULAR ECONOMY APPROACHES IN THE TEXTILE SECTOR

In South Africa, the textile and garment sector contributes significantly to the national economy and is one of the priority sectors identified in the green industrial policy, especially as it concerns the reduction of persistent organic pollutants in wastewater, water and energy consumption.

The NCPC-SA is working with the textile sector over the next five years to address the textile sector's upstream and downstream processes through sustainable chemical and waste management. The interventions will focus on resource use, green and sustainable chemistry, and the reuse, recycling and conversion of textile/garment discards and related wastes into economically viable and socially beneficial products and services.

This project is also being implemented in Madagascar and Lesotho in partnership with the United Nations Industrial Development Organization (UNIDO), funded by the Global Environment Facility.

CIRCULAR APPROACHES SUPPORT ACCESS TO FINANCE

To further strengthen the South African textile sector, promote circularity, sustainability and enhanced competitiveness, the NCPC-SA, the United Nations Environment Programme, and the Centre for African Resource Efficiency and Sustainability are implementing a project to accelerate enterprises' access to finance while strengthening participation in eco-innovation.

Eco-innovation is a new business approach that promotes sustainability throughout the lifecycle of a product while boosting a company's performance and competitiveness. In this way, companies can access new and expanding markets, increase productivity, attract new investment, increase profitability, and stay ahead of regulations and standards through eco-innovation.

ECO-INDUSTRIAL PARKS AS A CIRCULAR ECONOMY APPROACH IN A DEDICATED GEOGRAPHICAL AREA

The NCPC-SA Global Eco-Industrial Parks Programme is a national focus to revitalise and demonstrate the viability and benefits of greening industrial parks.

Businesses in this eco-system encourage an exchange of synergies known as industrial symbiosis – a means by which companies can gain a competitive advantage through the physical exchange of materials, energy, water and by-products – eliminating the waste of resources and reducing environmental impacts.

The eco-industrial park concept also embraces community collaboration, thereby fostering inclusive and sustainable development. The advantage of this concept is that it can be adopted by new or existing industrial parks.

The approach, based on an international framework for eco-industrial parks developed by the World Bank, UNIDO and GIZ, supports the Industrial Park Revitalisation Programme of **the dtic**, matching the core focus areas of economic, social and environmental benefit in support of the national priorities of addressing poverty, unemployment, inequality and growth.

The NCPC-SA's focus on eco-industrial parks forms part of a broader offering to industry and the centre currently plays a leading role in this space along with government partners **the dtic** and National Treasury.

ENQUIRIES:

ncpc@csir.co.za

CSIR GUIDELINES FOR PRODUCT LIFE CYCLE **ASSESSMENT STUDIES**

A STEP TOWARDS REDUCING THE TOTAL ENVIRONMENTAL IMPACT OF A PRODUCT AND ITS PACKAGING

By Dr Valentina Russo and Anton Nahman

A CSIR team is developing guidelines for life cycle assessment studies in South Africa to help producers meet regulatory and export market requirements for their products.

Extended producer responsibility is a policy approach in which producers are given responsibility for the full life cycle of the products and packaging that they put on the market, including the end-of-life stage. By encouraging producers to design products for reuse and recycling, extended producer responsibility can play an important role in driving a circular economy.

In South Africa, extended producer responsibility regulations were gazetted in 2020, with the final regulations published in 2021. Among other things, the regulations require producers, brand owners and importers of identified products to undertake life cycle assessment studies; focus on material minimisation; product redesign to facilitate reuse, recycling or recovery; and reduction of the environmental toxicity of their waste streams.

In addition, several of South Africa's key trade partners, including the European Union and the United States of America, are introducing strict requirements for products entering their markets to report on their product environmental footprint, or to make environmental product declarations – both of which inherently require a life cycle assessment to be undertaken. South African producers will therefore increasingly be required to conduct life cycle assessment studies to meet regulatory requirements, gain access to international markets and improve their competitiveness.

Life cycle assessment is a systematic approach for evaluating the environmental impacts of a product throughout its entire life cycle, from extraction of raw materials through to final disposal. Such studies can support the transition to a circular economy; for example, by assessing and comparing products and alternatives (including the use of different materials or designs) in terms of the extent to which they contribute to circularity, and making recommendations to improve circularity.

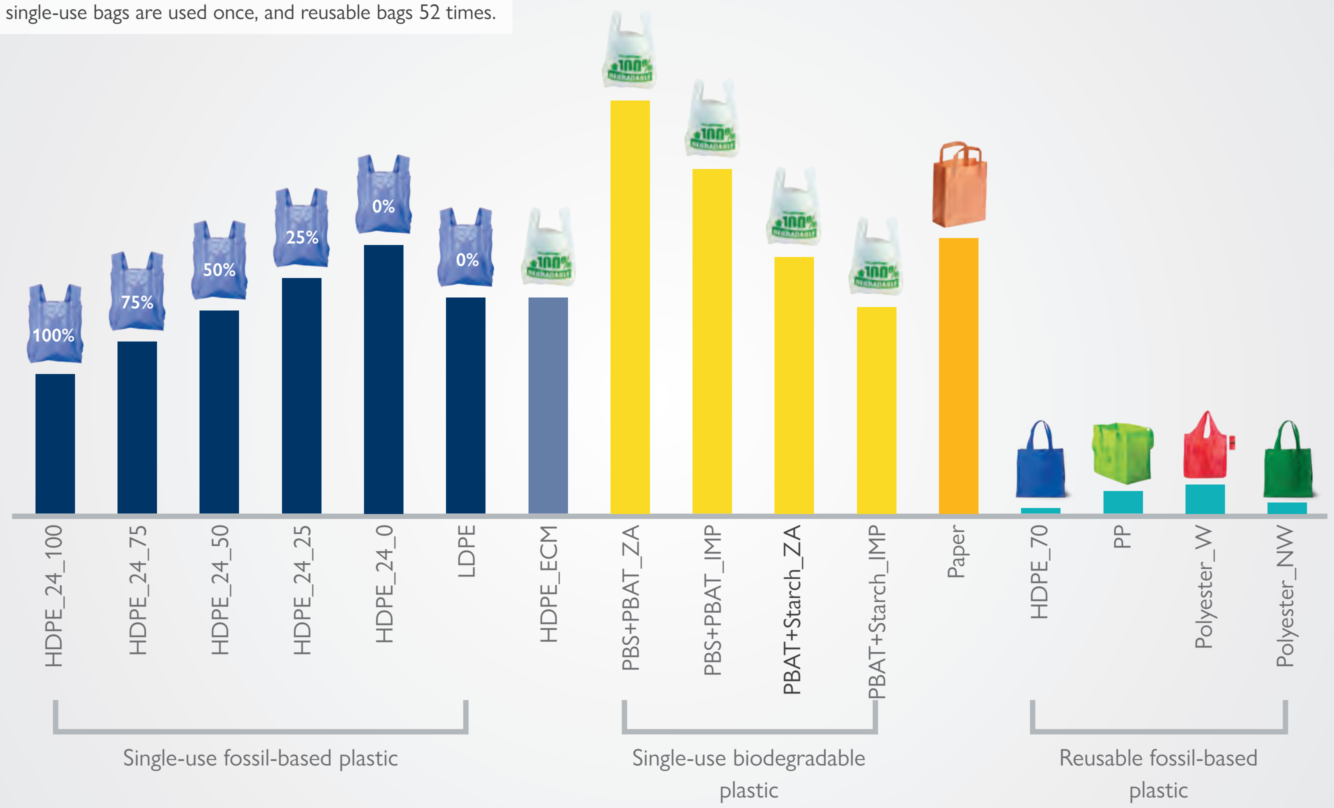
The CSIR's Sustainability, Economics and Waste Research Group, which has substantial expertise in life cycle assessment, has recognised the need to empower producers to navigate the life cycle assessment landscape. With funding from the Department of Science and Innovation and the Department of Trade, Industry and Competition, the team is developing a series of guidelines for conducting life cycle assessment studies in South Africa.

The CSIR's Life Cycle Assessment Guideline Series is intended to guide producers on how to conduct life cycle assessment studies in accordance with both the extended producer responsibility regulations and export market requirements. Similarly to the European Union's product environmental footprint approach, the intention is to provide a standardised set of recommendations regarding the various methodological choices that need to be made when conducting a life cycle assessment study. Ultimately, the intention is to ensure relevance, consistency, completeness, comparability and transparency in the way in which life cycle assessment studies are conducted in South Africa.

The guidelines are being developed based on an extensive review of available standards, data and methods, and in consultation with relevant South African experts and stakeholders. The aim is to build on (rather than replicate) existing knowledge and tools, and to provide up-to-date information to ensure alignment with global initiatives while being tailored to the South African context.

ENQUIRIES:
>> **Dr Valentina Russo**
vrusso@csir.co.za

Total environmental impact of different types of carrier bags, assuming single-use bags are used once, and reusable bags 52 times.



EXPANDING CONVENTIONAL LIFE CYCLE **ASSESSMENT TO ADDRESS CIRCULAR ECONOMY IMPERATIVES**

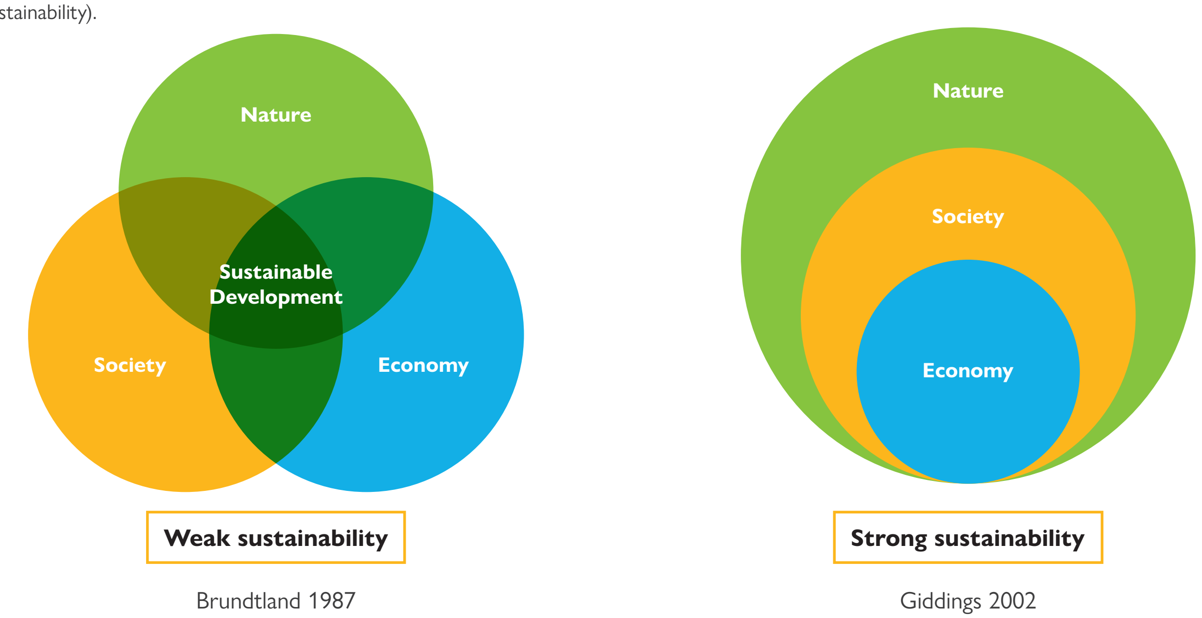
By Dr Valentina Russo, Prof. William H. L. Stafford, Anton Nahman

The CSIR is developing a novel approach to life cycle sustainability assessment that expands on conventional environmental life cycle assessment by incorporating social and economic aspects. The aim is to support decision-making towards a circular economy.

Life cycle assessment is a systematic approach for evaluating the environmental impacts of a product throughout its entire life cycle, from extraction of raw materials through to final disposal. Life cycle assessment studies can provide an important evidence base to support the transition towards a circular economy.

However, in a developing country context like South Africa, the transition to a circular economy must take social and economic imperatives into account, in addition to environmental aspects. Life cycle sustainability assessment, which has emerged more recently, attempts to expand on conventional life cycle assessment by incorporating social and economic considerations, in addition to environmental impacts.

