SCIENCE FOR SOUTH AFRICA

Quest

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From Kenyan villager to international researcher

RENEWABLE ENERGY

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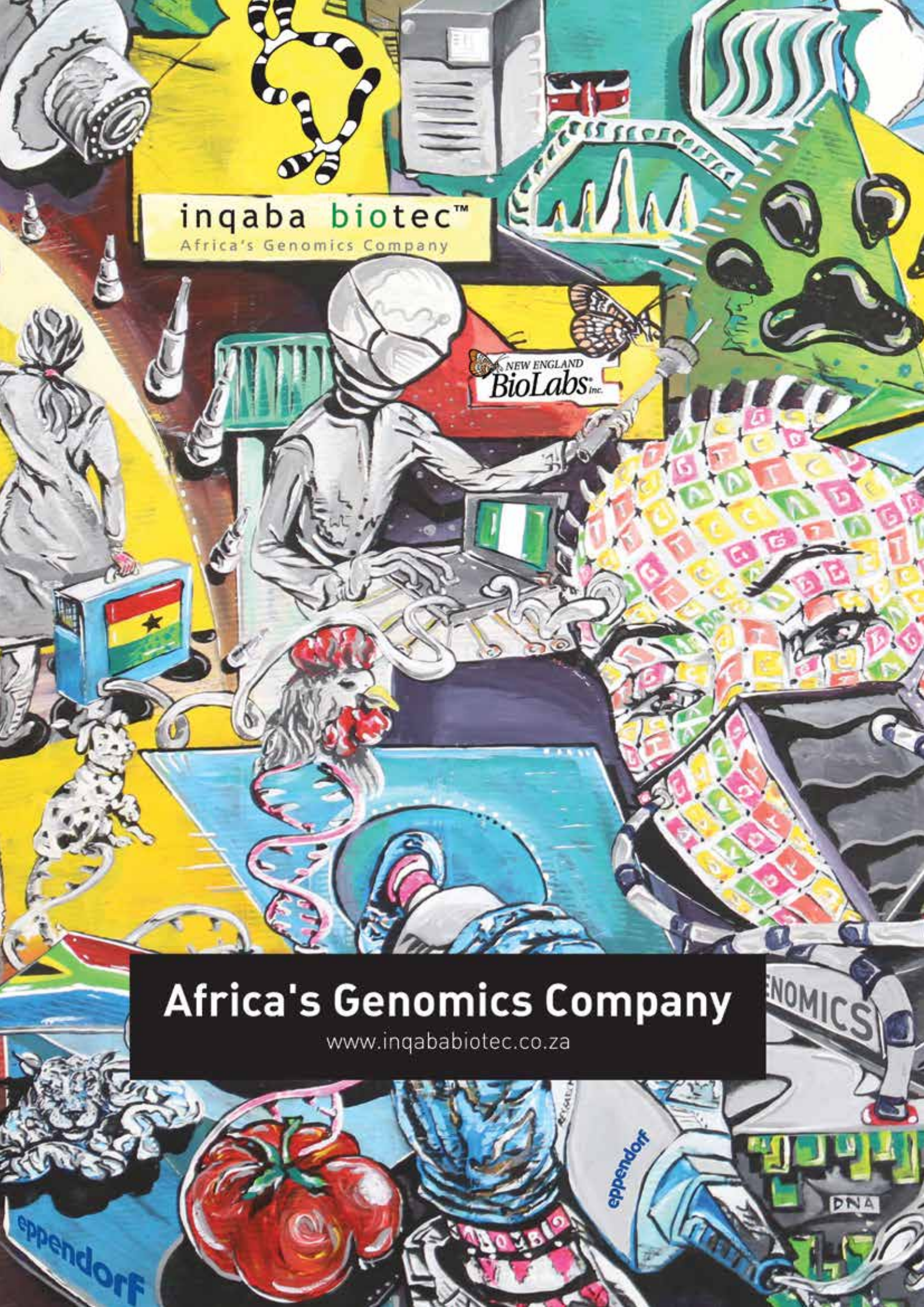
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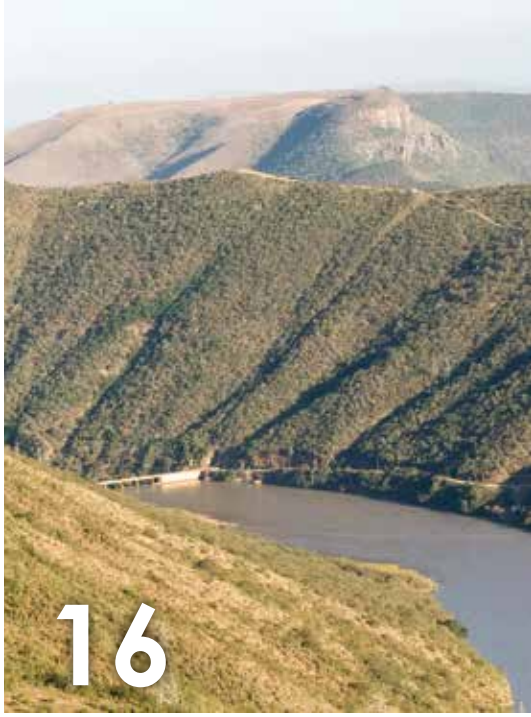

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Subscription enquiries and back ssues
Tsepo Majake | Tel: (012) 349 6645
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Turning coal shovels into turbine blades

At the conclusion of the 26th Conference of the Parties (COP26) to the United Nations Framework Convention on Climate Change (UNFCCC) in November, most participating countries as well as climate change campaigners around the world were disappointed that the final agreement was watered down at the last minute. The key change in the agreement, known as the Glasgow Climate Pact, called for an acceleration of efforts towards the 'phase down' – rather than the 'phase out' – of unabated coal power. This refers to coal-fired power plants that do not implement technologies to reduce carbon dioxide emissions, such as carbon capture and utilisation (see page 26).

South Africa was one of the countries that had objected to the 'phase out' version of the agreement, given that more than 80% of our electricity comes from coal-fired power plants. These polluting power plants are the main contributing factor for the country being the 12th biggest emitter of carbon dioxide in the world, but government is ramping up efforts to increase the contribution of renewable energy to the energy mix. It is doing this not only to meet its obligations in terms of UNFCCC treaties, but also because many of our ageing power stations need to be 'retired' from service.

Indeed, Eskom CEO André De Ruyter – in delivering the 2021 Hendrik van der Bijl Memorial lecture hosted by the University of Pretoria and the South African Academy of Engineering in August – spoke of the intention to decommission 22 GW of coal-fired generation capacity by 2035, which represents about half of the current total installed capacity. He explained that persisting with coal could lead to another era of isolation and punitive trade measures, but pivoting to "cleaner and greener" renewable energy would potentially create a competitive advantage for South African exports. What's more, new solar and wind farms could be implemented in a quarter of the time it would take to commission a coal-fired power station.

Making the transition would be enormously costly in terms of both financial resources and job losses, he said, so Eskom is pursuing a Just Energy Transition Strategy. This aims to ensure that jobs falling away through power station shutdowns would be replaced by those created through local manufacturing of renewable energy components – as he put it, "let's turn our coal shovels into turbine blades". International partners were being approached for financing to enable this strategy and accelerate South Africa's decarbonisation.

A few days after the start of COP26, we heard the outcome of those discussions. The governments of France, Germany, the United Kingdom and the United States, along with the European Union, have joined South Africa in a Just Energy Transition Partnership, committing to provide US$8.5 billion of financing for the first phase over the next three to five years. The Partnership is expected to prevent up to 1.5 gigatonnes of emissions over the next 20 years and support South Africa in moving away from coal.

The theme of this issue of *Quest* – my final one as Editor – focuses on renewable energy, and since the magazine is mostly distributed to schools offering science at Grade 10–12 level, it's hoped that the cross-section of articles might be useful to teachers as a curriculum-related resource.

Sue Matthews
Quest Editor

Inqikithi yalesisiqephu seQuest sikhuluma ngokuphehla ugesi ngamandla elanga Kanye nezinye izindlela ezihlanzekile. Lokhu kunikeza iningizimu Africa ithuba lokwehlisa izincolisi moya kuphinde kuxazulule nenking kagesi ebhekene nayo.

Translated by Zamantimande Kunene

South Africa's **power generation** plans are out of date

Hartmut Winkler says an urgent rethink is needed

South Africa's economy has taken a number of very heavy body blows recently. These include a slowdown due to measures taken to control the spread of COVID-19, on top of increased state dysfunctionality due to corruption. In July, the country experienced the worst riots since it became a democracy in 1994. All have left it struggling financially, while investor confidence has been shaken.

The country's president, Cyril Ramaphosa, and then finance minister, Tito Mboweni, put measures in place to try to soften some of the hardships caused by the pandemic, as well as the arson and violence. But a host of additional adjustments need to be made – to economic plans as well as budgets. One of these is the country's power generation and electricity supply programmes.

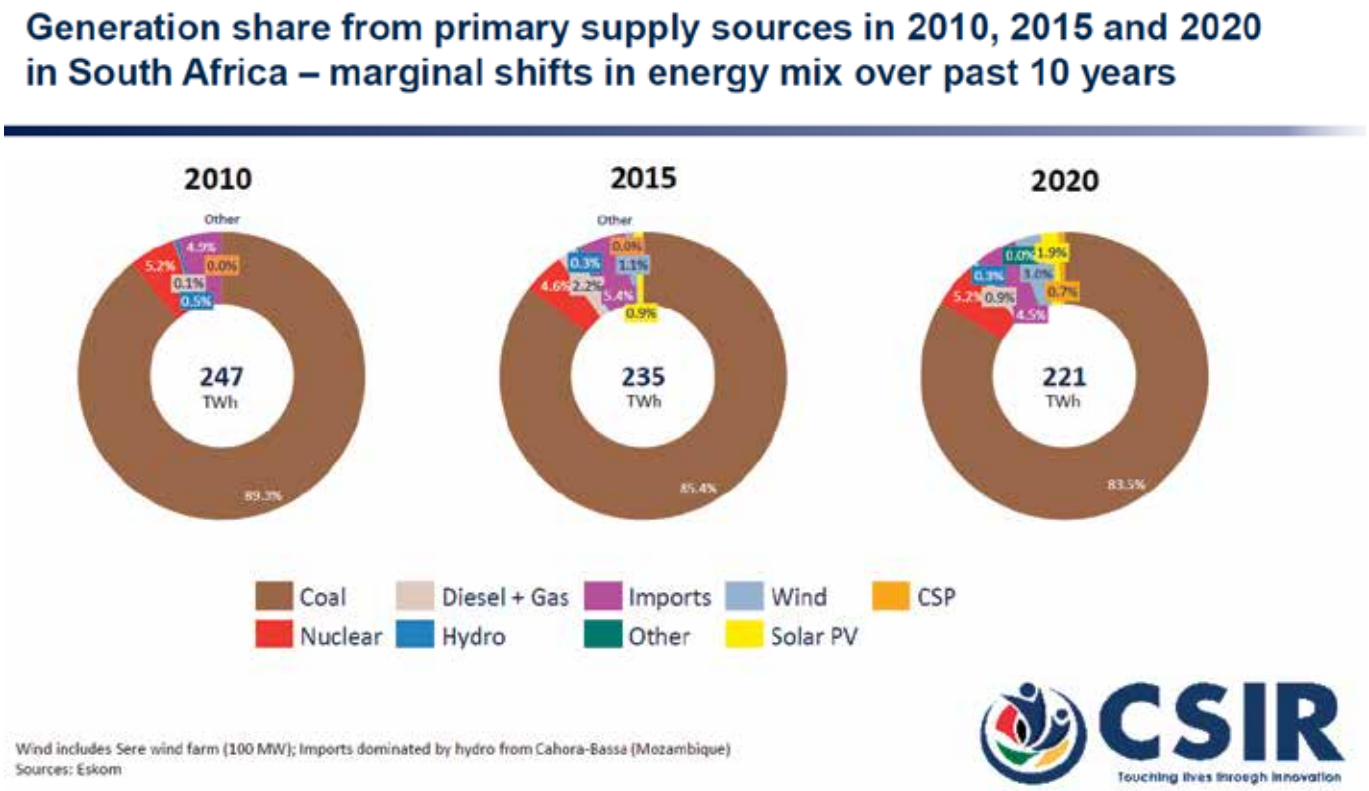
Electricity demand projections are interlinked with economic progress. Changes in the economy therefore have a direct impact on the energy sector. In addition, energy generation technologies are evolving rapidly, affecting available technological choices and associated costs. A reappraisal of the country's long-term electricity requirements – and a review of technologies best suited under the circumstances – has therefore become a priority.

Energy planning

South Africa's energy policy is managed through the Integrated Resource Plan. The document is prepared by a panel of experts and sets out the preferred evolution of the power generation landscape (additions, closures, technologies to be used) based on scenario planning. These plans are supposed to be reformulated every two years. The most recent one was gazetted in 2019.

Since then there have been a number of significant developments in the sector. The first revolves around technology, in particular electricity storage, a major enabler of wind and solar as sources of electricity generation. Renewables currently make up only 10.5% of electricity generation in South Africa. But there's widespread recognition that this needs to be increased. The push factor is that the country needs to reduce its dependency on coal. The pull factor is that it has ample supplies of both wind and sun.

The cost of storage is a massive obstacle. Wind and solar can only function at specific times. The way round this is to store some of the electricity in batteries, to be released at times when the sun or wind aren't available. At the moment



Coal still dominates the South African energy mix, but the contribution from renewable energy sources now totals almost 11%.

Eskom

Koeberg is South Africa's only existing nuclear power plant, but Eskom has applied for a nuclear installation site licence for Thyspunt, between Oyster Bay and St Francis Bay on the south coast.

building batteries large enough to see the grid through dozens of hours without wind or sun is both impractical and too expensive.

But batteries with more capacity are being developed with the use of hydrogen. Better and cheaper storage will make the intermittent renewable electricity generating technologies more viable and increasingly attractive.

The other reason the plan needs to be revised is that it would allow South Africa to settle the lingering confusion about possible future nuclear builds. The 2019 plan did not envisage any new nuclear developments until at least 2030. Despite this, and in the face of opposition from various quarters, the government has been encouraging the nuclear sector to engage in preparatory work leading to a new build.

In my view this option should be left out of any revised plan. The main reasons are South Africa's national fiscal shortages – nuclear is very expensive – as well as the ongoing global decline in nuclear technology. The other reason that the plan needs to be revised urgently is the changing patterns of demand.

Electricity demand will grow less than projected

A number of assumptions that were used to develop the integrated resource plan two years ago are no longer accurate. One has been a drop in electricity demand from the power utility Eskom. This has been driven by slower economic activity as was evident during the COVID-19 lockdowns. In addition, demand has been dampened by steep rises in electricity rates. Power cuts have also been a contributor to the drop in demand.

This trend is likely to continue as the move to solar generation accelerates. Mines have been keen to set up their own on-site solar plants and there has been significant growth in solar installations on domestic rooftops and in shopping malls and factories. This will be given further wings by the fact that the government is changing the regulatory environment to make it easier for independent developers to set up power plants up to 100 megawatts (MW).

While a quicker than imagined economic recovery is always possible, this would be accommodated in future electricity plan revisions. But even here caution is required. Economic growth only leads to slightly higher electricity demand – an increase that's always been overestimated in the past.

Plugging the gaps in the interim

The national power utility, Eskom, has been unable to provide a steady power supply due to ageing infrastructure and an abnormally high number of breakdowns. This has led to periodic electricity blackouts at times when demand has exceeded supply.

To alleviate power shortages in the interim, the Ministry of Mining and Energy launched an initiative to solicit 2 000 MW of emergency power from private developers. But the plans aren't panning out very well. Most of the capacity awarded under the programme was to a Turkish company that operates a fleet of ships with gas power stations on board. Three ships were to be moored off South Africa's coast, but the floating power stations ran into major difficulties related to environmental authorisation requirements, and there were also court challenges. However, the successful

bidders were all then granted an extension until the end of January to reach financial closure – when all the project and financing agreements have been signed.

The remainder of the interim plan was to be taken up by renewable energy-based projects. But a new requirement in the plan for emergency power was that wind and solar plants must be able to deliver power continually from 5 am until after 9 pm. This means that renewable projects require supplementation when there is no sun or wind, making them expensive.

The most problematic aspect of the emergency power programme is that it will award 20-year contracts to successful bidders. So a short- to medium-term power shortfall is to be settled by long-term contracts that will supply electricity at considerably higher cost than alternative sources. The emergency power programmes were supposed to be operational by 2022. This deadline is clearly not going to be met.

What next

South Africa needs a detailed and thoroughly researched set of scenarios mapped out to inform a new electricity plan. These would weigh up the various options – from renewables through to nuclear, coal or gas plants. They would also factor in the eventual completion of the three remaining, much-delayed units at the Kusile coal plant. These will add 2 400 MW when they come on line in the next few years, corresponding to about 5% of the country's electricity generating capacity.

- **UPDATE**

On 28 October 2021, government announced 25 new renewable energy projects that are envisaged to produce 1 600 MW of wind power and 1 000 MW of solar power. Most of these are to be located close to the main powerlines crossing the Karoo and Free State. They are expected to be up and running in 2024, but will not be able to cover the present electricity shortfall. Many more such developments will be needed in future, and the current national electricity plan envisages similar annual additions up to 2030.

An interesting development is that the electricity produced by these projects will be sold to Eskom at significantly cheaper prices than existing solar and wind farms. This price drop is due to the steady worldwide decline in the cost of building renewable power plants. It implies that there are now strong economic incentives for the long-term replacement of polluting, global climate change-inducing coal-fired power stations with clean energy.

Prof. Hartmut Winkler is a Professor of Physics at the University of Johannesburg, and a vocal commentator on South African energy issues, especially the renewables versus nuclear debate.

This article originally appeared in The Conversation in August 2021 and is republished under Creative Commons licence CC BY-ND 4.0. The bullet was added by Prof. Winkler to update it for Quest. https://theconversation.com/south-africas-power-generation-plans-are-out-of-date-an-urgent-rethink-is-needed-162771

Images sourced and captioned by the editor with Prof. Winkler's approval. The CSIR graphic was extracted from Calitz, J & Wright, JG, 2021. Statistics of utility-scale power generation in South Africa in 2020. Available online at http://hdl.handle.net/10204/11865

Karpowership SA

In March 2021, Karpowership SA was announced as a preferred bidder to provide power to South Africa's national electricity grid under the Risk Mitigation Independent Power Producer Procurement Programme. Karpowership SA is a 49% South African-owned BBBEE company, with the remaining 51% owned by Karadeniz Holding, based in Istanbul, Turkey.

