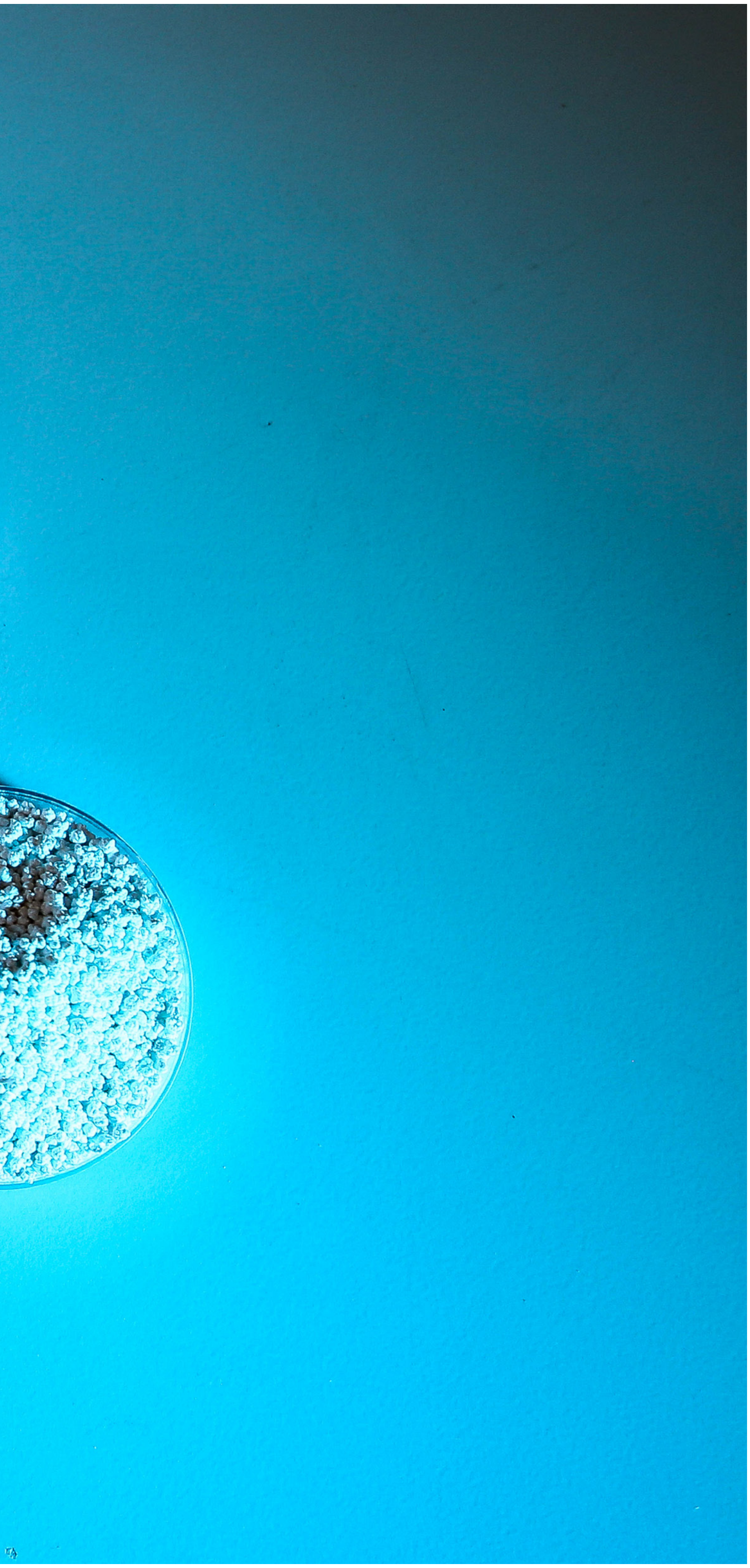
ADVANCING HYDROGEN AND CARBON DIOXIDE UTILISATION

science, technology & innovation

Department:
Science, Technology and Innovation
REPUBLIC OF SOUTH AFRICA

CSIR
Touching lives through innovation



CO_2 capture and utilisation at the CSIR

The CSIR's Carbon Capture and Utilisation (CCU) capability, based in the Future Production: Chemicals cluster in Pretoria, works with industry to convert captured carbon dioxide (CO_2) into methanol, syngas, dimethyl ether (DME), mineral products and other high-value chemicals. Current work spans heterogeneous catalysis, biocatalysis and materials synthesis, and is being consolidated into a shared, industry-relevant CCU testing and development facility. By testing and de-risking conversion technologies locally, South African industry can validate and scale CO_2 conversion technologies without relying on international facilities or external research.