Life cycle sustainability approaches. Early literature on life cycle sustainability assessment focused on conducting three separate assessments, followed by integration of the results (weak sustainability). The CSIR is developing a more integrative, efficient and streamlined approach. The aim is to improve integration among the environmental, social and economic dimensions through the adoption of a transdisciplinary approach (strong sustainability).



The current practice of life cycle sustainability assessment, however, is based on a 'weak' sustainability approach, with a lack of integration between the environmental, social and economic aspects.

In pursuit of the concept of 'strong' sustainability, the CSIR's Sustainability, Economics and Waste Research Group is developing a more integrative, efficient and streamlined approach to life cycle sustainability assessment.

The team's life cycle sustainability assessment framework reduces the cost of such studies and speeds up the time in which such assessments can be done.

As part of the framework, the team is developing new indicators to expand the analysis and ensure relevance to the South African context, including job creation, affordability and material pollution (including plastic pollution).

"We are integrating these new indicators with the conventional environmental life cycle assessment indicators, which typically focus on resource use and various types of emissions to air (including greenhouse gases), soil and water," says CSIR senior engineer Dr Valentina Russo.

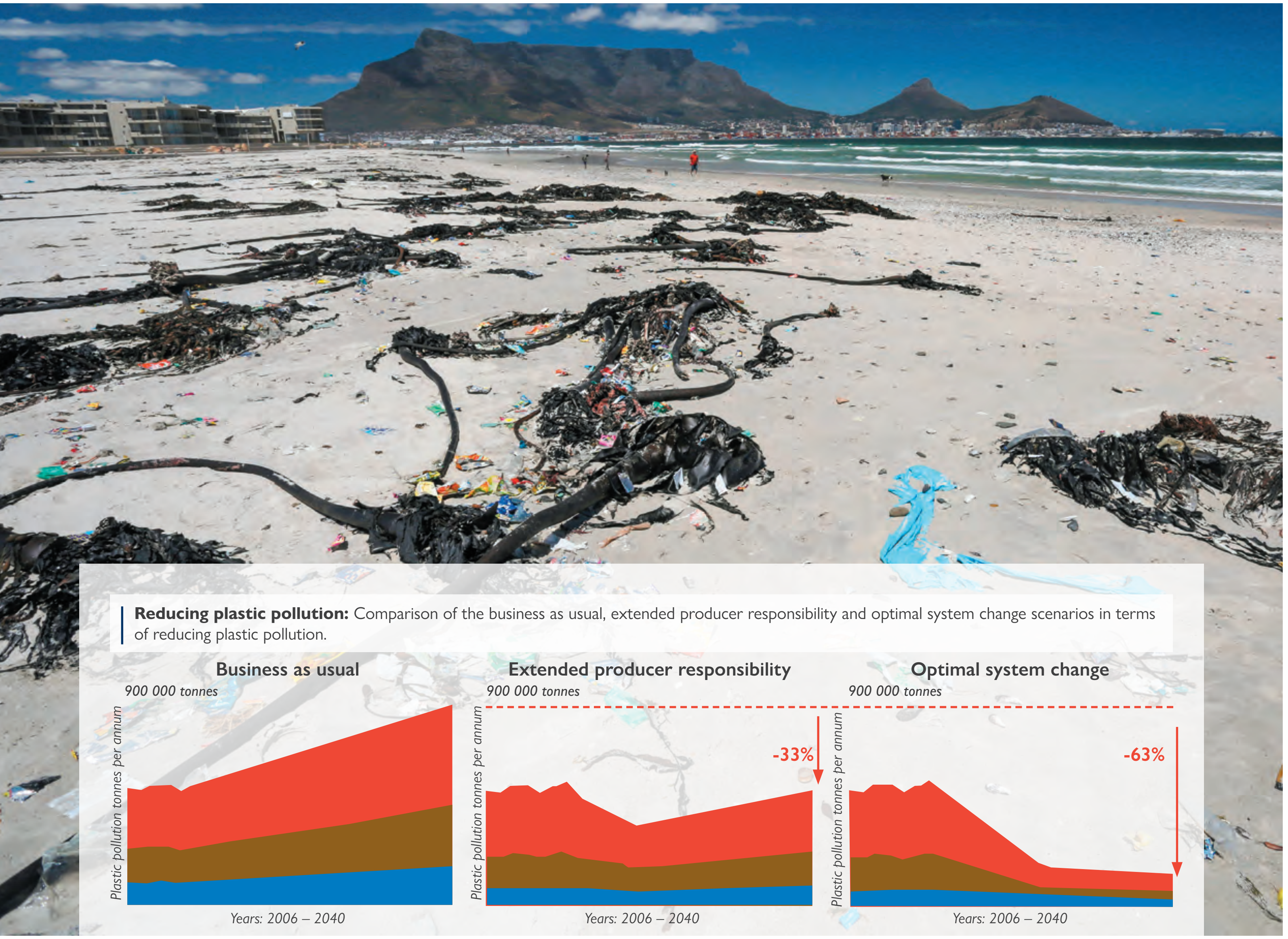
To date, the CSIR's life cycle sustainability assessment framework has been applied to two case studies, namely grocery carrier bags, and take-away (single-use) food containers and cups. In both cases, the assessment included various alternatives, such as reusable or biodegradable options, and was aimed at identifying the most suitable material option in each case.

In the case of grocery carrier bags, the study found that reusable plastic carrier bags are the best option in South Africa, as they have a substantially lower environmental impact compared to single-use bags – provided that consumers do actually reuse them. In the case of take-away containers, the study found that conventional polystyrene containers performed very well on the conventional life cycle assessment indicators, but poorly in terms of material pollution and job creation. Biodegradable materials (paper, bagasse and biodegradable plastics like PLA [butylene succinate]) and PBS (polybutylene succinate) showed the best trade-offs in terms of environmental and socioeconomic indicators.

By expanding the conventional environmental life cycle assessment approach through the incorporation of social and economic aspects, the CSIR can ensure that South Africa's socioeconomic development priorities are addressed in the analysis. Life cycle sustainability assessment studies can therefore provide an important evidence base to inform the transition to a circular economy in South Africa.

ENQUIRIES:

>> Dr Valentina Russo
vrusso@csir.co.za



Reducing plastic pollution: Comparison of the business as usual, extended producer responsibility and optimal system change scenarios in terms of reducing plastic pollution.

CSIR FIRST TO APPLY INTERNATIONALLY **DEVELOPED TOOL TO ADDRESS PLASTIC POLLUTION AT A NATIONAL LEVEL**

CSIR researchers are leading the charge in addressing plastic pollution in South Africa and Africa to effectively address plastic pollution, now and into the future. The organisation has released a comprehensive, evidence-based strategy aimed at reducing plastic pollution in South Africa. The *South African Pathways* report is viewed as an important contribution to the country's transition towards a more circular plastics economy.

The multidisciplinary CSIR team partnered with The Pew Charitable Trusts and Oxford University, developers of the Pathways Tool for the seminal global *Breaking the Plastic Wave* study. Through the CSIR's research, South Africa became the first country to implement this tool at a country level.

Dr Suzan Oelofse, project manager and CSIR principal researcher, shares, "Applying the Pathways Tool has increased our understanding of plastic flows in the South African context, offering valuable insights into the anticipated impacts of policies over time. This tool represents a freely available and empowering product for stakeholders, enabling evidence-based decision-making to foster a more resilient environment."

Plastic pollution is a growing concern and, without intervention, is set to almost double by 2040. While global attention has predominantly focused on marine plastic pollution, it is imperative to note that plastic pollution manifests differently in the South African context. According to the Pathways report, the majority of plastic pollution in South Africa arises through air emissions from the open burning of waste (56%), followed by land pollution (30%) and aquatic pollution (freshwater and marine) (14%).

The *South African Pathways* report provides scientific evidence to inform policy aimed at achieving near-zero plastic leakage into the environment, based on the assessment of three scenarios modelled over the period 2023 and 2040, each representing different intervention strategies:

1. Business-as-usual: This scenario assumes no interventions to address plastic leakage are put in place.
2. Extended producer responsibility: This scenario operates on the premise that the five-year collection and recycling targets mandated by the Extended Producer Responsibility Regulations, gazetted in South Africa in 2021, are achieved.
3. Optimal system change: This scenario encompasses a multifaceted approach, combining upstream strategies such as reducing the demand for plastic, substituting materials where it makes sense to do so, and downstream interventions such as increasing waste collection and recycling efforts, and ensuring proper disposal in sanitary landfills.

Under South Africa's business-as-usual scenario, with a projected annual growth in plastic consumption of 1.33% (driven by population growth and increased consumption trends), plastic pollution is set to almost double between 2020 and 2040. For the extended producer responsibility scenario, 33% of plastic pollution can be avoided over the period 2023 to 2040. However, this will be balanced by growth in plastic consumption, resulting in 2040 levels of plastic pollution being similar to current levels. Finally, a combination of intervention strategies, in line with the optimal system change scenario, can avoid 63% of plastic pollution over the period 2023 to 2040, compared to the business-as-usual scenario.

The report highlights that addressing the plastic pollution problem requires a comprehensive system change rather than relying on isolated strategies. This entails implementing a suite of interventions to facilitate the transition toward a more circular plastics economy, including:

- Reducing plastic production and consumption by eliminating unnecessary and problematic plastic, switching from single-use to reusable items and adopting innovative product delivery models like refill services and dispensing systems;
- Substituting problematic (non-recyclable) materials with alternative materials that are more readily recyclable or compostable, ensuring these alternatives meet functional requirements and are environmentally sustainable;
- Improving the collection of waste for all;
- Increasing the diversion of waste away from landfills towards recycling; and
- Where waste cannot be diverted, controlled disposal to sanitary facilities rather than dumpsites.

In partnership with Zambian researchers, the CSIR team is extending the application of the Pathways Tool to that country. This initiative aims to build capacity for using the tool and addressing plastic pollution in other African countries.

ENQUIRIES:

>> Dr Suzan Oelofse
soelofse@csir.co.za

CSIR DEVELOPS ROADMAP FOR A CIRCULAR **SOUTH AFRICAN PLASTICS ECONOMY**

A CSIR team, together with the World Bank and National Treasury, has framed a circular economy vision for plastics in South Africa and developed a set of recommendations for transitioning towards a more circular economy.

Plastic is an incredibly useful and versatile material, which brings significant value to society and provides several environmental benefits. However, the leakage of waste plastics to the environment is becoming an issue of increasing global concern.

Transitioning to a circular economy for plastics is critical for addressing the issue of plastic leakage, while potentially bringing a range of additional socioeconomic and environmental benefits.

The World Bank appointed the CSIR to support the South African government in developing a roadmap to advance the circularity of plastics.