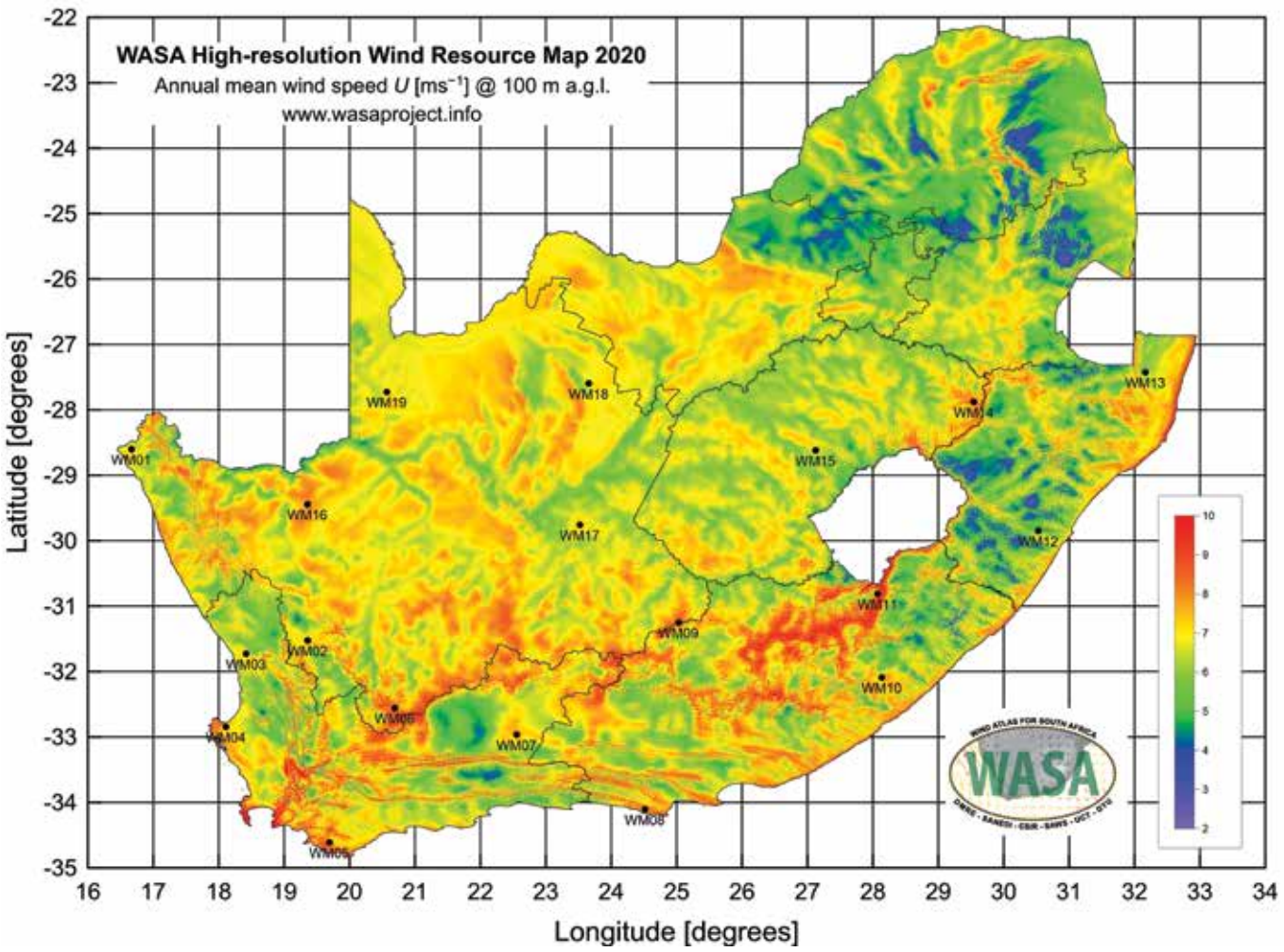
Karadeniz already has 25 powerships in 15 locations in Africa and Asia. A powership is a fully self-contained floating power station, which relies on liquid natural gas (LNG) to generate electricity using gas reciprocating engines and steam turbines. LNG is a natural gas that is cooled to −162°C to convert it to the liquid state, which can then be easily stored and transported because its volume is 600 times smaller than the gaseous state.

Karpowership SA's bid was to berth five powerships in three harbours around the South African coast – two in Richard's Bay, two in Port of Ngqura in Algoa Bay and one in Saldanha Bay. Each of the harbours will also have one floating storage regasification unit (FSRU) moored nearby. The FSRU is where the LNG is warmed in heat exchangers to convert it back into the gaseous state before it is piped to the powership. The FSRUs would be resupplied with imported LNG by tankers, known as LNG carriers, every 20–30 days. Together, the three powerships would be capable of producing 1 220 MW, which would be enough to reduce load-shedding by one level.

Karadenizsosyal

Petter Thorden

The five powerships planned for South Africa will be accompanied by three floating storage regasification units, where liquid natural gas (LNG) is stored before being converted back to the gaseous state and piped to the powership for electricity generation.



WASA 3 winds up

A webinar marked the end of Phase 3 of the Wind Atlas for South Africa (WASA) project

The preferred bidders announced in October by energy minister Gwede Mantashe for Bid Window 5 of the Renewable Energy Independent Power Producer Procurement Programme (REIPPPP) included 12 wind power projects, representing some 1 600 MW of new generation capacity. If agreements are reached and all goes according to plan, these would add to the 34 wind farms procured under the first four bid windows, 27 of which were operational by December 2021 and providing 3 024 MW to the national grid. Another 1 600 MW of wind power will be procured under Bid Window 6 in 2022.

But long before wind farm developers submit such bids, they need to know whether their plans are viable. First and foremost, will the area they are considering have enough wind on a sustained basis to generate electricity at a financially feasible level? And once they get the go-ahead, where exactly should they install the wind turbines on their site for best performance?

Thanks to research and capacity-building efforts undertaken within the Wind Atlas for South Africa (WASA) project over more than a decade, these kinds of questions can be answered with confidence. The WASA project is a government initiative implemented by the South African National Energy Development Institute (SANEDI) with its partners – the Council for Scientific

WASA

Four more wind measurement masts (WM16–19 on map) were installed for WASA 3.

and Industrial Research (CSIR), the South African Weather Service (SAWS), the University of Cape Town (UCT) Climate System Analysis Group (CSAG), and the Technical University of Denmark (DTU) Wind Energy Department.

The project began in 2009 and initially focused on the Western Cape and areas of the Northern Cape and Eastern Cape provinces. This first phase, WASA 1, wrapped up with a Final Seminar for interested stakeholders in April 2014 and was followed by WASA 2, which covered KwaZulu-Natal, Free State and the remaining areas of the Eastern Cape. Based on this research, a High-resolution Wind Resource Map covering all nine provinces was released at the WASA 2 Final Seminar in April 2019. The most recent phase, WASA 3, included the remaining areas of the Northern Cape province and the rest of South Africa. The research component ended in 2020, with the Final Seminar held online in October 2021.

The research involved mesoscale wind modelling to downscale global weather data at a resolution of 200 km x 200 km to regional data at 3 km x 3 km. The final output was 30 years of wind simulations for the period 1990–2019 as a Numerical Wind Atlas, accompanied by time series of wind speed and direction at 20 m, 60 m, 100 m and 120 m above ground level (AGL), as well as temperature at 2 m AGL. This data, which was made freely accessible to all, was used for microscale modelling that took local terrain into account, with the results verified using measurements from wind stations. These are 62 m-high masts equipped with instrumentation measuring wind speed and direction, temperature, relative humidity and barometric pressure at various heights. During WASA 1, 10 such masts were erected in the area of interest, but another five were added in the eastern region for WASA 2 and then four more in the Northern Cape for WASA 3. This allowed the model to be refined for a more accurate High-resolution Wind Resource Map.

During the webinar, WASA project manager Andre Otto explained that wind power is directly proportional to wind speed cubed. Wind farm developers can therefore use wind speed and power density data to estimate their energy production, and hence their potential profit margins. The microscale data can also be used to plan a farm's layout to take account of wind hotspots or

Lekela Power

The Perdekraal East Wind Farm near Ceres in the Western Cape commenced commercial operations in October 2020.

SAWEA

Under the first four bid windows (BW) of the REIPPPP, 34 wind farms were procured (BW1 = red, BW2 = yellow, BW3 = blue, BW4 = green).

E-GIS, DFFE

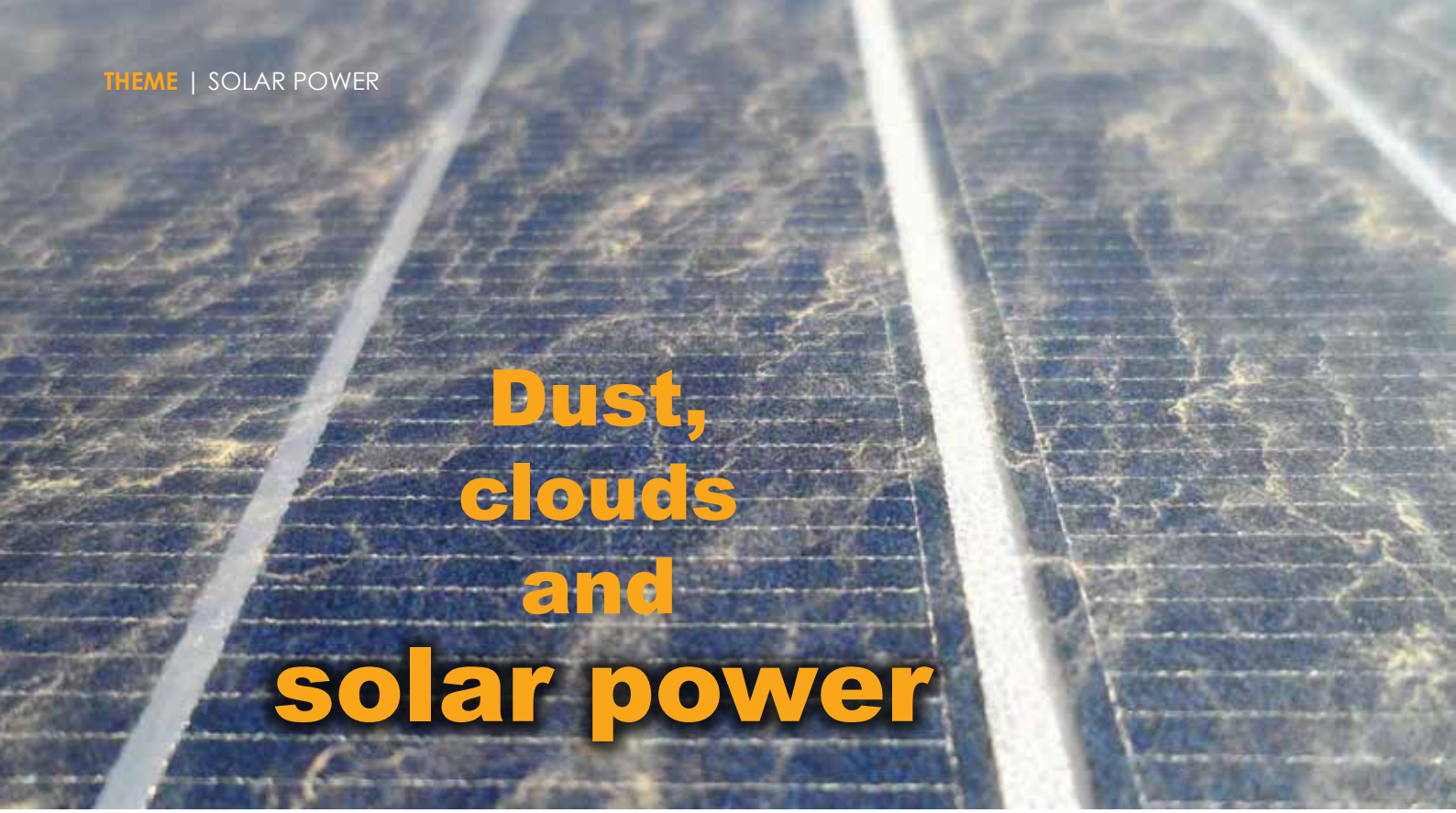
Six Renewable Energy Development Zones (REDZ) have been identified for large-scale wind energy facilities through two Strategic Environmental Assessment processes that made use of the WASA data. The middle one in the Beaufort West area was added in February 2021 to the others announced in February 2018.

turbulence effects. And since developers also need to assess the threat of extreme winds, which might cause costly turbine damage, an extreme wind atlas was developed too. This would allow developers to either avoid areas prone to 1:50 year extreme wind events or choose a stronger class of turbine, rated for such conditions.

Dr Karen Surridge, Manager of SANEDI's Renewable Energy Centre of Research and Development (RECORD), noted in her presentation on WASA's status and future that climate change – with associated changes in storm events and near-surface atmospheric flow – could potentially impact energy generation by wind farms. Accurate forecasting would be required, highlighting the importance of ongoing, long-term meteorological measurements.

- WASA is implemented by SANEDI and financially supported by the Global Environment Facility (GEF) through the South African Wind Energy Project (SAWEP) with UNDP Country Office support and with the Government of Denmark, which co-funded WASA 1 and funded WASA 2.

For more information and access to wind data, see https://www.wasaproject.info/



Dust, clouds and solar power

Armand du Plessis reports on his research on photovoltaic power systems

With the global movement towards renewable energy, solar power has provided a wonderful opportunity for more entrepreneurs to access the energy market. On the flip side, this has set the stage for a very competitive industry, where investors cannot afford financial losses caused by lower power production.

In photovoltaic (PV) power systems, soiling of the PV module surface from dust, pollen, bird droppings and particulate air pollutants reduces the solar cells' exposure to sunlight, translating to lower power output. Dust is particularly concerning for the large-scale solar 'farms' located in dry regions, where irradiance tends to be highest. Some studies have shown annual losses in desert or semi-desert regions of up to 40%, but losses of 1–7% are more typical worldwide.

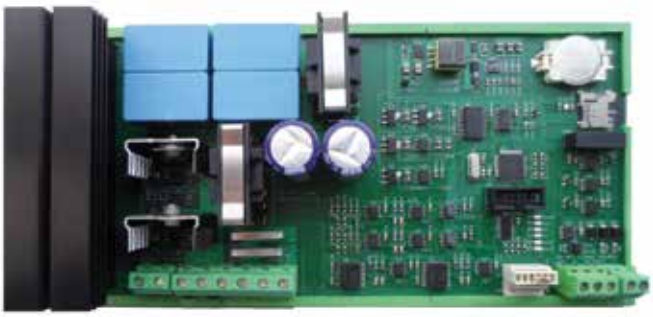
Dirty PV panels do not only deliver less power but can be badly damaged in the long term. Dense patches of dust can create 'hotspots', where there is a concentrated build-up of heat, damaging the solar cells on the PV module.

The local solar power energy sector has naturally wanted to know what the influence of dust on PV power systems in South Africa might be. Some years ago, our research team at Stellenbosch University's Department of Electrical and Electronic Engineering decided to find out, in what would be the country's first formally documented study quantifying the effects of dust on PV power output. The research also aimed to determine whether commercial PV system operators could apply a dust mitigation strategy to reduce the impact of dust on PV modules.

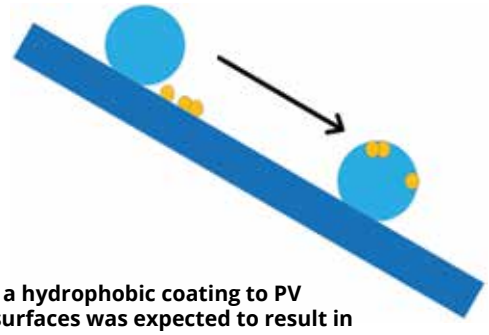
The experiments

Determining the influence of dust on PV power production was not as easy as simply throwing a handful of dust on a PV module and measuring the output. To get reliable results, our research had to reflect a real-world scenario. A fully operational PV research station was therefore

The PV system constructed for the research, with both stationary modules (left) and single-axis-trackers (right).



Circuit boards developed by the research team were deployed at each PV module for data collection.



Applying a hydrophobic coating to PV module surfaces was expected to result in larger water droplets that would displace dust better.

constructed in the De Aar–Hopetown area of the Northern Cape, the province where most utility-scale PV power plants are located. With our own PV research facility, designed to our specifications, we had complete control over the data captured.

High-tech electronics were also developed by our research team, as shown above. One of these circuit boards was dedicated to each PV module, which allowed us to extract a specific set of data points regarding power output. Along with on-site weather data, this PV module data was then uploaded onto a cloud-based server, from which the research station could be monitored remotely.

One set of PV modules was cleaned regularly, to serve as a baseline for comparison to other PV modules that were left indefinitely to accumulate dust. Passive cleaning strategies – those that require little to no human intervention – were investigated as a possible dust mitigation strategy. Passive cleaning is ideal for large commercial PV systems, which can easily be 100 hectares in size (about 100 rugby fields) and consist of 300 000 PV modules or more.

Today, there are multiple approaches to module cleaning. The most general of these solutions is washing PV modules with handheld brushes. This solution, however, becomes very inefficient as PV system size increases. A more practical approach often applied in South Africa is the use of long brushes, attached to a moving vehicle or tractor. However, manual labour costs and safety issues are also a big problem for these types of highly involved cleaning solutions. This is why semi-autonomous robotic cleaning has started to become a plausible solution, in some cases involving water-free, 'dry cleaning'.

Since our research team had a passive and less expensive option in mind, an obvious question to ask was whether rainfall could be used as a natural agent for a cleaning strategy. Although rainfall does occur in

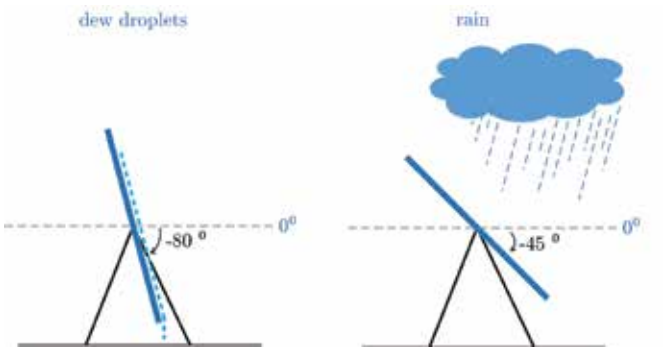
Rainfall at the study site was sometimes so light that it only shifted dust on the PV module surface, creating small wave-like dust lines.

Application of a hydrophobic coating to the surface of PV modules caused large water droplets to accumulate (left), while water spread out uniformly on untreated PV modules (right).

The hydrophobic coating caused small dust patches to form over time.

the Northern Cape throughout the year, it is not always enough to remove dirt from PV modules. Where dust has accumulated over time, small water droplets typically only shift and further concentrate it. In an attempt to improve the ability of rain droplets to remove the more stubborn dust particles, we investigated the application of a hydrophobic anti-soiling coating to the PV module surfaces. The idea was that this thin, colourless coating would allow for the formation of larger water droplets, which would more effectively capture and displace dust. Unfortunately, the coating tended to make water stay on the module surfaces for longer, rather than dispersing.