The team comprises scientists and engineers, working across several interrelated technology tracks: methanol, dry reforming of methane (CH_4), DME and methanation catalysts; CO_2 mineralisation and low-carbon concrete; and biocatalytic CO_2 conversion. The capability is being expanded to add a multi-catalyst bed reactor system, dedicated biocatalysis reactors and expanded analytical infrastructure, enabling parallel, industry-relevant catalyst screening and process de-risking under one roof.

CRACKED: HOW SOUTH AFRICA COULD TURN WASTE INTO HYDROGEN AND CARBON MATERIALS

Researchers have developed a long-lasting catalyst that can split methane waste into hydrogen and solid carbon. The technology, developed at the CSIR-based Hydrogen South Africa (HySA) Infrastructure facility, has the potential to bring decentralised hydrogen production to South Africa, using biogas waste streams from mines, wastewater treatment plants and other industries.


Using a fluidised bed reactor, biogas waste streams from mines, wastewater treatment plants and other industries can be converted into hydrogen and solid carbon. CSIR researchers advancing the process envision setting up cracking units in shipping containers to meet local demand for low-carbon hydrogen and green carbon.

Ashton Swartbooi, a chemical engineer at HySA, says that while methane "cracking" has been done before – either at high temperatures or using existing catalysts that deactivate more quickly, this novel catalyst enables sustained chemical cracking of the methane molecule at lower temperatures.

"We now have a demonstration-scale reactor using our catalyst, which allows for continuous operation," says Swartbooi. "The reactor converts a methane gas feed into hydrogen and the carbon-coated catalyst can then be extracted from the bottom of the reactor."

He adds that the reactor maintains constant hydrogen production rates by continuously feeding in fresh catalyst.

The reactor, technically known as a fluidised bed reactor, is ideal for South African and broader African markets looking to expand circular economy initiatives, such as waste repurposing and renewable energy resources.

"Wastewater treatment plants, for example, currently vent biogas directly into the atmosphere," says Swartbooi. "While they could use this biogas to generate electricity directly, our reactor would

A new long-lasting catalyst that can split methane waste into hydrogen and solid carbon has been developed at the CSIR-based Hydrogen South Africa (HySA) Infrastructure facility. Researchers have demonstrated constant hydrogen production rates using the catalyst in a specialised reactor: fresh catalyst and methane are continually fed into the reactor, producing hydrogen and solid carbons.

Hydrogen South Africa (HySA) is a flagship project of the Department of Science, Technology and Innovation's National Hydrogen and Fuel Cells initiative. HySA Infrastructure, one of three centres of competence, consists of two facilities, one at North-West University and the other at the CSIR. It addresses SDG 7, SDG 9, SDG 11, SDG 12 and SDG 13.

allow them to generate hydrogen that can be used in fuel cells or vehicle applications, while simultaneously reducing emissions."

He says the term for hydrogen generated in this way is low-carbon hydrogen or turquoise hydrogen. It represents a promising stream of clean energy in line with the South African government's Hydrogen Society Roadmap, including the "hydrogen corridor" between the provinces of Limpopo and KwaZulu-Natal.

In addition, researchers are looking into how the carbon captured by the catalyst could potentially be processed to supply global markets requiring various grades of green carbon. This includes high-quality graphite and carbon nanofibres, as well as lower-quality carbon black.

Swartbooi's team at HySA will be demonstrating the benefits of the new methane-cracking technology to various facilities that produce methane-rich gases, including sewage treatment plants, mines and private companies, during 2026.