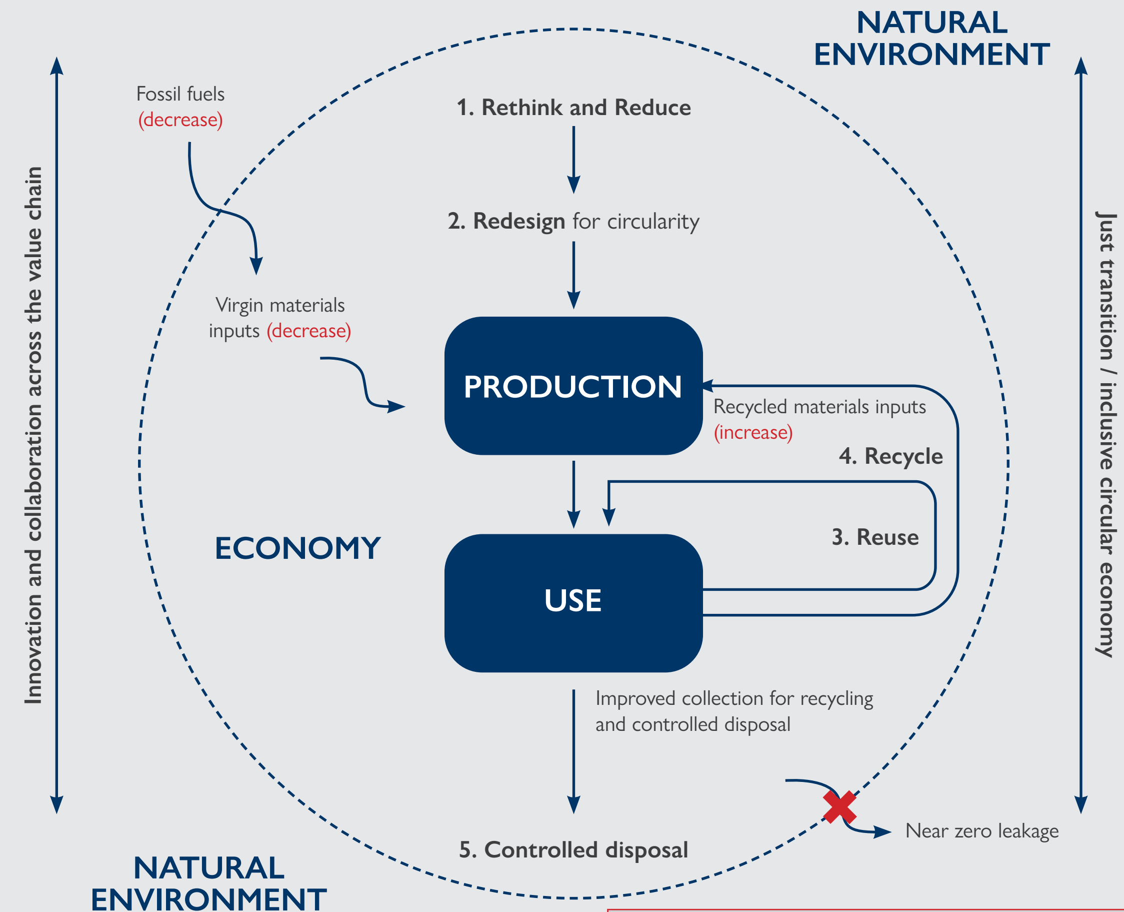
As part of this study, a vision for a circular plastics economy in South Africa was developed.

VISION FOR A CIRCULAR PLASTICS ECONOMY IN SOUTH AFRICA

South Africa has a **thriving, equitable** and **inclusive circular plastics economy**, which is **driven by innovation and generates well-being** for **society and the environment.**

The circular plastics economy is characterised by the following **principles**:

- **Designing out** plastic items that are either **problematic** or **unnecessary** (or both);
- All plastic products are **reusable, recyclable** or **compostable** in the South African context;
- Plastics **are circulated within the economy (at their highest value** and **for as long as possible**) and **kept out of the natural environment;**
- **Decoupling** plastic production from the consumption of finite resources, in favour of using **recycled materials;**
- There is **collaboration** across the value chain. All role-players are engaged and active in keeping plastic in the economy and out of the environment; and
- There is a **just transition** to the circular economy; the health, safety and livelihoods of all role-players across the value chain are respected.



Conceptual framework for a circular plastics economy

The study provided a set of short-, medium- and long-term interventions required to achieve this vision.

"The broad range of required actions highlights that there is no silver bullet to address the challenge of plastic pollution and that no single role-player can bring about the required changes in isolation. Instead, system-wide interventions are required; through a concerted, collaborative effort among all role-players, working towards a shared vision," says CSIR principal researcher Anton Nahman.

In particular, the recommendations highlight the importance of upstream measures, such as reducing and redesigning, rather than relying primarily on end-of-pipe interventions (recycling and disposal) to drive a circular economy.

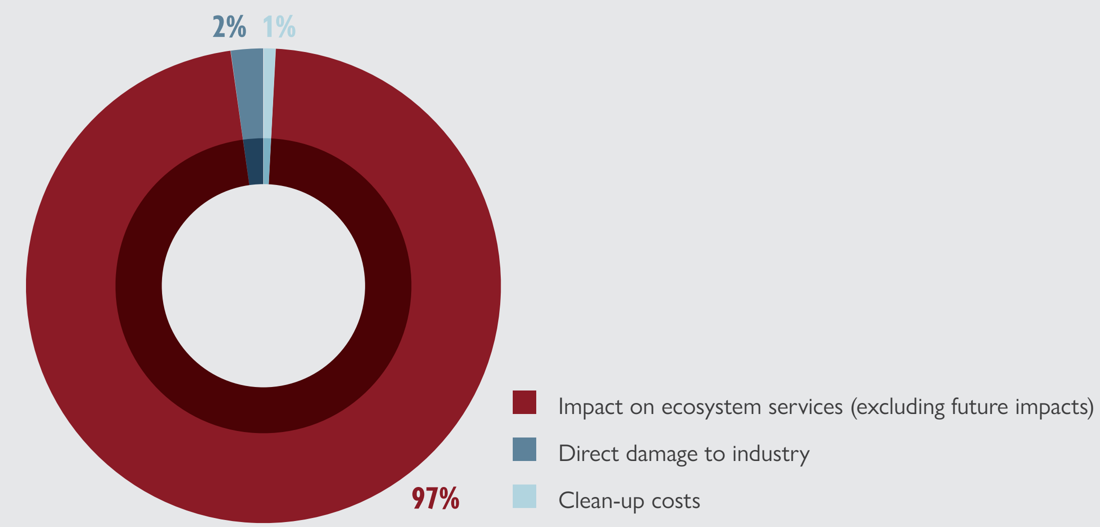
The recommendations are grouped under 10 broad themes:

1. Adopting a common vision and roadmap for the circular economy;
2. Creating an effective and enabling environment;
3. Improved waste collection and management to ensure the recovery of recyclables and elimination of leakage;
4. Designing out unnecessary and problematic plastic items;
5. Driving design for circularity;
6. Scaling up reuse models;
7. Further development of recycling capacity where required;
8. Driving demand for post-consumer recyclate;
9. Improved communication, education and behavioural change; and
10. Promoting inclusivity and a just transition.

ENQUIRIES:

>> **Anton Nahman**
anahman@csir.co.za

Plastic bottles and other rubbish that had washed up on Durban beach after heavy rains.



Percentage contribution of each component to the total economic impact associated with plastic pollution.

MARINE PLASTIC POLLUTION COSTS **SOUTH AFRICA R14 BILLION PER YEAR**

The CSIR has conducted an assessment of the economic implications of plastic pollution in South Africa's marine environment. The study, funded by the Department of Science and Innovation, offers a preliminary estimation of the costs linked to marine plastic debris in South Africa. It encompasses the impacts on marine ecosystem services, direct damage to industry, and the expenses associated with the cleanup of plastic debris.

The issue of plastic waste leakage into the environment is of growing concern both globally and in South Africa. It is estimated that approximately 50 000 tonnes of mismanaged plastic waste enter the marine environment annually in South Africa. This plastic debris poses significant threats to marine ecosystems; impacting the delivery of ecosystem services and causing direct damage to industries such as fisheries, shipping and tourism; with resulting impacts on the economy.

The CSIR estimated that the economic impact associated with plastic entering the marine environment each year ranges from R3.5 billion to R34.9 billion, per year. This equates to between 0.05% and 0.5% of South Africa's annual gross domestic product (GDP), or 4.7% to 46% of the plastics industry's direct contribution to GDP. The mid-range estimate places the annual economic impact at R14.1 billion (0.2% of GDP or 18.6% of the plastics industry's direct contribution to GDP), equivalent to R282,028 per tonne of plastic.

Impacts on ecosystem services were found to make up 97% of the total costs associated with marine plastic.

However, these estimates of the annual economic impact only reflect the damage caused by plastic that enters the environment in a single year, says CSIR principal researcher Anton Nahman.

"Plastic entering the marine environment takes hundreds to thousands of years to break down and will continue to impose negative impacts on ecosystem services throughout its lifetime," he explains. "This means that the actual economic impact per year is even higher, as plastic that entered the marine environment in the past is still impacting ecosystem services today; while plastic entering the environment each year will continue to cause damage in future."

The lifetime cost per tonne of marine plastic, purely in terms of impacts on ecosystem services, ranges between R3.4 million and R33.8 million, with a mid-range estimate of R13.5 million. This implies a total cost of between R169 billion and R1.69 trillion (2.5% to 25.5% of South Africa's annual GDP), with a mid-range estimate of R677 billion (10.2% of annual GDP), in terms of impacts on ecosystem services over the lifetime of plastic entering the marine environment each year.

Given the lack of South African specific data on the impacts of marine plastics on ecosystem processes, these cost estimates were derived using the 'benefits transfer' method. This involved adapting the best available unit impact values from international studies to the South African context, based on relevant local variables and through consultation with relevant local experts and stakeholders.

"Given the urgency of the problem, the current lack of local data should not be used as an excuse to delay action. There is a clear need for systemic change, incorporating a broad range of upstream and downstream interventions, in line with the principles of a circular economy," says Nahman.

Nahman highlights the need for greater emphasis on upstream solutions, such as rethinking, reducing and redesigning plastic products for circularity to prevent the generation of plastic waste in the first place; in addition to the current focus on removing plastic already present in the environment.

"Allowing waste plastic to continue to leak into our marine environment creates a very real economic risk to our tourism and fisheries industries, as has been evident in other countries," he says.

ENQUIRIES:

>> Anton Nahman
anahman@csir.co.za

CSIR researchers evaluate the biodegradability of polymeric materials under composting conditions by using the automated respirometer system in the organisation's biodegradation testing facility.

CSIR PIONEERS NATIONAL STANDARDS FOR **HOME COMPOSTABILITY OF POLYMER PRODUCTS**

The use of biobased compostable bioplastics presents a significant opportunity to foster a more circular economy. Manufacturers are increasingly recognising the importance of sustainable end-of-life options for plastic and bioplastic products, specifically those derived from renewable resources and featuring biobased compostable polymers. However, to ensure safe end-of-life management, the establishment of comprehensive standards for the compostability of such polymer products is crucial. The CSIR has completed the development of standards for the home compostability of polymer products, with approval from the South African Bureau of Standards (SABS) in 2023.

Led by CSIR biodegradable polymer experts, a technical committee was set up to develop the national standards (Ref. SANS/CD 2066). This committee also included pioneers from academia, the SABS and the environmental sector in the fields of biodegradation and compostability.

The new standards primarily address the disintegration and complete biodegradation of compostable materials into carbon dioxide, water and new microbial biomass. They also assess potential negative effects of the composting process, negative effects on resulting compost quality – including the presence of regulated metals – and other harmful outcomes.

Dr Sudhakar Muniyasamy, a CSIR expert in biodegradable polymers and biodegradation says, "Prior to the recent establishment of a biodegradability laboratory at the CSIR, there was no certified biodegradation testing facility available in Africa for testing biodegradable and compostable product claims, especially under African environmental conditions. It is also necessary to have a national standard to regulate and oversee the import of plastics claiming compostability, as well as to certify locally produced biodegradable plastics."

These standards specify detailed procedures and requirements for materials and projects intended for single-use suitable for home composting, in line with the International Organization for Standardization (ISO 17088).

"These national standards play a pivotal role in validating and labelling materials and products – imported and locally manufactured – as biodegradable and compostable. They provide a comprehensive framework for qualifying environmentally friendly materials and labelling products accordingly. Furthermore, this initiative represents new opportunities for South Africa, stemming from the adoption of new regulations in the environmental sector and the management of solid waste," Muniyasamy adds.

Biomaterials represent an emerging area of research that focuses on fostering a low-carbon economy by harnessing agricultural biomass for diverse industrial applications, ranging from consumer products to packaging materials. Ensuring that each industrial bioproduct is certified and verifiably biodegradable and compostable offers responsible end-of-life solutions for plastics waste, in harmony with the principles of the circular economy model.

ENQUIRIES:

>> **Dr Sudhakar Muniyasamy**
smuniyasamy@csir.co.za


Aseptic sampling during a fermentation processes.

PUTTING MICROBES TO WORK TO CREATE ENVIRONMENTALLY FRIENDLY AND SAFE **PRODUCTS IN LINE WITH PRINCIPLES OF A CIRCULAR ECONOMY**

Imagine plastics derived from sugarcane molasses instead of petroleum-based chemicals, or pesticides and fertiliser made by bugs rather than from harsh chemicals. The CSIR has produced a variety of biobased products which are not only less harmful than their chemical counterparts, but are also made using waste streams that have the potential to pollute our air, water and soils.