Next, we used the custom-built single-axis-tracker modules to test two passive cleaning strategies in combination. The hydrophobic coating was once again applied, but a self-cleaning manoeuvre was executed whereby – when it started to rain – the trackers were automatically tilted at a 45° angle facing into the rain. Tracking was then resumed as usual after 20 minutes.



Passive cleaning strategies making use of dew droplets and rainfall were investigated.

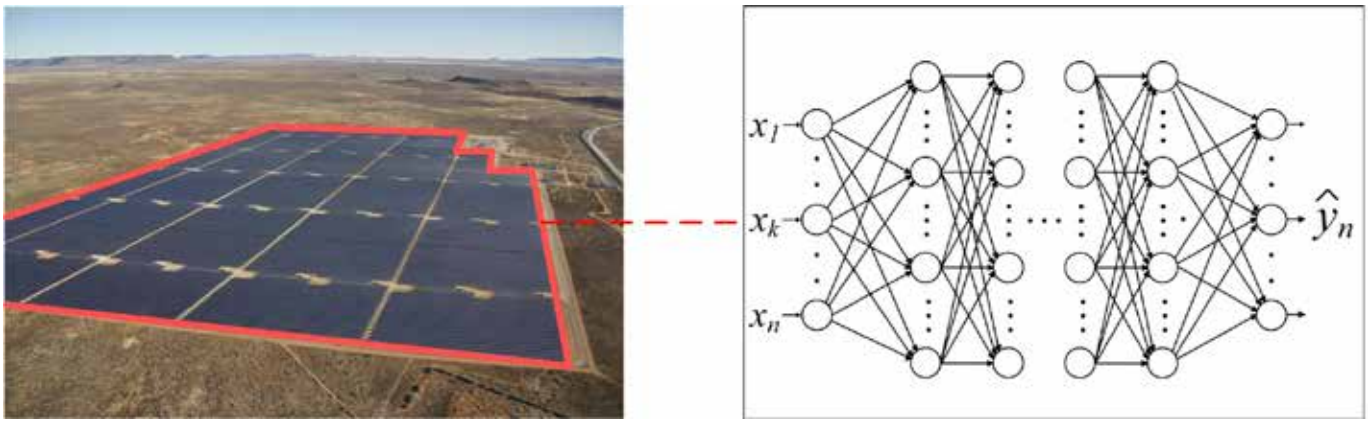
A third cleaning strategy was the application of coordinated movement, where the single-axis-tracker modules were cleaned by making use of early-morning dew. In this self-cleaning strategy, the trackers were instructed to tilt at 80° (almost vertical) a few minutes before sunrise to use any available dew droplets to displace dust.

Our findings

After carefully processing and analysing the raw data, interesting and somewhat counter-intuitive results were obtained. Firstly, the big question concerning the influence of dust soiling on performance was answered with a direct comparison of the cleaned reference modules to the ordinary uncoated PV modules. For the six-month analysis, the results indicated that after a 75-day absence of rainfall, the largest decrease in ideal performance of the stationary PV modules was approximately 2% – much less than the expected 5–10 %. This low percentage was attributed to the uniform dust distribution on the PV modules, primarily due to regular wind flow that helped to remove dust particles and avoid build-up of dust spots.

Ironically, it was found that the hydrophobic coating actually promoted dust soiling on the PV modules. As expected, the hydrophobic coating effectively allowed large water droplets to accumulate on the module surfaces, then roll down, capturing and removing dust. As time passed, however, it was observed that dense dust patches started to appear on all of the coated PV modules.

Importantly, the in-field observations revealed that the wave-like dust lines were not always present on the uncoated modules. Also, these dust lines did not occur on the single-axis-tracker modules, since the steeper incline of the modules allowed water to disperse faster, leaving no water layer to accumulate dust. For the coated single-axis-tracker modules, the formation of small dust patches resulted in a maximum performance reduction of about 5.4%. Regarding the passive cleaning strategies, the self-cleaning manoeuvre did not deliver any conclusive results.



The research team developed a machine-learning model to emulate the behaviour of Scatec Solar's 75 MW Kalkbult PV system.

With the overall effects of dust quantified at a performance reduction of about 2% for the experimental site, PV module operators in the Northern Cape can seemingly relax their concerns of dust soiling a little, but maintaining a set of cleaned reference modules is advisable for ongoing monitoring. Gathering data on the effects of dust on power output at their own sites will allow them to make ad hoc decisions about cleaning, which could make a huge difference in overall PV system efficiency.

Expanded research focus

Our research team then tackled a more pressing issue, which is the unpredictability of solar power. In sharp contrast to stable fossil-fuel driven generators, energy supplied from large PV systems is characteristically intermittent, due to a high dependence on atmospheric and environmental variables such as sunshine, clouds, temperature and dust soiling. This means that as we continue to add more solar PV systems to our electrical grid, the volatility of power supply will increase. This added level of uncertainty can be strenuous on the electrical grid, complicating grid balancing and planning, and hence threatening grid stability.

To address this growing problem of PV system volatility, PV power forecasting serves as a vital tool that allows us to predict the expected power to be delivered within the next few hours and days. Employing artificial intelligence and machine learning, the research team developed forecast models to assist grid and PV system operators, using data provided by our research partner Scatec Solar for its 75 MW PV system.

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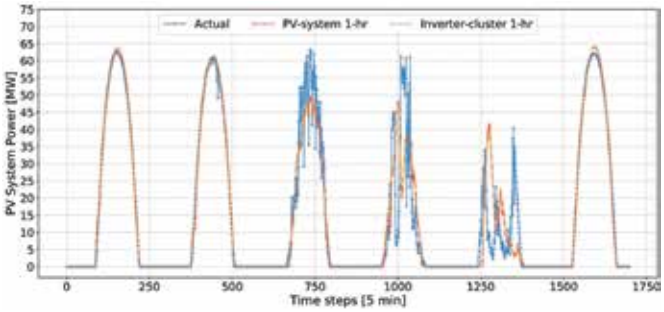
Resources and sustainability: Non-conventional energy sources



In this time-series forecast, the bell-shaped curves represent the energy delivered from the sun for six days. As the sun rises, the power output increases until it peaks at midday. The third, fourth and fifth bell-shaped curves represent cloudy days. The blue line represents the actual power output and the orange and red lines represent the power output predicted by the machine-learning models.

After executing this intensive research project, forecasts one to six hours ahead with an error of 1.27–8.29% were obtained for all weather types. Bluntly stated, this means that power forecasting accuracy is mostly above 90%.

The research also investigated other interesting ideas, like using multiple machine-learning models to predict the power output of smaller PV module segments within the larger 75 MW PV system. Internationally, this was one of the few forecast research projects conducted at such a grand scale. Apart from this research also being the first of its kind in South Africa, it has received international recognition, being published in one of the highest-ranking journals for this research field.

Since South Africa is blessed with so much sunshine, solar power is a resource that we simply must utilise to the best of our ability. We have the best engineers in the world working on solar power, and this research field has a direct impact on our country and its people.

Dr Armand du Plessis was awarded his MEng degree for his thesis on dust soiling, and his PhD for his thesis on PV power output forecasting. The dust soiling research was conducted with Dr Johann Strauss and the PV forecasting research with Dr Johann Strauss, Dr Arnold Rix and Scatec Solar.

RENEWABLE HYDROGEN

Quest explores how solar and wind energy can be used to produce 'green hydrogen'

Opponents of investment in renewable energy often point out that solar and wind energy is not a reliable or consistent power source. Sunshine and wind naturally vary throughout the day, so some kind of energy storage is required, typically in the form of batteries. Back-up power is also needed for longer periods of insufficient sunshine or wind, and currently that comes from coal-fired, nuclear or gas-based power plants.

In future though, both energy storage and back-up power could be provided by 'renewable hydrogen' emanating from wind farms or photovoltaic power plants. At times of excess supply, the electricity from these renewable energy installations could be passed to an electrolyser, where hydrogen is produced through electrolysis – using an electrical current to induce a chemical reaction that splits compounds or elements into smaller parts. In this case, electrolysis would be used to split water into hydrogen and oxygen. The hydrogen could then be stored until it is needed at peak demand periods to generate electricity in a hydrogen fuel cell or hydrogen internal combustion engine. Alternatively, the hydrogen could be used in vehicles running on these technologies.

Adoption of hydrogen technologies is partly dependent on the ability to store and transport hydrogen safely and efficiently, so this has become a key focus area of research worldwide. Hydrogen is the lightest gas in the universe, with an enormous volume under atmospheric pressure, so its density must be increased in order to store and transport it. The three options for storage are (a) as a compressed gas in high-pressure tanks, (b) as a liquid in cryogenic tanks that keep the temperature at around −253°C and (c) as a solid or liquid in another material, through adsorption or chemical reaction.

In South Africa, the HySA Infrastructure Centre of Competence, co-hosted by North-West University (NWU) and the CSIR, conducts research and development on hydrogen production, storage and delivery. The CSIR team has largely focused on developing porous materials-based storage technologies, such as metal-organic frameworks and carbon nanostructures, as well as high-pressure composite cylinders for lightweight applications, for use in portable power systems and fuel cell vehicles.

At NWU, much of the emphasis has been on water electrolysis stack development and on chemical carriers, including ammonia, formic acid and LOHC. The latter stands for Liquid Organic Hydrogen Carrier, and it refers to organic compounds capable of reversible hydrogenation and dehydrogenation – in other words, those that can absorb and release hydrogen through chemical reactions. In an LOHC system, a hydrogen-lean organic compound is loaded with hydrogen in a catalytic reaction for hydrogen storage; when the hydrogen is needed another catalytic reaction converts this hydrogen-rich compound back to the hydrogen-lean one, releasing hydrogen in the process.

Hydrogen production pathways

Grey hydrogen: Currently, over 95% of H_2 produced worldwide comes from fossil fuels, mostly via steam methane reforming (SMR) of natural gas, which releases CO_2 into the atmosphere.

Brown/black hydrogen: Gasification of either lignite (brown) or bituminous (black) coal produces syngas, comprised mostly of H_2 and carbon monoxide (CO), with CO_2 released in the process.

Blue hydrogen: The same processes as for grey/brown/black hydrogen, but the CO_2 is captured and stored, reducing the environmental impact.

Green hydrogen: Hydrogen produced by the electrolysis of water. If the electricity used in the electrolysis is produced from renewable energy sources, there are no CO_2 emissions.

HySA

HySA Infrastructure's solar-to-hydrogen facility on the NWU Potchefstroom campus relies on a 55 kW photovoltaic (PV) installation and an electrolytic hydrogen-generation system.

One of the best LOHCs identified to date is dibenzyltoluene, so the NWU team – led by Prof. Dmitri Bessarabov, who is also the Director of HySA Infrastructure – has investigated the potential of Marlotherm SH, a heat-transfer fluid produced by Sasol. It is a mixture of dibenzyltoluene isomers and is used in various industries for indirect heating of reactors, polymerisation vessels, distillation columns, as well as in heat exchangers and heat-recovery systems. The advantage of dibenzyltoluene as an LOHC is that it is stable when stored for long periods under ambient temperature and pressure conditions. It can also be distributed via existing pipelines, tankers and petrol stations used for liquid fuels, but unlike petrol and diesel it has low toxicity and is non-flammable and non-explosive.

After conducting tests on lab-scale hydrogenation and dehydrogenation systems, the HySA NWU team successfully commissioned a pre-commercial scale hydrogenation plant using this LOHC technology in collaboration with Framatome GmbH. The plant is linked to the HySA NWU solar-to-hydrogen facility, which comprises a 55 kW photovoltaic installation and an electrolytic hydrogen-generation system, with facilities to test various fuel cells provided by manufacturers or to conduct research projects by students.

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The Cofimvaba Science Centre in the Eastern Cape, officially opened on 6 October 2021, has an electrolytic hydrogen-generation system coupled to a 35 kW solar PV system and a 5 kw hydrogen fuel cell installed by HySA Infrastructure.

HySA

The HySA NWU team conducted extensive tests using this laboratory-scale hydrogenation system to assess the performance of dibenzyltoluene as a Liquid Organic Hydrogen Carrier (LOHC).

Apart from this 'power-to hydrogen' system, research is also carried out on 'power-to-methane' technology, which combines the hydrogen with carbon dioxide (CO_2) in a catalytic Sabatier reaction to form methane (CH_4). This gas is in high demand for its uses in industry and as a fuel for heating, lighting and (when burned in gas- or steam-turbines) electricity generation. Interest in methane-fuelled vehicles is also growing – according to a *Forbes* webpost from 8 November 2020, there are already 23 million such vehicles worldwide, although these 'fill up' with methane from underground natural gas sources, landfills or food waste processing facilities.

The HySA NWU team is currently participating in the EU-funded SherLOHCk project, which aims to reduce the system cost for LOHC technology to 3€/kg for large-scale applications. Their specific input will be contributing towards the fundamental understanding of catalyst activities for dehydrogenation reactions.

For more information about the HySA NWU facilities, visit https://hysainfrastructure.com/our-facilities/nwu-facilities/ There is a link to a 360-degree virtual tour. Click on the navigation bar on the left for specific facilities, or click on the round mirror on the opening screen to tour the building from the entrance.

HYDROPOWER

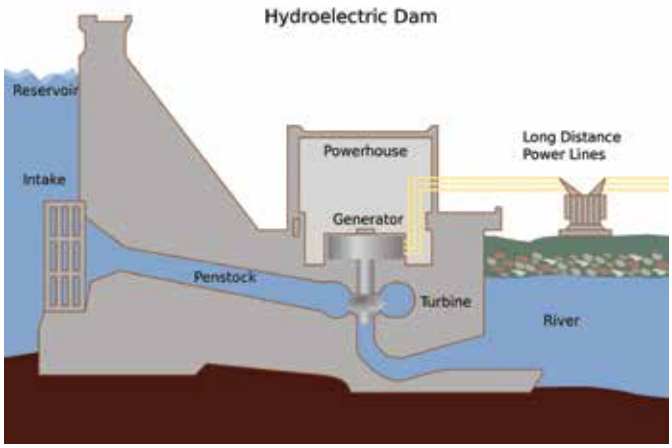
It's thanks to hydropower that Cape Town suburbs are often spared the inconvenience of load-shedding – for example, if Eskom has announced Stage 2 load-shedding, municipality-supplied electricity consumers may only be subject to Stage 1. This is because Cape Town's municipality owns its own hydroelectric facility, the 180 MW Steenbras Hydro Pump Station. As its name suggests, it's a pumped storage scheme, the very first in Africa when commissioned in 1979.

City of Cape Town

The Steenbras Dam forms part of the City of Cape Town's water supply system, but is also used for electricity generation when water is channelled down to the small reservoir on the outskirts of Gordon's Bay.

In pumped storage schemes, the hydroelectric power plant is situated on a waterway linking an upper and lower reservoir. Electricity is generated when water flows from the upper to the lower reservoir, in this case from the Steenbras Dam – partly visible from the N2 at the top of Sir Lowry's Pass – through a series of tunnels down the mountain to a small reservoir 300 m below. Just before reaching the lower reservoir, which is situated on the outskirts of Gordon's Bay, the water flows through four 45 MW reversible pump-turbines for electricity generation. During off-peak periods, when demand for electricity is low, water is pumped back up to the Steenbras Dam.

Eskom has three of its own pumped storage schemes: the smallest is the 400 MW Palmiet scheme that lies adjacent to the Steenbras scheme, the oldest is the 1 000 MW Drakensberg scheme, and the newest and largest is the 1 332 MW Ingula scheme, also in the Drakensberg.



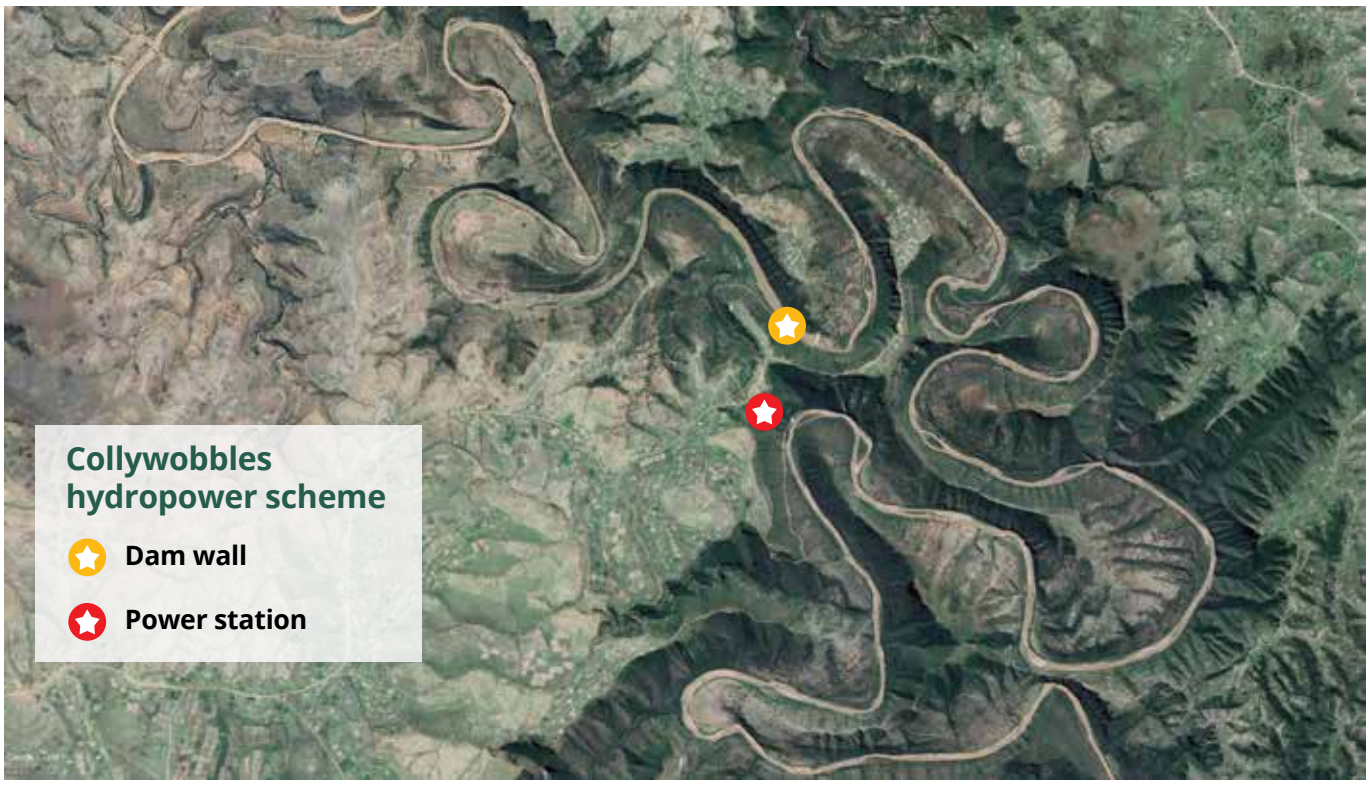
Tennessee Valley Authority, CC BY 2.5

Conventional storage-regulated hydropower scheme.