"The cost to produce hydrogen in this way would be much cheaper than using water electrolysis technologies that are currently available. It would also be comparable to fossil fuel-based hydrogen generation, yet our reactor simultaneously repurposes methane waste and captures carbon in a solid form for green chemical production."

He adds that methane is an excellent feedstock for hydrogen generation since a methane molecule consists of four hydrogen atoms connected to one carbon atom. This means that the amount of hydrogen generated compared to the amount of carbon (a ratio of 4:1) is much higher than in other gases like propane (2.6:1) or butane (2.5:1).

Research is still ongoing to fully demonstrate and optimise the technology so that methane-producing facilities can set up a customised version of the reactor unit, in line with the quality of hydrogen and the type of carbon they want to produce. "We envision that a unit could be installed within a shipping container-type of housing, alongside other analytical equipment to monitor purity and quality," says Swartbooi.

The CSIR is also developing hydrogen storage technologies that could eventually be coupled with reactors like these.

One group of researchers, led by Dr Mike Masukume, has advanced a technology to compact one kilogram of hydrogen

Chemical engineer Ashton Swartbooi inspects a novel methane cracking catalyst developed at the CSIR-based Hydrogen South Africa (HySA) Infrastructure facility. His team will be visiting sewage treatment plants, mines and other industries that produce waste biogas, to demonstrate how the catalyst can be used to split methane into hydrogen and solid carbon within the pilot-scale reactor.

into a 20-litre cylinder at just 100 bars – 86% less pressure than current compression technology allows for.

This technology is being developed alongside international partners as part of an international European Union-funded project, Mast3RBoost, and is expected to be demonstrated in the coming months.

"As the CSIR, we are leading the work package that is responsible for developing ultra-porous materials known as metal-organic frameworks at scale, as well as their composites," says Masukume. "The porosity allows the material to store more hydrogen, thereby achieving hydrogen storage below 100 bars."

As for the HySA methane-cracking reactor, Swartbooi's team is working to improve the performance of the catalyst even further and to produce it at various scales to meet demand.

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SCIENTISTS CLOSE TO 86% REDUCTION IN HYDROGEN CYLINDER STORAGE PRESSURE

CSIR researchers are at an advanced stage of developing a technology to compact one kilogram of hydrogen into a 20-litre cylinder at just 100 bars – 86% less pressure than current compression technology allows for. This technology, which is currently under development and is expected to be demonstrated in the coming months, will make it possible for hydrogen-powered vehicles to store the fuel at reduced pressures, thus enhancing the technology's safety and affordability.

Principal researcher at the CSIR, Dr Mike Masukume, says hydrogen has been identified as a viable clean energy source for the transportation sector.

"Fuel cells and hydrogen represent the practical solution for decarbonising trucks, buses, ships, trains and large cars, with commercial vehicles being considered the early adopters," he says. "But with current compression technology, it would have to be stored at a very high pressure of 700 bars, which is costly and unsafe."

The CSIR is one of 13 international collaborators developing the world's first one kilogram low compression hydrogen storage

This innovation is funded by Horizon Europe, the technology development consortium consists of the CSIR, Envirohemp (Spain), Contactia (Spain), Cidetec (Spain), Consejo Superior de Investigaciones Cientificas (Spain), Spike Renewables (Italy), Edag Engineering (Germany), Nanolayers (Estonia), the University of Nottingham (UK), Peugeot Citroen Automotive Portugal (Portugal), LKR Leichtmetallkompetenzzentrum Ranshofen GmbH (Austria) and the University of Pretoria (South Africa). It addresses SGD 7.

device, with a target of 100 bars or lower. The collaboration, known as Mast3RBoost, is funded by the Horizon Europe programme.

"As the CSIR, we are leading the work package that is responsible for developing ultra-porous materials known as metal-organic frameworks (MOFs) at scale, as well as their composites," says Masukume. "The porosity allows the material to store more hydrogen, thereby achieving hydrogen storage below 100 bars."

In parallel, his team also synthesised MOFs using metals recovered from waste, like packaging materials, to enhance their cost-effectiveness and eco-friendliness.