CSIR experts in bioprocess development are actively working on replacing common products used in South African cosmetics, agriculture, food packaging and other sectors with products made by microorganisms.

"Our focus is on using renewable and sustainable feedstocks or redirecting waste sources, instead of petrochemical feedstocks to produce a number of products," says Dr Santosh Ramchuran, who leads the CSIR's bioprocessing team.

Sustainable feedstocks include sugars from molasses, which is a by-product of the sugar industry, as well as those from the waste streams of dairy, food processing and paper industries.

The problem with using non-renewable petroleum and harsh chemical processes to manufacture products is that it becomes highly resource intensive. And the products themselves, like plastic packaging, fertilisers and crop sprays, end up polluting the environment as they are not biodegradable.

By repurposing waste streams as feedstocks for indigenous microbes to consume, unique bioprocesses are developed that essentially convert waste into useful products that can be further channelled into other, greener manufacturing processes. This aligns neatly with the circular economy principles of designing out pollution and waste and regenerating natural systems, by using renewable materials and producing eco-friendly products.

The CSIR has established three distinct research and development platforms to innovate and assist in the commercialisation of these bio-based products. The first is the bioconversion platform, which focuses specifically on developing alternate routes to manufacture chemicals using sustainable feedstocks or industrial by-products into something useful such as lactic acid, ethanol and butanol. The second platform focuses on the utilisation of microbes and enzymes for the production of bio-based products such as biofertilisers and probiotics. The third platform assists researchers, small, medium and micro enterprises (SMMEs) and industry in the scale up, biomanufacturing and commercialisation of these developed technologies and products. The team has already developed a novel bioprocess to convert sugarcane molasses into lactic acid using an indigenous microbial strain.

Ramchuran says lactic acid can be converted into a high-value biopolymer called polylactic acid, which is used to manufacture biodegradable bioplastics. It is also used in other industries like food processing and cosmetics.

The next step will be to scale up the production of the lactic acid together with an interested commercial partner. The goal is to localise the manufacture of lactic acid for South African and African markets.

In another project, researchers are growing various indigenous microbes in the lab to find ones with possible fertiliser and pesticide properties. The goal is to create biofertilisers, biocontrol agents and plant growth stimulants that can be locally manufactured.

"In South Africa, the products used in the industry contain non-indigenous microbes that are present in imported products," says principal investigator Yrielle Roets-Dlamini. "These products are also neither affordable nor accessible by small-scale and subsistence farmers."


CSIR candidate researcher Boitumelo Mokoatsi monitoring the production of microbes in a stirred tank bioreactor.

Ramchuran says they have already developed several prototypes and products using various consortiums of bacterial and fungal strains isolated from South African environments. "Two of these have been licensed to local companies," he says, with more expected to be ready for commercialisation in the next 12 months.

"These projects have a global impact and demonstrate the country's ability to develop green manufacturing processes that are relevant for local SMMEs, and which can be integrated into existing commercial manufacturing industries," says Ramchuran.

ENQUIRIES:

>> **Dr Santosh Ramchuran**
sramchuran@csir.co.za

COAL ORE ON A CONVEYOR BELT IN MPUMALANGA, SOUTH AFRICA. THE MINING SECTOR IS RESOURCE-INTENSIVE IN PROVISION AND CONSUMPTION.

CIRCULAR ECONOMY: THE PATHWAY TO **HEALTHIER AND MORE SUSTAINABLE MINES IN SOUTH AFRICA**

South Africa is richly endowed with mineral resources and the minerals-energy complex plays a critical role in the country's economy, domestically and globally. In recent times, however, the mining industry's contribution to the country's development has experienced a gradual decline due to increasing operating costs, complex ore bodies, declining productivity and ore grades, as well as health and safety, social and environmental challenges. The mining sector, as a resource-intensive sector in provision and consumption, stands to benefit greatly from the CSIR's ongoing research into and implementation of the circular economy.

The circular economy presents opportunities for economic, environmental and social prosperity. Its systemic approach to economic development is designed to benefit businesses, society, governments and the environment, making it an increasingly beneficial component of the progression of the mining sector in modern times. This has, however, not been a historical view, as the circular economy has, for the most part, been perceived as a threat to the mining sector. This perception suggested that the reuse and recycling of secondary minerals and metals would be prioritised over primary resource extraction, potentially impacting the mining demand. Early concepts of the circular economy also often excluded mining from the loop. Recent studies, however, show that the circular economy can offer significant value to the mining sector through sustainable resource use.

CSIR senior researcher Sumaya Khan says, "The key value drivers for a circular economy in the mining sector are numerous – it presents opportunities for minimising adverse environmental impacts, the creation of alternate economies including skills development and subsequent job opportunities, as well as the possibility of exploring new business models for the mining companies. Some of the circular economy opportunities for the mining sector include water recovery and recycling, processing of residues and secondary metals, and remining tailings and waste dumps. The circular economy also promotes the practice of keeping materials in use through reduction, reuse, repair, refurbishment, recycling and repurposing. Some of these practices are already being adopted by mining companies under the banner of 'waste management'. However, a circular economy in the mining sector is not just about waste management. It is about the sustainable use of mineral resources and metals, through designing out waste and pollution from the mining processes, keeping materials in use for as long as possible, and regenerating natural systems."

For mines, clearing invasives around their sites could significantly benefit the company and the communities. This action could potentially lead to the rehabilitation and repurposing of old mine sites as educational training centres. The transition to renewable energy, facilitated by a green industrialisation strategy, can also contribute to a circular economy. Green hydrogen production holds significant economic potential for South Africa and would result in an increased demand for platinum group metals.

Transitioning to a more circular economy is also expected to create new opportunities for the South African mining sector. The global adoption of green energy technologies and growing digital economies is expected to result in an increased demand for several minerals and metals, including aluminium, copper, lead, lithium, manganese, nickel, silver, steel, zinc, and rare earth elements such as indium, molybdenum and neodymium.

The circular economy can unlock many benefits in and for the mining sector, both in the short and long term. Adopting its principles will support the mining sector's role in providing minerals and metals to downstream economic sectors such as manufacturing, human settlements and mobility. Within a circular economy framework, the South African mining industry is poised to become more competitive and innovative on a global scale.

ENQUIRIES:

>> Sumaya Khan
skhan@csir.co.za

Miners in a South African platinum mine drill holes in the rock for blasting. Mining is an energy intensive operation that requires cooling, lighting, ventilation, pumping, transportation, drilling and other mechanised activities. Opportunities for energy conservation abound in many of these activities.

A lit underground mine tunnel.

Solar energy panels at a coal mine.

OPPORTUNITIES TO REDUCE THE COST **OF ENERGY IN MINES**

The mining sector is inherently energy-intensive and faces mounting energy expenses, primarily driven by rising electricity tariffs. Recognising the significance of resource optimisation within the mining industry, the CSIR initiated a project focusing on cost reduction opportunities using energy optimisation studies. Researchers compared current and alternative energy sources in underground gold as well as platinum group metal mines to determine the potential energy cost savings achievable through the adoption of alternative energy in mining production activities. They also identified areas with high energy consumption and identified opportunities for implementing measures to reduce energy costs.

The mining industry has historically been a significant global energy consumer. With the introduction of new technologies and machinery aimed at modernising the sector, this trend is expected to escalate. The CSIR explored alternative energy sources for underground mining operations, coupled with strategies to enhance energy efficiency.

Projections have indicated that solar photovoltaic and wind energy are to become the most cost-effective alternative energy sources in the future. CSIR experts believed that the mining sector would benefit from a more in-depth study, with a particular focus on specific mining operations, to understand the financial and production implications of incorporating alternative energy sources and renewable energy solutions into production activities.

The four key components of the work focused on:

- Understanding the energy consumption of various mining production activities;
- Demonstrating the advantages and potential financial savings associated with the adoption of alternative energy sources;
- Understanding how energy consumption data is collected and packaged at different mines; and
- Investigating alternative energy sources and technologies.

Several analytical exercises were performed during the study. This included assessing energy consumption for various mining activities across different mining operations over a specific period. Additionally, an analysis was conducted to evaluate the technical and socioeconomic feasibility of designing a grid-connected solar power system for these mining operations.

One of the key findings from this analysis was that implementing energy efficiency and energy management strategies could lead to a reduction of approximately 10% in electrical energy consumption. The reduction of electrical energy consumption presents various benefits including the increased efficiency of refrigeration and ventilation achieved through eliminating waste; taking a ventilation on demand approach and monitoring and controlling recirculation; reduced pumping energy costs by storing incoming water during peak periods; and the reduction of the usage of diesel-powered technologies by exploring electric-powered, battery-powered and hybrid technologies.

Through partnerships with mining companies, the CSIR hopes to enhance the measurement of the mine's primary energy loads, both on the surface and underground, and support mines in becoming more competitive, regenerative and resource efficient.

ENQUIRIES:

>> Busi Sereme
bsereme@csir.co.za


Pellets from invasive plants.

> "WE SUCCESSFULLY DEMONSTRATED THE VIABILITY OF PELLETS MADE FROM INVASIVE PLANTS AS A COST-EFFECTIVE AND SAFER ALTERNATIVE TO PARAFFIN FOR HOME COOKING AND HEATING."
> *– Godrey Black, Impact Catalyst*

CONVERSION OF INVASIVE PLANTS TO **ENERGY PELLETS BRINGS HOPE TO RURAL COMMUNITIES**

Invasive plants that wreak havoc on local ecosystems can be converted to energy pellets – a cost-effective and safer alternative to paraffin for home cooking and heating, as well as animal feed. The technology was recently demonstrated in Blouberg, a mining community in Limpopo.

The Impact Catalyst has recently demonstrated how alien vegetation, which is typically removed because of its negative impact on the environment, can be beneficiated. Founded by Anglo American, the CSIR, Exxaro and World Vision South Africa, the Impact Catalyst fosters large-scale, socio-economic development initiatives through public-private partnerships. The alien vegetation removal initiative is one of three Social Employment Fund initiatives operating across the Northern Cape, Limpopo, Mpumalanga and the Free State.

"Our alien vegetation removal programme is designed to tackle environmental degradation while simultaneously addressing the socio-economic needs of communities in which we operate. Through our approach to this programme, we hope to empower our participants, showing that they can create high-value products and contribute to the circular economy while reaping economic benefits from the removal of invasive species," says Waldi Le Grange, SEF Programme Manager at the Impact Catalyst.

Invasive plant species such as eucalyptus, wattle and poplar not only consume excessive water but also threaten biodiversity by outcompeting native vegetation. The proliferation of these invasive species wreak havoc on local ecosystems, often encroaching on grazed land. This has a negative impact on the local agricultural sector and food security, ultimately contributing to increased rural poverty.

"We recently conducted biomass trials in Taaiboschgroet, Limpopo, where we successfully demonstrated the viability of pellets as a cost-effective and safer alternative to paraffin for home cooking and heating. Additionally, the interest of the participants and community members was piqued when we demonstrated how the goats at Taaiboschgroet enjoy the animal feed produced from the invasive biomass," adds Godfrey Black, SEF Project Manager: Invasive Plant Clearing at the Impact Catalyst.

According to Future Market Insights, the global biomass pellet industry is projected to grow exponentially between 2023 and 2033. Currently valued at US$ 20 409 million, Europe accounts for 60% of the global biomass pellet sales. With South Africa leading green energy efforts in Africa, the South African government is actively investing in infrastructure to support the production of biomass pellets from waste material as part of its Renewable Energy Independent Power Producer Programme.

Building on this momentum, the Impact Catalyst, as an implementing agent of the SEF's alien vegetation removal initiative, aims to work together with its partners – the Anglo American Group, De Beers, Eskom and Sasol – to garner additional support to scale this initiative across its operational areas.


Equipment used to produce pellets from invasive plants.

"The interest shown by the participants, community members and local business provides a business case for us to attract additional funding to equip rural communities with advanced training and suitable equipment, empowering them to actively participate in the growing biomass industry," says Black.

The Impact Catalyst is one of 37 strategic implementation partners of the SEF programme, which is managed by the Industrial Development Corporation. To date, the Impact Catalyst has onboarded 2 300 participants who receive monthly stipends and training in alien vegetation removal, community farming and waste management.