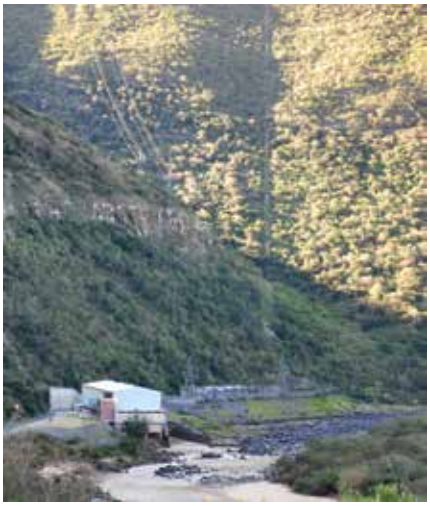
In addition, Eskom has a number of conventional hydropower schemes that are either storage-regulated systems with a dam or run-of-river systems relying on the river's natural flow and 'fall', typically with water temporarily diverted from the watercourse. The former includes the 360 MW Gariep and 240 MW Vanderkloof schemes on the Orange River. The 42 MW Collywobbles scheme on the Mbashe River, commissioned in 1985 by the former Transkei Electricity Corporation (TESCOR), has a small dam but is a run-of-river system, where water is channelled through the mountain separating two bends of the river. This means that it takes a fast shortcut of 1.4 km down to the power plant, instead of slowly flowing 34 km through the winding watercourse. Eskom also operates three other former TESCOR hydropower stations – the 6 MW First Falls and 11 MW Seconds Falls stations on the Mthatha River and the 2.4 MW Ncora station on the Tsomo River.

Furthermore, Eskom purchases electricity from three hydropower facilities constructed under the Renewable Energy Independent Power Producer Procurement Programme (REIPPPP). These are the 4.4 MW Stortemelk Power Plant near Clarens in the Free State, the 10 MW Neusberg Hydro Electrical Project at Kakamas in the Northern Cape and the 4.7 MW Kruisvallei Hydro, also near Clarens.

There are numerous other small facilities operated by municipalities, farms and businesses for their own use, and potential for many more. South Africa also imports electricity generated by the Cahora Bassa hydropower scheme on the Zambezi River in Mozambique.



The Collywobbles hydropower scheme on the Mbashe River has a penstock through the canyon ridge, diverting water from the dam down to the power station 1.4 km away. Below, clockwise from left: dam wall and intake, power station, control room, generating units, substation.



Micro-hydropower for remote communities

The village of Kwa-Madiba lies in a loop of the Thina River, which flows down a narrow rock cleft at Thina Falls.

A University of Pretoria (UP) academic helped to design and build a small-scale hydropower plant to generate 50 kW of electricity for the remote rural village of Kwa-Madiba in the Mhlontlo Local Municipality, north-east of Mthatha in the Eastern Cape.

The new plant was handed over on 4 October 2021 at an official ceremony that was attended by senior officials of the Department of Science and Innovation (DSI), along with representatives of UP, the Water Research Commission (WRC), Mhlontlo Local Municipality and the Kwa-Madiba community.

"The Kwa-Madiba scheme borrows a small proportion of water flowing over the Thina River Falls by diverting it into a steep and narrow tunnel," said Marco van Dijk, a lecturer in UP's Department of Civil Engineering in the Faculty of Engineering, Built Environment and Information Technology, and principal researcher for several WRC projects.

The 450 mm diameter tunnel was drilled through the surrounding rock to provide a penstock – a steeply sloped water passage that is used to divert water to spin a turbine. After passing through the turbine's blades, the water is returned to the main river. "Environmentally, the project will have minimal to no impact on the river environment due to the fact that only small amounts of river water will be rerouted through the turbine," said Van Dijk, who received the WRC Knowledge Tree Award for Empowering Communities on 23 September 2021 for his role in steering the project to finality.

Such run-of-river schemes do not have the negative effects of large-scale hydropower dams that may inundate extensive areas of fertile land, disrupt fish migration and create other environmental disturbance. The Kwa-Madiba WRC project, which was funded by the DSI, also created very little visual impact on the scenic value of the Thina Falls, because much of the piping infrastructure is underground, while the turbine is housed in a small, 6 m-long shipping container.

Importantly, the project team participated in the public consultation process for the review of the General Authorisation (GA) in terms of the National Water Act of 1998. The revised GA system now allows for the construction of small-scale run-of-river hydropower projects without the need for a full-scale Water Use Licence Application (WULA), provided they do not exceed 300 kW and adhere to specific requirements. The WULA process can be lengthy and costly, which acts as a disincentive to the roll-out of similar cost-effective hydropower projects.

Implementing the small-scale hydropower scheme at Thina Falls involved drilling a tunnel in the rock for the penstock, through which water flows to the turbine room at the base of the falls. The electricity is then fed to the Kwa-Madiba community, about a kilometre away.

The turbines, housed in a retrofitted shipping container, generate enough electricity for about 50 rural homes.

"South Africa is a dry country compared to the rest of the world, but there is no reason why the country's water resources cannot be tapped to deliver green electricity to many isolated rural communities," Van Dijk explained.

While the government is committed to providing universal access to electricity, the reality is that many isolated communities will not be connected to the national grid for the foreseeable future, due to the high cost of transmission and distribution infrastructure to the more remote parts of South Africa. However, Van Dijk said, there are several areas in the comparatively water-rich Eastern Cape, KwaZulu-Natal and Mpumalanga provinces where the Kwa-Madiba standalone scheme could be replicated or adapted with little difficulty, while other types of innovative small-scale hydropower schemes can be established in other provinces.

Van Dijk noted that South Africa has almost 4 500 registered dams and several weirs, transfer schemes and pipelines, many of which could be retrofitted to accommodate small-scale turbine systems nationwide – without reducing water yield or reliability of water supply.

The Hydropower Research Group at UP is currently compiling a national hydropower atlas for the country as part of another WRC-funded project. This atlas, the first of its kind in South Africa, will help to identify areas where hydropower projects of different sizes can potentially be implemented. It will also provide information on the different technologies available. The researchers hope their efforts will provide policymakers with a way to address the current slow pace of small-scale hydropower development.

"What we're saying is let's harness the water resources that we have responsibly, for the benefit of all," Van Dijk said. "Small-scale hydropower projects like Kwa-Madiba have the potential to be integrated into a number of our river systems."

Article issued by the University of Pretoria, and republished with permission:
https://www.up.ac.za/news/post_3023207-up-researcher-leads-the-way-to-green-hydropower-for-remote-communities

A video about the project is available on the Water Research Commission's YouTube channel:
https://www.youtube.com/watch?v=BDqch8vrSbg

BIOENERGY

For thousands of years, humans have burned wood and other plant material for light, warmth and cooking, but such plant-derived 'biomass' can also be used to generate electricity and other forms of energy.

Biopower

Construction of the first biomass power plant dedicated to supplying electricity for Eskom has recently been completed at Sappi's Ngodwana Mill in Mpumalanga. This follows the selection in 2015 of the Ngodwana Energy Project as a preferred bidder in the fourth bid window of the government's Renewable Energy Independent Power Producer Procurement Programme (REIPPPP). Once fully operational, the 25 MW power plant will burn biomass waste from the surrounding forestry plantations and from the mill production process in a boiler to generate steam. The steam will drive a turbine to generate electricity, which will be fed into the national grid and purchased by Eskom according to a long-term power purchase agreement.

The concept is not new. Sappi had already been generating electricity in this way to run the mill, which produces pulp and paper products, and was selling surplus energy to Eskom. In fact, as early as 1939 a similar power station was built on Thesen Island in Knysna to provide electricity for the sawmill there, and later – until the 1970s – the towns of Knysna and Plettenberg Bay too. The sawmill ceased operation in 2001, and in 2010 the power station building was relaunched as the Turbine Hotel & Spa, with much of the old machinery incorporated into the design.

Many of the sugarcane mills in KwaZulu-Natal and Mpumalanga also have their own power stations to provide electricity for processing operations. In this case they burn bagasse, the crushed sugarcane stalks left behind after the juice has been extracted. But the country's sugarcane industry is in decline, so it is keen to diversify into the production of biofuels.

Sweeter Alternative, CC BY-ND 2.0

Sugarcane is used in other parts of the world, notably Brazil, for bioethanol production, and the South African industry is keen to do the same.

Sappi

South Africa's first biomass power plant to be constructed under the Renewable Energy Independent Power Producer Procurement Programme (REIPPPP) will soon become operational at Sappi's Ngodwana Mill in Mpumalanga.

Bioethanol

For example, bioethanol can be produced by fermenting sugarcane juice, bagasse as well as the residue left in the fields after harvesting. During fermentation, yeast and bacteria metabolise the plant sugars and produce ethanol, which can be blended with other fuels or converted into Sustainable Aviation Fuel (SAF). There is a huge demand for SAF, because the aviation industry is well aware that many long-distance travellers and 'frequent flyers' feel guilty about their carbon footprint. The member airlines of the International Air Transport Association (IATA) have committed to achieving net-zero carbon emissions from their operations by 2050, anticipating that SAF production will increase to 65% of the industry's total fuel requirement by then, up from an expected 2% in 2025.

In Brazil, the sugarcane sector made the transition to bioethanol some years ago and is now the second largest producer after the United States, which mainly uses maize (known there as corn) for its bioethanol production.

Development of a South African bioethanol industry has been hindered by the regulatory environment, although government published a Biofuels Industrial Strategy as far back as 2007. In August 2012, the Regulations Regarding the Mandatory Blending of Biofuels with Petrol and Diesel were gazetted, and these were meant to come into effect from October 2015. They stipulated a minimum blending of 2% bioethanol into petrol and 5% biodiesel into diesel, but they were never enforced. This was largely because there was no local supply of biofuels, and no financial incentive for fuel manufacturers to source them, given that biofuels are more expensive to produce than conventional fuels.

More recently, in February 2020, the South African Biofuels Regulatory Framework and National Biofuels Feedstock Protocol was gazetted, and in September 2021

neufcen19, Flickr, CC BY-NC-ND 2.0

South Africa's recently amended 'mandatory blending regulations' stipulate that petrol should contain a minimum of 2% bioethanol. Overseas, blends of 10% are common and can be used in any vehicle without modification, while special flexible-fuel vehicles (FFV) can use blends of up to 85%.

an amendment of the 'mandatory blending regulations' was published. The regulatory framework now provides for a subsidy mechanism to support the development of a biofuels industry, while the feedstock protocol prohibits the use of maize for biofuel production to ensure that food security won't be compromised. It also prioritises rain-fed feedstock production to protect South Africa's scarce water resources, and excludes jatropha as a biodiesel feedstock because it is a threat to biodiversity, being an alien plant with toxic leaves and pods.

Biodiesel

Biodiesel can be made from a variety of natural plant oils, as well as animal fats and waste cooking oils. Currently, the dominant feedstocks internationally are soybean in the United States, rapeseed (canola) in Europe and palm oils in South-East Asia, primarily Indonesia. The most common method of making biodiesels is transesterification, which uses an alcohol such as methanol or ethanol in the presence of a catalyst such as potassium hydroxide or sodium hydroxide to break down triglycerides in the oils and fats to fatty acid methyl esters (FAME). Glycerol is released as a by-product, and can be recovered for use in soaps, cosmetics, foods, pharmaceuticals and the broader chemistry industry.

The FAME is sold as biodiesel, but it causes clogging problems if used 'neat', so it is usually blended with normal mineral diesel. Biodiesel made from rapeseed oil is called RME – rapeseed methyl ester – rather than FAME, and its lower proportion of saturated fatty acids makes it more suitable for cold climates. However, the greenhouse gas lifecycle assessment for these biofuels is not particularly favourable, because the transesterification process generally uses fossil fuel-derived methanol, carbon emissions from vehicles using biofuels are not always significantly lower than those using normal diesel, and massive tracts of natural vegetation (such as tropical forest in Indonesia and Malaysia) are being converted to agricultural land for feedstock crops, resulting in direct and indirect carbon emissions.

Using bioethanol instead of methanol would improve its green credentials, and such biodiesel is known as FAEE, because it produces fatty acid ethyl esters. Other options are to use biomethanol (see page 27) or to increase the use of waste cooking oil as the feedstock, which would reduce concerns about land conversion while also addressing a major source of environmental pollution, given that incorrect disposal of used oil and fat residues by restaurants often results in contamination of watercourses.

There is also increased focus now on 'second-generation biofuels', which use waste biomass such as wood pellets, sugar bagasse, grain straw, maize leaves and stalks (known as corn stover) or even specially grown 'energy grasses', but never food crops, while 'third-generation biofuels' are those produced from algal biomass. The second-generation feedstocks are high in lignocellulose, so thermochemical processing technologies involving gasification or pyrolysis are preferred to convert them into petrol and diesel substitutes.

Biochemical conversion of biomass via anaerobic digestion is also possible but requires more pre-treatment to break down the lignocellulose. Anaerobic digestion is especially important in producing another type of bioenergy, called biogas (see page 22).

Kansas Soybean 1980, CC BY 2.0

Soybean is the dominant feedstock for biodiesel production in the United States.

BIOGAS
– the power of microbes

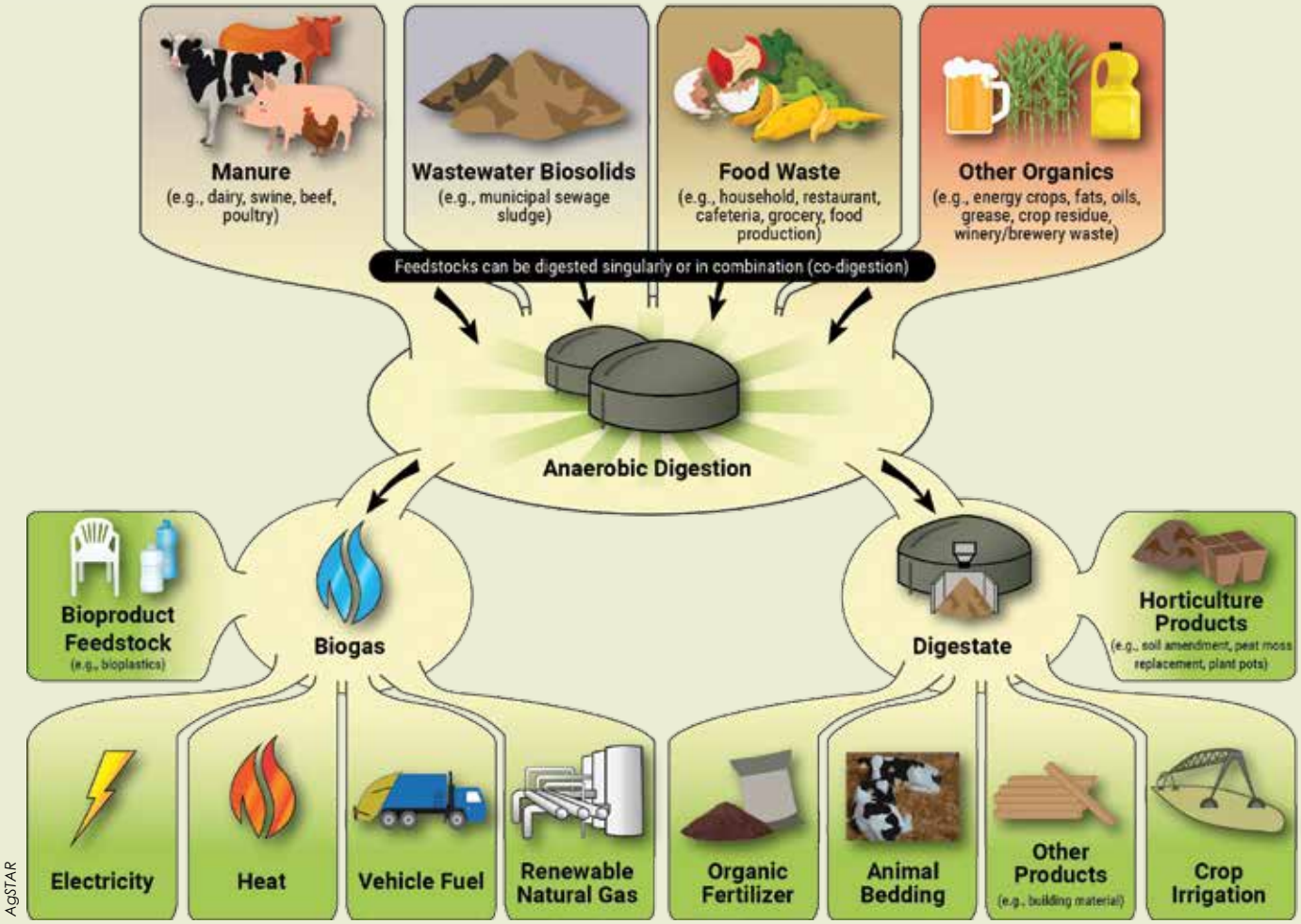
Sugarcane is South Africa's most promising biofuel feedstock, so it comes as no surprise that a research group located in the centre of the country's main sugarcane-growing area is exploring its bioenergy potential. But rather than trying to optimise processing technologies for bioethanol or biodiesel production – already well advanced elsewhere – the group at Durban University of Technology's Department of Chemical Engineering is concentrating on the use of bagasse to produce biogas and other useful products, with the twin benefit of waste treatment.

"Our research focuses on integrated systems to produce biofuels and hydrocarbons from suitable industrial wastewaters, agricultural biomass, sewage sludge, food waste and algae," explains Dr Maggie Chetty, a senior lecturer in the department and one of the project leaders of the Green Engineering and Sustainability research group.

Biogas is a type of biofuel that consists primarily of methane, with carbon dioxide making up most of the remainder along with small amounts of water vapour and other gases. Like liquid petroleum gas (LPG) purchased in cylinders for household stoves, geysers and heaters, it can be used for cooking and heating purposes, but also for electricity generation when burned in gas turbines or gas engines. When purified to biomethane, it can even be used in methane-fuelled vehicles (see page 15).

Biogas is one of two end products of anaerobic digestion, whereby organic matter is broken down by bacteria that live in oxygen-free environments. The other is the nutrient-rich digestate, the solid and liquid organic matter left behind after this microbial decomposition process. The digestate can be used as fertilizer, so small-scale farmers in many parts of the world, including South Africa, are slowly adopting the use of anaerobic digesters to help meet their energy needs while improving their crop yields. Typically, the digesters are 'fed' regularly with livestock waste, such as cow dung or poultry droppings, along with some water, and the biogas produced is piped into the home for use in gas stoves, and sometimes lamps.