"The CSIR has made tremendous progress on the Mast3RBoost project, which is in its third year of four," explains Masukume. "We have synthesised the best-performing MOFs in the laboratory and scaled production up to 1 200-litres capacity."

He adds that the team densified the pristine MOF materials and their composites into granules and pellets, and characterised them in terms of surface area, mechanical strength, porosity, bulk density, thermal conductivity and hydrogen uptake at one bar.

"Due to the unavailability of high-pressure hydrogen testing equipment at the CSIR and within the country, selected samples have been sent to the University of Nottingham, a member of the consortium, for hydrogen uptake measurements at 100 bars," he says.

Other members of the Mast3RBoost consortium are also exploring other porous materials, such as activated carbons, and applying machine-learning algorithms to enhance their performance. They are also designing and fabricating the cylinder, developing compatible coatings for its lining and testing the final cylinder in a stationary testing rig.

"We are excited to be just months away from demonstrating the storage of one kilogram of hydrogen in a 20-litre tank at 100 bars," says Masukume. "This will be revolutionary for the transportation sector and we look forward to the adoption of clean alternative fuel sources throughout the world as a result of this project. If the technology is successfully demonstrated in the European Union, it will also be localised for South Africa and will have a major impact on global transportation."

CSIR chemical engineering intern, Zandile Mabasa, displays the final granulated metal-organic framework product.

CSIR chemical engineering intern, Zandile Mabasa, and chemical engineering graduate trainee, Simphiwe Ncwane, collect a slurry product from a reactor.

Metal-organic framework cakes are collected after mechanical dewatering using a pilot-scale filter press.

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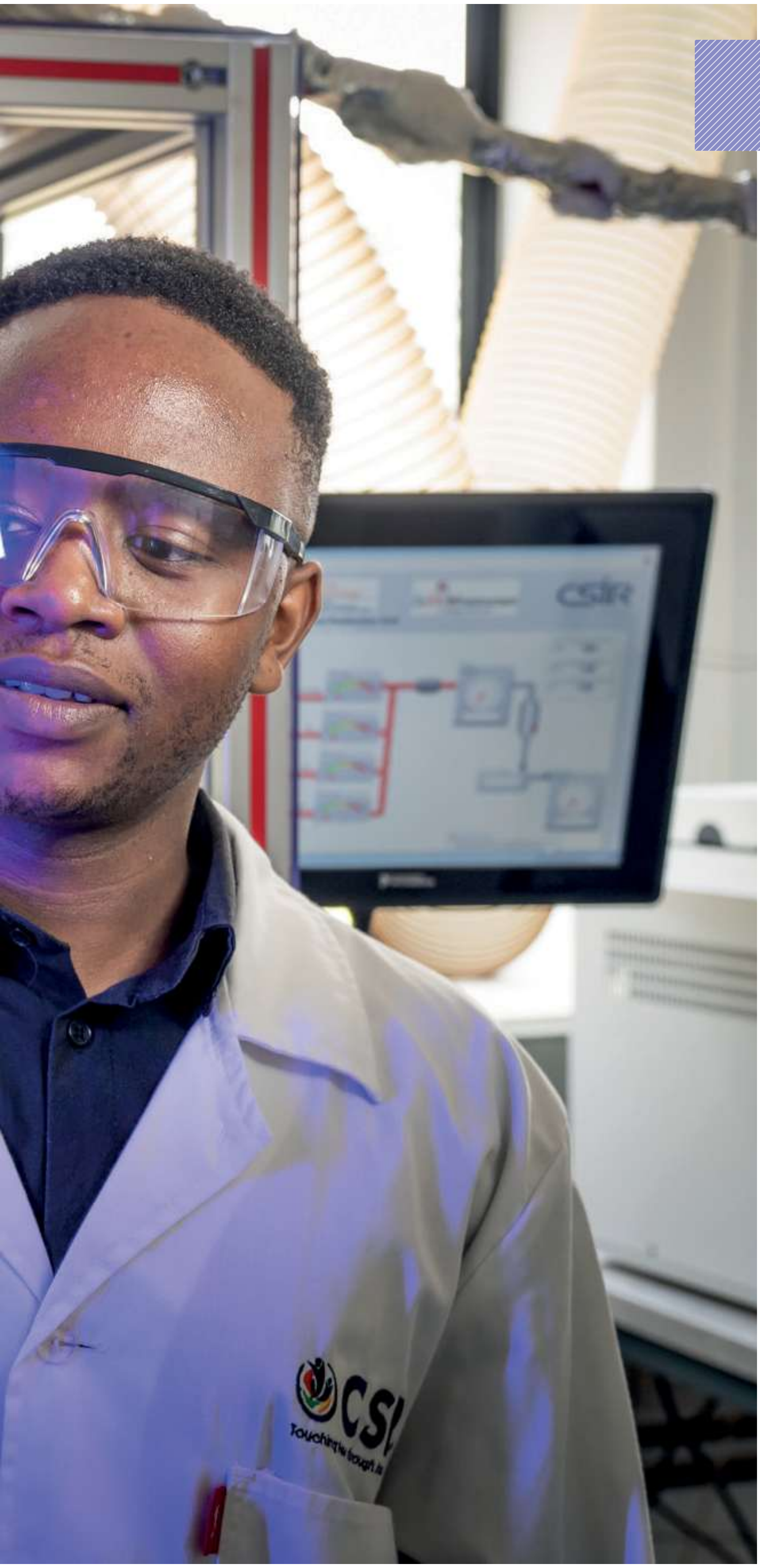
CSIR researcher Zama Duma with eco-friendly ethanol. The CSIR has used its proprietary metal-organic frameworks to enhance the conversion efficiency of CO_2 into methanol. This process not only repurposes waste gases but also produces a sustainable alternative to fossil fuel-based methanol, which is currently derived from natural gas.