ENQUIRIES:

>> Godfrey Black
gblack@impactcatalyst.co.za

FOUR MINES IN THE NORTHERN CAPE ARE FUNDING THE ESTABLISHMENT OF MINI-TRANSFER STATIONS WHERE SELECTED LOCAL UNEMPLOYED COMMUNITY MEMBERS WILL COLLECT, SEPARATE AND SORT WASTE TO GENERATE INCOME.

GREEN ECONOMY PROGRAMME TO OPEN **NEW OPPORTUNITIES FOR WASTE BUYERS AND PICKERS**

The Impact Catalyst, in collaboration with its partners, is spearheading a transformative green economy programme which will bolster waste buyers, pickers and small to medium enterprises in catalysing a waste economy across Limpopo, the Northern Cape, Mpumalanga and North West provinces.

The Impact Catalyst's Green Economy Programme includes various circular economy initiatives in agriculture, energy and waste. One such programme aims to foster the development of waste infrastructure initiatives, equip programme participants with essential skills, and generate employment opportunities for local community members. It is expected that the programme will absorb 1 300 participants who had enrolled for the Impact Catalyst Social Employment Fund (SEF) waste management pathway.

"Following SEF training, the Impact Catalyst will work with entrepreneurs to secure infrastructure and grow their businesses in the waste sector. We envision the birth of a new market sector that bolsters the circular economy, fostering sustainable employment for participants and potentially for community members," says Mlungisi Sindane, Project Manager at Impact Catalyst.

In an effort to boost this initiative, four mines in the Northern Cape – Anglo American, Assmang, Kudumane Manganese Resources and South32 have allocated R4.7 million towards the establishment of mini-transfer stations and a comprehensive feasibility study which will inform the various waste beneficiation streams.

"These mini-transfer stations will serve as hubs managed and utilised by local unemployed community members who are project participants, to collect, separate and sort the waste," Sindane says.

Transfer stations play a crucial role in the waste value chain by facilitating the efficient and environmentally responsible management of waste. They are considered as waste collection and handling centres that enable community members to dispose of their waste in a more responsible manner, mitigating challenges associated with illegal dumping, and through the recovery of recyclables, reduce the burden on landfills.

Other areas of focus of the programme include waste education, advocacy and awareness, unlocking the waste economy value chain and facilitating capability building for SMMEs through enterprise development.

"All initiatives within this programme are designed to contribute towards the United Nations Sustainable Development Goals and Environmental, Sustainable and Governance best practices. By driving the waste reduction, reuse, recycling and recovery narrative, we aspire to fostering an enabling environment for waste buyers and pickers to forge sustainable livelihoods that will benefit them and their families," adds Sindane.

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

ENQUIRIES:

>> **Mlungisi Sindane**
mlungisi.sindane@impactcatalyst.co.za

The M5 freeway in Cape Town in the Western Cape.

SUSTAINABLE ECONOMIC DEVELOPMENT **THROUGH CIRCULAR MOBILITY**

Mobility is at the heart of economic development. It is the link between businesses and their respective markets, households and communities. Traditional, linear mobility approaches have contributed to increased greenhouse gas emissions, depletion of finite resources, congestion and decreased productivity.

The movement of goods and people is an energy and resource-intensive activity. CSIR senior researcher Refiloe Mokoena says, "The transport sector accounts for 19% of South Africa's total energy demand. The majority (98%) of the sector's energy is supplied through petroleum products. This, in turn, contributes to the transport sector's estimated 10.7% contribution to national greenhouse gas emissions."

An estimated 77% of land freight is still transported via road in South Africa, which, in addition to consuming significant quantities of fossil fuels, has a direct bearing on national productivity and competitiveness. The heavy reliance on road transport also negatively impacts the condition and maintenance of the national road network.

South Africa's resource-intensive transport systems provide the perfect impetus for transitioning to a more circular mobility system. Applying circular economy principles of designing out waste, closing resource loops and regenerating natural systems provides a framework for South Africa to improve the efficiency and competitiveness of mobility systems.

For mobility, **designing out waste** could entail solutions for shared and multimodal mobility, increased use of zero-emission mobility, as well as encouraging remote and flexible working. **Keeping materials** in use could include scaling up vehicle remanufacturing, recycling and vehicle and infrastructure design for circularity. **Regenerating natural systems** could include mobility systems based on renewable energy and climate-resilient transport infrastructure.

Mokoena says that circular mobility requires a primary focus on designing for users and goods instead of vehicles – such as planning transport networks that provide reduced travel distance and time per journey.

She says that while many underlying circular economy principles are already being applied in mobility, more needs to be done to accelerate and scale up action to ensure meaningful impact.

ENQUIRIES:

>> **Refiloe Mokoena**
rmokoena@csir.co.za

A 100 m test section of road is being paved in a patented mix of traditionally non-recyclable plastic and bitumen on one side, and a standard road surface mix on the other. This section is undergoing 20 years of traffic and weather stress in just three months, using the CSIR Heavy Vehicle Simulator (bottom right).

FINDING INNOVATIVE SOLUTIONS FOR **NON-RECYCLABLE PLASTIC FRACTIONS**

South Africans appreciate the familiar sound of the waste picker's makeshift trolley on rubbish day, whizzing down a suburban street to collect recyclables from the wheelie bins lined up along it. However, there are many plastics left behind in the bins as they either do not have a recycling market or the price paid is too low to warrant collection. Finding solutions for these non-recyclable plastics has the potential to improve livelihoods for informal and formal collectors, according to CSIR researchers working on a sustainable road surface mix.

The CSIR has built a 100 m test section of road, paved in a patented mix of traditionally non-recyclable plastic and bitumen on one side and paved in a standard road surface mix on the other. This section is about to undergo 20 years of traffic and weather stress in just three months.

If the new plastic-bitumen mix performs as well or better than the conventional paving, the technology will help solve two critical problems.

The first deals with reducing the current waste burden by returning waste plastic that is not currently being recycled back into the economy, and the second is about building roads with improved performance that are more resilient to extreme heat and storms.

PROJECT SPONSORS AND ROAD PAVEMENT INDUSTRY PARTNERS

Department of Science and Innovation, AECI Much Asphalt, Dow, WBHO, BSS, Roadspan, Afrimat - Lyttelton, Road Materials Consulting, Keabetswe Pholo, University of Pretoria.

Refiloe Mokoena, a senior researcher at the CSIR who specialises in the resilience of South African roads against the impacts of climate change, says South Africa has a giant waste problem.

"The plastic waste used in the test section has been sourced locally, and in that way, is directly addressing the national waste problem," she says.

To source the plastic waste for the South African road mix, a CSIR team toured the country's material recovery and recycling facilities to understand what waste plastics were not being collected and processed for mechanical recycling.

Once the CSIR team settled on suppliers that could melt the right kind of plastic waste into pellets, they were ready to begin testing some plastic paving mixes.

"The project team decided to use plastic that is not currently recycled. This was done for two reasons: to find new markets for problematic plastic waste streams and to ensure that current mechanical recycling value chains are not disrupted by this new technology through increased competition for the material," explains CSIR pavement researcher Michandre Smit.

Laboratory testing funded by the Department of Science and Innovation yielded a novel, technically sound and strong mix of plastic and bitumen, which was patented and is now ready for on-site testing for 'rutting'.

"Rutting is when you see deformation in the form of grooves in the pavement," says Smit. She explains that it is a permanent, longitudinal surface depression in pavements due to loading.

Her team will now try their best to destroy the 100m road test section using a machine called the Heavy Vehicle Simulator (HVS). The HVS is a CSIR innovation that simulates the heavy traffic and weather stress a road might experience in two decades within just three months.

"To achieve that with the HVS, we are going to heat up the section because bitumen is very susceptible to heat, and we are going to load it with traffic simultaneously.

"We are testing it side by side with a conventional pavement so we will be able to see the real-life differences between how the two pavements react to the heat and the load that we're putting on to it," she says.

Mokoena says a successful HVS test will demonstrate that the CSIR has repurposed a waste material into a useful product that still meets the high technical standards required.

She says this evidence is critical for the road industry, which has supported the multidisciplinary team at the CSIR with research funding and technical advice.

"It's been very encouraging to see everyone come together and to actually see this happen because it is something they are interested in as the roads industry, and my view is that they are committed to improving and constructing roads in a sustainable way," said Mokoena.

If the technology proves viable, these CSIR researchers hope the government will eventually mandate and provide institutional support for road builders to include recycled materials as alternative and viable road construction materials.

Smit says this would mean that recycling plants can scale up operations to keep up with new demands, and with that comes the potential for increased plastic waste collection by both informal and formal waste collectors, resulting in tangible benefits for all across the waste and recycling value chain.

ENQUIRIES:

>> Michandre Smit
msmit@csir.co.za

CSIR senior researcher Reatile Pitso inside the CSIR Road Materials Testing Laboratory.

GLASSPHALT FOR ROAD CONSTRUCTION **HOLDS PROMISE AS A CIRCULAR ECONOMY INNOVATION**

Increasingly, discarded materials are viewed as resources with significant economic value. The circular economy deals with channelling these resources back into the economy for further economic growth. Glass waste is one such resource that is increasingly being investigated internationally for its potential as a road construction material. Locally, CSIR researchers are undertaking tests in which they combine crushed glass with hot asphalt mixes for use in pavement infrastructure.

The use of glass waste material as an engineering aggregate in pavement infrastructure continues to be the subject of civil engineering studies around the world. Experts believe that non-recyclable glass can reduce the reliance on virgin aggregate such as gravel or even sand and will divert waste glass from landfills. Locally, the CSIR is also undertaking tests, spurred on by the government's mandate to find ways of alleviating waste materials at landfills.

The engineering performance of recovered non-recyclable glass in South African asphalt mixes is not fully understood. CSIR senior researcher Reatile Pitso says the crushed glass is locally available, is durable and easy to compact, and therefore has the potential to replace asphalt aggregates, such as crushed stone, gravel and sand. The team therefore set out to determine how non-recyclable crushed glass affects the engineering performance of a continuously graded asphalt-wearing course mix.

"Ultimately, we are interested in developing better South African asphalt mixes and building stronger, longer-lasting roads. But for a material to be pervasively used in pavement infrastructure, it needs to be thoroughly tested, in the lab and the field, before it can be included in South African mix design methods and specifications," he says.

The current established asphalt mix design methods and specifications in South Africa limit the use of alternative materials, including waste materials, in asphalt, resulting in the use of expensive materials. As a solution, the research study aims to optimise the design, construction and maintenance of roads through the use of cost-effective and sustainable materials, including non-recyclable crushed glass.

The crushed glass asphalt mix design considers the properties of bitumen, susceptibility to moisture, and the stiffness of the pavement-wearing course. "The mix design was conducted according to the current methods for conventional asphalt mixes in South Africa, with the results indicating that the glass-asphalt mix conforms to South African mix design standards. The findings of this study reveal a significantly increased performance that could be achieved with the use of crushed glass in continuously graded asphalt-wearing course mixes in South Africa," says Pitso.

The next phase is to build a trial section of the road made up of crushed glass asphalt mix as a wearing course to assess the engineering properties in practice.

ENQUIRIES:

>> Reatile Pitso
rpitso@csir.co.za

Crushed glass.

Conventional aggregates used in an asphalt mix.

CSIR senior researcher Reatile Pitso prepares a sample of an asphalt mix containing crushed glass in the laboratory.

Glassphalt sample.

Coal fly ash supplied by a South African mine.

UTILISATION OF COAL FLY ASH AS **AN ALTERNATE MATERIAL IN ROAD CONSTRUCTION**

A research study has identified coal fly ash, a waste material from electricity generation, as a potential alternative road construction material. The use of fly ash would reduce the reliance on virgin construction materials and minimise the environmental impact associated with the disposal of these materials in landfills – supporting the principles of the circular economy.

In South Africa, electricity generation operations produce a huge amount of coal ash – some 35 million tonnes per year – comprising fly ash and bottom ash. Currently, only about 10% of the coal ash is used.

Fly ash is a byproduct of coal-fired electricity operations. It is stored at ash disposal facilities but becomes a challenge over time. CSIR senior researcher Gculisile Mvelase says that these facilities have space limitations and can cause significant environmental impacts. Alternative uses of fly ash, such as for road construction, would present a welcome solution.