On a larger scale, many wastewater treatment works (WWTW) use anaerobic digestion to treat sewage sludge



A variety of biomass-based feedstocks can be used in digesters to produce biogas and digestate.

– the solids that settle out during the treatment process. In some cases, the resulting biogas is used to heat the digesters to improve the efficiency of the process and kill pathogens. But many WWTW don't exploit this energy source at all, and simply flare the biogas, which burns off the flammable methane but releases CO_2. This is undesirable from a greenhouse gas emissions perspective, so a concerted effort should be made to maximise the production of biogas, which would make its recovery more financially viable. One way of doing this is to supplement the sewage sludge in the digesters with plant-based biomass such as sugarcane bagasse or corn silage – maize waste that has been shredded, then compressed and stored in a silo or pit for a few weeks, where it gets 'pickled' through natural fermentation.

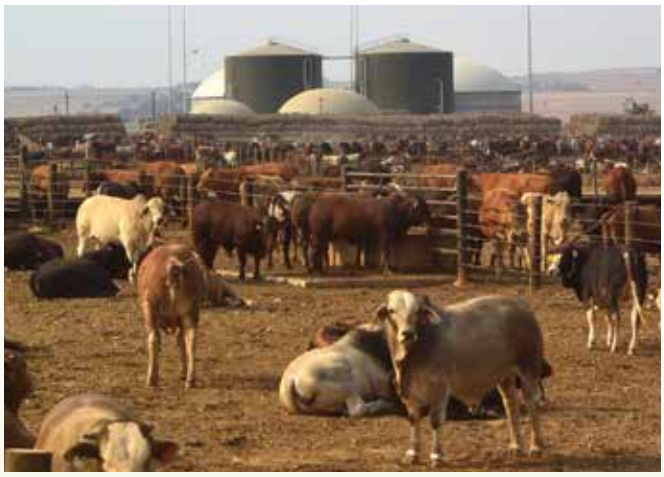
"The co-digestion of these substrates with sewage sludge enhances the conventional digestive process and increases the yield of biogas," says Chetty. Many WWTW already dispose of treated sewage sludge – the digestate – by making it available to farmers to use as fertilizer, so cooperative arrangements could be made to provide digestate in exchange for biomass feedstock. To date, the research has been conducted on laboratory-scale systems, and the results have been very promising, especially when nutrient-rich dairy or brewery wastewater has been added to the digesters too.

"In South Africa, several industries produce millions of cubic metres of wastewater annually, with large volumes treated on site before being either released into water-bodies or piped to municipal treatment plants. Industries in most parts of the world continue to battle against effluent discharges of poor quality, which affects ecosystems, but effluent with high carbon content and nutrients has the potential for transformation into valuable bioproducts."

The research group has also been investigating what useful bioproducts could be developed from food industry waste such as vegetables, coffee grounds and used cooking oil, all of which are normally disposed of in landfill sites.

"Methane leaks from landfills are an ongoing problem," says Chetty. "Spontaneous fires and explosions caused by build-up of gas have been recorded in many regions of the world, illustrating a major problem which needs to be confronted by waste management companies. When this gas is trapped, however, it can be made useful, instead of just being a nuisance."

Preventing methane from reaching the atmosphere is important, because although it breaks down faster than CO_2, it is much more effective in trapping heat, making it the greenhouse gas with the second-largest contribution to global warming. Municipal authorities and volunteer groups in many parts of the world have implemented urban food waste collection programmes to divert this waste from landfills. Typically, food waste from homes, hotels and restaurants is composted for subsequent use in gardens, but increasingly these programmes are installing digesters



IRENA

The 4.4 MW Bronkhorstspruit Biogas Plant, developed by Bio2Watt on the Beefcor feedlot 40 km east of Pretoria, is South Africa's first industrial-scale biogas-to-electricity plant. It began producing renewable electricity from cow dung and other organic waste in 2015, and supplies 30% of the nearby BMW Rosslyn factory's electricity requirements.

UNIDO

A rural household's newly completed digester, constructed as part of the Waste-to-Energy South Africa Project, which is supported by the United Nations Industrial Development Organisation (UNIDO) and the Global Environment Facility (GEF).

too. Apart from improving the carbon footprint of the waste sector, these programmes can help reduce the transport costs and health hazards associated with waste disposal.

Chetty says that sugarcane bagasse and spent coffee grounds are also an alternative for high-value hydrocarbons that are normally produced from fossil fuels. Their transformation into such bioproducts is being investigated by the group, using green engineering principles that incorporate the use of green solvents, catalysts and sustainable chemicals like ionic liquids – salts that are in a liquid state.

"The next phase of the research is to scale up and carry out techno-economic studies," says Chetty. "The treatment of large volumes of waste will mitigate ecosystem effects and prompt a culture of zero waste if the benefits show economic value. A lifecycle analysis will be incorporated into our projects, together with an economic analysis of implementing these interventions."

Written by Quest Editor, Sue Matthews, based on information provided by Dr Chetty.

EnergyDRIVE 2021

On 1 September 2021, the EnergyDRIVE truck departed from its home base at the Durban University of Technology (DUT) for a three-week tour, visiting schools and wind farms in eight different communities in the Eastern, Western and Northern Cape to raise awareness about renewable energy.

The much-loved yellow 'edu-tainer' is a collaborative project between DUT and the South African Wind Energy Association (SAWEA), the first tour having taken place in 2017. For the 2021 tour – the third – the South African National Energy Development Institute (SANEDI) joined as a partner.

The truck features a solar roof structure, biogas digester, photovoltaic panel display unit as well as a solar hot water display unit. A battery bank, photovoltaic components and a TV and display cupboards are built into the container walls, providing a variety of interactive demonstration models. Apart from informing learners about renewable energy technologies, the EnergyDRIVE team cover issues associated with climate change as well as potential career opportunities within the renewable energy sector.

At the first stop on the tour, at the Dorper Wind Farm situated 14 km south-east of Molteno in the Eastern Cape, the EnergyDRIVE team engaged with learners from Molteno's Joe Slovo Freedom High School. The final stop was the Kangnas Wind Farm in the Springbok area of the Northern Cape, with learners from Okiep High School in attendance.

After the tour, the truck was exhibited in Cape Town at WindAc Africa, a conference for the academic community that took place from 5–7 October, as well as the Windaba conference for wind industry representatives from 7–8 October.

DEPARTMENT OF CHEMICAL ENGINEERING PROGRAMMES

The Chemical Engineering qualifications are the starting points of career paths, and are still generic enough to allow maximum mobility, within this diverse industry. Skills, knowledge, values and attitudes reflected in these qualifications are building blocks for the development of engineering competence. These qualifications are intended to promote the development of engineering knowledge and skills that are required to serve public and private needs. The Department of Chemical Engineering offers the following programmes:

BACHELOR OF ENGINEERING TECHNOLOGY IN CHEMICAL ENGINEERING

This is a 420-credit qualification which is primarily professionally oriented. The learning programme consists of a coherent assembly of knowledge areas associated with chemical engineering practice, these include: mathematics, natural sciences, engineering sciences, design and synthesis, computing and IT, and relevant complementary studies. This assembly of knowledge areas provides a viable platform for further studies and lifelong learning, and will produce graduates who can function in today's fast changing, dynamic and evolving industrial marketplace.

The minimum entry requirement is the National Senior Certificate or the National Certificate (Vocational) with appropriate subject combinations and levels of achievement as defined in the *Government Gazette*, Vol 751, No 32131 of 11 July 2008, and in the *Government Gazette,* Vol. 533, No. 32743, November 2009. In addition the minimum admission requirements, rule G7, is stipulated in the DUT General Rules Handbook.

BACHELOR OF ENGINEERING TECHNOLOGY HONOURS IN CHEMICAL ENGINEERING

This qualification is primarily oriented to meet the needs of practicing Engineers ready for the industry. The knowledge emphasizes general principles and application of technology transfer. The qualification provides students with a sound further knowledge base in the discipline of chemical engineering and the ability to apply their knowledge and skills to particular career or professional contexts, while equipping them to undertake more specialized and intensive learning. This learning programme has a strong professional and career focus and holders of this qualification are customarily prepared to enter a specific niche in the chemical and allied industries. Specifically, the purpose of the learning programme is to strengthen the necessary knowledge, understanding, abilities and skills required for further learning towards becoming a competent engineering practitioner in the discipline of chemical engineering.

Candidates admitted to this programme are required to hold a Bachelor of Engineering Technology in Chemical Engineering. Applicants who did not complete the Bachelor of Engineering Technology in Chemical Engineering at this University may apply for Conferment of Status as stated in Rule G10A. (*Note: These applicants may need to complete additional undergraduate courses to gain admission.)*

The Department of Chemical Engineering also offers postgraduate qualifications, namely: The Master of Engineering and Doctor of Engineering. Information is available in the departmental handbook.

The Department of Chemical Engineering also hosts the Department of Pulp and Paper. The Department of Pulp and Paper offers a Diploma in Pulp and Paper. A student that obtains this qualification will be competent in applying theoretical knowledge, engineering principles, proven techniques, practical experience, and appropriate skills to the solution of well-defined problems in the field of pulp and paper technology. This qualification is designed to prepare students for positions as operational staff in the pulp and paper industry.

In addition to the Institution's General Minimum Admission Rule, the applicant must have a Mathematics - rating code 4 (Adequate achievement), and Physical Science - rating code 4 (Adequate achievement). Prospective students who did not write the Mathematics Paper 3 (Geometry Paper) will be required to attend an additional Mathematics I sub-module which will be run concurrently with the normal Mathematics I course. The onus is on the students to prove that they wrote the Mathematics Paper 3 otherwise they will be required to attend the additional Mathematics I sub-module.

Alternatively, a matriculation certificate, with at least a D symbol (Higher Grade) or B symbol (Standard Grade) in Physical Science and Mathematics. A pass in the subjects Technical Drawing and/or Computer Studies will be an added recommendation.

Applicants who do not have the required matric symbols/ratings in Mathematics or Physical Science, but have passed Mathematics 1, Chemistry 1 and/or Physics 1 at an accredited tertiary educational institution will also be considered for entry into the program.

In addition to the above requirements, bursary students will have to meet additional criteria prescribed by their sponsor company, which may include interviews, psychometric assessments, and work-based skills tests. Favourable results of such assessments can also mitigate for lower matric symbols/ratings, subject to the minimum institutional requirements.

A comprehensive Booklet is available on the departmental website, https://www.dut.ac.za/faculty/engineering/chemical_engineering_and_pulp_paper-3/

Carbon capture and utilisation

Xolile Fuku explains how carbon emissions can be put to good use for a more sustainable world

It's now well established that carbon dioxide (CO_2) is a greenhouse gas that contributes to global warming and other effects of climate change. The global mean CO_2 level reached 410 ppm in 2019, up from 340 ppm in 1980, and it has continued rising despite the economic slowdown caused by the COVID-19 pandemic. To address the climate crisis, more than 190 countries, including South Africa, have joined the Paris Agreement adopted in December 2015, pledging to reduce CO_2 emissions with the goal of limiting global warming to well below 2°C, preferably 1.5°C.

Such a political goal necessitates a paradigm shift, aided by technology advancements. One approach is to undertake carbon capture and storage (CSS), also known as carbon capture and sequestration. This involves capturing CO_2 before it reaches the atmosphere, converting it to a fluid and storing it deep underground in geological formations, where it will remain for centuries.

Another approach is to view CO_2 as an abundant carbon resource rather than a pollutant. Carbon capture and utilisation (CCU) aims to recycle the CO_2 for use in the manufacture of high-value products, including chemicals, plastics and fuels.

There are three main types of carbon capture: post-combustion, pre-combustion, and oxy-fuel combustion. In post-combustion capture, CO_2 is separated from the flue gas, or exhaust, emitted from the combustion process. In this case, CO_2 can be separated out via absorption, adsorption, cryogenic and membrane separation. Pre-combustion capture entails gasification of carbon-based fuels to produce syngas – a mixture of H_2, CO and CO_2 – that is processed further to separate out CO_2. Finally, in oxy-fuel combustion the fuel is burned in pure oxygen or oxygen-rich air, so the emitted flue gas contains mainly CO_2 and water vapour, making it easier to separate out the CO_2.

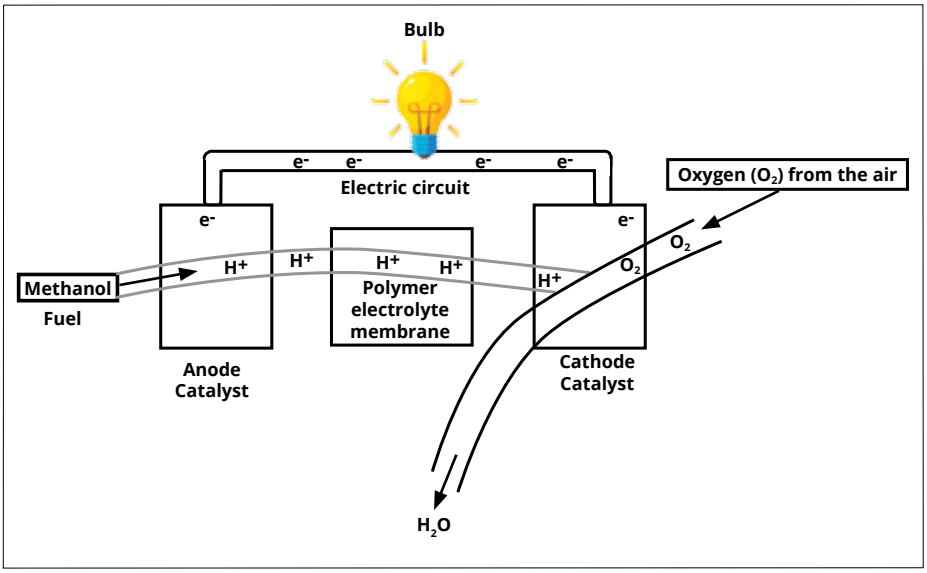
Once the CO_2 has been captured, it can be converted into useful, value-added products in a variety of ways. One such product is methanol (CH_3OH), the most basic member of the group of organic compounds known as alcohols. It is mainly used to produce other chemicals such as formaldehyde and acetic acid, used in everyday products like plastics, paints, car parts and construction materials, but methanol is also an emerging energy fuel.

Currently, nearly all methanol production is derived from fossil fuels, involving either steam reforming of natural gas or gasification of coal to produce syngas. However, in much the same way that solar energy can be used to produce 'renewable hydrogen' (see page 14), there is potential for producing 'renewable methanol' from green hydrogen and CO_2 using a combination of photovoltaic and electrochemical components. Another option is to produce biomethanol from biomass feedstocks such as agricultural waste, landfill biogas and sewage sludge.

Being a biodegradable and clean-burning fuel, methanol's environmental and economic benefits are increasingly making it a desirable alternative for powering vehicles and ships. It can be used in conventional internal combustion engines, but also in fuel cells that transform chemical energy into direct current electrical energy.

Stena Line, CC BY 2.0

The *Stena Germanica*, a ferry owned by the Swedish company Stena Line, has been using methanol as fuel since 2015.



Schematic of a direct methanol fuel cell system.

Most fuel cells are fuelled by hydrogen and oxygen (air), which produce water as a by-product when combined. The direct methanol fuel cell (DMFC), on the other hand, is an electrochemical cell that generates energy through methanol oxidation and oxygen reduction. This eliminates the requirement for an external hydrogen fuel supply and opens the door to tiny devices ranging from a few watts to several kilowatts in capacity. Probable applications include use in video cameras, drones, boats and caravans, where batteries can often only be used for short operating periods before recharging is required. By contrast, fuel cells are capable of continuous operation provided they are supplied with fuel.

Methanol can also be used for cooking and heating in homes, offering an opportunity to address a significant social and environmental issue. According to the World Health Organisation (WHO), nearly three billion people heat their homes and cook with fuels like coal, wood, waste, dung and paraffin, burned in open flames and basic stoves, and almost four million people per year die prematurely from illnesses caused by indoor air pollution. The majority of those impacted are women and children.

In South African townships, paraffin is not only one of the worst contributors to pollution-related disease, but also results in large shack fires every year when combined with faulty stoves. Methanol has therefore been proposed as a paraffin replacement. If produced through either CCU technologies or from renewable sources, it could aid in the mitigation of climate change by lowering carbon emissions, while also reducing local air pollution and enhancing energy security.

Dr Xolile Fuku is a senior lecturer at UNISA's Institute for Nanotechnology and Water Sustainability (iNanoWS). His research focuses on energy storage and conversion systems as well as electrochemical and biological sensors.

From **Kenyan villager** to **international researcher**

Rebekka Stredwick helped Francis Otieno tell his story

Francis Otieno / Diamond Light Source

Dr Francis Otieno from the University of the Witwatersrand (Wits) on a visit to the University of Oxford in the United Kingdom.

My name is Francis Otieno and I am telling this story to inspire school kids, emerging researchers, and everyone – your dreams are possible!

My story begins as I progressed into high school and experienced the heavy environmental pollution from the congested slums of Mathare in Nairobi, Kenya. Large numbers of smoking cars in the streets and continuous electricity blackouts were the norm, especially at the slightest onset of rains. When I look back, this was the start of my dream of making a difference to society and our communities, the start of a long journey in the quest for clean, sustainable renewable energy.

Today I am a GCRF START Postdoctoral Research Fellow in the field of solar energy research. I was born in a rural part of Kenya called Seme Kadero, in Kisumu County, to a big polygamous family of four mothers and 27 children. I was number 20 in our family and my father, born in 1928, was quite passionate about his kids attending school but none before me made it to university. We were allowed to go to school in the mornings but had essential chores in the afternoons. We grew up grazing cattle barefoot and cultivating land in alternation with school hours – we couldn't even afford to buy shoes.

My father saved some money for me to attend high school but soon realised this was sufficient only to buy the school uniform and other items required for admission, but not school fees. I had to make do with a new school uniform, including long trousers and shoes for the first time, which I wore at home while waiting for my father to raise the fees. I didn't know what to read during those weeks, so after putting on my school uniform each day, I would go to the newspaper vendor and ask to read all the daily newspapers with him, and then go home in the evening.

My passion was to realise my father's dreams one day and return home with a title earned from studying. I wanted to be a teacher and contribute immensely to society. My physics teacher at Eastleigh High School in Nairobi really believed in me, which made a huge difference. He gave

Francis Otieno / Diamond Light Source

A childhood photo of Francis (left) with his brother Jacktone at home in Kenya.

The Global Challenges Research Fund's (GCRF) Synchrotron Techniques for African Research and Technology (START) project builds partnerships between world-leading scientists in Africa and the United Kingdom, working together on research using synchrotron science. The project develops research along two lines of scientific investigation: developing and characterising new energy materials (for example, in the development of solar cells or improving energy efficiency through novel catalysts), and structural biology to understand diseases and develop drug targets.
For more information, see https://start-project.org/home/about/

me a project using angular inclination and the concept of rectilinear propagation of light to design a device that could be used to measure the height of any building or tree from a distance without having to climb it! This kickstarted my love of science and drove my research career ambition.