This research is co-funded by the CSIR and the Royal Society-Foreign, Commonwealth and Development Office Africa Capacity Building Initiative Programme and the Department of Science, Technology and Innovation. It addresses SDG 7 and SDG 13.



CARBON DIOXIDE POLLUTION CONVERTED INTO GREEN METHANOL FUEL

Researchers at the CSIR developed a catalyst that converts carbon dioxide (CO_2) into eco-friendly methanol. The technology is poised to help stimulate South Africa's green methanol economy.

Methanol is an essential component in various industries, including plastics manufacturing and chemical synthesis. It can also be used as a potential fuel in maritime travel, says CSIR researcher Zama Duma.

Duma says the ability to produce green methanol from captured CO_2 represents a crucial step towards achieving the United Nations Sustainable Development Goals (SDGs) around climate action and clean energy.

"The primary issue this research seeks to address is global warming, which is primarily caused by the accumulation of greenhouse gases such as CO_2 and methane in the atmosphere," he says. "These gases trap heat, leading to erratic climate patterns, severe droughts and more frequent flooding."

Industrial sectors, including power generation, oil and gas production, cement manufacturing and steel production, are among the largest contributors to carbon emissions.

The CSIR's innovation was supported by the Department of Science, Technology and Innovation-funded Hydrogen South Africa programme and seeks to target emissions from both anthropogenic (manmade) and biogenic (natural) point sources and convert them into valuable chemicals. This would reduce their negative environmental impact.

Thus, the innovation aims to mitigate greenhouse gas emissions while contributing to global efforts for cleaner, more sustainable energy sources. The study also aligns with South Africa's green

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energy policies and international carbon reduction strategies, such as the United Nations SDGs.

“The key breakthrough in this research lies in the catalyst design,” says Duma, adding that the findings have been published in various scientific journals, reinforcing South Africa’s position as a leader in sustainable energy innovation.

“The CSIR has used its proprietary metal-organic frameworks to enhance the conversion efficiency of CO_2 into methanol. This process not only repurposes waste gases but also produces a sustainable alternative to fossil fuel-based methanol, which is currently derived from natural gas,” he adds.

While the catalyst was shown to be active towards methanol production and the process technically feasible, it still requires further optimisation, says Duma.

In the broader context, the economic viability of green methanol remains a challenge. The current cost of methanol derived from fossil fuels is between US $303 to US $824 per ton, and current techno-economic evaluations indicate that the cost of methanol derived from renewable, low-carbon hydrogen and captured CO_2 may be two to three times higher.