Laboratory-scale demonstration of soil-ash mixtures at the CSIR.

"Research has revealed that the advantage of using coal fly ash in road construction lies in its ability to both tackle environmental challenges and contribute to the economy of South Africa," says Mvelase.

The CSIR's research on the utilisation of waste coal fly ash focuses on its possible use in constructing unbound pavement layers.

"By harnessing this waste material and converting it into a valuable resource, we would contribute to sustainable infrastructure development and reduce the environmental impact. In line with the principles of a circular economy, we would be keeping products and materials in use, thereby minimising our reliance on road-making materials that have to be removed from the natural environment," says Mvelase.

The study involves comprehensive laboratory testing and characterisation of the physical and chemical properties of unclassified coal fly ash. The CSIR Advanced Materials Testing Laboratory conducts the testing. This facility also tests other types of pavement materials.

"We evaluate the material strength properties. We look for compatibility or equivalence to conventional granular material used in roadmaking," says Mvelase. So far, the researchers found that some 20% of the coal fly ash can be incorporated into some of the road layers. Coal fly ash therefore still needs to be blended with conventional soil/gravel material.

The laboratory testing and characterisation results will be optimised through construction in a real-life environment. "We plan to construct a short 100 m road using coal fly ash in one of the layers and do a performance-based testing using the CSIR-developed heavy vehicle simulator. This phase of the study will give us an indication of how the road that contains fly ash performs when carrying low-volume road traffic," Mvelase says.

Work on the laboratory testing and characterisation phase continues while preparations for the test road are being finalised.

ENQUIRIES:

>> **Gculisile Mvelase**
gmvelase@csir.co.za

> "OUR ROADS RECEIVE ABUNDANT SUNLIGHT AND BY INTEGRATING ENERGY HARVESTING TECHNIQUES INTO ROAD SURFACES, WE CAN CONVERT THE CAPTURED SUNLIGHT INTO USEFUL ENERGY."
> *– Refiloe Mokoena, CSIR*

ENERGY HARVESTING FROM **ROAD PAVEMENT**

Human energy consumption is ever-increasing and does not match the rate at which society has been able to renew its conventional energy sources. This energy crunch has motivated researchers around the world to look at unconventional energy solutions that will help reduce the dependence on finite resources. The use of asphalt road surfaces to generate renewable energy is an energy-harvesting solution that could contribute to a circular economy in South Africa.

Climate change is causing rising temperatures globally and South Africa is no exception. With hotter temperatures projected, roads are directly impacted, heating up and leading to premature temperature-related road failures. At the same time, South Africa continues to find itself in an energy crisis. But do our roads have the potential to offer an energy solution?

Energy harvesting is the process by which energy is captured by exploiting an external source such as solar power, thermal energy, wind energy or kinetic energy. In road engineering, the energy sources that can potentially be turned into useful energy include solar and kinetic energy. While energy harvesting is still regarded as being in its infancy, researchers believe that the potential for reduced carbon emissions and reliance on conventional energy sources is worth investigating.

The CSIR has investigated many potential climate adaptive solutions that exploit changing climate conditions that result from global warming. Initially, the research focused on developing and validating pavement temperature algorithms on different types of road surfaces and pavement structures on the CSIR campus. CSIR senior researcher Refiloe Mokoena says that the team developed a 3D model to optimise how an asphalt solar collector system would work. This formed the basis for an initial road structure that can harness solar energy under local conditions.

"Our roads receive abundant sunlight and by integrating energy harvesting techniques into road surfaces, we can convert the captured sunlight into useful energy. There is also an option to explore geothermal energy from the ground beneath the roads. As temperatures rise, the ground becomes a relatively stable temperature source that can be used for cooling and heating," says Mokoena.

The researchers have also explored the concept of sourcing energy that is readily available. Mechanical energy from the movement of vehicles and pedestrians can be exploited using innovative technologies, like piezoelectric materials, which convert road infrastructure vibrations into electrical energy.

"Succeeding in harvesting energy in one of these ways would mean that we can use it within our urban environments or in energy-intensive industrial processes and use clean energy, thereby creating a positive contribution that benefits both the environment and energy security. Specifically for South Africa, energy harvesting from road pavement would diversify our energy mix and reduce reliance on traditional energy sources. It has the potential to generate employment opportunities through technology development, installation and maintenance," says Mokoena.

ENQUIRIES:

>> Refiloe Mokoena
rmokoena@csir.co.za

Asphalt solar collector prototype at the CSIR Pretoria Innovation site.

Cape Town, Western Cape.

HUMAN SETTLEMENTS AND CIRCULARITY

By Dr Jeremy Gibberd, CSIR chief researcher

Human settlements are the built environments where people live and work. They play a central role in the economy of the country and in how we relate to each other and the environment. The way settlements are currently planned, constructed, designed and operated is unsustainable and creates multiple negative impacts. Poorly planned cities and urban sprawl result in inefficient high-carbon and resource-intensive public transport, water, energy and waste systems. Very large volumes of materials are mined for building products and construction contributes 30-40% of waste globally. Inadequately designed buildings are not only unhealthy and unproductive to live and work in; they also require high levels of maintenance, energy and water to operate.

Circular economy concepts can be used to address sustainability shortcomings of conventional human settlements by moving away from linear systems to circular regenerative approaches. Through design that decouples growth from resource consumption and by using principles such as sharing, sufficiency, durability, renewability, reuse, repair, replacement, upgrades, refurbishment, and reduced material use, circular approaches:

- Design out waste
- Keep materials in use, and
- Regenerate natural systems.

> - CITIES OCCUPY **3%** OF THE EARTH'S LAND SURFACE, BUT THEY ARE RESPONSIBLE FOR **60-80%** OF ENERGY CONSUMPTION AND MORE THAN 75% OF THE WORLD'S NATURAL RESOURCE CONSUMPTION.
> - CITIES CONTRIBUTE UP TO **75%** OF GLOBAL CARBON EMISSIONS, WITH TRANSPORT AND BUILDINGS AMONG THE BIGGEST CONTRIBUTORS.

Some examples of circular economy applications in human settlements are provided below.

DESIGN OUT WASTE AND POLLUTION

Using a modular design approach based on product sizes avoids the need to cut materials and reduces construction waste. Energy-as-a-service models can be used to provide affordable access to highly efficient renewable energy systems and reduce reliance on unreliable high-carbon grid electricity. Onsite greywater systems recycle water for flushing toilets and for irrigation and reduces wastewater directed to municipal systems. Composting systems avoid organic waste being directed to landfills and provide fertility for gardens and urban agriculture. Local production of food nearer where it will be consumed reduces waste, pollution and energy associated with transport, processing and refrigeration.

KEEP MATERIALS IN USE

Designing more flexible and adaptable buildings accommodates a wider range of functions and enables change to happen. This avoids the need for demolition and new buildings and the resource consumption and waste associated with this. Building assemblies that can be easily accessed, modified and disassembled support maintenance without the waste and disruption associated with conventional repairs and retrofits. Careful cataloguing of buildings enables disassembly and the retention of valuable components such as windows, doors and structural timber and steel so that these can be reused in other buildings. This avoids resource consumption and demolition waste streams and creates deconstruction enterprises and jobs.

REGENERATE NATURAL SYSTEMS

Biobased materials are materials like timber, bamboo, hemp, straw, mycelium and bioplastics that are renewable, sequestrate carbon and can be used to promote sustainable farming practices and biodiversity. This avoids the large-scale impacts of mining, transport, pollution and carbon emissions associated with non-renewable materials like cement and steel. Ecological sanitation systems work with natural systems to provide water and organic fertiliser for plants. Integrating planting, permeable surfaces and sustainable urban drainage systems in buildings, such as roof gardens, swales and retention ponds replenishes groundwater, reduces flooding, supports biodiversity, and provides more comfortable local microclimates.

CSIR researcher Batsi Matome, CSIR senior researcher Mandla Dlamini and CSIR senior researcher Nozonke Dumani showing the stock bricks and a concrete roofing tile manufactured using a CSIR cement blend as well as a sample of the CSIR 'green' cement blend and different aggregates.

AN INNOVATION TO PRODUCE AN **AFFORDABLE, LOW-CARBON CEMENT ALTERNATIVE**

The smart selection of green concrete materials in building projects can promote sustainable construction practices and help achieve a more circular economy. In one example of such an undertaking, the CSIR has developed technology to affordably produce green cement.

Globally, the cement industry faces mounting pressure to address the issue of carbon dioxide (CO_2) emission. Cement production is a significant emitter, releasing as much as 1 000 kg of CO_2 for every tonne of cement manufactured, thus accounting for approximately 5–7% of the world's anthropogenic CO_2 emissions.

One approach to mitigate these emissions involves the increased use of supplementary cementitious materials such as fly ash, slag and silica fume, to partially substitute Ordinary Portland Cement clinker. However, the geographical limitations of these alternative materials means that there is a critical need to identify additional cementitious materials that are abundantly accessible, capable of meeting demand, and competitively priced.

The CSIR has developed a cost-effective process for beneficiating South Africa's extensive reserves of kaolinitic clays to produce metakaolin 2 (calcined clay) through the use of vertical shaft kiln technology. The CSIR has protected its intellectual property on the optimised processes, production equipment, mix formulations, as well as specialised applications and products. Kaolinitic clay deposits, used in metakaolin production, are abundant and ubiquitously available across at least six of the country's provinces, including the Eastern Cape, Gauteng, Limpopo, North West, KwaZulu-Natal, Mpumalanga and the Western Cape. This widespread availability of kaolinitic clays renders metakaolin an accessible and viable choice for cement production.

Metakaolin-based cement blends offer several advantages, including significantly reduced carbon footprints, cost-effectiveness, enhanced durability, greater strength and improved reliability of strength, often featuring faster setting times compared to most available cement products. Remarkably, metakaolin-based cement blends can be produced at a mere 45–50% of the cost of ordinary cement with a similar strength rating. Metakaolin can replace up to 70% of ordinary cement, resulting in the elimination of up to 40% of CO_2 emissions while maintaining cement quality. Furthermore, the application process for metakaolin-based cement blends mirrors that of ordinary cement, ensuring a seamless transition to this more sustainable and cost-efficient option.

Despite its potential as a cement extender or supplementary cementitious material, metakaolin has struggled to gain market traction due to its high market price. Conventionally, metakaolin is manufactured on an industrial scale using processes such as rotary kilns, flash calciners and multiple hearth furnaces.

Three different cement blends are used for plastering, binding mortar and stock bricks.

These methods entail substantial capacity demands and capital investments, and intricate operational procedures. The core of cost-effective metakaolin production for green, affordable metakaolin/cement blends revolves around the innovative design and operation of the vertical shaft kiln.

The employment of vertical shaft kiln technology for calcination consumes significantly less fuel compared to ordinary cement production methods. This not only reduces production costs but also plays a pivotal role in reducing environmental impact. Consequently, metakaolin-based cement blends, which are not only greener but also more economical and high-performing than ordinary cement, can be introduced to the market at competitive prices.

The mini cement business model being implemented means reduced capital expenditure and simplified plant operations. The model creates opportunities for emerging broad-based black economic empowerment entrepreneurs to venture into the cement industry by establishing mini plants. By setting up the mini plants in proximity to abundant sources of kaolinitic clays and target markets, transportation costs are minimised.

CSIR principal researcher Dr Joe Mapiravana says, "We are optimistic that our green cement will gain traction, locally and regionally in the next five years, exerting a significant impact on Africa's construction industry while championing sustainability."

ENQUIRIES:

>> **Dr Joe Mapiravana**
jmapiravana@csir.co.za

Onsite demonstration of a prototype block machine with specialised moulds.

Up to 70% of the traditional raw materials in the block can be replaced by recyclable materials such as collected glass and construction and demolition waste.

BUILDING CIRCULARITY INTO CONSTRUCTION MATERIAL: **A CIRCULAR, GREEN BLOCK**

A new type of interlocking brick that supports all the principles of a circular economy, which was first introduced in the market in KwaZulu-Natal, holds promise for rapid, sustainable construction in South Africa.