I competed through the district and province and became the second best in the National Science Congress. The fire for research was then fully ignited, fuelled by the fact that I didn't have a stable light source at night to study, in addition to the effects of environmental pollution. School and learning were vital. To avoid being mugged for our precious textbooks, we would walk the 6 km to and from school, rising early each morning and singing on the way back home to deter anyone from stealing our books to sell for drugs.

My father had long retired from active business, relying instead on peasant farming. Our tradition holds that our elder brothers help to cover school fees, which was a challenge as they were equally struggling to settle down in life. With all these hardships, my ambition was to improve performance at school, which had back then only a 2–5% pass rate to public university. As a group of high school learners, we managed to turn this around and many secured a place at our public university, where we could access government funding.

The best teacher teaches from the heart and not just the textbook, and this is what I intended when I chose a Bachelor of Education degree at Egerton University, almost 200 km north-west of Nairobi. I knew my heartfelt approach meant a lot to my father, who has always urged me to do well and surpass any problems on the way. When I got my first degree in education, teaching physics and mathematics, many of my pupils did well in my subjects. I am a proud teacher, having seen them move into good careers using the physics and mathematics they had been taught.

My next thought was that the combination of research and teaching would be more impactful to society, so I enrolled for an MSc in Physics at the University of the Witwatersrand (Wits) in South Africa. Getting accepted on the course wasn't easy, and I was rejected four times. Finally, in 2014, I joined Wits after resigning from my high school teaching job. This bold step would not have been possible without the encouragement of Prof. Daniel Wamwangi, Associate Professor in the School of Physics at Wits. I am forever grateful for the trust he had in me, the strong motivation he gave, and incredible guidance he has accorded me during my research journey at Wits.

Through his dedicated supervision I was able to successfully earn my MSc, within the time limit, and immediately enrol for a PhD, which I completed within a record time of 30 months together with an output of several publications. During my PhD journey, Prof. Daniel Wamwangi and Prof. Alex Quandt, Professor in Computational Physics in the School of Physics at Wits, formed the best team for supervision. From their immense expertise and with much hard work, I learnt so much within a record time and got exposure to advanced techniques, as well as collaborations within and beyond Africa.

Francis Otieno / Diamond Light Source

Francis with his PhD supervisors, Professor Alex Quandt and Professor Daniel Wamwangi, at his graduation ceremony at Wits in 2018.

Francis Otieno / Diamond Light Source

Francis with his father, Mzee Christopher Otieno Oluoch, at the graduation ceremony.

I invited my then 92-year-old father to my graduation, and tears of joy flowed freely when he landed in Johannesburg for this happy event, and throughout his three-week stay with me in South Africa. It was his first time owning a passport and boarding an aeroplane, and seeing his child graduate with the much-desired title of a Doctor of Philosophy. When my father returned to our village in Kenya, he would host sessions of storytelling about these experiences and remembers every tiny detail: his 20th child brought home his dream!

Daniel Wamwangi / Diamond Light Source

Diamond Light Source

Francis tours beamline I07 at Diamond Light Source, the UK's national synchrotron situated on the Harwell Science and Innovation Campus in Oxfordshire.

I told myself that although I was the first in the family to climb to this height of education, I would not be the last. Through this inspiration, four of my younger siblings have now earned their first degrees, and former students, friends and relatives have followed suit in South Africa and Kenya.

GCRF START Postdoctoral Research Fellowship

Through hard work with good output, I was approached by my current host, Prof. Dave Billing in the Department of Chemistry at Wits, and he suggested that I apply for a postdoc position funded by the GCRF START grant, even before my PhD thesis examination results were back. I was highly convinced that this was the best news ever, and indeed, being accepted by START would help my career and personal growth, because I needed exposure outside of Africa as well as within to move my research forward.

START was a real blessing at the right time when I truly needed it. The GCRF START grant funded my Postdoctoral Fellowship at Wits for two and a half years. With START, I have been able to obtain lots of data results that have enabled me to publish in reputable journals. Being part of the START network has given me opportunities to collaborate with like-minded researchers at the UK's University of Oxford, the University of Sheffield and the UK's world-renowned national synchrotron – Diamond Light Source (Diamond). Through these interactions, I have learnt many new skills and exchanged knowledge and various perspectives.

In addition, back in South Africa and with support from the GCRF START grant to purchase the necessary kits, I participated in several community outreach programmes, including hosting an awareness and outreach activity at Wits for the 69th Lindau Nobel Laureate Meeting in 2019, which I attended in Germany. This was funded by the Academy of Science of South Africa (ASSAf), in partnership with the then Department of Science and Technology (now DSI). The 2019 meeting – known by its Twitter hashtag #LINO19 – was dedicated to physics and was attended by 39 Nobel laureates and 580 young scientists from 89 countries. It was particularly meaningful for our South African contingent because South Africa hosted the International Day that year. I also participated in the Wits Yebo Gogga Exhibition and Focus Day, which assists young learners who need guidance on future careers, such as in physics.

Cleaner, cheaper energy sources

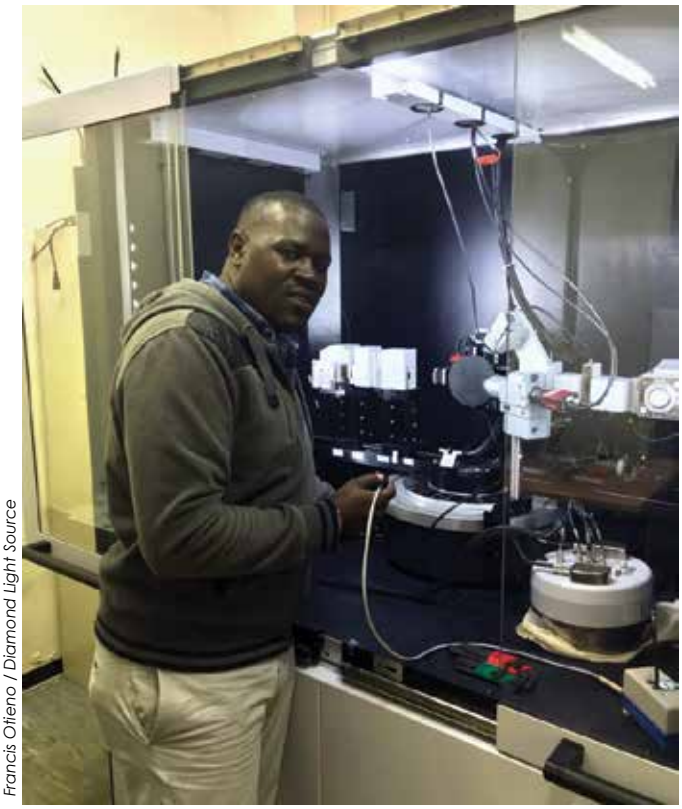
Finding alternative, cheaper energy sources using locally available materials, such as organic polymers, is the basis of my research. To provide clean renewable energy sources, the current market is dominated by silicon-based solar cells, which are high cost because of the expense of extracting silicon from its raw materials (sand), and they also have lower efficiency. Thin-film solar cells are known as second-generation solar cell fabrication technologies to produce electrical energy.

Patrick Kunkel/Lindau Nobel Laureate Meetings

Francis (back row, 3rd from right) was one of 20 young scientists selected by ASSAf to attend the 2019 Lindau Nobel Laureate Meeting in Germany.

I focus on using nanoparticle technology such as plasmonics to find alternatives to silicon solar cells. My research interests are renewable energy, energy policy and emerging solar technologies, with my focus under the GCRF START grant on materials' characterisation, device fabrication and testing of thin-film solar cells such as Organic Solar Cells (OSCs), perovskites, and dye-sensitised solar cells. My project also explores ways to enhance the performance of these thin-film devices through incorporation of nanoparticle technology and spectral conversion thin films, with the ultimate goal of realising an efficient, cheaper source of solar energy and device-making for local and global markets.

The GCRF START grant facilitated buying my research materials, and made and strengthened Africa-UK collaborations,



Francis Otieno / Diamond Light Source

Francis in the laboratory at the Wits School of Chemistry, undertaking D10 Grazing Incidence X-ray diffraction. This technique is used to determine the phases of thin films at the sample surface and multi-layer films.

with lab visits to the UK. This gave me exposure to cutting-edge opportunities and joint proposals to perform advanced materials characterisation such as Grazing Incidence Wide Angle X-ray Scattering (GIWAXs) at Diamond, and access to UK laboratories in the Materials Physics Group at the University of Sheffield with GCRF START Co-I, Prof. David Lidzey, and to the Advanced Functional Materials and Devices Group (AFMD) with GCRF START Co-I, Prof. Moritz Riede at the University of Oxford.

The newly acquired National Thin-Film Cluster Facility for Advanced Functional Materials based at the University of Oxford is capable of being an epicentre for novel thin-film development within the UK and beyond. This facility certainly places the UK at the centre of the development of next-generation materials and devices for applications in energy, photonics and electronics. Access to this facility through my ongoing collaboration with Oxford will certainly revolutionise my research prospects, with increased potential of producing publications in collaboration with the AFMD group, namely Dr Pascal Kaienburg and Irfan Habib.

Irfan Habib /Diamond Light Source

Francis (front left) with members of the START network from Wits on a visit to the University of Oxford. Left to right: Professor Daniel Wamwangi, Professor Dave Billing, Adam Shnier, Dr Ramesh Pandian and Professor Yasien Sayed.

In the Materials Physics Group at Sheffield University, Rachel Kilbride and Dr Joel Smith assisted me with carrying out GIWAXs on organic thin films. At Diamond, Dr Thomas Derrien guided me with joint beam time proposals enabling us to do measurements both at Diamond and the European Synchrotron Radiation Facility (ESRF).

These collaborations and networks I aim to continue being involved in, and were made possible by Prof. Billing, who has much expertise in powder diffraction and energy materials across research networks within and beyond Africa. I am always grateful for the faith he had to appoint me as a Postdoctoral Research Fellow, and I have valued his immense support. Also key is Prof. Wamwangi, who has been a great mentor in my research journey, from experimental techniques to manuscript preparation. As a result, I have contributed to several papers looking at solar cell materials and device-making instrumental to industries working on improving the performance of solar cell devices, highly needed in the global market.

We believe that the future of all technologies is 'smart', and Organic Solar Cells (OSCs) research is critical to realise efficient energy sources with advantages over current silicon solar cells, due to the abundance of materials and ability for scalable production processes that OSCs offer. Our aim is to contribute to the Sustainable Development Goals 7 (energy) and 3 (climate) and the growing global demand for innovative, world-class solar energy. Also, our research findings form the basis for teaching solar cell technology to undergraduate and postgraduate students, as well as other Research Fellows back home.

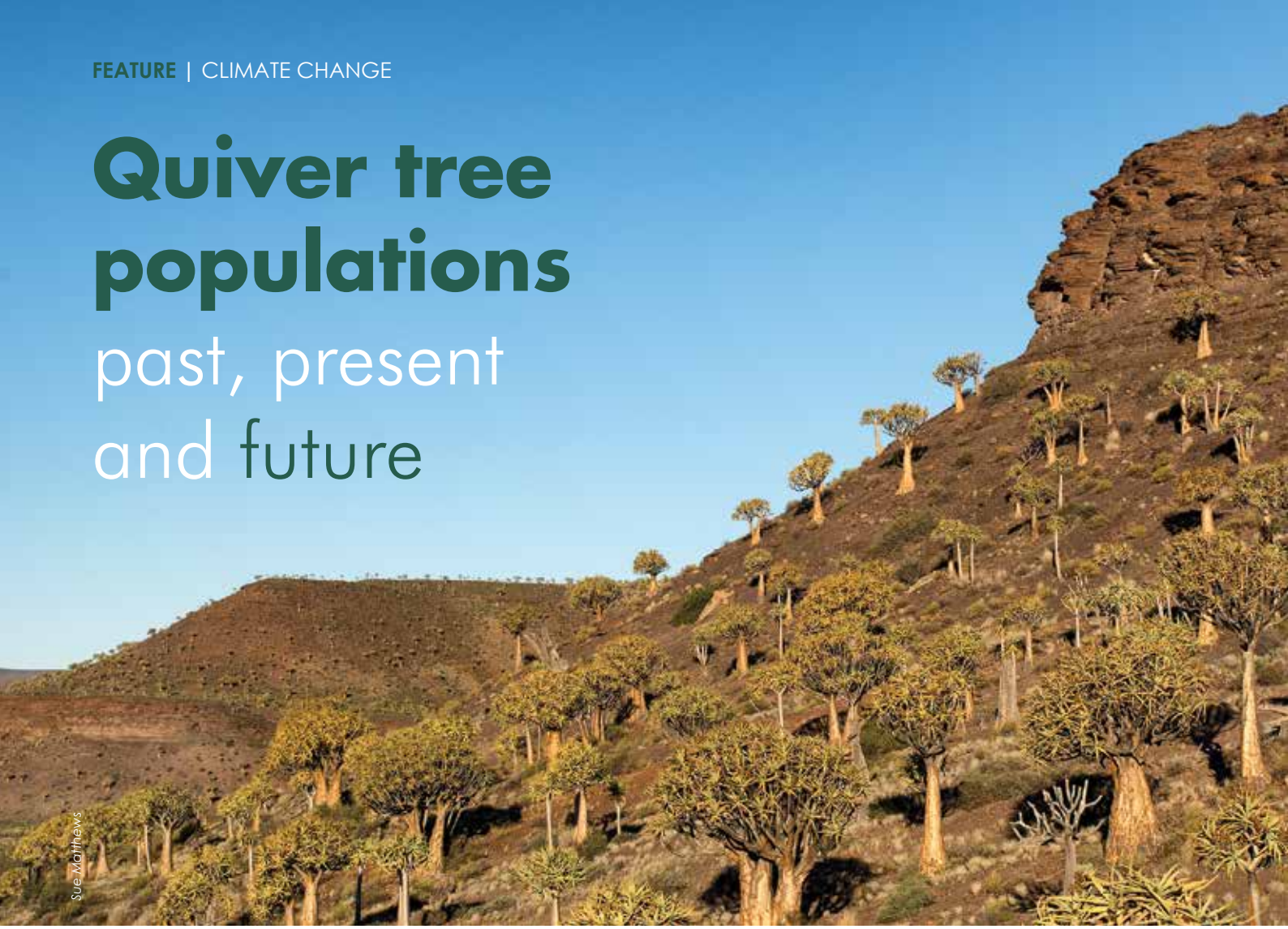
Inspiring hope, enabling others to dream

Although the journey is a long one, I am excited to have embarked on making a difference in society through our research, and I am proud that my dream of impacting young people from rural areas like my own was realised when I became a teacher. To continue investing in developing others, I have started mentoring undergraduate and postgraduate students at Wits and now at Maseno University, Kenya, where I have been offered a job as a lecturer.

The GCRF START grant exposed me to new skills and advanced equipment, and through my successes and links to START, I was able to receive the British Council Newton Travel Grant, which will enable me to visit Oxford for a period of six weeks. This exposure, together with much sought-after skills and strong collaborations, will be very useful to me as a young researcher looking forward to supervising postgraduate students back in Kenya, upon the completion of my Postdoctoral Fellowship.

This article was republished from the Wits website, but was originally published on the GCRF START website.

Quiver tree populations past, present and future


Sue Matthews

Going back 22 000 years into the past and projecting 50 years into the future, ecologists from Stellenbosch University simulated the palaeo- and future geographic range of the quiver tree, *Aloidendron dichotomum*, previously known as *Aloe dichotoma*. This iconic tree occurs in the arid landscapes of Namibia and South Africa's Northern Cape, and the ecologists hoped to understand how its past response to natural climate change could be used to predict its future response to anthropogenic, or human-induced, climate change.

Prof. Guy Midgley, head of the global change research group in SU's Department of Botany and Zoology, says research studies and observations worldwide have shown that biological systems and species are already responding to human-induced climate change.

"A common prediction for plants is that they will shift their geographic ranges in response to warming, either poleward or upward in elevation. The other options are on-site adaptation by genetic changes or changes in biology or behaviour," he explains.

In the case of long-lived trees, however, the adaptive options are limited, which could result in local extinctions. While trees may have been able to migrate or adapt to previous changes in the palaeo-climate that took place over thousands of years, they may not be able to do so fast enough to survive more rapid, human-induced climate change.

For example, over the past 10 000 years the surface air temperature in south-western Africa likely rose by 5°C during glacial to interglacial warming at the end of the Pleistocene. In contrast, according to the latest report from the Intergovernmental Panel on Climate Change (IPCC), surface air temperatures in Africa are projected to rise in excess of 5°C in the dry, subtropical areas in less than a century.

Over the past two decades, Midgley and his postgraduate students have been observing and documenting the response of quiver tree populations to climate change. In 2007 Wendy Foden – now the General Manager of SANParks' Cape Research Centre and an associate professor at Stellenbosch University – was able to show signs of a coming southward and upward shift, with individual trees dying off in the warmer parts of the range towards the equator and at lower elevations throughout the northern half of the range. Repeated observational studies over the years are needed to confirm the findings that such a range shift may be under way.

The latest study

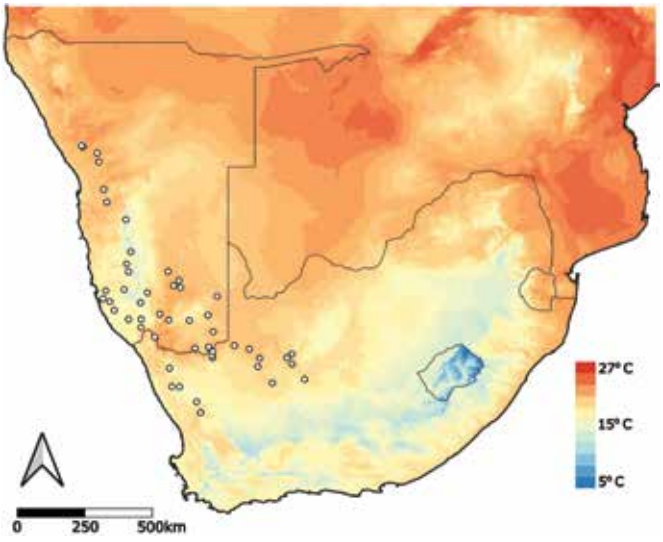
More recently, Midgley's postgraduate student Lara Brodie used species distribution modelling to reconstruct the

likely spatial extent of the quiver tree's range during glacial periods. She then used population genetic methods to test the results. The findings were published in the journal *Frontiers in Ecology and Evolution* in October 2021.

The models indicated that 22 000 years ago – in the time period known as the Last Glacial Maximum (LGM) because continental ice sheets were at their maximum extent – about two-thirds of the quiver tree's suitable habitat was around 650 km further north than the current range. As temperatures became more favourable, the trees started expanding their range polewards – in other words, to the south – at a rate of 0.4 km per decade. During the mid-Holocene, about 6 000 years ago, the available quiver tree range was more or less in the same location as the current range. This means that it took the species up to 18 000 years to migrate 650 km poleward.