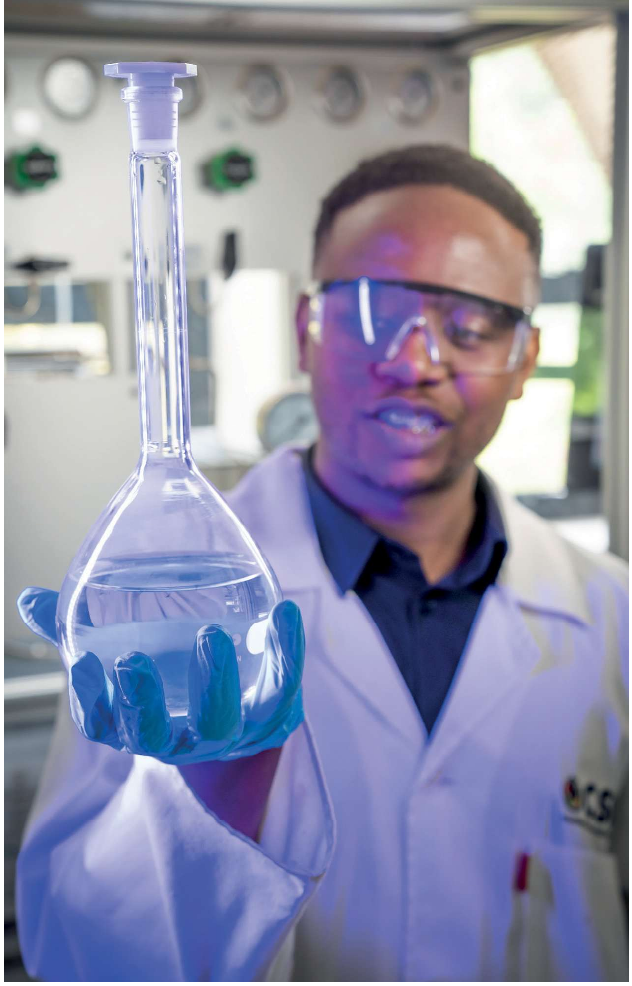
“Clean energy technologies are still in their infancy, making them more expensive than conventional fossil fuels. To address this, the CSIR is working with policymakers and industry stakeholders to make green technologies more competitive,” says Duma.

The research has gained recognition, with a presentation made to the Southern African German Chamber of Commerce in November 2023, where project developers introduced the market to a planned green methanol corridor.

“One of the most exciting applications of this technology could be in the proposed Green Methanol Corridor in the Vaal Special Economic Zone. This initiative aims to use wastewater treatment plants to produce green hydrogen, which, when combined with captured CO_2, will generate methanol for local use and export. The corridor is envisioned to run from the Vaal region to the Port of Durban, establishing South Africa as a key player in the global green methanol market,” he says.

The success of this innovation hinges on collaboration among governments, industries and research institutions. The CSIR has partnered with international organisations, including entities in France, to advance this technology beyond the laboratory and into industrial-scale production.

Despite the promising advancements, significant hurdles remain. The cost of scaling up green methanol production and the



CSIR researcher Zama Duma operating a fixed-bed tubular reactor for eco-friendly methanol production using proprietary metal-organic frameworks to enhance the conversion efficiency of carbon dioxide into methanol.

The CSIR-developed catalyst for the conversion of carbon dioxide into eco-friendly methanol.

need for policy support are critical factors in determining the widespread adoption of this technology. Public awareness and industry buy-in are also crucial to ensure a just transition away from carbon-intensive fuels.

The CSIR is advocating for increased funding, both domestically and internationally, to drive further research and commercialisation. The hydrogenation of CO_2 into green methanol represents a transformative step in the fight against climate change and provision of clean technologies.

While challenges persist, the CSIR's pioneering research has the potential to reshape the energy landscape, reduce carbon footprints and create economic opportunities through sustainable innovation.

"If supported by appropriate policies and investments, this technology could play a crucial role in South Africa's transition to a greener economy and contribute to global climate goals," says Duma.

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WORK WITH US

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