Circular economy innovation is an emerging area for South Africa. The CSIR partnered with USE-IT, a KwaZulu-Natal-based waste beneficiation and small, medium and micro enterprise (SMME) incubator, and Key Bricks, a brick machine design and fabricator SMME, to showcase their innovative green, circular block. The partners were successful in securing grant funding through the Department of Science and Innovation's (DSI) Circular Economy Demonstration Fund aimed at demonstrating, de-risking and scaling circular innovations. The block aligns with all principles of the circular economy.

DESIGNING OUT WASTE AND POLLUTION

Two important aspects of the block's design allow for waste and pollution to be designed out. Firstly, the blocks are designed to interlock mechanically – there is only one way it can be placed or fitted – with minimal use of cement required to bond the bricks between courses.

"The blocks can be easily assembled with some basic technical expertise, almost like laying LEGO® blocks," says CSIR senior researcher Aubrey Muswema. "Because no mortar is required, the structure can be deconstructed by taking the bricks apart in the same fashion. This results in intact bricks with minimal breakage, which can be used for the next building project."

Secondly, the blocks are designed to allow internal services for electricity conduits, water piping or networking points. "The internal channel reduces the need to chase the bricks to insert these internal services. This reduces broken blocks. Conventional blocks need to be cut, creating waste. Steel rebar with cement could be used in these channels for additional strength, but this is not a requirement," he says.

KEEPING MATERIALS IN USE

Between 30% (and up to 70%) of the block can be substituted with recovered glass or construction and demolition waste. Damaged blocks can be crushed and made into new blocks. The design of the block allows for easy dismantling where mortar is not used. This allows for whole and intact blocks to be re-used on other projects, while aggregate or broken blocks can be pulverised to make feedstock material for new blocks.

REGENERATING NATURAL SYSTEMS

The bricks enable savings in virgin materials and natural resources, including water, river sand and stone. Illegal sand mining along riverbeds contributes to increased siltation and impacts on river systems. This can be avoided with recovered materials. The blocks make use of recovered construction and demolition waste and glass (from bottles) prevalent in terrestrial and riverine natural systems in South Africa.

The CSIR is collaborating with Use-it and Key Bricks on a circular economy green block demonstration project, based in Hammarsdale in KwaZulu-Natal. The river sand used in building materials can be replaced by recovered crushed glass and construction and demolition waste.

Glass collected by community members is crushed in a hammer mill. The aggregate is channelled through a rotating screen trommel to separate the different grades of recovered glass.

"Illegally dumped waste is a problem for municipalities. It makes sense to beneficiate the glass locally into a block. Collection of construction and demolition waste and glass can also contribute to additional income for waste pickers, who remove the waste from the natural environment," says Muswema.

The green block design is set to be demonstrated to the public and potential stakeholders. The partners will also be looking to certify the block through Agrément, the regulator of non-standardised construction products and systems in South Africa.

Muswema says the project partners are indebted to the DSI for funding the project, as it is an opportunity to demonstrate a project that highlights the potential of a circular economy for South Africa and helps to address major socioeconomic and housing challenges faced by communities.

ENQUIRIES:

>> Aubrey Muswema
amuswema@csir.co.za

The nonCrete team preparing a variety of nonCrete cube samples for testing using the biomass of alien invasive plants and low-cement binders. The team members, from left, are Sandiswa Dambatya, Grabeth Nduna, Andrei Sakhamba, Jackson Ojesi, Philani Kuze and Peter Mafuwe.

PLANS FOR GREEN HOUSING, FLOWING **WATER AND JOBS FOR RE-SETTLED ELANDSKLOOFERS**

Next winter, Elandskloof toddlers could be settling into a brand-new crèche, roofed and floored in a zero-carbon cement made from invasive plants cleared by their elders.

The construction of a new crèche and clean-up of nearby rivers and streams in Elandskloof is a planned circular economy demonstration project that will be overseen by the CSIR. When it is completed in June 2025, the community hopes to start building at least an additional 100 new houses in this picturesque Cederberg town in the Western Cape.

They also plan to establish businesses that will provide the building sector with bio-based bricks, window frames and other sustainable building materials and technologies.

"Basically, you clear invasive plants that are threatening our water catchment systems, and you take them through a machine that creates wooden chips by cutting it into little pellets or pieces," says Thabang Molefi, a CSIR senior technologist. "That becomes a substitute for typical sand or stone aggregate that would have been used in conventional concrete."

This method was previously developed by Cape Town-based design and research company nonCrete, which the CSIR has partnered with for the technical heavy lifting on the project.

Molefi explains that the wood chips of alien invasive plants are mixed with a low-cement binder to make the nonCrete building alternative. "The resulting product optimises the use of steel and cement in conventional construction," he says, adding that typical cement and steel materials used in construction have a very high carbon manufacturing footprint.

A research and development facility in Cape Town is currently producing custom-made material mix designs for a variety of building systems, which focus on the creation of low-tech, labour-intensive building methods aimed at providing safe and dignified housing for those most in need of it, says nonCrete's Stephen Lamb.

Infrastructure like the planned crèche will serve to localise the technology, explains Molefi. It will demonstrate that the nonCrete alternative can be used locally for sustainable manufacturing and building while supporting community development and the restoration of water resources for nearby and downstream users.

This is key in a place like Elandskloof, which represents the first successful land restitution case in South Africa's post-apartheid history. "This community lost their land previously," says Molefi. "Now that the land has been restituted, the majority of people are living in inadequate conditions."

Molefi says the crèche will show the value of this bio-based material in a community like Elandskloof. "The market for this type of thing would even include government agencies that are responsible for the delivery of housing," he says.

The other important outcome of the project, to ensure buy-in from contractors and the building sector in general, is getting the floor and roofing system certified by Agrément South Africa.

"They will check things like thermal performance, fire resistance and all the things needed to make it safe. But they go further to check the sustainability of the materials, so the Agrément certification is very important for a circular economy project like this," says Molefi.

Once the crèche is built with supervision and training support from the CSIR and nonCrete, the plan is to issue the intellectual property (IP) of the building system and the Agrément certificate to the Elandskloof community.

"After June 2025, the IP is going to be devolved to the community, perhaps through licensing or making it open source," says Molefi. Contractors and other members of the community will also be trained.

"So this is not a once-off engagement of a community in a hall," he says. "There is nothing that will stop local contractors as entrepreneurs from building even more homes elsewhere."

Molefi says this project clearly shows cross-pollination between environmental issues, human settlements and scientific innovation.

"We are facing challenges brought about by climate change and it has serious impacts on all sectors of the economy and society," he says. "Regenerative, circular economy projects such as this one, that can be implemented in human settlements, can go a long way to mitigate the climate change crisis."

ENQUIRIES:

>> Thabang Molefi
tmolefi@csir.co.za

Peter Mafuwe of nonCrete preparing a sample of the building material that contains biomasss from invasive plants.

DECOUPLING DEVELOPMENT FROM WATER **DEMAND THROUGH A CIRCULAR ECONOMY**

South Africa's economy is dependent on water – a resource under threat and one that cannot be guaranteed even with current initiatives to reduce demand and increase supply. New approaches are required to reconcile future national water withdrawals with supply. A circular economy approach can help to counter water depletion and ecosystem pressures.

South Africa is using an estimated 98% of its available water supply. Growth projections and current water use efficiency levels suggest that the demand for water will outstrip supply by 17% by 2030.

"If left unchecked, this will constrain South Africa's future growth," says CSIR water specialist, Ashwin Seetal.

Seetal, like many experts in the water sector, says that a mainstreamed circular economy paradigm in the water sector can contribute substantially to national water security, social stability and economic prosperity.

Water is linked to all economic sectors and social needs. The largest demand for water is in the agricultural sector (61%), followed by human settlements (27%). However, Seetal points out, "There is a discrepancy between the largest water user sectors and their financial returns on the water use. In the case of agriculture, the 61% water allocation stands in stark contrast with the economic benefits, estimated at 2%. Although water is a critical resource input, decoupling agricultural production from water demand, must be prioritised," he says.

Other priorities include decreasing wastage and increasing water use efficiency in urban and industrial water usage sectors, increasing on-site wastewater treatment and re-use to minimise pollution impacts and strengthening public-private sector partnerships by involving the private sector more extensively in innovative circular economy interventions.

CIRCULAR ECONOMY PRINCIPLES APPLIED TO WATER

When applied to water resources, the circular economy principles of eliminating waste and pollution, closing resource loops and regenerating natural systems provide a framework for South Africa to address water security.

DESIGN OUT WASTE AND POLLUTION

To close the gap between water supply and demand, a strong focus must be placed on water conservation and demand management. Municipalities can reduce leakages, industries can partake in industrial water efficiency programmes and the agricultural sector can optimise its irrigation and production practices.

KEEP PRODUCTS AND MATERIALS IN USE

Transitioning to a circular economy goes beyond waste prevention and minimisation. It involves the sustainable use of water; where maximum value is extracted from water resources while in use. This includes the reuse of water and wastewater. While the use of treated wastewater for irrigation in agriculture has been practiced for many years, the uptake of water reclamation at mines, for example, is not as pervasive. Additional resources can be recovered from wastewater, including biogas, biosolids and nutrients.

REGENERATE NATURAL SYSTEMS

The rehabilitation and regeneration of South Africa's natural systems, crucial for water purification and supply, are integral to the country's economy. These systems can be regenerated through improved water flow and quality, achieved by controlling invasive alien plants and rehabilitating and protecting wetlands and riparian systems. Nature-based solutions have the potential to address sustainable livelihoods and enhance the well-being of people and water resources.

Seetal highlights that the circular economy concept is not new to the South African water sector. The country has a track record dating back to the mid-1990s in addressing water supply-demand concerns. Several of these have endured and matured as scalable solutions in other parts of the country. However, it is clear that more needs to be done to achieve the scale required for meaningful impact.

ENQUIRIES:
>> **Ashwin Seetal**
aseetal@csir.co.za

Spekboom, a drought-resistant, indigenous succulent.

LAND AND WATER RESTORATION: **MAKING A CASE FOR BUSINESS BUY-IN**

Water is a critical resource in any economy, but how will we ensure that South Africans have enough good-quality water in a country facing existing water scarcity, growing water demands and climate change? For Dr Shingirirai Mutanga, the answer to this triple threat lies in landscape restoration and a triple alliance between business, government and society.

Mutanga says it is time South Africa buys into nature-based, regenerative solutions that support the principles of a circular economy. This means we should manage water and other resources in a way that is sustainable and benefits both people and ecosystems.

On the ground, a nature-based solution might look like combating invasive alien plants in a dam using an insect that naturally feeds on the plant so that water flow and quality may be improved.

It could involve planting Spekboom on the overgrazed farmlands of Kariega (Eastern Cape) to improve soil moisture and reduce surface run-off.

Or it might mean hiring workers from local communities to clean, rehabilitate and protect polluted wetlands, riverbanks and floodplains.

Mutanga, a CSIR ecosystem and climate researcher, says these are very broad and very expensive tasks that would look different for every natural resource and landscape, so investing in nature-based solutions still seems like a risk to the private sector.

This is why he and other experts are currently identifying specific sites in South Africa that can be rejuvenated through quick and simple interventions as part of the Restoring Landscapes in South Africa (ReLISA) research project.

Their goal is to show immediate and obvious benefits to surrounding communities and, critically, to businesses around South Africa's savannah, thicket and grassland biomes.

"People look for interventions that will provide quick returns, so if we can build a case through this project, we hope we'll be able to show the business case for investing in regenerative solutions in the water sector," says Mutanga.

When removing alien invasive plants from critical water sources, for instance, he explains, there is a business opportunity to repurpose that plant waste as a product needed by another sector of the economy.

"That waste could be a key feedstock for energy and power generation as a biofuel," he says.

In this case, government, business and researchers could immediately work together to map the invasives and quantify the potential to generate energy.

Put another way, a nature-based solution to a water problem exacerbated by climate change can help the country adopt a mix of renewable energy technologies.

"When you bring in the interactable challenges that we have today of climate change and the serious impacts that it has, we have to look at it from a broader perspective. Once we are looking at it from that holistic lens, then we are driving the circular economy imperative," says Mutanga.