This migration was indirectly confirmed by the results from the genetic population analyses. On average, the older northern populations support higher levels of genetic diversity than the more recently established populations in the southern and south-eastern regions. Biologists call this reduction in genetic variation brought about by a small subset of a population establishing a new colony the 'founder effect'.

The models predict that by 2070 quiver trees will have to shift 191 km eastwards in order to adapt to a changing climate. The models yielded different results for latitudinal shift, with two predicting a poleward range shift and the other a slight equatorward shift. Averaged out, the species would need to migrate 42 km in 70 years, which translates to 6 km per decade. This is roughly 15 times faster than what was expected of it 18 000 years ago.



The current geographic range of the quiver tree, superimposed on mean annual temperature. Previous research has shown that trees in the warmer areas have greater mortality than those in the cooler areas.

Sue Matthews

The quiver tree, also known as the kokerboom, is classified as vulnerable in the Red List of South African Plants. The English name refers to the fact that the San people used to make quivers in which to hold their arrows from the hollowed-out branches.

According to the researchers, the quiver tree will likely survive in the wild, but its geographic range would be much narrower. Populations in the south may struggle to adapt and survive due to lower levels of genetic variation, while those in the north will likely be lost as climatic conditions become unsuitable. To avoid losing the unique genetic diversity of the northern populations, the researchers recommend proactive conservation measures, such as safeguarding individuals in botanical gardens and implementing carefully considered assisted colonisation in suitable areas.

After decades of research, the iconic quiver tree still stands as a sentinel for human-induced climate change. The latest findings will not only inform conservation responses for this species, but potentially also for a wide range of others that occur only in this region.

- Brodie LP, Grey K-A, Bishop JM and Midgley GF (2021). Broadening predictive understanding of species' range responses to climate change: the case of *Aloidendron dichotomum*. *Front. Ecol. Evol.* 9:715702. *https://doi.org/10.3389/fevo.2021.715702*

Article written by Wiida Fourie-Basson, Media & Science Communication Officer for the University of Stellenbosch Science Faculty.

Phosphorites

Eugene Bergh explains how mineral-rich rocks offer insight into ancient Namibian ecosystems

Minerals are an important part of our everyday lives. They're in the mobile phones we use, the cars we drive and even in the food we eat.

Phosphorus is a mineral with many uses. It is extracted from rocks called phosphorites and used in fertilizer, animal feed, as a food additive, in detergents and in herbicides, as well as in various other industries. But it can also be useful in an entirely different way: to help scientists learn more about how our climate, the oceans and the environment have changed over long periods of time.

Southern Africa is an important region for phosphorite mining. As a geologist, I have spent years studying the phosphorite deposits of southern Africa, particularly those of offshore Namibia, to gain a better understanding of how they form and how they are related to both past and modern environments, and to map their changes.

Studying these deposits gives scientists information about how past environments change. That, in turn, gives us informed estimates on how climates and environments will change in the near future. This is important for the sustainability of our lives, environments and the ecosystems we depend on.

John Compton

Components extracted from the phosphorite layers.

Namibian deposits

Phosphorites form in different ways. Some are sedimentary – they form from pre-existing sediments that are cemented together over time and harden, or they precipitate from a pre-existing source. Others are igneous, meaning the rocks form from volcanic or magmatic activity. Guano deposits are another source of phosphate, either through cave deposits where bat droppings accumulate or from the accumulation of bird droppings.

Rising demand for phosphate, amid decreasing reserves of this non-renewable resource, piqued interest in southern Africa's extensive offshore phosphorite deposits during the first decade of the 21st century.

The Namibian phosphorites are marine sedimentary; they are brown to black and look either like sand-sized grains, small pebbles or rock fragments. They're found with fossil material, such as whale bone, fish bone, the remains of sponges and echinoids (sea urchins), bivalves (such as clams), marine gastropods (sea snails), as well as the fossils of small marine organisms, called ostracods and foraminifera.

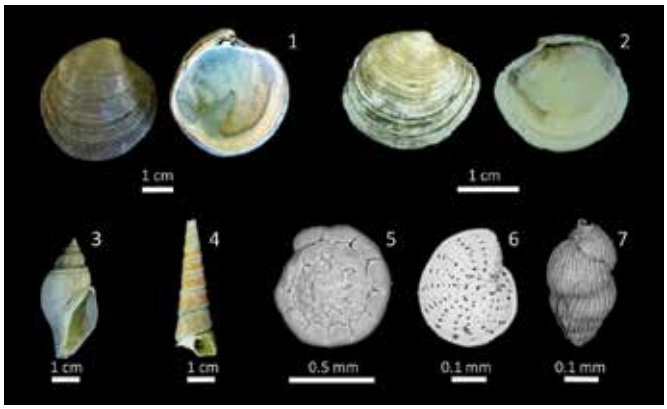
The offshore Namibian phosphorites started forming seven million years ago. The deposits in which these phosphorites are found can tell us a great deal about how the marine environments along western southern Africa have changed since then.

I looked at the internal structures of these phosphorites under a microscope. This revealed concentric bands that may represent different episodes and repeated cycles of formation at different ages. Many of the phosphorite grains also contained the remnants of fossil material or other minerals (such as quartz and glauconite) in the centre of the structure. This means that the phosphate precipitated from or grew around the non-phosphatic nucleus.

So, how did these deposits form?

Formation

Between five and seven million years ago, the Benguela Upwelling System, a highly productive marine system that runs along the western ocean of southern Africa, began off Namibia. Upwelling is the process where sea surface waters are replaced by colder, nutrient-rich water from



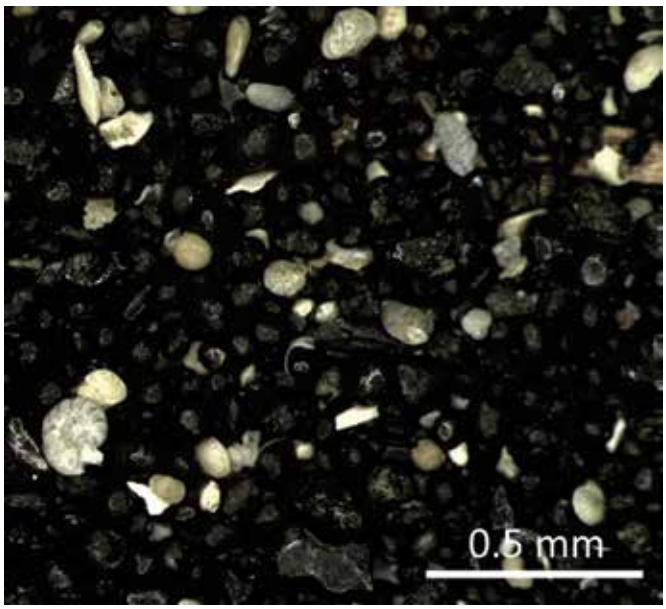
Eugene Bergh

Fossil shells (numbers 1–4) and microfossils (numbers 5–7) found in the phosphatic layers, which supported the environmental indicators of the phosphorite. 1. *Dosinia lupinus* (bivalve); 2. *Lucinoma capensis* (bivalve); 3. *Nassarius vinctus* (gastropod); 4. *Turritella declivis* (gastropod); 5. *Ammonia batava* (foraminifer); 6. *Elphidium advenum* (foraminifer); 7. *Uvigerina peregrina* (foraminifer).

below, and the Benguela is regarded as one of the world's most productive upwelling systems. This means that there is a high amount of organic matter available to support a functioning marine ecosystem.

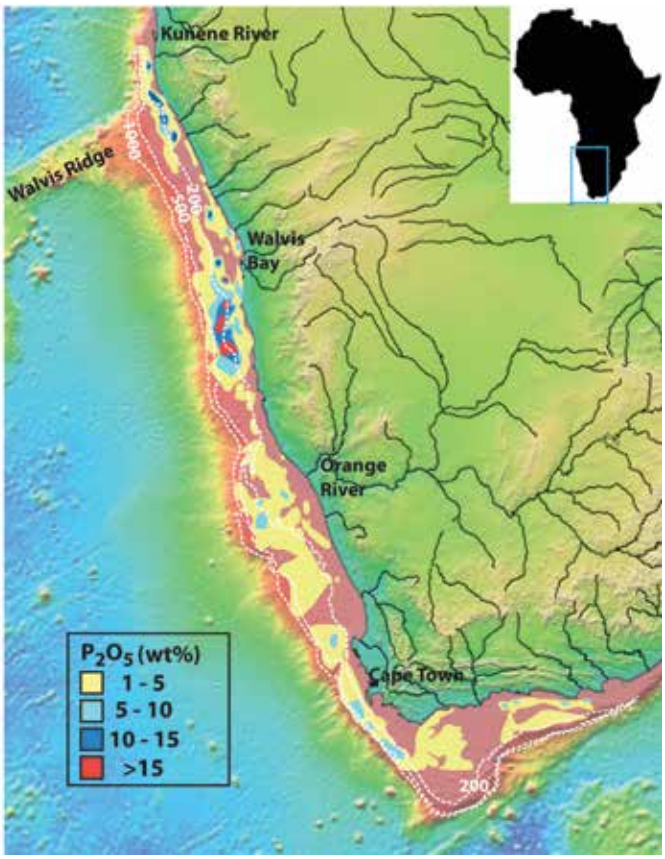
The age of the initiation of the Benguela Upwelling System is consistent with the oldest offshore phosphorites found in the area. The later, higher concentration of phosphorites that are younger than five million years old indicates the intensification of upwelling along Namibia's ocean margin.

Upwelling delivered phosphorous to the surface waters; the mineral was taken up by marine primary producers – organisms in the ocean that convert light and chemical energy into their food source – and delivered again to the seafloor as these organisms died. Microbial activity on the sea floor released more phosphorus, which created supersaturated conditions that led to the formation of phosphorus-rich minerals. This repeated cycling caused the phosphorus-enrichment in these marine deposits.



Eugene Bergh

Some phosphorite layers contain shell material and the fossilised remains of marine organisms called foraminifera. The numerous black grains are pelletal phosphorite.



John Compton and Eugene Bergh

There is interest in mining the phosphorus-rich deposits off Namibia.

The fossils mixed in with the phosphorites reveal that the region's climate started shifting around this time: sea levels dropped as the ocean became colder and upwelling intensified. The fossils that have been found with the phosphorites indicate that marine fauna that were adapted to warmer waters became fauna that were adapted to shallower water depths and ocean conditions that became colder. This is also consistent with fossils and marine terraces that have been found onshore. These fossils and geologic structures indicate that the sea level was much higher three million years ago and gradually lowered with time. This was also a time period in which the carbon dioxide levels were at similar levels as they are today.

Important information

This is a good example of why scientists study ancient environments. By knowing what happened when carbon dioxide levels increased millions of years ago – in the case of Namibia and South Africa, higher sea levels – we can determine how environments change with these types of conditions. The marine environments in which phosphorites are found can therefore provide us with important information on past, current and future climate and environmental change.

Dr Eugene Bergh is a research scientist at Iziko Museums of South Africa and the University of Cape Town, where he received his PhD in Geology in 2019.

Collaborative action to protect **South Africa's only endemic parrot**

The University of KwaZulu-Natal's Professor Colleen Downs – holder of the South African Research Chair (SARChI) in Ecosystem Health and Biodiversity in KwaZulu-Natal and the Eastern Cape – is playing a leading role in efforts to conserve South Africa's only endemic parrot. The Cape parrot, *Poicephalus robustus*, was only confirmed as a distinct species in 2017, and its population in the wild is estimated at just 1 800 birds.

Downs is Chair of the Cape Parrot Working Group (CPWG), which was initiated at the university in 1998. In 2019, BirdLife South Africa appointed the CPWG and the Wild Bird Trust's Cape Parrot Project (CPP) in Hogsback as species guardians for the Cape parrot, and more recently hosted a webinar showcasing their work to date. The CPP's Dr Kate Carstens joined Downs to discuss efforts to conserve the parrots, such as restoring habitats, establishing community projects and undertaking key research projects.

Downs and Carstens have been driving the implementation of the Cape Parrot and Mistbelt Forest Conservation Action Plan, published in March 2020. They spoke about the major threats to the parrots – categorised as regionally endangered on the Red List of South African Species – while also highlighting the success of initiatives to conserve the birds and their habitats.

Despite its name, the Cape parrot is not confined to the Cape. Its patchy distribution extends from the Amathole mountains of the Eastern Cape to the Karkloof in KwaZulu-Natal, with a relic population in Limpopo's Magoebaskloof and Wolkberg areas, matching the location of the southern mistbelt forests, which are dominated by yellowwoods.

The Cape parrot depends on yellowwoods for food and nesting sites, so it is threatened by fragmentation and loss of these forests. Downs explained that having a strong bill allows the birds to open yellowwood fruit to get to the kernel inside. When these fruits aren't in season, they feed on the fruits and seeds of other plants, such as black wattle, syringa, pecan nut and even proteas. In fact, more than 50 indigenous and alien plant species have been identified as food sources across their range, and the birds may fly more than 100 km in a day on long foraging journeys beyond the forest boundaries.

Umsebenzi we-CPWG nowe-CPP usanda kudingidwa kwiwebhina ebihlelwe yi-BirdLife South Africa, lapho uDkt Kate Carstens wase-CPP ebebambisene noSolwazi Colleen Downs emkhankasweni wokuvikela opholi okubalwa kukhona ukulungisa izindawo zabo, ukusungulwa kwezinhlelo zomphakathi nokwenza imisebenzi yocwaningo emqoka.

Translated by NdabaOnline

The Cape parrot nests in tree cavities, so to encourage breeding the Cape Parrot Project has constructed artificial nest boxes that are being placed in tall trees, usually yellowwoods, in the forest around Hogsback. Nest boxes installed a decade ago were never used by the birds, so these are a new design based on observations of the parrots' nest preferences.

The parrots often travel in small flocks, especially as juveniles, but may gather in very large flocks at pecan orchards when the nuts are in season.

The Cape Parrot Project employs members of the local community to help clear alien vegetation and plant indigenous seedlings to restore forest habitat.

The parrot is a secondary cavity nester, which means it nests in cavities hollowed out in trees – usually tall yellowwoods – by other animals, as well as those resulting from fallen branches, although it will spend time modifying a cavity to its own preferences. For example, deeper cavities may ensure that chicks are beyond the reach of predators, such as African harrier hawks and samango monkeys. Apart from these threats, parrots are vulnerable to human snatchers, as well as diseases.

For more than two decades, the CPWG has hosted an annual Cape Parrot Big Birding Day, in which citizen scientists help count the parrots in different areas so as to estimate the population size of the species. The CPP coordinates the census in the Hogsback area, as just one of many activities involving the local community.

"Using our acronym CPP slightly differently, communities, plants and parrots sums up what we are all about in three words," said Carstens. "We at the Cape Parrot Project see ourselves as leveraging the Cape parrot as a flagship species to conserve the threatened mistbelt forests and all the species that call these forests their home, while ensuring that local communities derive benefits by partnering with us to restore forest habitat."

The CPP employs local labourers to clear alien species and plant thousands of indigenous seedlings, which are sourced from community projects established by the project. They are also working on filling key knowledge gaps by conducting research on the species' nesting sites, demographics and health, identifying critical forest patches, and establishing whether the Cape parrot is successfully adjusting to feeding on exotic species.

Article adapted from a news story by Christine Cuénod, journalist for UKZN's College of Agriculture, Engineering and Science, in NdabaOnline Vol 9 (29).

Images courtesy of Cassie Carstens and other members of the Cape Parrot Project team.

The webinar can be viewed on Birdlife South Africa's YouTube channel, and includes an excellent video about the birds.

Follow Cape Parrot Project on Facebook and Instagram, or see https://www.wildbirdtrust.com/projects/cape-parrot-project

HERA

Dara Storer

Each wire-mesh dish has an antenna feed suspended above it.

Detecting radio signals from the early universe in the here and now

A telescope built in the Karoo from wooden poles, PVC piping and wire mesh will allow astronomers to look back in time to when the first stars and galaxies formed, about 13 billion years ago.

The HERA telescope is a project of the United States' National Science Foundation, the Gordon and Betty Moore Foundation and member institutions, including some from South Africa. In fact, the South African Radio Astronomy Observatory (SARAO) is the hosting organisation, because the telescope is situated next to SARAO's MeerKAT telescope, about 75 km north-west of Carnarvon in the Northern Cape. Like MeerKAT, the telescope is a radio telescope, in this case designed to detect low-frequency radio waves in the 100–200 MHz range.

A team of between five and 20 artisans from Carnarvon have been constructing the telescope since 2015, and it has now been completed. Astronomers could get to work with observations during the construction phase, though, and the first scientific papers detailing these were published in 2021.

Scott Dynes

Some of the artisans from Carnarvon who helped build the HERA telescope, with visiting scientists.

This is because the telescope is made up of 350 antennas, each consisting of a 14 m-diameter wire-mesh dish with a feed suspended above it. The immobile dishes point straight up at the sky, with 318 of them packed close together in a hexagonal grid 300 m wide, and the remaining 32 set apart as 'outriggers' to increase the resolution by a factor of four. The first observations were carried out over the 2017–2018 summer using about 50 dishes.

HERA stands for Hydrogen Epoch of Reionisation Array, and the telescope is specifically designed to detect fluctuations in the hydrogen emissions signal (as measured by the 21 cm spectral line) during and prior to the period known as the 'epoch of reionisation'.

After the Big Bang, some 13.7 million years ago, the universe was initially just a hot, dense 'soup' of fundamental particles. Protons and neutrons soon combined into nuclei, but it took more than 300 000 years for the soup to cool enough for these nuclei to bind with electrons to form neutral atoms, mostly of hydrogen but with some helium too.

As the universe cooled and expanded further, the fog of neutral atoms obscured any light being emitted, so astronomers call this time the cosmic Dark Ages. Eventually, the first stars and galaxies began forming as fog and dust clumped together under gravitational forces, producing light in the so-called Cosmic Dawn. Their ultraviolet radiation reionised the surrounding hydrogen atoms by splitting them into protons and electrons, forming bubbles of transparency amidst the fog.

Over time, as more stars and galaxies burned bright, the universe became completely ionised and transparent, about a billion years after the Big Bang.

MeerKAT

MeerKAT dwarfs the hexagonal, honeycomb-like HERA telescope.

Large data release reveals beautiful new cosmic puzzles

An international team led by a young South African researcher, Dr Kenda Knowles, announced a comprehensive overview paper for the MeerKAT Galaxy Cluster Legacy Survey (MGCLS) in November. The paper, to be published in the journal *Astronomy & Astrophysics*, presents some novel results, and is accompanied by the public release of a huge trove of curated data. This will allow astronomers worldwide to address a variety of challenging questions, such as those relating to the formation and evolution of galaxies throughout the universe.