Indeed, the circular economy principles of designing out pollution and waste, closing resource loops and regenerating natural systems apply very much to ensuring a clean, steady water supply. This is especially true in a dry country like South Africa, with unpredictable rainfall and an ever-growing population.

As an environmentalist with a background in industrial systems engineering, earth observation and climate science, Mutanga says researchers across all fields of expertise are needed to develop and identify more nature-based solutions.

Over the years, he has used various scientific techniques to understand water resources, including analysing water quality in the lab, mapping water resources using geospatial technologies like satellite imagery and coupling the changing climate with water resource assessments.

"Often there is a missing link between solutions to environmental issues, and some of the pertinent economy-wide grand challenges, yet these are inextricably linked. This has challenged me to delve into the nexus paradigm of water, food and energy (WEF). Our holistic climate change group has developed WEF as one of its anchor programmes, advancing innovative solutions to foster the transition from nexus thinking to nexus doing," he says.

The ReLISA project is a big step in that direction, bringing together diverse skills from the CSIR and other local and international environmental experts from the United Nations Environment Programme, the Endangered Wildlife Trust, the UN Development Programme, the UN Educational, Scientific and Cultural Organization, C4 EcoSolutions (Pty) Ltd., and UNIQUE forestry and land use GmbH.

The project is set to be completed in 2026.

As part of a preparatory phase for a project aimed at restoring landscapes in South Africa, a group comprising experts from across the country visited sites in three biome settings, namely, from the top, grasslands, thickets and savannas. Degradation of biomes influences the sustainability of water sources.

ENQUIRIES:

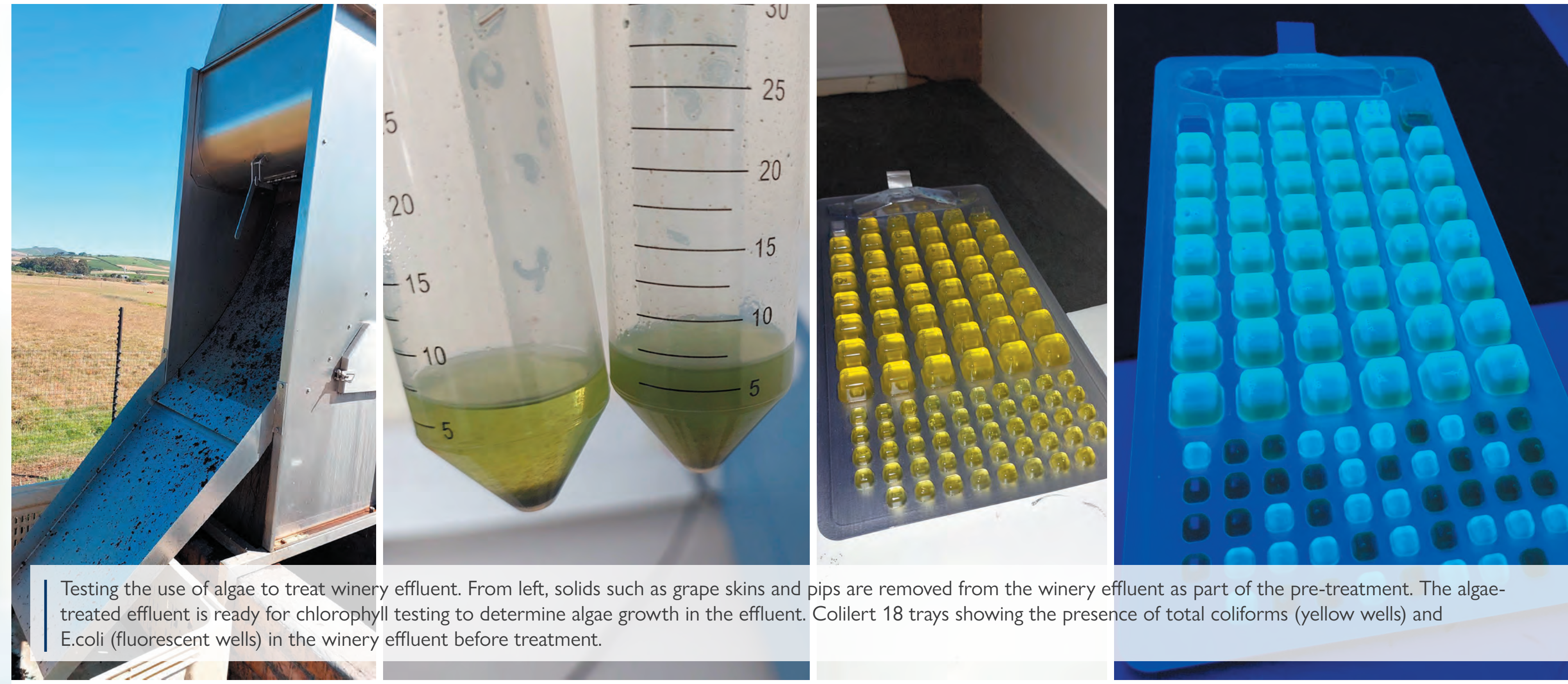
>> Dr Shingirirai Mutanga
smutanga@csir.co.za

CSIR researchers are studying the removal of nutrients from wastewater by means of microalgae.

REMOVING UNWANTED NUTRIENTS FROM **WASTEWATER USING MICROALGAE**

FROM PROVEN TECHNOLOGY FOR DOMESTIC WASTEWATER TO CANDIDATE FOR INDUSTRIAL WASTEWATER TREATMENT

Phycoremediation, the use of green microalgae to bioremediate wastewater, is an almost perfect example of how the circular economy should work. With a strong focus on regenerating natural systems, it encompasses aspects of the circular economy such as enabling reuse, reduction, regeneration and repair.



Testing the use of algae to treat winery effluent. From left, solids such as grape skins and pips are removed from the winery effluent as part of the pre-treatment. The algae-treated effluent is ready for chlorophyll testing to determine algae growth in the effluent. Colilert 18 trays showing the presence of total coliforms (yellow wells) and E.coli (fluorescent wells) in the winery effluent before treatment.

Green microalgae are photosynthetic cells that can grow on wastewater and produce biomass suitable for various applications such as biofertiliser, bioenergy, bioplastics, food and feed. Incorporating microalgae into a circular system offers numerous benefits, including water quality and quantity improvement, wastewater reuse, greenhouse gas emission reduction, soil fertility enhancement, increased crop productivity, renewable energy generation and creating green jobs.

The CSIR's phycoremediation technology has proven successful in several domestic wastewater treatment plants across South Africa. Now the technology is also showing positive preliminary results for industrial wastewater treatment in which the removal of chemical pollutants is key. CSIR senior researcher Maronel Steyn says the CSIR team is currently doing work on using the CSIR technology to test its removal efficiencies in the paper and pulp sector, the petroleum industry and for winery effluent.

The technology uses a consortium of green microalgae, particularly *Chlorella protothecoides* and *Chlorella vulgaris,* known for their high affinity for nitrates and phosphates.

"We designed the technology with the primary objective of minimising implementation costs and energy input at rural wastewater treatment plants across Southern African Development Community countries," says Steyn.

"The ponds are gravity fed; therefore, they do not require any electricity. No expensive chemicals are required. Phycoremediation is increasingly viewed as a solution for closing the nutrient or phosphorous cycle as part of the green economy in that the algae biomass can be used for beneficial products such as biofertilisers or animal feed containing high levels of nutrients," says Steyn.

The technology can be applied to existing waste stabilisation pond systems, only requiring installation of three to five tanks, which serve as bioreactors. Treatment plants that are overburdened or unable to treat residential wastewater due to population increase and urban migration can use the low-cost technology to upgrade their plants and reduce environmental pollution.

Steyn says some of the key achievements of the CSIR phycoremediation technology include the removal of 73.1% nitrogen and 74.4% phosphates contaminants at wastewater treatment facilities in Motetema in Limpopo; Brandwacht and Bitterfontein in the Western Cape and the University of Malawi in Malawi.

She says that for the technology to be lauded for the comprehensiveness of its circular design, further innovation should be directed at improving the algae harvesting process and the product (biofertiliser and biofuel) design.

ENQUIRIES:

>> Maronel Steyn
msteyn@csir.co.za

WATER METERING AND MONITORING GUIDELINE FOR THE AGRI-PROCESSING SECTOR

T *he Metering and Monitoring Guideline for the Agri-processing Sector in South Africa,* published by the National Cleaner Production Centre South Africa (NCPC-SA), assists agricultural processing companies transition to better water and resource efficiency practices and mitigate water supply risks in the sector.

The *Metering and Monitoring Guideline for the Agri-processing Sector in South Africa* was developed in line with the NCPC-SA's Industrial Water Efficiency Project's mandate to promote the transformation of industrial water use practices in South Africa, to reduce water consumption and improve industrial water effluent quality.

The business case is evident: South Africa's population has grown but the resource and capacity requirements to sustain the growth have not kept up. Consequently, water and electricity supply constraints have emerged, impacting costs, availability and the risk of interrupted supply. Similar cost dynamics are also observed in municipal water and wastewater services as supply and treatment infrastructure capacity constraints increase.

In the agri-processing sector, South African companies vary widely in their metering practices. Some rely on monthly utility bills, often estimated by the local councils, while others have sophisticated metering systems with hundreds of metering points measuring at one-second intervals. Generally, South African companies have limited sub-metering systems in place and most rely on intensity targets (such as kWh or litre per kg of production) to determine performance. In contrast, companies with world-class resource management systems invest significantly in metering and measurement systems to drive efficiencies. These companies typically target projects with a payback period of two to three years and utilise the data from the metering systems to motivate for additional budget and approval of capital expenditure.

The guideline includes a few case studies of successful efficiency implementations, as well as a list of references for further information.

It was jointly developed and distributed by the NCPC-SA and the International Finance Corporation in South Africa, with inputs from the Danish Strategic Water Sector Cooperation, represented by the Royal Danish Embassy and the Department of Water and Sanitation. The NCPC-SA is an industry support programme of the CSIR.

The *Metering and Monitoring Guideline for the Agri-Processing sector in South Africa* is available on www.industrialefficiency.co.za

ENQUIRIES:

>> Constance Mokhoantle
mmokhoantle@csir.co.za *or* ncpc@csir.co.za

RESOURCE EFFICIENCY INTERVENTIONS COULD HELP THE DAIRY INDUSTRY SAVE MILLIONS

T he dairy processing industry uses some 12% of the water consumed by the agri-processing sector, excluding pulp and paper. To help improve the industry's resource efficiency, South Africa's National Cleaner Production Centre undertook a dairy benchmarking study to identify practical measures that can be adopted to improve water and energy consumption and management.

Dairy processing is a cleaning-intensive industry, with more than 60% of the water used for cleaning and sanitation purposes. Without effective cleaning methods, pathogens can compromise dairy products and cause serious illnesses. The industry's energy reliance stems from driving steam boilers and operating heat and cooling systems.

The National Cleaner Production Centre South Africa (NCPC-SA), funded by the Department of Trade, Industry and Competition, and hosted by the CSIR, develops guides and tools for manufacturers who wish to improve resource efficiency in production, specifically those of water, energy and waste, and drive greater circularity in manufacturing.

The study results indicated significant potential savings for the dairy sector, including a potential reduction of 69% in potable water consumption, with an associated saving of up to R200 million annually. Additionally, 25-50% of electricity consumption could be reduced with an associated saving of up to R500 million annually. Fuel consumption could also be reduced by 30-50% and greenhouse gas emissions by 50% (assuming a 50% uptake in switching fuels), resulting in a possible saving of up to R180 million annually.

Interventions that can bring about savings are often simple, such as repairing compressed air leaks; using restriction orifices and shut-off valves on hoses, which reduce water use while increasing cleaning efficacy; keeping bottling areas dry by piping bottle rinse to drains to minimise microbiological growth; and collecting rainwater from rooftops.

The complete set of recommendations and findings is available from *Resource Efficiency for the Cheese and Yoghurt Dairy Sector in South Africa* at https://www.industrialefficiency.co.za/industrial-water-efficiency-project/.

ENQUIRIES:

>> Constance Mokhoantle
mmokhoantle@csir.co.za or ncpc@csir.co.za

ScienceScope

www.csir.co.za