Using the MeerKAT telescope operated by the South African Radio Astronomy Observatory (SARAO), this first observatory-led survey demonstrates MeerKAT's exceptional strengths by producing highly detailed and sensitive images of the radio emission from 115 clusters of galaxies. The observations, amounting to approximately 1 000 hours of telescope time, were done in the year following the inauguration of MeerKAT in 2018.

"In those days we were still characterising our new telescope, while developing further capabilities required by numerous scientists," said Dr Sharmila Goedhart, SARAO head of commissioning and science operations. "But we knew that MeerKAT was already very capable for studies of this sort, and we observed galaxy clusters as needed to fill gaps in the observing schedule."

This was only the start. More than two years of work followed to convert the raw data into radio images, using powerful computers, and to perform scientific analysis addressing a variety of topics. This was done by a team of 40 scientists representing 19 institutions, including 10 in South Africa. Team leader Knowles completed her PhD at the University of KwaZulu-Natal at the end of 2015 and stayed on there as a postdoctoral fellow until taking up a research fellowship at Rhodes University in March 2021.

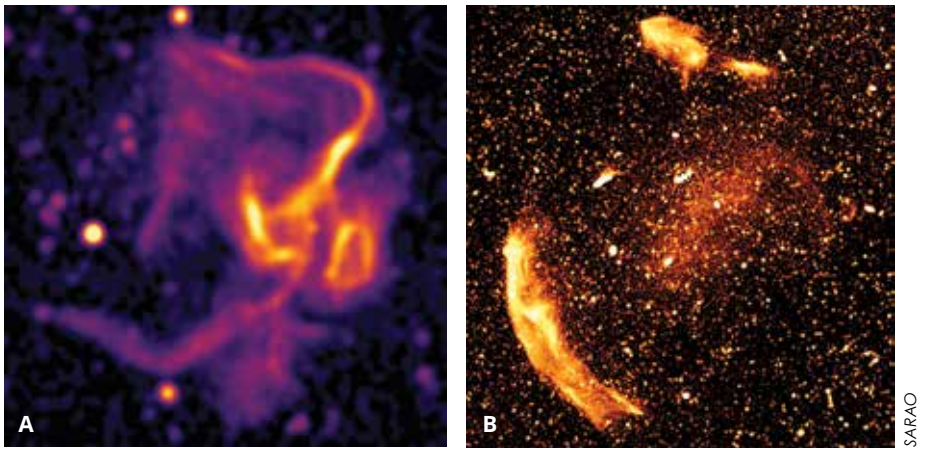
Mysteries of the universe

The force of gravity has filled the expanding universe with objects extending over an astounding range of sizes,

SARAO

The MeerKAT telescope is an array of 64 interlinked receptors, each consisting of an antenna positioner (a steerable dish on a pedestal), a set of radio receivers, and associated digitisers and other electronics.

from comets that are 10 km (one thirty-thousandth of a light-second) across, to clusters of galaxies that can span 10 million light-years. These galaxy clusters are complex environments, host to thousands of galaxies, magnetic fields, and large regions of extremely hot gas, electrons and protons moving close to the speed of light, as well as dark matter. Those 'relativistic' electrons, spiralling around the magnetic fields, produce the radio emission that MeerKAT can 'see' with unprecedented sensitivity, opening new horizons for the deeper understanding of these structures.



SARAO SARAO

A) MeerKAT view of a complex network of radio filaments and diffuse structure, spanning more than half a million light-years. B) MeerKAT evidence of a powerful merger taking place between two or more massive groups of gas and galaxies.

This means that MeerKAT, particularly when supplemented with information from optical and infrared and X-ray telescopes, is exceptionally well suited to studying the interplay between the components that determine the evolution of galaxy clusters – the largest structures in the universe held together by gravity.

Just as we live in air that we cannot see unless it's filled with smoke or dust or water droplets, creating visible gusts, streams and swirls, so are the motions of the X-ray-glowing plasma in galaxy clusters usually hidden from us. Radio emission from the sprinkling of relativistic electrons in this plasma can reveal the dramatic storms stirred up when clusters collide with each other, or when jets of material spew out of supermassive black holes in the centres of galaxies.

SARAO, SDSS

Two giant radio galaxies (more than one million light-years from end to end) at the centre of a large group of galaxies in the cluster Abell 194, revealing the presence of relatively narrow magnetic filaments in the region, as well as complex interactions between the radio emission from the two galaxies. The MeerKAT radio image is shown in orange, with an optical image dominated by normal galaxies shown in white.

The MGCLS paper accepted for publication presents more than 50 such newly discovered patches of emission. Some of them we can understand and others remain a mystery, awaiting advances in our understanding of the physical behaviour of cluster plasmas. A few examples are shown here, some associated with the bright emission from so-called 'radio galaxies,' powered by the jets of supermassive black holes. Others are isolated features, illuminating winds and intergalactic shock waves in the surrounding plasma.

Other types of science enriched by the MGCLS include the regulation of star formation in galaxies, the physical processes of jet interactions, the study of faint, cooler hydrogen gas – the fuel of stars – in a variety of environments, and as yet unknown investigations to be facilitated by future discoveries.

The MGCLS has produced detailed images of the extremely faint radio sky, while surveying a very large volume of space. "That's what's already enabled us to serendipitously discover rare kinds of galaxies, interactions, and diffuse features of radio emission, many of them quite beautiful," explained Knowles.

But this is only the beginning. A number of additional studies delving more deeply into some of the initial discoveries are already under way by members of the MGCLS team. Beyond that, the richness of the science resulting from the MGCLS is expected to grow over the coming years, as astronomers from around the world download the data from the SARAO MeerKAT archive, and probe it to answer their own questions.

- Knowles, K, Cotton, WD, Rudnick, L et al., The MeerKAT Galaxy Cluster Legacy Survey. I. Survey Overview and Highlights. *Astronomy & Astrophysics*, in press.

Issued by the South African Radio Astronomy Observatory (SARAO).

Three Minute Thesis 3MT

Rhodes University PhD candidate Siphokazi Msengana won the national Three Minute Thesis competition at the end of October, and was rewarded with a R15 000 cash prize. She eloquently explained the topic of her PhD thesis in under three minutes in a talk titled 'Natural alternatives to controlling the diamondback moth, a cabbage pest'.

The competition was first held in 2008 at Australia's University of Queensland, which then promoted it to other Australian and New Zealand universities and registered a trademark over the 3MT brand. Today, 3MT competitions are held in more than 900 universities and institutions in 85 countries around the world. The South African competition has been hosted by the University of the Free State (UFS) since 2016, but the 2020 and 2021 events were virtual ones due to the pandemic, with entrants judged on video submissions. Otherwise, the rules remained unchanged: entrants had to present their research in a way that could be understood by an audience with no background in the field, and could use no more than one PowerPoint slide, without any other resources or props.

Both master's and PhD students could take part in the heats organised by the participating universities – UFS, University of Johannesburg, University of South Africa, University of KwaZulu-Natal, North-West University, Wits University, Rhodes University, Durban University of Technology, and Central University of Technology – but only the first- and second-placed PhD students from each university were eligible for the 'final' in accordance with 3MT brand rules.

Siphokazi Msengana won both the Rhodes University 3MT heat as well as the national competition.

In her winning talk, Msengana explained that cabbage is widely grown by subsistence farmers in the Eastern Cape but is vulnerable to attack by the diamondback moth. Synthetic chemical insecticides are not only expensive and potentially hazardous to the environment and human health, but also lose their effectiveness over time as the insect develops resistance.

"Perhaps a more sustainable option to consider would be insecticides that are derived from plants, which we term botanical insecticides," she said, "They can range from essential oils to plant extracts, or even dried plant parts that are crushed to a powder and then dispersed on the cabbage to control the insect."

Her doctoral research is therefore investigating the chemical properties of the weed *Tagetes minuta* and the indigenous shrub *Lippia javanica*, both of which have been shown in the past to repel insects or kill certain microorganisms. Msengana has undergraduate, honours and master's degrees in chemistry, all completed at Rhodes University, and she is employed as a scientific technician at the Eastern Cape government's agriculture and rural development department.

Nonkanyiso Pamella Shabalala from UNISA came second in the 3MT competition with her talk 'The exploration of environmental education interventions', and Zakithi Mkhize from University of KwaZulu-Natal came third for 'Solving HIV latency is the key to HIV cure'.

Patrick Clement, CC BY 2.0

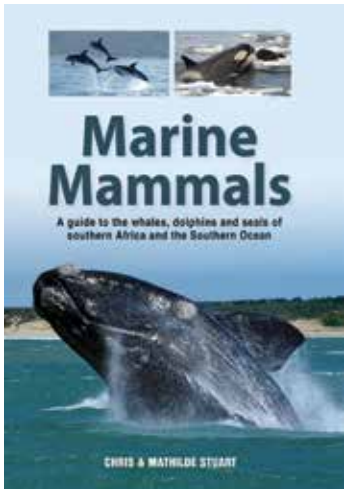
Alton N. Sparks, Jr., University of Georgia, Bugwood.org, CC BY 3.0

The caterpillars of the diamondback moth are destructive pests of cabbage and its relatives, such as cauliflower, kale and broccoli.

Books

Marine Mammals:
A guide to the whales, dolphins and seals of southern Africa and the Southern Ocean

By Chris and Mathilde Stuart



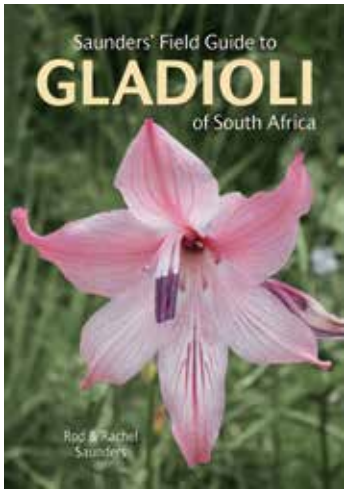
This is a short and sweet little booklet, totalling less than 75 pages, but all you should need to identify the marine mammals of the region, providing you get a good look at some key features. It's easy-to-use and very colourful, containing a mixture of photographs and beautiful illustrations. The main species entries each have an informative description and a box listing details such as the weight, length, blow height, tail fluke position when diving, lifespan and range. The best viewing opportunities are also highlighted. An introductory section covers the biological background, adaptations to aquatic life, and whale and dolphin behaviour, including breaching, spyhopping, lob-tailing and bow-surfing.

Chris and Mathilde Stuart have co-authored a wide range of books, field guides and mobile applications on African mammals, wildlife and conservation over more than three decades. Much of their time is spent travelling the world, searching for wild mammals and promoting conservation. Mathilde holds a doctorate from the University of Innsbruck, while Chris holds an MSc from the University of KwaZulu-Natal.

The recommended retail price (RRP) of the softcover booklet is R150, but it is also available as an e-book for R130.

Saunders' Field Guide to Gladioli of South Africa

By Rod and Rachel Saunders



At the opposite end of the identification guide scale is this chunky and comprehensive book providing the first complete photographic record of the 166 species of gladioli found in our country. Although gladioli occur throughout Africa, Madagascar, Europe and the Middle East, South Africa is home to more than half the world's species.

The book follows the normal field guide format, with an introductory section on gladioli history, morphology and taxonomy, followed by detailed species entries with identification features and maps, as well as information on ecology, pollinators, similar species and conservation status.

Rod and Rachel Saunders were well-known botanists, widely respected for their knowledge of South Africa's indigenous plants. They set out to find and photograph every known member of the genus *Gladiolus* in South Africa, but their work on the book was tragically cut short when they were murdered during a field trip to KwaZulu-Natal in 2018. The book was therefore completed posthumously by Fiona C. Ross, a UCT Professor of Anthropology who established the Saunders Guide Trust to secure the Saunders' work on gladioli.

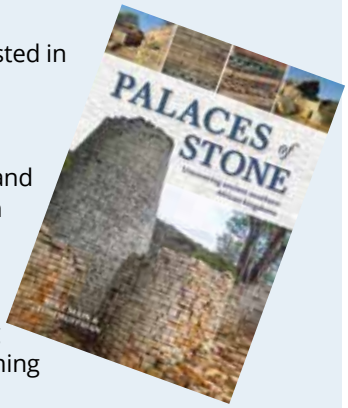
The RRP is R420 for the softcover book and R360 for the e-book.

Palaces of Stone: Uncovering ancient southern African kingdoms

By Mike Main & Tom Huffman

This book brings to life the history of various African societies, from AD 900 to approximately 1850. By exploring a selection of sites, the authors uncover the emergence of ancient civilisations and reconstruct the meaning of the ruins they left behind. Woven into the narrative are stories of powerful political states, flourishing local economies, long-distance trade, and the destruction wrought by colonialism and modern-day treasure hunters.

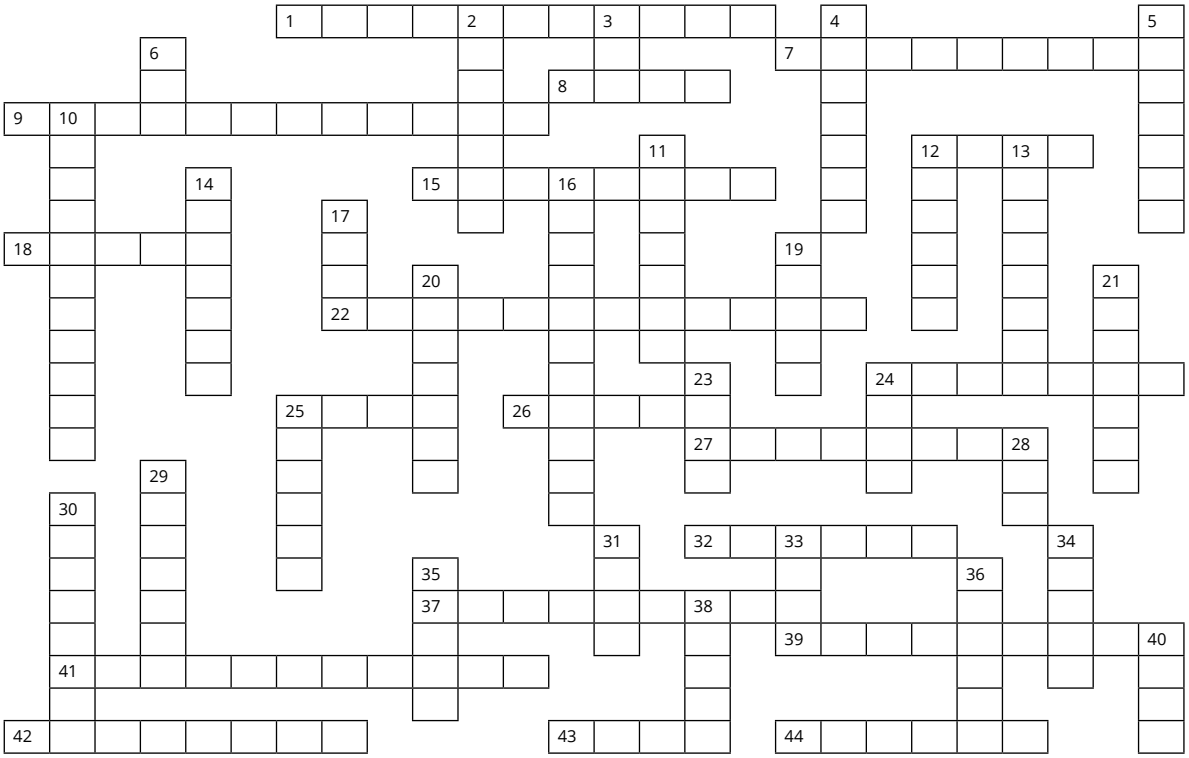
The book's clear and colourful design, with many photographs, maps and boxes, ensure that its appeal is not limited to readers interested in history. Its RRP is R240.



Mike Main is a management consultant, freelance writer and lay archaeologist who lives in Gaborone, Botswana, while Tom Huffman is Professor Emeritus of Archaeology at Wits University and a leading authority on precolonial farming societies in southern Africa.

Test your knowledge

All of the answers can be found in this issue of *Quest*



ACROSS

1 The ___ moth is a major pest of cabbage, cauliflower, broccoli and kale
7 Term for energy from natural sources or processes that are constantly replenished
8 Acronym for an organic compound capable of reversible hydrogenation and dehydrogenation
9 Technical term for a solar panel
12 Acronym for areas identified as strategically important for development of wind and solar farms
15 A channel or pipe conveying water to the turbines of a hydropower plant
18 Energy derived from the sun
22 Sedimentary rocks that are rich in phosphorus
24 A large radio telescope in the Northern Cape
25 Acronym commonly used to describe biodiesel
26 The main output from the WASA project
27 Descriptive species name for the Cape parrot
32 An iconic tree of the arid landscapes of the Northern Cape and Namibia
37 Describes survival or process occurring in the absence of air or free oxygen
39 Relates to very low temperatures that keep hydrogen and helium in the liquid state
41 The 'edu-tainer' tour that aims to raise awareness about renewable energy
42 The company ___ship SA plans to operate moored gas power stations in South Africa
43 The African harrier ___ preys on Cape parrot nestlings
44 A gas comprised mostly of hydrogen and carbon monoxide with some carbon dioxide

DOWN

2 A type of hydropower scheme known as run-___
3 Methane is the main component of ___gas
4 Verb describing conversion of plant sugars to ethanol
5 A system of categorising species in need of conservation
6 Brand name for a student speaking competition
10 Describes a water-repellent substance or surface
11 South Africa's only nuclear power plant
12 The ___ Programme aims to procure power from renewable sources
13 Some rural households install these to break down organic waste into useful products
14 A rotary machine that harnesses energy of a moving fluid such as water or air
16 Diamond Light Source is this kind of cyclic particle accelerator
17 The Steenbras Hydro ___ Station reduces load-shedding in Cape Town
19 Solar and wind energy can be used to produce ___ hydrogen
20 The main feedstock for biodiesel in the USA
21 The waste product left behind after sugarcane is crushed for juice extraction
23 Acronym for a ship where liquid natural gas is converted back to the gaseous state
24 The Cape parrot's primary habitat is ___belt forest
25 Coal, petroleum and natural gas are ___ fuels
28 Acronym for a bioethanol-based fuel used in the aviation industry
29 Term for trapping carbon dioxide at emission sources
30 An upwelling system on southern Africa's west coast
31 A telescope designed for observations of the epoch of reionisation
33 The United Nations body for assessing the science related to climate change
34 The waterfall in the Eastern Cape with a micro-hydropower system
35 The French city lending its name to the international agreement to limit global warming to well below 2°C
36 South Africa's largest pumped storage scheme
38 ___ hydrogen is produced from gasification of bituminous coal
40 A type of bivalve mollusc

The Kansas Energy Programme in the United States has put together a number of riddles, games and brainteasers focused on energy. *https://www.kansasenergyprogram.org/games*

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